Modern Automotive Technology

Ninth Edition

by

James E. Duffy

Automotive Writer
ASE Master Automobile Technician

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Preface

Modern Automotive Technology is an easy-to-understand, up-to-date textbook detailing the operation, diagnosis, service, and repair of automobiles and light trucks. It has been designed to help prepare aspiring technicians for exciting and productive careers in automobile technology. It also provides the information needed to prepare for ASE automobile certification tests.

No longer can the untrained person effectively diagnose and repair modern vehicles. As technology has evolved, even the most basic automotive systems have become dauntingly complex. Multiple onboard computers are now used to monitor and control the engine, transmission, suspension, brakes, emission controls, and other vital vehicle systems. As the demand has grown for technicians who can diagnose and repair these increasingly sophisticated automotive systems, so has the need for a learning solution that prepares students for entry-level employment in this exciting field. ***Modern Automotive Technology*** will give you the tools you need to succeed in the challenging and ever-changing world of automotive technology.

The 2017 edition of ***Modern Automotive Technology*** is organized around the ASE automobile test areas and correlated to the NATEF Task List. It has been thoroughly revised by the author and carefully vetted by a panel of experts in the field of automotive education, as well as a team of technical editors, to make sure the material is technically accurate, up-to-date, and presented in the most logical and effective manner.

Modern Automotive Technology has been painstakingly designed to provide a student-focused approach to learning. Short sentences, concise definitions, and thousands of color illustrations will help you learn quickly and easily.

Information is presented using a building-block approach that starts with simple principles and general rules, and progresses gradually to more complex subjects. Each major automotive system is covered in two or more chapters. The first chapter explains the construction and operation of a specific system. The second chapter expands on this by discussing diagnosis, service, and repair of the same system.

As society transitions from printed textbooks to digital learning tools, we know it is important to provide the content you need in the format you need it in. The ***Modern Automotive Technology*** textbook and the accompanying workbook and shop manual are available in both print and digital formats, and are supported with professionally developed, user-friendly online resources. These resources include electronic study tools, videos, animations, simulations, and interactive activities designed to prepare you for success in your studies and career.

We congratulate you on your study of automotive technology and encourage you to take advantage of all the resources available as part of the ***Modern Automotive Technology*** learning solution.

About the Author

James E. Duffy has devoted much of his professional life to developing educational materials that help people understand vocational and technical subjects. Mr. Duffy earned a Bachelor of Science degree in Industrial Technology from Indiana State University. After college, Mr. Duffy worked as an automotive instructor at Brandon High School in Brandon, Florida, and at Hillsborough Adult Education Center in Tampa, Florida. After teaching for several years, Mr. Duffy joined Goodheart-Willcox Publisher as a technical editor and eventually began writing textbooks. In addition to ***Modern Automotive Technology***, Mr. Duffy's books include ***Auto Electricity and Electronics***, ***Auto Engine Repair***, ***Automatic Transmissions and Transaxles***, and ***Manual Drive Trains and Axles***.

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ZF Transmissions

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Reviewers

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Together, We Build Careers

At Goodheart-Willcox, we take our mission seriously. Since 1921, G-W has been serving the career and technical education (CTE) community. Our employee-owners are driven to deliver exceptional learning solutions to CTE students to help prepare them for careers. Our authors and subject matter experts have years of experience in the classroom and industry. We combine their wisdom with our expertise to create content and tools to help students achieve success. Our products start with theory and applied content based on a strong foundation of accepted standards and curriculum. To that base, we add student-focused learning features and tools designed to help students make connections between knowledge and skills. G-W recognizes the crucial role instructors play in preparing students for careers. We support educators' efforts by providing time-saving tools that help them plan, present, assess, and engage students with traditional and digital activities and assets. We provide an entire program of learning in a variety of print, digital, and online formats, including economic bundles, allowing educators to select the right mix for their classroom.

Student-Focused Curated Content

Goodheart-Willcox believes that student-focused content should be built from standards and/or accepted curriculum coverage. Standards from NATEF, ASE, and Precision Exams were used as a foundation in this text. ***Modern Automotive Technology*** also uses a building block approach with attention devoted to a logical teaching progression that helps students build on their learning. We call on industry experts and teachers from across the country to review and comment on our content, presentation, and pedagogy. Finally, in our refinement of curated content, our editors are immersed in content checking, securing and creating figures that convey key information, and revising language and pedagogy.

ASE and NATEF Connections

Modern Automotive Technology is correlated to standards established by the National Institute for Automotive Service Excellence (ASE) and the National Automotive Technicians Education Foundation (NATEF). These standards were developed with input from industry experts to ensure they reflect the skills students and technicians must master to succeed in the automobile service and repair industry.

ASE certification is becoming the benchmark for automobile repair technicians. It is recommended that you seek ASE certification once you have sufficient knowledge and meet the work experience requirements. Visit the ASE website for more information on ASE certification.

NATEF has established a training program accreditation process designed to improve the quality of training offered at both secondary and postsecondary levels. NATEF grants accreditation to programs that comply with their evaluation procedure, meet established standards, and adhere to the policies set forth by the organization. To learn more about the NATEF accreditation process, visit the NATEF website.

Precision Exams Certification

Goodheart-Willcox is pleased to partner with Precision Exams by correlating ***Modern Automotive Technology*** to their Automotive Service Introduction Standards. Precision Exams Standards and Career Skills Exams™ were created in concert with industry and subject matter experts to match real-world job skills and marketplace demands. Students who pass the exam and performance portion of the exam can earn a Career Skills Certification™. Precision Exams provides:

- Access to over 150 Career Skills Exams™ with pre- and post-exams for all 16 Career Clusters.
- Instant reporting suite access to measure student academic growth.
- Easy-to-use, 100% online exam delivery system.

To see how ***Modern Automotive Technology*** correlates to the Precision Exams Standards, please visit www.g-w.com/modern-automotive-technology-2017 and click on the Correlations tab. For more information on Precision Exams, including a complete listing of their 150+ Career Skills Exams™ and Certificates, please visit www.precisionexams.com.

Features of the Textbook

Features are student-focused learning tools designed to help you get the most out of your studies. This visual guide highlights the features designed for the textbook.



Illustrations have been designed to clearly and simply communicate the specific topic.

Learning Objectives clearly identify the knowledge and skills to be obtained when the chapter is completed.



Cautions identify situations that may cause damage to a vehicle, equipment, or tools if proper procedures are not followed.

Service Procedures are highlighted throughout the textbook to provide clear instructions for hands-on service activities. You can refer back to these procedures easily.

Tech Tips provide supplemental technical information and service hints related to the procedure or system being explained.

Warnings identify repair operations that can result in personal injury if proper procedures or safety measures are not followed.

Troubleshooting Charts help you develop critical-thinking, diagnostic, and troubleshooting skills needed in the workplace today.

Workplace Skills, Customer Relations, Green Tech, In the Rearview Mirror, Industry Trend, Safety First, and **Hybrid Tip** features help you develop the professional skills, behaviors, and traits employers look for in their employees.

Review Questions allow you to demonstrate knowledge, identification, and comprehension of chapter material.

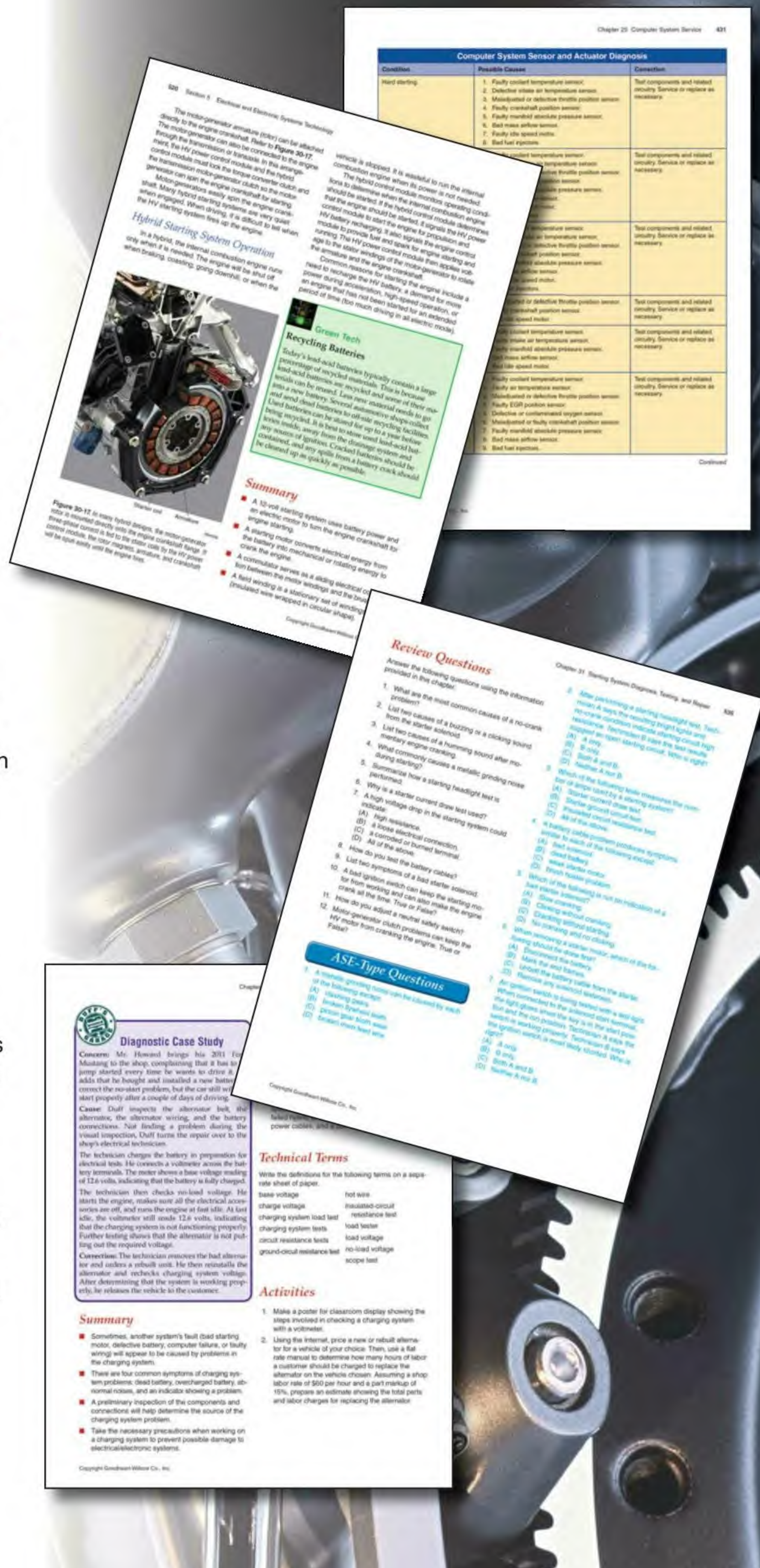
ASE-Type Questions help you prepare for the types of questions encountered on the ASE certification tests.

Diagnostic Case Studies help you develop logical troubleshooting techniques and reinforce the 3Cs approach to vehicle diagnosis and repair.

Technical Terms list the key terms that were presented in the chapter.

Activities extend your learning and help you analyze and apply knowledge.

Summary feature provides an additional review tool for you and reinforces key learning objectives.



Student Resources

Textbook

The ***Modern Automotive Technology*** textbook provides an exciting, full-color, and highly illustrated learning resource. The textbook is available in print or online versions.

Workbook

The student workbook includes a variety of questions, in various formats, to help reinforce textbook content. Each chapter corresponds to the text and reinforces key concepts and applied knowledge. Step-by-step jobs in the workbook guide students through important service and repair procedures.

Shop Manual

The shop manual provides hands-on practice of 100% of the tasks in all three sections of the NATEF Task List (MLR, AST, and MAST). Each job in this manual is a hands-on activity that corresponds to one or more NATEF Tasks. The jobs help students develop the hands-on skills needed to succeed in the field and are intended to be completed in a shop setting under the guidance of an instructor.

MLR Shop Manual

The MLR Shop Manual provides hands-on practice of 100% of the tasks in the NATEF Maintenance and Light Repair Task List. It is designed specifically for use in MLR-accredited training programs, as well as in programs seeking MLR accreditation. Each of the jobs in this manual is designed to be accomplished in a single lab session.

Online Learning Suite

Available as a classroom subscription, the Online Learning Suite provides the foundation of instruction and learning for digital and blended classrooms. An easy-to-manage shared classroom subscription makes it a hassle-free solution for both students and instructors. An online student text and workbook, along with rich supplemental content, brings digital learning to the classroom. All instructional materials are found on a convenient online bookshelf and are accessible at home, at school, or on the go.

Online Learning Suite/Student Textbook Bundle

Looking for a blended solution? Goodheart-Willcox offers the Online Learning Suite bundled with the printed text in one easy-to-access package. Students have the flexibility to use the print version, the Online Learning Suite, or a combination of both components to meet their individual learning style. The convenient packaging makes managing and accessing content easy and efficient.

Instructor Resources

Instructor resources provide information and tools to support teaching, grading, and planning; course administration; class presentations; and assessment.

Instructor's Presentations for PowerPoint®

Help teach and visually reinforce key concepts with prepared lectures. These presentations are designed to allow for customization to meet daily teaching needs. They include objectives, outlines, and images from the textbook.

ExamView® Assessment Suite

Quickly and easily prepare, print, and administer tests with the ExamView® Assessment Suite. With hundreds of questions in the test bank corresponding to each chapter, you can choose which questions to include in each test, create multiple versions of a single test, and automatically generate answer keys. Existing questions may be modified and new questions may be added. You can prepare pretests, formative tests, and summative tests easily with the ExamView® Assessment Suite.

Instructor's Resource CD

One resource provides instructors with time-saving preparation tools such as answer keys; lesson plans; correlation charts to NATEF, ASE, and Precision Exam standards; and other teaching aids.

Online Instructor Resources

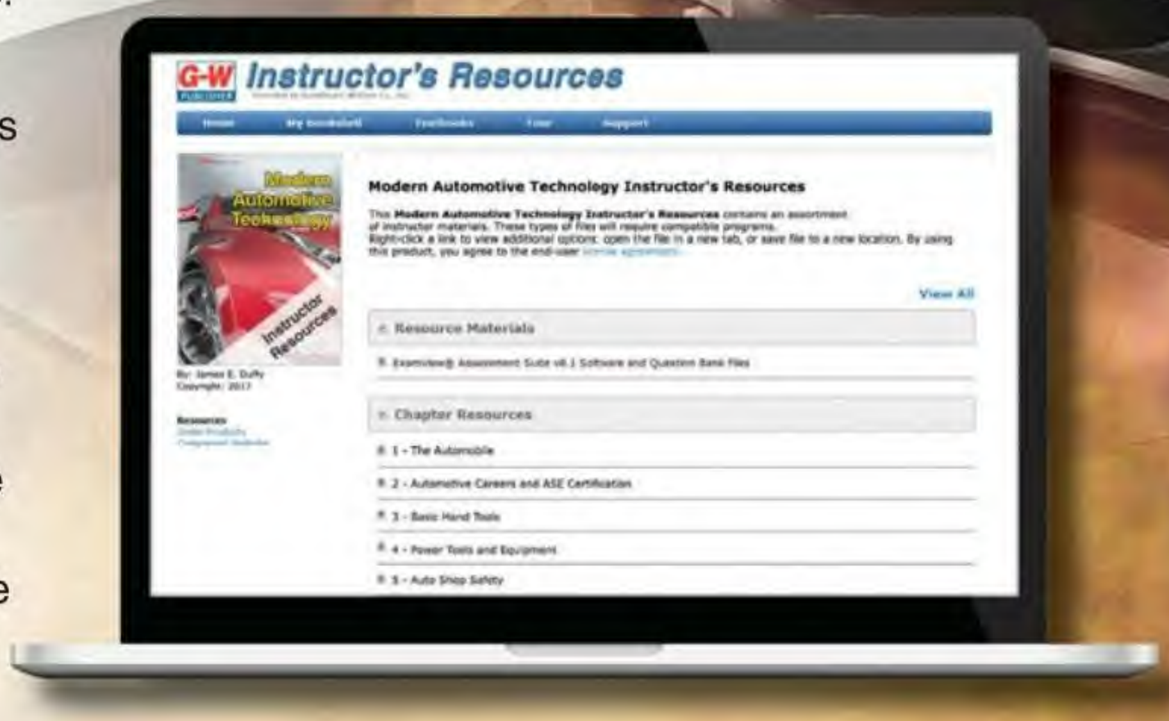
Online Instructor Resources provide all the support needed to make preparation and classroom instruction easier than ever. Available in one accessible location, support materials include Answer Keys, Lesson Plans, Instructor Presentations for PowerPoint®, ExamView® Assessment Suite, and more! Online Instructor Resources are available as a subscription and can be accessed at school or at home.

Video Clip and Animations Library

Live-action videos and animations provide students the opportunity to watch hands-on demonstrations of essential skills.

G-W Online

This exciting new learning product brings the text and learning alive for your students! The textbook's interactive learning activities engage your students, providing them with dynamic visuals and immediate feedback. It enhances your course with course management and assessment tools that accurately monitor and track student learning. The ultimate in convenient and quick grading, G-W Online allows you to spend more time teaching and less on administration. This G-W Online also contains DVOM Simulations with activities that allow students to practice using this important electrical testing tool.



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Section 1

Introduction to Automotive Technology

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Automotive Measurement and Math

Chapter 7
Service Information and Work Orders

Chapter 8
Fasteners, Gaskets, Seals, and Sealants

Chapter 9
Vehicle Maintenance, Fluid Service, and Recycling

Chapter 10
Career Success

We are truly living in a "world of wheels." Every day, millions of people depend on their cars, trucks, vans, and sport-utility vehicles as their primary means of transportation. As a result, economic experts predict a strong demand for skilled automobile technicians and related professionals for the foreseeable future. You have chosen to study an area of employment that pays well and will require thousands of new graduates yearly.

Section 1 will introduce you to the basics of automotive technology, including information on automobile construction and operation, ASE certification, safety, tools and equipment, fasteners, service information, careers, and vehicle maintenance. This section will give you the knowledge needed to secure an entry-level job. It will also lay the groundwork for later chapters, which provide in-depth coverage of automotive service and repair.

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Chapter 1
The Automobile

After studying this chapter, you will be able to:

- Identify and describe primary automotive assemblies and major automotive systems.
- Explain the frequent electronic interaction of major automotive systems or circuits.
- Describe and compare major automobile design variations.
- Identify and locate the most important systems used to operate conventional and hybrid passenger vehicles.
- Comprehend later textbook chapters with a minimum amount of difficulty.
- Correctly answer ASE certification test questions that require a general understanding of the major parts and systems of a vehicle.

The term ***automobile*** is derived from the Greek word *autos*, which means self, and the French word *mobile*, which means moving. Today's "self-moving" vehicles are engineering marvels of safety and dependability. Over the last century, engineers and skilled workers the world over have used all facets of ***technology*** (application of math, science, physics, engineering, and other subjects) to steadily give us a more efficient means of transportation.

You are about to begin your study of the design, construction, service, maintenance, and repair of modern passenger vehicles. This chapter provides a "quick look" at different makes and models of cars and how they operate. By knowing a little about all major systems, you will be better prepared to learn the more detailed information presented later in this textbook.

Today, a vehicle is as much electronic as it is mechanical. Failure of one computer-controlled system can affect the operation of a seemingly unrelated system. This makes a thorough understanding of the whole automobile and its major systems critical.

Tech Tip

Try to learn something new about the automotive industry every day. In addition to studying this book and doing all the hands-on activities, read automotive magazines, browse the Internet, and watch "motor-sport" television programs. Increasing your knowledge daily will help you become a better technician with little effort!

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Parts, Assemblies, and Systems

A ***part,*** sometimes called a ***component***, is the smallest removable item on a car. A part is not normally disassembled. It is often a one-piece casting or forging made of metal or plastic. An electrical component is a part in an electrical circuit or system.

An ***assembly*** is a set of fitted parts designed to complete a specific function. For example, the engine is an assembly that converts fuel into useable power to move the vehicle. Technicians must often take assemblies apart and put them back together during maintenance, service, and repair operations. See **Figure 1-1.**

An automotive ***system*** is a group of related parts and assemblies that performs a specific function (job or task). For example, your vehicle's steering system contains the steering wheel, steering shaft, steering gears, linkage rods, and other parts. These parts allow you to control the direction of the wheels and tires for maneuvering (turning) your vehicle. **Figure 1-2** shows the major systems of a vehicle. Memorize the name and general location of each system. The following sections will provide you with an overview of the parts and systems found on late-model vehicles.



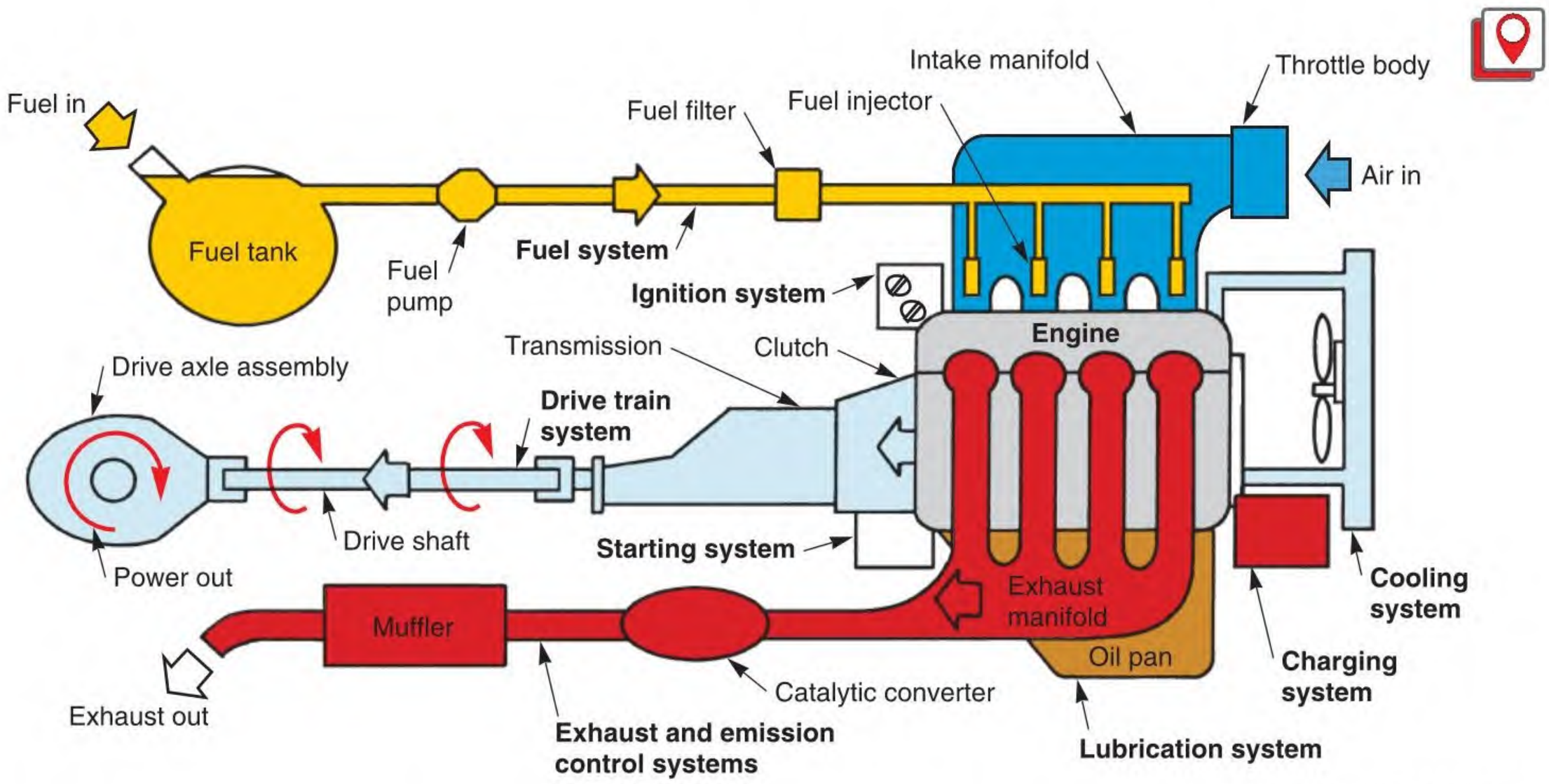
Assembly

Audi

Figure 1-1. An assembly is a group of parts that work together to perform a function. For example, an engine is an assembly that contains pistons, which convert the fuel's heat energy into useable kinetic energy (motion). As you will learn, an engine has many other parts.

Frame, Body, and Chassis

The frame and body are the two largest sections, or parts, of a motor vehicle. The ***frame*** is the strong metal structure that provides a mounting place for all the other



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Figure 1-2. Note the general location of the major vehicle systems. Study the fuel, air, exhaust, and power.

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parts. The frame holds the engine, transmission, suspension, steering, and other assemblies in position.

The ***body*** is a steel, aluminum, fiberglass, plastic, or composite (carbon fiber) skin forming the outside of the vehicle. The body is painted to give the vehicle an attractive appearance.

The term ***chassis*** is often used when referring to a vehicle's frame and everything mounted to it except the body—tires, wheels, engine, transmission, and drive axle assembly.

In ***body-over-frame construction***, or full-frame construction, the frame consists of thick steel members. The chassis parts and the body bolt to this frame. This heavy, strong design is used on some cars, vans, pickup trucks, and sport-utility vehicles (SUVs). Full size trucks always use body-over-frame construction. Refer to **Figure 1-3**.

With ***unibody construction***, sheet metal body panels are welded together to form the body and frame. Also called unit-body construction or unitized construction, this is the most common design used to build small and medium passenger cars. Unibody vehicles are generally lighter and more fuel efficient than body-over-frame vehicles and have a high strength-to-weight ratio. See **Figure 1-4**.

General Vehicle Specifications

The following section describes common vehicle specifications. Manufacturers generally publish these specifications for each model they produce.

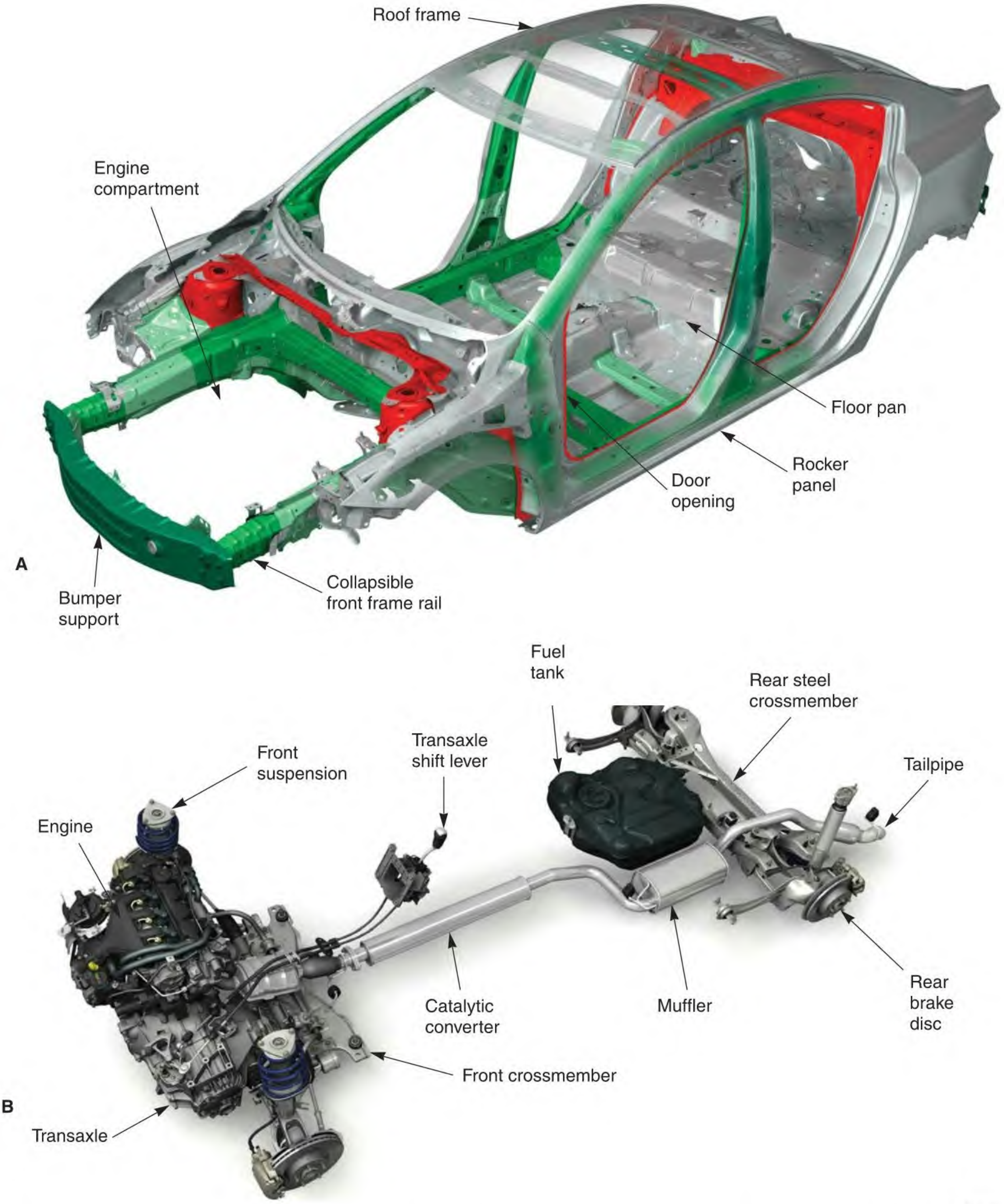
Vehicle curb weight is the total weight of the vehicle with a full tank of gas and no driver. Vehicle curb weights vary. Generally, pickup trucks and SUVs



Ford

Figure 1-3. With body-over-frame construction, the chassis parts bolt to a strong frame.

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Mazda

Figure 1-4. Unibody vehicles do not have a separate frame. Steel or aluminum panels are normally welded together at the factory to produce a unibody vehicle. A—Unibody with the chassis removed. B—Chassis components attach directly to the sheet metal body structure through large steel crossmembers.

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are the heaviest vehicles and weigh two and a half tons. Full-size cars, station wagons, and full-size vans weigh about two tons. Compact cars have a low curb weight of about 3000 lb (1360 kg). Small sports cars and micro cars are the lightest passenger vehicles, weighing in at about 2000 lb (907 kg).

Vehicle weight distribution is a measurement of how much force is pushing down on the front and rear tires of the vehicle. An ideal weight distribution for economy and cornering ability (ability to turn a corner while maintaining directional stability) is 50/50, or 50% front and 50% rear. A 50/50 weight distribution can be found on many high-performance sports cars. Front-wheel drive vehicles have about a 70% front and 30% rear weight distribution for good tire traction with the road surface.

Vehicle wheelbase is the distance from the centerline of the front wheels to the centerline of the rear wheels. A typical wheelbase for a full-size car might be 100″ (254 cm) for a small, compact car and up to 150″ (381 cm) for a full-size pickup truck.

Track width is the distance between the centerlines of the two wheels on the same axle (right and left front wheels or left and right rear wheels). The trend is to make vehicles wider so they can corner more quickly without a rollover accident. A typical track width might be 62″ (157 cm) at the front axle and 64″ (163 cm) at the rear axle.

Vehicle length is a measurement from the outermost point on the front bumper to the outermost point on the rear bumper. ***Vehicle width*** is the distance between the two widest points from the right to left sides of the body measured perpendicular to the vehicle's centerline. Refer to **Figure 1-5**. ***Vehicle height*** is measured from the ground to the highest point on the roofline.

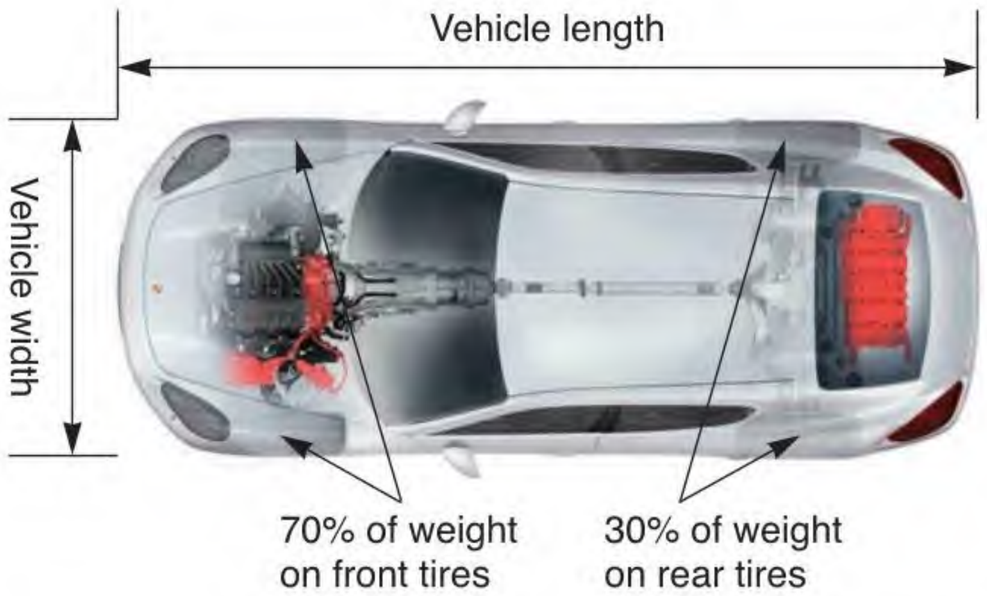


Figure 1-5. Note how the vehicle dimensions and weight distribution are given for a passenger vehicle.

Vehicle Size

A full-size car is capable of carrying four or five adults. It usually has four doors and is rear- or all-wheel drive with a relatively large engine. Full-size cars are the heaviest passenger cars, but they still get slightly better gas mileage than most trucks and SUVs.

A midsize car is shorter and lighter than a full-size car, but it can still carry up to four adults comfortably. It often has a smaller engine and gets better fuel economy than full-size cars because of its reduced curb weight and frontal cross section.

A compact car usually has front-wheel drive with a small 4- or 6-cylinder engine. Compact cars are generally very fuel efficient because they are smaller and lighter than full-size and midsize cars.

The minicompact car is the smallest car allowed on public roads. It often only seats two people. Its wheelbase is very short, and the diameter of its wheels and tires is normally smaller than that of other vehicles. Their low weight and tiny engine make the minicompact car one of the most fuel-efficient vehicles on the market. See **Figure 1-6**.

Vehicle Aerodynamics

Aerodynamics is the study of the motion of air as it interacts with a moving object. In automotive engineering, aerodynamics is the study of the resistance to airflow over and under the car body at highway speeds. Aerodynamic drag is the "worst enemy" of good gas mileage.

The goal of auto manufacturers is to design a vehicle with a very low drag, or resistance to movement through the air. This is done by designing cars



Figure 1-6. This micro car is an example of a minicompact car.

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with very small frontal cross-sectional areas. The height and width of the car body should be very small. A vehicle with a small cross-sectional area produces less resistance to airflow than a vehicle with a large cross-sectional area. Refer to **Figure 1-7**.

Coefficient of drag (Cd) is a number that represents the force required to move a passenger vehicle through air. A good Cd for a small sports car is 0.26. The Cd for a larger vehicle, such as a truck or van, might be as high as 0.40. Fuel economy is reduced by an increase in Cd, as the vehicle has to push more air out of its way when moving.

Vehicle Body Types

Automobiles are available in several models, or body types, including the sedan, convertible, hatchback, station wagon. In addition, the minivan, crossover vehicle, sport-utility vehicle (SUV), pickup truck, and micro car have become increasingly popular.

A sedan is a car that has front and back seats and will carry four to six people. Both two-door and four-door sedans are available. They have center body pillars, or "B" pillars, between the front door and rear quarter panel, **Figure 1-8A**.

A convertible has a roof panel that can be raised and lowered into a well located behind the back seat. The convertible roof can be made of metal, a composite, or a synthetic fabric. Metal roofs fold into the trunk area. A convertible has no door pillars, and its strength is designed into the center area of the frame or floor pan. Convertibles are normally two-door models, **Figure 1-8B.**

A hatchback, or liftback, has a large rear door for easy access when hauling items. This style car is available in three- and five-door models, **Figure 1-8C.**

A station wagon has a long, straight roof that extends all the way to the rear of the vehicle. Station wagons have large rear interior compartments and come in two- and four-door models. See **Figure 1-8D**.

A full-size van has a large body for large families or commercial service. The minivan is midsize and similar to the station wagon, but it has a higher roofline for more headroom and cargo space. Most minivans are designed to carry seven passengers. They are usually front-wheel drive. See **Figure 1-8E**.

A pickup truck is a front-engine, cab-forward vehicle with a large, open cargo area in the rear. Full-size pickups use a frame made of heavy gauge steel. The cab, bed, fenders, and other body panels are bolted to the frame. Rubber bushings fit between body panels and the frame to prevent noise and vibration from entering the passenger area.

Sport-utility vehicles are often equipped with four-wheel drive systems and have a high roofline and floor pan. Because of the high floor pan, SUVs have ample



Mazda

Figure 1-7. A low-slung car body with smooth shapes and a small frontal cross section decreases aerodynamic drag and amount of power needed to keep the vehicle moving at any speed. The trend is moving away from heavy SUVs and trucks to smaller vehicles that get better gas mileage.

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ground clearance for off-road driving. They provide the comfort of a passenger car, the interior space of a station wagon, and the durability of a truck. Since an SUV is very heavy, with a complex heavy-duty four-wheel drive system, it is not as fuel efficient as other types of vehicles, **Figure 1-8F**.

The crossover vehicle is a design mix. It is an SUV built on a passenger car or station wagon chassis. The crossover is about half as tall as a minivan, which lowers its center of gravity for more rollover stability when cornering rapidly. The crossover also has a smaller cross section for improved aerodynamics.

Common names for various automobile body parts are shown in **Figure 1-9**. Note that a vehicle's right and left sides are denoted as if you were sitting in the car looking forward.

Fuel Efficiency

Fuel efficiency, or fuel economy, is a rating of how far a vehicle can travel on only one gallon of fuel



A—Sedan



B—Convertible



C—Hatchback



D—Station Wagon



E—Minivan

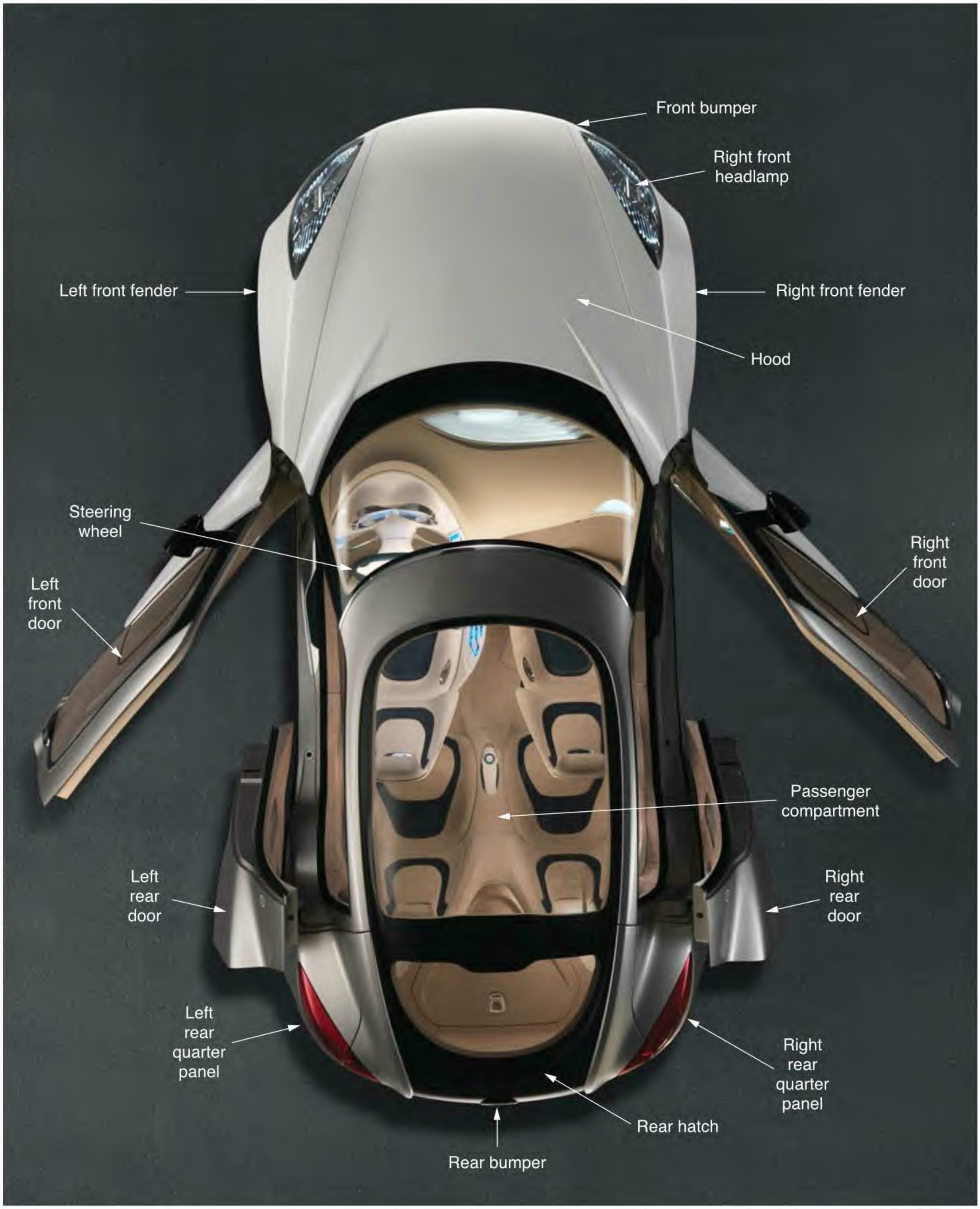


F—Sport-Utility Vehicle

Chrysler, Porsche, Ford, Subaru, Honda

Figure 1-8. Note the various vehicle body styles.

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Figure 1-9. Study the part and panel names on the right and left sides of a vehicle.

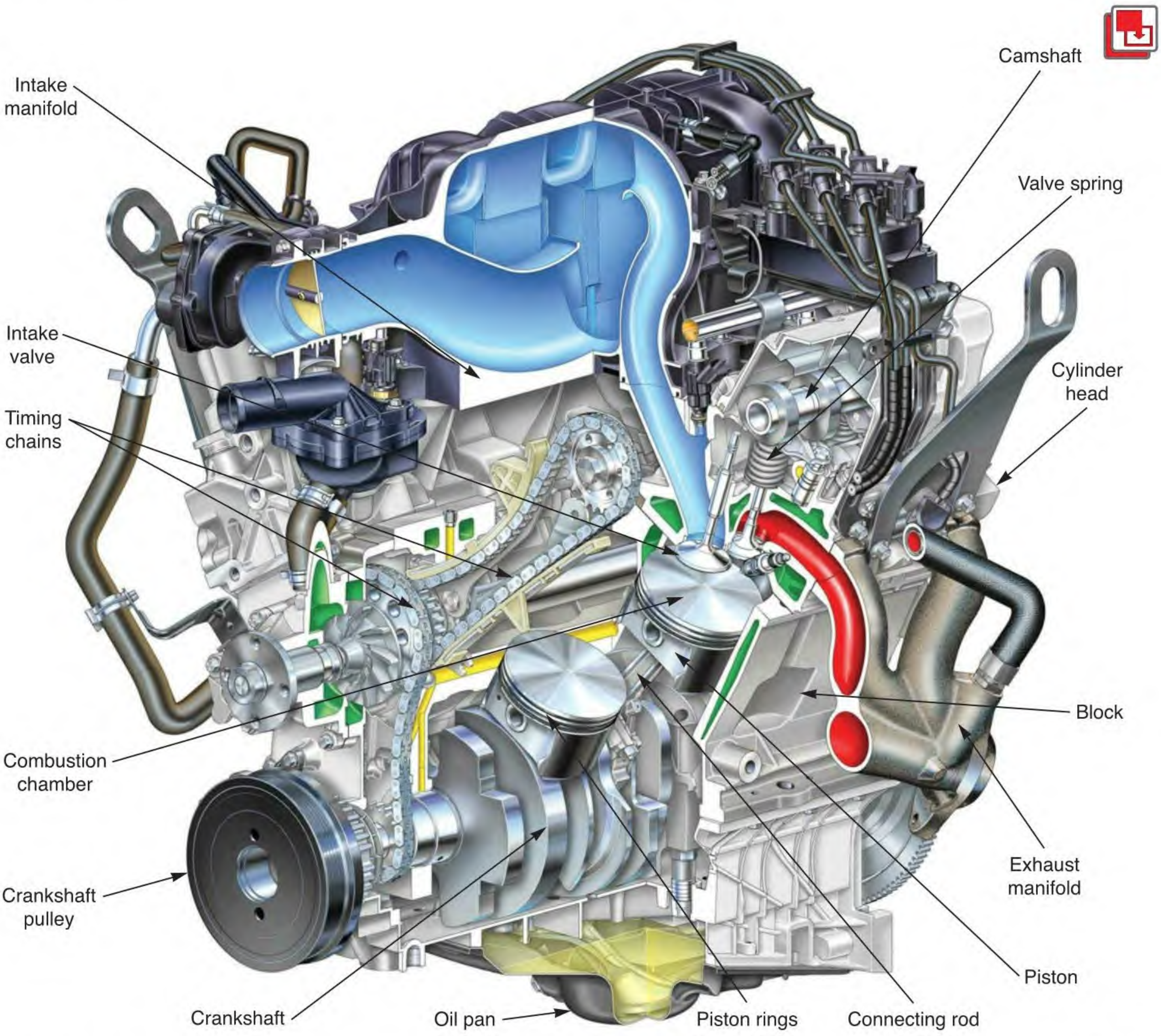
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(gasoline or diesel fuel). The EPA tests and rates cars to give them an average city and highway fuel economy rating. A typical fuel economy rating for a small economy car might be 40 miles per gallon (mpg) city and 43 mpg highway.

Estimated city EPA fuel economy testing is done with a preset number of stops so the car has to accelerate to cruising speeds. Estimated highway EPA fuel economy ratings are for steady state interstate cruising speeds.

Engine

The ***engine*** provides the energy to propel (move) the vehicle and operate other vehicle systems. Most engines consume gasoline or diesel fuel. The fuel burns inside the engine to produce heat. This heat causes hot gas expansion, creating high pressure inside the engine to move its parts to produce power. See **Figure 1-10**.



Ford

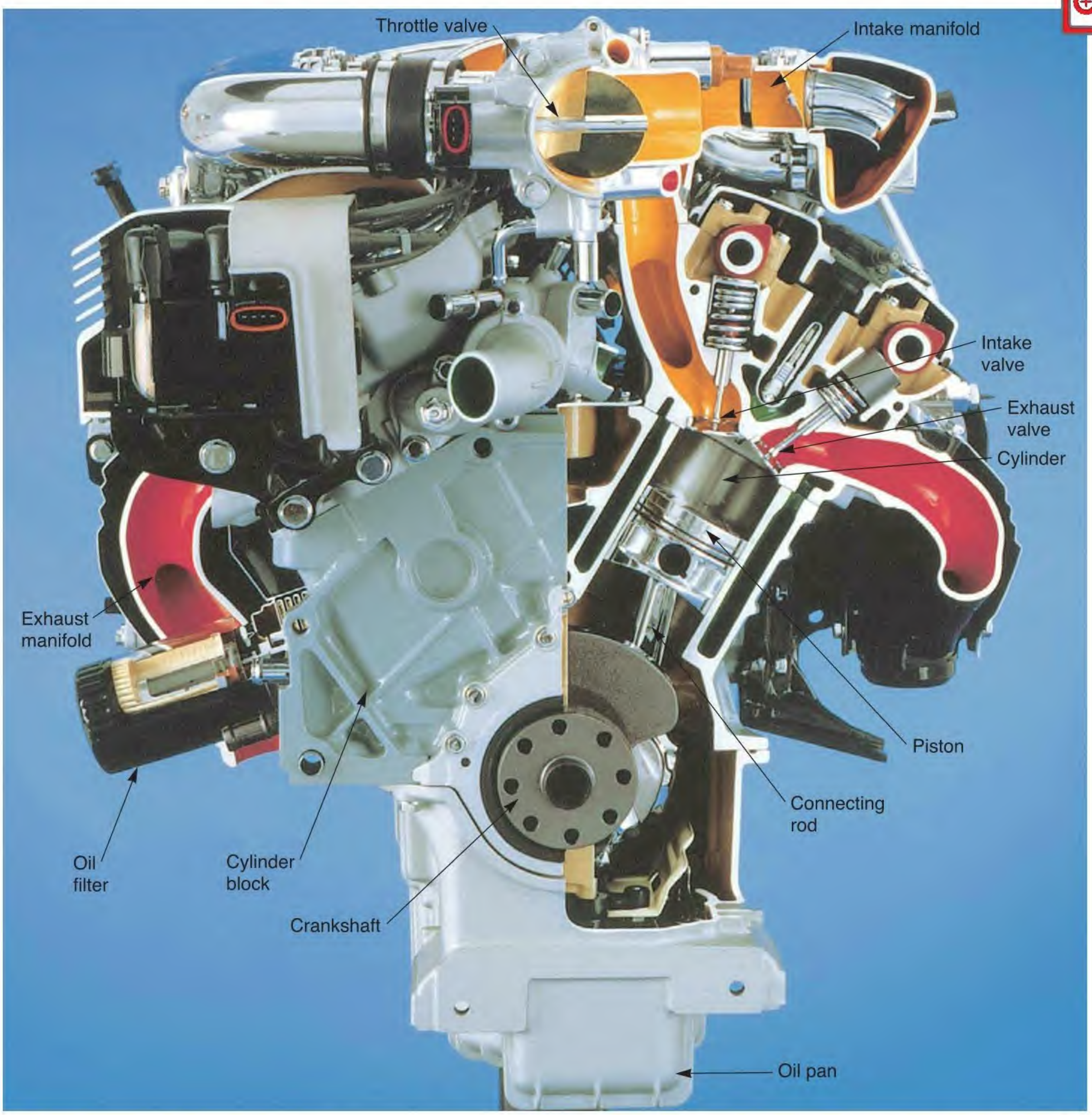
Figure 1-10. Study the major parts from the front view of a modern engine.

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Basic Engine Parts

The basic parts of an engine are shown in **Figures 1-10** and **1-11**. Refer to these illustrations as each part is introduced.

- Block—The metal casting that holds all the other engine parts in place is the block.
- Cylinder—The cylinder is a round hole that is bored (machined) in the block. It guides piston movement.
- Piston—The piston is a cylindrical component that transfers the energy of combustion (burning of air-fuel mixture) to the connecting rod.



Ford

Figure 1-11. Locate the major parts with the rear view of the engine. The clutch and transmission often bolt to the steel crankshaft flange to harness the engine's high power output.

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- Rings—The small gap around the sides of the piston are sealed by rings. They keep combustion pressure and oil from leaking between the piston and the cylinder wall (cylinder surface).
- Connecting rod—The connecting rod links the piston to the crankshaft.
- Crankshaft—The crankshaft changes the reciprocating (up-and-down) motion of the piston and rod into useful rotary (spinning) motion.
- Cylinder head—The top of the cylinder is covered and sealed by the cylinder head. It also holds the valves, rocker arms, and often, the camshaft.
- Combustion chamber—The combustion chamber is a small cavity (hollow area) between the top of the piston and the bottom of the cylinder head. The burning, or combustion, of the air-fuel mixture occurs in the combustion chamber.
- Valves—The valves open and close to control the flow of air or an air-fuel mixture into the combustion chamber and exhaust gases out of the combustion chamber.
- Camshaft—The opening of the valves is controlled by the camshaft.
- Valve springs—The valve springs keep the valves closed when they do not need to be open.
- Rocker arms—The rocker arms transfer camshaft action to the valves.
- Lifters—The lifters, or cam followers, ride on the camshaft and transfer motion to the other parts of the valve train.
- Flywheel—The flywheel helps keep the crankshaft turning smoothly. It also provides a large gear that is engaged by the starting motor during engine starting.

Automotive Engines

Automobile engines normally use a four-stroke cycle. Four separate piston strokes (up or down movements) are needed to produce one cycle (complete series of events). The piston must slide down, up, down, and up again to convert heat energy (burning fuel) into kinetic energy (spinning crankshaft).

Automotive engines are ***multi-cylinder engines***, which means they have more than one piston and cylinder. Today's vehicles can have 2-, 3-, 4-, 5-, 6-, 8-, 10-, or 12-cylinder engines. Additional cylinders generally increase engine size and power output, but they lower fuel economy. The industry trend is to smaller engines with 2, 3, and 4 cylinders. More power is needed for speeding up, or accelerating, as well as towing and traveling uphill. The additional cylinders smooth engine operation because there is less time (degrees of crankshaft rotation) between power (energy producing) strokes.

Computer System

The ***computer system*** uses electronic and electrical devices to monitor and operate various mechanical systems. Electronic controls are provided for the engine, drive train, suspension, instrumentation, restraint, and other systems. The use of computer systems has improved vehicle efficiency and dependability. Additionally, all on-board computers now have a powerful self-diagnostic capability. Today's vehicle computers can troubleshoot every major assembly, circuit, component, and system almost instantly.

There are three major parts of an automotive computer system:

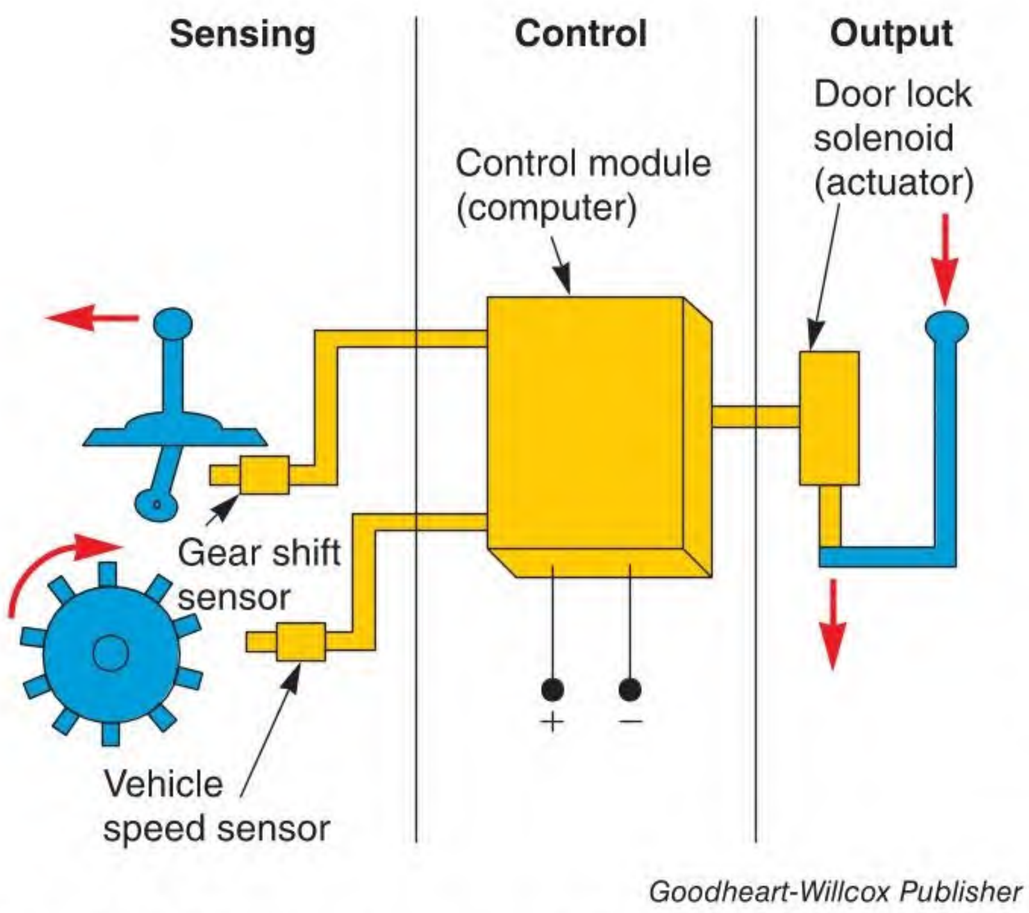
- Sensors—Sensors are input devices that can produce or modify electrical signals with a change in a condition, such as motion, temperature, pressure, speed, location, etc. The sensors are the "eyes, ears, and nose" of the computer control system.
- Electronic control module—The electronic control module is a computer (complex electronic circuits) that uses signals from input devices (sensors) to control various output devices (actuators). The control module is the "brain" of the computer control system.
- Actuators—Actuators are output devices, such as small electric motors or electromagnets, that can move parts when energized by the control module. The actuators serve as the "hands and arms" of the computer control system.

A modern car can have several control modules and dozens of sensors and actuators, all "talking" (transferring data) with a main computer processor. See **Figure 1-12**. A main computer processor is a larger, more complex control module with more memory than the other control modules wired into the vehicle's network. All system control modules are wired to this main computer processor to exchange data on vehicle operation. If any other sensor or system control module detects a problem, it will signal the main computer processor so it can turn on a dash warning light.

Tech Tip

Learn all you can about electricity and electronics. Now that an electronic network operates every major vehicle system, it is almost impossible to service anything on a car without handling some type of electric or electronic component. This book covers electronics in almost every chapter.

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Figure 1-12. This computer can operate the fuel injectors, fire the spark plug, and lock the car doors. When the sensors send the correct signals to their control modules, the electronic circuit energizes one or more of its circuit actuators. Solenoids and small electric motors can then convert the electrical signal into motion. This basic type of electronic control module is used in most major vehicle systems.

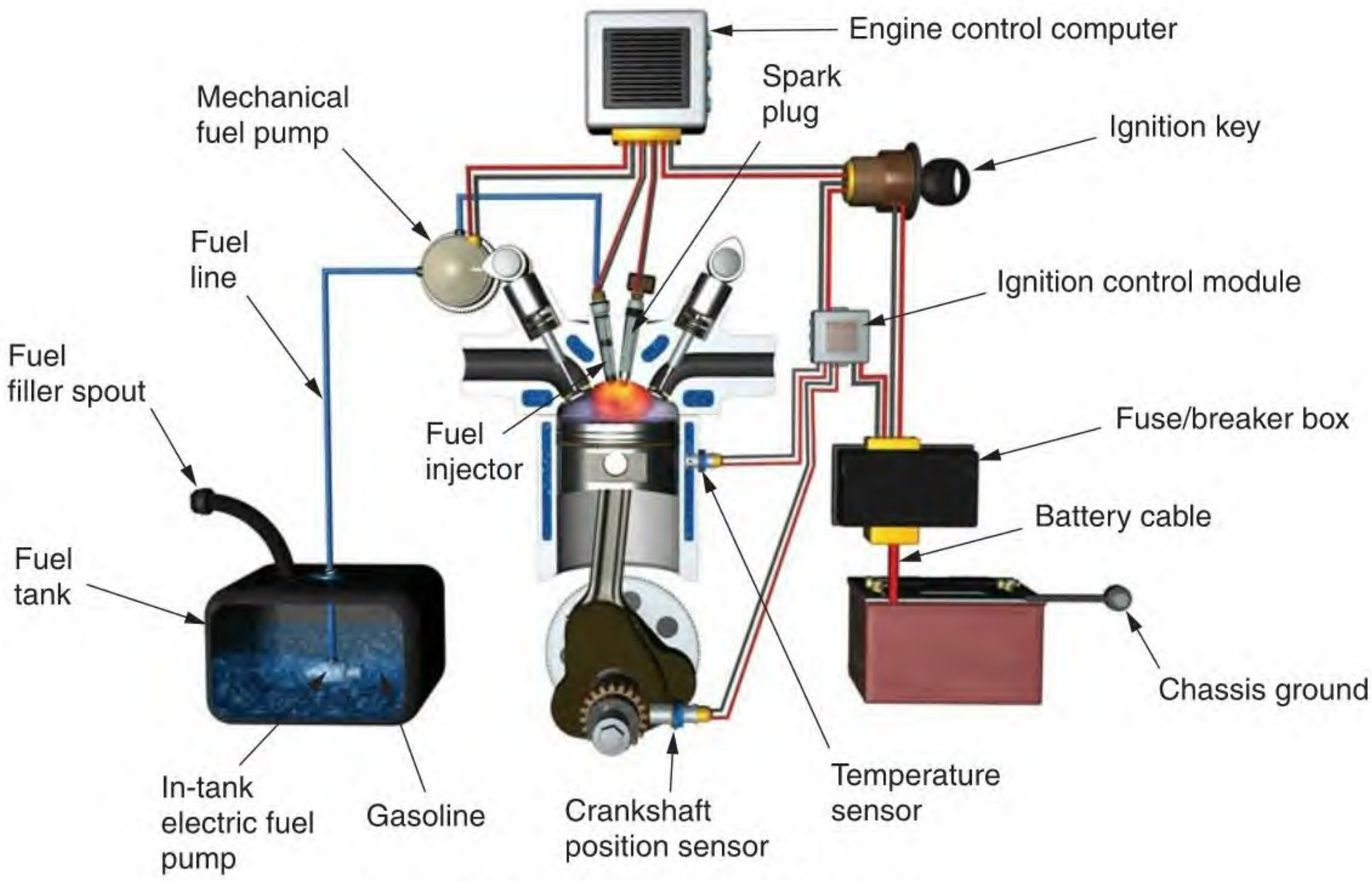
Fuel System

The ***fuel system*** must introduce the correct amount of fuel into the cylinders for efficient combustion (burning) inside the engine. This ensures that a very volatile (flammable) mixture exists inside the combustion chambers when the electric arc lights the mixture at a spark plug during the compression stroke. A spark plug provides an air gap between two large electrodes so a high-voltage electrical arc can ignite the air-fuel mixture in the combustion chamber of a gasoline engine cylinder. The ignition system spark plugs screw into the cylinder heads so electrodes and air gaps extend inside the combustion chambers of the gasoline engine.

The fuel system must also alter the ***air-fuel ratio*** (percentage of air and fuel) with changes in engine operating conditions (temperature, altitude, engine speed, load, and other variables). Refer to **Figure 1-13**.

Gasoline Injection System

Almost all late-model engines use ***direct gasoline injection systems***, which spray gasoline right into the combustion chambers above the pistons. In this type of system, an in-tank electric fuel pump forces



Basic Engine Ignition and Fuel Systems

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Figure 1-13. Note the basic parts and operation of an engine's fuel and ignition systems. The fuel tank usually stores gasoline. The in-tank electric fuel pump forces gasoline to an engine-mounted fuel pump. This pump increases fuel pressure to about 3000 psi and delivers this fuel to the injectors. The ignition system is used to start combustion. The spark plug must fire at the correct time during the compression stroke.

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fuel from the fuel tank to the engine. Another engine-mounted mechanical fuel pump highly pressurizes this fuel and forces it to the electrically operated fuel injectors (fuel valves). The engine control module, reacting to electrical data it receives from the engine sensors, energizes the fuel injectors. When the computer energizes an injector, an electromagnet inside the injector pulls the injector nozzle open to allow a fine mist of fuel to spray into the combustion chamber, mixing with the air already inside the cylinder.

A throttle valve controls airflow, engine speed, and engine power. When the throttle valve is open for more engine power output, the computer holds the injectors open longer, allowing more fuel to spray out into the combustion chambers. When the throttle valve is closed, the computer opens the injectors for only a small amount of time, reducing engine power output. The throttle valve (air valve) is mechanically or electrically connected to the accelerator pedal. When the floor-mounted pedal is pressed, the throttle valve opens. This increases the amount of air and fuel entering the engine for more power and speed.

Electrical System

The vehicle's electrical system consists of several subsystems (smaller circuits), including the ignition, starting, charging, and lighting systems. Each subsystem is designed to perform a specific task, such as "fire" the spark plugs to ignite the engine's air-fuel mixture, electrically rotate the crankshaft to start the engine, illuminate the highway for safe night driving, etc.

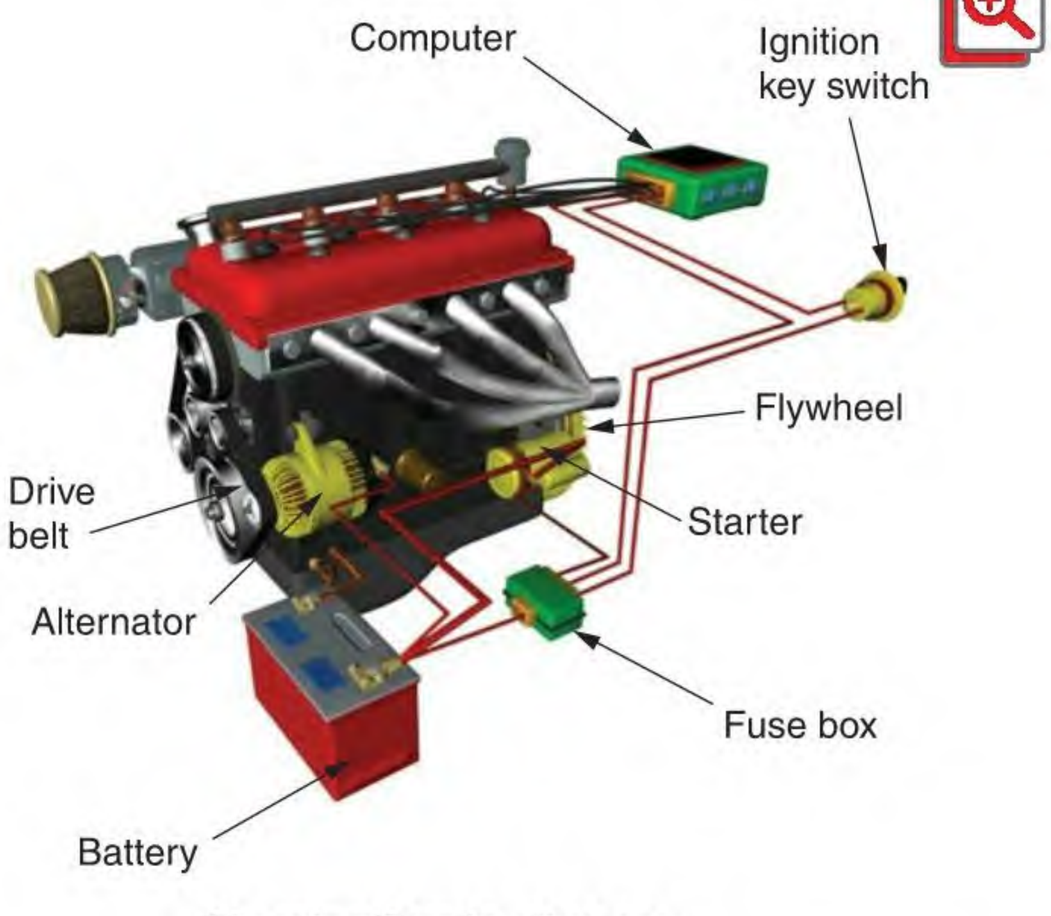
Ignition System

An ***ignition system*** is needed on gasoline engines to ignite the air-fuel mixture. It produces a high-voltage surge that jumps, or arcs, across the air gap at the spark plug tip at the correct time. This causes the air-fuel mixture to start to burn and expand in the combustion chamber.

Starting System

The ***starting system*** has a powerful electric starting motor, which rotates the engine's crankshaft until the engine "fires" and runs on its own power. The major parts of the starting system are shown in **Figure 1-14**.

A battery provides the electricity for the starting system. The driver turns the ignition key to the start position or presses an engine start button. The current then flows through the starting circuit to energize the starting motor. The starting motor then spins the crankshaft. As soon as the engine starts, the driver releases the key or button so the engine keeps running. With late-model cars, the computer de-energizes and disengages the starting motor as soon as the engine starts and its speed increases.



Charging/Starting Systems

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Figure 1-14. Note the location of basic parts of conventional starting and charging systems. These parts are eliminated in hybrid vehicles with the motor-generator.

Charging System

The ***charging system*** is needed to replace electrical energy drawn from the battery. With a 12-volt battery, a belt-driven alternator forces electric current back into the battery.

When the engine is running, a drive belt spins the alternator pulley. The alternator can then produce electricity to recharge the battery and operate other electrical needs of the vehicle. A voltage regulator, usually built into the alternator, controls the voltage and current output of the alternator.

Tech Tip

Most late-model hybrid vehicles do not need conventional starting and charging systems with a separate alternator and starting motor. Instead, hybrids use a motor-generator to recharge the batteries and "crank the engine" for start-up. This reduces vehicle weight and complexity for added fuel economy and dependability.

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Lighting System

The ***lighting system*** consists of a vehicle's interior and exterior lights and all the components that operate them (fuses, wires, switches, relays, etc.). The exact circuit and part configurations will vary from one model to another.

The exterior lights typically include the headlights, turn signals, brake lights, parking lights, backup lights, and side marker lights. The interior lights include the dome light, trunk light, instrument panel lights, and other courtesy lights.

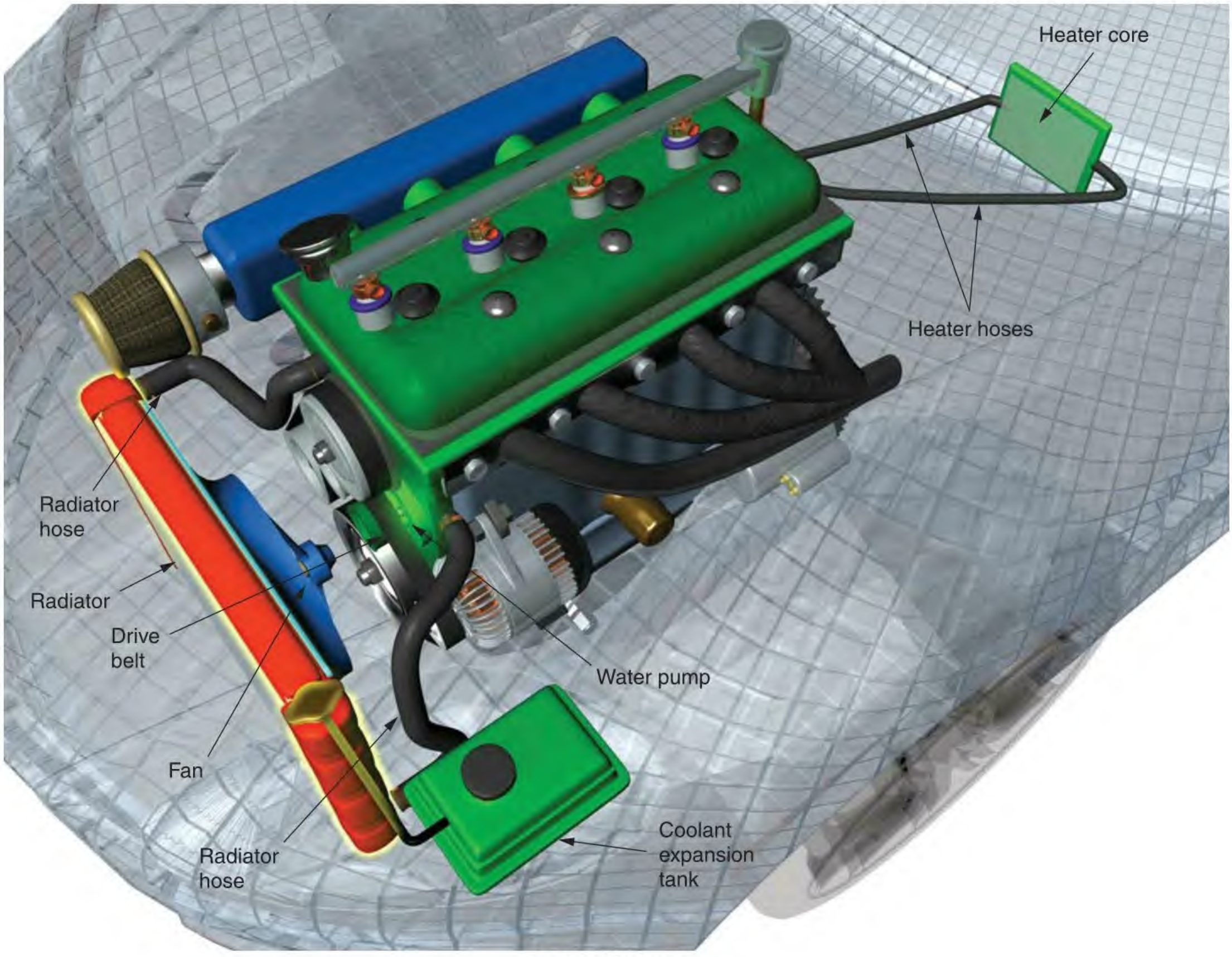
Cooling and Lubrication Systems

The cooling and lubrication systems are designed to prevent engine damage and wear. They are vital systems that prevent the engine from self-destructing.

The ***cooling system*** maintains a constant engine operating temperature. It removes excess combustion heat to prevent engine damage and also speeds engine warm-up. Look at **Figure 1-15**.

The water pump forces coolant (water and antifreeze solution) through the inside of the engine, hoses, and radiator.

The coolant collects heat from the hot engine parts and carries it back to the radiator. The radiator



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Figure 1-15. The cooling system must protect the engine from the heat of combustion. Combustion heat could quickly and easily melt and ruin many aluminum engine parts. For exhaust cleanliness, the cooling system must also speed engine warm-up and maintain a constant operating temperature.

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allows the coolant heat to transfer into the outside air. An engine fan draws cool air through the radiator.

The thermostat controls coolant flow and engine temperature. It is usually located where the top radiator hose connects to the engine.

The ***lubrication system*** reduces friction and wear between internal engine parts. It circulates clean, filtered oil to high-friction points in the engine, such as bearings, camshaft, crankshaft, and pistons. The lubrication system also helps cool the engine by carrying heat away from high-friction points in the engine.

Exhaust and Emission Control Systems

The ***exhaust system*** quiets the noise produced during engine operation and routes engine exhaust gases to the rear of the vehicle body. **Figure 1-16** illustrates the basic parts of an exhaust system. Trace the flow of exhaust gases from the engine exhaust manifold to the tailpipe. Learn the names of the parts.

Various ***emission control systems*** are used to reduce the amount of toxic (poisonous) substances produced by an engine and fuel system. Some systems prevent fuel vapors from entering the atmosphere (air surrounding the earth). Other emission control systems remove unburned and partially burned fuel from the engine exhaust. Later chapters cover these systems in detail.

Drive Train Systems

The ***drive train*** transfers turning force from the engine crankshaft to the drive wheels. Drive train configurations vary, depending on vehicle design. The most common drive-train configurations are front-wheel drive, rear-wheel drive, and all-wheel drive.

Front-wheel drive is commonly found on passenger cars. A front-wheel drive vehicle has superior traction because the weight of the engine and transaxle is directly above the drive wheels. Note the lightweight "dead axle" in the rear of the car. See **Figure 1-17A**.

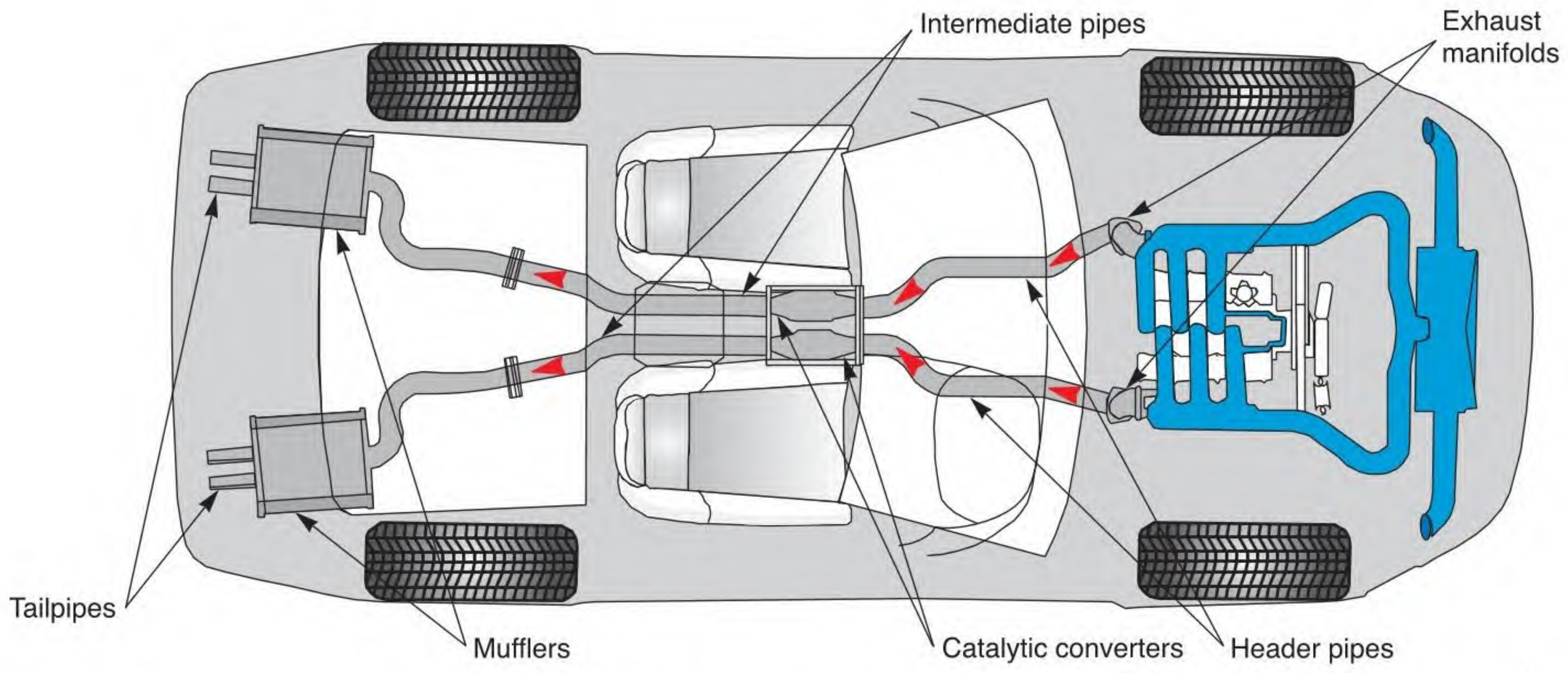
The front-engine, ***rear-wheel drive*** configuration shown in **Figure 1-17B** is popular because the heavy engine is still in the front for safety. Because of the weight distribution, vehicles with this drive train configuration have more precise steering than front-engine, front-wheel drive vehicles. However, they have less traction on slippery surfaces than front-wheel drive vehicles because less of the vehicle's weight is over the drive wheels.

Some rear-wheel drive vehicles have a ***mid-engine drive train***. In this configuration, the engine is located right behind the driver's seat with a transaxle mounted behind it. This provides for almost equal weight distribution to each tire for high cornering capabilities. See **Figure 1-17C**.

A vehicle with ***all-wheel drive*** often has the engine in the front and twin differentials to distribute engine/electric power to all four wheels and tires. It has the excellent traction on wet or snow-covered roads. See **Figure 1-17D**.

Drive Train Parts

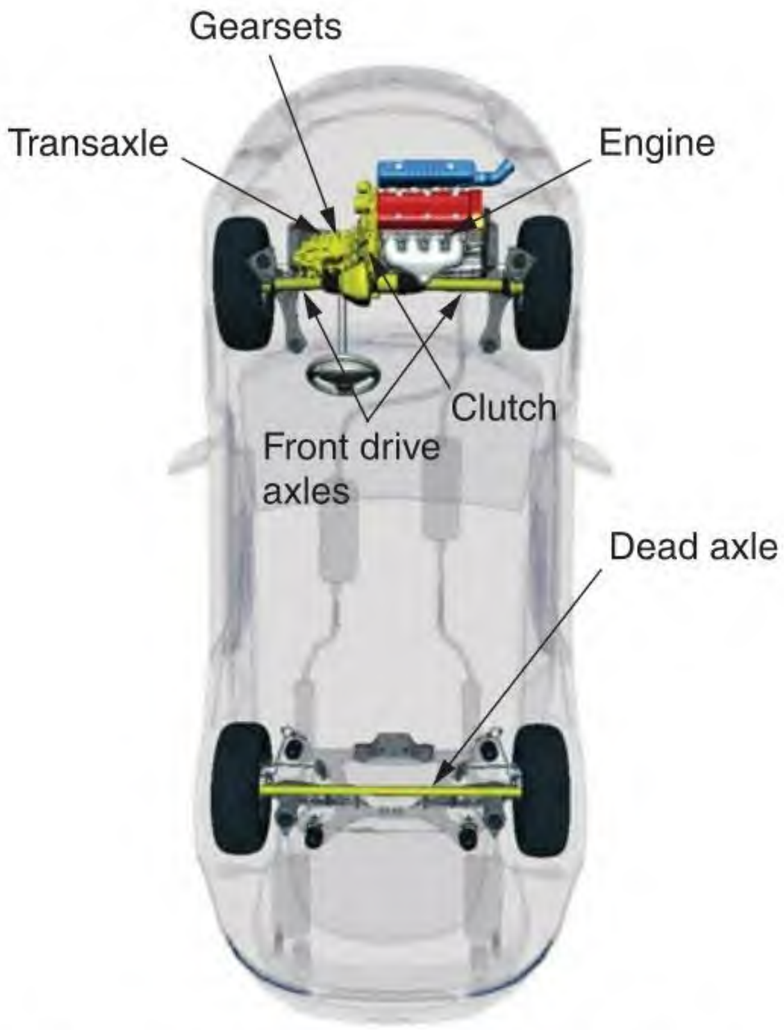
The drive train parts commonly found on a front-engine, rear-wheel-drive vehicle include the clutch,



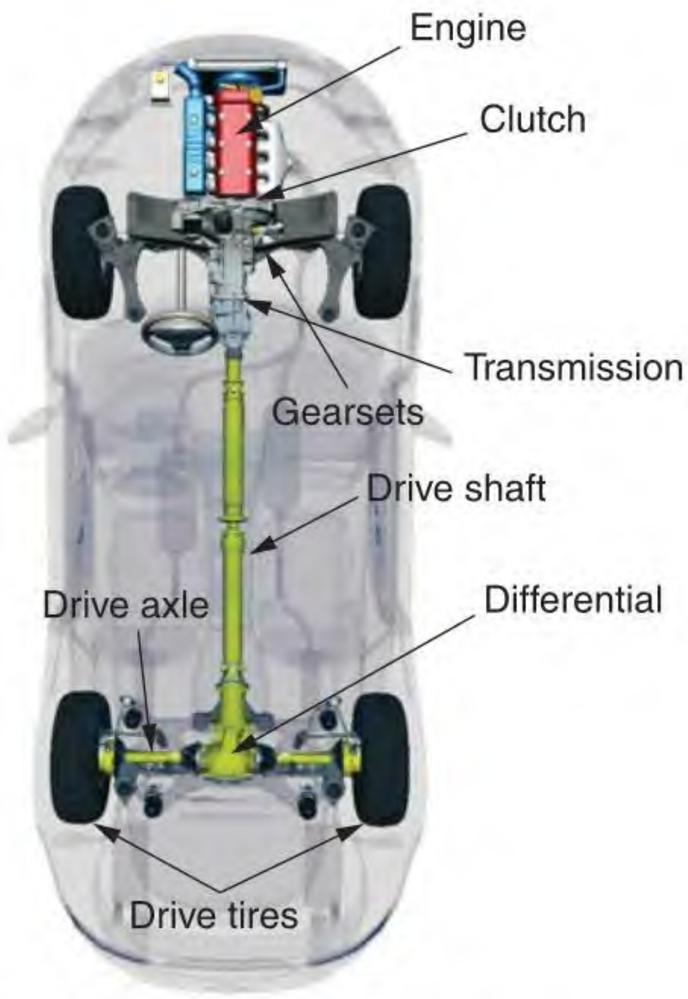
Nissan

Figure 1-16. The exhaust system carries burned gases to the rear of the vehicle. It also reduces engine noise.

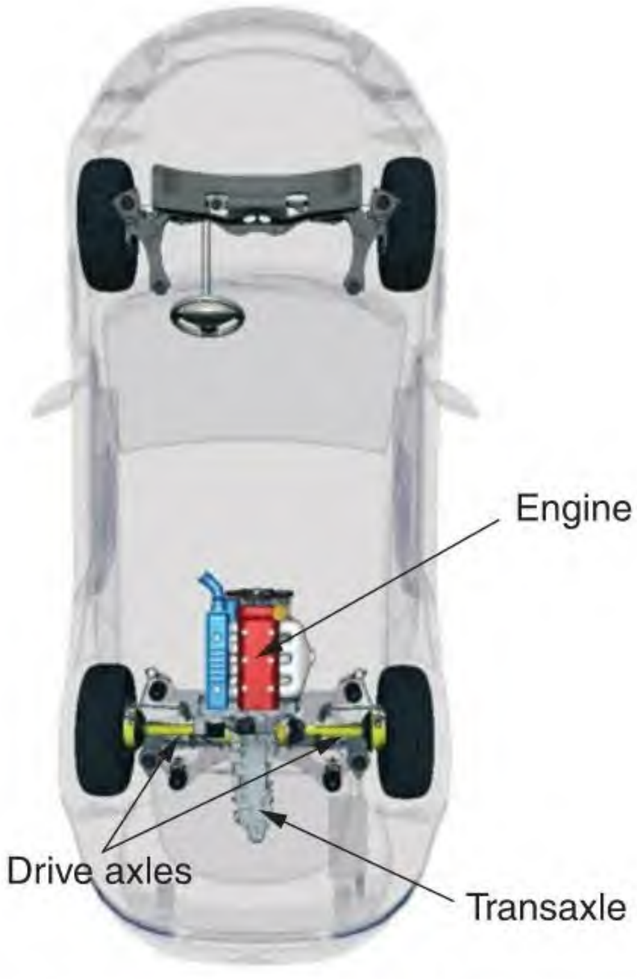
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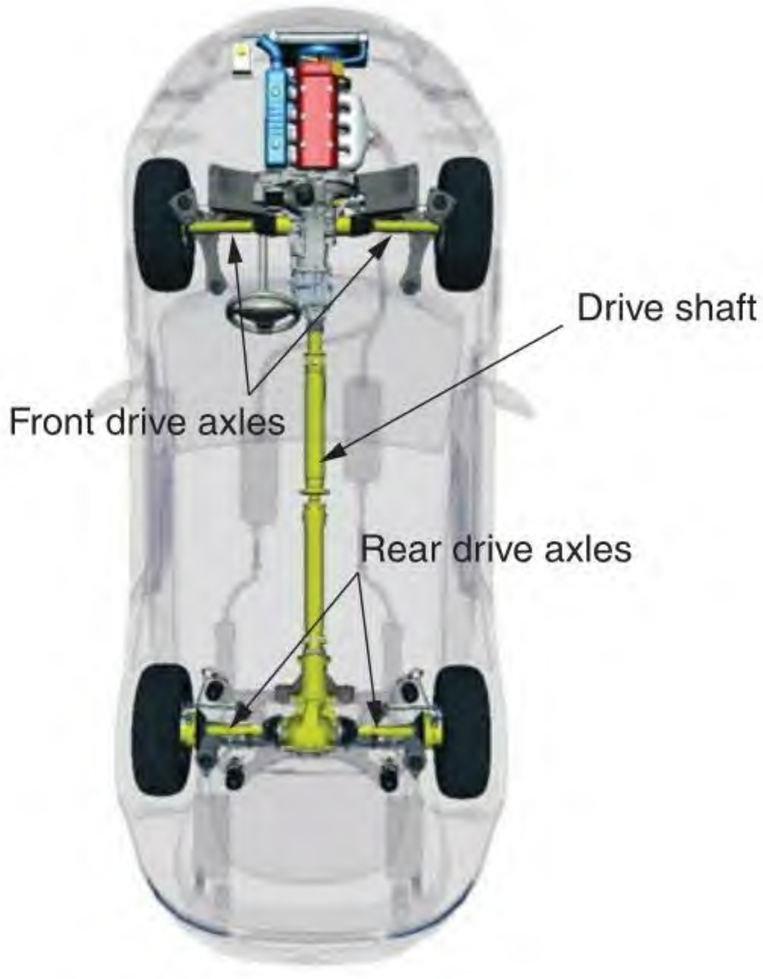
A—Front-Engine, Front-Wheel Drive



B—Front-Engine, Rear-Wheel Drive



C—Mid-Engine, Rear-Wheel Drive



D—All-Wheel Drive

Figure 1-17. Note the location of the engine in different drive train designs. A—Front-engine, front-wheel drive is the most common type of drive train found on modern passenger vehicles. B—Front-engine, rear-wheel drive is often used on large luxury cars and pickup trucks. C—Mid-engine, rear-wheel drive is found on a few high performance sports cars. D—All-wheel drive is superior to front- or rear-wheel drive on wet or snow-covered roads.

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transmission, drive shaft, and rear axle assembly. The drive train parts used on most front-engine, front-wheel-drive vehicles include the clutch, transaxle, and drive axles. Refer to **Figure 1-17** as these components and assemblies are discussed.

Discussed briefly, the parts included in the drive train can vary with vehicle design and whether the vehicle is front-wheel drive or rear-wheel drive.

Clutch

The clutch allows the driver to engage or disengage the engine and manual transmission or transaxle. When the clutch pedal is in the released position, the clutch locks the engine flywheel and the transmission input shaft together. This causes engine power to rotate the transmission gears and other parts of the drive train to propel the vehicle. When the driver presses the clutch pedal, the clutch disengages power flow and the engine no longer turns the transmission input shaft and gears. Refer to **Figure 1-17**.

Transmission

The transmission uses various gear combinations, or ratios, to multiply engine speed and torque to accommodate driving conditions. Low gear ratios allow the vehicle to accelerate quickly. High gear ratios permit lower engine speed, providing good gas mileage.

A manual transmission lets the driver change gear ratios to better accommodate driving conditions, **Figure 1-18A**. A clutch is used to engage and disengage the gearsets when changing gear ratios and vehicle speeds.

A ***semi-automatic transmission*** often uses paddle shift buttons on the steering wheel instead of a console shift lever. The computer control system reacts to signals from the paddle shifter switches to change gear engagement semi-automatically using electric actuators.

An automatic transmission, on the other hand, does not have to be shifted by the driver. It uses an internal hydraulic system and electronic controls to shift gears. The input shaft of an automatic transmission is connected to the engine crankshaft through an oil-filled torque converter (fluid coupling) instead of a dry friction clutch. The elementary parts of an automatic transmission are pictured in **Figure 1-18B**.

Drive Shaft

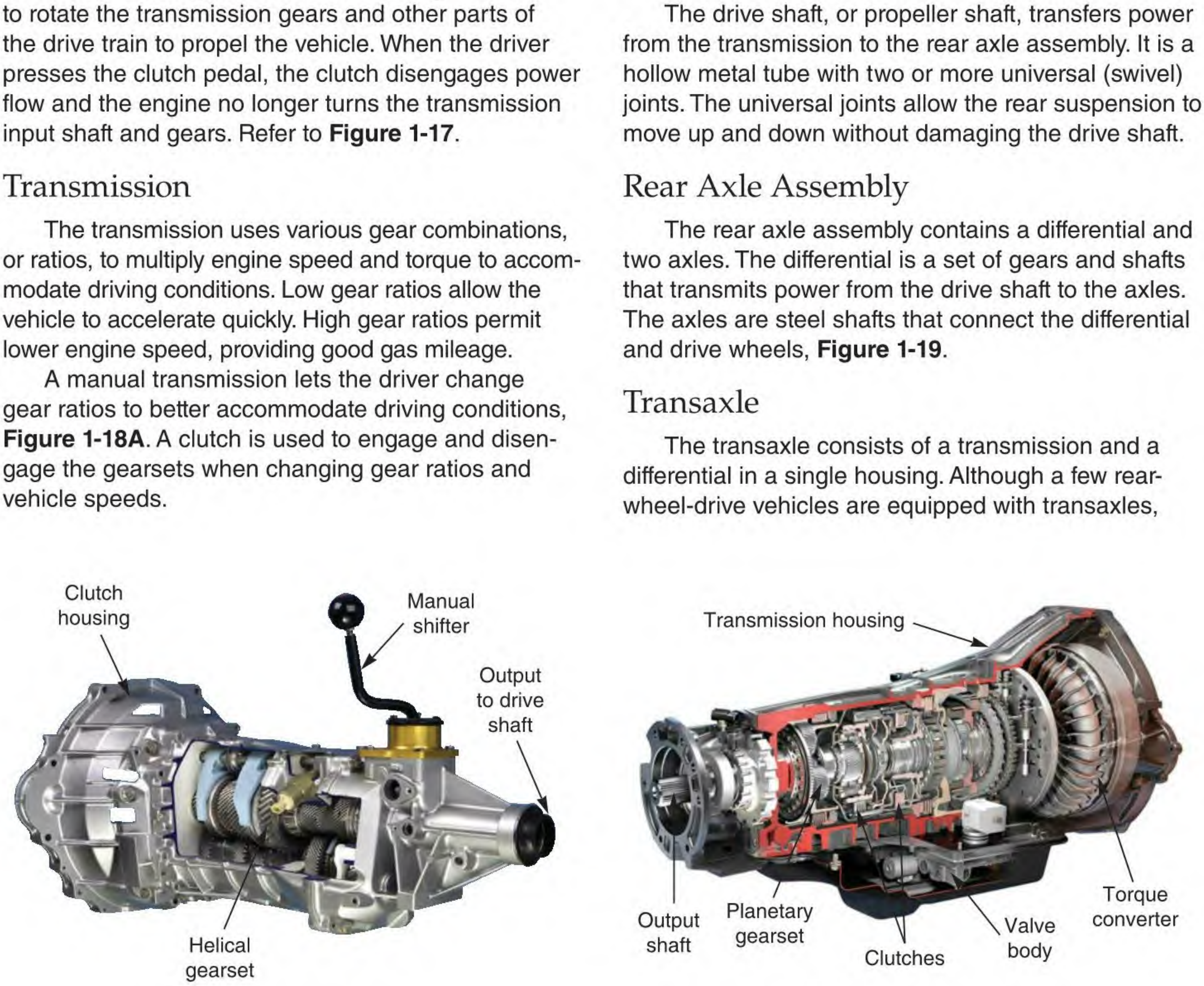
The drive shaft, or propeller shaft, transfers power from the transmission to the rear axle assembly. It is a hollow metal tube with two or more universal (swivel) joints. The universal joints allow the rear suspension to move up and down without damaging the drive shaft.

Rear Axle Assembly

The rear axle assembly contains a differential and two axles. The differential is a set of gears and shafts that transmits power from the drive shaft to the axles. The axles are steel shafts that connect the differential and drive wheels, **Figure 1-19**.

Transaxle

The transaxle consists of a transmission and a differential in a single housing. Although a few rear-wheel-drive vehicles are equipped with transaxles,

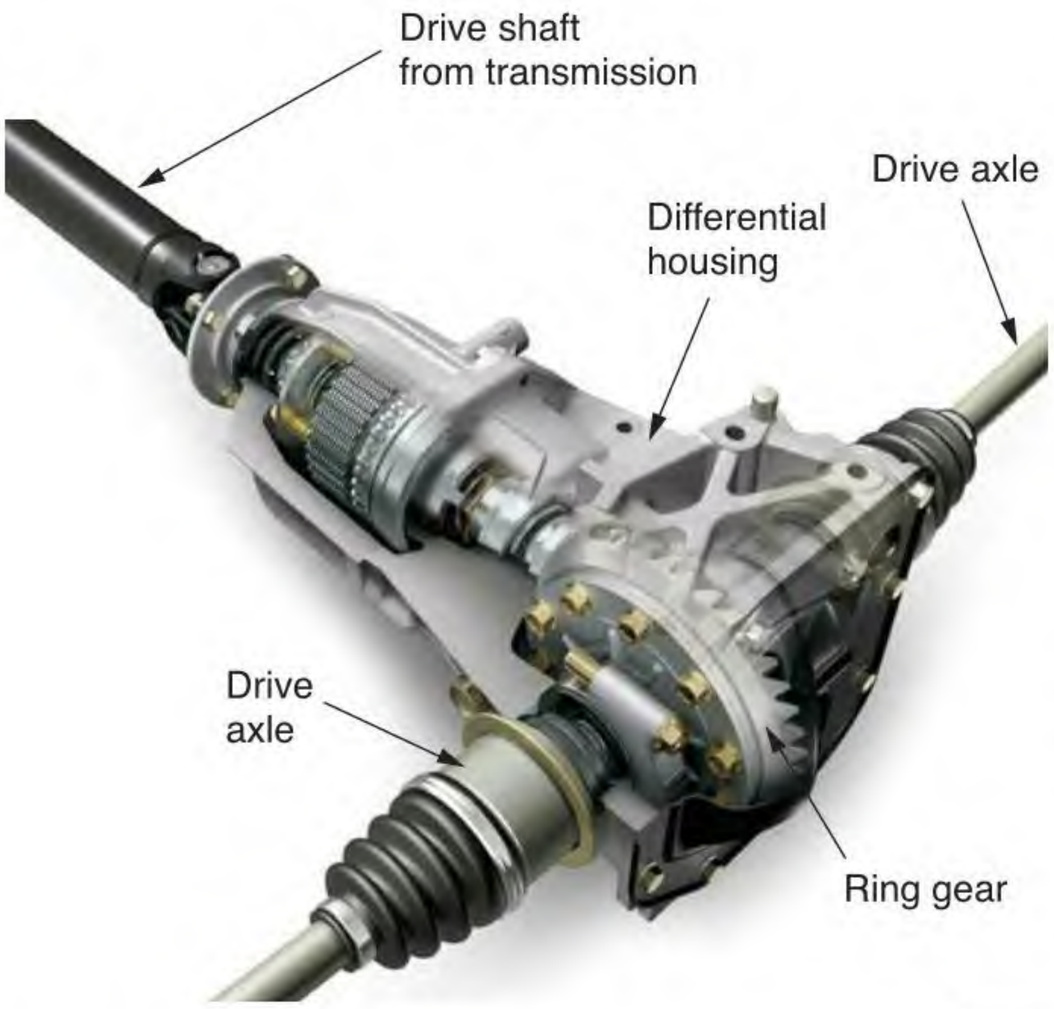


A—Manual Transmission **B—Automatic Transmission**

Chrysler, Ford

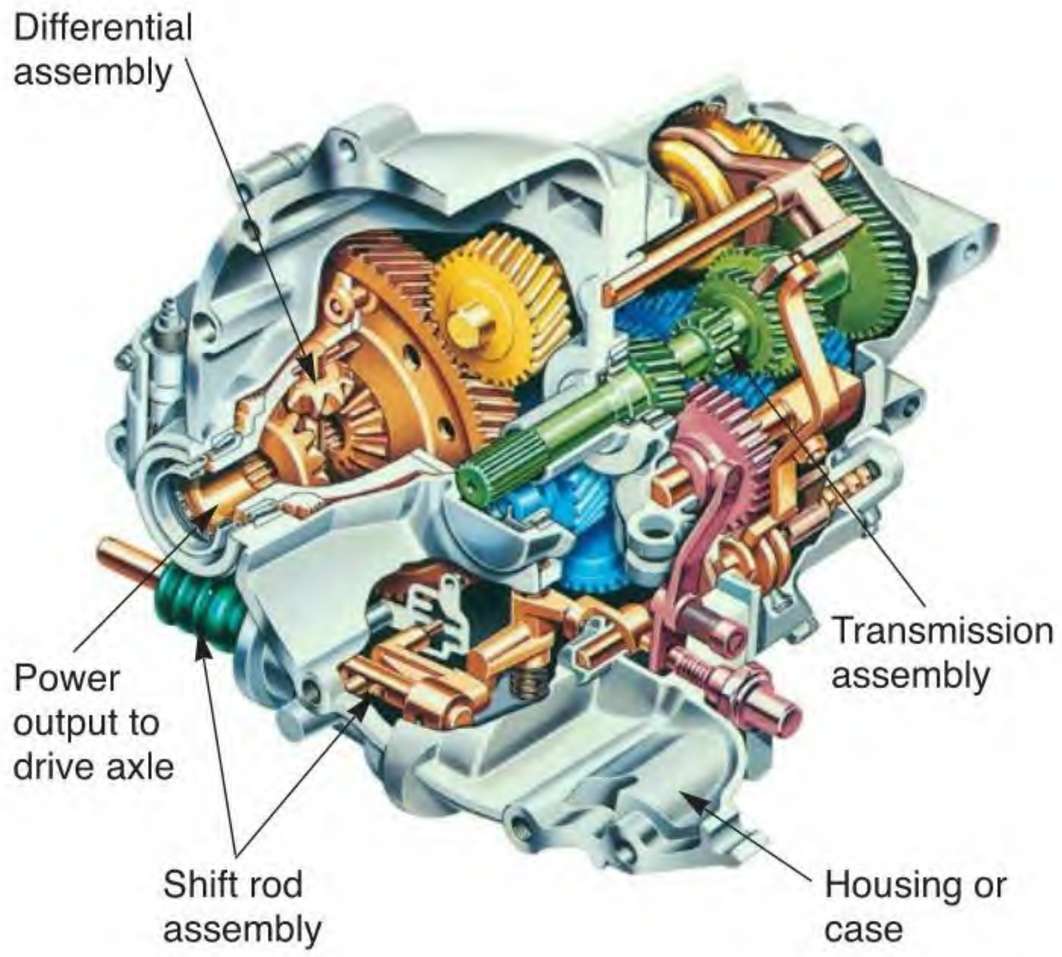
Figure 1-18. Study the two major types of automobile transmissions.

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Mazda

Figure 1-19. The rear axle assembly contains the differential and two axles that turn the rear drive wheels. The drive shaft sends power to the rear axle assembly.



Ford

Figure 1-20. A transaxle contains a transmission and a differential in one housing.

they are most commonly used with front-wheel-drive vehicles. Both manual and automatic transaxles are available. The internal parts of a modern transaxle assembly are illustrated in **Figure 1-20**.

Front Drive Axles

The front drive axles connect the transaxle differential to the hubs and wheels of the vehicle. These axles are equipped with constant-velocity joints, which allow the front wheels to be turned to the left or right and to move up and down.

Suspension, Steering, and Brake Systems

The suspension, steering, and brake systems are the movable parts of the chassis. They bolt or anchor to the frame and provide directional stability when maneuvering. Directional stability is the ability of a vehicle to corner, brake, and accelerate with minimal body roll and body dive. Poor directional stability will cause a car to skid off the road in a high-speed turn or to skid out of control during high-speed braking.

Suspension System

The ***suspension system*** allows the vehicle's wheels and tires to move up and down with little effect on body movement. This makes the vehicle's ride smooth and safe. The suspension system also prevents excessive body lean when turning corners quickly. As you can see in **Figure 1-21**, various springs, bars, swivel joints, and arms make up the suspension system.

Steering System

The ***steering system*** allows the driver to control vehicle direction by turning the wheels right or left. It uses a series of gears, swivel joints, and rods to do this. Study the names of the parts in **Figure 1-21**.

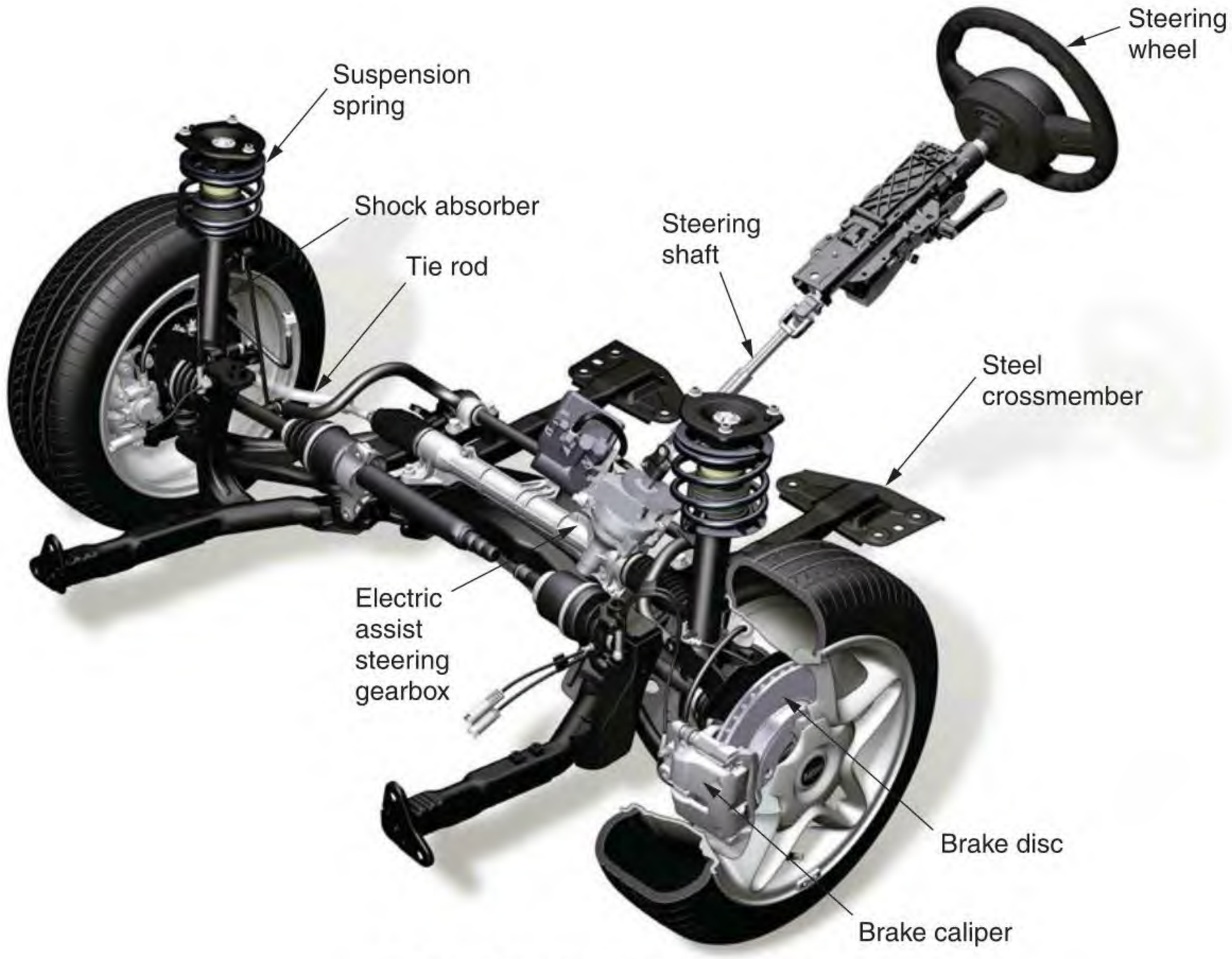
Brake System

The ***brake system*** produces friction to slow or stop the vehicle. When the driver presses the brake pedal, fluid pressure actuates a brake mechanism at each wheel, forcing friction material (brake pads or shoes) against metal discs or drums to slow wheel rotation. **Figure 1-22** shows the fundamental parts of a brake system.

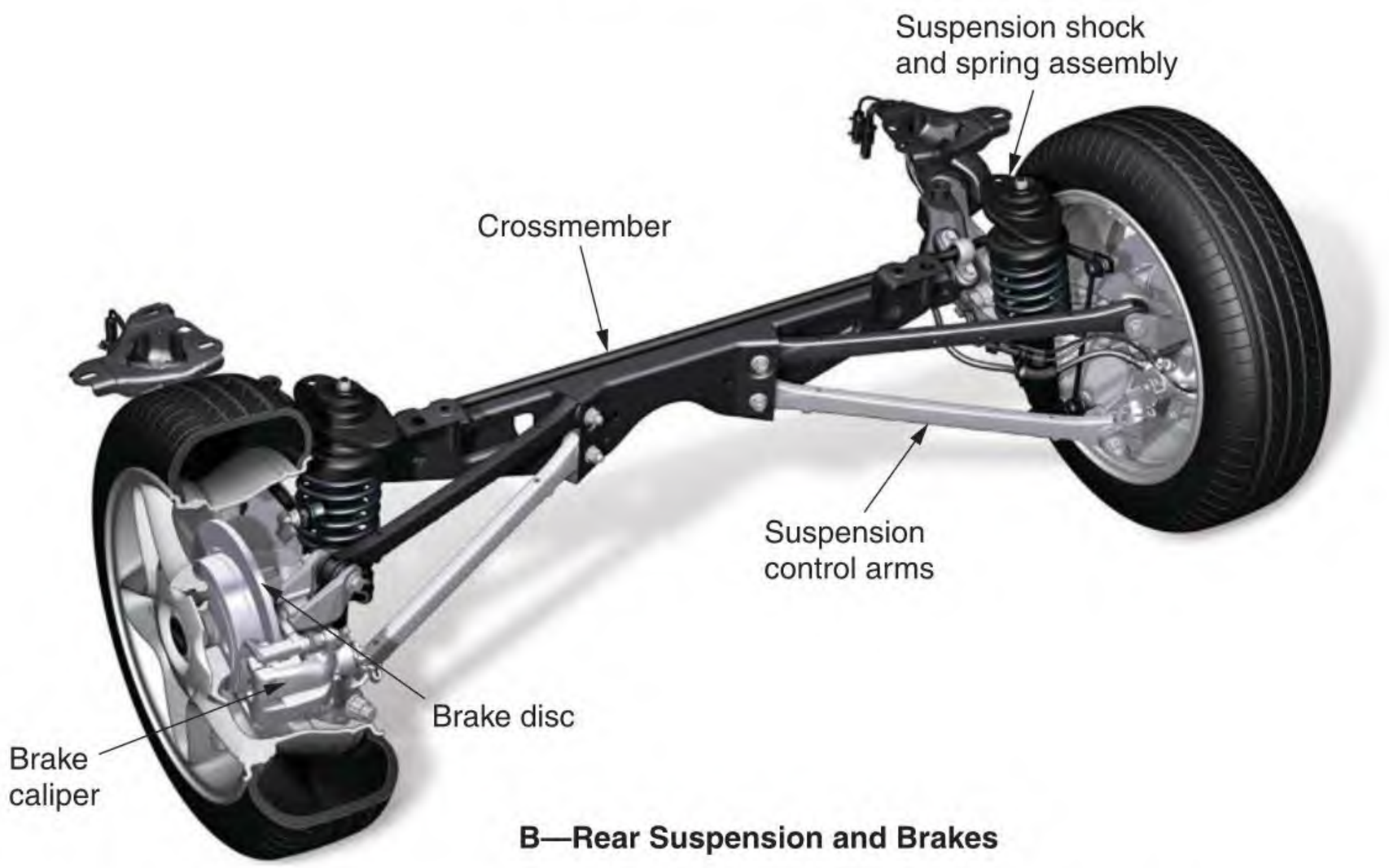
Accessory and Safety Systems

Common ***accessory systems*** include the air conditioner, sound system, power seats, power windows, and rear window defogger. Common ***safety systems*** include seat belts, air bags, and security systems. See **Figures 1-23** and **1-24**.

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A—Front Steering and Suspension

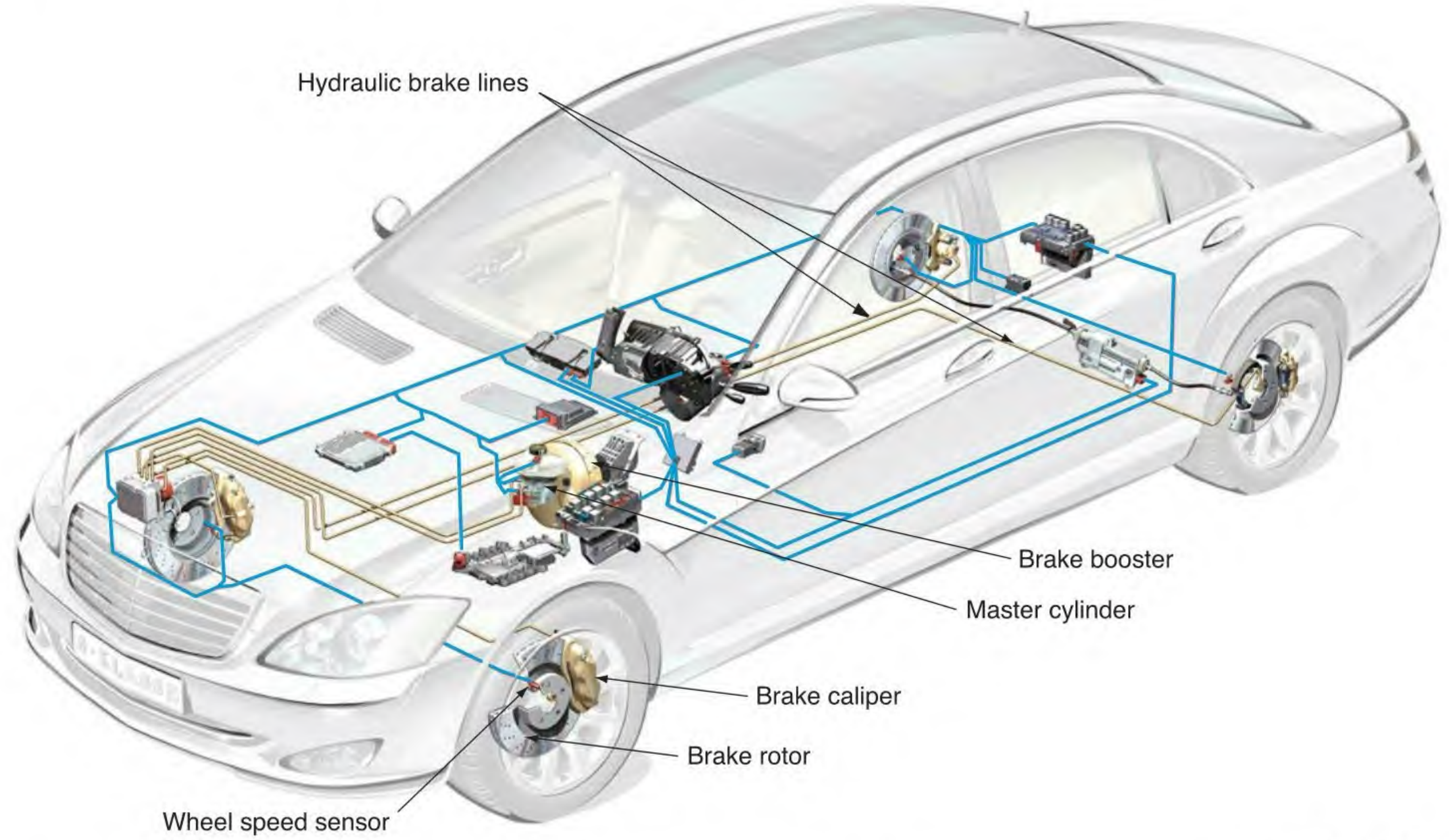


B—Rear Suspension and Brakes

Mini Cooper

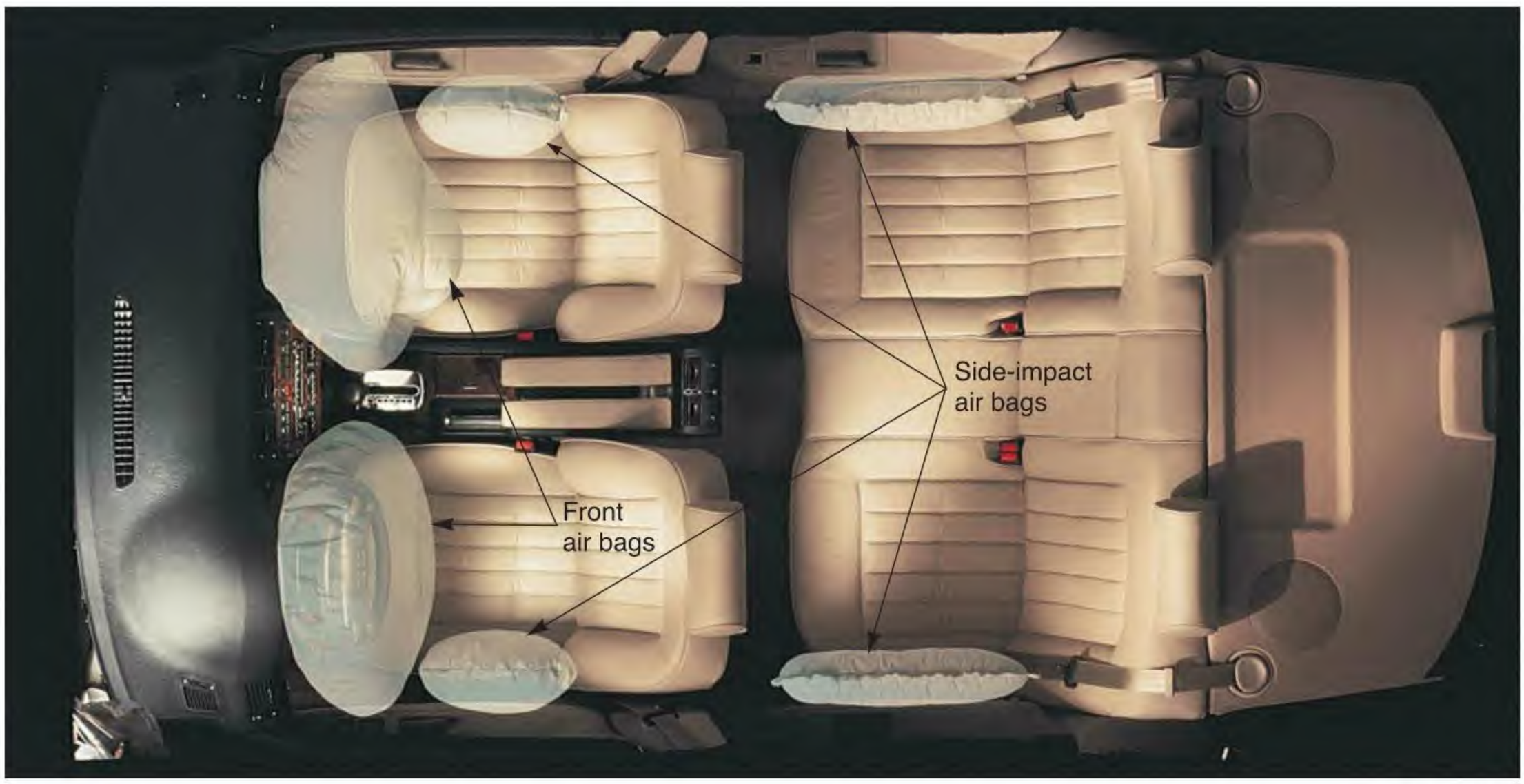
Figure 1-21. The suspension and steering systems mount on the steel cross members bolted to the unibody or frame. Memorize the part names and locations. A—Study how the steering wheel is connected to the front wheels and tires for turning and maneuvering the vehicle. Also note how the wheels bolt to the suspension system. The front wheel must swivel right and left while also going up and down over rough road surfaces. B—Note the basic parts of a rear suspension system. It is much simpler than a front suspension.

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Mercedes-Benz

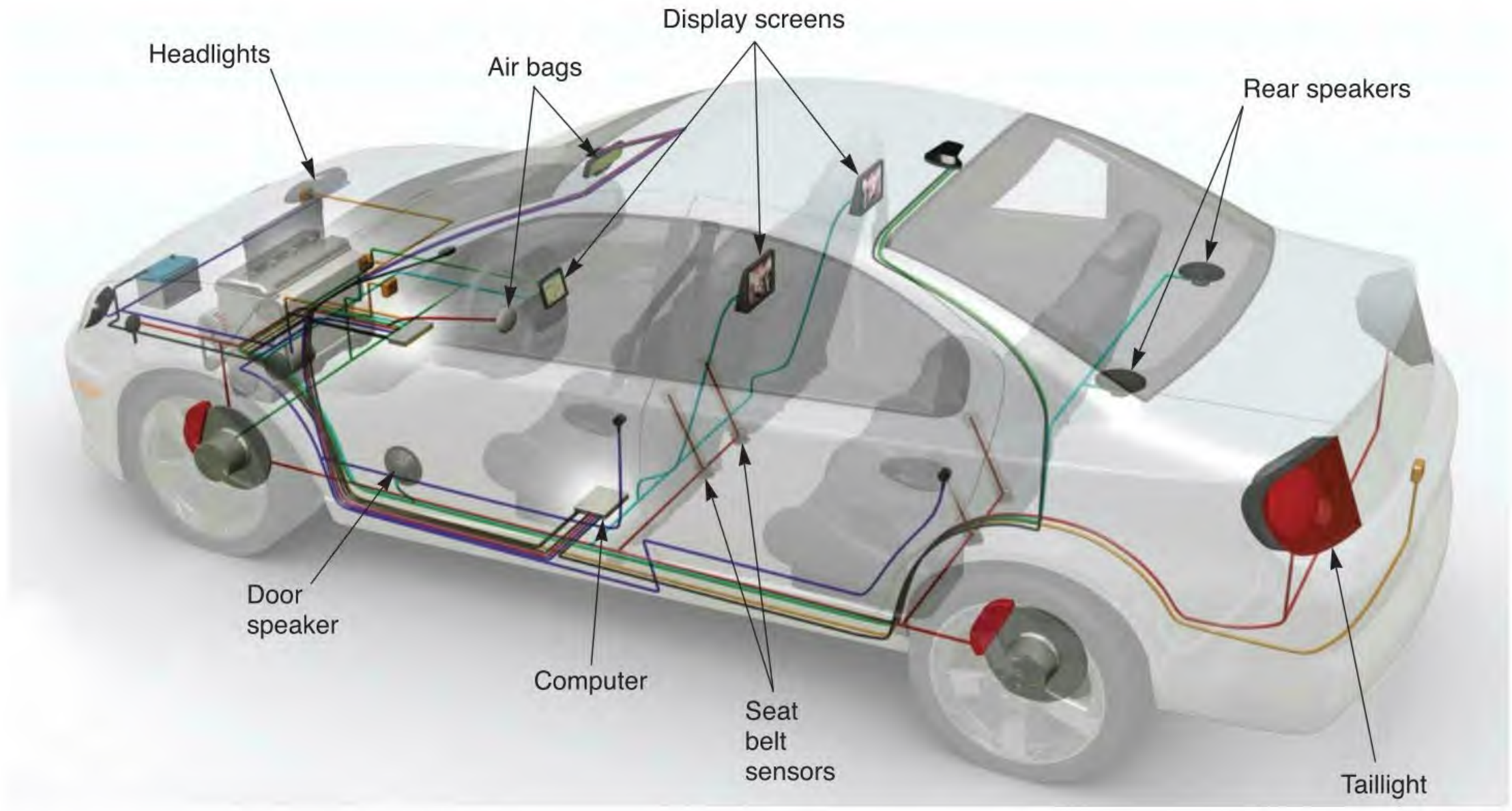
Figure 1-22. When the brake pedal is pressed, pressure is placed on a confined fluid. The fluid pressure transfers through the system to operate the brake calipers. An emergency brake is a separate mechanical system that applies the rear wheel brakes independent of the hydraulic brakes.



Audi America

Figure 1-23. Various safety systems are used on modern vehicles to protect both the driver and the passengers. This vehicle is equipped with both front and side-impact air bags.

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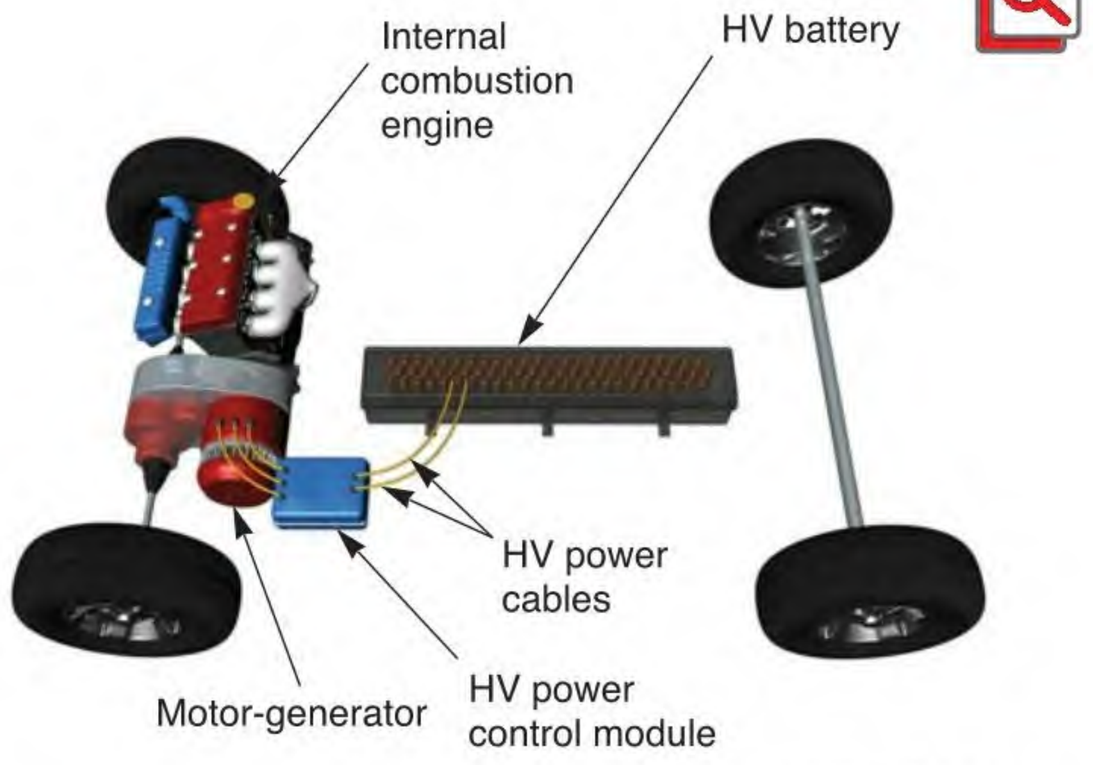
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Figure 1-24. The lighting and instrumentation systems are now controlled and connected with the body computer separate from the engine or drive train control computers. Wheel speed sensors tell when to re-aim the headlights, sound an alarm through the stereo speakers, energize the turn signals, put a hot engine warning display up in the dash, or tell you the car's present location on a detailed map. These complete electronic networks are fully explained in later chapters.

Hybrid Vehicles

A ***hybrid electric vehicle (HEV)*** uses two methods of propulsion: an internal combustion engine and an electric drive train, which consists of a high voltage (HV) battery and at least one motor-generator assembly. All major auto manufacturers now build and sell hybrid vehicles. Study **Figure 1-25**.

When the HV battery has an adequate charge, the hybrid vehicle will operate in the all-electric mode, without the internal combustion engine ever starting or running. In the all-electric mode, the motor-generator, powered by electricity from the HV battery, propels the vehicle. After the energy stored in the HV battery has been depleted, the motor-generator "fires up" the internal combustion engine, which in turn spins the motor-generator's armature. This causes the motor-generator to produce enough electricity to recharge the HV battery. By linking the running engine's crankshaft to the transmission input shaft, the vehicle is propelled by the engine while the motor-generator is spun by the engine to recharge the HV battery.



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Figure 1-25. A basic hybrid power train contains an internal combustion engine, a motor-generator, large HV power cables, HV battery, and an HV power control module. If the HV battery is fully charged, the vehicle will drive in full electric mode for about 50 miles. When the battery becomes discharged, the engine starts up to operate the motor-generator, which begins to recharge the HV battery.

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All hybrids use ***regenerative braking*** to convert the kinetic energy of the moving vehicle into large amounts of stored electrical energy. When the driver presses the brake pedal, the vehicle's drive axles rotate the motor-generator. Since the large permanent magnet armature shaft is difficult to turn, the "electrical/mechanical friction" inside the motor-generator helps slow the car while also recharging the batteries. The conventional hydraulic brake system has to do little or no work, unless the brake pedal is suddenly pressed down hard.

In the Rearview Mirror

Early automobile manufacturers originated in various ways. In many instances, they evolved from bicycle makers, carriage and wagon makers, and other types of industry. Early motorcars were similar to horse-drawn carriages, but they were equipped with noisy gasoline-powered engines, steam engines, or electric motors and batteries. A single lever called a tiller was used to steer the vehicle. Another hand lever would apply "rawhide brake shoes" to rub on the wagon wheels to slow the loud, self-propelled buggy! Imagine driving one of these contraptions.

Summary

- The body and frame support, stop, and enclose the vehicle.
- The engine provides dependable, efficient power for propulsion and electrical systems.
- The computer system uses electronic and electrical devices to monitor and control various auto assemblies.
- The fuel system provides the correct mixture of air and fuel for efficient and complete combustion.
- Electrical systems operate the electrical-electronic circuits, components, and devices, as well as propulsion in hybrid vehicles.
- The cooling system maintains a constant operating temperature for improved combustion efficiency.
- The lubrication system reduces friction between moving parts inside the engine.
- Emission control systems reduce air pollution produced by the vehicle.
- Drive train systems transfer turning force from the engine crankshaft and/or the motor-generator to the drive wheels.
- Suspension, steering, and brake systems support and control vehicle handling, maneuvering, and deceleration.
- Accessory and safety systems increase passenger comfort, safety, security and convenience.
- A hybrid electric vehicle uses two methods of propulsion—an internal combustion engine and an electric drive train.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

accessory system
aerodynamics
air-fuel ratio
all-wheel drive
assembly
automobile
body
body-over-frame construction
brake system
charging system
chassis
coefficient of drag (Cd)
component
computer system
cooling system
direct gasoline injection systems
drive train
emission control system
engine
exhaust system
frame
front-wheel drive
fuel efficiency
fuel system
hybrid electric vehicle (HEV)
ignition system
lighting system
lubrication system
mid-engine drive train
multi-cylinder engine
part
rear-wheel drive
regenerative braking
safety system
semi-automatic transmission
starting system
steering system
suspension system
system
technology
track width
unibody construction

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vehicle curb weight
vehicle height
vehicle length
vehicle weight distribution
vehicle wheelbase
vehicle width

Activities

1. Draw an automotive engine and drive train and label the parts. Then describe how the power is transferred from the engine to the drive wheels.
2. Using information from the text, write a report discussing any major vehicular system.
3. Arrange a field trip to tour an automobile assembly plant or to an auto shop.
4. Measure and record all four tire air pressure values on a car. Compare actual pressure to recommended tire pressure. Use the internet to research the effects low tire pressure has on fuel economy, vehicle handling, and tire wear. Write a report summarizing your findings.
5. Use the Internet to theoretically "build" a new car. Go to any major automobile manufacturer's website, select the vehicle model you would like to build, and choose the *Build and Price* option. Then, equip the vehicle as you wish. Write a paragraph describing the vehicle you selected. Be sure to included information on the make, model, engine, drive train configuration, fuel economy, interior and exterior colors, options, and price.

Review Questions

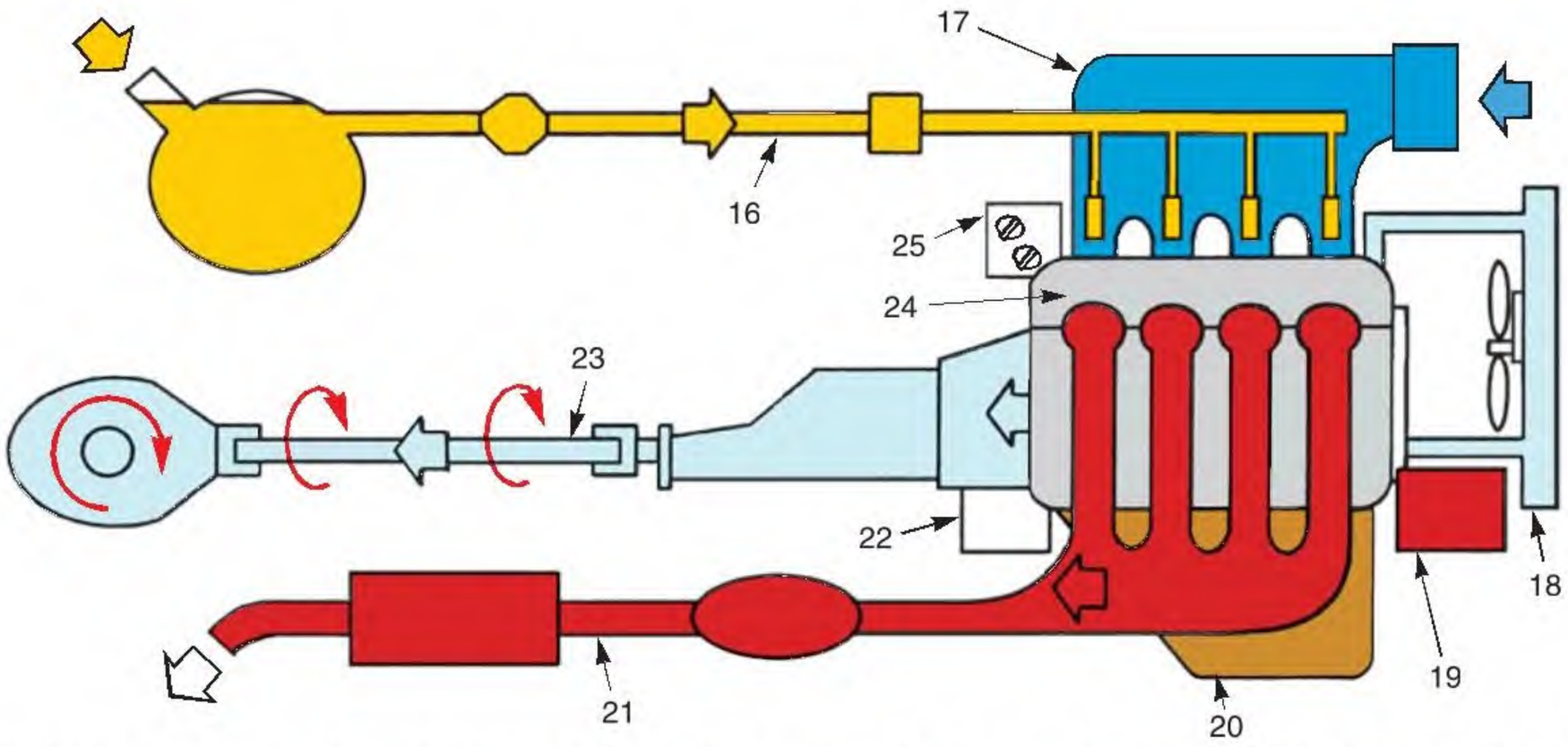


Answer the following questions using the information provided in this chapter.

1. What is an automotive system?
2. In _____ construction, sheet metal body panels are welded together to form the vehicle's body and frame.
3. Explain how an engine turns fuel into power to move the car.
4. Which of the following is *not* part of an engine?
   (A) Block.
   (B) Piston.
   (C) Muffler.
   (D) Crankshaft.
5. Most car engines are multi-cylinder engines. True or False?
6. There are three major part of an automotive computer system. Name them.
7. A direct gasoline injection system sprays fuel into the _____ chambers above the pistons.
8. The car's electrical system consists of the:
   (A) ignition, starting, lubrication, and lighting systems.
   (B) ignition, charging, lighting, and hydraulic systems.
   (C) lighting, charging, starting, and ignition systems.
   (D) None of the above.
9. The _____ system reduces the amount of toxic substances released by the vehicle.
10. Summarize the major differences between manual transmissions, hybrid drive transmissions, and automatic transmissions.
11. A one-piece drive shaft rotates the drive wheels on most front-wheel-drive cars. True or False?
12. A rear axle assembly contains two _____ and a(n) _____.
13. Explain the term *transaxle*.
14. The suspension system mounts the car's wheels solidly on the frame. True or False?
15. List four `accessory systems.

16–25. Identify the parts and systems in the following illustration. Write the numbers 16–25 on your paper. Then write the correct letter and words next to each number.

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Can you identify the following parts and systems? (A) Starting system. (B) Charging system. (C) Drive train. (D) Fuel system. (E) Cooling System. (F) Engine. (G) Ignition system. (H) Lubrication system. (I) Exhaust system. (J) Intake manifold.

ASE-Type Questions

1. Technician A says that unibody vehicles are generally lighter and more fuel efficient than body-over-frame vehicles. Technician B says that full-size trucks always use body-over-frame construction. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. The _____ controls the opening of engine's valves.
   (A) camshaft
   (B) crankshaft
   (C) valve springs
   (D) combustion chamber
3. All of the following are major components in the computer system *except:*
   (A) calipers.
   (B) sensors.
   (C) actuators.
   (D) computer.
4. In modern gasoline injection systems, where does the fuel injector spray gasoline?
   (A) Top of the intake manifold.
   (B) On the intake manifold.
   (C) Into the intake port.
   (D) Into the combustion chamber.
5. The ignition system produces a high-voltage surge that jumps across the air gap at the tip of the _____.
6. The _____ system uses a powerful electric motor to rotate the engine's crankshaft until the engine fires and runs on its own power.
7. A car with a dead 12-volt battery is brought into the shop. Technician A says to check the output of the alternator. Technician B says to check the condition of the spark plugs. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. A vehicle is brought into the shop with a slipping clutch. Technician A says that the clutch is part of the drive train. Technician B says that the clutch is part of the suspension system. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Gear ratios are being discussed. Technician A says that low gear ratios allow a vehicle to accelerate quickly. Technician B says that high gear ratios permit lower engine speeds, providing good gas mileage. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. A transaxle case contains both the:
    (A) injector and drive shaft.
    (B) transmission and differential.
    (C) torque converter and clutch.
    (D) electric motor and brakes.

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Chapter 2
Automotive Careers and ASE Certification

After studying this chapter, you will be able to:

- List the most common automotive careers and related fields of employment.
- Describe the types of skills needed to be a qualified automotive technician.
- Explain the specialized tasks completed by each type of auto technician.
- Summarize the ASE certification program.

Economists predict a continued demand for skilled automotive technicians and other automotive-related professionals for many years into the future. Because many technicians will be needed to fill job openings, you are in an ideal situation.

Today, there are well over 250 million registered passenger vehicles on the road in the U.S. alone. Americans spend approximately eight-hundred billion dollars to own and operate their vehicles every year. There are about thirty million people employed in the automotive field. About one in every seven working Americans is employed in an automotive-related field. All of these people are needed to build, sell, insure, and service passenger vehicles.

Globally, auto production has increased tremendously. Look in almost any newspaper or browse online job sites and you will find job openings for qualified, technicians in all areas of expertise.

The Automotive Technician

An ***automotive technician***, or technician, makes a living diagnosing, servicing, and repairing cars, vans, and light trucks. The technician must be highly skilled and well trained.

He or she must be a "jack-of-all-trades," being able to perform a wide variety of tasks. For example, an experienced master automobile technician is usually capable of performing operations common to the following occupations:

- Machinist—Machinists perform precision measurements and repairs on various high-tolerance parts suffering from wear.
- Plumber—Plumbers work with high-pressure fuel lines, vacuum hoses, power steering tubing, and air suspension lines.

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- Computer technician—Computer technicians test, replace, and reprogram modern on-board computers.
- Residential/commercial electrician—These electricians work on charging, starting, and high-voltage electric drive train circuits.
- Electronic technician—This type of technician tests and repairs low-voltage analog and digital circuits common in passenger vehicles.
- TV-radio technician—TV-radio technicians install and repair vehicle sound and entertainment systems.
- Air conditioning technician—Air conditioning technicians diagnose, repair, and recharge auto air conditioning systems.
- Welder—Welders must safely weld exhaust system parts and make repairs.
- Bookkeeper—Bookkeepers are needed to fill out repair orders, calculate hours on a job, order parts, total work order costs, and figure out weekly paychecks.
- Automotive engineer—Automotive engineers understand the construction and operation of complete vehicle systems and know how to diagnose vehicle problems efficiently.

As this list demonstrates, an automobile technician's job can be very challenging. Today's technician is called on to perform a variety of repair tasks, which prevents boredom on the job. If you like to use your mind and your hands, the field of passenger vehicle repair can be a rewarding and interesting profession.

General Job Classifications

A wide variety of jobs are available in the automotive field. Many of these jobs involve troubleshooting, service, and repair. Others involve getting parts, dealing with customers, and shop management.

Apprentice

One way to get started in automotive service is to become an apprentice. The ***apprentice***, or helper mechanic, works under the direction of an experienced technician. This is a good way to get paid for an education. As an apprentice, you learn about automotive technology by running for parts, cleaning parts, maintaining tools, and helping with repairs. See **Figure 2-1**.

Many schools partner with local service facilities and dealerships to offer ***cooperative training programs***. These programs combine classroom instruction with real-world experience. The employer helps the student technician learn the trade while receiving relatively low-cost labor and the opportunity to identify future technicians for hire. Ask your program advisor or automotive instructor about a possible cooperative training program in your school.



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Figure 2-1. An apprentice works under the direction of an experienced automotive technician. This is an excellent way to learn the trade.

Specialized Technician

A ***specialized technician*** is an expert in one area of automotive repair, such as engines, brakes, electrical, or other areas. Because of the increasingly complex nature of today's vehicles, the trend is toward specialization. It is much easier to learn to repair one system than all systems. After specializing in one area, you can expand your abilities to include other areas of repair. Common areas of specialization include engines, transmissions, steering and suspension, brakes, electrical, heating and cooling, driveability and performance, exhaust systems, tires, and lubrication.

An engine technician troubleshoots, services, and repairs automobile engines. This requires a knowledge of all types of engines, such as gasoline, diesel, 4-cylinder, 6-cylinder, and 10-cylinder. The engine technician has one of the most physically demanding automotive jobs. It requires a fairly strong individual who can lift heavy assemblies and easily torque large fasteners. Refer to **Figure 2-2**.

A transmission technician works on automatic, manual, and hybrid transmissions; transaxles; clutches; and sometimes, rear axle assemblies. Because transmissions are so complex, the transmission technician must receive very specialized training

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Figure 2-2. The engine technician must be highly skilled. Late-model engines are very complex. One mistake during assembly can cause major engine damage.

and must frequently retrain. Some large service facilities have a rear axle specialist, who works on nothing but differentials, axle shafts, and drive shafts.

A steering and suspension technician is responsible for checking, replacing, and adjusting steering and suspension components. This technician must use specialized equipment, such as the wheel alignment rack, to line up the wheels. A steering and suspension technician may also take care of tire and wheel problems.

A brake technician specializes in brake system service and repair. This individual must be capable of rapidly diagnosing problems and making adjustments or repairs. A brake technician's job is one of the easiest to master. Jobs are available in both small and large shops, service stations, and tire outlets.

The electrical system technician must be able to test and repair lighting systems, charging systems, computer control systems, starting systems, hybrid electric drives, and other electrical systems. Compared to other specialties, this area of repair might be desirable because it requires less physical strength than other areas. See **Figure 2-3**.

A heating and air conditioning technician must troubleshoot, service, and repair heaters, vents,



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Figure 2-3. This electrical system technician is using a digital voltmeter to measure battery voltage.

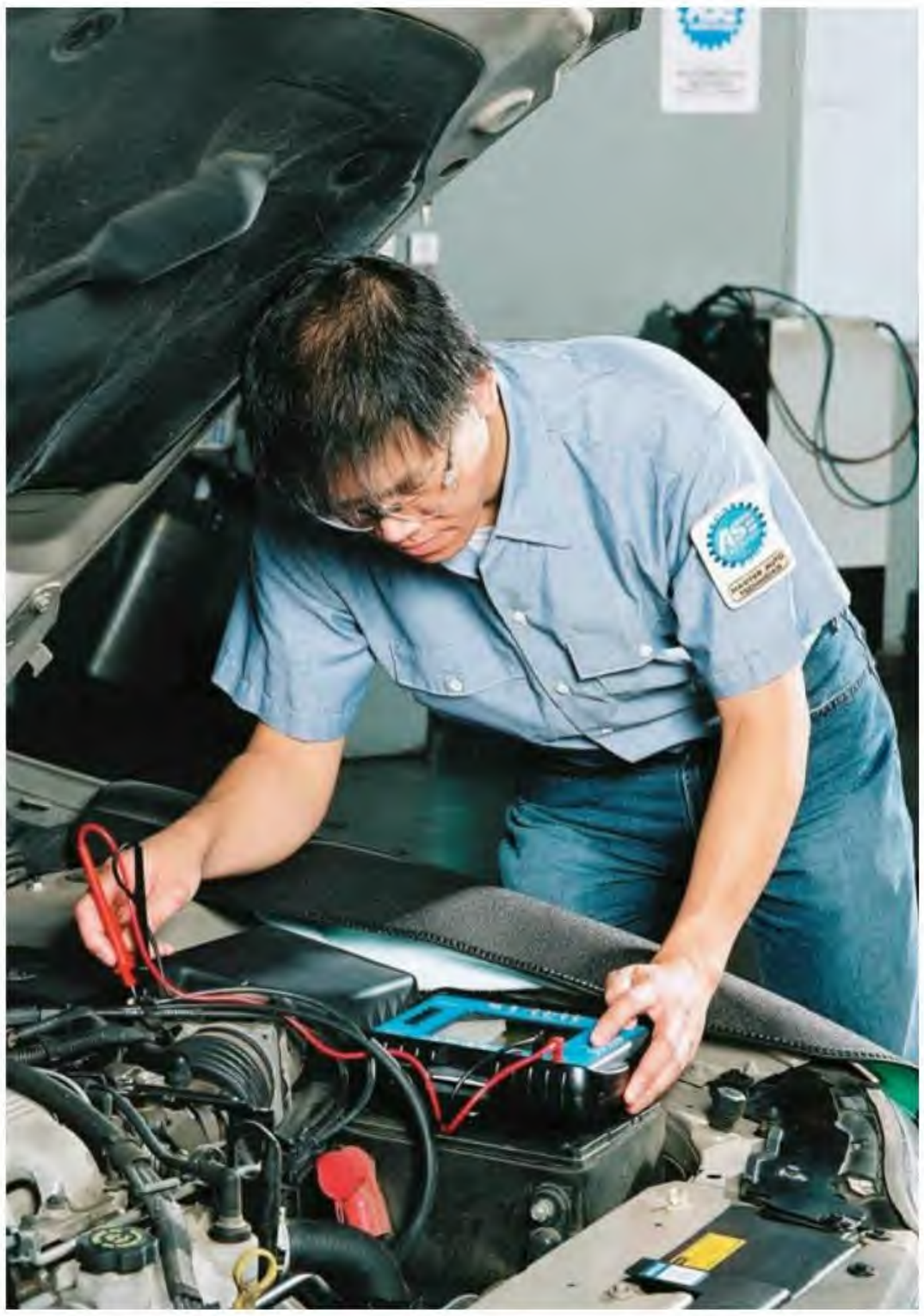
and air conditioning systems. He or she must use a charging station to capture and store the old refrigerant so it is not released into the atmosphere. The charging station is also used to fill the air conditioning system with oil and refrigerant.

The driveability and performance technician must test and service engine fuel, ignition, computer, and emission systems. This involves the use of special test equipment to keep engines in top running condition. See **Figure 2-4**.

The lubrication specialist changes engine oil, filters, and transmission fluid. He or she checks various fluid levels and performs "grease jobs" (lubricates pivot points on suspension and steering systems).

A hybrid specialist has special training in the diagnosis and repair of very dangerous high-voltage electric drive systems. They must be competent at

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Figure 2-4. The driveability and performance technician must use state-of-the-art equipment, such as this diagnostic analyzer, to find the source of engine performance problems.

following all safety measures that must be taken to safely work on the high-voltage battery pack, motor-generator, and other high-voltage components. A hybrid specialist is usually sent to special training classes conducted by the vehicle manufacturer. Refer to **Figure 2-5**.

Master Technician

A ***master technician***, or general technician, is an experienced professional who has mastered all the specialized areas of automotive technology and is capable of working on almost any part of a vehicle. This person can service and repair engines, brakes, transmissions, axles, heaters, air conditioners, and electrical systems. A master technician generally has enough experience to advance to a position as a shop supervisor, a service manager, or an instructor.



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Figure 2-5. This hybrid specialist is using a laptop computer to analyze trouble codes with the electric drive system. Special training is needed to safely service hybrid vehicles.

Shop Supervisor

The ***shop supervisor*** is in charge of all the other technicians in the service facility. The supervisor must be able to help others troubleshoot problems in all automotive areas. The shop supervisor must also communicate with the service manager, parts manager, and technicians.

Service Manager

The ***service manager*** is responsible for the complete service and repair operation of a large repair facility. This person must use a wide range of abilities to coordinate the efforts of the shop supervisor, parts specialist, service writer, service dispatcher, and other shop personnel. The service manager must also handle customer complaints, answer questions, and ensure that the technicians are providing quality service for their customers.

Other Automotive Careers

There are numerous other automotive careers that do not require extensive mechanical ability. They do, however, require a sound knowledge of automotive technology. A few of these careers are discussed next.

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An ***auto parts specialist*** must have a general knowledge of the components and systems of a vehicle. This person must be able to use customer requests, parts catalogs, price lists, and parts interchange sheets to quickly and accurately find needed parts.

A ***service writer***, or service consultant, prepares work orders for vehicles entering the shop for repair or service. This person greets customers and listens to descriptions of their problems. The service writer must then fill out the repair order, describing what might be wrong.

A ***service dispatcher*** must select, organize, and assign technicians to perform each auto repair. The dispatcher must also keep track of all the repairs taking place in the shop.

An ***auto salesperson*** informs potential buyers of the features and equipment on a vehicle while trying to make a sale. By understanding how a vehicle works, the salesperson will be better prepared to answer questions. Positions are also available selling automotive-related parts and equipment, **Figure 2-6**.

An ***automotive designer*** has art training and can make sketches or models of new body and part designs. This person is employed by automobile or automotive part manufacturers, **Figure 2-7**.

An ***automotive engineer*** designs new and improved automotive systems and parts. This person must use math, physics, and other advanced technologies to improve automotive designs. An engineer is a



Mitsubishi

Figure 2-7. Automotive designers must have extensive engineering knowledge and a strong art background to design buildable yet aesthetically pleasing vehicles.



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Figure 2-6. A convention allows manufacturers of parts, tools, and equipment to display new and established products. People well versed in automotive technology and sales are needed to work at these events.

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highly paid, college-trained individual with a working knowledge of the entire automobile, **Figure 2-8**.

Automotive instructors are experienced technicians capable of sharing their knowledge effectively. In addition to on-the-job experience, most instructors are required to have a college degree, **Figure 2-9**.

There are dozens of other job titles in the automotive field. Check with your school guidance counselor for more information.



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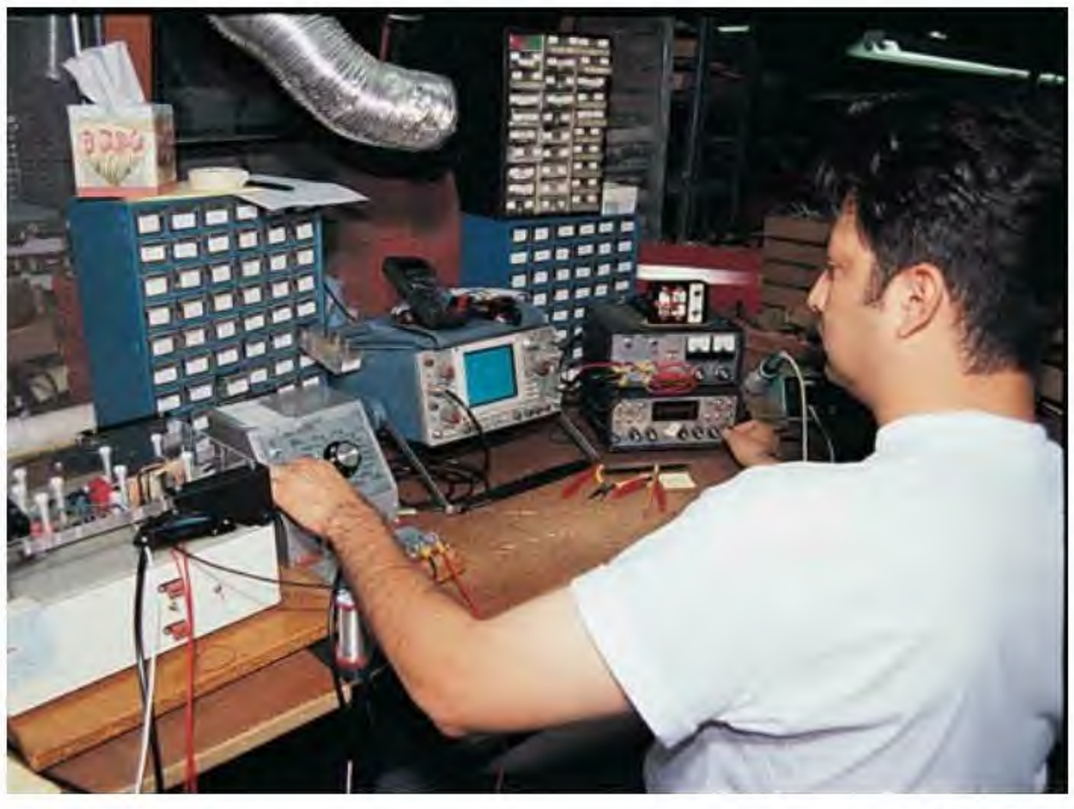
Figure 2-9. An automotive instructor must have a strong background in automotive technology and must also be able to communicate well.

Tech Tip

Many people start their careers as automotive technicians and then move to other related job areas or into management of auto repair facilities. Never limit your sights on the future. Always try to improve your skills and potential for a new and better job.

Entrepreneurship

An ***entrepreneur*** is someone who starts a business, such as a muffler shop, tune-up shop, parts house, or similar facility. To be a good entrepreneur, you must be able to organize all aspects of the business: bookkeeping, payroll, facility planning, hiring, etc. After gaining several years of on-the-job experience, you might want to consider starting your own business.



MSD Ignitions

Figure 2-8. Automotive engineers normally have a bachelor's degree in a related engineering discipline. A working knowledge of automotive technology is a must for the engineer.

Most successful entrepreneurs have a quality known as leadership. Effective leaders have the courage to set a course of action and get the cooperation of others in meeting goals. Leaders are willing to accept responsibility for their actions. If their decisions show signs of failure, they take action to correct mistakes. If their decisions are good, they are willing to share the "glory." Good leaders readily credit the work of others who have contributed to the success of the business venture.

Preparing for a Career in Automotive Technology

A career as an automobile technician can be quite challenging. Late-model cars and light trucks are very complex. They are constantly being updated and redesigned. This makes it difficult to keep up with the latest technology.

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Many of the basic skills needed to succeed in automotive technology are learned in the classroom. Automobile technicians must have above-average math and English skills. They must be proficient at working with numbers to calculate part clearances and fill out work orders. They must also have good verbal skills to effectively communicate with customers and other technicians. After graduation from high school, many automotive students seek further training at trade schools or in colleges.

ASE Certification

The ***National Institute for Automotive Service Excellence***, or ***ASE***, is a nonprofit, nonaffiliated (no ties to industry) organization formed to help ensure the highest standards in automotive service.

ASE directs an organized testing and certification program under the guidance of a 40-member board of directors. The members of this board represent all aspects of the automotive industry—educators, shop owners, consumer groups, government agencies, aftermarket parts distributors, auto manufacturers, etc. This broad group of experts guides the ASE certification program and helps ASE stay in touch with the needs of the industry.

ASE certification is a program in which persons take written tests to prove their knowledge of automotive technology. ASE certification tests are voluntary. They do not have to be taken, and they do not license technicians.

Some countries have made technician certification a requirement. In the United States, however, technicians take the tests for personal benefit and to show their employers and customers they are fully qualified to work on a system of a car or an engine.

Over 500,000 technicians have passed ASE certification tests. Thousands of these technicians have been retested and recertified after five years to maintain their credentials.

Test Categories

In the automobile and light truck category, there are nine certification tests: Engine Repair, Automatic Transmission/ Transaxle, Manual Drive Train and Axles, Suspension and Steering, Brakes, Electrical Systems, Heating and Air Conditioning, Engine Performance, and Light Vehicle Diesel Engines. You can take any one or all of these tests. However, ASE suggests that you attempt no more than 250 questions per testing session. There are also eight medium/heavy truck tests, four collision repair and refinish tests, and one advanced engine performance test. ASE automobile and light truck certification categories are shown in **Figure 2-10**. ASE test categories include:

- Auto Maintenance and Light Repair Certification Test (G1)
- Automobile & Light Truck Certification Tests (A1–A9 Series)
- Collision Repair & Refinish Certification Tests (B2–B5 Series)
- Damage Analysis & Estimating Certification Test (B6)
- Automobile Service Consultant Certification Test (C1)
- Truck Equipment Certification Tests (E1–E3)
- Alternate Fuels Certification Test (F1)
- Transit Bus Certification Tests (H1–H8)
- Advanced Engine Performance Specialist Certification Test (L1)
- Electronic Diesel Engine Diagnosis Specialist Certification Test (L2)
- Light Duty Hybrid/Electric Vehicle Specialist Test (L3)
- Parts Specialist Certification Tests (P1 and P2)
- School Bus Certification Tests (S1–S7)
- Medium-Heavy Truck Certification Tests (T1–T8)
- Undercar Specialist Exhaust Systems Test (X1)

Tech Tip

Visit the *National Institute for Automotive Service Excellence* at www.ase.com. You can learn more about their testing/certification programs, take sample tests, and find other information that will help you in your career.

Tech Tip

Become a certified automobile technician! If you master the material in this textbook, you should have no trouble passing all the ASE automobile certification tests. As an ASE-certified technician, you will gain added respect from your employer and your customers.

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A1 Engine Repair Test

50 Questions

General engine diagnosis	15 questions
Cylinder head and valve train diagnosis/repair	10 questions
Engine block diagnosis/repair	10 questions
Lubrication and cooling systems diagnosis/repair	8 questions
Fuel, electrical, ignition, and exhaust systems inspection/service	7 questions

A2 Automatic Transmission/Transaxle

50 Questions

General transmission/transaxle diagnosis	25 questions
In-vehicle transmission/transaxle repair	12 questions
Off-vehicle transmission/transaxle repair	13 questions

A3 Manual Drive Train and Axles

40 Questions

Clutch diagnosis/repair	6 questions
Transmission diagnosis/repair	7 questions
Transaxle diagnosis/repair	7 questions
Drive shaft/half shaft and universal joint/CV joint diagnosis/repair	5 questions
Rear axle diagnosis and repair	7 questions
Four-wheel drive/all-wheel drive component diagnosis/repair	8 questions

A4 Suspension and Steering

40 Questions

Steering systems diagnosis/repair	10 questions
Suspension systems diagnosis/repair	11 questions
Related suspension and steering service	2 questions
Wheel alignment diagnosis/ adjustment/ repair	12 questions
Wheel and tire diagnosis/repair	5 questions

A5 Brakes

45 Questions

Hydraulic system diagnosis/repair	12 questions
Drum brake diagnosis/repair	5 questions
Disc brake diagnosis/repair	10 questions
Power assist units diagnosis/repair	4 questions
Misc. systems diagnosis/repair	7 questions
Electronic brake control systems diagnosis/repair	7 questions

A6 Electrical/Electronic Systems

50 Questions

General electrical/electronic system diagnosis	13 questions
Battery diagnosis/service	4 questions
Starting system diagnosis/repair	5 questions
Charging system diagnosis/repair	5 questions
Lighting systems diagnosis/repair	6 questions
Gauges, warning devices, and driver information systems diagnosis/repair	6 questions
Horn and wiper/washer diagnosis/repair	3 questions
Accessories diagnosis/repair	8 questions

A7 Heating and Air Conditioning

50 Questions

A/C system service/diagnosis/repair	13 questions
Refrigeration system component diagnosis/repair	10 questions
Heating and engine cooling systems diagnosis/repair	4 questions
Operating systems and related controls diagnosis/repair	19 questions
Refrigerant recovery, recycling, handling, and retrofit	4 questions

A8 Engine Performance

50 Questions

General engine diagnosis	12 questions
Ignition system diagnosis/repair	8 questions
Fuel, air induction, and exhaust systems diagnosis/repair	9 questions
Emission control systems diagnosis/repair	8 questions
Computerized engine controls diagnosis/repair	13 questions

A9 Light Vehicle Diesel Engines

50 Questions

General diagnosis	9 questions
Cylinder head and valve train diagnosis/repair	5 questions
Engine block diagnosis/repair	5 questions
Lubrication and cooling systems diagnosis/repair	6 questions
Air induction and exhaust systems diagnosis/repair	12 questions
Fuel system diagnosis/repair	13 questions

ASE

Figure 2-10. These are the test categories for ASE automobile certification. If you pass a test in a given area and have two years of applicable work experience, you will be certified as an ASE Automobile Technician. If you pass A1–A8 tests and have the required work experience, you will be certified as an ASE Master Automobile Technician.

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Applying for ASE Tests

Anyone may take the ASE tests; however, a passing grade does not lead to automatic certification. To receive certification, the applicant must also have at least two years of experience as an automobile or truck technician. This experience does not have to be in any specific area of automotive service. In some cases, training programs, apprenticeship programs, or time spent performing similar work can be substituted for all or part of the work experience.

In some cases, formal training can be substituted for all or part of the experience requirement:

- High school training for two full years in automotive technology can be substituted for one year of work experience.
- Post-high school training for two years in a public or private facility can be substituted for one year of work experience.
- Two months of short training courses can be substituted for one month of work experience.
- Three years in an apprenticeship program can be substituted for two years of work experience.
- Two years in a post-secondary, factory-sponsored training program that results in an associate degree or equivalent, such as an ASEP, ASSET, or T-Ten.

To have schooling substituted for work experience, you must include a copy of your transcript (list of courses taken) or a certificate verifying your training or apprenticeship, as well as your completed Work Experience Reporting Form, your registration form, and fee payment. Each should give your length of training and subject area.

To apply to take ASE tests, find the registration information online at www.ase.com. The ASE website contains the proper registration form, as well as instructions for completing the form. You can fill in the form online or print it out and mail it in to the address given on the ASE website. Fill out the form carefully.

ASE tests are given year round. The tests are given at designated test centers at over 300 locations in the United States.

Consult the ASE website for test locations. Be sure to determine the closest test center and record its number in the appropriate space on the application form. Most test centers are located at local colleges, high schools, or vocational schools.

When submitting the application, you can pay online with a credit card or send a check, money order, or credit card information with your mailed registration form to cover all necessary fees. You can also register by phone. A fee is charged to register for the test series, and a separate fee is charged for each test taken. Refer to the ASE website for the current fee structure. In some cases, employers pay the registration and test fees. Check with your employer before submitting your application.

After receiving your application and fees, ASE will send you a confirmation e-mail or fax. You should receive the ticket by mail about two weeks after submitting your application.

Test-Taking Techniques

Follow all instructions given by the test administrators. During the test, read each question carefully before deciding on a proper answer. You must select the *most correct* response. Sometimes more than one response is correct. However, one answer will always be more correct than the others.

You will not be required to recall exact specifications unless they are general and apply to most makes and models of cars. For example, compression test pressure readings and engine clearances are typically about the same for all gasoline engines. This type of general information might be needed to answer some questions.

After completing all the questions in a particular test, recheck your answers to ensure that you did not make a careless error. In most cases, rechecking your answers more than once is unnecessary and may lead you to change correct answers to incorrect ones. The time allowed for each testing session is usually about four hours. However, you may leave after completing your last scheduled test and handing in all test material.

A few tips that might help you pass ASE certification tests include:

- Read the statements or questions slowly. You might want to read through them twice to make sure you fully understand the questions.
- Analyze the statement or question. Look for hints that make some of the possible answers wrong.
- Try to answer the question as if you were the technician trying to fix the car. Think of all possible situations and use common sense to pick the most correct response.
- When two technicians give statements concerning a problem, try to decide if either is incorrect. If both are valid statements about a situation,

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choose the answer stating that both technicians are correct. If only one is correct or neither is correct, mark the answer accordingly. This is one of the most difficult types of questions.

- If the question gives only limited information, make sure you do not pick one answer as correct because it describes a more common condition. If the question does not let you conclude that one answer is better than another, both answers are correct.
- Your first thought about which answer is correct is usually the correct response. If you think about a question too much, you may read something into the question that is not there. Read the question carefully and make a decision.
- Do not waste time on any one question. Make sure you have enough time to answer all the questions on the test.
- Visualize yourself performing a test or repair when trying to answer a question. This will help you solve the problem more accurately.

Types of ASE Test Questions

ASE tests are designed to measure your knowledge of three things:

- The operation of various automotive systems and components.
- The diagnosis and testing of various automotive systems and components.
- The repair of automotive systems and components.

All test questions are multiple choice and contain four possible answers. Sample questions are given below. The answer to each question is explained in detail.

One-Part Questions

In a one-part question, you must choose the best answer out of all the possibilities.

1. Which of the following components ignites the fuel in a gasoline engine?
   (A) Injector.
   (B) Valve.
   (C) Spark plug.
   (D) Glow plug.

The spark plug produces the electric arc to start the fuel burning. Therefore, the correct answer is *(C) Spark plug*. The injector simply sprays fuel into the engine. The valve allows the air-fuel mixture to flow into the engine. The glow plug is only used in a diesel engine to warm the combustion chamber to aid combustion.

Two-Part Questions

Two-part questions require you to read two statements and decide if they are true. Both statements can be true or both can be false. In some cases, only one of the statements is true.

1. Technician A says a locking rear differential assembly can be refilled with regular gear oil. Technician B says the differential assembly allows the vehicle to turn corners without wheel hop. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

In this question, the statement made by Technician A is wrong. A locking rear wheel differential assembly must be refilled with special nonslip oil. Technician B's statement is correct, since the purpose of the differential assembly is to allow the vehicle to turn corners without wheel hop. Therefore, the correct answer is *(B) B only*. Note that Technician A and Technician B appear in many ASE test questions. You must carefully evaluate the statements of each technician before deciding which answer is correct.

Negative Questions

Some questions are called negative questions. These questions require you to identify the *incorrect* answer. Negative questions will usually contain the word "*except.*"

1. An engine contains all of the following bearings *except:*
   (A) connecting rod bearings.
   (B) crankshaft main bearings.
   (C) camshaft bearings.
   (D) reverse idler bearings.

Since reverse idler bearings are used in transmissions and there is no bearing with that name used in the engine, the correct answer is *(D) reverse idler bearings*.

A variation of the negative question contains the word "*least.*"

1. An automatic transmission installed in a late-model vehicle slips during acceleration. Which of these defects is *least* likely to be the cause?

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(A) Clogged transmission oil filter.
(B) Defective transmission oil pump.
(C) Bad shift solenoid.
(D) Low fluid level.

In this case, the least likely cause of transmission slippage is a bad shift solenoid, which is much more likely to cause shifting problems than slippage. Therefore, the correct answer is *(C) Bad shift solenoid*.

Completion Questions

Some test questions are simply sentences that must be completed. One of the four possible answers correctly completes the sentence.

1. A torque wrench is used to measure:
   (A) twisting force on fasteners.
   (B) shear applied to fasteners.
   (C) horsepower applied to fasteners.
   (D) transmission slip yoke angles.

Once again, the question calls for the best answer. The torque wrench is used to measure twisting force, or torque, so *(A) twisting force on fasteners* is correct.

Test Results

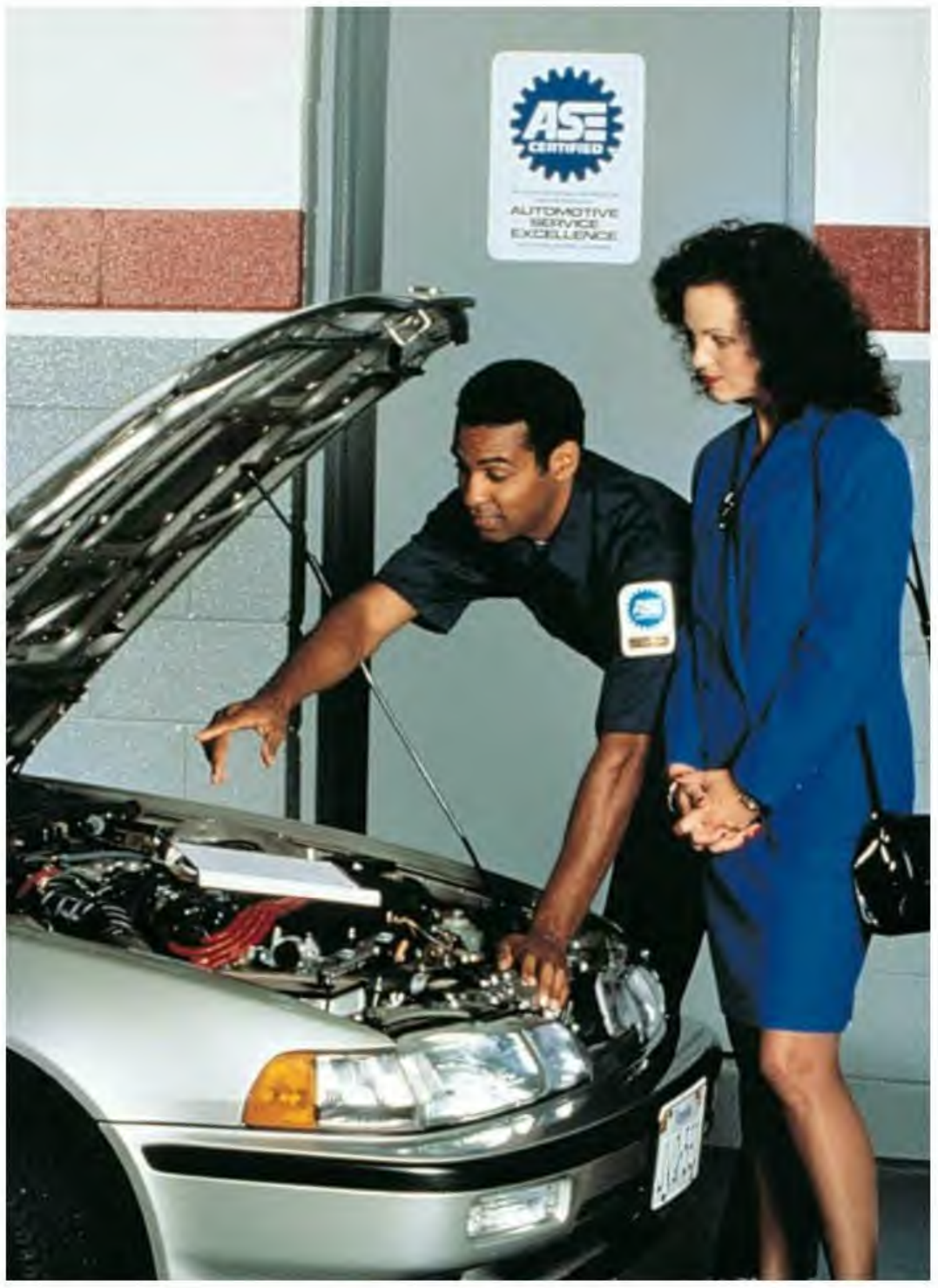
The results of your test will be available before you leave the test center. Only you will find out how you did on the tests. You can then inform your employer if you like.

If you pass a test, you should consider taking more tests. If you fail, you will know that more study is needed before retaking the test.

Certification Status

Assuming the work experience requirements have been met, ***ASE-certified automobile technician*** status is granted for each ASE automobile test passed. ***ASE-certified master automobile technician*** status, previously called certified general technician status, is granted when eight automobile tests have been passed and the experience requirements have been met. Test A9 is not required for master technician status.

Certificates and wallet cards are awarded for each test passed. You also have the option to buy sleeve or shirt patches for each test passed. This will let your customers know that you are fully capable of repairing their vehicles. See **Figure 2-11**.



ASE

Figure 2-11. If you become certified, your customers and your employer will know that you are prepared to properly repair cars and light trucks.

Recertification Tests

Once you are certified in any area, you must take a recertification test every five years to maintain your certification. Recertification test questions concentrate on recent developments. This ensures that certified technicians will keep up with changes in technology.

Applying to take recertification tests is similar to applying for original certification tests. If you allow your certification to lapse, you must take the regular certification test(s) to regain your certification.

Text Organization and ASE Certification

This textbook will help you prepare for ASE certification. The content, scope, and organization were developed with the ASE certification tests in mind. Each chapter contains a section of ASE-type questions, which will help you pass the ASE certification tests.

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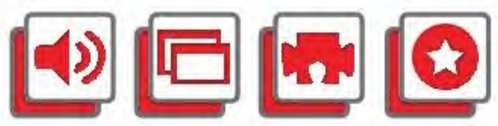
Workplace Skills

The automotive industry is one of the largest industries in the United States. A wide variety of jobs and career fields are available within the automotive industry. As you study automotive technology, keep other automotive-related professions in mind. For example, you might enjoy selling cars more than working on them. Nevertheless, your knowledge of automotive technology will make you a better employee in any field within the automotive industry. Try to learn something new every day to become a better-qualified automotive worker.

Summary

- Economists are predicting a continued demand for automotive technicians for many years.
- An automotive technician makes a living by diagnosing, servicing, and repairing cars and light trucks.
- One way to get started in automotive service is to become an apprentice or helper mechanic, working under an experienced technician.
- A specialized technician is an expert on one system of a car. This type of specialist may work only on brakes, transmissions, engines, tune-ups, electrical systems, or air conditioning.
- An engine technician must be able to troubleshoot, service, and repair automobile engines.
- A transmission technician usually works on automatic and manual transmissions, transaxles, clutches, and sometimes, rear axle assemblies.
- A steering and suspension technician is responsible for checking, replacing, and adjusting steering and suspension components.
- A brake technician specializes in brake system service and repair.
- The electrical system technician must be able to test and repair lighting systems, charging systems, computer control systems, and starting systems.
- The driveability and performance technician must test and adjust engine fuel, ignition, and emission systems.
- The hybrid specialist has had special training working with dangerous high-voltage electric drive systems.
- A master technician is an experienced professional who has mastered all specialized areas and is capable of working on almost any part of a vehicle.
- A shop supervisor is in charge of other technicians in a large garage.
- An entrepreneur is someone who starts a business. This might be a muffler shop, tune-up shop, parts house, or similar facility.
- Auto technician certification is a program where persons voluntarily take written tests to prove their knowledge as an auto technician.

Technical Terms



Write the definitions for the following terms on a separate sheet of paper.

apprentice
ASE-certified automobile technician
ASE-certified master automobile technician
auto parts specialist
auto salesperson
automotive designer
automotive engineer
automotive instructor
automotive technician
cooperative training program
entrepreneur
master technician
National Institute for Automotive Service Excellence (ASE)
service dispatcher
service manager
service writer
shop supervisor
specialized technician

Activities

1. Research an automotive career of your choice. Using word processing software, prepare a written report covering such topics as duties, working conditions, pay range, and opportunities for advancement.
2. Interview a manager of a parts department for a local garage. Report on the duties performed.

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Review Questions

Answer the following questions using the information provided in this chapter.

1. List four skills that may be needed when working as an automotive technician.
2. What is a cooperative training program?
3. Which of the following is *not* a typical specialized technician?
   (A) Engine technician.
   (B) Steering and suspension technician.
   (C) Brake technician.
   (D) Drive shaft technician.
4. Describe some of the responsibilities of a drive-ability and performance technician.
5. A(n) _____ specialist may have to do grease jobs.
6. What is a master technician?
7. Explain the job of a service manager.
8. A(n) _____ is an individual who starts a business.
9. List the eight test categories of ASE certification.
10. You will receive a(n) _____ and a(n) _____ for each ASE certification exam passed.

ASE-Type Questions

1. Technician A says that an automotive technician must be a "jack-of-all-trades." Technician B says that the technician's job is seldom boring. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. A used car needs a wheel alignment. Which technician would usually complete this operation?
   (A) Engine technician.
   (B) Steering and suspension technician.
   (C) Wheel technician.
   (D) Brake technician.
3. A vehicle comes into the shop for repairs. Technician A says to check with the service writer for the details of the customer complaint. Technician B says to check with the shop supervisor to get information on the complaint. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. Technician A says some ASE questions cover the operation of various automotive systems and components. Technician B says some ASE questions cover the repair of various automotive systems and components. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. All the following are automatic benefits of ASE certification, *except:*
   (A) recognition.
   (B) the option to purchase a sleeve patch.
   (C) a pay raise.
   (D) a wall certificate.

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A speed handle is an often-underutilized hand tool. It can be used to start and quickly tighten small nuts and bolts.

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Chapter3
Basic Hand Tools

After studying this chapter, you will be able to:

- Identify common automotive hand tools.
- List safety rules for hand tools.
- Select the right tool for a given job.
- Maintain and store tools properly.
- Use hand tools safely.
- Explain why insulated tools must be used when servicing electric drive trains.
- Correctly answer ASE certification test questions referring to hand tools.

Professional auto technicians invest thousands of dollars on their tools, and for good reason. It is almost impossible to do even the simplest auto repair without using some type of tool.

Tools serve as extensions to parts of the human body. Tools increase the physical abilities of fingers, hands, arms, legs, eyes, ears, and back. A well-selected set of tools speeds up repairs, improves work quality, increases profits, and makes mechanical repair work easier and more enjoyable.

Tech Tip

It is very frustrating trying to fix a vehicle without the right tools. It can be like trying to "fight a forest fire with a squirt gun"—impossible! Invest in a complete set of quality tools.

Tool Rules

There are several basic tool rules that should be remembered. These are as follows.

- Purchase quality tools—With tools, you usually get what you pay for. Quality tools are lighter, stronger, easier to use, and more dependable than off-brand, bargain tools. Many manufacturers of quality tools provide guarantees. Some are for the lifetime of the tool. If the tool fails, the manufacturer will replace it free of charge. This can save money in the long run.
- Keep tools organized—A technician has hundreds of different tools. For the tools to be located quickly, they should be neatly arranged. There should be a place for every tool, and every tool should be in its place. If tools are just thrown into

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the toolbox, time and effort are wasted "digging and searching" instead of fixing the vehicle.

- Keep tools clean—Wipe tools clean and dry after each use. A greasy or oily tool can be dangerous! It is very easy to lose a grip on a dirty tool, cutting or breaking a finger or hand.
- Use the right tool for the job—Even though several different tools may be used to loosen a bolt, usually one will do a better job. It may be faster, grip the bolt better, be less likely to break, or require less physical effort. A good technician knows when, where, and why a particular tool will work better than another. Keep this in mind as you study automotive tools.

Tech Tip

The time spent maintaining your tools and toolbox is time well spent. Well-organized tools will save time on each job and help you get more work done. Unorganized or poorly maintained tools will hurt your on-the-job performance and your appearance as a professional technician.

Tool Storage

A ***toolbox*** stores and protects a technician's tools when not in use. There are three basic parts to a typical toolbox, **Figure 3-1**. These include:

- A large lower roll-around cabinet.
- An upper tool chest that sits on the roll-around cabinet.
- A small carrying tray. This is usually placed in the upper tool chest.

The lower roll-around cabinet holds bulky, heavy tools. Large power tools are normally kept in this part of the box. Extra storage compartments can be attached to the sides of the roll-around cabinet.

Commonly used tools are normally placed in the upper tool chest. Being near eye level, tools can be easily seen and reached without bending. This saves time and energy, and increases production.

Toolbox Organization

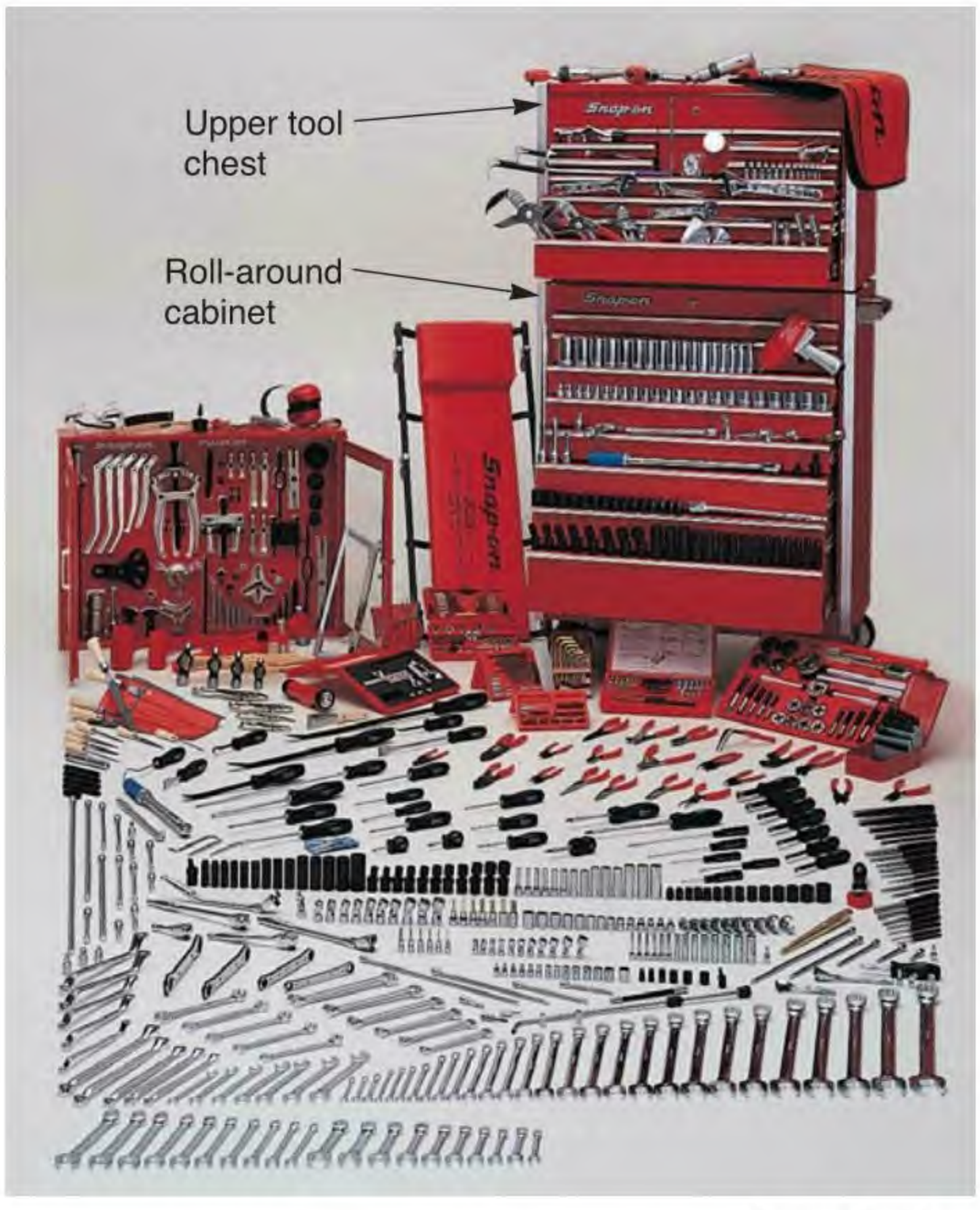
Related tools are normally kept in the same toolbox drawer. For example, various types of hammers may be stored in one drawer and all screwdrivers in another. Small or delicate tools should not be kept with large, heavy tools to prevent damage. ***Tool holders*** help organize small tools. These include small clips, magnetic racks, cloth or plastic pouches, and socket trays. They are often used to protect tools and to keep them organized by size. Holders also allow a full set of tools to be taken to the job.

Warning

Never open several toolbox drawers at one time. If you do, the heavy toolbox might flip over. Serious injury or death can result since a full toolbox can weigh up to 2000 pounds (907 kg). Close each drawer before opening the next.

Wrenches

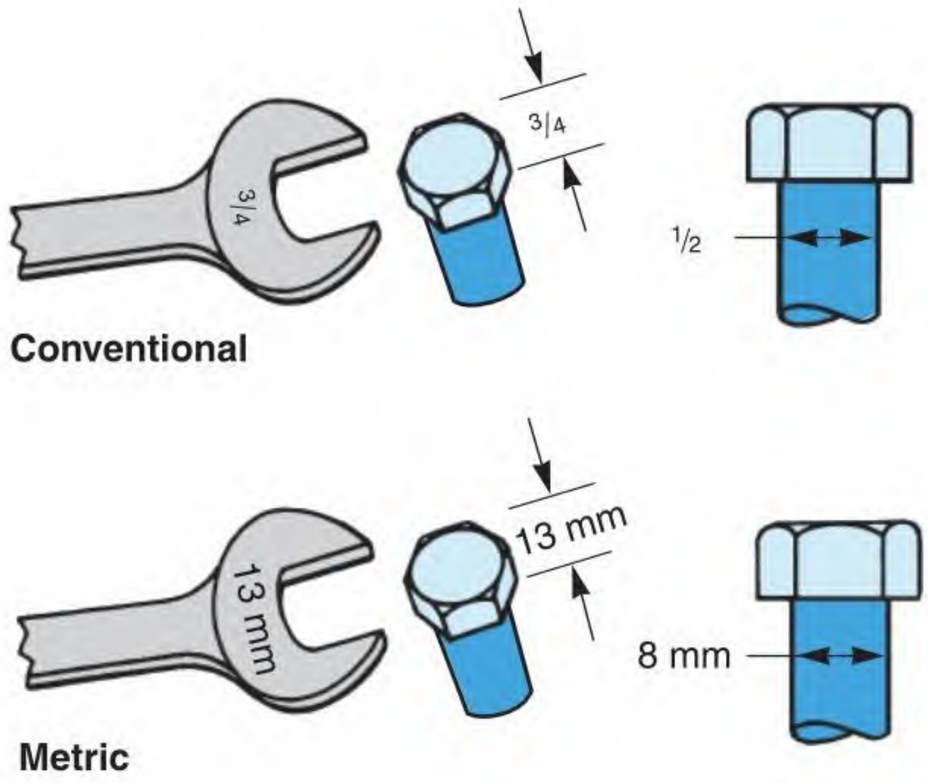
Wrenches are commonly used to install and remove nuts and bolts. ***Wrench size*** is determined by measuring across the wrench jaws. Refer to



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Figure 3-1. A toolbox is used to organize the wide variety of tools a technician needs.

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Figure 3-2. Look at conventional and metric wrenches. A—Conventional tool sizes are given in fractions of an inch. The measurement is the width of the jaw opening. As shown here, these sizes are not the same as bolt sizes. B—Metric wrench sizes are given in millimeters. The measurement is the width of the jaw opening. The wrench size is not the same as the bolt size (bolt diameter).

Figure 3-2. Wrenches come in both conventional (inch) and metric (millimeter) sizes. The size is stamped on the side of the wrench. Here are a few wrench rules to follow.

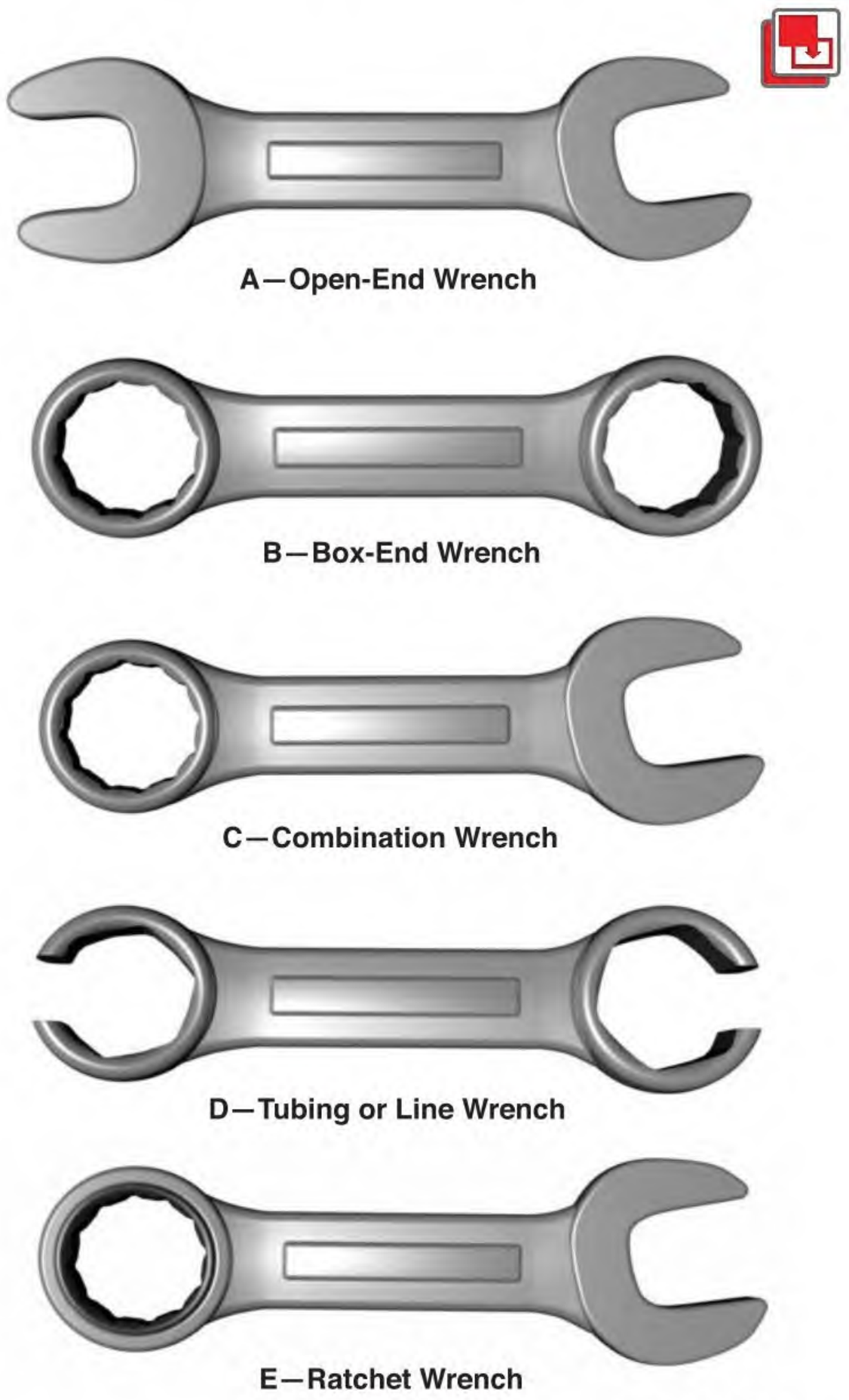
- Always select the right size wrench. It must fit the bolt head snugly. A loose-fitting wrench will round off the corners of the bolt head.
- Never hammer on a standard wrench to break loose a bolt or large nut. Use a longer wrench or a special slug wrench. A longer wrench will provide more leverage. A slug wrench is designed to be hit with a hammer.
- When possible, pull on the wrench. Then, if the wrench slips, you are less likely to hurt your hand. When you must push, use the palm of your hand and keep your fingers open.
- Never use a steel bar or pipe to increase the length of a wrench for leverage. Excess force can bend or break the wrench.

Open-End Wrenches

An open-end wrench has an open, or split, jaw on both ends. Each end is a different size and set at an angle, **Figure 3-3A**. This angle allows the open-end wrench to turn bolts and nuts with little wrench swing space. The wrench can be turned over after each swing to get a new "bite" on the bolt head. An open-end wrench has weak jaws. It should not be used on extremely tight nuts or bolts. Its jaws will flex outward and round off the bolt head if too much torque is applied.

Box-End Wrenches

Box-end wrenches are completely closed on both ends. They fully surround and grip the head of a bolt or nut, **Figure 3-3B**. A box-end wrench will not round off bolt heads as easily as an open-end wrench. Box-end wrenches are available with either 6- or 12-point openings. A 6-point opening is the strongest configuration. It should be used on extremely tight, rusted, or partially rounded bolt or nut heads.



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Figure 3-3. Study the basic types of hand wrenches.

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Combination Wrenches

A combination wrench has a box-end on one end and an open-end on the other, **Figure 3-3C**. Both ends are usually the same size. A combination wrench provides the advantage of two types of wrenches for the price of one.

Line Wrenches

A line wrench, also called a tubing wrench or flare nut wrench, is a box-end wrench with a small opening, or split, in the jaw, **Figure 3-3D**. The opening allows the wrench to be slipped over fuel lines, brake lines, or power steering lines and onto the fitting nut. A line wrench prevents damage to soft fittings.

Ratcheting Wrenches

A ratcheting wrench has a gear and lever mechanism so the wrench can be moved back and forth for rapid fastener installation or removal. Most ratcheting wrenches come with ends that are the same size, with one open-end and one closed-end. See **Figure 3-3E**.

Socket Wrenches

A socket wrench consists of a socket and a socket handle. A ***socket*** is a cylinder-shaped, box-end tool for removing or installing bolts and nuts. See **Figure 3-4**. One end fits over the fastener. The other end has a square opening that fits on a socket handle. The socket handle provides leverage to turn the socket and fastener.

A socket's drive size is the size of the square opening for the ratchet or tool handle. As pictured in **Figure 3-5**, sockets come in four drive sizes: 1/4″, 3/8″, 1/2″, and 3/4″.

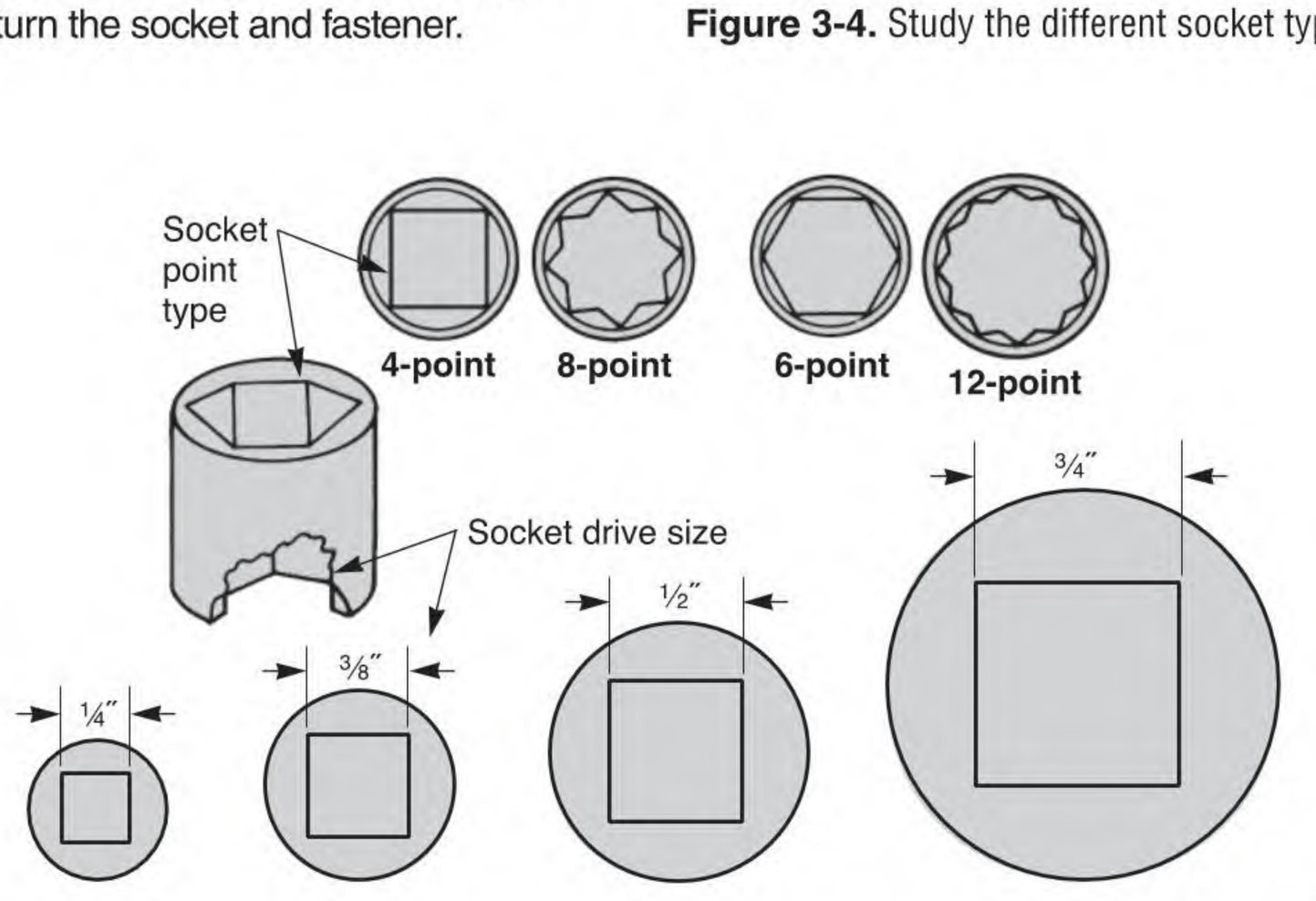
If a small drive size is used on large or tight fasteners, the socket or handle can be broken. A large drive may be too awkward for small nuts and bolt heads. Generally, a 1/4″ drive should be used on bolt and nut heads 1/4″ and smaller. A 3/8″ drive is adequate on bolt head and nut sizes between 1/4″ and 5/8″. A 1/2″ drive is strong enough to handle bolt or nut heads from 5/8″ to 1″. A 3/4″ drive is for bolts and nuts with a head size larger than 1″.

They also come in four different points: 4-point, 6-point, 8-point, and 12-point. A 6-point socket is required when a bolt is very tight and you do not want to "round off" and strip the bolt head flats. A 12-point socket is handy on bolts that are not rusted or bound up and will rotate with little torque.



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Figure 3-4. Study the different socket types.



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Figure 3-5. Sockets come in four drive sizes and four point types. The most commonly used drives are 3/8″ and 1/2″. The most common point types are 6-point and 12-point.

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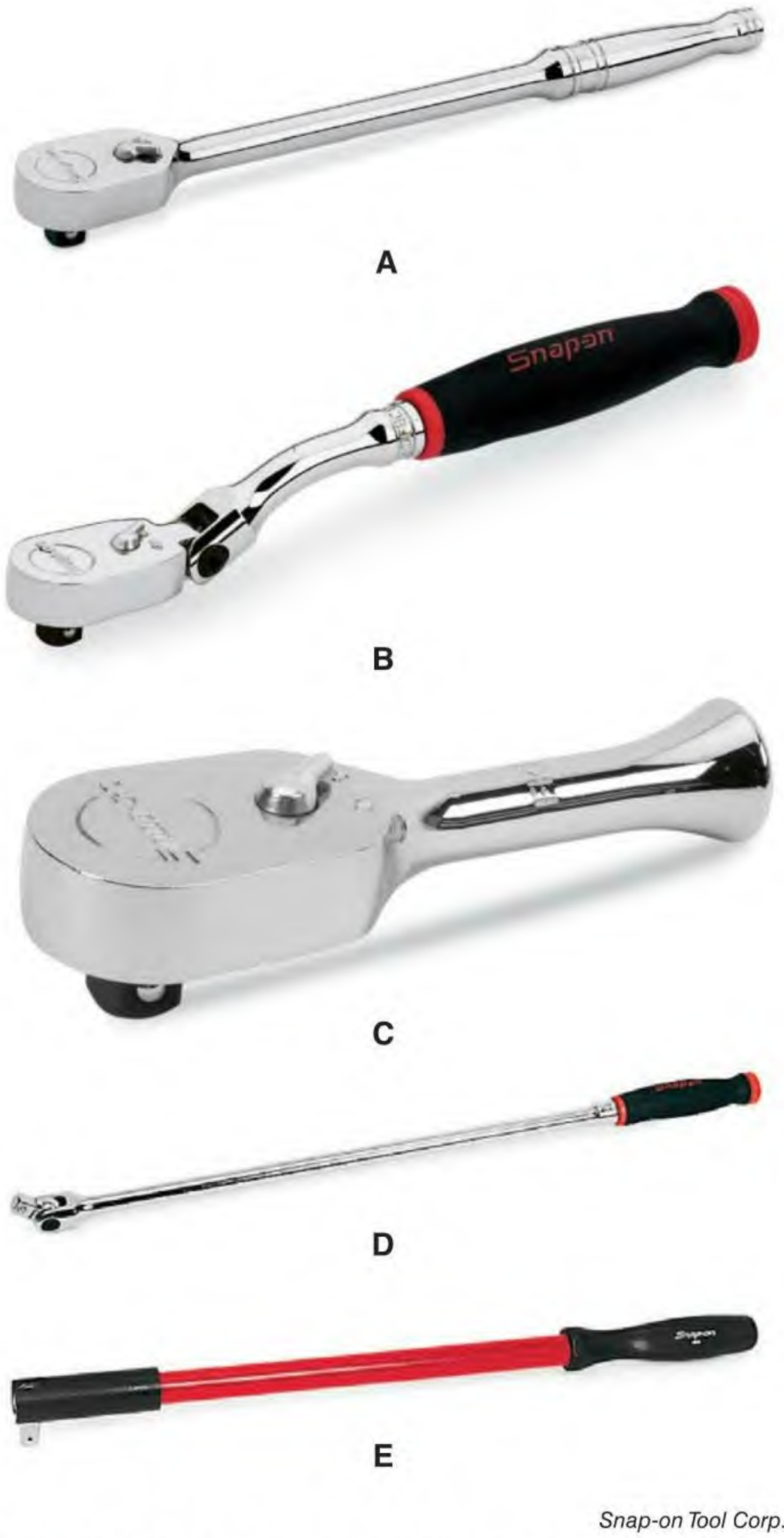
Socket Handles

Socket handles fit into the square opening in the top of the socket. Several types are shown in **Figure 3-6**.

Like a ratcheting wrench, a ratchet handle has a gear and lever mechanism so the wrench can be moved back and forth for rapid fastener installation or removal. The ratchet handle can often be used to remove fasteners in obstructed areas without having to reposition the handle. Ratchet handles can be short for tight quarters or long to apply more torque to stubborn nuts and bolts.

A flex bar, or breaker bar, is the strongest socket handle and provides the most leverage. It should be used when breaking loose large or extremely tight bolts and nuts.

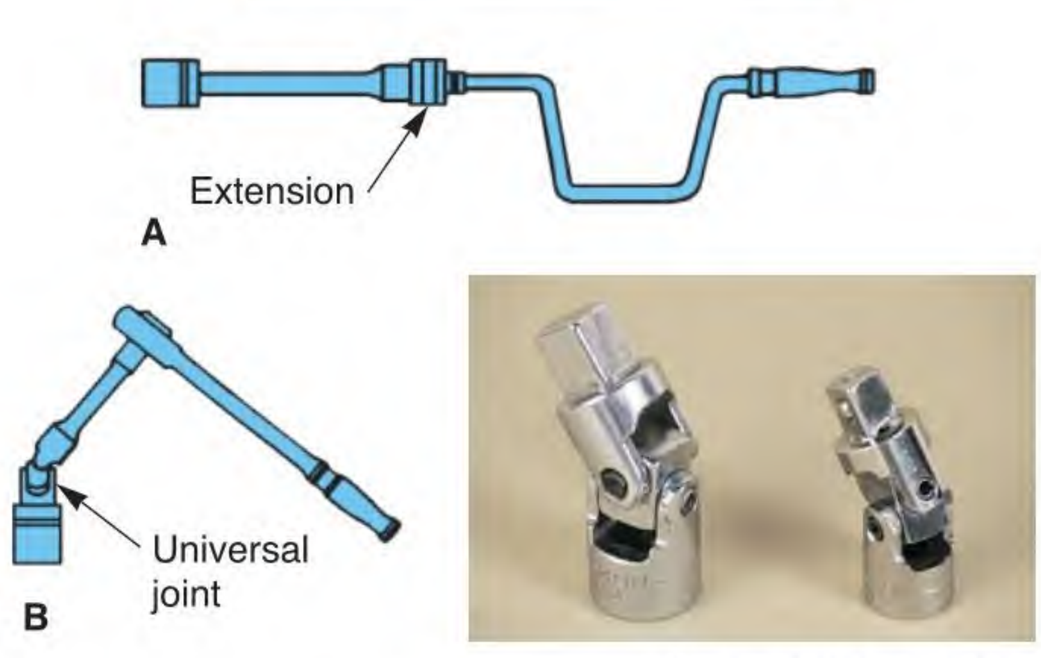
Extensions are used between a socket and its handle. See **Figure 3-7A**. They allow access to difficult-to-reach fasteners.



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Figure 3-6. Study the various socket handles. A—Standard ratchet has straight handle with reversing lever. B—Offset ratchet will reach over parts to reach fastener. C—Stubby ratchet is for tight places. D—Breaker bars or flex handles are required for loosening stubborn nuts and bolts. E—Insulated breaker bars are used for hybrid vehicles.





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Figure 3-7. Extensions and universal joints are needed to reach hidden fasteners. A—An extension moves the socket away from the handle for more ratchet clearance. B—A universal joint allows the socket to be turned from an angle to the fastener.

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A ***universal joint*** is a swivel that lets the socket wrench reach around obstructions, **Figure 3-7B**. It is used between the socket and handle, with or without an extension. Avoid putting too much bend into a universal joint, or it may bind and break.

Other Wrench Types

An ***adjustable wrench***, or Crescent wrench, has jaws that can be adjusted to fit different size bolt and nut heads. It should be used only when other type wrenches will *not* fit. Adjustable wrenches can loosen and round off fasteners during use. An adjustable wrench is a handy tool to carry for emergencies. It is like having a full set of open-end wrenches.

A ***pipe wrench*** is an adjustable wrench used to grasp cylindrical objects. The toothed jaws actually dig into the object. For this reason, never use it on parts that will be ruined by marks or nicks.

An ***Allen wrench*** is a hexagonal (six-sided) shaft-type wrench. It is used to turn setscrews on pulleys, gears, and knobs. To prevent damage, make sure the Allen wrench is fully inserted into the fastener before turning. These and other types of wrenches are shown in **Figure 3-8**

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Figure 3-8. Study wrench types. A—Adjustable, or Crescent, wrenches can be set to various sizes. B—Pipe wrenches will turn with great force, but can mar the surface of a part. C—Allen, or hex, wrenches have six sides and come in many sizes. D—Insulated ratcheting wrenches will help prevent electrocution. E—Reversing ratcheting wrenches are handy and narrow. F—Flex combination wrench. G—Half-moon, 12-point wrenches will work in tight quarters. H—Chain wrenches will grasp oil filters for removal.

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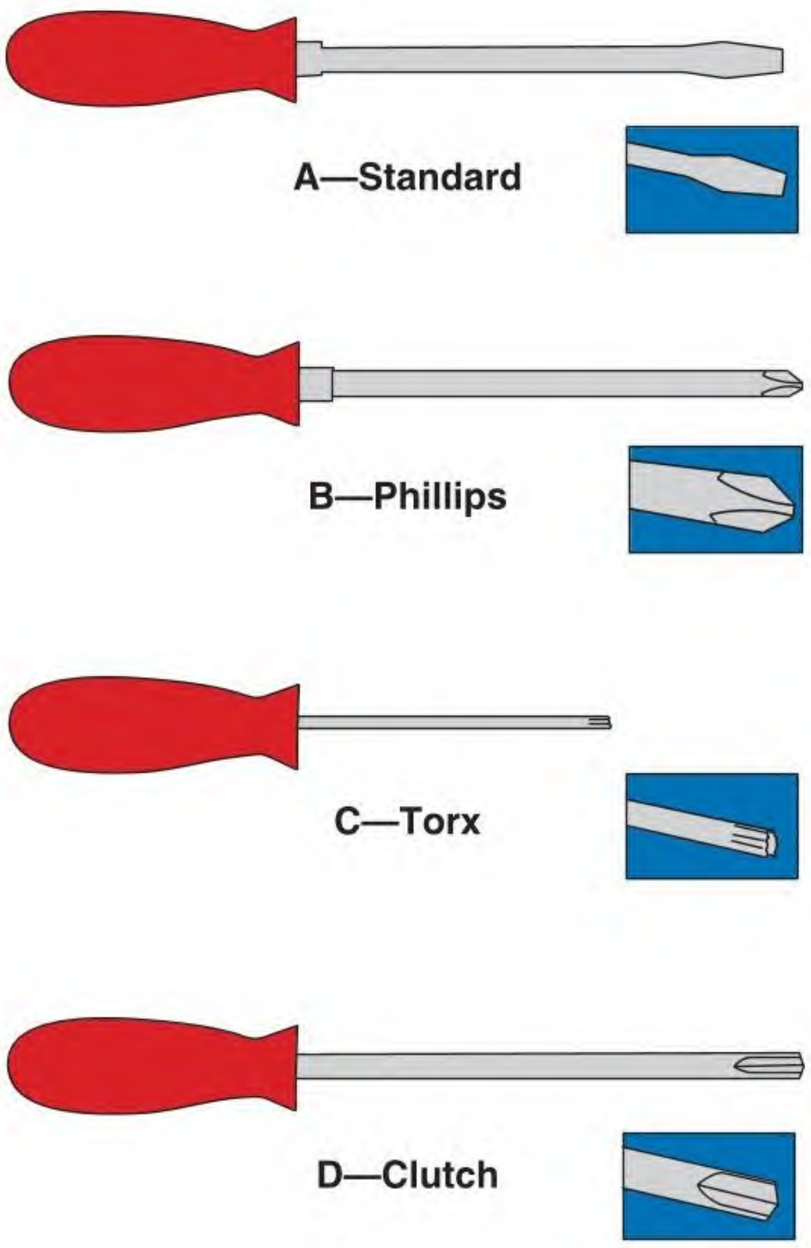
Screwdrivers

Screwdrivers are used to remove or install screws. They come in many shapes and sizes. A standard screwdriver has a single blade that fits into a slot in the screw head. A Phillips screwdriver has two crossing blades that fit into a star-shaped screw slot.

Torx and clutch-type screwdrivers are used to remove and install special types of screws. Torx screwdriver is used to tighten or loosen Torx screws. This type of screw has a 6-point, star-shaped indentation formed into its head. The shape of the indentation allows Torx screws to be rotated with a great deal of force, or torque, without damaging the head.

A clutch-type screwdriver is used for clutch-head fasteners. A clutch-head fastener has a bow-tie shaped opening in its head. Clutch-head fasteners are sometimes found on small parts, allowing for quick removal during repairs. Study the types of screwdrivers shown in **Figure 3-9**.

Offset and stubby screwdrivers are good in tight places, **Figures 3-10A** and **B**. For example, a stubby screwdriver is needed for loosening screws inside a glove box. Starting screwdrivers hold the screw securely until started in its hole. They prevent the screw from being dropped and lost, **Figure 3-10C**.



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Figure 3-9. Memorize screwdriver types.

A ***scratch awl*** looks like a screwdriver, but it has a sharp, pointed tip, **Figure 3-10D**. It is used for marking sheet metal and other parts. An ***impact driver*** can be used to loosen extremely tight screws. When struck with a hammer, the driver exerts powerful turning and downward forces. This is shown in **Figure 3-11**.



A—Offset Screwdriver



B—Stubby Screwdriver



C—Starting Screwdriver



D—Scratch Awl

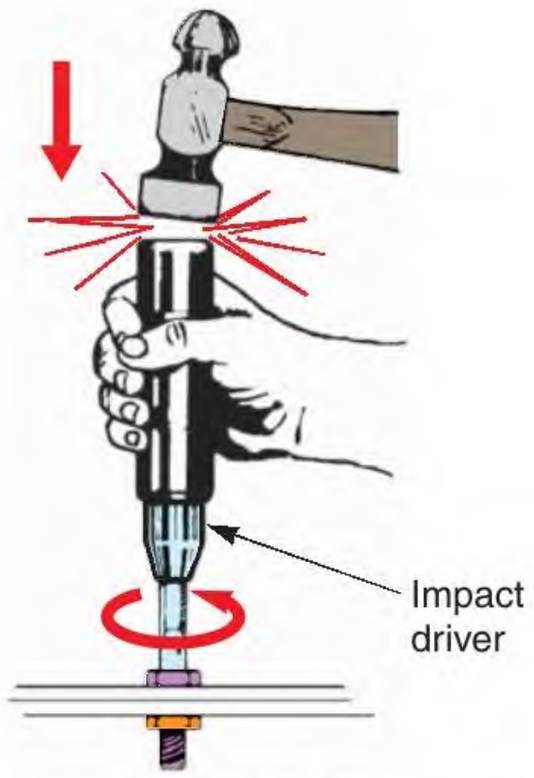
Lisle

Figure 3-10. Compare different types of specialty screwdrivers.

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A



B

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Figure 3-11. A—An impact driver can be used to loosen stubborn fasteners. B—Hit the impact driver squarely with a hammer to free and turn stubborn or stripped out fasteners.

When selecting a screwdriver, pick one that is wide and thick enough to completely fill the screw head. If the screwdriver is too large or too small, damage to the screwdriver or screw may occur. Most screwdrivers are not designed to be hammered on or pried with. Only heavy-duty screwdrivers with a full shank can withstand light hammering and prying.

Pliers

Pliers are used to grip, cut, crimp, hold, and bend various parts. Different pliers are helpful for different situations. Never use pliers when another type of tool will work. Pliers can nick and scar a part. Several types of pliers are pictured in **Figure 3-12**.

Combination pliers, or slip-joint pliers, are the most common pliers used by an automotive technician. The slip joint allows the jaws to be adjusted to



A—Slip-Joint Pliers



B—Rib Joint Pliers



C—Needle Nose Pliers



D—Diagonal Cutting Pliers



E—Vise Grip Pliers



F—Snap Ring Pliers

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Figure 3-12. Study different types of pliers.

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grasp different size parts, **Figure 3-12A**. Rib joint pliers, also called channel lock pliers, open extra wide for holding very large objects, **Figure 3-12B**.

Needle nose pliers are excellent for handling extremely small parts or reaching into highly restricted areas, **Figure 3-12C**. Do not twist too hard on needle nose pliers, or the long thin jaws can be bent.

Diagonal cutting pliers are the most commonly used cutting pliers, **Figure 3-12D**. Their jaw shape allows them to cut items flush with an adjacent surface. Diagonal cutting pliers are often used to cut off cotter pins, wires, and plastic ties.

Locking pliers, or vise grips, clamp onto and hold a part, **Figure 3-12E**. This frees both hands to do other tasks. Because of their clamping power, vise grips can sometimes be used to unscrew fasteners with stripped or rounded heads. However, never use them on undamaged nuts or bolts because the jaws can distort the surfaces they are clamped onto.

Snap ring pliers have sharp, pointed tips for installing and removing special clips called snap rings. A pair of snap ring pliers is shown in **Figure 3-12F**.

Wire stripping pliers are designed to easily remove plastic insulation from different sized wires. Battery pliers have jaws for grasping corroded fasteners on battery cables.

Hammers

Various types of hammers are used for operations that involve striking a tool or part. Several hammers are shown in **Figure 3-13**. The following are some general rules governing hammers.

- Select the right size hammer. If a large part is struck by a small hammer, the hammer can fly backwards dangerously. If the hammer is too large, however, it may damage the part.
- Always check that the hammer head is tight on the handle. If not, the head may fly off and cause injury or damage.
- Use a brass, plastic, or dead blow hammer on parts and tools that can be damaged by a steel hammer. Use a steel hammer only when maximum driving force is required.
- Grasp the hammer near the end of the handle and strike the part or tool squarely.

A ***ball peen hammer*** is the most common type of hammer used in automotive work, **Figure 3-13A**. It has a flat face for general striking. It also has a round end for shaping metal parts, such as sheet metal or rivet heads.



A—Ball Peen Hammer



B—Sledgehammer



C—Plastic Hammer



D—Rubber Mallet



E—Dead Blow Hammer

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Figure 3-13. Note different hammer types.

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A ***sledgehammer*** has a very large head, **Figure 3-13B**. It is usually the heaviest hammer and produces powerful blows. A sledgehammer is sometimes used to free frozen parts.

The brass hammer has a soft, heavy head and is useful when scarring the surface of a part must be avoided. The relatively soft head deforms to protect the part surface from damage.

A ***plastic hammer*** is light and has a soft head, **Figure 3-13C**. It is used where light blows are needed to prevent part breakage or damage to surfaces on small and delicate parts.

A ***rubber mallet*** has a head made of solid rubber, **Figure 3-13D**. It will rebound, or bounce, upon striking and is not effective on solid metal parts. It is recommended on many sheet metal or plastic parts, such as garnish molding and plastic or sheet metal wheel covers.

The head of a ***dead blow hammer*** is filled with small metal balls called lead shot. The extra weight of lead shot prevents a rebound of the hammer when striking. Some dead blow hammers have plastic-coated faces, which help prevent damage to the work surface. See **Figure 3-13E**.

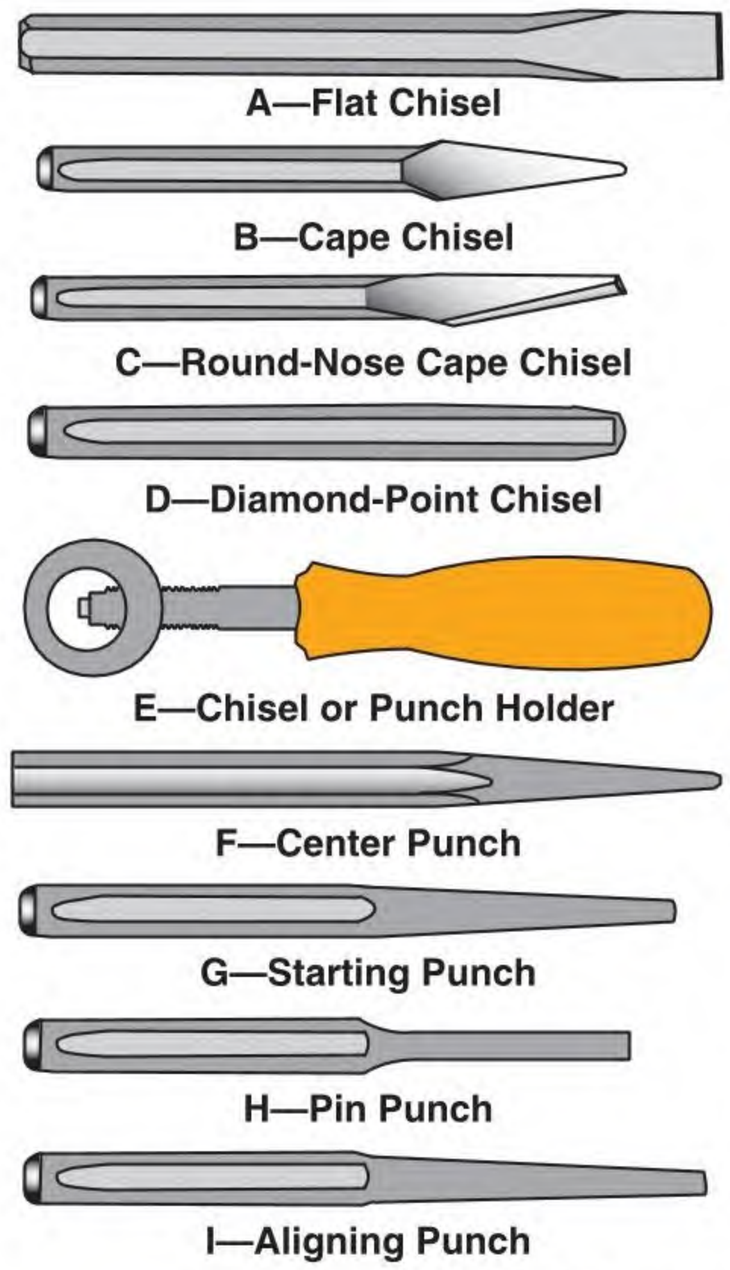
Chisels and Punches

Chisels are for cutting off damaged or badly rusted nuts, bolts, and rivet heads. There are various chisel shapes, **Figure 3-14**. Use common sense when selecting a chisel shape.

Punches also come in several configurations. See **Figure 3-14**. A center punch is frequently used to mark parts for reassembly and to start a hole before drilling. The indentation made by a center punch will keep a drill bit from moving when first starting to drill. Look at **Figure 3-15**.

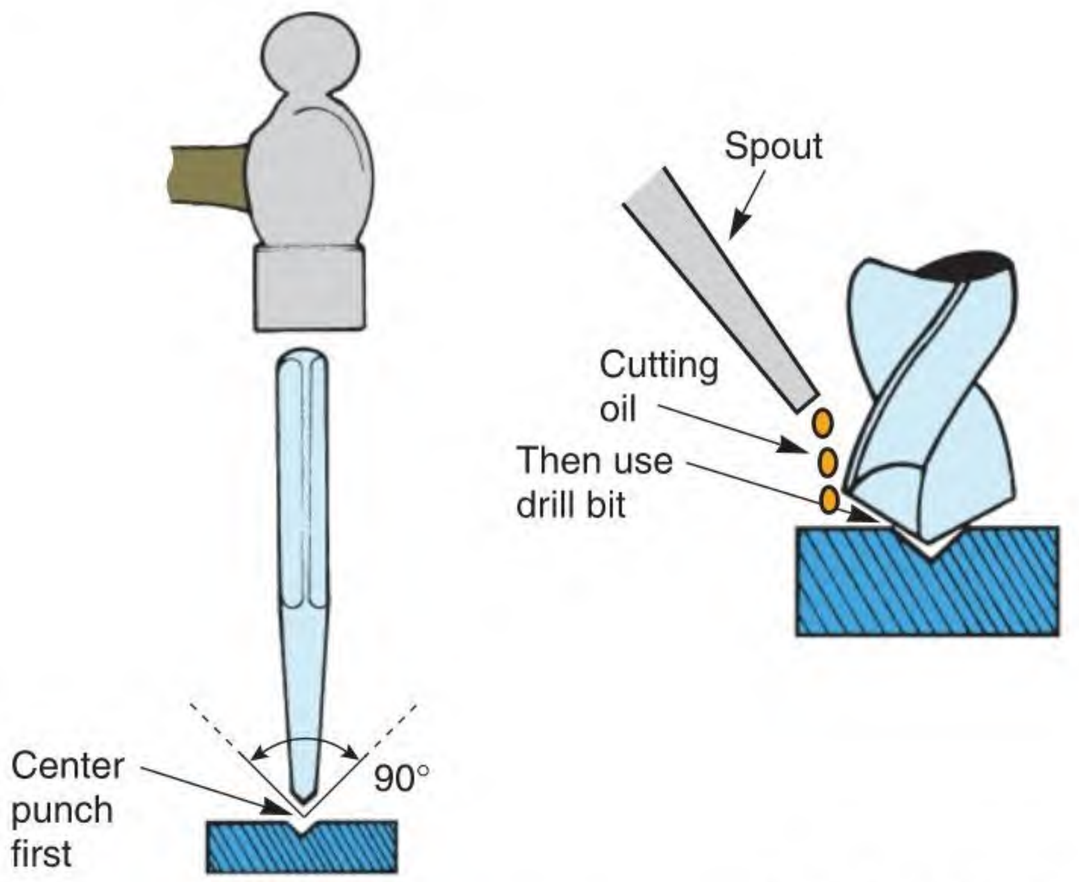
A starting punch, or drift punch, has a shank tapered all the way to the end. It is strong and can withstand moderate blows. It is used to drive pins, shafts, and metal rods partway out of a hole. A pin punch has a straight shank and is lighter than a starting punch. It is used after a starting punch to push a shaft or rod the rest of the way out of a hole.

An aligning punch has a long, tapered shaft and is handy for lining up parts during assembly. An aligning punch can be inserted into holes in mating parts and then wiggled to match up the holes. Never use an aligning punch as a center punch. Its tip is too soft and would be ruined.



Snap-on Tool Corp., OTC/SPX Corp., and Proto Tools

Figure 3-14. Note chisel and punch set with large safety handle to protect from injury.



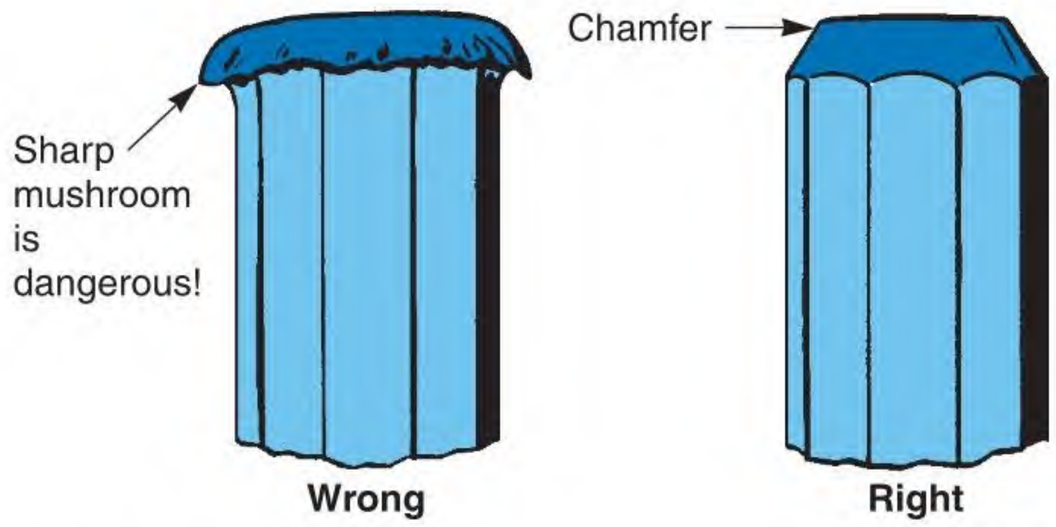
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Figure 3-15. A center punch makes a small indentation in metal parts. This can then be used to start a drill bit.

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Remember these chisel and punch rules:

- Use the largest punch or chisel that will work. If a small punch is used on a very large part, the punch can rebound and fly out with tremendous force. The same is true for chisels.
- Keep both ends of a chisel or punch properly ground and shaped. A chisel's cutting edge should be sharp and square. A starting punch or a pin punch should also be ground flat and square. A center punch should have a sharp point.
- After prolonged hammering, the top of a chisel or punch can become deformed and enlarged. This is called mushrooming. A mushroomed chisel or punch is dangerous! Grind off the mushroom and form a chamfer, as shown in **Figure 3-16**.
- When grinding a chisel or punch, grind slowly to avoid overheating the tool. Excessive heat will cause the tool to turn blue, lose its temper, and become soft.
- Make sure to wear eye protection when using or grinding a chisel or punch.



Deere & Co.

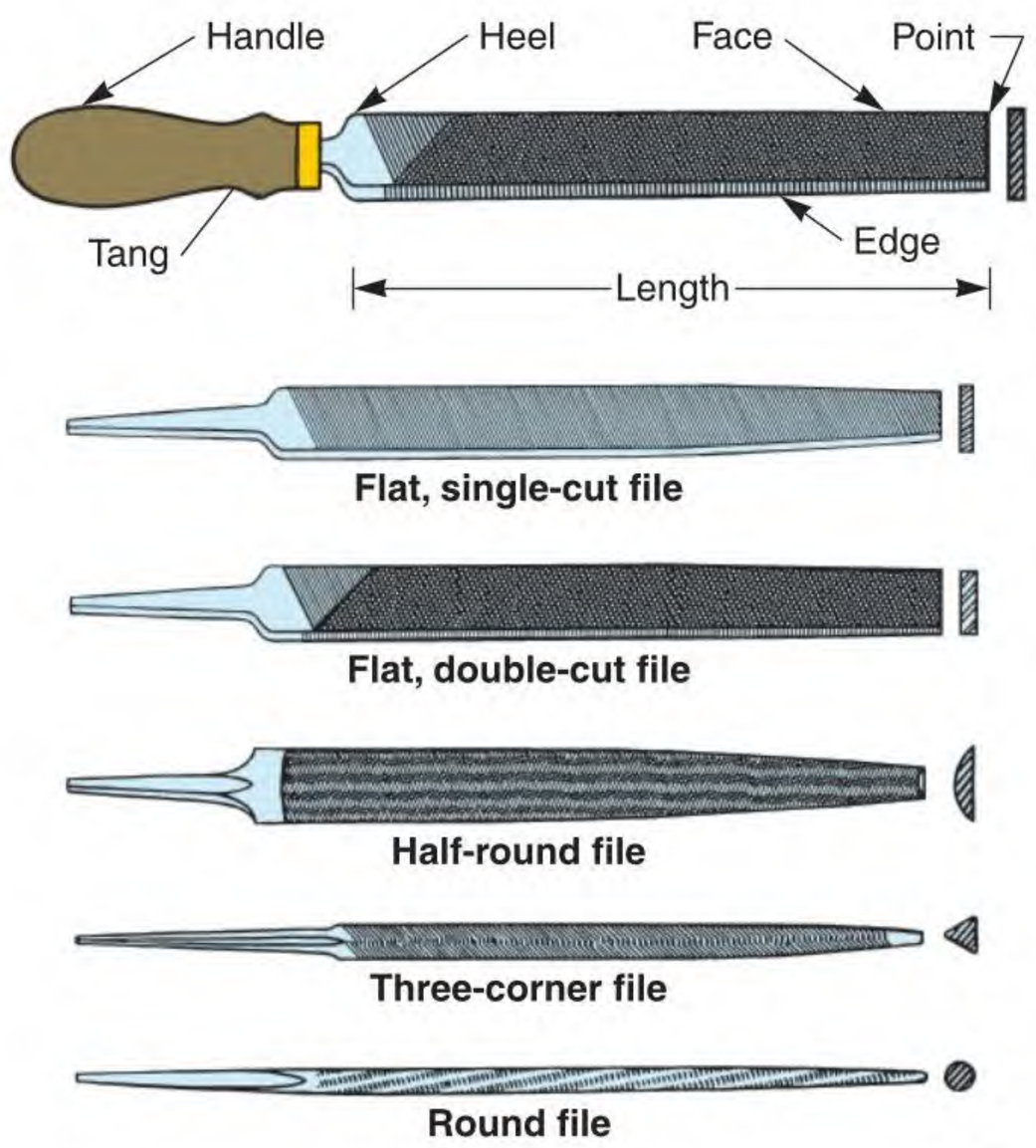
Figure 3-16. Always keep the head of a chisel or punch ground to a chamfer. A sharp, mushroomed end is dangerous.

Files

Files remove burrs, nicks, and sharp edges and perform other smoothing operations. They are useful when only a small amount of material must be removed. Refer to **Figure 3-17**.

A file is classified by its length, shape, and cutting surface. Generally, a coarse file with large cutting teeth should be used on soft materials, such as plastic, brass, and aluminum. A fine file with small cutting teeth is needed to produce a smoother surface and to cut harder materials, like cast iron or steel.

There are several file safety rules that should be remembered. These are:



Starrett

Figure 3-17. A file is used for smoothing metal. Note the different parts of a file and the different types of files available.

- Never use a file without a handle securely attached. If the file is used without a handle, the pointed tang can puncture your hand or wrist.
- To prevent undue file wear, apply pressure only on the forward stroke. Lift the file on the backstroke.
- When filing, place one hand on the handle and the other on the file tip. Hold the file firmly but do not press too hard.
- Do not file too rapidly. One file stroke every second is fast enough. Count to yourself: one thousand one, one thousand two, one thousand three, one thousand four, etc. This will time your strokes properly at about 50–60 strokes per minute.
- If a file becomes clogged, clean it with a file card or a stiff wire brush.
- Never hammer on or pry with a file! A file is very brittle and will break easily. Bits of the file can fly into your face or eyes.

Saws

A ***hacksaw*** is used to cut metal objects. Blades of various lengths can be mounted in the saw's adjustable frame. The blade teeth should point away from the handle, and the blade should be fastened tightly in the frame.

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Select the appropriate blade for the job. As a rule of thumb, at least two saw teeth should contact the material being cut at any given time. If not, the teeth can catch and break.

When cutting, place one hand on the hacksaw handle and the other on the end of the frame. Press down lightly on the forward stroke and release pressure on the backstroke. As with a file, use 50–60 strokes per minute. If cuts are made faster than this, the blade will quickly overheat, soften, and become dull. See **Figure 3-18**.



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Figure 3-18. Hacksaws are sometimes used to cut metal in old exhaust systems or during fabrication of small parts. Hold the saw as shown and only push down on the forward stroke.

Holding Tools

There are several different types of tools used for holding objects in the automotive shop. It is important that you know how to use each without part damage or injury to yourself or others.

Vise

A ***vise*** is used to hold parts during cutting, drilling, hammering, and pressing operations. See **Figure 3-19**. It is mounted on a workbench. Avoid clamping a smooth, machined part in the uncovered jaws of a vise. If a machined surface is scarred, the part may be ruined.

Vise caps or wood blocks should be used to prevent damage when mounting precision or delicate parts in a vise. Vise caps are soft metal jaw covers. They will not only protect the part, but will provide a more secure grip on the part.



Snap-on Tool Corp.

Figure 3-19. A vise mounts on the workbench. It holds parts securely.

A few vise rules include:

- Never hammer on a vise handle to tighten or loosen the vise. Use the weight of your body to turn the vise handle.
- Keep the moving parts of the vise clean and oiled.
- Wear safety glasses when using a vise. Tremendous clamping force can be exerted and parts may break and fly out.
- Use vise caps when a precision part is held in a vise. This will prevent part damage.

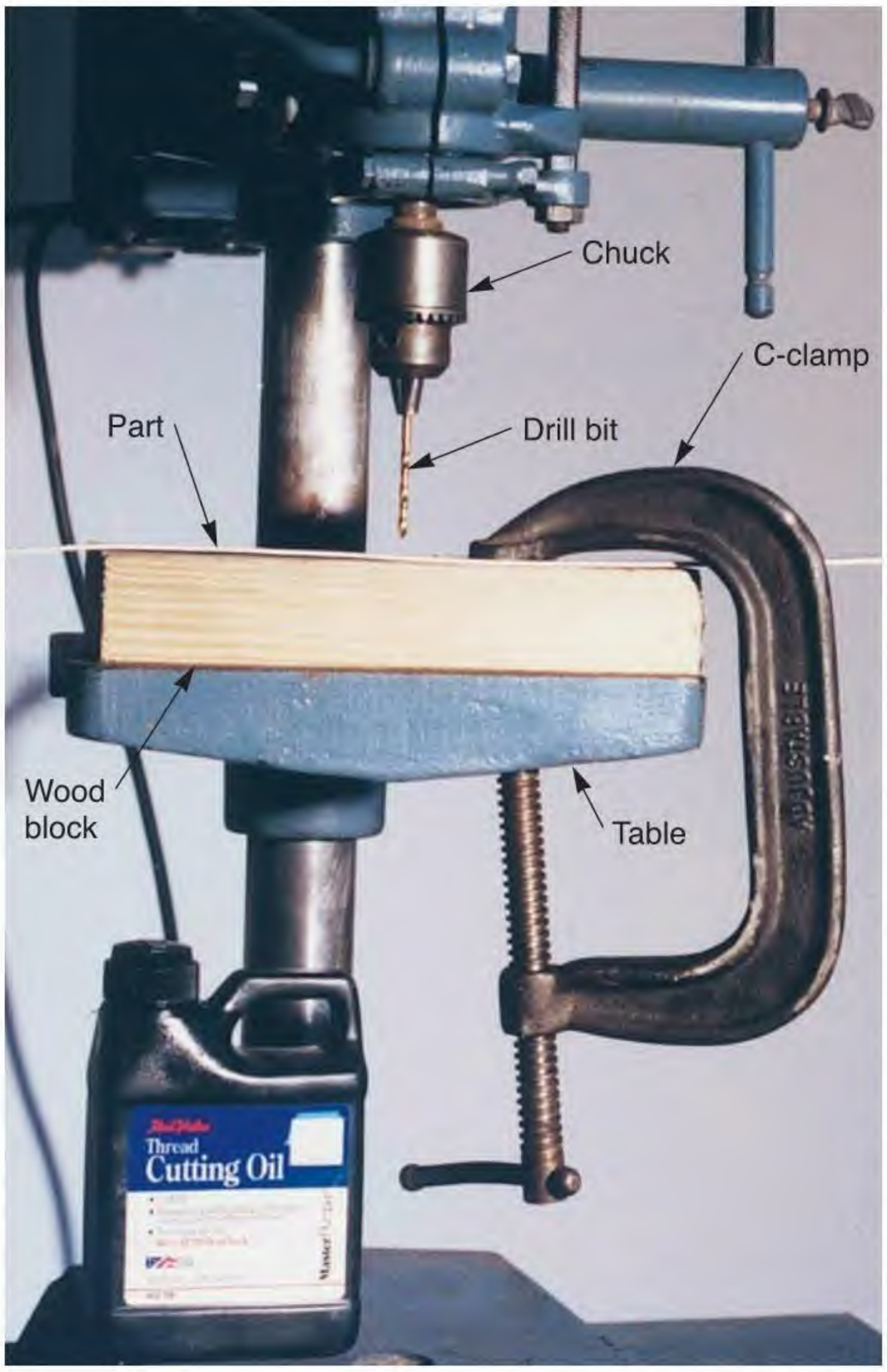
C-Clamp

A ***C-clamp*** holds parts on a work surface when drilling, filing, cutting, welding, or doing other operations. Being portable, it can be taken to the job. C-clamps come in many different sizes. Refer to **Figure 3-20**.

Stands and Holding Fixtures

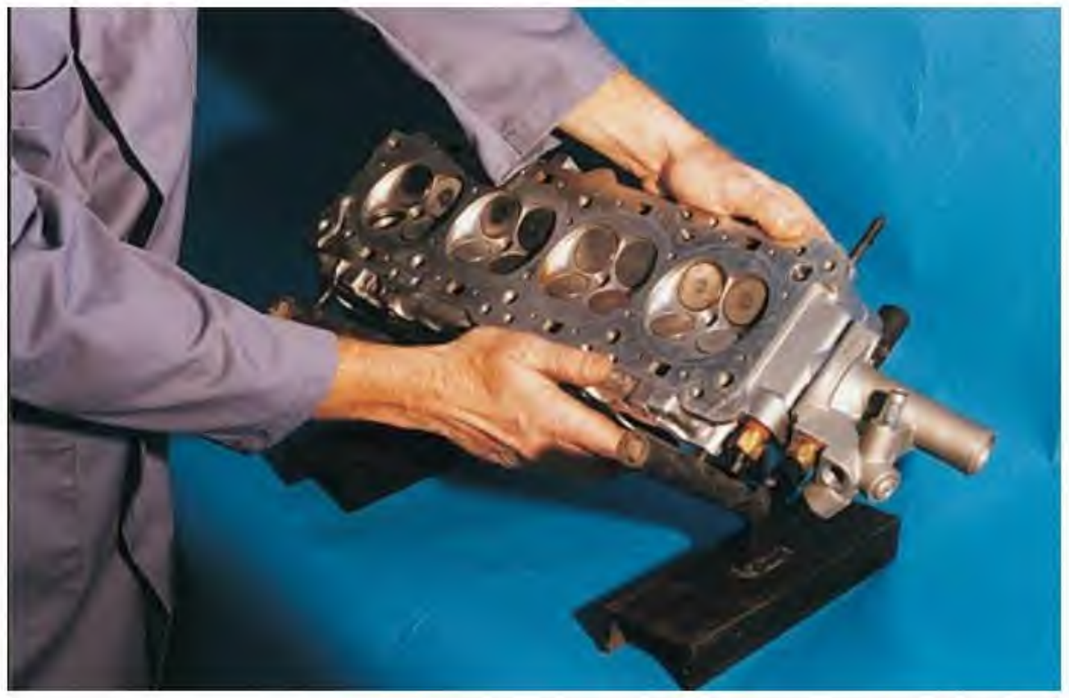
Stands and ***holding fixtures*** can be used to secure heavy or clumsy parts during repairs. Cylinder head stands, transmission fixtures, rear axle holding stands, and others will make your work safer and easier. Look at **Figure 3-21**.

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Figure 3-20. A C-clamp is a portable means of securing parts. It can also be used for light pressing operations.



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Figure 3-21. A cylinder head stand holds the head in position during valve and seat work. Other specialized stands are available for transmissions, differentials, and other parts.

Cleaning Tools

There is an old saying, "if you do the job right, you will spend most of your time cleaning parts." Dirt is a major enemy of a vehicle and your repairs.

Tech Tip

One grain of hard crystalline sand can cause severe part damage and failure. Sand can easily clog small internal passages in castings, or scratch and mar rubber seals and soft aluminum parts.

Cleaning tools, such as scrapers and brushes, help the technician remove carbon, rust, dirt, grease, old gaskets, and dried oil from parts.

Scrapers remove grease, gaskets, sludge, dried oil, and carbon on flat parts. Wear work gloves and keep your other hand out of the way to avoid deep cuts.

Brushes are used to remove light rust, paint, and dirt on round or irregularly shaped parts. They are slow and should be used only when heavy, flaky, chalky deposits are coming off the curved surface of the part.

Probe and Pickup Tools

Pickup tools are needed when bolts, nuts, or other small parts are dropped and cannot be reached by hand. A magnetic pickup tool is a magnet hinged to the end of a rod. It can usually be shortened or lengthened and swiveled to reach into any area. If a ferrous (iron) metal part is dropped, it will be attracted and stick to the magnet, **Figure 3-22A**. A finger pickup tool grasps nonmagnetic parts (aluminum, plastic, or rubber), which will not stick to a magnet, **Figure 3-22B**.

A mirror probe allows you to look around corners or behind parts, **Figure 3-22C**. For example, a mirror probe will allow you to see an oil leak behind the engine.

Cutting Tools

Various cutting tools are needed to open part boxes, cut off insulation, and to do similar tasks. A few types of cutting tools used by the auto technician are shown in **Figure 3-23**.

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A—Magnetic Pickup Tool



B—FInger Pickup Tool



C—Mirror Probe

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Figure 3-22. Different probe and pickup tools.



A—Razor Blade Scrapers



B—Gasket Scapers or Putty Knives



C—Spring Gasket Scrapers

Snap-on Tool Corp.

Figure 3-23. Cutting and scraping tools must be used carefully.

Pry Bars

Pry bars are strong steel bars. They are helpful during numerous assembly, disassembly, and adjustment operations. They are also used to align heavy parts. When prying, always be careful to not damage any part of the vehicle.

Insulated Tools

Insulated tools are designed to protect against electric shock and electrocution when working on electric circuits. Insulated tools designed specifically for use on high-voltage circuits should be used for hybrid electric drive train service. Only use tools rated at 1000 V for high-voltage service work. You can purchase sets of insulated tools to be used for hybrid drive vehicles.

Warning

Conventional insulated steel tools, such as those intended for residential electrical work, must never be used in place of tools designed for servicing the high-voltage systems found in hybrid vehicles. A conventional steel wrench or ratchet with a rubber or plastic handle will have thin insulation that is not designed for use with high voltages.

Insulated wrenches are conventional steel coated with synthetic plastic that prevents electric current from accidentally flowing through the wrench and your body. Refer to **Figure 3-24A**.

Electrician's pliers have gripping and cutting surfaces for working with wiring, **Figure 3-24B**. An insulated handle is provided to help prevent electrocution from high-voltage sources. High-voltage pliers, or cable pliers, have jaw and handle insulation to prevent

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A—Insulated Wrench



B—Electrician's Pliers

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Figure 3-24. Insulated tools are used when working with high-voltage circuits, such as electric drive trains.

electric shock from spark plug wires. Plastic pliers are made of solid insulating material for the highest protection when working with high-voltage hybrid electric drive train circuits.

Graphite and HV screwdrivers have a plastic handle and a plastic shank, while only the tip of the tool is made of conductive, hardened steel. Since the whole screwdriver, apart from the tip, is made of high-strength plastic, it will not conduct high voltage into your hand the way a conventional metal shank screwdriver would.



Workplace Skills

A properly designed tool acts as an extension of your body or mind. Tools are essential to the repair of any motor vehicle. For this reason, you should learn about new tools as they are developed. A good tool is a wise investment that will help you be a more productive, successful technician. To learn more about tools, visit tool manufacturer websites.

Summary

- It is almost impossible to do even the simplest auto repair without using some type of tool.
- Professional auto technicians invest thousands of dollars in tools. A well-selected set of tools will speed up repairs, improve work quality, and increase profits.
- Purchase quality tools. Quality tools are lighter, stronger, easier to use, and more dependable than off-brand, bargain tools.
- Keep tools organized. There should be a place for every tool and every tool should be in its place.
- Use the right tool for the job. A good technician will know when, where, and why a particular tool will work better than another.
- A 6-point wrench is the strongest wrench configuration.
- A socket is a cylinder-shaped, box-end tool for removing or installing bolts and nuts.
- Socket handles fit into the square opening in the top of the socket.
- A ratchet is the most commonly used and versatile socket handle. It can either loosen or tighten bolts.
- Extensions are used between a socket and its handle.
- Pliers are used to grip, cut, crimp, hold, and bend various parts.
- A vise is used to hold parts during cutting, drilling, hammering, and pressing operations.
- Cleaning tools, such as scrapers and brushes, help a technician remove carbon, rust, dirt, grease, old gaskets, and dried oil from parts.
- Pry bars are strong steel bars that are helpful during numerous assembly, disassembly, and adjustment operations.
- Insulated wrenches have a plastic or carbon fiber shank with metal ends. They are required when working on high-voltage hybrid drivetrain components.

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Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

adjustable wrench
Allen wrench
ball peen hammer
C-clamp
chisel
cleaning tool
dead blow hammer
extension
file
hacksaw
holding fixture
impact driver
pickup tool
pipe wrench
plastic hammer
pliers
pry bar
punch
rubber mallet
scratch awl
screwdriver
sledgehammer
socket
socket handle
stand
tool holder
toolbox
universal joint
vise
vise cap
wrench
wrench size

Activities

1. Create a list of hand tools needed to equip an automotive shop. Provide an estimate of what it will cost to purchase the tools. Use automotive websites, such as www.snapon.com, for tool descriptions and prices.
2. Discuss tool safety with your instructor. Prepare a list of safety regulations for your shop area.

Review Questions

Answer the following questions using the information provided in this chapter.

1. List and explain four general tool rules.
2. A bolt head is rusted and partially rounded off. Which wrench would work best for removing the bolt?
   (A) Open-end wrench.
   (B) 6-point box-end wrench.
   (C) 12-point box-end wrench.
   (D) None of the above.
3. What are the four socket drive sizes? Explain when each should be used.
4. _____ or _____ screwdrivers are useful in very tight places, such as inside a glove box.
5. Describe four rules to follow when using hammers.
6. What is the difference between a center punch, a starting punch, and an aligning punch?
7. A coarse file should be used on _____ materials. A fine file should be used on _____ materials.
8. When should you use vise caps?
9. List and explain four vise rules.
10. Which of the following tools should be used to remove old gasket material from a flat surface?
    (A) Hand scraper.
    (B) Chisel.
    (C) Probe.
    (D) Pry bar.

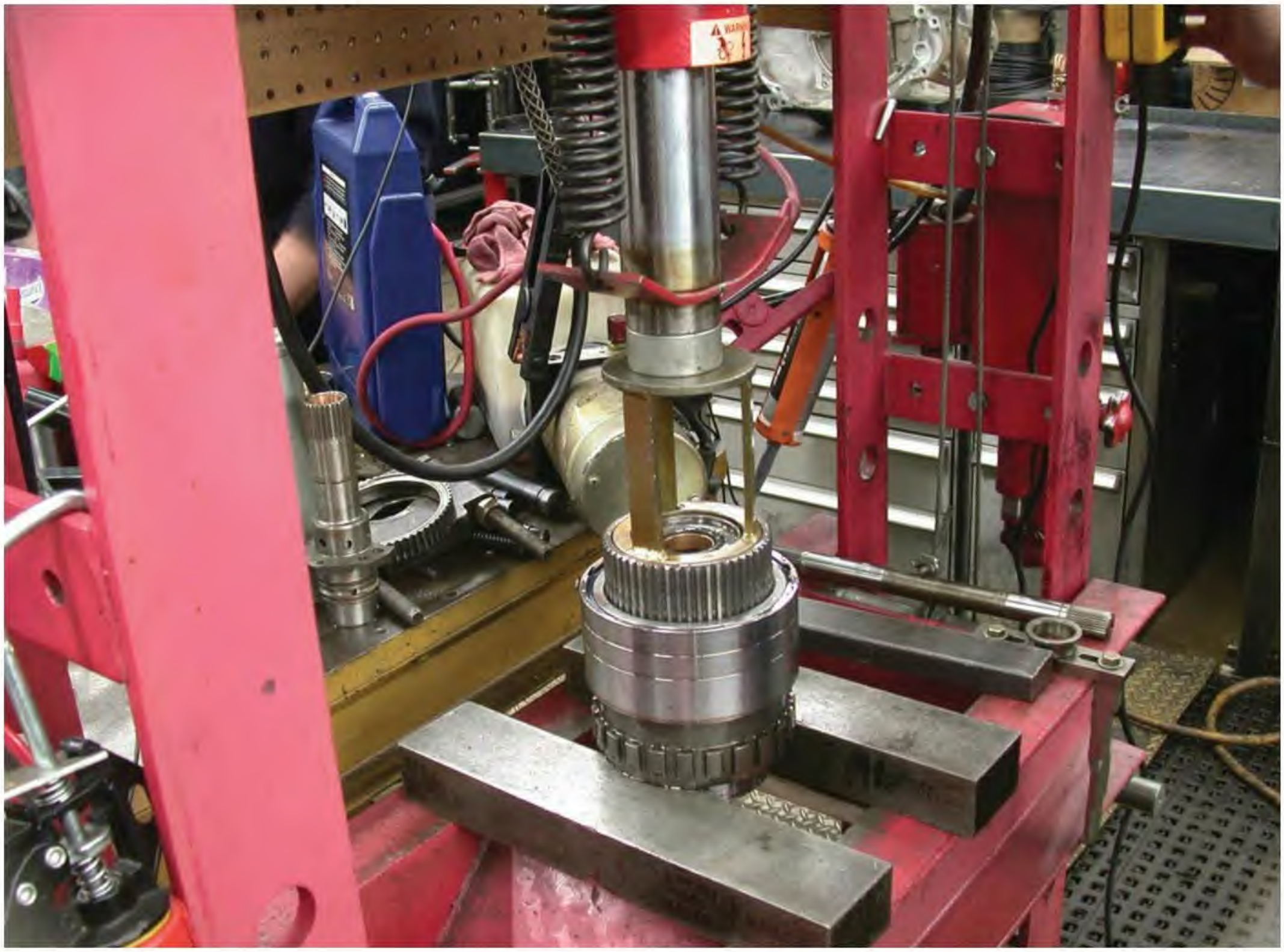
ASE-Type Questions

1. A bolt head is badly rusted and is difficult to loosen. Technician A says to use a pair of pliers to loosen the rusted bolt. Technician B recommends a six-point wrench or socket. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Which of the following is *not* a common socket drive size?
   (A) 1/4″
   (B) 3/8″
   (C) 5/8″
   (D) 1/2″
3. The socket handle that has a gear and lever mechanism that allows it to be moved back and forth for rapid fastener removal or installation is the:
   (A) ratchet.
   (B) flex bar.
   (C) breaker bar.
   (D) speed handle.

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4. A(n) _____ is a swivel that lets the socket wrench reach around obstructions.
   (A) extension
   (B) hand spinner
   (C) flexible driver
   (D) universal joint
5. When working with sockets, Technician A states that a socket's "point" is the size of the square opening for the handle. Technician B states the point of a socket is the box configuration for the bolt head. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Which type of screwdriver is especially good to use in tight spaces?
   (A) Torx.
   (B) Stubby.
   (C) Phillips.
   (D) Clutch head.
7. Pliers are used on various parts to do each of these *except:*
   (A) cut.
   (B) grip.
   (C) bend.
   (D) screw.
8. Which type of pliers open extra wide to hold very large objects?
   (A) Rib joint.
   (B) Locking.
   (C) Slip joint.
   (D) All of the above.
9. The heaviest kind of hammer is:
   (A) lead.
   (B) brass.
   (C) sledge.
   (D) dead blow.
10. Which punch configuration is used to mark parts for reassembly or to start a drilled hole?
    (A) Center.
    (B) Aligning.
    (C) Tapered.
    (D) Diamond.

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A hydraulic press is being used to compress springs so a snap ring can be installed in a clutch assembly during a transmission overhaul.

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Chapter 4
Power Tools and Equipment

After studying this chapter, you will be able to:

- List the most commonly used power tools and equipment.
- Describe the uses for power tools and equipment.
- Explain the advantages of one type of tool over another.
- Explain safety rules that pertain to power tools and equipment.
- Correctly answer ASE certification test questions that require a knowledge of power tools and equipment.

To be a productive technician in today's auto service facility, you must know when, why, and how to use power tools and equipment. ***Power tools*** are tools driven by compressed air, electricity, or pressurized liquid. They make many repair operations easier and quicker. Large shop tools, such as floor jacks, parts cleaning tanks, steam cleaners, and battery chargers, are called ***shop equipment***.

This chapter discusses the proper selection and use of common power tools and equipment. Specialized power tools and equipment are covered in later chapters. Refer to the index to find more information on them as needed.

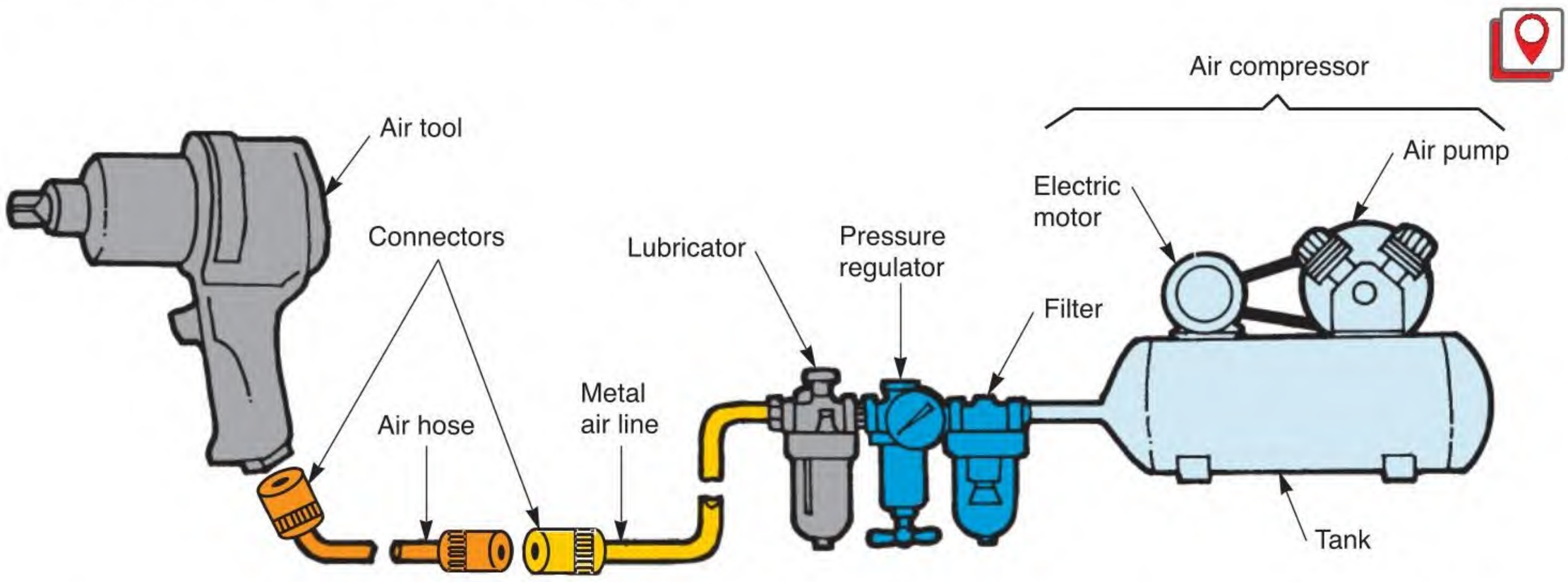
Caution

Auto shop equipment can be very dangerous if misused. Always follow the operating instructions from the equipment manufacturer. If in doubt, ask your instructor or shop service manager for a demonstration of the power tool or equipment.

Compressed-Air System

The components of a compressed-air system include an air compressor, air lines, air hoses, and air tools. In addition, a pressure regulator, filter, and lubricator may be attached to the system. Air tools are driven by the compressed-air system. Air-powered tools can be found in nearly every service facility. Look at **Figure 4-1**.

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Figure 4-1. Study the basic parts of a typical compressed air system. The air compressor develops air pressure. The filter removes moisture. The pressure regulator allows the technician to control system pressure. Metal lines and flexible hoses carry pressurized air to the tool. A lubricator can be added to the system to keep the air tools oiled and functioning properly.

Air Compressor

An ***air compressor*** is the source of compressed air for an automotive service facility. An air compressor normally has an electric motor that spins an air pump. The air pump forces air into a large, metal storage tank. The air compressor turns on and off automatically to maintain a preset pressure in the system.

Warning

Shop air pressure usually ranges from 100–150 psi (689–1034 kPa). This is enough pressure to kill or severely injure a person. Respect shop air pressure!

Air Lines and Hoses

Metal air lines feed out from the air compressor's tank to several locations in the shop. Technicians can then connect their flexible high-pressure ***air hoses*** to the metal lines. These hoses allow the technician to take a source of air pressure to the vehicle being repaired. ***Quick-disconnect couplings*** are used to connect air hoses and air tools to the compressed air system without using a wrench. To join or separate a quick-disconnect coupling, pull back on the coupling's outer sleeve with finger pressure. With the sleeve pulled back, you can push the coupling together or pull it apart.

Pressure Regulator, Filter, and Lubricator

A ***pressure regulator*** is used to set a specific pressure in the compressed-air system. This pressure is often called shop pressure. In most cases, shop pressure is between 100 and 150 pounds per square inch (psi). A filter may be connected to the system. The filter removes water from the compressed air. This increases the life of air tools. In addition, a lubricator may also be connected to the system. The ***lubricator*** introduces oil into the airstream. This also increases the life of air tools.

Air Tools

Air tools, or pneumatic tools, use the stored energy of compressed air for operation. Air tools are labor-saving devices and well worth their cost. Always lubricate the tool before and, more importantly, after use. While pressing the air tool's trigger, squirt a few drops of air tool oil into the tool's air inlet fitting. Not only will the oil protect internal parts of the tool, but it will also prevent the internal parts from rusting during storage. Hold a rag around the air outlet and run the oiled tool briefly to circulate the lubricant through the air motor. Excess oil will be sprayed into your shop rag. Wipe the tool clean before use or storage.

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Snap-on Tool Corp.

Figure 4-2. 1/2″ drive impact wrench.

Impact Wrenches

Impact wrenches are heavy-duty air wrenches that produce a great deal of torque to remove or install fasteners. They use an air motor to produce a striking, or hammering, force that rotates the driving head. The driving head holds a special impact socket. Look at **Figure 4-2**.

Impact wrenches come in 1/4″, 3/8″, 1/2″, and 3/4″ drive sizes. The 1/4″ drive is for tiny machine screws in the interior or on trim pieces of the vehicle. A 3/8″ drive impact is ideal for small fasteners, such as 1/4″–9/16″ bolts. A 1/2″ drive is for general purpose use with medium to large fasteners, such as 1/2″–1″ bolts and wheel lug nuts. The 3/4″ drive impact is for extremely large fasteners found on trucks. A button or switch on the impact wrench controls the direction of rotation, usually clockwise to tighten and counterclockwise to loosen. The positions are typically labeled.

Caution

Until you become familiar with the operation of an impact wrench, be careful not to overtighten bolts and nuts or leave them too loose. It is easy to strip or break fasteners with this air tool. It is best to use a torque wrench on all fasteners so you are sure the repair is safe.

Air Ratchet

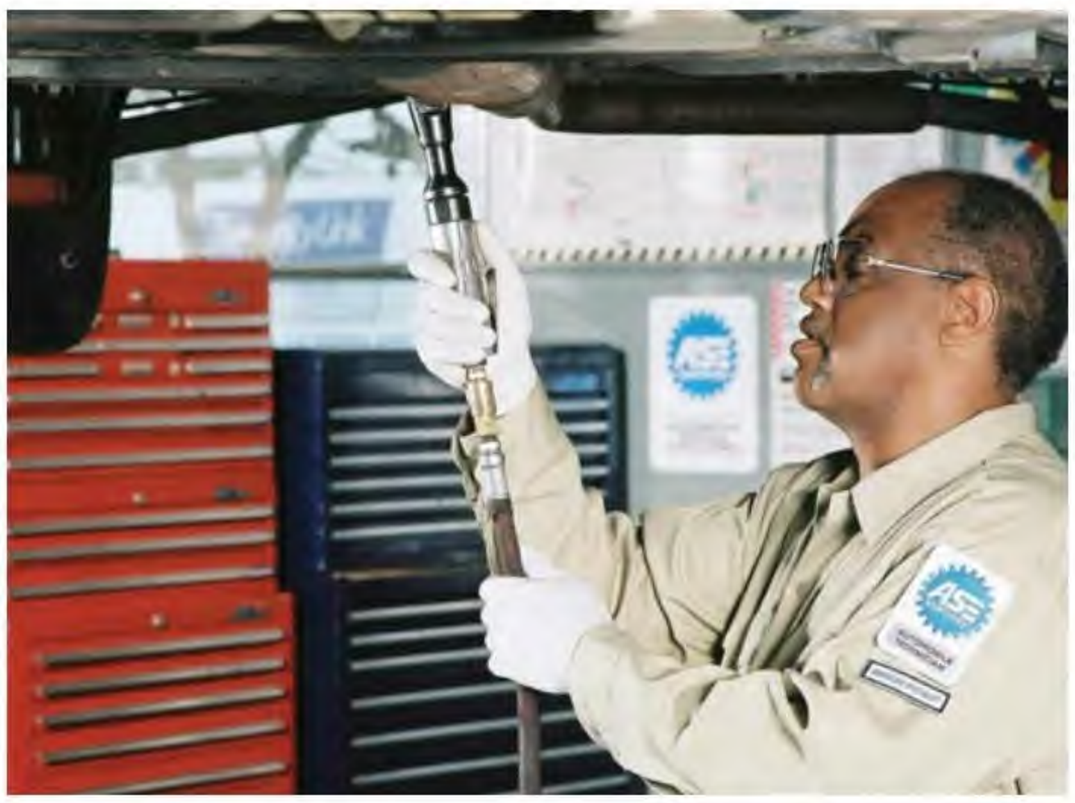
An ***air ratchet*** is a special air wrench designed to quickly install or remove fasteners. It can be used for working in limited spaces. However, it does not have very much turning power. Final tightening and initial loosening must often be done with hand tools. For instance, an air ratchet is commonly used when removing water pumps. It will fit between the radiator and engine easily. It works in much the same way as a hand-tool ratchet. Air ratchets are available as 1/4″, 3/8″, and 1/2″ drives. See **Figure 4-3**.

Impact Sockets and Extensions

Special black ***impact sockets*** and ***impact extensions*** must be used with air and electric wrenches. Impact tools are case-hardened steel, and are thicker and much stronger than conventional chrome-plated sockets and extensions. A conventional chrome socket can be easily broken or damaged by the hammering blows of an impact wrench. Impact sockets and extensions can be quickly identified because they have a flat black finish.

Caution

Know when to use power tools. In most situations, power tools will speed up your work. However, there are times when they should not be used. For example, never use an impact wrench in place of a torque wrench. An impact wrench will not torque critical fasteners to their correct specification. Vehicle problems, shop comebacks, customer complaints, and even auto accidents can result from improperly torqued fasteners.



ASE

Figure 4-3. This technician is using an air ratchet to spin out small fasteners under the vehicle.

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Figure 4-4. An air hammer is useful for tasks such as quickly cutting off a rusted exhaust system. *Always* wear safety glasses.

Air Hammer

An ***air hammer***, or ***air chisel***, is useful during various driving and cutting operations. Look at **Figure 4-4**. An air hammer is capable of producing about 1000–4000 impacts per minute. Several different cutting or hammering attachments are available. Be sure to select the correct one for the job.

Warning

Never turn on an air hammer unless the tool head is pressed tightly against the workpiece. Otherwise, the tool head can fly out of the hammer with great force, as if shot from a gun!

Blowgun

An air-powered ***blowgun*** is commonly used to dry and clean parts washed in solvent. It is also used to blow dust and loose dirt from parts before or during disassembly. See **Figure 4-5**. When using a blowgun, wear eye protection. Direct the blast of air away from yourself and others. Do not blow clean brake and clutch parts. The dust from these parts may contain asbestos. Asbestos is a cancer-causing substance. Another type of blowgun is a ***solvent gun***. It can be used to wash parts that will not fit into a cleaning tank.



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Figure 4-5. Blowguns are used to clean parts.

Air Drill

An ***air drill*** is excellent for many tasks because of its power output and speed adjustment capabilities. Its power and rotating speed can be set to match the job at hand. With the right attachments, air drills can drill holes, grind, polish, and clean parts. Look at **Figure 4-6**.

A ***rotary brush*** is used in an air or electric drill for rapid cleaning of parts. It can quickly remove old gasket material, carbon deposits, and rust with a minimum amount of effort.



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Figure 4-6. The chuck speed of an air drill can be adjusted by controlling airflow into the tool. The air drill is capable of very high turning force.

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Warning

Use a high-speed rotary brush in an air drill. A brush designed for an electric drill may fly apart. To be safe, always adjust an air drill to the slowest acceptable speed when using a rotary brush. Also, always wear eye protection.

An ***abrasive pad*** is another type of cleaning tool that can be used in an air or electric drill. It is used for removing old gasket material. It has the advantage of not scratching aluminum like a rotary brush can.

A ***rotary file***, or stone, can be used in an air drill, electric drill, or air (die) grinder. It is handy for removing metal burrs and nicks. Make sure the stone is not turned too fast by the air tool. Normally, the maximum speed is printed on the file or stone container. See **Figure 4-7**.

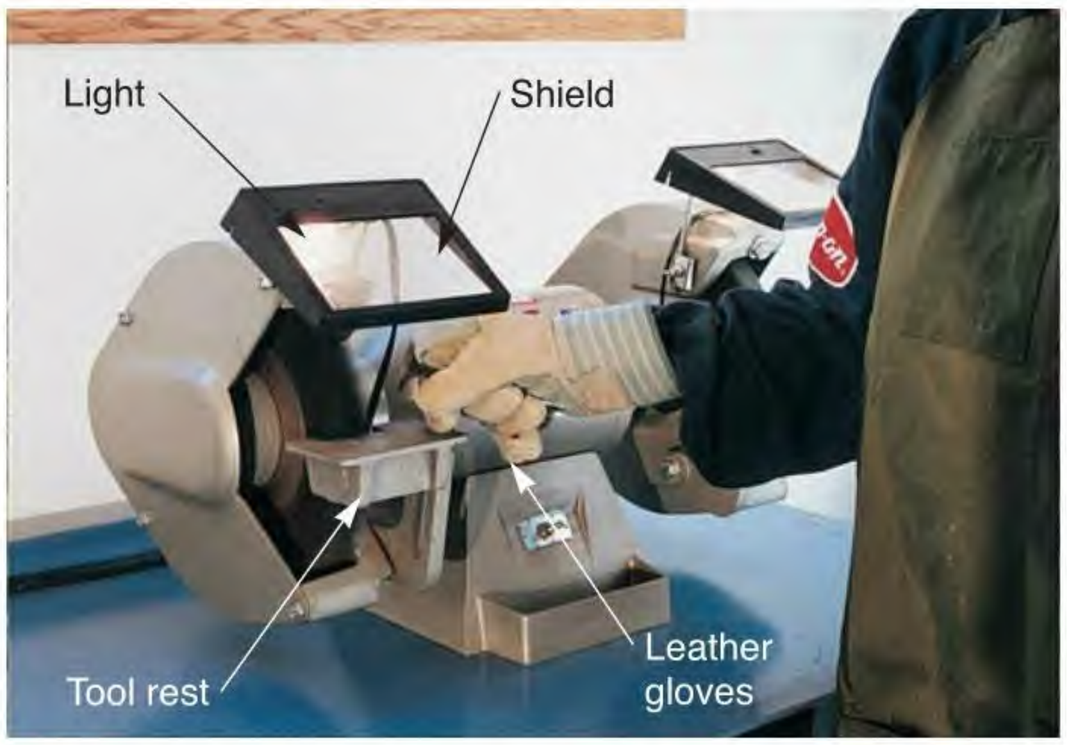
Electric Tools

There are many ***electric tools*** that can be useful to a technician. Some of these tools, such as a drill press or grinder, may be fixed to the floor or a bench. Other tools, such as a rechargeable drill or a rechargeable electric impact gun, are portable and can be taken to the job site. Rechargeable power tools are becoming more common because you do not have to struggle with a clumsy, heavy air hose connected to the tool.



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Figure 4-7. This die grinder is equipped with a high-speed stone. This tool is used for removing burrs and for other smoothing operations. Here, the technician is making minor repairs to a damaged cylinder head combustion chamber.



Snap-on Tool Corp.

Figure 4-8. The grinding wheel on a bench grinder is used to sharpen tools. The wire wheel can be used to clean and polish small parts. *Always* keep shields, tool rests, and guards in place.

Bench Grinder

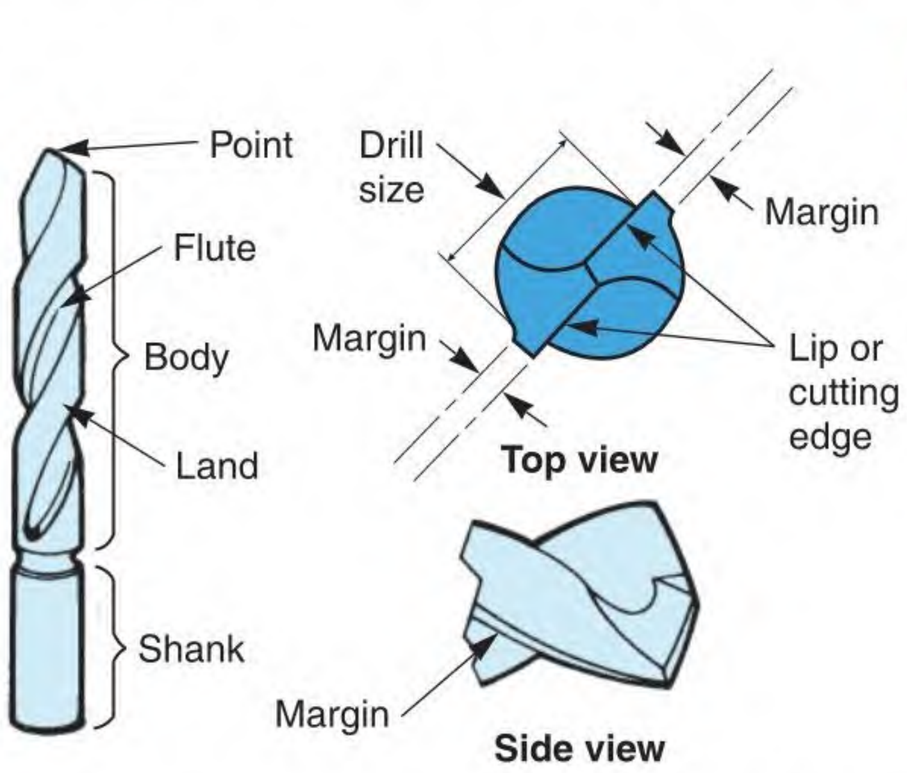
A ***bench grinder*** can be used for grinding, cleaning, or polishing operations, **Figure 4-8**. A bench grinder usually has two wheels—a grinding wheel and a wire wheel. The hard, abrasive grinding wheel is used for sharpening and deburring metal tools, such as chisels and punches. The soft wire wheel is used for cleaning and polishing metal tools, such as scrapers and putty knives. A few bench grinder rules to follow are:

- Always wear eye protection and keep your hands away from the wheel.
- Make sure the grinder shields are in place.
- Keep the tool rest adjusted close to the wheel. If the rest is not close to the wheel, the part being ground can catch in the grinder.
- Do not use a wire wheel to clean soft metal parts, such as aluminum pistons or brass bushings. The abrasive action of the wheel can remove metal or scuff the part and ruin it. Instead, use a solvent and a dull hand scraper on soft metal parts.

Drills

Drills are used to create holes in metal and plastic parts. Some drills are portable; others are mounted on a workbench or the floor. Drills use different-sized bits to create the size of hole needed.

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Figure 4-9. Note the basic parts of a drill bit.

Bits

Drills use ***drill bits***, or twist drills, to drill holes in metal and plastic parts, **Figure 4-9**. A drill bit is mounted in the drill chuck. A special key, called a chuck key, is sometimes needed to tighten the drill bit in the chuck, **Figure 4-10**. A keyless chuck uses a ribbed, rubber thumbwheel to adjust the chuck jaws without a key. Drill bits are commonly made of either carbon steel or high-speed steel. High-speed steel is better because of its resistance to heat. It will not lose its hardness when slightly overheated.

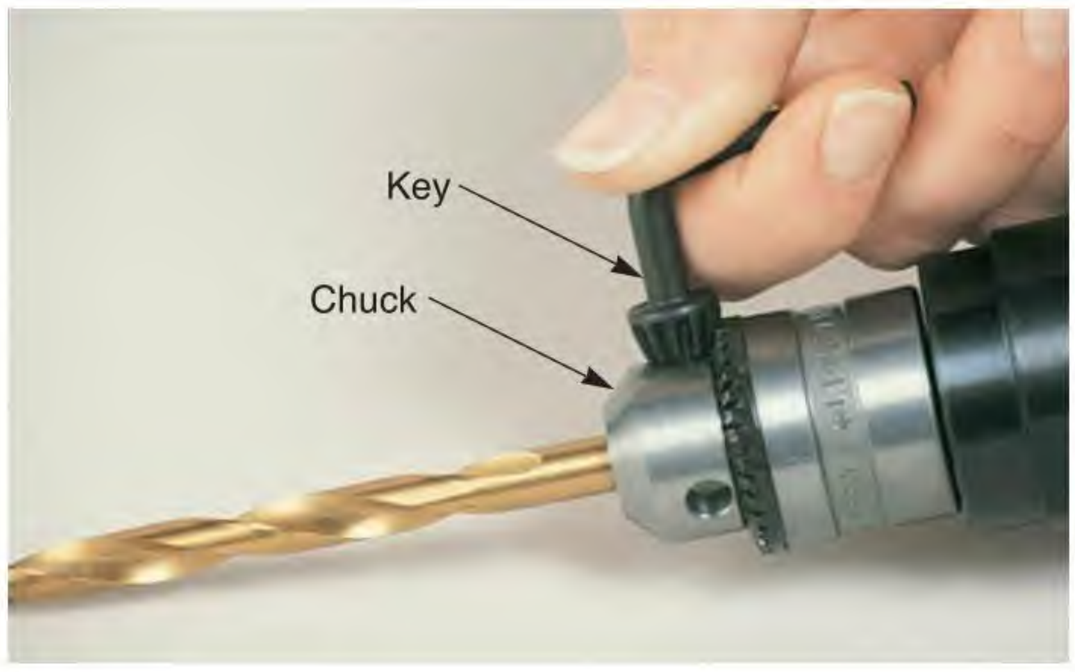
Portable Electric Drill

Portable electric drills are handheld drills. They come in different sizes. The size of a drill is an indication of the capacity of its chuck. Today's rechargeable electric drills work fine for virtually all automotive applications. However, an electric drill with a power cord is needed for difficult or high-torque operations. Commonly used sizes are 1/4″, 3/8″, and 1/2″, **Figure 4-11**.

Drill Press

A ***drill press*** is a large, floor- or bench-mounted drill needed for drilling large holes, deep holes, or a great number of holes in several parts, **Figure 4-12**. The drill press handle allows the bit to be pressed into the work with increased force. Also, very large bits can be used. A few drill press rules to follow include:

- Remove the key from the chuck before turning on the drill press.
- Secure the part to be drilled with C-clamps or other holding fixtures.



A



B

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Figure 4-10. The drill chuck has adjustable jaws that hold the drill bit securely in place. A—A key is sometimes used to tighten a bit in the chuck. B—Keyless drill chucks can be tightened by hand.

- Use a center punch to indent the part and start the hole.
- To prevent injury, release drilling pressure right before the bit breaks through the bottom of the part. A drill bit tends to catch when breaking through. This can cause the drill or the part to rotate dangerously.
- Oil the bit as needed. Oil pulls heat out of the bit and transfers it into the base metal being drilled. Without oil, a drill bit can overheat and lose its hardness before dulling quickly.

Hydraulic Tools

Hydraulic tools are powered by pressurized liquid. The hydraulic tools typically used in the automotive shop include jacks, cranes, and presses. These tools are discussed in the next sections.

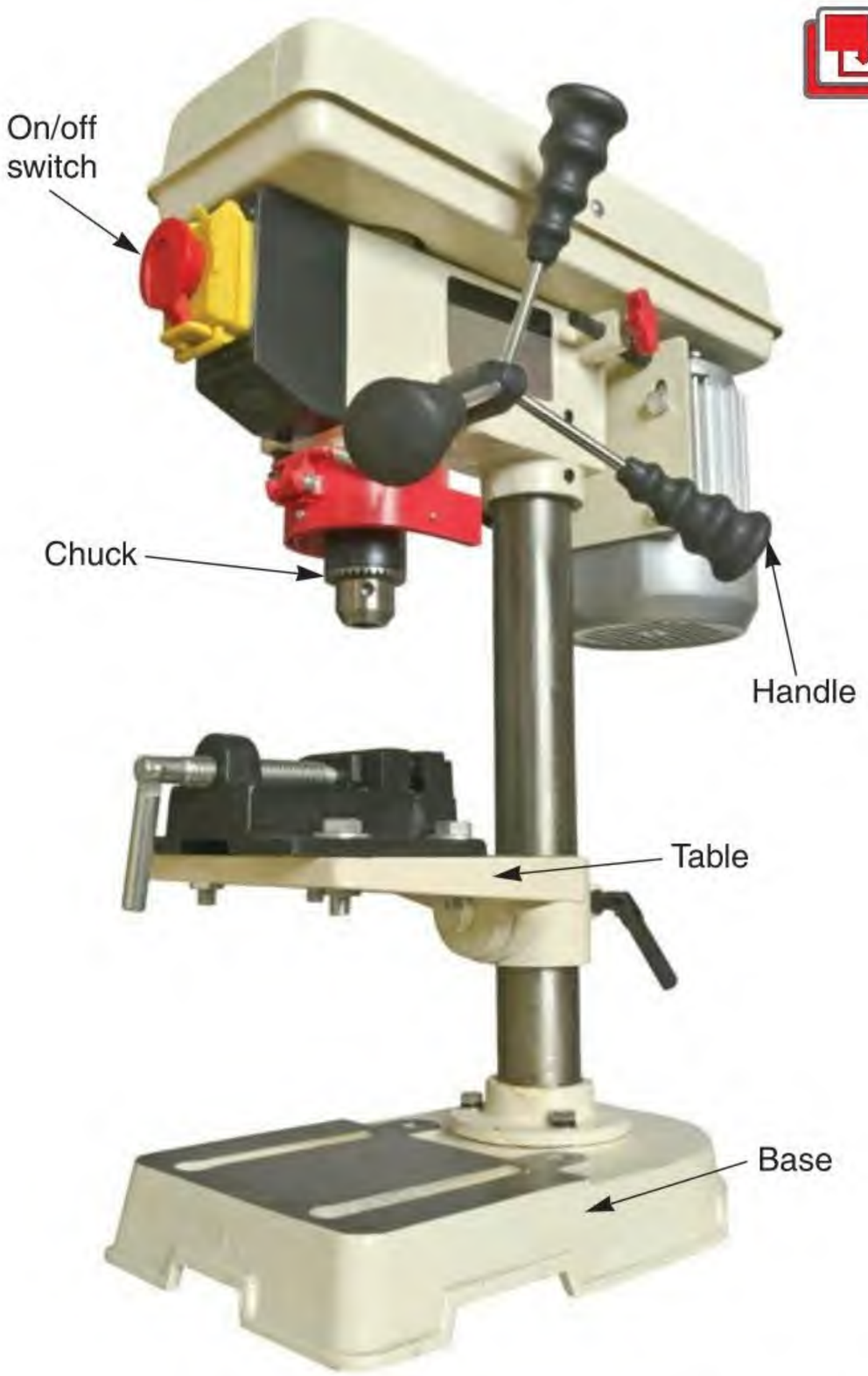
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A—3/8″ Drill **B—1/2″ Drill** **C—Cordless Drill**

Robert Bosch

Figure 4-11. Note the styles of portable electric drills.



a_v_d/Shutterstock.com

Figure 4-12. The parts of a drill press. A drill press is for drilling deep or large holes when a part will fit on the table.

Floor Jack

A ***floor jack*** is used to raise either the front, sides, or rear of a vehicle. To avoid vehicle damage, place the jack saddle under a solid part of the car, such as the frame, suspension arm, or axle housing. If the saddle is not properly located, it is very easy to smash the oil pan, muffler, floor pan, or another part of the vehicle. To raise the vehicle, turn the jack handle or knob clockwise and pump the handle. To lower the vehicle, turn the handle or knob counterclockwise slowly to open the pressure-release valve. Look at **Figure 4-13**.



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Figure 4-13. Remember to use a floor jack with jack stands to secure the vehicle. A floor jack is only for raising the vehicle off the ground.

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When raising a vehicle, place the transmission in neutral and release the parking brake. This lets the vehicle roll, preventing it from pulling off the jack. After raising, secure the vehicle on jack stands. Place an automatic transmission in park and a manual transmission in gear. Apply the emergency brake and block the wheels. It is then safe to work under the vehicle.

Caution

Most floor jack handles tend to stick when the pressure-release valve is opened. This makes it easy for you to lower the vehicle too quickly. When opening the valve, turn it very slowly. This will prevent the car or truck from slamming to the ground violently!

Transmission Jack

Transmission jacks are designed to hold transmissions and transaxles during removal or installation. One type is similar to a floor jack. However, the saddle is enlarged to fit the bottom of a transmission. Another type of transmission jack is designed to be used when the vehicle is raised on a lift. It has a long post that can reach high into the air to support the transmission, **Figure 4-14**.

Engine Crane

A portable ***engine crane*** is used to remove and install heavy engine assemblies. It has a hydraulic hand jack for raising engines and a pressure-release valve for lowering engines. The engine crane is also handy for lifting intake manifolds, cylinder heads, engine blocks, transmissions, transaxles, and other heavy parts, **Figure 4-15**.

Hydraulic Press

A ***hydraulic press*** is used to install or remove gears, pulleys, bearings, seals, and other parts requiring a high pushing force. A hydraulic ram extends as the pump handle is worked. The ram presses the parts against a table. See **Figure 4-16**.

Warning

A hydraulic press can literally exert tons of force. Wear eye protection and use recommended procedures. Parts can break and fly out with deadly force!



A—Low-Profile Transmission Jack



B—High-Lift Transmission Jack

OTC/SPX Corp.

Figure 4-14. Note the types of hydraulic transmission/transaxle jacks found in an auto repair facility.

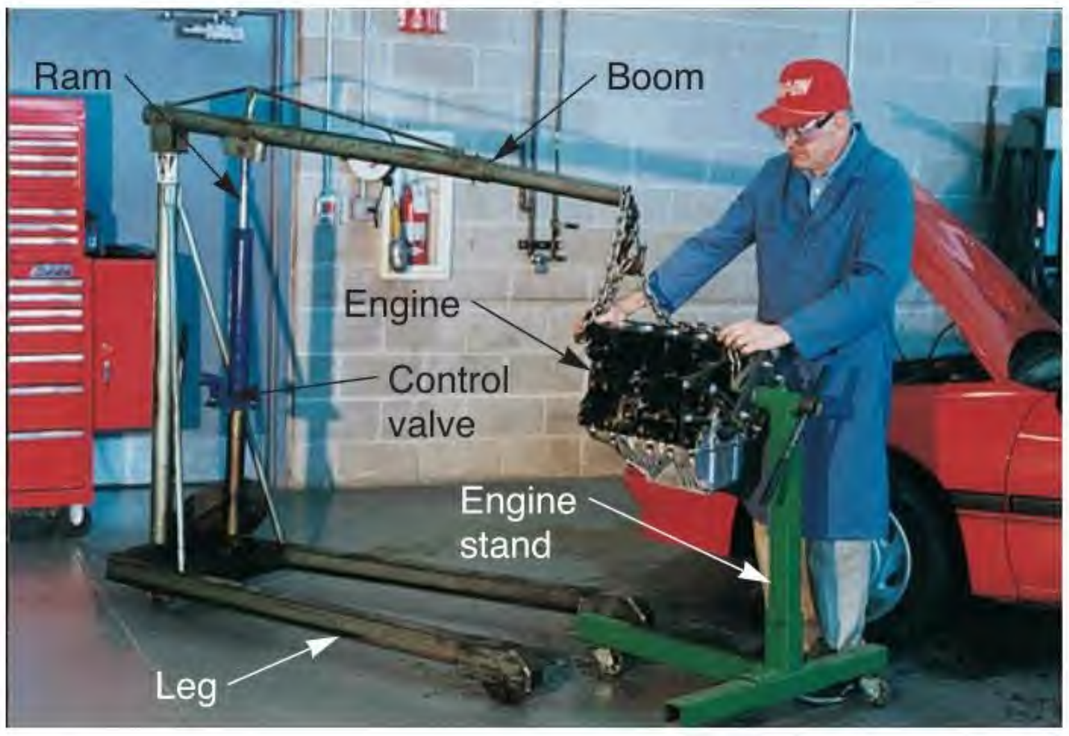
Shop Equipment

In addition to pneumatic, hydraulic, and electric tools, there are various pieces of shop equipment that a technician may find useful. These include tire changers, stands, cleaners, welders, lights, and creepers. Typical shop equipment is discussed in the following sections.

Tire Changer

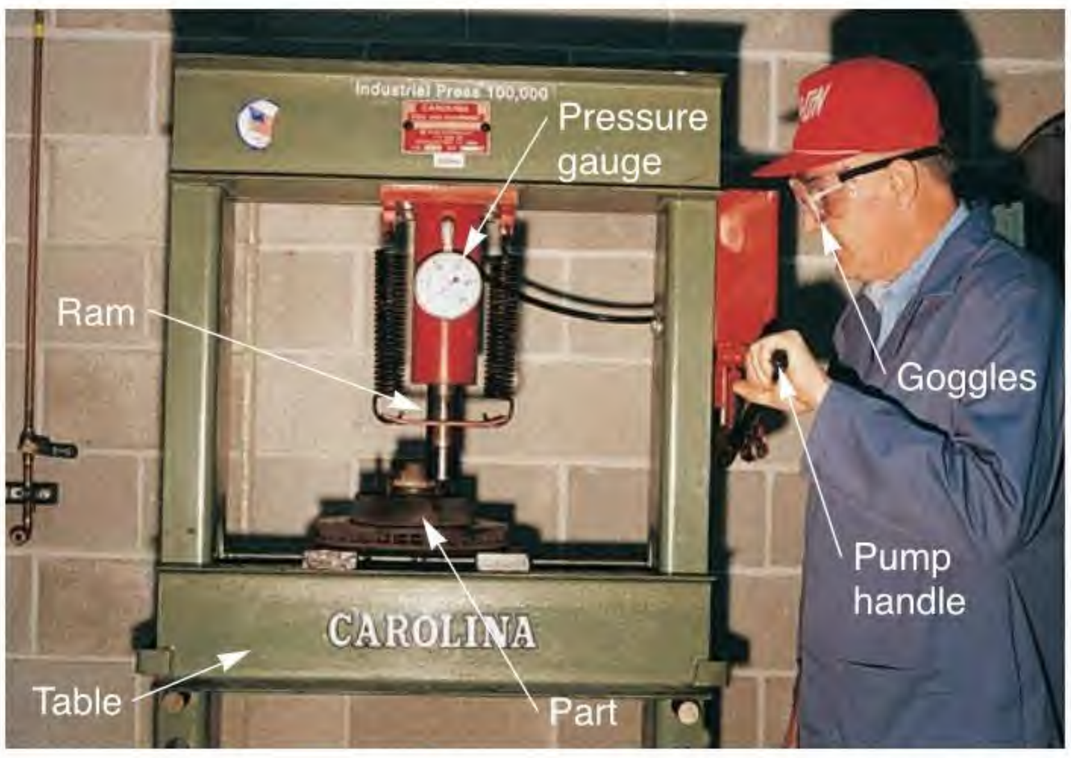
A ***tire changer*** is used to remove and replace tires on wheels. It is a common piece of shop equipment. Some tire changers are pneumatic; others

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Figure 4-15. A hydraulic engine crane can be used to lift heavy objects, such as engines, transmissions, transaxles, and rear axle assemblies. This technician has used a crane to mount an engine on a stand.



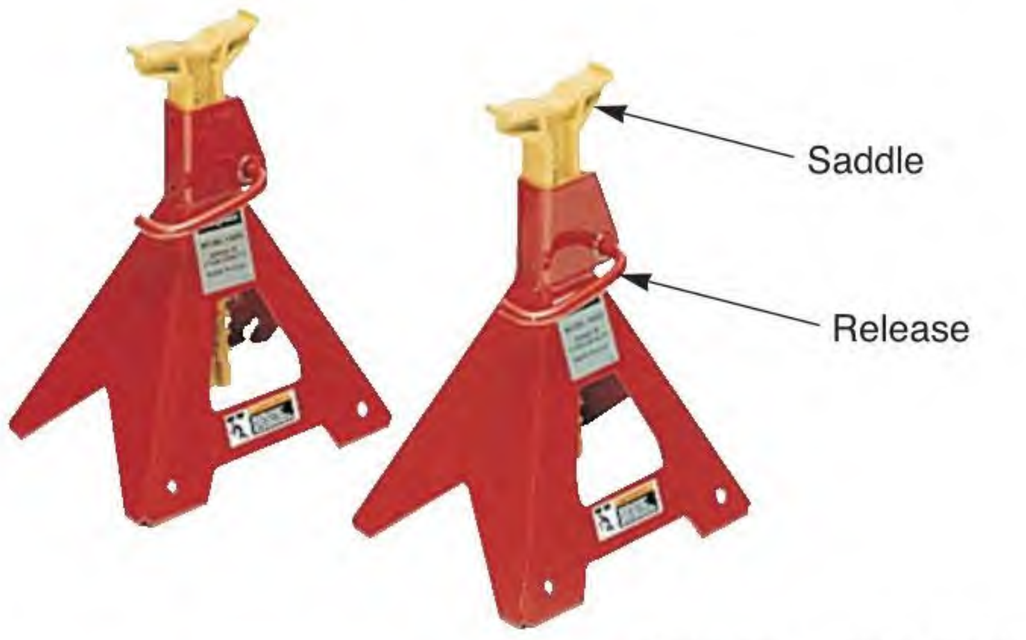
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Figure 4-16. A hydraulic press is needed for numerous pressing operations. It is commonly used to remove and install bearings, bushings, seals, and other pressed-on parts.

are hand operated. Do not attempt to operate a tire changer without proper instruction. Follow the directions provided with the changer.

Jack Stands

Jack stands support a vehicle during repairs. After raising the vehicle with a jack, place jack stands under the vehicle. Be sure the jack stands are placed in secure positions. For example, place jack stands under the frame, axle housing, or suspension arm, **Figure 4-17**.



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Figure 4-17. Jack stands are essential for safely supporting the weight of the vehicle.

Warning

It is *not safe* to work under a vehicle held up by only a jack. Secure the vehicle on jack stands before placing any part of your body under the vehicle. Even a small car can weigh well over a ton. The next chapter details the safe use of lifts, jacks, and jack stands.

Engine Stand

An ***engine stand*** is used to hold an engine assembly once it is removed from the vehicle for rebuilding or repair. The engine cylinder block bolts to the stand just as it would to the transmission or transaxle. The engine can usually be rotated and held in different positions on the stand, making it easy to work on different parts.

Cold-Solvent Tank

A ***cold-solvent tank*** contains a pump, reservoir, and solvent, and it is used to remove grease and oil from parts. After removing all old gaskets and scraping off excess grease, you can scrub the parts clean in the solvent. A blowgun is then normally used to dry the solvent. See **Figure 4-18**.

High-Pressure Washer and Steam Cleaner

A ***high-pressure washer*** or a ***steam cleaner*** can be used to remove heavy deposits of dirt, grease, and oil from the outside of large assemblies, such as engines, transmissions, and transaxles. Look at **Figure 4-19**. To help keep the environment clean, wire

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Figure 4-18. A cold-solvent tank will quickly remove oil and light grease from parts. The unit sprays filtered solvent onto parts. Rub the parts with a bristle brush for rapid cleaning.



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Figure 4-19. A high-pressure washer will remove greasy buildup from the outside of assemblies before teardown.

brush the item to be cleaned and collect oil-soaked dirt before steaming or washing. Then, dispose of the oil-soaked material properly.

Warning

A steam cleaner operates at high pressures and temperatures. Follow the manufacturer's safety rules and specific operating instructions.

Pressure Blaster

A ***pressure blaster*** is sometimes used to clean rusty or corroded parts. It is an enclosed cabinet that has rubber gloves that extend into the cabinet for sandblasting and for cleaning dry parts.

Oxyacetylene Torch

An ***oxyacetylene torch*** can be used to heat, cut, weld, or braze metal parts. The oxyacetylene setup consists of an oxygen tank, an acetylene tank, pressure regulators, hoses, and a handheld torch. Tremendous heat is produced by the burning acetylene gas and oxygen. The oxyacetylene cutting torch is often used to remove old, rusted exhaust systems, **Figure 4-20A**.

Service Procedure

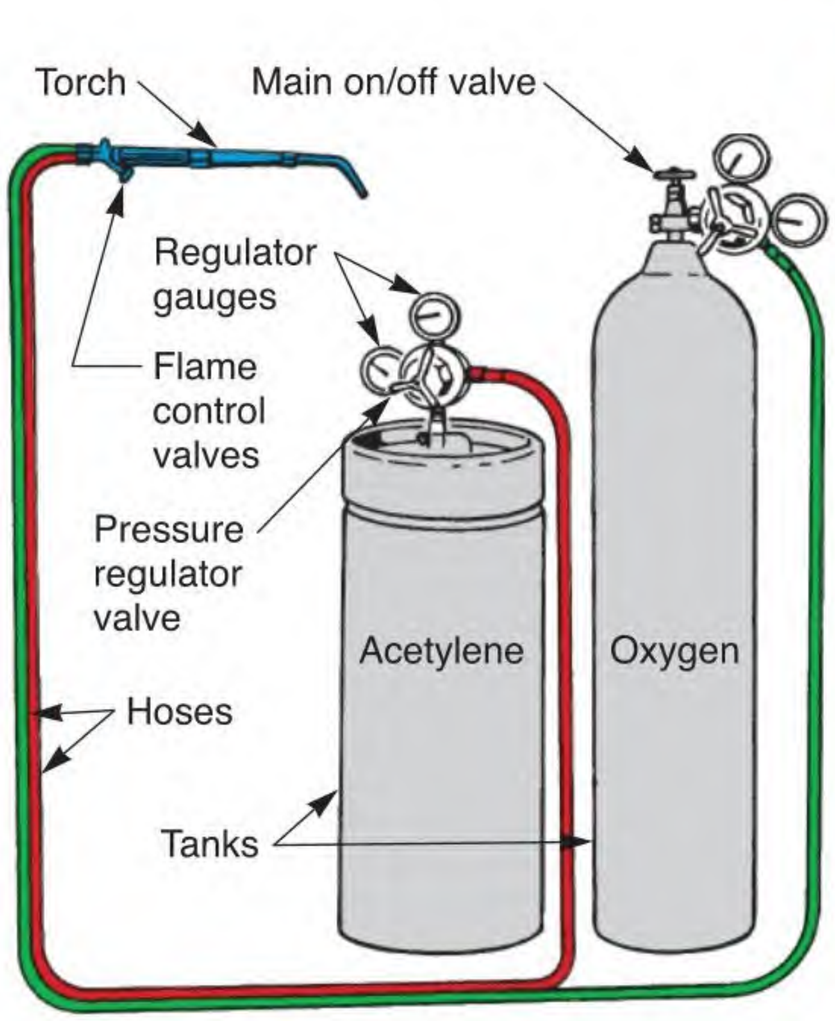
To use an oxyacetylene cutting torch:

1. Put on all necessary protective gear, including a welding helmet or tinted goggles, thick leather welding gloves, and a leather jacket.
2. Inspect the oxyacetylene equipment for damage and make sure all cylinder, regulator, and torch valves are closed. Turn on the main gas valves on both tanks and check hoses for leaks.
3. Light the cutting torch according to the manufacturer's recommendations.
4. With the torch held at a 90° angle to the workpiece, concentrate the flame on the spot where the cut will begin.
5. When the spot becomes cherry red, depress the oxygen-cutting lever to begin the cut.
6. Move the torch along the workpiece slowly and steadily to make a continuous cut.
7. As soon as the cut is complete, release the cutting lever and shut off the torch and main tank valves.

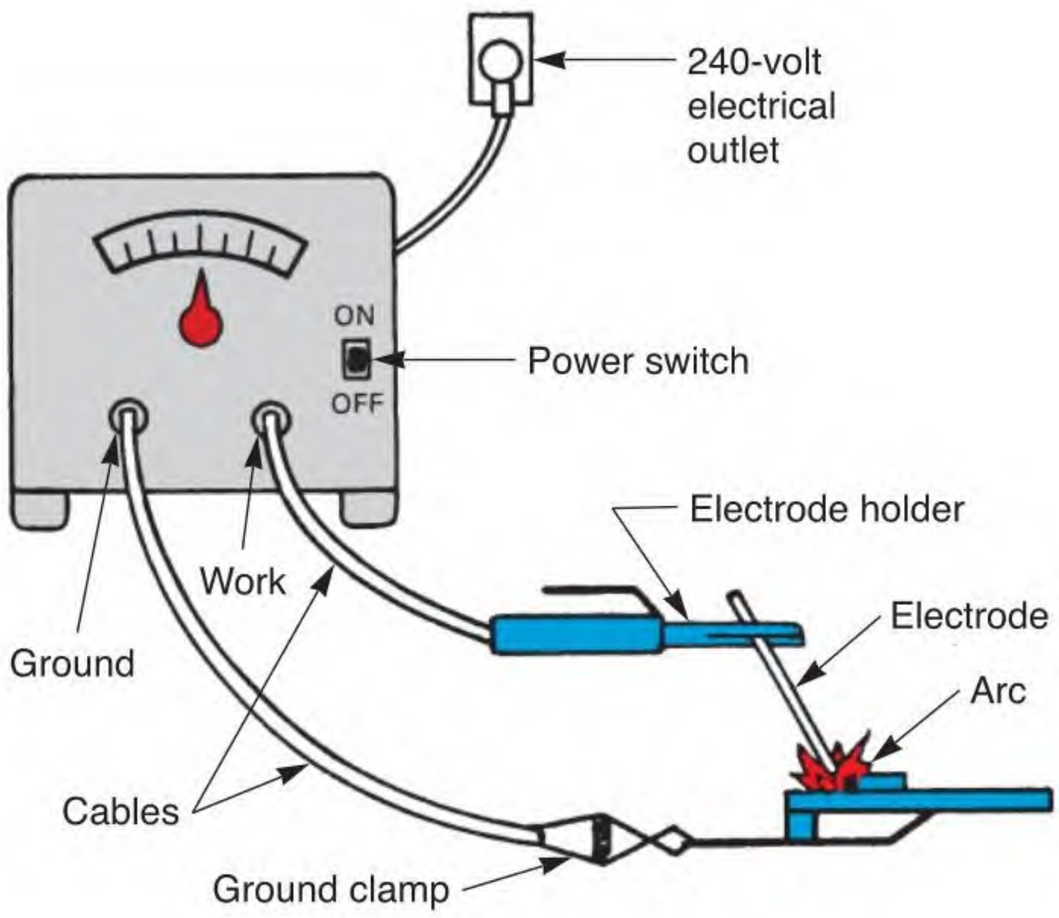
Tech Tip

There are several types of cutting torches available, and the lighting procedure may vary from one type to another. Follow the torch manufacturer's recommendations for lighting, adjusting, and shutting down the torch.

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A—Oxyacetylene Outfit



B—Basic Arc Welder

Sun

Figure 4-20. Technicians must occasionally use welding and cutting equipment.

Welder

A ***welder*** uses high electric current to create a high-power electric arc (voltage jumping from the electrode to the workpiece) to melt and fuse metal parts together, **Figure 4-20B**. Be sure to complete proper training before attempting to weld. Using a welder improperly can result in personal injury or damage to parts.

Warning

Whenever working with a torch or welder, there is always a chance of fire. Always observe standard safety practices.

Soldering Gun

A ***soldering gun*** or ***soldering iron*** is used to join wires during electrical repairs. An electric current heats the tip of the gun or iron. The hot tip is used to heat the wires. Solder is then applied to the hot wires and it melts. Solder is a lead-tin alloy. When the solder cools, it hardens into a strong, solid connection. Look at **Figure 4-21**.



A—Soldering Iron



A—Soldering Gun

Yotsatom Laonalonglit/Shutterstock.com
ConstantinosZ/Shutterstock.com

Figure 4-21. Soldering irons and guns produce enough heat to melt solder for joining wires and small metal terminals.

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Figure 4-22. Car batteries often become discharged. This is a battery charger.

Battery Charger

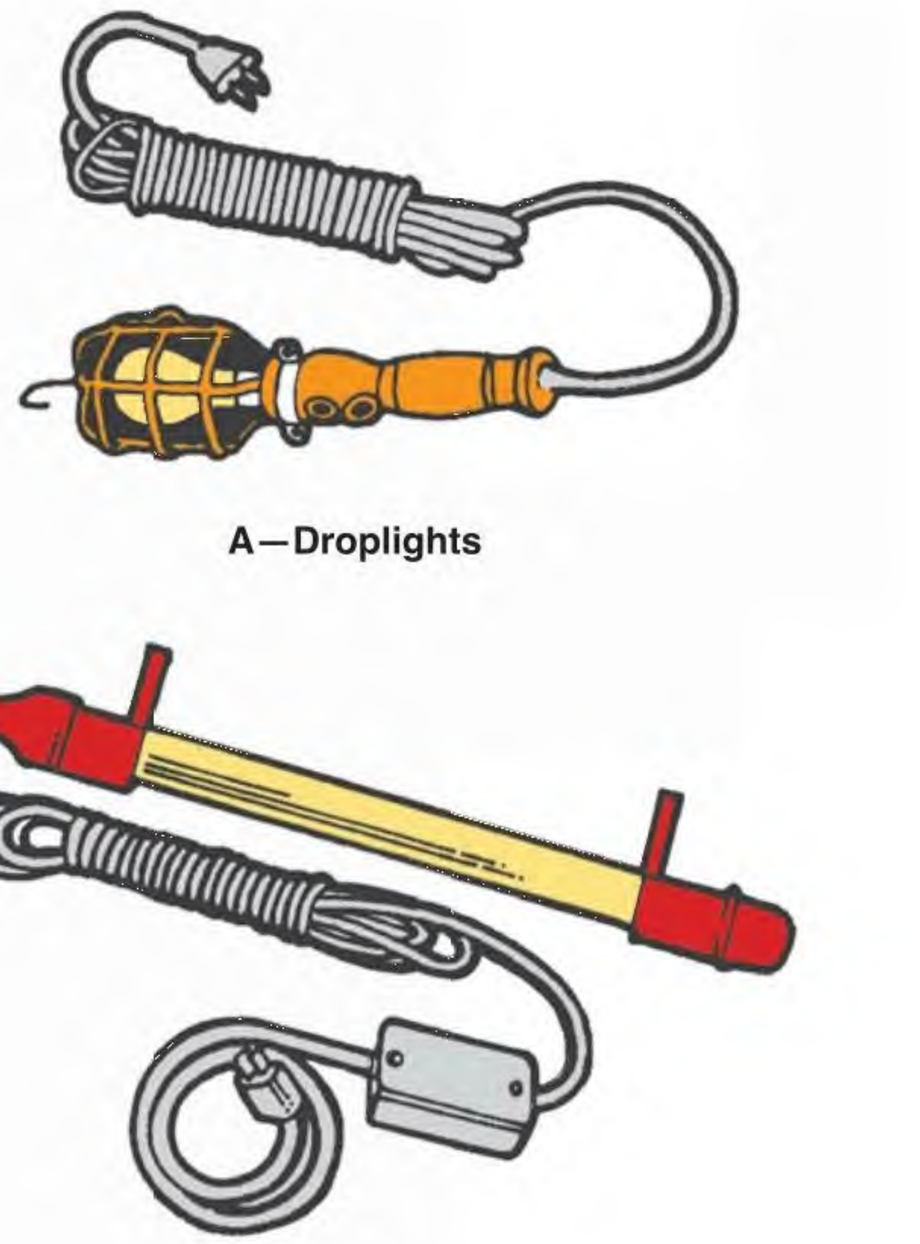
A ***battery charger*** is used to re-energize a "dead," or discharged, battery. It forces current back into the battery to recharge it. The red charger lead connects to the positive (+) battery terminal. The black charger lead connects to the negative (–) battery terminal. Refer to **Figure 4-22**.

Warning

The gases around the top of a battery can explode. Always connect the battery charger leads to the battery *before* turning on the charger. This prevents sparks, which could ignite the battery gases.

Tech Tip

HV battery chargers are quite different from 12-volt battery chargers. Always refer to the HV battery charger operating instructions for more safety-related information. Refer to the index to find more information on HV battery charger use.



A—Droplights

B—Fluorescent Droplights

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Figure 4-23. Good lighting is important for quality work.

Droplight

A ***droplight*** provides a portable source of light. The light can be taken to the repair area under the vehicle or in the trunk, passenger compartment, or engine compartment. Droplights are shown in **Figure 4-23**.

Pullers

Pullers are used to remove seals, gears, pulleys, steering wheels, axles, and other pressed-on parts. A few puller types are pictured in **Figure 4-24**. Special pulling operations are covered in later chapters.

Warning

Pullers can exert tons of force. They must be used properly to prevent personal injury or part damage. Always wear eye protection!

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Figure 4-24. Pullers are often needed to remove the steering wheel, engine balancer pulleys, and similar pressed-on parts.

Creepers

A ***creeper*** is useful when working under a car supported on jack stands. It lets the technician easily roll under vehicles without getting dirty. A ***stool creeper*** allows the technician to sit while working on parts that are near the ground. For example, a stool creeper is often used during brake system repairs. The brake parts and tools can be placed on the creeper. The service technician can sit and still be at eye level with the brake assembly. See **Figure 4-25**.

Roll-Around Cart

A large ***roll-around cart*** or table is handy for taking a number of tools to the job. A technician can quickly place all needed tools in the cart and take them to the vehicle. The cart places the tools within hand's reach. This saves time and effort during and after the job. Refer to **Figure 4-26**.



A B

Snap-on Tool Corp.

Figure 4-25. Creepers help you work on your back or while sitting. A—A creeper is for working under a vehicle. B—The stool creeper is commonly used during brake and suspension repairs. You can sit on the stool and store tools on the bottom.



Snap-on Tool Corp.

Figure 4-26. A roll-around cart allows you to take many tools to the vehicle. This saves several trips to the toolbox. It also saves time during cleanup at the end of the day.

Covers

Fender covers are placed over the fenders, upper grille, or other body sections to prevent vehicle damage. They protect the paint or finish from nicks, scratches, and grease. Never lay tools on a painted surface. Scratches may result. ***Seat covers*** are placed over seats to protect them from dirt, oil, and grease that might be on your work clothes. These covers should be used while driving the vehicle or while working in the passenger compartment. See **Figure 4-27**.



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Figure 4-27. Always take good care of your customer's vehicle.

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Personal Computer

A personal computer, often a laptop, is now used by some technicians to help with tasks including problem diagnosis, preprogramming of computer chips, bookkeeping, and reference to service literature. Look at **Figure 4-28**.

Workplace Skills

Social skills are the techniques you use to conduct yourself in such a way that your customers and fellow employees like and respect you. Many times, you will need the help of another technician to complete a difficult task. If your co-workers dislike you, you may have trouble finding help when you need it.



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Figure 4-28. This technician is using a laptop to monitor engine operating parameters as the vehicle is operated on a chassis dynamometer.

Summary

- Power tools use electricity, compressed air, or hydraulic pressure. Large shop tools, such as floor jacks, parts cleaning tanks, and steam cleaners, are classified as shop equipment.
- An air compressor is the source of compressed air for an auto shop.
- High-pressure air hoses are connected to the metal lines from the air compressor.
- Air tools, also called pneumatic tools, use air pressure for operation. They are labor-saving tools and are well worth their cost.
- Air wrenches, or impact wrenches, provide a very fast means of installing or removing threaded fasteners.
- Special impact sockets and impact extensions must be used with air wrenches.
- A blowgun is commonly used to dry and clean parts washed in solvent.
- An air drill is excellent for many repairs because of its power output and speed adjustment capabilities.
- A bench grinder can be used for grinding, cleaning, or polishing operations. The hard grinding wheel is used for sharpening or deburring. The soft wire wheel is for cleaning and polishing.
- Drill bits, or twist drills, are used to drill holes in metal and plastic parts.
- A drill bit is mounted in and rotated by a drill. A special key is sometimes needed to tighten the drill bit in the drill chuck.
- A floor jack is used to raise either the front, sides, or rear of a vehicle.
- Jack stands support a vehicle during repair. After raising a vehicle with a jack, place stands under the vehicle.
- A tire changer is a common piece of shop equipment used to remove and replace tires on wheels.
- A portable engine crane is used to remove and install engines.
- An engine stand is used to hold an engine while it is overhauled (rebuilt) or repaired.
- A cold-solvent tank can be used to remove grease and oil from parts.

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- An oxyacetylene torch outfit can be used to heat, cut, weld, or braze metal parts.
- A welder is used to melt and fuse metal parts together.
- A soldering gun or iron is used to solder wires.
- A battery charger is used to recharge a discharged 12-volt battery.
- A droplight provides a portable source of light.
- Pullers are needed to remove seals, gears, pulleys, steering wheels, axles, and other pressed-on parts.
- Fender covers are placed over the fenders, the upper grille, or other body sections to protect them.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

abrasive pad
air chisel
air compressor
air drill
air hammer
air hoses
air ratchet
air tools
battery charger
bench grinder
blowgun
cold-solvent tank
creeper
drill bits
drill press
drills
droplight
electric tools
engine crane
engine stand
fender covers
floor jack
high-pressure washer
hydraulic press
hydraulic tools
impact extensions
impact sockets
impact wrenches
jack stands
lubricator
oxyacetylene torch
portable electric drills
power tools
pressure blaster
pressure regulator
pullers
quick-disconnect couplings
roll-around cart
rotary brush
rotary file
seat covers
shop equipment
soldering gun
soldering iron
solvent gun
steam cleaner
stool creeper
tire changer
transmission jacks
welder

Activities

1. Using the Internet or an automotive tool catalog, develop a list of power tools needed to equip your school's automotive repair shop. Find prices and add up the cost.
2. Research safety information on power equipment used in an automotive repair facility.
   (A) Develop a bibliography of resources for safe use of power equipment.
   (B) Develop a list of safety rules for their use.

Review Questions

Answer the following questions using the information provided in this chapter.

1. Power tools use _____, _____, or _____ as sources of energy.
2. Which of the following is *not* a commonly used air tool?
   (A) Impact wrench.
   (B) Air ratchet.
   (C) Air chisel.
   (D) Drill press.
3. A 1/2″ drive impact wrench is used for fasteners with head sizes between 1/2″ to 1″. Which of the following sockets can be used by this particular tool?
   (A) 5/8″ chrome-plated socket.
   (B) 9/16″ flat black socket.
   (C) 7/16″ flat black socket.
   (D) None of the above.
4. A(n) _____ is used to blow dirt off parts and to dry parts after cleaning.
5. A rotary file is frequently used to remove _____.
   (A) old gasket materials
   (B) carbon deposits
   (C) metal burrs and nicks
   (D) None of the above.
6. List four important rules for a bench grinder.
7. List five important rules for a drill press.

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8. _____ are used to support a vehicle while working under it.
   (A) Floor jacks
   (B) Jack stands
   (C) Transmission jacks
   (D) Bumper jacks
9. Explain the use of a solvent tank.
10. What are pullers used for?

ASE-Type Questions

1. Power tools are tools that use:
   (A) electricity.
   (B) hydraulics.
   (C) compressed air.
   (D) All of the above.
2. Technician A says that shop air pressure usually ranges from 100–150 psi. Technician B says shop air pressure is much higher, around 300 psi. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. Which of the following is *not* a common impact wrench drive size?
   (A) 1/4″
   (B) 3/8″
   (C) 1/2″
   (D) 3/4″
4. Technician A says to use a 1″ drive on sockets from 1/4″ to 9/16″. Technician B says to use a 3/8″ drive on these socket sizes. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. Special impact sockets and extensions are easily identified because they are:
   (A) chrome.
   (B) aluminum.
   (C) flat black.
   (D) hard rubber.
6. Each of the following can be used to clean parts *except:*
   (A) air drill.
   (B) blowgun.
   (C) air ratchet.
   (D) bench grinder.
7. Which of the following is *not* a rule to follow when using a bench grinder?
   (A) Wear eye protection.
   (B) Make sure shields are in place.
   (C) Use the wire wheel to clean soft metal parts.
   (D) Keep the tool rest adjusted close to the stone and brush.
8. When using a drill press, Technician A believes drilling pressure should not be released until the bit breaks completely through the bottom of the part. Technician B believes pressure release should occur just before the bit breaks through. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. After using a floor jack to raise the front of a car:
   (A) place the car in park.
   (B) block the car's wheels.
   (C) secure the car on jack stands.
   (D) All of the above.
10. The _____ press can be used to install gears, pulleys, bearings, seals, and other parts requiring a high pushing force.
    (A) arbor
    (B) steam
    (C) rotary
    (D) hydraulic

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Chapter 5
Auto Shop Safety

After studying this chapter, you will be able to:

- Describe the typical layout and sections of an auto shop.
- List the types of accidents that can occur in an auto shop.
- Explain how to prevent auto shop accidents.
- Describe general safety rules for the auto shop.

An auto shop can be a safe and enjoyable place to work and earn a good living. Most shops are clean, well lighted, and relatively safe, **Figure 5-1**. However, if basic safety rules are *not* followed, an auto shop can be very dangerous. In this chapter, the layout of a typical automotive service facility will be discussed and the most important safety rules will be emphasized.

Tech Tip

Subject-specific safety rules will be given throughout this textbook. To live a long and productive life, follow all automotive industry safety policies.



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Figure 5-1. A well-maintained automotive shop can be an enjoyable place to work. Always do your part to keep the shop clean and well organized.

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Auto Shop Layout

There are several different areas in an auto shop. You must know their names and the basic rules that apply to each. It is important that you learn your shop layout and organization to improve work efficiency and safety. The auto shop includes the following work areas:

- Repair area.
- Toolroom.
- Classroom.

Repair Area

The ***repair area*** includes any location in the shop where repair operations are performed, such as the shop stall, lift, alignment rack, and outside work area. It normally includes every area except the classroom, locker room, and toolroom.

Shop Stall

A ***shop stall*** is a small work area where a vehicle can be parked for repairs. Sometimes, each stall is numbered and marked off with lines painted on the floor.

Some auto shop facilities have an ***outside work area*** adjacent to the garage overhead doors. In good weather, this area can be used for auto repairs.

Always raise the shop doors all the way and pull cars through the doors very slowly.

Tech Tip

Check the height of trucks and campers to make sure they will clear (top of vehicle will not hit doors or be crushed when raised fully on a lift).

Lift

The ***lift*** is used to raise a vehicle into the air. It is handy for working under the car (draining oil, greasing front end ball sockets, or repairing exhaust systems). Refer to **Figure 5-2**.

Remember these lift safety steps:

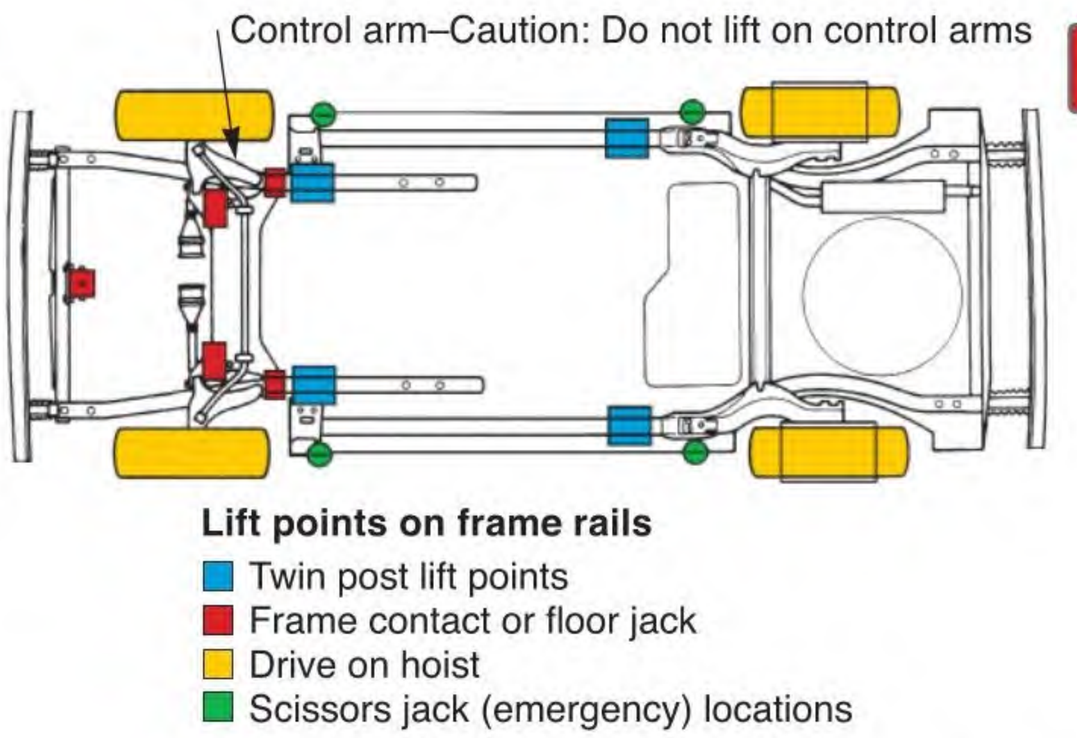
1. Ask your instructor for a demonstration and get permission before using the lift.



Eagle Equipment

Figure 5-2. A lift is handy for repairs on parts under the vehicle. Lifts are commonly used when changing oil, greasing the chassis, and repairing the exhaust system.

2. Position the vehicle's center of gravity (point of perfect balance) on the lift as described in its service manual, **Figure 5-3**. If a front-engine vehicle or a pickup truck with no weight in the bed, position the lift arms (if applicable) more to the front of the chassis. In a mid- or rear-engine car, place the lift pads more to the rear so the car will not slide or tilt off the lift.

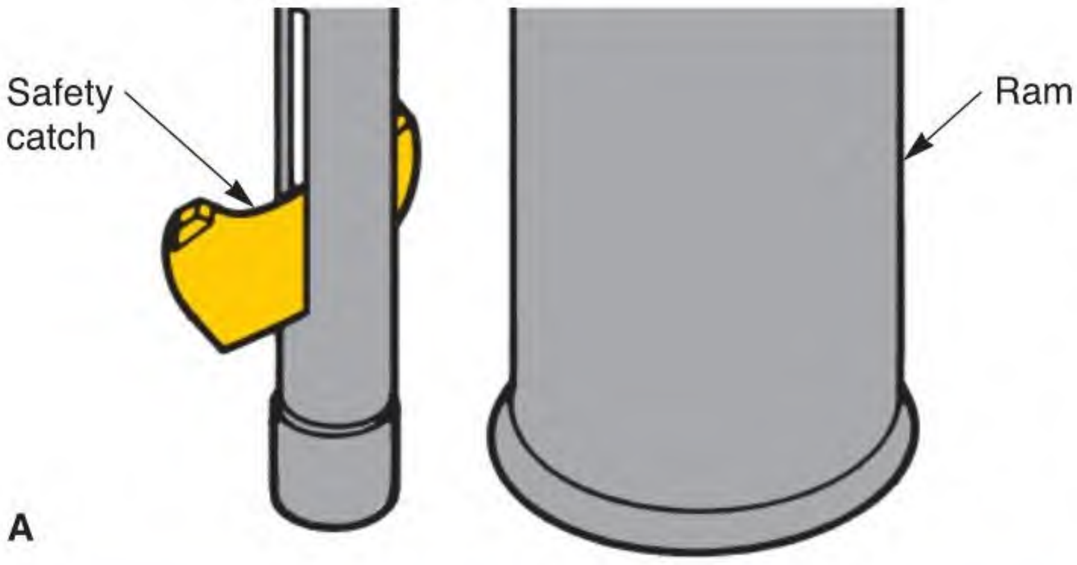


Chrysler

Figure 5-3. Follow the service manual instructions when raising a car on a lift. Note the specific lifting instructions and lift points for this specific vehicle.

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3. Raise vehicle slowly while keeping your fingers away from any moving parts on the lift. Raise the car about one inch off the ground. Double-check your lift points and make sure the vehicle is perfectly level. Always place your head next to the shop floor so you can see the alignment of the lift pad and vehicle pinch welds or frame rails.
4. When the vehicle is high enough to be worked on, make sure the lift's mechanical safety catch is engaged. Do not walk under the lift without the catch in the fully locked position, **Figure 5-4**.



Ford

Figure 5-4. Always read manufacturer's operating instructions closely before using a lift. If a lift lowers a car on someone, they will be crushed and killed instantly. A—Most lifts have a mechanical safety catch. A large metal lug must be engaged fully into the metal post before working under the vehicle. Without the mechanical catch engaged, a hydraulic failure could make the vehicle drop instantly to the ground with deadly crushing force. B—Always place your head next to the shop floor so you can see the alignment of the lift pad and vehicle pinch welds or frame rails.

Alignment Rack

The ***alignment rack*** is used when working on a car's steering and suspension systems. One is shown in **Figure 5-5**. It may contain a special tool board and equipment used when replacing worn suspension and steering parts or adjusting wheel alignment.

When using an alignment rack, the car should be pulled onto the rack slowly and carefully. Someone should guide the driver and help keep the tires centered on the rack. As with other complicated and potentially dangerous equipment, obtain a full demonstration before using the alignment rack.

Toolroom

The ***toolroom*** is a shop area where larger pieces of repair equipment are stored. The toolroom is used to store shop tools, small equipment, and supplies, such as nuts, bolts, and oil. It is normally located adjacent to (next to) the repair area or classroom.

When working in the toolroom, you will be responsible for keeping track of shop tools. Every tool checked out of the toolroom must be recorded and called in or retrieved before the end of the class period.

Normally, the tools hang on the walls of the toolroom for easy access. Each tool may have a painted silhouette, which indicates where it should be kept. Your instructor will detail specific toolroom policies and procedures, **Figure 5-6**.



Pavel L Photo and Video/Shutterstock.com

Figure 5-5. An alignment rack is used in most shops. It is often needed when servicing steering and suspension systems.

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Figure 5-6. Keep all shop tools clean and organized. Make sure you return every tool to its correct location.

Classroom

The ***classroom*** is usually an office-like area in a school or large repair facility, where students or mechanics can meet to increase their knowledge of auto service and repair. Either a certified instructor or the service manager presents the information to the students or experienced technicians. The classroom is used for seminars, demonstrations, and other technician training activities. It is often located adjacent to the repair area.

Shop Safety

Every year, thousands of technicians are accidentally injured or killed on the job. Most of these accidents resulted from a broken safety rule. The injured persons learned to respect safety rules the hard way—by experiencing a painful injury. You must learn to respect safety rules the easy way—by studying and following the safety rules given in this book.

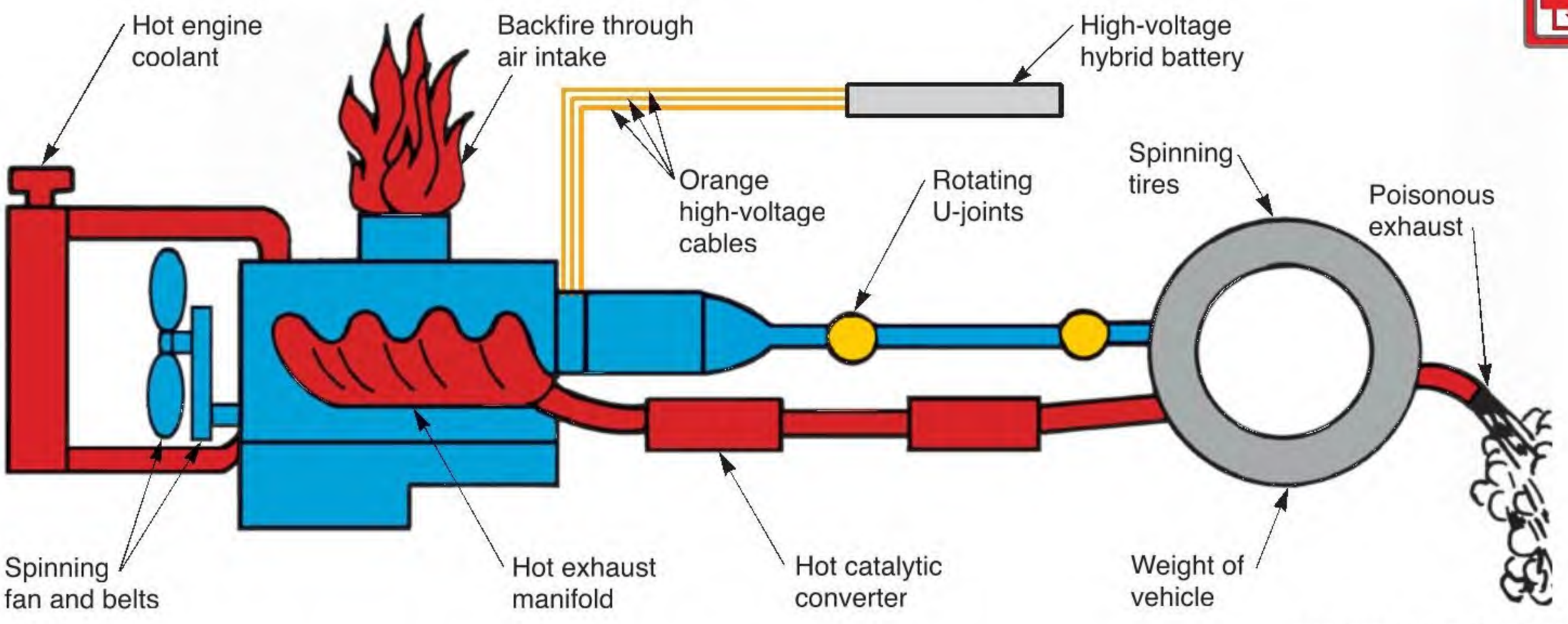
While working, constantly think of safety. Look for unsafe work habits, unsafe equipment, and other potentials for accidents.

Some areas in the automotive repair shop are more dangerous than others. Areas where dangerous equipment is used or toxic chemicals are stored are often identified by brightly colored floor markings or signs to alert employees to the potential hazards. When working in these marked safety areas, take extra precautions to prevent injury.

Evacuation routes should be posted in prominent areas throughout the shop. These routes show you how to quickly exit the building in case of a fire, gas leak, or other emergency. Always study the evacuation routes and be aware of your location in relation to these routes whenever you are working in the shop. Being able to quickly exit the building during an emergency could save your life.

When working in an auto shop, you must always remember that you are surrounded by other technicians. This makes it even more important that you concentrate on safety to prevent injury to yourself and to others in the shop. See **Figure 5-7**.





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Figure 5-7. An automotive shop has the potential to be very dangerous. Just a few of the dangers present around an automobile are shown.

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Types of Accidents

Basically, you should be aware of and try to prevent six kinds of accidents:

- Fires.
- Explosions.
- Asphyxiation (airborne poisons).
- Chemical burns.
- Electric shock.
- Physical injuries.

If an accident or injury occurs in the shop, notify your instructor immediately. Use common sense when deciding whether to get a fire extinguisher or to take other actions.

Fires

Fires are terrible accidents capable of causing severe injury and permanent scar tissue. Therefore, every precaution must be taken to prevent fires in the automotive shop. There are numerous combustible substances (gasoline, oily rags, paints, thinners) found in an auto shop.

Gasoline is by far the most dangerous and underestimated flammable substance in an auto shop. Gasoline has astonishing potential for causing a tremendous fire. Just a cupful of gasoline can instantly engulf a car in flames.

A few gasoline safety rules include:

- Store gasoline and other flammable substances in approved, sealed containers.
- Never use gasoline as a cleaning solvent.
- When disconnecting a vehicle's fuel line or hose, wrap a shop rag around the fitting to keep fuel from squirting or leaking.
- Wipe up gasoline spills immediately. Do not place oil absorbent (oil-dry) on gasoline because the absorbent will become highly flammable.
- Keep any source of heat away from open or exposed fuel system parts.
- Disconnect the battery or HV battery pack before working on a fuel system.

Oily rags can also start fires. Soiled rags should be stored in an approved safety can.

Paints, thinners, and other combustible materials should be stored in a fire cabinet. Also, never set flammable substances near a source of sparks (grinder), flames (welder or water heater), or heat (furnace, for example).

Electrical fires can result when a "hot wire" (wire carrying current to component) touches ground (vehicle frame or body). The wire can heat up, melt the insulation, and burn. Then, other wires can do the same. Dozens of wires could burn up in a matter of seconds.

To prevent electrical fires, always disconnect the battery when told to do so in a service manual. If possible, keep the battery disconnected during repairs.

Locate the ***fire extinguishers*** in your shop and learn how to use them before they are needed. The few seconds spent learning how to operate a fire extinguisher could be the difference between life and death during a fire.

Figure 5-8 shows various fire classifications and fire extinguisher types. Always use the recommended type of extinguisher. Using the wrong extinguisher can actually cause the flames to spread. Multipurpose fire extinguishers can be used for a variety of fires. The most common type of multipurpose extinguisher is an A, B, C, dry-chemical fire extinguisher.

To use a fire extinguisher, pull the safety pin from the handle. Aim the nozzle at the flames as outlined in **Figure 5-8** and squeeze the extinguisher handle.

Explosions

An ***explosion*** is the rapid, almost instant, combustion of a material that causes a powerful shock wave to travel through the shop. Several types of explosions are possible in an auto repair facility. You should be aware of these sources of sudden death and injury.

Hydrogen gas can surround the top of a car battery that is being charged or discharged (used). This gas is highly explosive. The slightest spark or flame can ignite the hydrogen gas, causing the battery to explode. Battery acid and pieces of the battery case can blow into your eyes and face. Blindness, facial cuts, acid burns, and scars can result. Always wear eye and face protection when working around a battery. See **Figure 5-9**.

Fuel tanks, even seemingly empty ones, can explode. A drained fuel tank can still contain fuel gum and varnish. When this gum is heated and melts, it can emit vapors that may ignite.

Keep sparks and heat away from fuel tanks. When a fuel tank explodes, one side will usually blow out. Then, the tank will shoot across the shop as if shot out of a cannon. You or other workers could be killed or seriously injured.

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Fires	Type	Use	Operation
Class A Fires Ordinary Combustibles (Materials such as wood, paper, textiles.) *Requires... cooling-quenching* Old: A New: 	**Soda-acid** Bicarbonate of soda solution and sulfuric acid 	Okay for use on: A Not for use on: B, C, D	Direct stream at base of flame.
Class B Fires Flammable Liquids (Liquids such as grease, gasoline, oils, and paints.) *Requires...blanketing or smothering.* Old: B New: 	**Pressurized Water** Water under pressure 	Okay for use on: A Not for use on: B, C, D	Direct stream at base of flame.
Class C Fires Electrical Equipment (Motors, switches, etc.) *Requires... a nonconducting agent.* Old: C New: 	**Carbon Dioxide (CO_2)** Carbon dioxide (CO_2) gas under pressure 	Okay for use on: B, C Not for use on: A, D	Direct discharge as close to fire as possible, first at edge of flames and gradually forward and upward.
Class D Fires Combustible Metals (Flammable metals such as magnesium and lithium.) *Requires...blanketing or smothering.* 	**Foam** Solution of aluminum sulfate and bicarbonate of soda 	Okay for use on: A, B Not for use on: C, D	Direct stream into the burning material or liquid. Allow foam to fall lightly on fire.
	Dry Chemical 	Multi-purpose type — Okay for: A, B, C; Not okay for: D Ordinary BC type — Okay for: B, C; Not okay for: A, D	Direct stream at base of flames. Use rapid left-to-right motion toward flames.
	Dry Chemical Granular type material	Okay for use on: D Not for use on: A, B, C	Smother flames by scooping granular material from bucket onto burning metal.

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Figure 5-8. There are several different types of fires. Fire extinguishers are rated by the type of fire on which they should be used.

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Snap-on Tool Corp.

Figure 5-9. Wear approved eye, ear, and face protection when needed.

Various other sources can cause shop explosions. For example, special sodium-filled engine valves, welding tanks, and propane-filled bottles can explode if mishandled. These hazards will be discussed in later chapters.

Warning

Air bags should be handled with extreme care. If accidentally deployed, they can break bones or even kill. Carry them with the trim cover pointed away from your body. Keep all sources of electricity away from undeployed air bags.

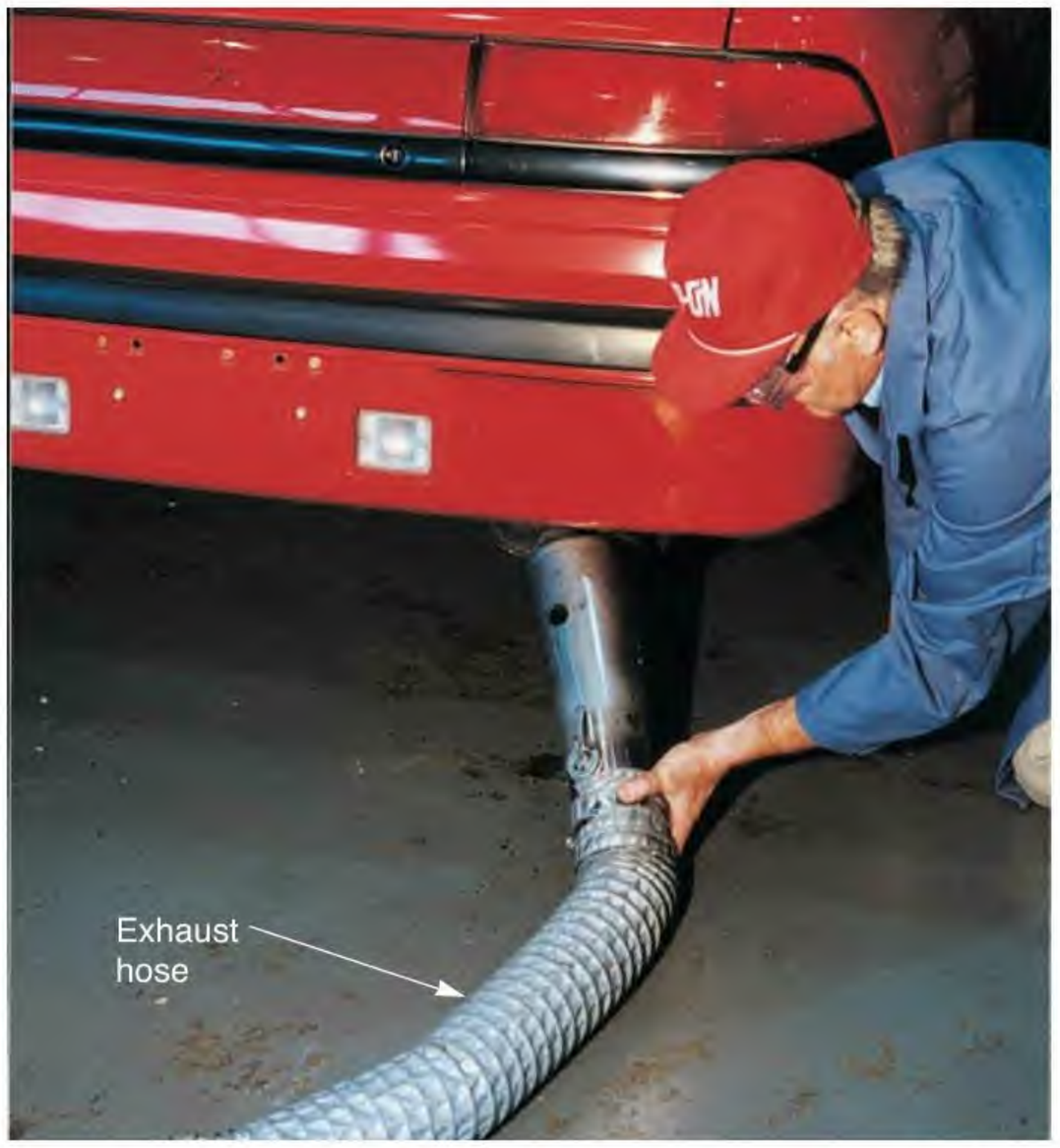
Asphyxiation

Asphyxiation is caused by breathing toxic or poisonous substances. Mild cases of asphyxiation will cause dizziness, headaches, and vomiting. Severe asphyxiation can cause death.

The most common cause of asphyxiation in an auto shop is the exhaust gases produced by an automobile engine. *Exhaust gases are poison.* If a vehicle must be operated in an enclosed shop, connect the vehicle's tailpipe to the shop's exhaust ventilation system as shown in **Figure 5-10**. Also, make sure the exhaust ventilation system is turned on.

Discussed in related chapters, other shop substances are harmful if inhaled. A few of these harmful substances include asbestos (brake lining dust, clutch disc dust), parts cleaners, and paint spray.

Respirators (filter masks) should be worn when working around any airborne impurities. Refer to **Figure 5-11**. Dust masks are made of treated paper



Kent-Moore

Figure 5-10. Place an exhaust hose over the tailpipe of any car running in an enclosed shop. This will prevent the shop from filling with deadly fumes.



Lab Safety

Figure 5-11. This technician is wearing a welding respirator to protect himself from toxic welding fumes. The welding helmet will shield the technician's face and eyes from hot sparks and the bright, blinding welding arc.

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and will only stop large particles from entering your body. Cartridge respirators provide good respiratory protection when potentially hazardous fumes are present in the shop. An air-supplied respirator must be worn when catalyzed paint products are applied in the shop.

Chemical Burns

Solvents (parts cleaners), battery acid, and various other corrosive shop substances can cause ***chemical burns*** to the skin. Always read the directions on all chemical containers. Also, be sure to wear proper protective gear when handling solvents and other caustic materials. See **Figure 5-12**.

Throttle body cleaner (decarbonizing type), for example, is very powerful and can severely burn your skin in a matter of seconds. Wear rubber gloves and a full face shield when using a decarbonizing throttle body cleaner. If a skin or eye burn occurs, follow label directions.



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Figure 5-12 Always dress properly when handling substances that can cause chemical burns. Note that this technician is wearing rubber gloves, a chemical-proof apron, a respirator, and safety goggles.

Electric Shock

Electric shock is a result of electric current passing through parts of your body, causing injury or death. It can occur when using improperly grounded electric power tools.

Never use an electric tool unless it has a functional ***ground prong*** (third, round prong on plug socket). This prevents current from accidentally passing through your body. Also, never use an electric tool on a wet shop floor.

Warning

Some late-model cars have heated windshields. The alternators on these vehicles are designed to put out more than 100 volts ac to quickly warm the windshield. This is enough voltage to cause electric shock. Work carefully around this high voltage.

Hybrid Safety

Hybrid vehicles use a high-voltage motor-generator and an HV battery pack that operates on approximately 300–600 volts. This is enough electrical energy to cause serious injury or even electrocution! Voltage levels and hybrid service procedures vary. Therefore, it is important to follow the vehicle manufacturer's instructions and safety rules when working on a specific make and model hybrid.

Always wear rubber electrician's gloves (rated for 1000 volts) when working on a high-voltage hybrid drive train system. The thick rubber gloves will prevent electric shock if you accidentally touch a conductor carrying high voltage and current. You must also use fully insulated tools to service the high-power cable connections on the battery. See **Figure 5-13**.

Most hybrids have a main power cutoff switch, or high-voltage disconnect, near the output cables of the battery pack. This switch allows you to electrically disconnect the battery pack from the rest of the hybrid drive train system. It should be turned to the off or disabled position before servicing a hybrid drive train system.

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Toyota

Figure 5-13. When working on high-voltage parts of a hybrid drive train system, always use insulated tools and thick rubber electrician's gloves to avoid electrocution.

Physical Injury

Physical injuries (cuts, broken bones, strained backs) can result from hundreds of different accidents. As a technician, you must evaluate every repair technique. Decide whether a particular operation is safe and take action as required.

For instance, if you are pulling on a hand wrench as hard as you can and the bolt will not turn, *stop!* Find another wrench that is larger. A larger tool has more leverage and is, therefore, safer. This approach will help prevent injuries and improve your mechanical abilities.

Warning

Never overexert your back by improperly lifting heavy assemblies. Once you injure your back, it can take months to recover. Sometimes, surgery is needed to repair the damage. When lifting a heavy object, keep your back straight. Bend your knees and lift the item with your legs. If necessary, use power equipment to move heavy objects.

General Safety Rules

Listed are several general safety rules that should be followed at all times.

- Wear eye protection during any operation that could endanger your eyes. This would include operating power tools, working around a running car engine, carrying batteries, etc.
- If debris or chemicals accidentally get into your eyes, flush your eyes using an ***eyewash station***. Always locate the eyewash station in your work area and learn how to use it before you need it. Refer to the eyewash station manufacturer's instructions for proper use.
- Avoid anyone who does not take shop work seriously. Inappropriate behavior leads to accidents.
- Keep your shop organized. Return all tools and equipment to their proper storage areas. Never lay tools, creepers, or parts on the floor.
- Dress in an appropriate manner. Never wear loose clothing, neckties, shorts, or open-toed shoes when working in the shop. Remove rings, bracelets, necklaces, watches, and other jewelry. They can get caught in engine fans, belts, drive shafts, and other rotating parts, causing serious injury. Also, button or roll up long sleeves and secure long hair; they too can get caught in spinning parts.
- Never carry sharp tools or parts in your pockets. They can puncture the skin.
- Wear full face protection when grinding, welding, and performing other operations where severe hazards are present.
- Work like a professional. When learning auto repair, it is easy to get excited about your work. However, avoid working too fast. You could easily overlook an important repair procedure or safety rule and be injured.
- Use the right tool for the job. There is usually a "best tool" for each repair task. Always be thinking about whether a different tool will work better than another, especially when you run into difficulty.
- Keep guards or shields in place. If a power tool has a safety guard, use it.
- Lift with your legs, not your back. There are many assemblies that are very heavy. When lifting, bend at your knees while keeping your back straight. On extremely heavy assemblies (transmissions, engine blocks, rear axles, transaxles), use a portable crane or hydraulic jack.

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- Use adequate lighting. A portable shop light not only increases working safety, but it increases working speed and precision.
- Ventilate your work area when needed. Turn on the shop ventilation fan when fumes are present in the shop.
- Never stir up asbestos dust. Asbestos dust (particles found in older brake and clutch assemblies) is a powerful cancer-causing agent. Do not use compressed air to blow the dust from brake and clutch parts. Use an enclosed vacuum system to remove brake dust from brake assemblies to avoid contaminating the shop.
- Jack up a vehicle slowly and safely. A car can weigh more than two tons (1814 kg). Never work under a vehicle not supported by jack stands. A floor jack is only for raising the vehicle, not holding it while working. A hydraulic jack can instantly blow a seal and allow the heavy car to crash down with tremendous force. Always secure a vehicle on jack stands and block the wheels before working under it.
- Drive slowly when in the shop area. With all the other technicians and vehicles in the shop, it is very easy to have an accident.
- Report unsafe conditions to your supervisor or instructor.
- Stay away from engine fans. The fan on an engine is like a spinning knife. It can inflict serious injuries. Also, if a part or tool is dropped into the fan, it can fly out and hit someone with great force. Remember, electric fans can turn on even with the ignition key off!
- Respect running engines. Before starting an engine, make sure the transmission is fully in park or neutral, the emergency brake is set, and the wheels are blocked. If these steps are not taken and the car is accidentally knocked into gear, it could run over you or a friend.
- Do not smoke in or near the auto shop. Smoking is a serious fire hazard, considering fuel lines, cleaning solvents, lubricants, and other flammables may be exposed.
- Obtain instructor or service manager permission before using any new or unfamiliar power tool, lift, or other shop equipment. If necessary, your instructor or service manager will give a demonstration.

Tech Tip

While safety should be a priority whenever you are working in the shop, it is easy to overlook potential hazards. Therefore, it is important to perform periodic (weekly or monthly) shop safety inspections. Walk through your shop and take note of any unsafe conditions found. Report unsafe conditions to your instructor or supervisor.

Right-to-Know Laws

Right-to-know laws give essential information and stipulations for safely working with hazardous materials. The majority of states have enacted their own right-to-know laws. It is up to you to read all printed material that describes the proper handling of hazardous materials.

Safety data sheets give detailed chemical composition and precautionary information for all products that can present a health or safety hazard. See **Figure 5-14**. They are available from product manufacturers. You can easily see all the dangers and actions that should be taken when using any potentially dangerous product.

The ***Occupational Safety and Health Administration (OSHA)*** is a federal agency that gives general guidelines for the safe operation of work sites. To ensure safe working conditions, OSHA has established safety and work regulations for all industries.

Store and dispose of hazardous waste properly. Environmental Protection Agency (EPA) regulations require the proper labeling, storage, and transport of these potentially harmful materials for controlled disposal.

Customer Relations

Most shop insurance policies do not cover customers who enter the shop work area. When informing customers that they are not allowed in the repair area, explain that the insurance company, not the shop, has made this rule. This will help prevent the customer from being offended by being told to leave the work area.

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MATERIAL SAFETY DATA SHEET | DATE PREPARED X/XX

HI-TEMP PRODUCTS CO. 14936 GROVER ST. OMAHA, NEBRASKA 68144	EMERGENCY PHONE NUMBER 1-402-333-8323 1-402-359-5796	TELEPHONE NUMBER FOR INFORMATION 1-402-330-3344

1 PRODUCT NAME: HT 0801 AKRYA Cut

2 PRECAUTIONARY STATEMENT FROM PRODUCT LABEL

WARNING

WEAR SAFETY GLASSES. MAY CAUSE EYE IRRITATION. IF EYE IRRITATION OCCURS, FLUSH EYES FOR 15 MINUTES WITH WATER. IF SWALLOWED, DO NOT INDUCE VOMITING. DRINK WATER OR MILK. IN EITHER CASE, CALL A PHYSICIAN IMMEDIATELY. REFER TO MSDS FOR CHEMICAL HAZARDOUS INFORMATION.

KEEP OUT OF THE REACH OF CHILDREN.

+ HEALTH	1
^ FIRE	0
* REACTIVE	0

HAZARD RATING
0 – LEAST
1 – SLIGHT
2 – MODERATE
3 – SERIOUS
4 – SEVERE

3 HAZARDOUS COMPONENTS OSHA – >

INGREDIENTS	%	CAS NO.	PEL/TLV a ppm	PEL/TLV 3 mg/m	TWA a ppm	TWA 3 mg/m	STEL c a ppm	STEL c 3 mg/m	CEILING a ppm	CEILING 3 mg/m
ISOPROPYL ALCOHOL	<3	67-63-0			400	983	500	1230		

4 PHYSICAL/CHEMICAL CHARACTERISTICS

Boiling Point	212° F	Specific Gravity (H20=1)	N/A
Vapor Pressure (mm Hg.)	N/A	Melting Point	N/A
Vapor Density (Air = 1)	N/A	Evaporation Rate (Butyl Acetate = 1)	N/A
Solubility in water	MISCIBLE		
Appearance and Odor	PURPLE THICK EMULSION, BANANA ODOR		

5 Fire and Explosion Hazard Data

Flash Point	N/A	Flammable Limits	N/A	LEL N/A	UEL N/A
Extinguishing Media	WATER TO COOL DOWN CONTAINERS				
Special Fire Fighting Procedures	N/A	DIRECT FLAME FROM BUTANE TORCH			
WILL NOT IGNITE MATERIAL.					
Unusual Fire and Explosion Hazards	N/A				

6 HEALTH HAZARD INFORMATION – SIGNS AND SYMPTOMS OF EXPOSURE

SKIN: MAY IRRITATE SKIN, CAUSE LIGHT REDDENING IN PATIENTS WITH PREEXISTING SKIN DISORDERS.
EYES: MAY CAUSE EYE IRRITATION, BURNING, AND REDNESS.

SWALLOWING: MAY CAUSE MOUTH AND THROAT IRRITATION, BURNING, AND POSSIBLE ABDOMINAL DISCOMFORT OR NAUSEA.
BREATHING: PROLONGED BREATHING OF MIST MAY IRRITATE NASAL PASSAGES.

7 EMERGENCY AND FIRST AID PROCEDURES

ON SKIN: WASH WITH SOAP AND WATER. IF IRRITATION PERSISTS, SEEK MEDICAL ATTENTION.

IN EYES: FLUSH EYES WITH PLENTY OF RUNNING WATER FOR 15 MINUTES, LIFTING EYELIDS OCCASIONALLY. GET IMMEDIATE MEDICAL ATTENTION.

SWALLOWED: CALL A PHYSICIAN IMMEDIATELY. DO NOT INDUCE VOMITING. IF CONSCIOUS, DRINK PLENTY OF WATER OR MILK.

BREATHED: REMOVE TO FRESH AIR. GIVE ARTIFICIAL RESPIRATION IF NOT BREATHING. SEEK IMMEDIATE MEDICAL ATTENTION.

8 TOXICITY DATA

ORAL: N/A | DERMAL: N/A

INHALATION: N/A

CARCINOGENICITY: NOT CONSIDERED TO BE A CARCINOGEN BY IARC.

NTP? N/A IARC MONOGRAPHS? N/A OSHA REGULATED? N/A

9 PERSONAL PROTECTION

VENTILATION: LOCAL OR MECHANICAL EXHAUST.
RESPIRATORY PROTECTION: IF NECESSARY, WEAR A PARTICLE MASK OR AN OSHA APPROVED MASK FOR MIST CONCENTRATIONS.
EYE PROTECTION: WEAR GOGGLES OR SAFETY GLASSES.
SKIN AND PROTECTIVE CLOTHING: WEAR RUBBER GLOVES.

10 HAZARDOUS REACTIVITY

STABILITY:	UNSTABLE?		CONDITIONS TO AVOID: N/A
	STABLE?	X	
INCOMPATIBILITY: N/A			
HAZARDOUS BYPRODUCTS: N/A			
HAZARDOUS POLYMERIZATION:	MAY OCCUR		CONDITIONS TO AVOID: N/A
	WILL NOT OCCUR	X	

Hi-Temp Products Co.

Figure 5-14. Study the types of information given on a safety data sheet.

Summary

- An auto shop can be a safe and enjoyable place to work. However, if basic safety rules are *not* followed, an auto shop can be very dangerous.
- The shop repair area includes any location in the shop where repair operations are performed.
- The toolroom is a shop area normally adjacent the main shop or classroom. It is used to store shop tools, small equipment, and supplies.
- Every year, thousands of technicians are injured or killed on the job. Most of these accidents resulted from a broken safety rule.
- Fires are capable of causing permanent scar tissue. There are numerous combustible substances found in an auto shop.
- Gasoline is by far the most dangerous and often underestimated flammable in an auto shop.
- Electrical fires can result when a “hot wire” (wire carrying current to component) touches ground (vehicle frame or body).
- An explosion is rapid combustion that causes a powerful shock wave to travel out through the shop.
- Asphyxiation is caused by breathing toxic or poisonous substances in the air.
- Respirators should be worn when working around any kind of airborne impurities.
- Electric shock results when electric current passes through your body, causing injury or death.
- Physical injuries (cuts, broken bones, strained backs) can result from a variety of accidents.

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Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

alignment rack
asphyxiation
chemical burn
classroom
electric shock
evacuation routes
explosion
eyewash station fire
fire extinguisher
fires
ground prong
lift
Occupational Safety and Health Administration (OSHA)
outside work area
physical injury
repair area
respirator
right-to-know laws
safety data sheets
shop stall
throttle body cleaner
toolroom

Activities

1. Sketch out a floor plan of your shop and label the different areas. Study the safety cautions in this chapter and determine if there are any safety hazards. Mark their location on the floor plan.
2. On the same floor plan, mark the location of fire extinguishers, exits, and eye flushing stations.
3. Examine a fire extinguisher in the shop area and read the instructions carefully. Demonstrate its use.

Review Questions

Answer the following questions using the information provided in this chapter.

1. List four safety rules to follow when using a vehicle lift.
2. A(n) _____ is used when working on a car's steering and suspension systems. It has special equipment for aligning the vehicle's wheels.
3. _____ is the most common and dangerous flammable found in an auto shop.
4. What causes an electrical fire in an automobile?
5. Car batteries can explode. True or False?
6. Which of the following cannot cause electric shock?
   (A) A missing ground prong on cord.
   (B) Using an electric drill on wet floor.
   (C) Using electric tools with a ground prong.
   (D) None of the above.
7. Explain what must be done to prevent physical injuries.
8. If you are pulling on a wrench as hard as you can and the fastener does *not* turn, what should you do to prevent injury?
9. When lifting heavy objects, always lift with your _____.
   (A) arms
   (B) legs
   (C) back
   (D) None of the above.
10. List 20 general safety rules.
11. Why is it important to perform periodic shop safety inspections?

ASE-Type Questions

1. In which auto shop area would an exhaust system repair most likely be done?
   (A) Shop stall.
   (B) Grease rack.
   (C) Alignment rack.
   (D) Outside work area.
2. Rules to remember when using gasoline include each of the following *except:*
   (A) store gas in approved containers.
   (B) keep gas away from sources of heat.
   (C) use oil absorbent to absorb any gas spills.
   (D) never use gasoline as a cleaning solvent.
3. Which of the following is a possible source of explosions in an auto shop?
   (A) Fuel tanks.
   (B) Car batteries.
   (C) Welding tanks.
   (D) All of the above.
4. Asphyxiation can be caused by:
   (A) touching a current-carrying wire.
   (B) improper lifting techniques.
   (C) breathing toxic substances.
   (D) None of the above.

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5. Asbestos dust, which can cause cancer, is found in:
   (A) fuel tanks.
   (B) transmissions.
   (C) propane-filled bottles.
   (D) brake and clutch assemblies.
6. A respirator is a:
   (A) filter mask.
   (B) type of chemical burn.
   (C) machine guard.
   (D) device to put out small fires.
7. Eye protection should be worn when:
   (A) carrying batteries.
   (B) operating power tools.
   (C) working by a running engine.
   (D) All of the above.
8. Which of the following is *not* a good tip when dressing for work?
   (A) Secure long hair.
   (B) Roll up long shirt sleeves.
   (C) Make sure all jewelry fits well.
   (D) Do not carry sharp tools in pocket.
9. An engine needs to be moved. Technician A says two people can slide the engine out of the way. Technician B says that an engine crane should be used to move the engine. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. When removing asbestos dust from parts, Technician A believes a vacuum system should be used. Technician B believes dust should be blown away using compressed air. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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Digital calipers can be used to take precision measurements during mechanical repairs.

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Chapter 6
Automotive Measurement and Math

After studying this chapter, you will be able to:

- Use both customary and metric measuring systems.
- Identify and use basic measuring tools
- Use decimal and metric conversion charts.
- Use basic math skills.
- Understand percentages and ratios.
- Correctly answer ASE certification test questions that require a basic understanding of measurement and math.

As an automobile is driven for thousands of miles, its moving parts slowly wear out. With enough part wear, mechanical failures and performance problems result. Manufacturers give specifications, or "specs", which are maximum wear limits and dimensions of new parts. Therefore, a technician must be able to take accurate measurements to determine whether a part is within these specifications. If the measurements of the part are not within the specifications, the part must be adjusted, machined and repaired, or replaced.

Tech Tip

Math and measuring tool use are explained throughout this textbook, where the information is applied to real-world situations and applications.

Measuring Systems

Two ***measuring systems*** are commonly used when working in the auto shop: the customary measuring system (inches, pounds, etc.) and the metric (SI) measuring system (millimeters, grams, etc.). The customary measuring system is also called the US customary units system or the English system. Most countries use the metric system. The customary system is mainly used in the United States. However, the United States uses the metric system as well. All new vehicles use metric bolts, nuts, and other parts. Manufacturer's specifications are often given in both customary and metric values for US made vehicles. See **Figure 6-1**.

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Quantity	Customary (abbreviation)	Metric (abbreviation)
Length	Inch (in) Foot (ft) Mile (mi)	Meter (m)
Weight (mass)	Ounce (oz) Pound (lb)	Kilogram (kg)
Area	Square inch (sq-in)	Square meter (m^2)
Dry volume	Cubic inch (cu-in)	Cubic meter (m^3) Cubic centimeter (cc)
Liquid volume	Ounce (oz) Pint (pt) Quart (qt) Gallon (gal)	Liter (L) Cubic centimeter (cc)
Road speed	Miles per hour (mph)	Kilometer per hour (km/h)
Torque	Foot-pounds (ft-lb)	Newton meter (N•m)
Power	Horsepower (hp)	Kilowatt (kW)
Pressure	Pounds per square inch (psi)	Kilopascal (kPa)
Temperature	Degrees Fahrenheit (°F)	Degrees Celsius (°C)

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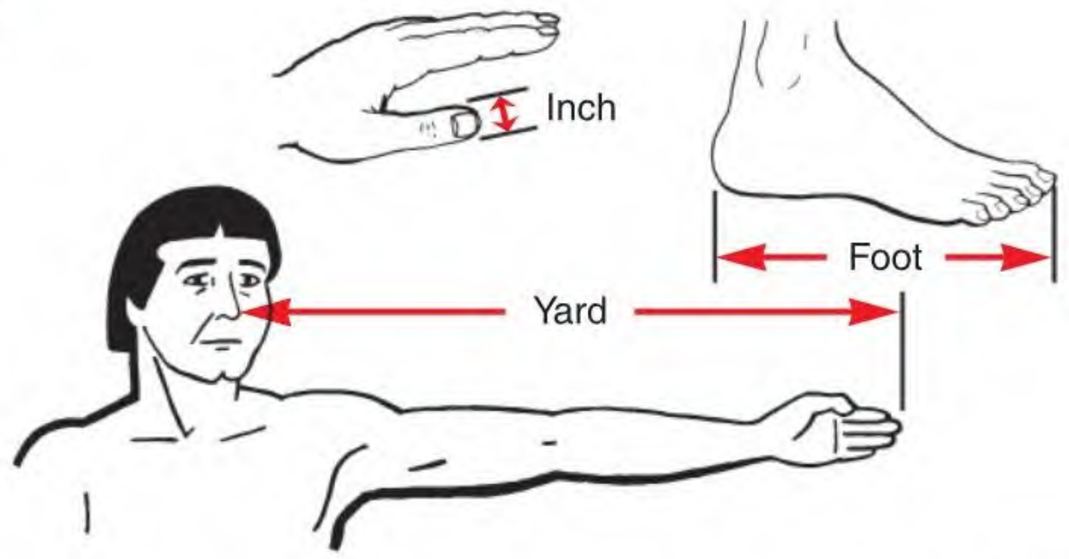
Figure 6-1. This chart compares customary and metric values. Study them carefully.

Customary Measuring System

The ***customary measuring system*** originated from sizes taken from parts of the human body. For example, the width of the human thumb was used to standardize the inch (25.4 mm). The length of the human foot was used to standardize the foot as 12″ (304.8 mm). The distance between the tip of a finger and nose was used to set the standard for the yard as 3 feet. Obviously, these were not very scientific standards since these distances vary from person to person, **Figure 6-2**.

Metric (SI) Measuring System

The ***metric (SI) measuring system*** is a simpler and more logical system than the customary system. Conversion between metric units is always based on a power of ten. Computation often requires nothing more than moving the decimal point. For instance, one meter equals 0.001 kilometer, 10 decimeters, 100 centimeters, or 1000 millimeters.



Starrett

Figure 6-2. The customary system was originally based on parts of the human body.

Conversion Charts

A measuring system ***conversion chart*** is needed when changing a value from one measuring system to another, such as when changing inches to centimeters, gallons to liters, or liters to gallons. A conversion chart lets the technician quickly convert customary values to equivalent metric values, or vice versa. One is shown in **Figure 6-3**.

A ***decimal conversion chart*** is commonly used to find equivalent values for fractional inches, decimal inches, and millimeters. These charts are typically accurate to the nearest 1/64″. For measurements that need greater precision, either decimals or millimeters should be used. A decimal conversion chart may be needed to change a fractional measurement to a decimal measurement. See **Figure 6-4**.

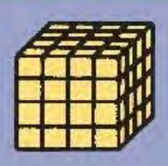
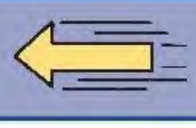
Measuring Tools

There are various tools used by a technician to make accurate measurements. Common measuring tools include the steel rule, caliper, micrometer, and dial indicator. Most of these are available in both customary and metric versions. These and other tools are covered in the next sections.

Steel Rule

A ***steel rule***, or ***scale***, is frequently used to make low-precision linear measurements. It is accurate to about 1/64″ (0.4 mm) in most instances. A ***customary rule*** has

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Measurement		When you know:	You can find:	If you multiply by:
	**Length**	inch (in) foot (ft) yard (yd) mile (mi) millimeter (mm) centimeter (cm) meter (m) kilometer (km)	millimeter (mm) meter (m) meter (m) kilometer (km) inch (in) inch (in) yard (yd) mile (mi)	25.4 .3 .9 1.6 .04 .39 1.09 .6
	**Pressure**	pounds per square inch (psi) kilopascal (kPa)	kilopascal (kPa) pounds per square inch (psi)	6.89 .145
	**Power**	horsepower (hp) kilowatt (kW)	kilowatt (kW) horsepower (hp)	.746 1.34
	**Torque**	foot-pounds (ft-lb) Newton-meter (N·m)	Newton-meter (N·m) foot-pounds (ft-lb)	1.36 .74
	**Volume**	quart (qt) liter (L) cubic inch (cu-in) liter (L)	liter (L) quart (qt) liter (L) cubic inch (cu-in)	.95 1.06 .016 61.02
	**Mass**	ounce (oz) gram (g) pound (lb) kilogram (kg)	gram (g) ounce (oz) kilogram (kg) pound (lb)	28.35 .035 .45 2.20
	**Speed**	miles per hour (mph) kilometers per hour (km/h)	kilometers per hour (km/h) miles per hour (mph)	1.61 .62

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Figure 6-3. To convert from one system to another, multiply the known value by the number in the right column. This will give an approximately equal value.

numbered lines that represent full inches, **Figure 6-5**. The smaller, unnumbered lines, or graduations, represent fractions of an inch, such as 1/2″, 1/4″, 1/8″, and 1/16″. The shortest graduations represent the smallest fractions. In **Figure 6-5**, this is 1/16″. A ***metric rule*** normally has lines representing millimeters (mm). Each numbered line usually equals 10 mm, or 1 cm (centimeter). This is also shown in **Figure 6-5**.

A ***pocket rule***, or pocket scale, is typically 6″ long. It is small enough to fit in your shirt pocket. A ***combination square*** is a sliding square that is mounted on a steel rule. It is needed when the rule must be held perfectly square against the part being measured. See **Figure 6-6**.

A ***tape measure***, or tape rule, extends to several feet or meters in length. It is sometimes needed for large distance measurements during body, suspension, and exhaust system repairs. Look at **Figure 6-7**. A ***yardstick*** or ***meterstick*** is a rigid measuring device used for large lineal measurements up to one yard or one meter.

Calipers

A ***vernier caliper*** is a sliding measuring device that can make inside, outside, and depth measurements with considerable accuracy, **Figure 6-8**. One is pictured in **Figure 6-9**. Vernier calipers can take measurements as small as 0.001″ (0.025 mm). Modern vernier calipers have a dial gauge or digital readout attached. The dial or digital readout makes the "thousandths" part of a measurement easier to read. A caliper is fast and easy to use, making it a very useful tool for the automotive technician to have when one-thousand of an inch accuracy is adequate.

Micrometers

A ***micrometer***, nicknamed a mike, is used to make very accurate measurements. It can measure to one ten-thousandth of an inch (.0001″) or one thousandth of a millimeter (0.001 mm). There are several types of mikes used in automotive service and repair. These include outside, inside, and depth micrometers.

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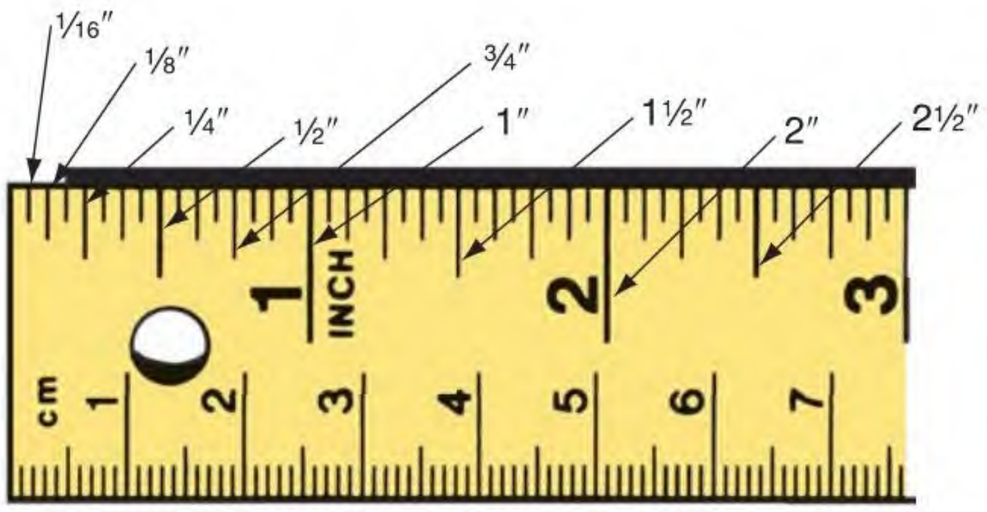
Fraction				Inches	mm
			1/64	.01563	.397
		1/32		.03125	.794
			3/64	.04688	1.191
	1/16			.06250	1.588
			5/64	.07813	1.984
		3/32		.09375	2.381
			7/64	.10938	2.778
1/8				.12500	3.175
			9/64	.14063	3.572
		5/32		.15625	3.969
			11/64	.17188	4.366
	3/16			.18750	4.763
			13/64	.20313	5.159
		7/32		.21875	5.556
			15/64	.23438	5.953
1/4				.25000	6.350
			17/64	.26563	6.747
		9/32		.28125	7.144
			19/64	.29688	7.541
	5/16			.31250	7.938
			21/64	.32813	8.334
		11/32		.34375	8.731
			23/64	.35938	9.128
3/8				.37500	9.525
			25/64	.39063	9.922
		13/32		.40625	10.319
			27/64	.42188	10.716
	7/16			.43750	11.113
			29/64	.45313	11.509
		15/32		.46875	11.906
			31/64	.48438	12.303
1/2				.50000	12.700

Fraction				Inches	mm
			33/64	.51563	13.097
		17/32		.53125	13.494
			35/64	.54688	13.891
	9/16			.56250	14.288
			37/64	.57813	14.684
		19/32		.59375	15.081
			39/64	.60938	15.478
5/8				.62500	15.875
			41/64	.64063	16.272
		21/32		.65625	16.669
			43/64	.67188	17.066
	11/16			.68750	17.463
			45/64	.70313	17.859
		23/32		.71875	18.256
			47/64	.73438	18.653
3/4				.75000	19.050
			49/64	.76563	19.447
		25/32		.78125	19.844
			51/64	.79688	20.241
	13/16			.81250	20.638
			53/64	.82813	21.034
		27/32		.84375	21.431
			55/64	.85938	21.828
7/8				.87500	22.225
			57/64	.89063	22.622
		29/32		.90625	23.019
			59/64	.92188	23.416
	15/16			.93750	23.813
			61/64	.95313	24.209
		31/32		.96875	24.606
			63/64	.98438	25.003
1				1.00000	25.400

Parker Hannifin Corp.

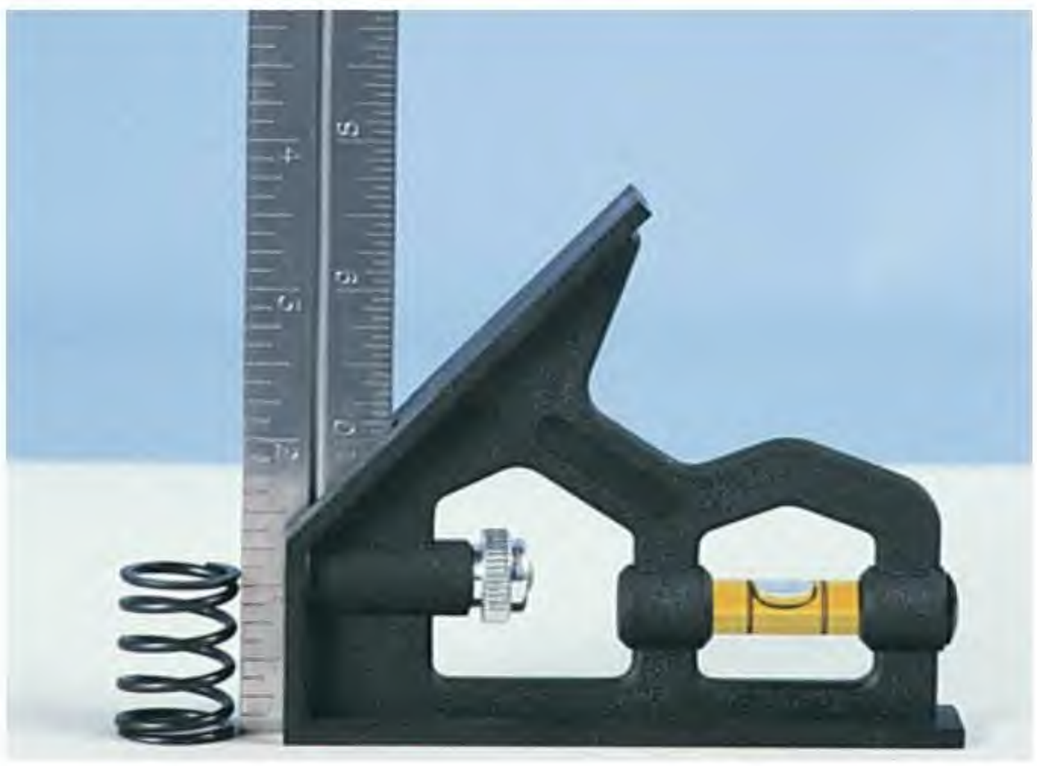
Figure 6-4. A decimal conversion chart lets you interchange fractions, decimals, and millimeters. What are equal decimal and millimeter values for 1/4″, 5/32″, 43/64″, and 7/8″?

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Fairgate

Figure 6-5. Compare inches to centimeters. Ten millimeters equals one centimeter. Twenty-five millimeters is a little less than one inch. The customary rule is divided into 1/16″ fractions.



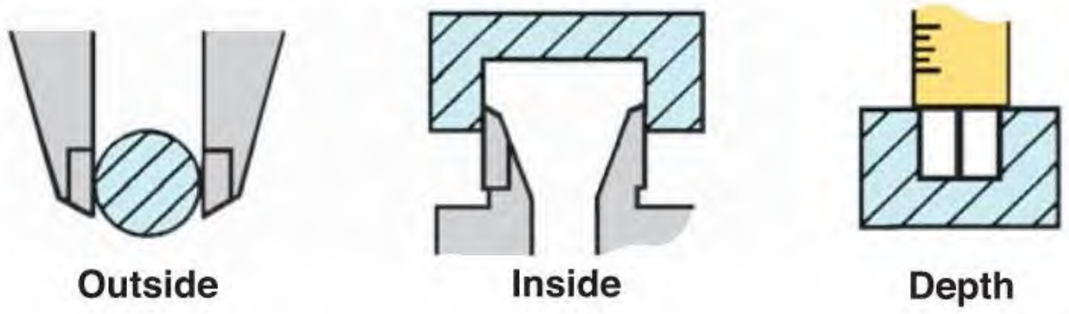
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Figure 6-6. A combination square is needed when the rule must be held perfectly parallel to the part.



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Figure 6-7. Tape measures are used when taking large measurements, such as when measuring to check for major structural damage to suspension parts from a collision.



K-D Tools

Figure 6-8. Study how calipers can be used to check measurements.



Starrett

Figure 6-9. A vernier caliper can be used to quickly check inside, outside, and depth measurements with considerable accuracy.

An outside micrometer is used for measuring external dimensions, diameters, or thicknesses, **Figure 6-10**. To use an outside micrometer, place it around the outside of the part. Then, turn the thimble until both the spindle and anvil are lightly touching the part, as in **Figure 6-11**. Finally, read the graduations on the hub and thimble to determine the measurement. It is also a good idea to check the accuracy of your micrometer, **Figure 6-12**.

An inside micrometer is used for internal measurements of large holes, cylinders, or other part openings, **Figure 6-13A**. To use an inside micrometer, place it inside the opening. Then, adjust the micrometer until it just touches the walls of the opening. Finally,

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Starrett

Figure 6-10. A micrometer is the precision measuring tool most commonly used by a technician. This one is easy to use because it has a digital readout.



Starrett

Figure 6-11. Move the micrometer over the part while holding it squarely. When you feel a slight drag, remove the micrometer and read the measurement.

remove the micrometer and read the measurement. The inside micrometer is read in the same manner as an outside mike.

A depth micrometer is helpful when precisely measuring the depth of an opening. Look at **Figure 6-13B**. The base of the micrometer is positioned squarely on the part. Then, the thimble is turned until the spindle contacts the bottom of the opening. The depth micrometer is read in the same way as an outside micrometer. However, the hub markings are reversed.

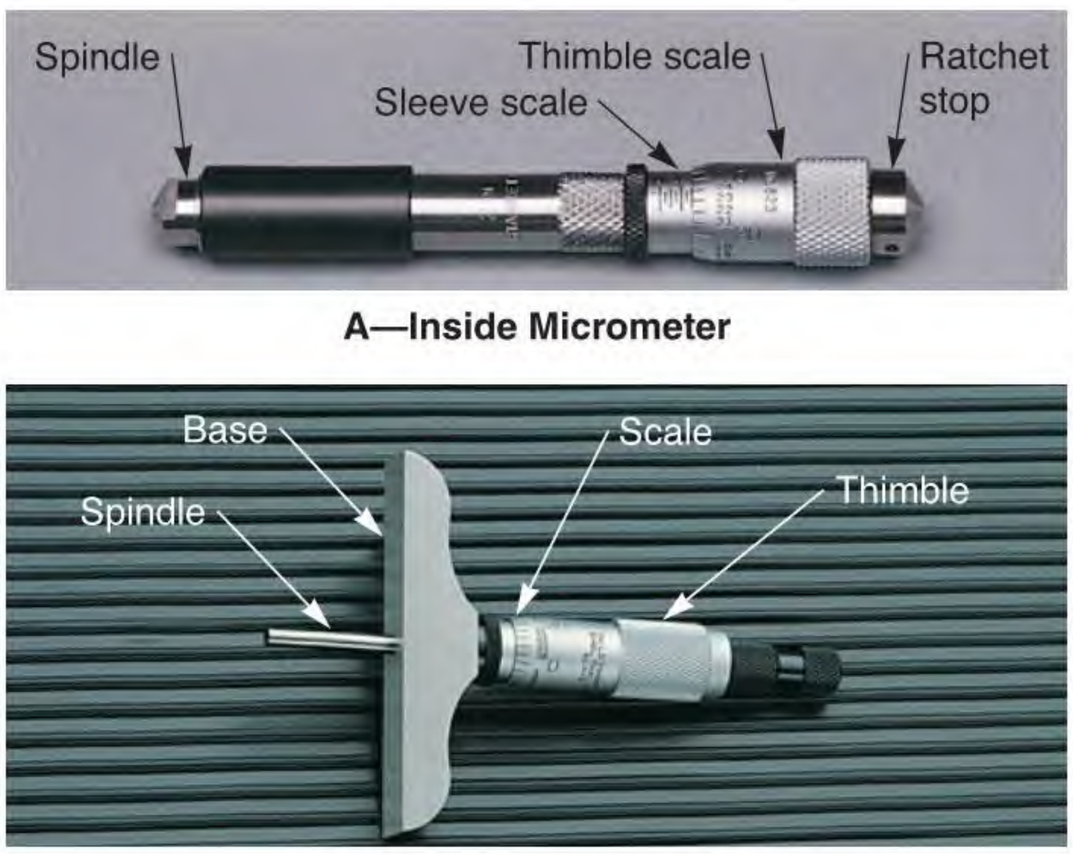
Reading a Customary Micrometer

To read a customary micrometer, follow the four steps listed below. Refer to **Figure 6-14**.



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Figure 6-12. A good way to check your skill and the accuracy of your micrometer is to measure a labeled flat feeler gauge. Compare your measurement to the one engraved in the blade.

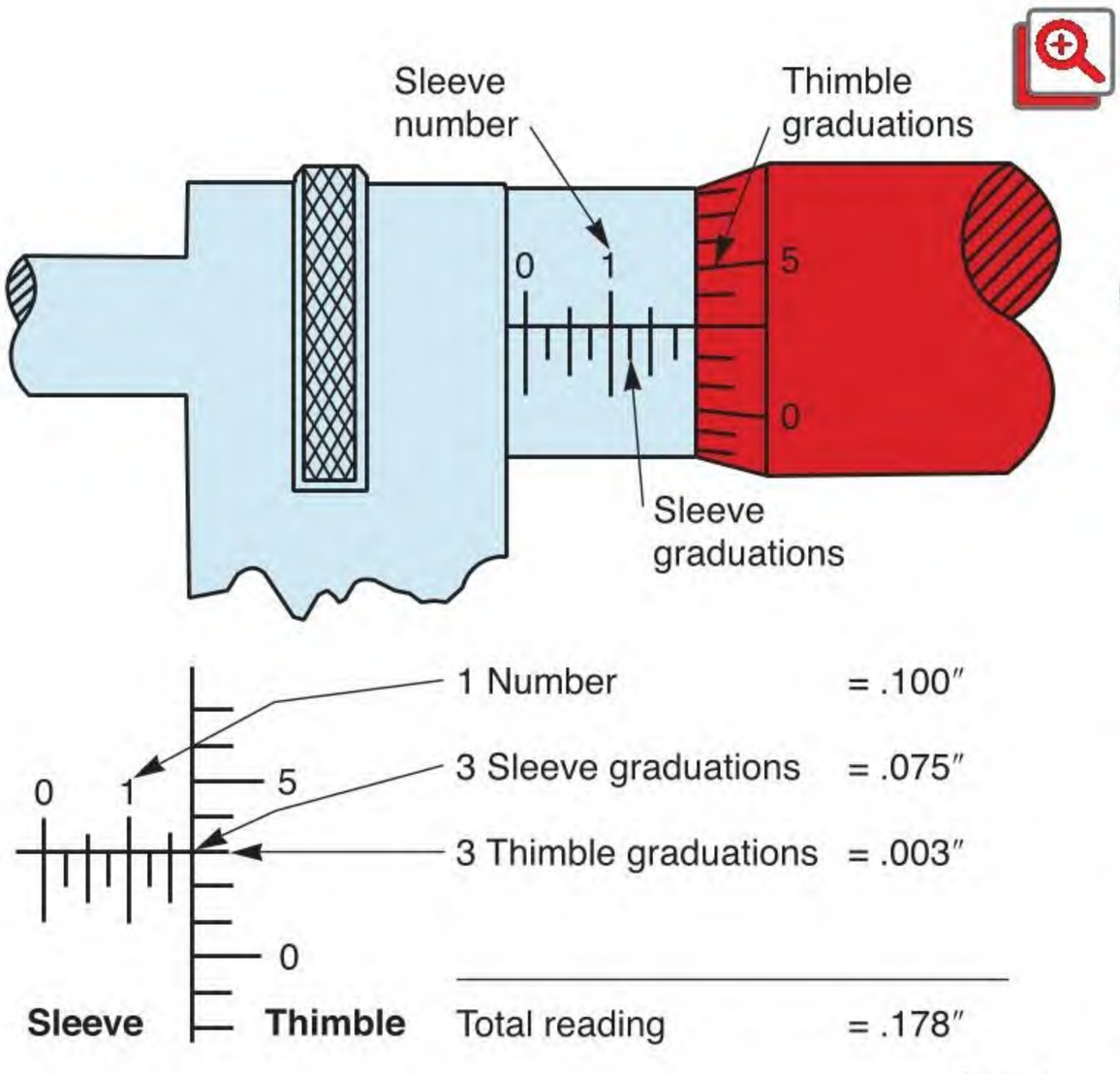


Starrett and Snap-on Tool Corp.

Figure 6-13. Compare the various types of micrometers.

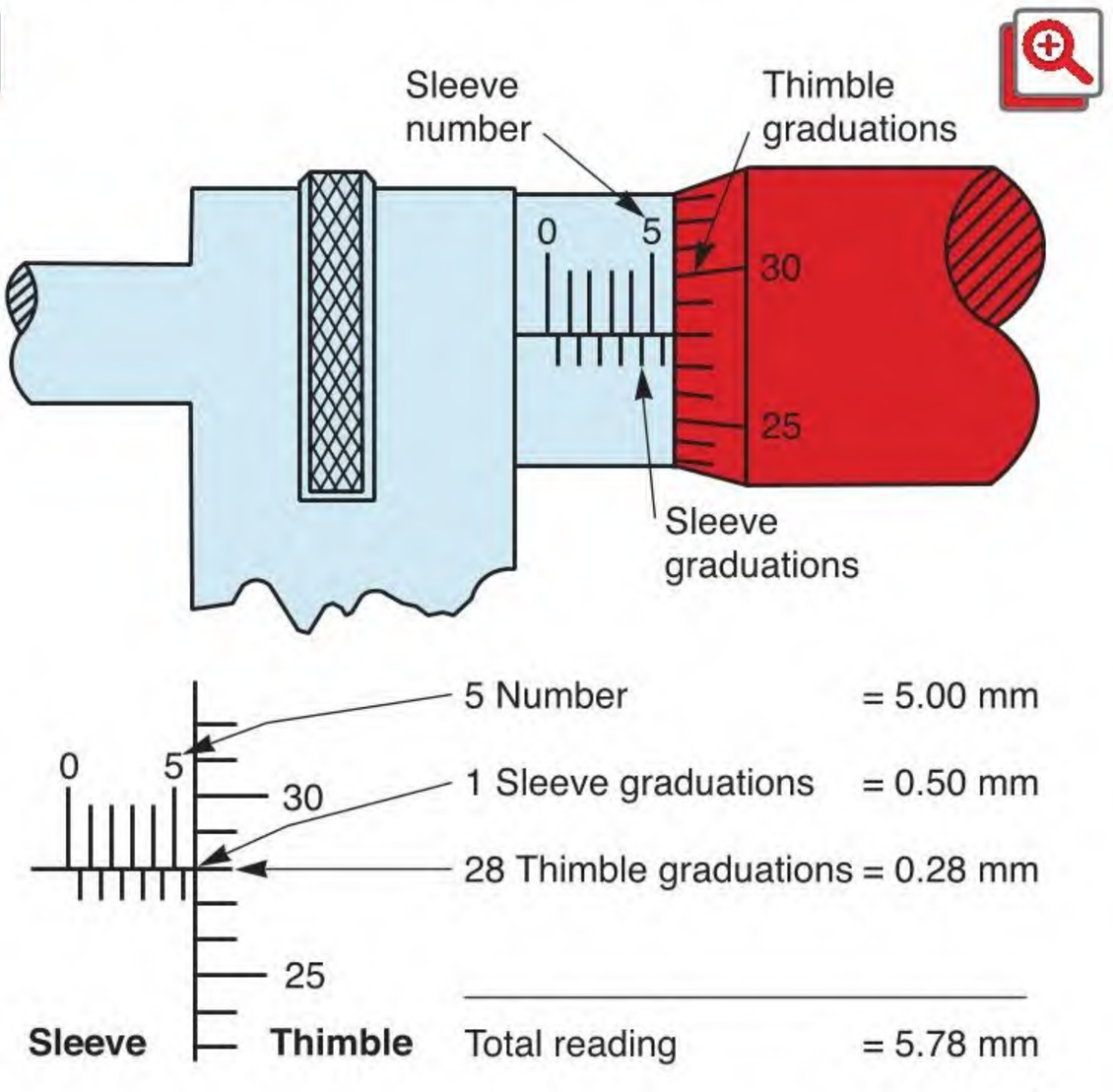
1. Note the largest number visible on the micrometer sleeve. Each number equals 0.100″ (2 = 0.200″, 3 = 0.300″, 4 = 0.400″).
2. Count the number of graduation lines to the right of the sleeve number. Each full sleeve graduation equals 0.025″ (2 full lines = 0.050″, 3 = 0.075″).
3. Note the thimble graduation aligned with the horizontal sleeve line. Each thimble graduation equals 0.001″ (2 thimble graduations = 0.002″, 3 = 0.003″). Round off when the sleeve line is not directly aligned with a thimble graduation.

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Starrett

Figure 6-14. To read a customary micrometer, read the sleeve number first. Then, read the sleeve graduations. Finally, read the thimble number. Add these three values to obtain the measurement in thousandths of an inch.



Starrett

Figure 6-15. A metric micrometer is read like a customary micrometer. However, metric values are used for the sleeve and thimble.

4. Add the decimal values from steps 1, 2, and 3. Also, add any full inches. This sum is the micrometer reading in inches.

Tech Tip

An easy way to practice using a micrometer is to measure the thickness of feeler gauge blades. Since the thickness is printed on the blades, you can read the mike and compare your results to the actual thickness of each blade.

Reading a Metric Micrometer

Metric micrometers are also available. They are similar to customary micrometers but have graduations and numbers in metric values. For example, one revolution of the thimble equals 0.500 mm. To read a metric micrometer, follow the four steps given below. Refer to **Figure 6-15**.

1. Read the largest number visible on the micrometer sleeve. Each number equals 1.00 mm (2 = 2.00 mm, 3 = 3.00 mm).
2. Count the number of graduation lines (both above and below the horizontal sleeve line) to the right of the sleeve number. Each full sleeve graduation equals 0.50 mm (2 = 1.00 mm, 3 = 1.50 mm).
3. Read the thimble graduation aligned with the horizontal sleeve line. Each thimble graduation equals 0.01 mm (2 = 0.02 mm, 3 = 0.03 mm).
4. Add the values from the steps 1, 2, and 3. This sum is the metric micrometer reading in millimeters.

Tech Tip

Technicians also purchase digital micrometers and digital calipers. Part size readings can be taken more easily and quickly without using math.

Measuring Tool Rules

A few important rules to remember include:

- Never drop or overtighten a micrometer or caliper. They are very delicate, and their accuracy can be thrown off easily.

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- Store micrometers, digital calipers, and other measuring tools where they cannot be damaged. Keep them in wooden or plastic storage boxes.
- Cradle the micrometer frame in the palm of your hand and turn the thimble with your thumb and fingers. The measuring faces should just drag on the part being measured.
- Hold the micrometer or caliper squarely with the work or false readings can result. Closely watch how the spindle or jaws are contacting the part.
- Rock or swivel the micrometer as it is touched on round parts. This will ensure the most accurate diameter measurement is obtained.
- Place a thin film of oil on the micrometer or caliper surfaces during storage. This will keep the tool from rusting.
- Always check the accuracy of a micrometer or caliper if it is dropped or struck, or after a long period of use. Standardized gauge blocks, available from your tool supplier, are used for checking micrometer accuracy.

Feeler Gauges

A ***feeler gauge*** is used to measure small clearances or gaps between parts. There are two basic types of feeler gauges: flat feeler gauges and wire feeler gauges. Both types are available in customary and metric versions.

A flat feeler gauge has precision-ground steel blades of various thicknesses, **Figure 6-16**. Thickness is written on each blade in thousandths of an inch and/or in hundredths of a millimeter. A flat feeler gauge is normally used to measure distances between parallel surfaces.

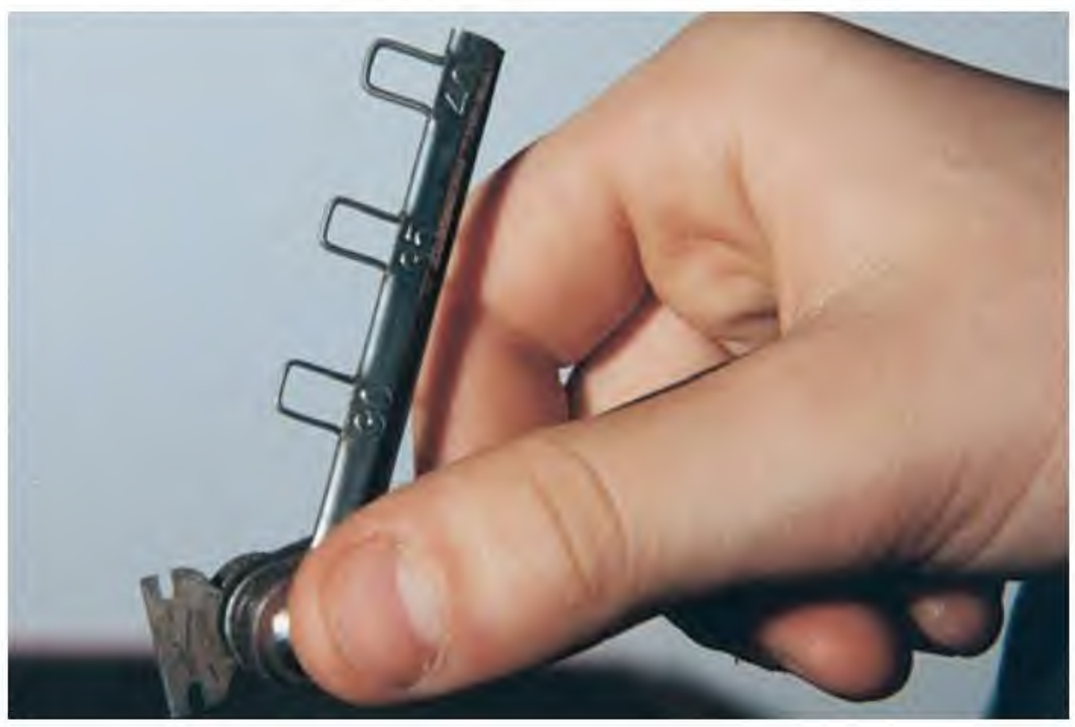
A wire feeler gauge has precise-size wires labeled by diameter or thickness. It is normally used to measure slightly larger spaces or gaps than a flat feeler gauge. A wire gauge is also used for measuring the distance between unparallel or curved surfaces.

Using a Feeler Gauge

To measure with either type feeler gauge, find the gauge blade or wire that just fits between the two parts being measured. The gauge should drag slightly when pulled between the two surfaces. The size given on the gauge is the clearance between the two components.



A



B

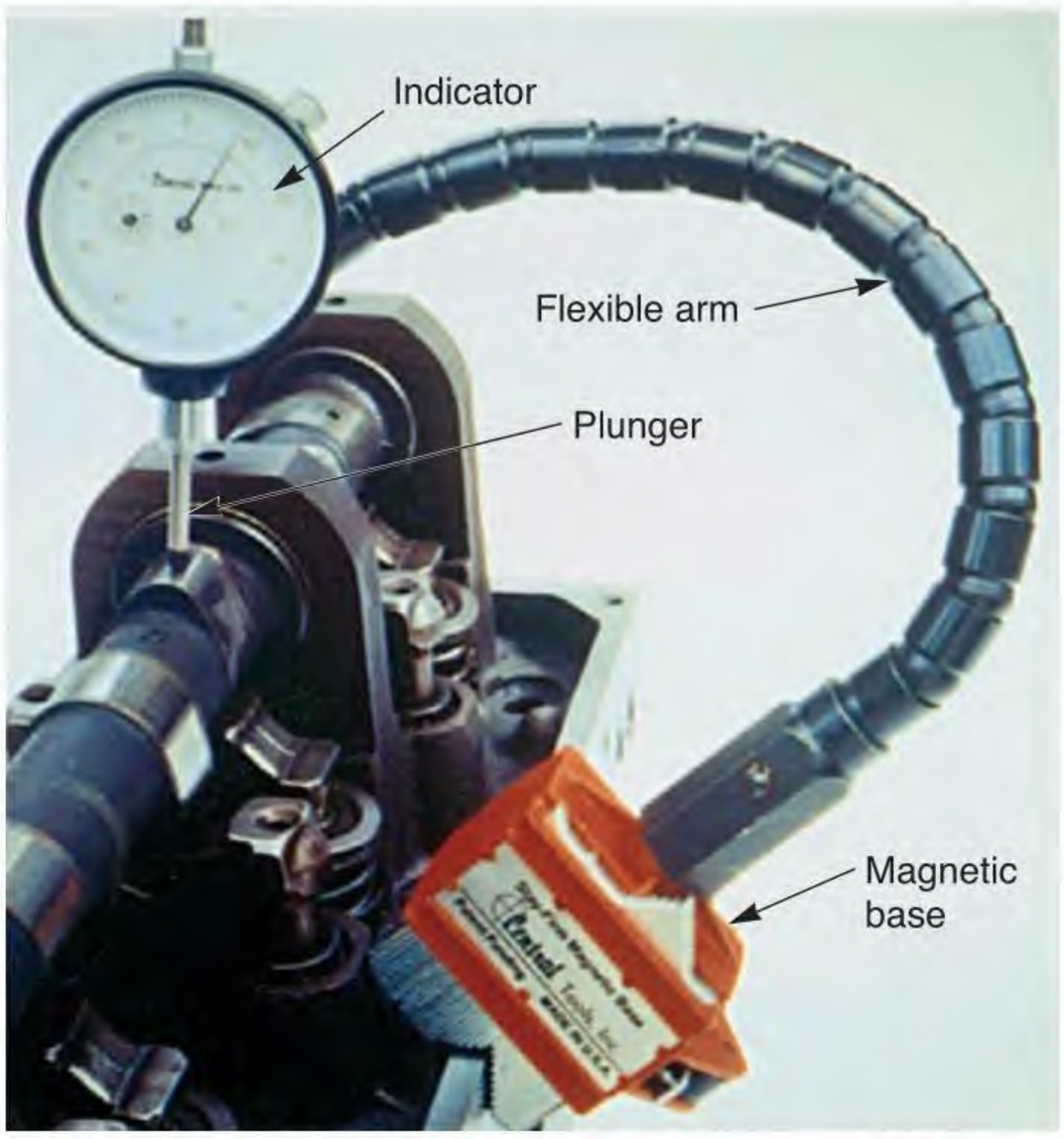
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Figure 6-16. Feeler gauge blades are slid between parts until a light drag or friction is felt. The size stamped on that steel blade is the measurement.

Dial Indicator

A ***dial indicator*** is used to measure part movement in thousandths of an inch (hundredths of a millimeter). The needle or digital display on the indicator face registers the amount of plunger movement. A dial indicator is frequently used to check gear teeth backlash (clearance), shaft end play, cam lobe lift, and similar kinds of part movements. A magnetic mounting base or clamp mechanism is normally used to secure the dial indicator to or near the work. Be careful not to damage a dial indicator. It is very delicate. See **Figure 6-17**.

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Central Tool Co.

Figure 6-17. A dial indicator is used when measuring part movement or out-of-round. In this example, the tool is set up to check height and wear of a camshaft lobe. The cam is rotated and the indicator reading is taken at different degrees of rotation. Measurements are then compared to camshaft specs to find wear.

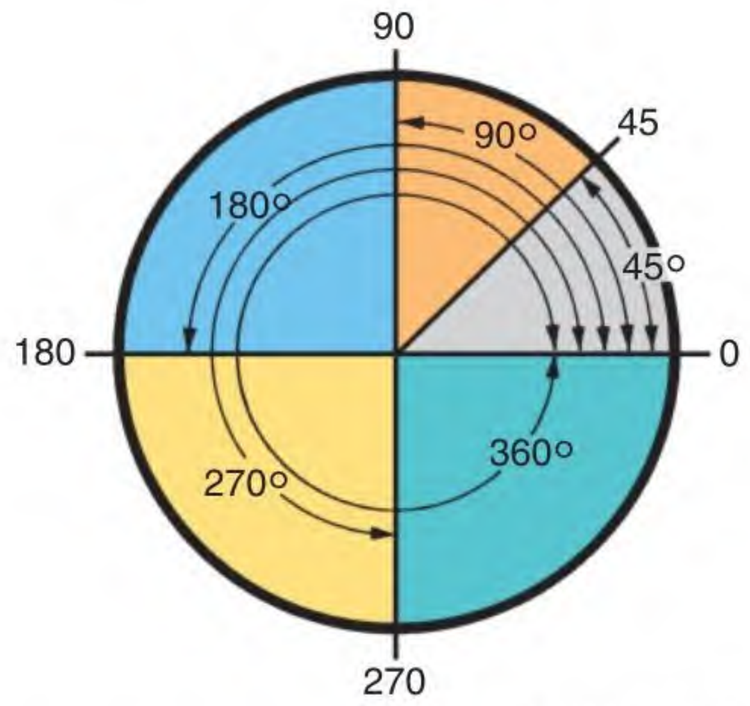
Using a Dial Indicator

To measure with a dial indicator, follow these basic rules:

1. Mount the indicator securely and position the dial plunger parallel with the movement to be measured.
2. Partially compress the indicator plunger before locking the indicator into place. This allows part movement in either direction to be measured.
3. Move the part back and forth or rotate the part while reading the indicator.
4. Subtract the lowest reading from the highest reading. The result equals the distance the part moved, the clearance, or the runout.

Other Measurements and Measuring Tools

A service technician may make other types of measurements and use other types of measuring tools than those discussed to the point. Some of these



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Figure 6-18. The amount of rotation and angles are measured in degrees with a full circle totaling 360°.

are discussed in the next sections. More specialized measurements are covered in later chapters.

Angle Measurement

A circle is divided into 360 equal parts called degrees, **Figure 6-18**. Degrees are abbreviated with "deg." or the degree symbol (°). One-half of a circle equals 180°, one-quarter of a circle equals 90°, and one-eighth of a circle equals 45°. Specifications are normally given in degrees when you are measuring rotation of a part or an angle formed by a part.

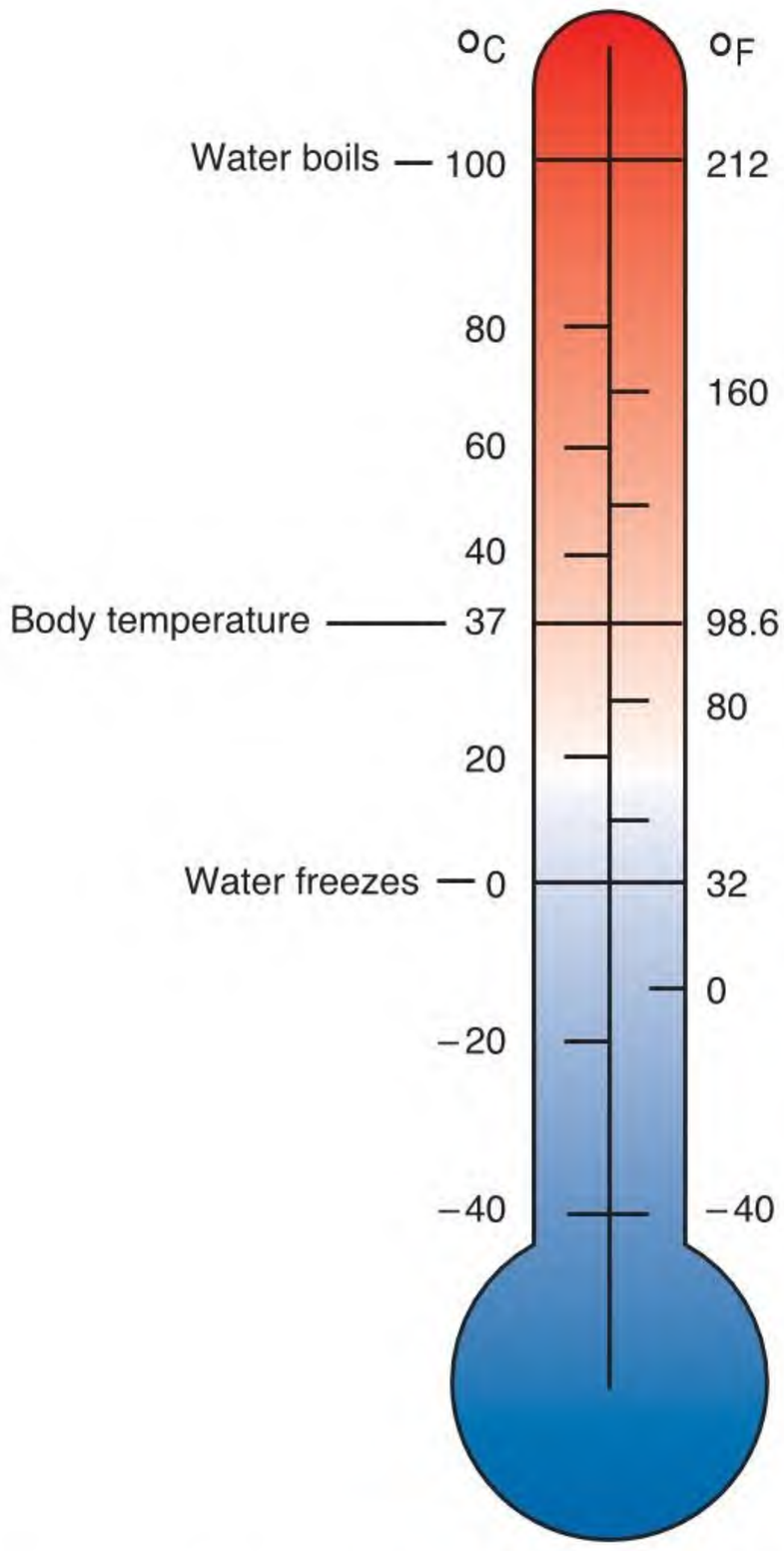
Temperature Measurement

Temperature gauges, or ***thermometers***, are used to measure temperature. For example, air conditioning output temperature or radiator temperature may need to be determined. The temperature obtained with the gauge can be compared to specifications. Then, if the temperature is too low or too high, you know that a repair or adjustment is needed. Temperature gauges are available that can read in either customary Fahrenheit (°F) or metric Celsius (°C), **Figure 6-19**.

Torque Wrenches

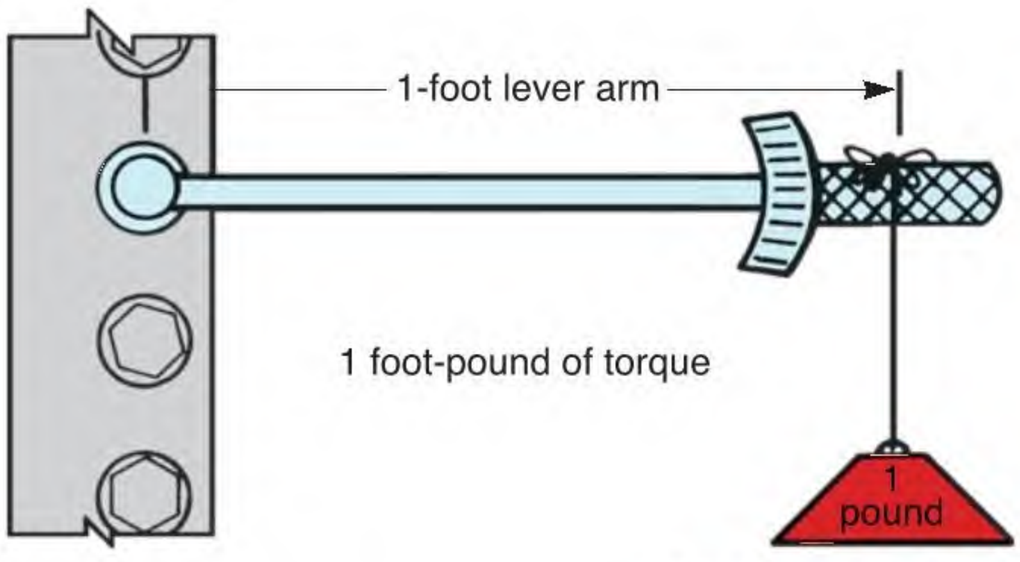
A ***torque wrench*** is not used for taking measurements. Rather, it is used to apply a specific amount of turning force to a fastener, such as a bolt or nut. A torque wrench uses the principle illustrated in **Figure 6-20**. Torque wrench scales usually read in foot-pounds (ft-lb) and Newton-meters (N•m). The four general types of torque wrenches are the flex bar, dial indicator, ratcheting, and digital types. These are shown in **Figure 6-21**.

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Figure 6-19. Note the relationship between customary Fahrenheit (°F) and metric Celsius (°C) temperature values.



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Figure 6-20. One foot-pound equals one pound of pull on a one-foot-long lever arm. This provides a means of measuring torque, or twisting motion.



A—Flex Bar Torque Wrench



B—Dial Indicator Torque Wrench



C—Ratcheting, or Snap-Type, Torque Wrench



D—Digital Torque Wrench

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Figure 6-21. Study different torque wrench types.

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Pressure Gauge

A ***pressure gauge*** is used to measure air or fluid pressure in various systems and components. For example, pressure gauges may be used to check tire air pressure, fuel pump pressure, air conditioning system pressure, or engine compression stroke pressure. Look at **Figure 6-22**. A pressure gauge normally reads in pounds per square inch (psi), kilograms per square centimeter (kg/cm^2), or kilopascals (kPa).

Vacuum Gauge

A ***vacuum gauge*** is used to measure negative pressure, or vacuum. It is similar to a pressure gauge. However, the vacuum gauge reads in inches of mercury (in/Hg) or metric kilograms per square centimeter (kg/cm^2). For example, a vacuum gauge is used to measure the vacuum in an engine's intake manifold. If the reading is low or fluctuating, it may indicate an engine problem.

Telescoping Gauge

A ***telescoping gauge*** is used to measure internal part bores or openings, **Figure 6-23A**. To use the gauge, compress the spring-loaded extensions and lock them with the thumb wheel. See **Figure 6-23B**.



A—Telescoping Gauge

B—Locked Telescoping Gauge

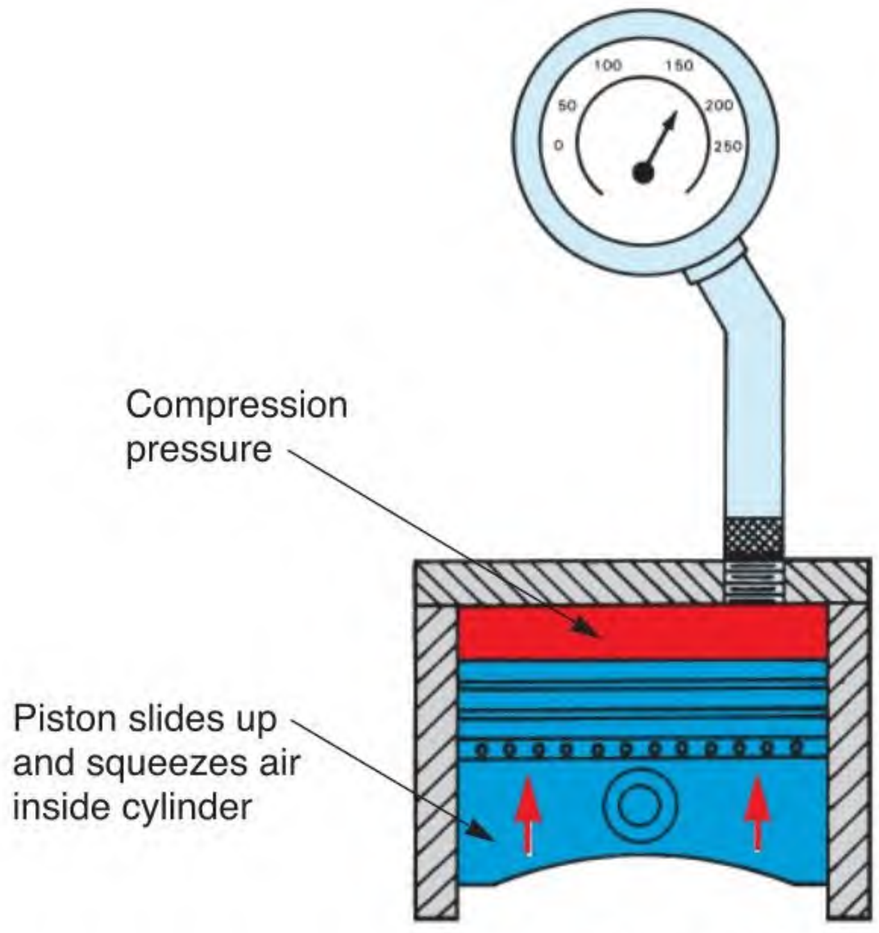
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Figure 6-23. Telescoping gauges measure internal part bores or openings.

Then, insert the gauge into the opening and release the thumb wheel. The extensions "snap" to the edges of the opening. Use the thumb wheel to lock the extensions to the size. Finally, use an outside micrometer to measure the distance across the extensions.

Hole Gauge

A ***hole gauge*** is used for measuring very small holes in parts. To use a hole gauge, first loosen the thumb wheel. Then, insert the gauge into the hole and tighten the thumb wheel until the gauge just touches the part. Finally, remove the gauge and measure it with an outside micrometer.



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Figure 6-22. A technician must frequently measure pressure. This example shows a gauge being used to measure the pressure developed during the engine compression stroke. If the pressure is not high enough, engine mechanical problems are indicated.

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Review of Shop Math

Automotive technicians often use mathematics during the service and repair of vehicles. Technicians must constantly work with whole numbers, fractions, and decimals.

Math skills are needed when working with specifications. For example, if you are working on an engine, you may need to measure piston diameter and cylinder diameter. By subtracting piston diameter from cylinder diameter, you would find piston clearance. This math must be done properly if the engine is to run normally after repairs. If your measurements or calculations are wrong, the engine could knock or lock up after improper repairs.

You will also use math when filling out work orders. You must calculate part prices, labor charges, tax percentage, and total charges.

Tech Tip

If you already have good math skills, skip this section of the chapter. If you need a review of math, study the following, especially the fraction/decimal summary.

Addition

Addition is the combining of two or more numbers to find the total quantity. The result of the addition process is called the sum or the total. A plus sign (+) is used to indicate that the numbers are to be added. Numbers to be added may be written two ways:

in a string: 5 + 3 + 4 = 12 *(sum)*

or

in a column:

$$\begin{array}{r} 5 \\ 3 \\ +\,4 \\ \hline 12 \end{array}$$ *(sum)*

When there are large numbers or a long series of numbers, it is best to write them in a column so sums of 10 and over can be carried to the next column. Always start adding from the right-hand column so sums exceeding 9 can be carried from that column to the next column to the left:

122 - - 2 *First, add the right-hand*
804 - - 4 *column.*
644 - - 4
+829 - - 9
19

1 *Since the total is 19,*
- 2 - *place the "9" under-*
- 0 - *neath the right-hand*
- 4 - *column and add the*
- 2 - *"1" to the next*
99 *column. Add up the 2nd column.*

1 - - *Now, add up the next*
8 - - *column to the left and*
6 - - *place the sum below*
8 - - *that column.*
2399 *(Answer is 2399)*

Addition is used in adding up the cost of parts and labor when preparing a customer's bill. If, for example, parts total $125, labor charges are $95, and tax is $8, the total bill would be $228.

Sample Problem 1—Addition

A vehicle's wheelbase is the distance from the centerline of the front wheels to the centerline of the rear wheels. One manufacturer's compact sedan has a wheelbase of 98″. The same manufacturer's full-size pickup truck has a wheelbase that is 47″ longer than that of its compact sedan. What is this truck's wheelbase?

To answer this question, you must add 47″ to the length of the compact sedan.

$$\begin{array}{r} 98'' \\ +\,47'' \\ \hline 145'' \end{array}$$

The wheelbase of the full size truck is 145″

Subtraction

Subtraction is taking away a certain quantity from another. The amount that is left after subtracting is called the remainder or the difference. The minus sign (–) indicates that the number to the right of it is to be subtracted. Subtraction problems might be written in two ways:

in a string: 495 – 125 = 370 *(remainder)*

or

in a column:

$$\begin{array}{r} 495 \\ -\,125 \\ \hline 370 \end{array}$$ *(remainder)*

Subtraction might be used in determining a customer's bill. It might also be used by the technician to check the deductions made on a paycheck for taxes and social security.

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Sample Problem 2—Subtraction

A customer's bill totals $253, but a $25 deposit had been paid before the work was started. How much will the customer have to pay when picking up the vehicle?

To determine the amount due from the customer, you would subtract the amount of the deposit ($25) from the total bill ($253).

$253 *Notice that we had to borrow 10 from the second*
−25 *column, since 5 cannot be subtracted from 3.*
$228

The amount due from the customer is $228

Sample Problem 3—Subtraction

Curb weight is the total weight of vehicle with a full tank of gas but no cargo or passengers. The curb weight of a late-model sedan is 1520 kb, and the gasoline in the tank weighs 49 kg. How much would this vehicle weigh if the fuel tank were empty?

To solve this problem, you must subtract weight of the gasoline in the tank (49 kg) from the curb weight of the vehicle (1520 kg).

1520 Kg
− 49 Kg
1471 Kg

The vehicle would weigh 1471 kg if the gas tank were empty.

Division

To find out how many times one number is contained in another, we use ***division***. The division sign (÷) indicates that one number is to be divided by another. The number being divided is called the dividend. The number a dividend is divided by is called the divisor. The answer is called the quotient. A division problem can be written one of three ways:

in a string: 860 ÷ 10 = 86 *(quotient)*

86 *(quotient)*
or: 10 ⟌860

or: 860/10 = 86 *(quotient)*

The technician must use division frequently in an automotive repair facility. For example, suppose that 10 fuel pumps had been ordered and placed in stock. The total bill for the pumps came to $860. What is the cost of each fuel pump?

The cost of each fuel pump is found by dividing $860 (total cost) by 10 (number of pumps). The cost of each pump is $86. This information would be used to determine what the customer would be charged for the pump.

When dividing, not all answers come out to full numbers. In such cases, a decimal point is placed to the right of the last number of the dividend. A decimal point is also placed in the answer directly above the decimal point in the dividend. One or more zeros may be added to the dividend, depending on how many places the decimal number must be carried out. For example, suppose that the cost of the fuel pumps in the previous example came to $865 instead of $860.

86.50 *(quotient—each pump costs $86.50)*
10 ⟌865.00
80
65
60
50
50
0

Sample Problem 4–Division

A 140 cubic inch engine is rated at 308 horsepower. How much horsepower is generated per cubic inch in this engine?

To find the answer, you must divide the total horsepower rating of the engine by the number in cubic inches.

140 cubic inch/308 hp = 2.2 hp

2.20
140 ⟌308.00
280
28.0
28.0
0

The engine in this example puts out 2.2 horsepower per cubic inch.

Multiplication

Multiplication is a shortcut for adding the same number over and over. Suppose that the number 15 were to be added 12 times: One could set up the problem as 15 + 15 + 15 + 15 + 15..., until there were 12 additions. It is faster, however, to multiply 15 by 12 once. The multiplication sign (×) indicates that numbers are to be multiplied. The number by which another number is multiplied is called the multiplier.

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The result of multiplication is called the product. Multiplication problems can be written two ways:

in a string: $15 \times 12 = 180$ *(product)*
or
in a column:
$$\begin{array}{r} 15 \\ \times\, 12 \\ \hline 180 \end{array}$$ *(product)*

Sample Problem 5—Multiplication

A customer purchased four new tires at a cost of $104 each. What is the total cost for all four tires?

To solve this problem, you must multiply $104 by 4.

$$\begin{array}{r} 104 \\ \times\, 4 \\ \hline 416 \end{array}$$

The price for four tires would be $416.

Numbers of more than one digit used as multipliers are multiplied one digit at a time. The products for each multiplication are stacked and then added together. Suppose that the customer in the previous example purchased 41 tires at $104 each.

$$\begin{array}{r} 104 \\ \times\, 41 \\ \hline 104 \\ 416_ \\ \hline 4264 \end{array}$$ *(product)*

Note that the second product (416) is shifted one column to the left. This is done because the multiplier is actually 40, not 4. To help make this clear, mentally place a 0 after the 6 in the second product ($104 \times 40 = 4160$).

Sample Problem 6—Multiplication

A shop orders 25 batteries that weigh 35 lb each. To determine shipping costs, the total weight of the batteries must be calculated.

To calculate the total weight, you multiply the weight of one battery (35 lb) by 25.

$$\begin{array}{r} 35 \text{ lb} \\ \times\, 25 \\ \hline 175 \\ 70_ \\ \hline 875 \text{ lb} \end{array}$$ *(product)*

The total weight of the batteries is 875 lb.

Fractions and Decimal Fractions

Fractions and decimal fractions are used to represent a portion of a whole number. Fractions are written as two numbers, one over the other or one beside the other:

$\frac{4}{5}$ or $4/5$ *(The fraction is read as "four-fifths.")*

The number below the line or after the slash is called the denominator. This number tells how many parts the whole is divided into; the number above the line or ahead of the slash tells how many parts are present in the fraction. This number is called the numerator. When reading a fraction, the top or first number is always read first; thus, read 12/32 as "twelve thirty-seconds."

Decimal fractions also have a numerator and denominator. The denominator is always a multiple of 10. However, it is never written. A dot or period, called a decimal point, is used in its place. For example, 9/10 is written as 0.9 in decimal notation. The number of digits to the right of the decimal point tells what multiple of 10 the denominator is. Thus:

0.9 is 9/10 *(nine-tenths)*
0.09 is 9/100 *(nine-hundredths)*
0.009 is 9/1000 *(nine-thousandths)*
0.0009 is 9/10,000 *(nine ten-thousandths)*

Since decimal fractions are easier to work with than fractions, it is common to convert fractions to decimal fractions. This is especially true in the automotive service field. Very small measurements are given in thousandths of an inch. However, wrenches are still sized in fractions.

Decimal fractions are used for fine measurements, such as the exact size of machined engine parts. Often, the technician must use a micrometer to check a dimension, such as the diameter of a crankshaft journal or the runout on the thickness of a brake rotor. Decimal fractions can be added, subtracted, multiplied, and divided in the same manner as whole numbers.

There are rules that must be remembered when working with decimal numbers. The first set of rules has to do with placement of zeros.

- A zero placed between a number and a decimal point changes the value of the number by a factor of ten (.45 is not the same as .045).
- A zero placed at the end of a decimal number does not change the value of the number. (.45 is the same as .450).

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- A zero placed at the very front of a decimal number does not change the value of the decimal number (.45 is the same as 0.45).

Addition and Subtraction of Decimals

The rules for addition and subtraction of decimal fractions are:

- Line up the decimal points in a column.
- The decimal point in the answer must be in the same position as the decimal point in the column.
- Since some decimal fractions will have more numbers to the right or left of the decimal point than others, you may fill in the ends of the shorter numbers with zeros. This is optional.

Example:		*could also be written with zeros in the blanks*	
	1.5		1.500
	9.356		9.356
	3.62		3.620
	.96		0.960
	15.436		15.436

Sample Problem 7—Adding Decimal Numbers

During the engine rebuilding process, worn cylinders are sometimes bored (machined) to a larger diameter. During the boring process, a thin layer of material is cut from the cylinder, increasing the cylinder's diameter. If a cylinder with an initial diameter of 91.44 mm is bored 0.76 mm oversize, what is the final diameter of the cylinder?

To solve this problem, you must add the oversize dimension to the initial piston diameter.

```
  91.44
+ 0.76
  92.20
```

The final diameter of the cylinder is 92.20 mm

Sample Problem 8—Subtracting Decimal Numbers

Piston-to-cylinder wall clearance is calculated by subtracting the diameter of the piston from the diameter of the cylinder. If the piston's diameter is 3.625″ and the cylinder's diameter is 3.628″, what is the piston-to-wall clearance?

```
  3.628
- 3.625
  0.003
```

Piston to cylinder wall clearance equals 0.003″

Multiplication and Division of Decimals

Multiplying decimal numbers is not much different from multiplying whole numbers. The rules explain how to deal with the decimal point.

- In setting up the problem, the decimal points do not need to be aligned.
- Multiply the two numbers, ignoring the decimal points.
- Count the total number of digits (places) to the right of the decimal points of both numbers. Starting from the right-hand digit, count to the left the same number of digits in the answer. Place the decimal point to the left of the last digit counted.

  Suppose you wanted to multiply 3.23 by 2.6.

  3.23 *(two numbers to the right of the decimal point)*
  × 2.6 *(one number to the right of the decimal point)*
  1938
  646
  8.398 *(total of 3 numbers to the right of the decimal point)*

Dividing decimals is also similar to dividing whole numbers. Several steps are involved.

- If neither the dividend nor divisor contain decimal points, but the division does not come out even:

  Place a decimal point to the right of the last number of the dividend. Add one or more zeros after the decimal and continue dividing to the number of decimal places necessary.

```
For example: 7/54.00    7.71   division carried out two decimal places
                       49
                       50
                       49
                        10
                         7
                         3
```

- When the dividend has a decimal and the divisor does not:

  Divide as usual.

  Place a decimal point in the answer directly above the decimal point in the dividend.

```
For example: 25/50.25   2.01
                       50
                        02
                         0
                        25
                        25
                         0
```

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- When the divisor has a decimal point:

  If the dividend does not have a decimal point, add one at the far right.

  If the dividend has a decimal point, move it one place to the right for each decimal place in the divisor. Move the decimal point in the divisor accordingly to the right. Use zeros as place holders, if necessary.

  Divide as usual.

  Place a decimal point in the answer directly above the relocated decimal point in the dividend.

For example: $2.5\overline{)50.25}$

$$\begin{array}{r} 20.1 \\ 25.\overline{)502.5} \\ \underline{50} \\ 02 \\ \underline{0} \\ 25 \\ \underline{25} \\ 0 \end{array}$$

Sample Problem 9—Multiplying Decimal Numbers

If each cylinder in a six-cylinder engine has a displacement of 0.5 liters, what is the total engine displacement?

To solve this problem, you should multiply the displacement for one cylinder by the number of cylinders in the engine.

$$\begin{array}{r} 0.5 \\ \times 6 \\ \hline 3.0 \end{array}$$

The total engine displacement is 3.0 liters.

Sample Problem 10—Dividing Decimal Numbers

A 2.5 liter engine is rated at 175 horsepower. How much horsepower is generated per liter in this engine?

To solve this problem, you must divide the total horsepower rating of the engine (175) by the number of liters (2.5).

$$\begin{array}{r} 70 \\ 2.5\overline{)175} \\ -\underline{175} \\ 0 \end{array}$$

The engine is this example puts out 70 horsepower per liter.

Percentages

Percentages are quantities expressed as a part of 100. For example, ten percent (10%) is equal to 10 out of every 100. Seventy five percent (75%) is equal to 75 out of every 100, and one hundred percent (100%) is equal to 100 out of 100. Percentage is commonly used to calculate tax on parts.

To find a percentage of any number, you must first convert the percentage to decimal format. This is done by dropping the percentage sign and moving the decimal point two places to the left. For example, 5% = 0.05 and 50% = 0.5. Once the percentage is in decimal format, this decimal can be multiplied by the number you wish to find the percentage of. For example, suppose you want to know what 65% of 50 is. You would begin by converting 65% to a decimal. 65% expressed as a decimal is 0.65. Next, you would multiply 0.65 by 50.

$0.65 \times 50 = 32.5$

65% of 50 is 32.5

Sample Problem 11—Calculating Percentage

A tire's recommended inflation pressure is 35 pounds per square inch (psi). If the tire is inflated to 80% of the recommended pressure, how much pressure is in the tire?

To solve this problem, you must first express 80% as a decimal.

80% = 0.80

Next, you must multiply this number by the recommended tire pressure.

0.80×35 psi = 28 psi

The tire is inflated to 28 psi.

For example, if a part costs $100 and sales tax is 7%, you can determine the amount of tax that will be charged on the part by calculating 7% of $100.

7% of $100 = $0.07 \times \$100 = \$7$

You can then add $7 to the $100 to determine the cost of the part including tax.

You may find it necessary to determine the percentage variation between two or more numbers. For example, specifications may require that certain numbers not vary by more than 5%. One way to determine this is to add the specified percentage to 100% and then covert this number to a decimal. For example, if the specified percentage was 5%, you would add 5% and 100% to arrive at 105%. Converting this to a decimal would give you 1.05. Next, multiply 1.05 by the

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lowest number and compare the new number (lowest value × 105%) to the highest value. If the new number is greater than or equal to the highest value, the variation between these readings is equal to or less than specified percentage. If the new number is less than the highest number, the variation between the numbers is greater than the specified percentage.

Sample Problem 12—Percentage Variation

If the compression test on an engine results in readings of 150 psi, 146 psi, 145 psi, and 130 psi, and the manufacturer specifies that there be no more than 10% variation between readings, does this engine pass its compression test?

Begin by calculating 10% of 130

$130 \times 10\% = 130 \times 0.1 = 13$

Add the product of the previous calculation (13) to the lowest value (130)

$130 + 13 = 143$

Compare the result of previous step (143) to the highest reading (150 psi)

Since 143 is less than 150, the variation between 150 psi and 130 psi is greater than 10%.

Ratios

A ratio is a mathematic expression comparing two numbers. It represents how many of one item there is compared to another. A ratio of 2 to 1 can be written as 2:1 or 2/1. This means that for every 2 of one item, there is one of a second item. For example, if the ratio of red cars on the road to blue cars on the road is 2:1, there are twice as many red cars on the road as there are blue ones. Notice that the ratio does not tell you how many red cars are on the road, just that there are twice as many.

Ratios are commonly used when expressing the relationship between gears. For example, if two gears have a ratio of 3:1, one gear would turn three revolutions to only one revolution for the other gear.



Workplace Skills

When working as an automotive technician, you will frequently have to take or use measurements. If your measurements are not within factory tolerances (acceptable ranges or limits), you know that the part requires repair, replacement, or adjustment. When working, remember that measuring tools are very delicate. Measuring tools can be damaged and knocked out of calibration by being dropped on the shop floor. Handle measuring tools carefully and never drop them!

Summary

- As a vehicle is driven, its moving parts slowly wear out. With enough part wear, mechanical failures and performance problems result.
- Auto manufacturers give "specs," or specifications, for maximum wear limits and dimensions of parts.
- Our customary measuring system originated from sizes taken from parts of the human body.
- Conversion between units in the metric (SI) measuring system is based on a power of ten.
- A steel rule, also called scale, is frequently used to make low-precision linear measurements.
- A vernier caliper is a sliding caliper with a dial gauge or digital readout attached.
- A micrometer, nicknamed a "mike," is commonly used when making very accurate measurements.
- Never drop or overtighten a micrometer. It is very delicate and its accuracy can be thrown off easily.
- A feeler gauge is used to measure small clearances or gaps between parts.
- Dial indicator will measure part movement in thousandths of an inch (hundredths of a millimeter).
- A torque wrench measures the amount of turning force applied to a fastener.
- A pressure gauge is frequently used in the auto shop to measure air or fluid pressure in various systems and components.
- Automotive technicians use mathematics during servicing and repair of vehicles and when filling out work orders for billing customers.

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Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

addition
combination square
conversion chart
customary measuring system
customary rule
decimal conversion chart
dial indicator
division
feeler gauge
hole gauge
measuring system
meterstick
metric (SI) measuring system
metric rule
micrometer
multiplication
pocket rule
pressure gauge
scale
steel rule
subtraction
tape measure
telescoping gauge
thermometer
torque wrench
vacuum gauge
vernier caliper
yardstick

Activities

1. Demonstrate the proper reading of a dial indicator.
2. Practice using a micrometer to measure a set of feeler gauges supplied by your instructor.
3. Demonstrate to the class the use of a wire feeler gauge to measure the gaps of spark plugs.
4. Use the Internet to calculate the cost of a basic set of measuring tools.

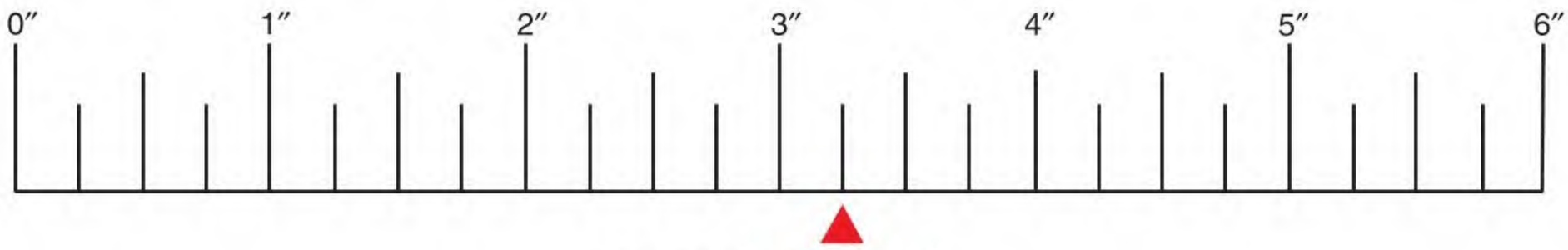
Review Questions

Answer the following questions using the information provided in this chapter.

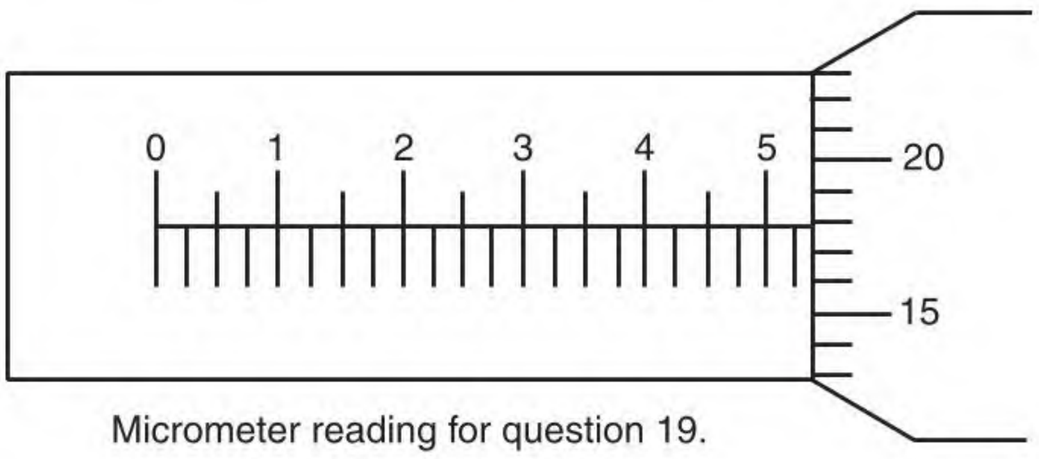
1. The two measuring systems are the _____ measuring system and the _____ measuring system.
2. Parts of the human body are used as the basis for the customary measuring system. True or False?
3. The metric system uses a power of 16 for all basic units. True or False?
4. Which of the following is a metric value?
   (A) Mile.
   (B) Psi.
   (C) Millimeter.
   (D) Inch.
5. What is a measuring system conversion chart?
6. An automotive piston's connecting rod is 8″ long. What is the approximate length of this connecting rod in millimeters?
   (A) 42 mm.
   (B) 173.6 mm.
   (C) 203.2 mm.
   (D) 307.8 mm.
7. A decimal system conversion chart is used to find equal values for _____, _____, and _____.
8. Which of the following is a special micrometer used in auto technology?
   (A) Inside micrometer.
   (B) Depth micrometer.
   (C) Width micrometer.
   (D) Both A and B.
9. Describe the four steps for reading a customary outside micrometer.
10. Describe the four steps for reading a metric outside micrometer.
11. Describe the differences between a flat feeler gauge and a wire feeler gauge.
12. A dial indicator will measure part _____ in thousandths of an inch or _____ of a millimeter.
13. List the four basic rules for measuring with a dial indicator.
14. For measuring purposes, the circle is divided into 720 degrees. True or False?
15. The four types of torque wrenches are the _____, _____, _____, and _____.

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16. Which of the following instruments measures in pounds per square inch (psi)?
    (A) Pressure gauge.
    (B) Flat feeler gauge.
    (C) Depth micrometer.
    (D) Combination square.
17. Explain the use of a vacuum gauge.
18. Note the inch rule below and give the measurement by full inches and fractions of an inch.
19. Give the micrometer reading for the micrometer scale shown below.
20. When using a vacuum gauge, Technician A states that the gauge reads in inches of mercury. Technician B says that the gauge reads in kilograms per square centimeter. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
21. If a cylinder with an initial diameter of 3.63″ is machined 0.030″ oversize, what is the final diameter of the cylinder?
22. A technician has spacer shims of the following thicknesses: 0.050 mm, 0.003 mm, and 0.010 mm. If these shims are stacked together, what is the thickness of the stack?
23. The load carrying capacity of a tire varies with the amount of air pressure in the tire. A specific tire's load carrying capacity is 1949 lb at 32 psi. At 26 psi, the tire's capacity is 196 lb less than it was at 32 psi. What is the tire's load carrying capacity at 26 psi?
24. A tire's usable tread depth is calculated by subtracting tread depth at which tire is considered worn out (1.59 mm) from the tread depth of the tire when new. If a new tire has a tread depth of 9.94 mm, what is the tire's usable tread depth?
25. One manufacturer's hybrid vehicle contains a high-voltage battery made up of 38 battery packs that produce 7.4 volts each. What is the total voltage produced by this battery?
26. An average vehicle is driven 24,000 kilometers each year. How many kilometers is an average vehicle driven in 6 years?
27. If a vehicle averaged 30 miles per gallon on a 750 mile trip, how many gallons of fuel were used on the trip?
28. If a 2.7-liter engine produces 325 horsepower, how much horsepower does the engine produce per liter?
29. Which of the following is the decimal equivalent of 35%?
    (A) 0.035
    (B) 0.35
    (C) 1.35
    (D) 3.5



Inch rule for question 18.



Micrometer reading for question 19.

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ASE-Type Questions

1. "Specs" are:
   (A) dimensions of parts.
   (B) maximum wear limits of parts.
   (C) provided by the manufacturer.
   (D) All of the above.
2. Technician A says the customary measuring system originated from sizes taken from parts of the human body. Technician B says customary units were derived from the landscape. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. Volume can be measured in each of these *except:*
   (A) liters.
   (B) quarts.
   (C) kilopascals.
   (D) cubic inches.
4. A decimal conversion chart is typically accurate to the nearest:
   (A) 1/16 of an inch.
   (B) 1/64 of an inch.
   (C) inch.
   (D) foot.
5. Which of the following is used to make high-precision measurements?
   (A) Steel rule.
   (B) Pocket scale.
   (C) Vernier caliper.
   (D) Combination square.
6. Which of the following measuring devices has an attached dial gauge or digital readout that makes measurements easier to read?
   (A) Divider.
   (B) Vernier caliper.
   (C) Pocket rule.
   (D) Combination square.
7. Each number on the sleeve of a customary micrometer equals:
   (A) 0.100″
   (B) 0.200″
   (C) 0.300″
   (D) 0.400″
8. Which of the following is *not* a good rule to remember when using a micrometer?
   (A) Never drop or overtighten a micrometer.
   (B) Hold the micrometer squarely with the work.
   (C) Grasp frame with fingers and turn the thimble with your palm.
   (D) Put a little oil on a micrometer when in storage.
9. Which type of gauge is used to measure the distance between unparallel or curved surfaces?
   (A) Flat feeler gauge.
   (B) Wire feeler gauge.
   (C) Telescoping gauge.
   (D) Spring gauge.
10. A dial indicator measures part movement in:
   (A) kilopascals.
   (B) millimeters.
   (C) hundredths of an inch.
   (D) thousandths of an inch.

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Chapter 7
Service Information and Work Orders

After studying this chapter, you will be able to:

- Describe the different types of service information.
- Explain the different kinds of information and illustrations used in service information.
- Describe the advantages of an online service information program.
- Understand the use and calculation of shop work orders.
- Order parts needed for vehicle repair.
- Correctly answer ASE certification test questions concerning service information.

Modern vehicles contain thousands of parts and hundreds of large assemblies. Most of these parts are assembled to close tolerances (exacting measurement standards). They constantly require you to follow intricate procedures during repairs. Often, a technician needs specific technical information to properly diagnose or troubleshoot hard to find vehicle problems. In these cases, you must refer to service information. Service information is one of the technicians' most important tools.

Service Information

Service information details how to diagnose and repair a vehicle. It may consist of step-by-step procedures, specifications, diagrams, exploded part illustrations, troubleshooting charts, descriptions of common problems for specific vehicle makes and models, and other useful information. Service information is written in a concise technical language. It is intended to be used by well-trained technicians who are already familiar with the technical language.

In the past, most service information was available in the form of printed service manuals. These manuals were used to look up procedures, diagnosis charts, specifications, illustrations, wiring diagrams, and other repair information. Today, computer-based service information is used in most shops. See **Figure 7-1**. Computer-based service information is defined as data stored on a hard drive, CD-ROM, or DVD, or accessed via the Internet.

Vehicle manufacturers host databases that provide their dealership service facilities 24/7 online access to accurate, up-to-date diagnosis, repair, and maintenance information. Additionally, online service information providers such as Identifix, Mitchell, and AllData compile service and repair information for thousands of vehicles and make this information available to independent repair facilities via the Internet. The information provided by these companies is

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OTC/SPX Corp.

Figure 7-1. A computer is now a commonly used tool of many technicians and service managers.

commonly offered on a subscription basis and often includes OEM service information, factory-correct wiring diagrams, part illustrations, diagnostic flowcharts, factory part numbers, component location lists (with illustrations showing the component's exact location on the vehicle), and technical service bulletins (TSBs).

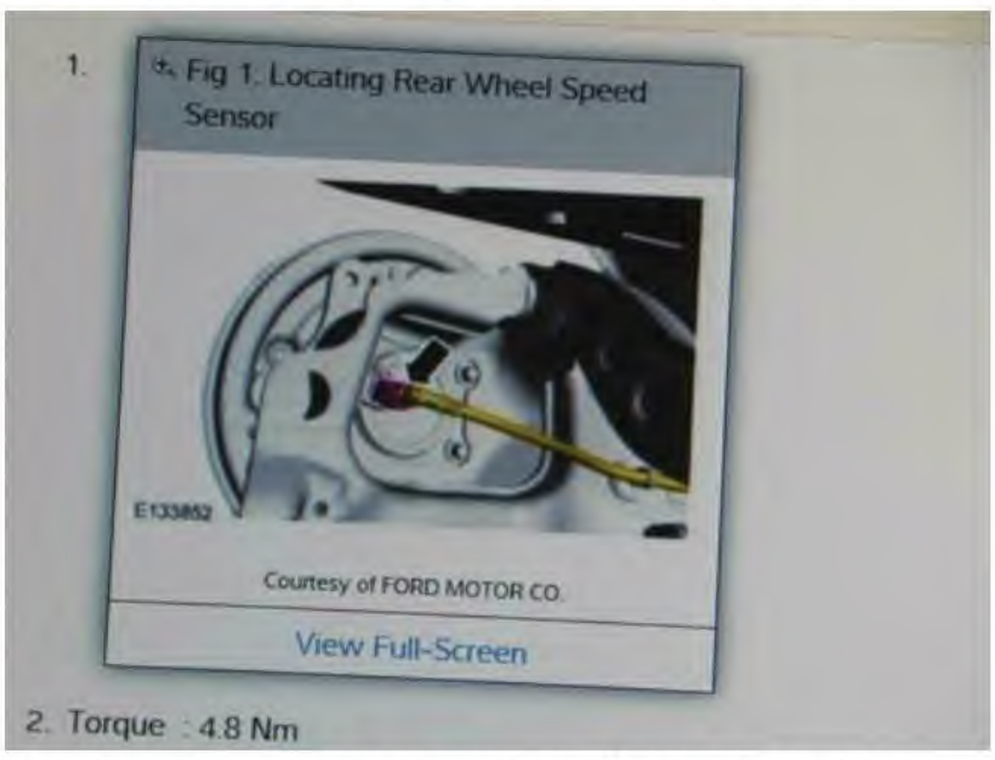
Some online service information providers also offer a library of tech articles, hyperlinks to related information, and access to up-to-date diagnostic trouble codes (DTC). All this information is presented in an easily searchable format that is intuitive, fast, and functional. Additionally, many systems generate accurate quotes on mechanical repairs using original equipment parts and industry-accepted labor information. Unlike a printed product, online service information can be instantaneously updated by the provider. Refer to **Figure 7-2**.



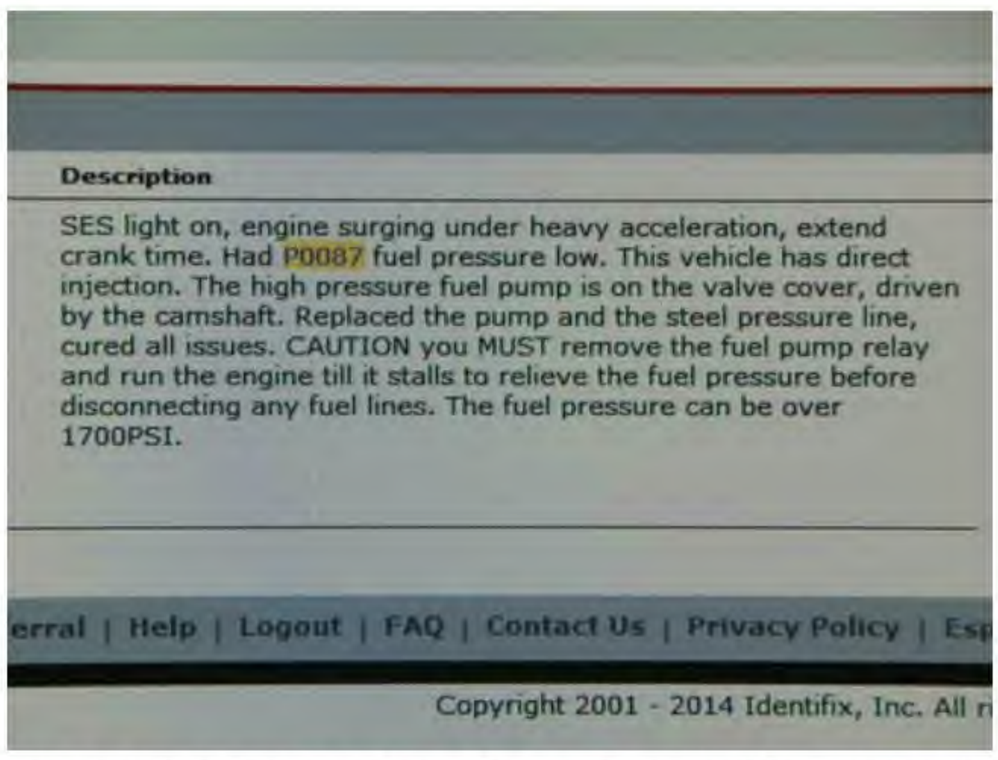
A—Buttons along top of screen allow the technician to navigate to the desired information. In this program, the technician can access service manuals, search for descriptions of actual repairs, review recommended maintenance schedules, and prepare a quote.



B—To search for common problems and fixes, simply type a description of the problem into the search box and hit the search button.



C—Illustrations can help you identify parts for repair or replacement.



D—This detailed repair description was posted by a technician who fixed a vehicle that had a P0087 trouble code and specific symptoms.

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Figure 7-2. Most computer-based service information systems make use of intuitive navigation features, allowing the technician to find the information they need quickly and easily.

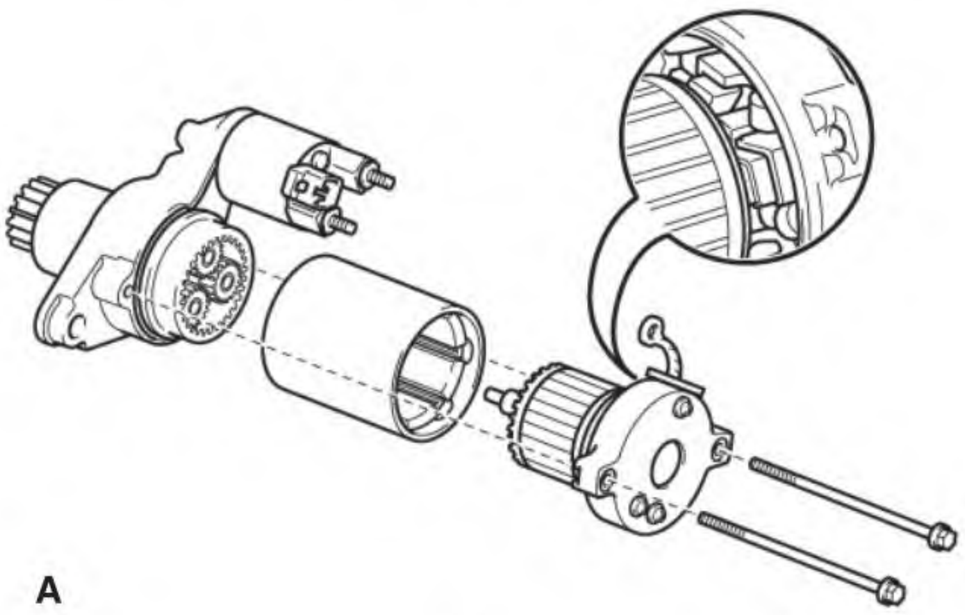
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Service Information Illustrations and Diagrams

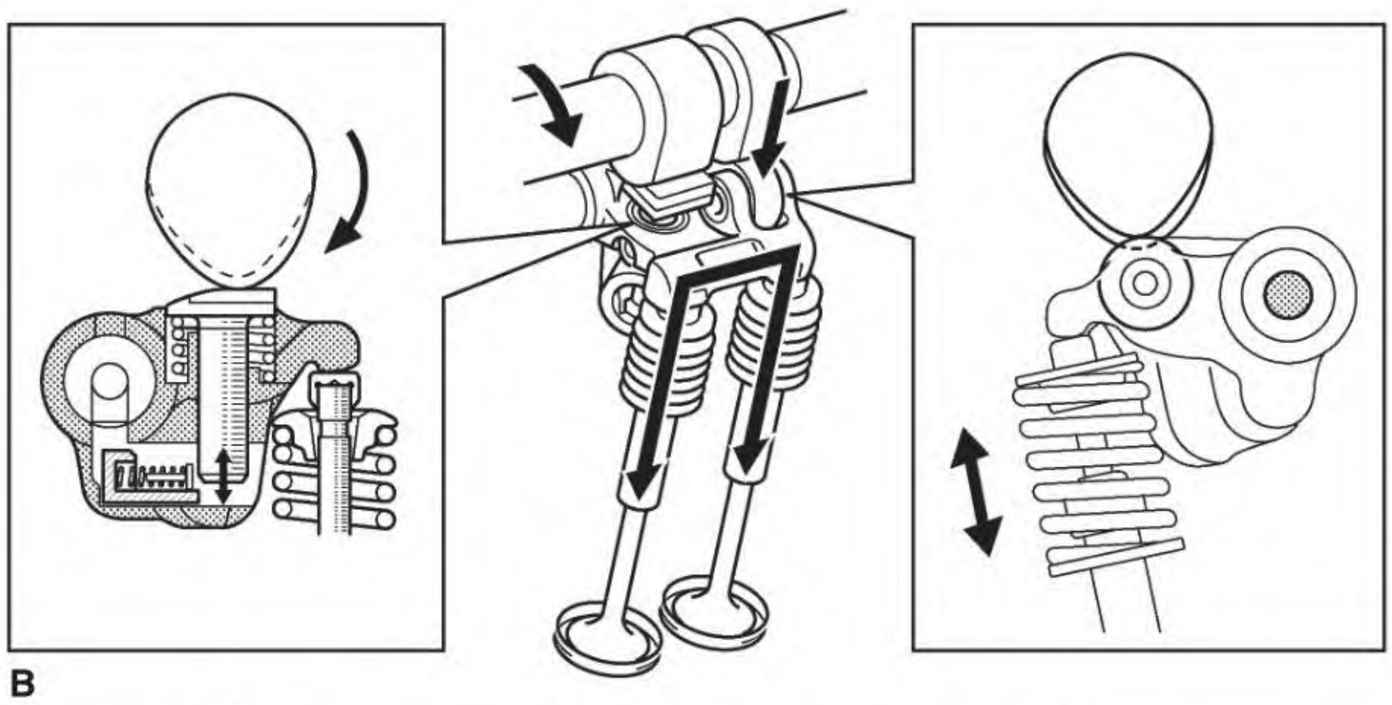
Various types of illustrations are used to supplement the written service information. Some show how to measure part wear, while others show how to install parts. Others show an exploded, or disassembled, view of parts and assemblies. These illustrations may show you what parts look like, how parts fit together, the most likely places where leaks might occur, etc.

Diagrams are drawings used when working with electrical circuits, vacuum hoses, and hydraulic circuits. They represent how wires, hoses, passages, and parts connect together. Wiring diagrams show how the wiring connects to the electrical components.

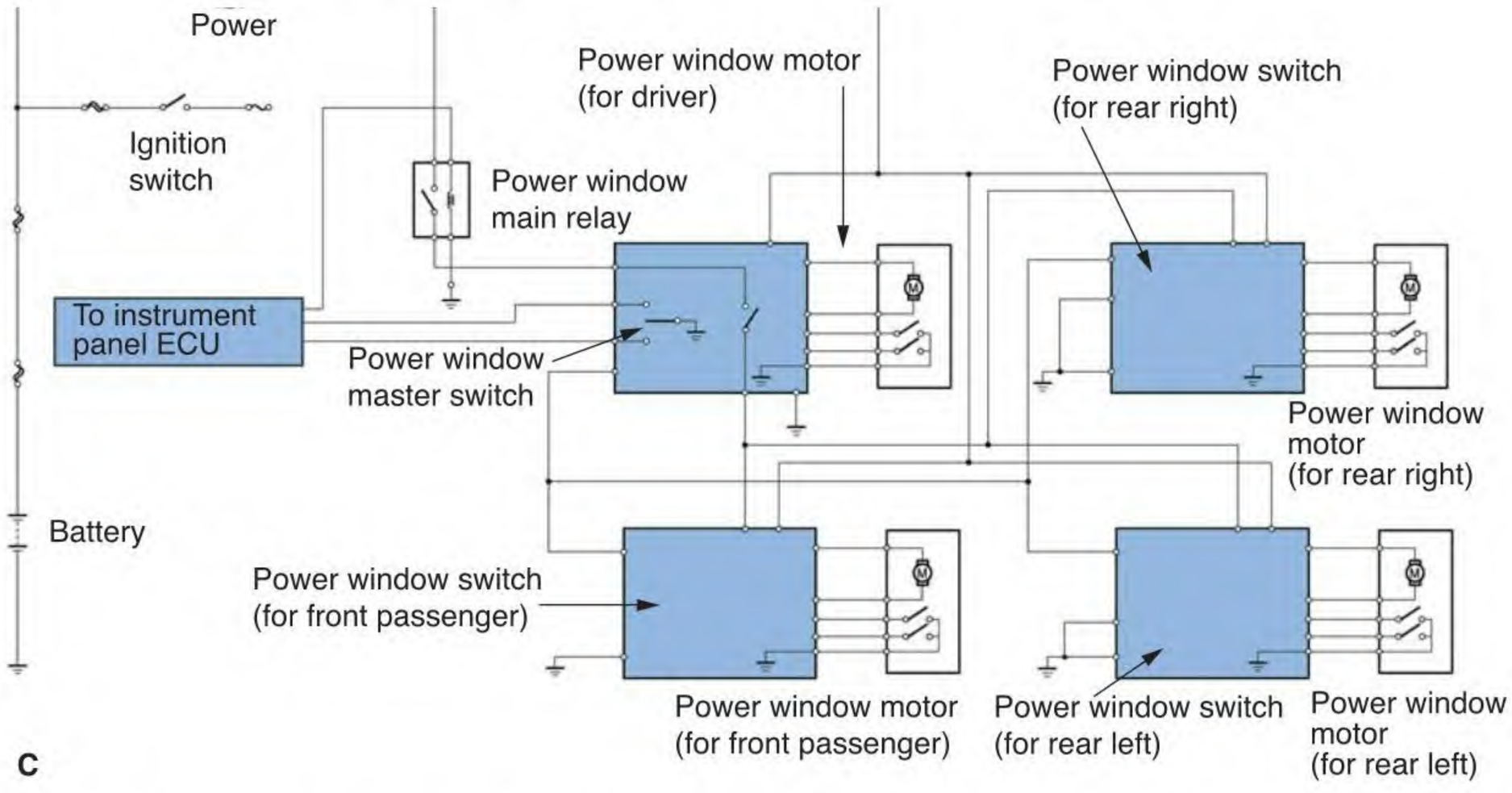
Vacuum diagrams help the technician determine how vacuum hoses connect to the engine and vacuum-operated devices. Hydraulic diagrams show how a fluid, usually oil, flows in a circuit or part. They are helpful in understanding how a component operates or how to troubleshoot problems. Hydraulic diagrams are commonly given for automatic transmissions and power steering systems. See **Figure 7-3**.



A



B



C

Toyota

Figure 7-3. Familiarize yourself with different types of service manual illustrations. A—An exploded view shows how parts fit together. B—An operational illustration shows how parts function. C—A wiring diagram shows how wires connect to components.

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Service Information Abbreviations

Abbreviations are letters that stand for an entire word. They are often used in service information. In most cases, the abbreviations are explained when they are first used. See **Figure 7-4**.

Tech Tip

This textbook uses only universally accepted SAE abbreviations. It does not use abbreviations that only apply to one manufacturer.

Service Information Diagnostic Charts

Diagnostic charts, or troubleshooting charts, commonly found in service information outline the steps for finding and correcting problems during automobile repair. If the source of the problem is hard to find, a diagnostic chart should be used. It will guide you to the most common causes of specific problems. There are four basic types of diagnostic charts. These are: tree, block, illustrated, and component location charts.

A tree diagnosis chart provides a logical sequence for what should be inspected or tested when trying to solve a problem. For instance, if a horn will not work, the top of the tree chart may tell you to check the horn's fuse. Then, if the fuse is good, it may have you measure the voltage going to the horn. You work your way down the "tree" until the problem is found, **Figure 7-5**.

A block diagnosis chart lists conditions, causes, and corrections in columns. The most common cause is at the top of the listing. For example, if an engine overheats, loss of coolant appears at the top of the "causes" column. Check the coolant level. If this is the problem, fill the radiator and check for leaks. If the coolant level is okay, go to the next listing on the chart. See **Figure 7-6**.

An illustrated diagnosis chart uses pictures, symbols, and words to guide the technician through a sequence of tests. If an engine oil pressure gauge shows low oil pressure, for example, the chart shows you exactly what to do, step by step, until the problem is found and corrected. This type of diagnosis chart not only tells you what to do, but it shows you how to do it.

A ***component location chart*** shows where various parts are located on the vehicle. This type of chart is often used for the engine compartment. The chart helps locate the numerous sensors, relays, fuses, and other components housed in this area.

Tech Tip

The layout and features of computer-based service information systems vary from one system to the next. The best way to learn how to use these systems is to practice using them. For example, on your lunch hour, look up specific service information for one make and model of vehicle. This will help you find data more quickly when working.

Other Sources of Vehicle Information

In addition to computer-based or printed service manuals, technicians often rely on other sources of information when diagnosing, servicing, or repairing a vehicle. These include owner's manuals, flat-rate manuals, and technical bulletins.

Owner's Manual

An ***owner's manual*** is a small booklet given to the purchaser of a new vehicle. It contains basic information on starting the engine, maintaining the car, fluid types, fluid capacities, and instructions on operating vehicle accessories for example.

Flat-Rate Manual

A ***flat-rate manual*** lists the flat-rate times for a variety of repairs. ***Flat-rate time*** is the average amount of time it will take a technician to complete a specific repair. Many shops use flat-rate time when calculating the labor charges for a repair. Flat-rate time is multiplied by the shop's hourly labor rate to find the labor charge in dollars. Using the flat-rate manual, you will be able to give the customer a cost estimate before beginning the actual repair and a bill after repairs have been completed.

Technical Bulletins

Technical bulletins help the technician stay up-to-date with recent technical changes, common repair problems, and other service-related information. These electronic publications are sent to the shop's main computer for use by the technicians.

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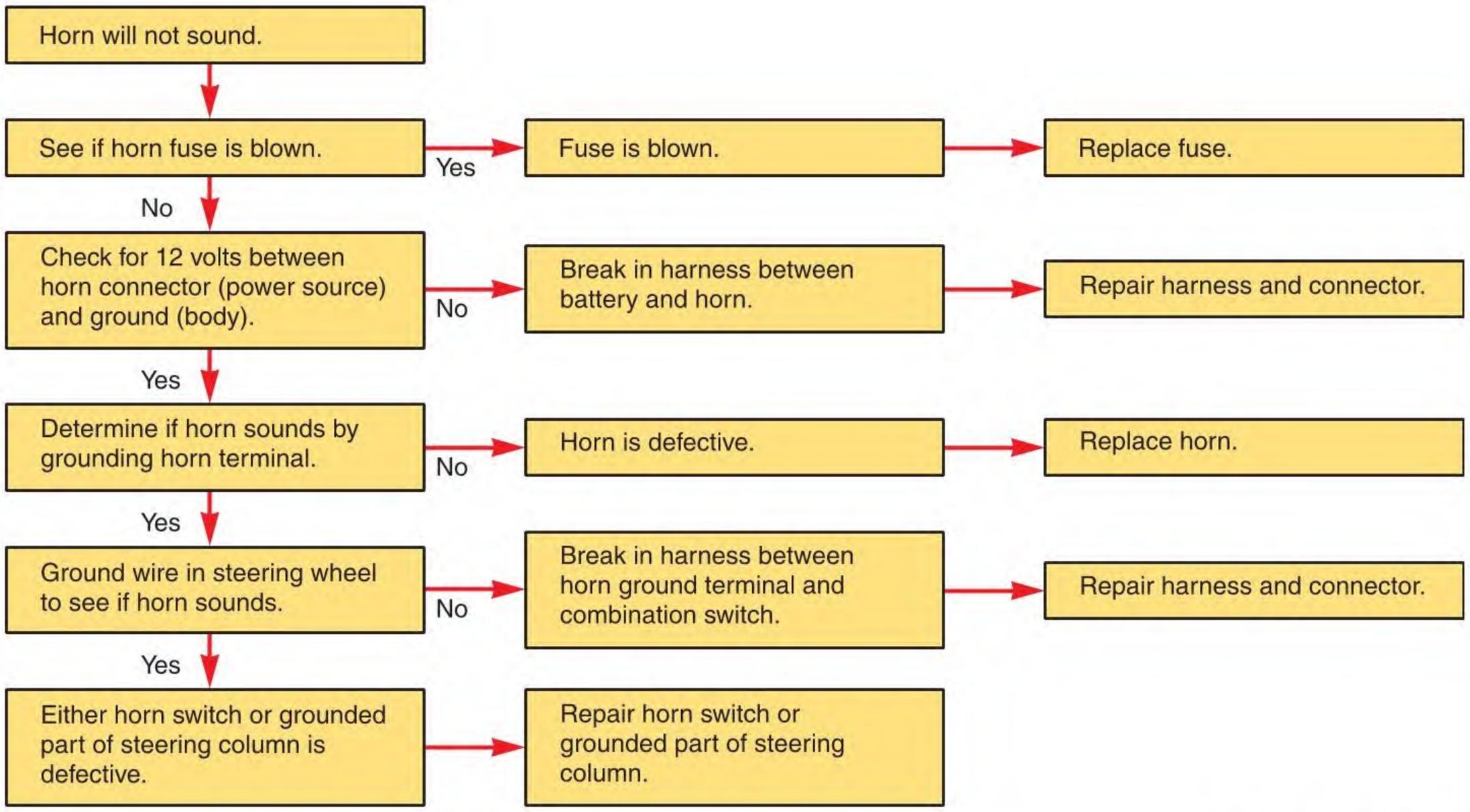
Accepted Abbreviation Samples

Term	Abbrevations	Term	Abbrevations
Accelerator pedal	AP	Ignition control	IC
Air cleaner	ACL	Ignition control module	ICM
Air conditioning	A/C	Inertia fuel shutoff	IFS
Automatic transaxle	A/T	Intake air	IA
Automatic transmission	A/T	Intake air temperature	IAT
Barometric pressure	BARO	Knock sensor	KS
Battery positive voltage	B+	Malfunction indicator lamp	MIL
Camshaft position	CMP	Manifold absolute pressure	MAP
Carburetor	CARB	Manifold differential pressure	MDP
Charge air cooler	CAC	Manifold surface temperature	MST
Closed loop	CL	Manifold vacuum zone	MVZ
Closed throttle position	CTP	Mass airflow	MAF
Clutch pedal position	CPP	Mixture control	MC
Continuous fuel injection	CFI	Multiport fuel injection	MFI
Continuous trap oxider	CTOX	Nonvolatile random access memory	NVRAM
Crankshaft position	CKP	On-board diagnostic	OBD
Data link connector	DLC	Open loop	OL
Diagnostic test mode	DTM	Oxidation catalytic converter	OC
Diagnostic trouble code	DTC	Oxygen sensor	O2S
Direct fuel injection	DFI	Park/neutral position	PNP
Distributor ignition	DI	Periodic trap oxidizer	PTOX
Early fuel evaporation	EFE	Positive crankcase ventilation	PCV
EGR temperature	EGRT	Power steering pressure	PSP
Electrically erasable programmable read only memory	EEPROM	Powertrain control module	PCM
		Programmable read only memory	PROM
Electronic ignition	EI	Pulsed secondary air injection	PAIR
Engine control	EC	Random access memory	RAM
Engine control module	ECM	Read only memory	ROM
Engine coolant level	ECL	Relay module	RM
Engine coolant temperature	ECT	Scan tool	ST
Engine modification	EM	Secondary air injection	AIR
Engine speed	RPM	Sequential multiport fuel injection	SFI
Erasable programmable read only memory	EPROM	Service reminder indicator	SRI
		Smoke puff limiter	SPL
Evaporative emission	EVAP	Supercharger	SC
Exhaust gas recirculation	EGR	Supercharger bypass	SCB
Fan control	FC	System readiness test	SRT
Flash electrically erasable programmable read only memory	FEEPROM	Thermal vacuum valve	TVV
		Third gear	3GR
Flash erasable programmable read only memory	FEPROM	Three way + oxidation catalytic converter	TWC+OC
		Three way catalytic converter	TWC
Flexible fuel	FF	Throttle body	TB
Fourth gear	4GR	Throttle body fuel injection	TBI
Fuel level sensor	-----	Throttle position	TP
Fuel pressure	-----	Torque converter clutch	TCC
Fuel pump	FP	Transmisson control module	TCM
Fuel trim	FT	Transmission range	TR
Generator	GEN	Turbocharger	TC
Governor	-----	Vehicle speed sensor	VSS
Governor control module	GCM	Voltage regulator	VR
Ground	GND	Volume airflow	VAF
Heated oxygen sensor	HO2S	Warm up oxidation catalytic converter	WU-OC
Idle air control	IAC	Warm up three way catalytic converter	WU-TWC
Idle speed control	ISC	Wide open throttle	WOT

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Figure 7-4. Memorize SAE-recommended abbreviations.

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Figure 7-5. A tree diagnosis chart starts at the top and guides you through repair operations.

Online Resources

Several websites are available that provide technical assistance and allow technicians to communicate with each other. The ***International Automotive Technicians Network (iATN)*** provides a platform for automotive technicians from around the globe to exchange service and repair information. See **Figure 7-7**. The iATN website also contains a database of repair information, a waveform library, component photos, and other useful features.

Work Orders

A ***work order***, also called repair order or shop ticket, is a form used by technicians to record information about a vehicle that is being serviced. It is often used as the invoice for the customer. In some cases, a work order is used when preparing a repair estimate.

Generally, the shop's service writer or manager initiates the work order by filling in customer and vehicle information on a computer. The work order will also contain a written description of the problems or symptoms described by the customer. The service writer often has the customer sign a printed work order, authorizing the shop to repair the vehicle.

The work order is then given to the technician electronically, who uses the information on the form as a starting point when servicing or repairing the vehicle. The technician or service writer records the services or repairs that were completed, as well as the time required to complete the repairs.

When repairs are completed, the service writer must calculate the total labor charge for the repair. The flat-rate time or the actual time required to complete the repair is multiplied by the shop's labor rate. For example, if the diagnosis and repair time is 5 hours and the labor rate is $50 per hour, the total labor charge would be $250.

Next, the technician calculates the total charges for the parts used during the repair. Most work orders have a separate section for listing the repair parts and their prices. In most cases, the part prices are based on a percentage markup of the wholesale part prices. For example, if the shop markup is 30% on a part, with a wholesale price of $25.00, the price charged to the customer is $32.50 ($25.00 x .30 = $7.50 + $25.00 = $32.00). Some shops charge an environmental fee for the disposal of hazardous wastes (oil, batteries, air bags, etc.). This charge must also be included on the work order.

Finally, the technician or service writer must calculate tax for the parts and then total the bill by adding

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Condition	Possible Cause	Correction
• Loss of coolant.	• Pressure cap and gasket.	• Inspect, wash gasket, and test. Replace only if cap will not hold pressure test specifications.
	• External leakage.	• Pressure test system. • Inspect hose, hose connections, radiator, edges of cooling system gaskets, core plugs, drain plugs, transmission oil cooler lines, water pump, heater system components. Repair or replace as required.
	• Internal leakage.	• Check for obvious restrictions. • Check torque of head bolts. Retorque if necessary. • Disassemble engine as necessary— check for cracked intake manifold, blown head gaskets, warped head or block gasket surfaces, cracked cylinder head, or engine block.
• Engine overheats.	• Low coolant level.	• Fill as required. Check for coolant loss.
	• Loose fan belt.	• Adjust.
	• Pressure cap.	• Test. Replace if necessary.
	• Radiator or A/C condenser obstruction.	• Remove bugs and leaves.
	• Closed thermostat.	• Test. Replace if necessary.
	• Fan drive clutch.	• Test. Replace if necessary.
	• Ignition.	• Check timing and advance. Adjust as required.
	• Temperature gauge or cold light.	• Check electrical circuits and repair as required.
	• Engine.	• Check water pump and block for blockage.
	• Exhaust system.	• Check for restrictions.
• Engine fails to reach normal operating temperature.	• Thermostat stuck open.	• Test. Replace if necessary.
	• Temperature gauge or cold light inoperative.	• Check electrical circuits and repair as required. Refer to electrical section.

Ford

Figure 7-6. A block diagnosis chart lists conditions, causes, and corrections in columns. Read to the right to match a condition with possible causes and corrections.

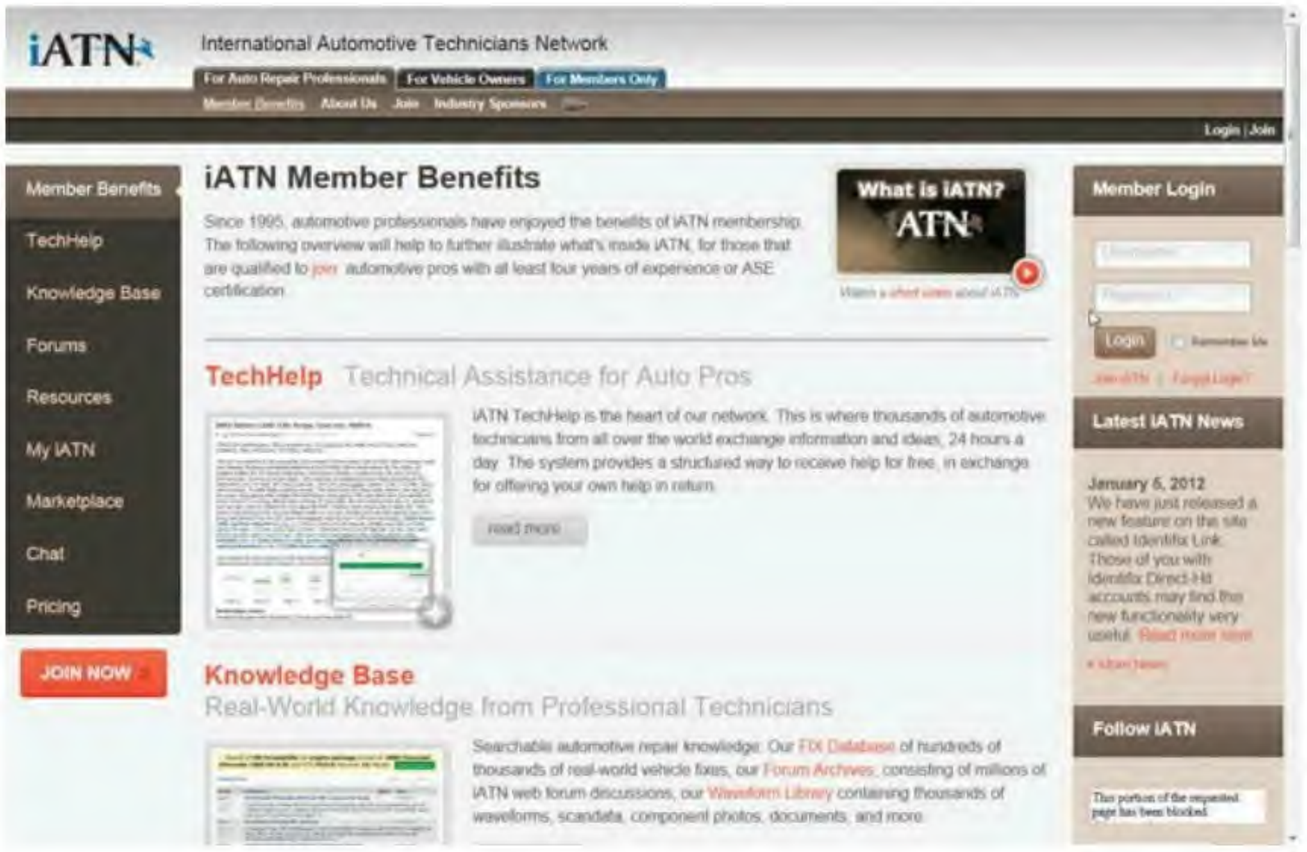
parts, labor, supplies, fees, and taxes to arrive at the final amount for the repair.

Decoding the Vehicle Identification Number

The ***vehicle identification number (VIN)*** is a unique 17-character code found on a plate located on a vehicle's dashboard or door opening. This code sets a vehicle apart from the millions of other vehicles. Most sources of service information include an explanation of what each character of the VIN means. Look at **Figure 7-8**.

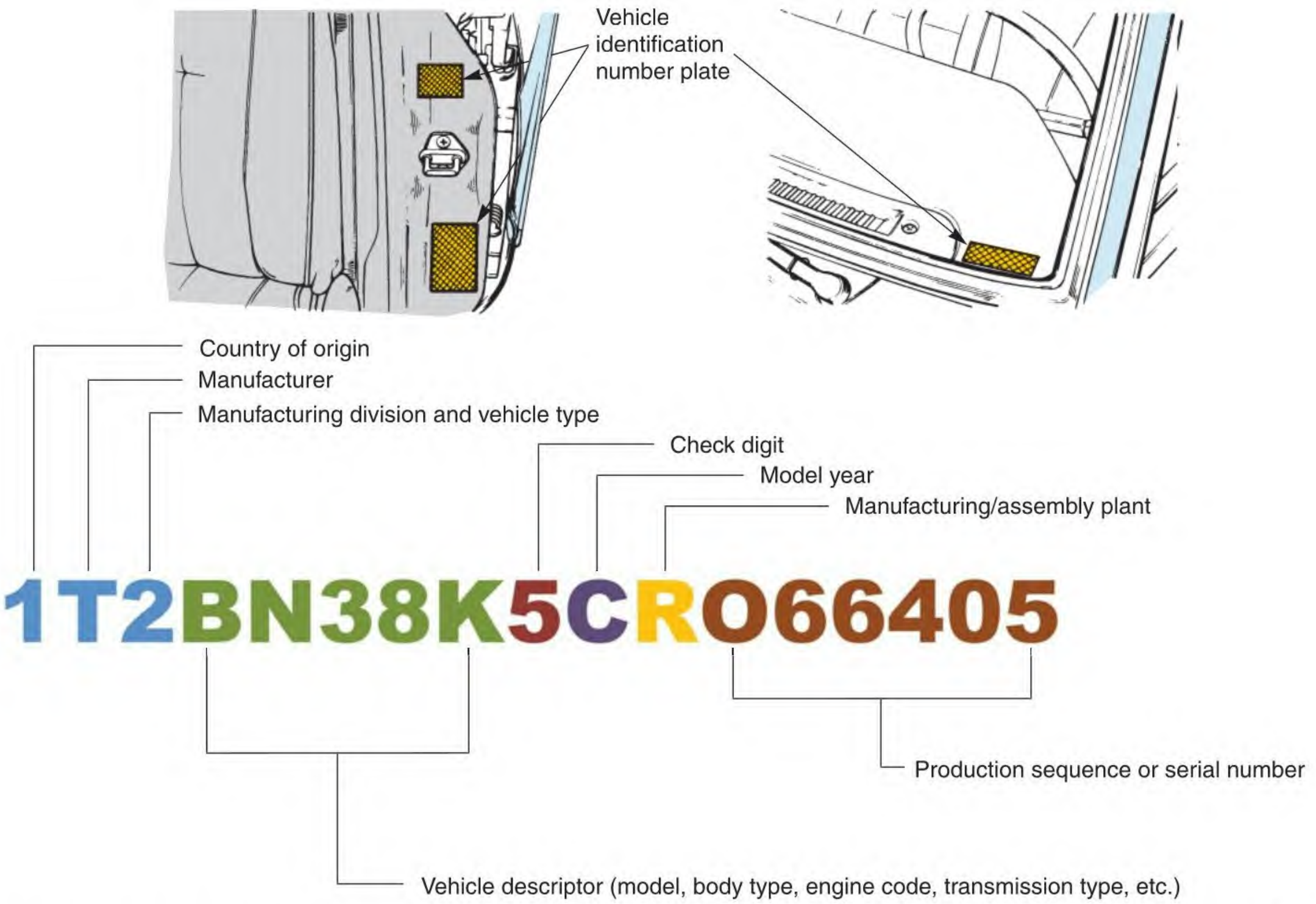
The VIN is important because it provides data about how the car is equipped and other useful information. It tells you what type of engine and transmission are in the vehicle. It can be used to track recalls, registrations, and warranty claims. Technicians are often asked to provide a vehicle's VIN to parts stores or warehouses to ensure that the correct parts are being ordered.

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iATN

Figure 7-7. The Internet can be a valuable source of information. Some Internet sites, such as the International Automotive Technicians Network, allow technicians to share their technical knowledge.



Subaru

Figure 7-8. The VIN can be located on the door, in the door opening, on the dashboard, or in the engine compartment. Refer to the service information for the vehicle at hand to determine the meaning of each character in the VIN.

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Obtaining Repair Parts

After you determine what repairs are needed, you must obtain the parts needed to make the repairs. Dealership repair shops generally stock a large selection of repair parts, eliminating the need for the technician to order parts from an outside vendor. Independent shops, on the other hand, keep commonly used supplies, such as oil, brake fluid, antifreeze, brake pads, hoses, filters, and batteries, in inventory. This saves time since the technician can perform common maintenance and repair tasks without having to order parts. However, less commonly used parts, such as starters and alternators, are not carried in inventory and must be ordered from an outside supplier.

New and rebuilt parts can be ordered by calling a local parts store or warehouse. You may be able to get the new parts the same day if they are in stock locally. If the parts are not in stock at a local store or warehouse, they may have to be shipped in from another state, which may take a day or two. In some cases, parts can be purchased using the Internet.

If new or rebuilt replacement parts are not available, you may have to call local salvage yards or search the Internet to find a good used part. Find out the mileage and price of the used parts, and determine if they come with a warranty. Always get an okay from the customer before ordering used components.

Large shops often employ one or more parts specialists, who maintain inventory and locate and order. In small shops, the technician may be responsible for monitoring the inventory of commonly used parts, as well as ordering and restocking these parts when the supply gets low.

Summary

- Service information provides detailed information on how to repair a vehicle. It may include step-by-step procedures, specifications, diagrams, part illustrations, and other data for each model of vehicle.
- Computer-based service information is data stored or retrieved using a personal computer.
- Various types of service illustrations are used to supplement the written information in a service manual.
- Diagrams are drawings used when working with electrical circuits, vacuum hoses, and hydraulic circuits.
- Abbreviations are letters that stand for entire words.
- A flat-rate manual is used to calculate how much labor to charge the customer for a repair.
- The International Automotive Technicians Network (iATN) provides a platform for automotive technicians from around the globe to share service and repair information via the Internet.
- Online service information programs are web-based databases that contain service information on thousands of vehicles.
- A work order, also called repair order or shop ticket, is a form used by technicians to record information about a vehicle that is being serviced.
- The VIN is a number code that indicates engine type, transmission type, and other useful information.
- After determining what repairs are needed, the technician must obtain the parts needed to make the repairs.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

abbreviations
component location chart
diagnostic chart
flat-rate manual
flat-rate time
International Automotive Technicians Network (iATN)
owner's manual
service information
technical bulletin
vehicle identification number (VIN)
work order

Activities

1. Use your shop's computer software to prepare a bill for replacement of a fuel pump on a vehicle of your choice. Check the manual for the amount of labor involved. Then, look up the cost of the part. Add up the costs plus the state tax for your state. (Figure labor cost at $48/hour.)

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2. Using computer-based service information, demonstrate how to find the procedure for removal and replacement of a part chosen randomly.
3. Complete a mock work order for replacement of worn shock absorbers. Include a description of the customer complaint and a detailed summary of the work performed to correct the concern.

Review Questions



Answer the following questions using the information provided in this chapter.

1. What is service information?
2. Which of the following is *not* found in service information?
   (A) Step-by-step procedures.
   (B) Driving tips.
   (C) Descriptions of common problems.
   (D) Specifications.
3. Explain the purpose of the following:
   (A) Wiring diagrams.
   (B) Vacuum diagrams.
   (C) Hydraulic diagrams.
4. List ten common abbreviations and explain them.
5. Which of the following is *not* a common type of diagnostic chart?
   (A) Track diagnosis chart.
   (B) Tree diagnosis chart.
   (C) Block diagnosis chart.
   (D) Illustrated diagnosis chart.
6. A(n) _____ manual is used to calculate how much labor to charge for a repair.
7. _____ help the technician stay up-to-date with recent technical changes, repair problems, and other service related information.
8. A _____ is a form used by technicians to record information about a vehicle that is being serviced.
   (A) Form 71D20
   (B) work order
   (C) diagnosis chart
   (D) service information form
9. What is the advantage of providing the parts supplier with the VIN when ordering repair parts?
10. What should be done if parts needed to make a repair are not carried in the shop's inventory?

ASE-Type Questions



1. Which of the following is an advantage of computerized service information when compared to a printed service manual?
   (A) Hyperlinks to related information.
   (B) Speed of search.
   (C) Service information can be instantaneously updated.
   (D) All of the above.
2. A technician who is having trouble finding the cause of a vehicle problem should refer to the following first.
   (A) Service bulletins.
   (B) Troubleshooting charts.
   (C) Spec sheets.
   (D) Repair procedures.
3. Which of the following should be used when calculating the cost of a repair?
   (A) Troubleshooting chart.
   (B) Service bulletin.
   (C) Flat-rate manual.
   (D) Cold rate manual.
4. Technician A says VIN information is needed to find information on the exact make and model car. Technician B says VIN information is no longer needed with modern vehicles. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. Technician A says that in some shops, the technicians are responsible for monitoring inventory, and ordering and stocking commonly used parts. Technician B says that dealership repair shops generally stock a large selection of repair parts. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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Chapter 8
Fasteners, Gaskets, Seals, and Sealants

After studying this chapter, you will be able to:

- Identify commonly used automotive fasteners.
- Select and use fasteners properly.
- Remove, select, and install gaskets, seals, and sealants correctly.
- Summarize safety rules relating to fasteners, gaskets, seals, and sealants.
- Correctly answer ASE certification test questions that require a knowledge of fasteners, gaskets, seals, and sealants.

Fasteners, both mechanical (bolts, nuts, and clips) and chemical (adhesives), literally hold a car together.

Many different fasteners, gaskets, seals, and sealants are used by the automotive technician. It is almost impossible to connect any two parts of a vehicle without them. The information presented in this chapter is important and will prepare you for many repair operations and other text chapters.

Fasteners

Fasteners are devices that hold the parts of a car together. Thousands of metal and plastic fasteners are used in vehicles, as shown in **Figure 8-1**.

Bolts and Nuts

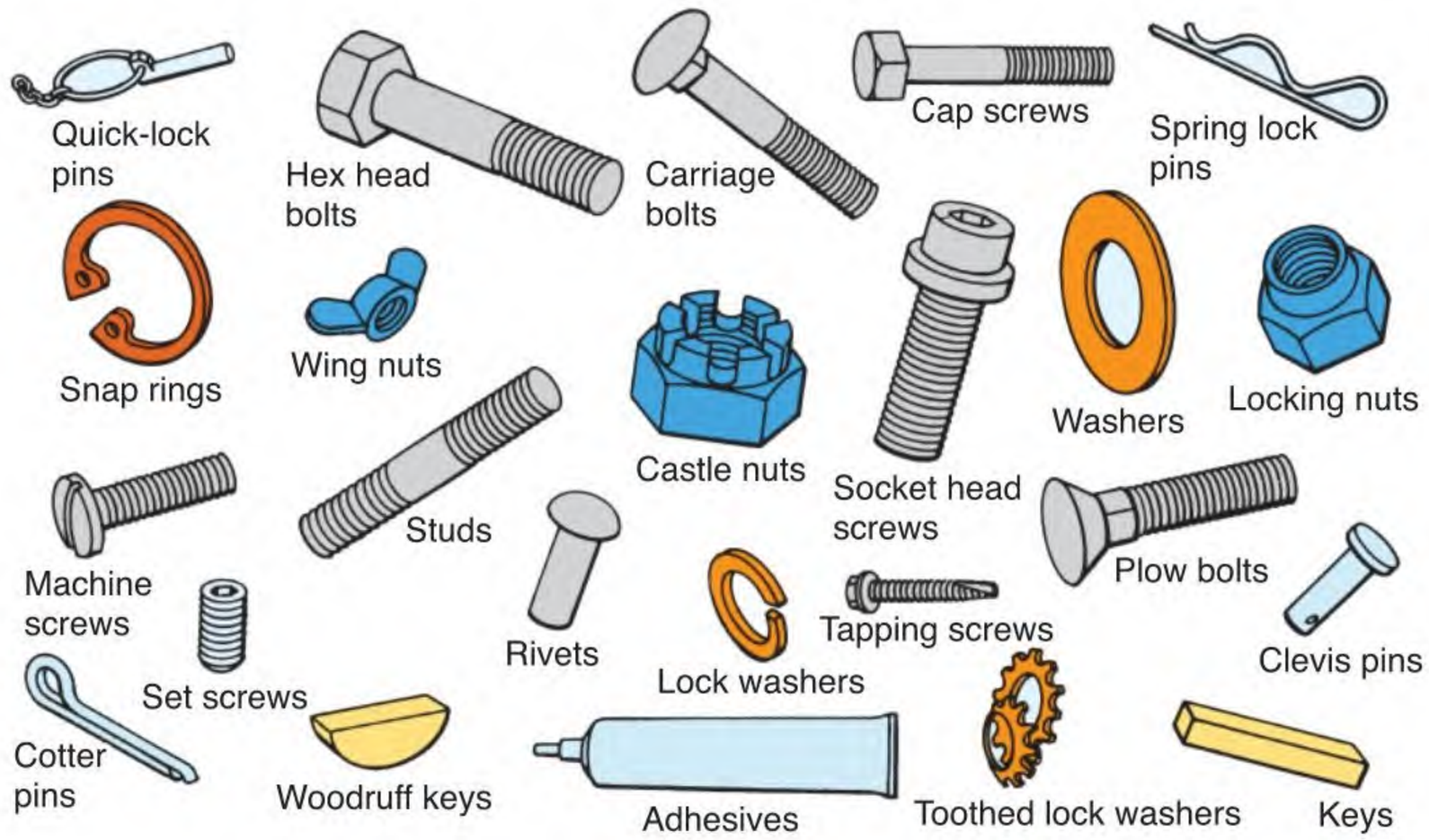
A ***bolt*** is a metal rod with external threads on one end and a head on the other. When a bolt is threaded into a part other than a nut, it can also be called a ***cap screw***. Head bolts and manifold bolts are also considered cap screws. A ***nut*** has internal threads and usually a six-sided outer shape. When a nut is screwed onto a bolt, a powerful clamping force is produced. Refer to **Figure 8-2**.

In automotive technology, bolts and nuts are named after the parts they hold. For instance, the bolts holding the cylinder head on the block are called cylinder head bolts. The bolts on an engine connecting rod are called connecting rod bolts.

Bolt and Nut Terminology

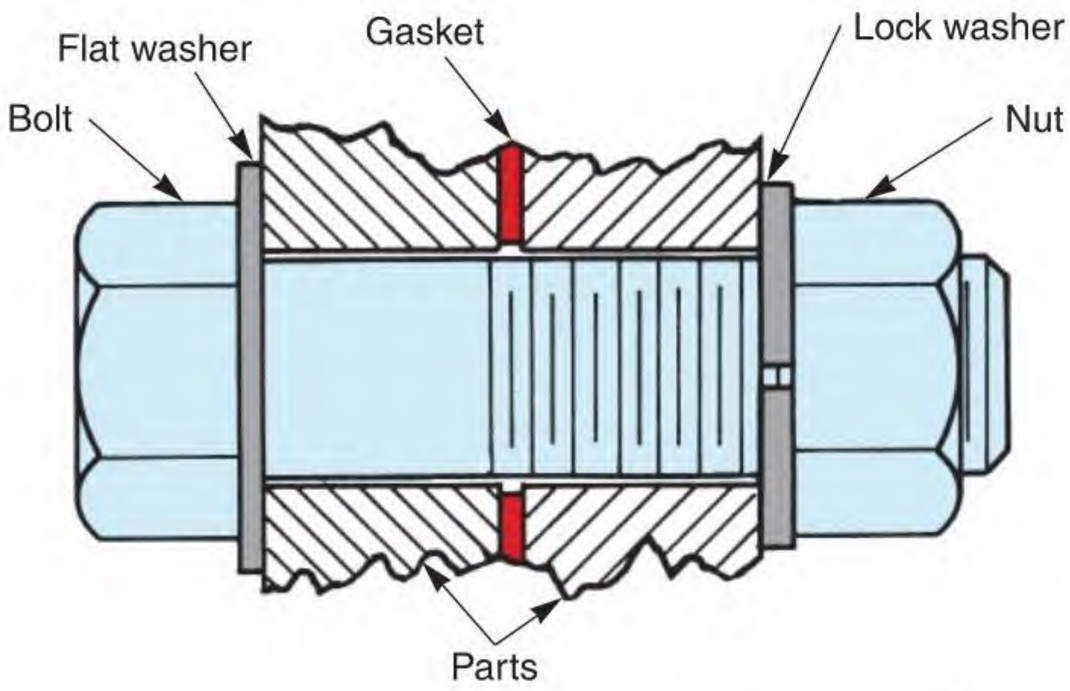
Bolts and nuts come in various sizes, grades (strengths), and thread types. It is important to be familiar with these differences. The most important bolt dimensions are shown in **Figure 8-3**. These dimensions include:

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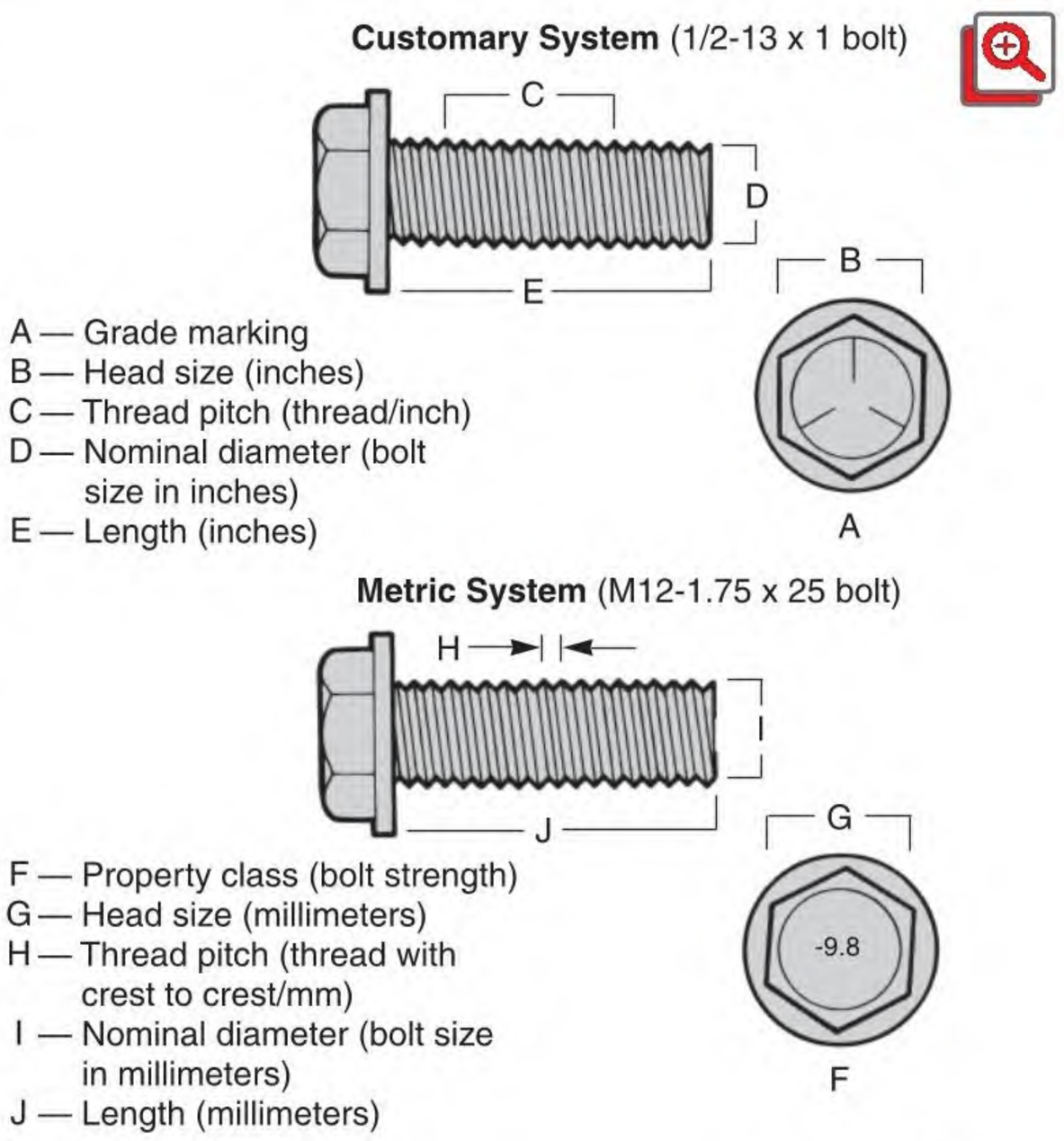
Figure 8-1. A fastener is any device or adhesive used to hold parts together. Study these basic automotive fasteners.



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Figure 8-2. A bolt and nut exert a powerful clamping force on parts. Notice the washers and gasket used.

- Bolt size—Bolt size is the measurement of the outside diameter of the bolt threads.
- Bolt head size—Bolt head size is the distance measured across the flats or outer sides of the bolt head. It is the same as the wrench size.
- Bolt length—Bolt length is measured from the bottom of the bolt head to the threaded end of the bolt.
- Thread pitch—Thread coarseness is the same as thread pitch. With U.S. conventional system fasteners, thread pitch is the number of threads per inch. With metric fasteners, it is the distance between each thread in millimeters.



Ford

Figure 8-3. Study the naming systems for both customary and metric bolts.

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Thread Types

There are three basic types of threads used on fasteners:

- Coarse threads (UNC-Unified National Coarse).
- Fine threads (UNF-Unified National Fine).
- Metric threads (SI).

Never interchange thread types or thread damage will result. Metric threads look very similar to customary threads. However, if a metric bolt is forced into a hole with fine threads, either the bolt or part threads will be ruined.

Bolts and nuts also come in right- and left-hand threads. With right-hand threads, the fastener must be turned clockwise to tighten. This is the most common style of thread. With left-hand threads, turn the fastener in a counterclockwise direction to tighten. Left-hand threads are not very common. The letter *L* may be stamped on fasteners with left-hand threads.

Bolt Grade

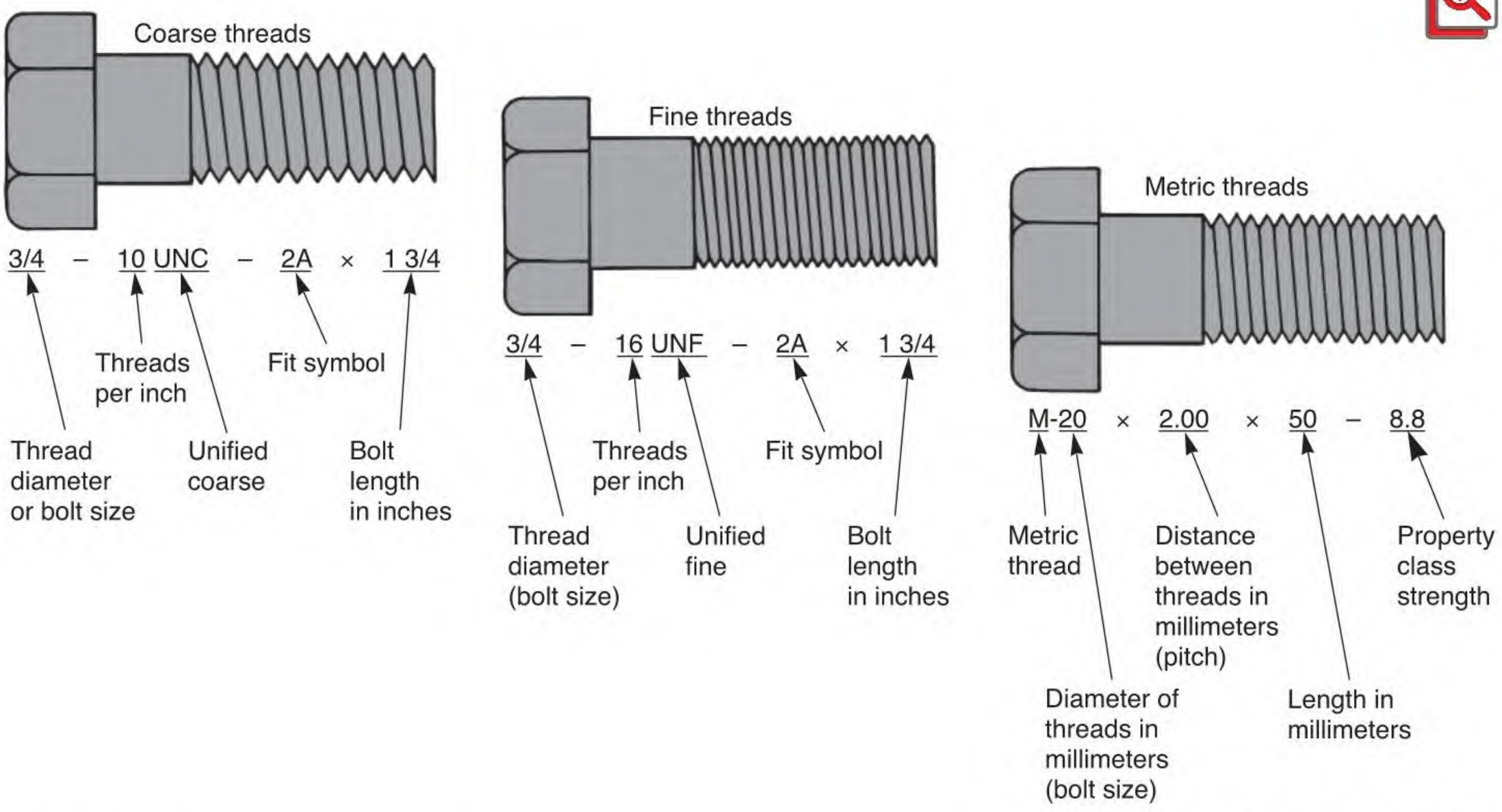
Bolt grade is an indication of a bolt's strength. A primary measure of bolt strength is its tensile strength. ***Tensile strength*** refers to the amount of pull a fastener can withstand before breaking. Bolts are made of different metals, some stronger than others. Tensile strengths can vary. ***Bolt head markings***, also called grade markings, specify the tensile strength of the bolt. US customary bolts are marked with lines or slash marks. The more lines, the stronger the bolt will be under stress. A metric bolt is marked with a numbering system. The larger the number, the stronger the bolt will be under high load or clamping stress.

Warning

Never replace a high-grade steel bolt with a lower grade bolt of inferior steel. The weaker bolt could easily snap, possibly causing part failure and a dangerous situation.

Bolt Description

A bolt description is a series of numbers and letters that describe the bolt. When purchasing new bolts, the bolt description information is needed. See **Figure 8-4**.



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Figure 8-4. The bolt description number gives information about the bolt. This number is commonly used when purchasing new bolts.

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Nut Types

Many types of nuts are used in a vehicle. Study their names closely. A slotted nut, or castle nut, uses a safety device called a ***cotter pin***. The cotter pin fits through a hole in the bolt or part. This keeps the nut from turning and possibly coming off. Look at **Figures 8-5** and **8-6**.

Self-locking nuts produce a friction fit when threaded onto a bolt or stud. The top of the nut can be crimped inward. Some have a plastic insert that produces a friction fit to keep the nut from loosening. Self-locking nuts may need to be replaced after removal.

Jam nuts are thin nuts used to help hold larger, conventional nuts in place. The jam nut is tightened down against the other nut to prevent loosening.

Wing nuts have two extended arms that allow the nuts to be easily turned by hand. They are used when a part must be removed frequently for service or maintenance. Air cleaner housings sometimes use wing nuts.

Acorn nuts are closed on one end for appearance and to keep water and debris off the threads. They can be used when they are exposed and looks are important.

Special types of nuts are used to hold parts onto the vehicle. Sometimes a washer is formed onto the nut. Termed *body nuts*, the flange on the nut helps distribute the clamping force of the thin body panel or trim piece to prevent warpage.

Washers

Washers are used under bolt heads and nuts. The two basic types are flat washers and lock washers. A flat washer increases the clamping surface under the fastener. It prevents the bolt or nut from digging into the part.

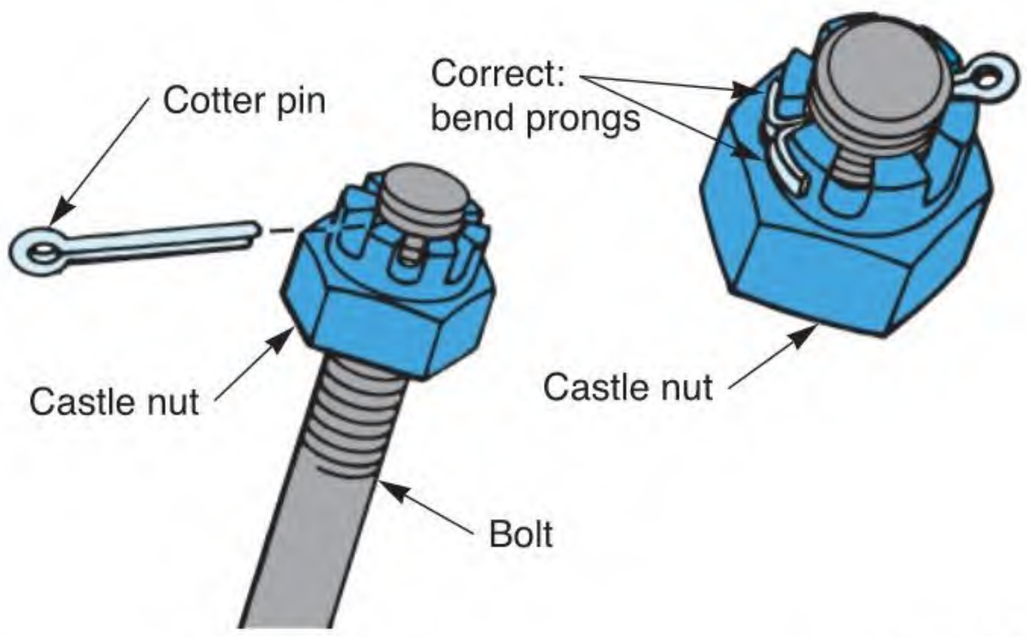
A lock washer prevents the bolt or nut from becoming loose under stress and vibration. Lock tabs, or lock plates, perform the functions of both flat washers and lock washers. They increase clamping surface area and prevent the fastener from loosening. Look at **Figure 8-7**.

Machine Screws

Machine screws are similar to bolts, but they normally have screw-type heads. They are threaded along their full length and are relatively small. Machine screws are used to secure parts when clamping loads are light. They come in various head shapes.

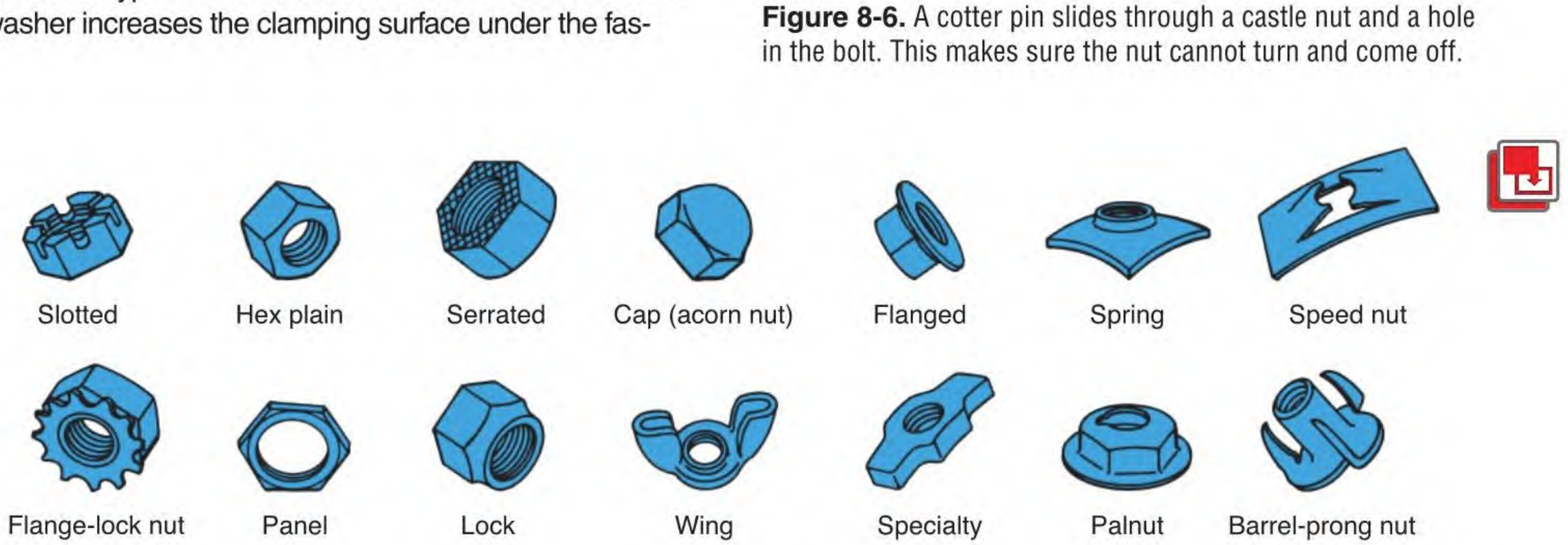
Sheet Metal Screws

Sheet metal screws, or ***tapping screws***, are commonly used on plastic and sheet metal parts, such as body trim, dashboard panels, and grilles.



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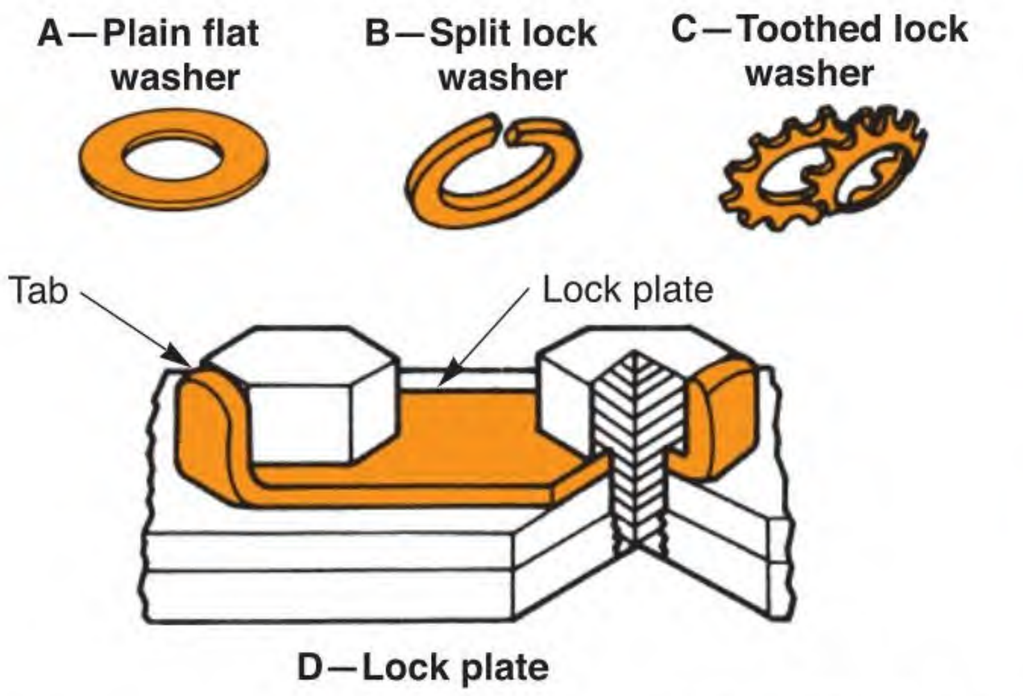
Figure 8-6. A cotter pin slides through a castle nut and a hole in the bolt. This makes sure the nut cannot turn and come off.



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Figure 8-5. Memorize common types of nuts used in vehicles.

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Figure 8-7. Compare basic washer types.

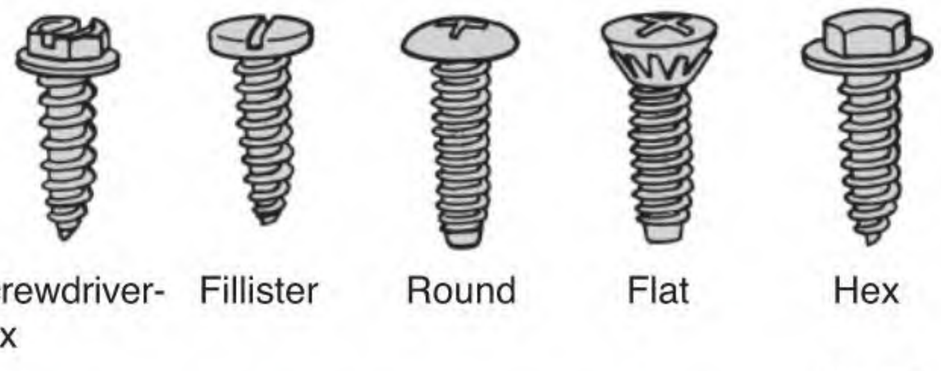
Sheet metal screws have tapering threads that are very widely spaced. They come in a wide range of head configurations and sizes. Several are shown in **Figure 8-8**.

Nonthreaded Fasteners

Numerous types of ***nonthreaded fasteners***, such as snap rings and adhesives, are used in the assembly of a vehicle. It is essential to learn the most common types.

Snap Rings

A ***snap ring*** fits into a groove in a part and commonly holds shafts, bearings, gears, pins, and other components in place. Snap ring pliers are needed to remove and install snap rings. Snap ring pliers have special jaws that fit into and grasp the snap ring, as pictured in **Figure 8-9**.



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Figure 8-8. Study basic types of sheet metal screws.

Warning

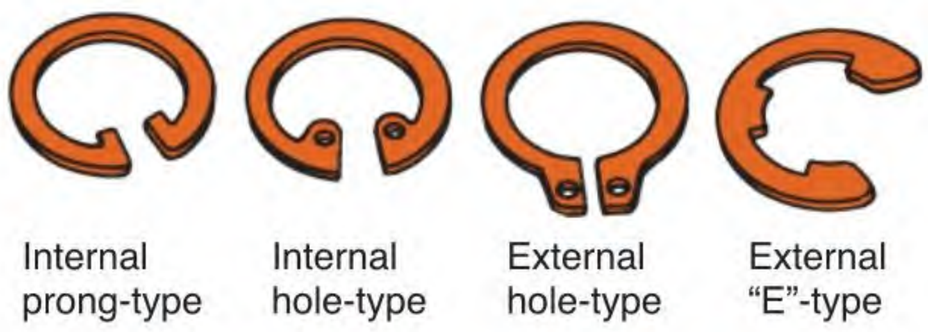
Wear eye protection when working with a snap ring. When flexed, the ring can shoot into your face with considerable force.

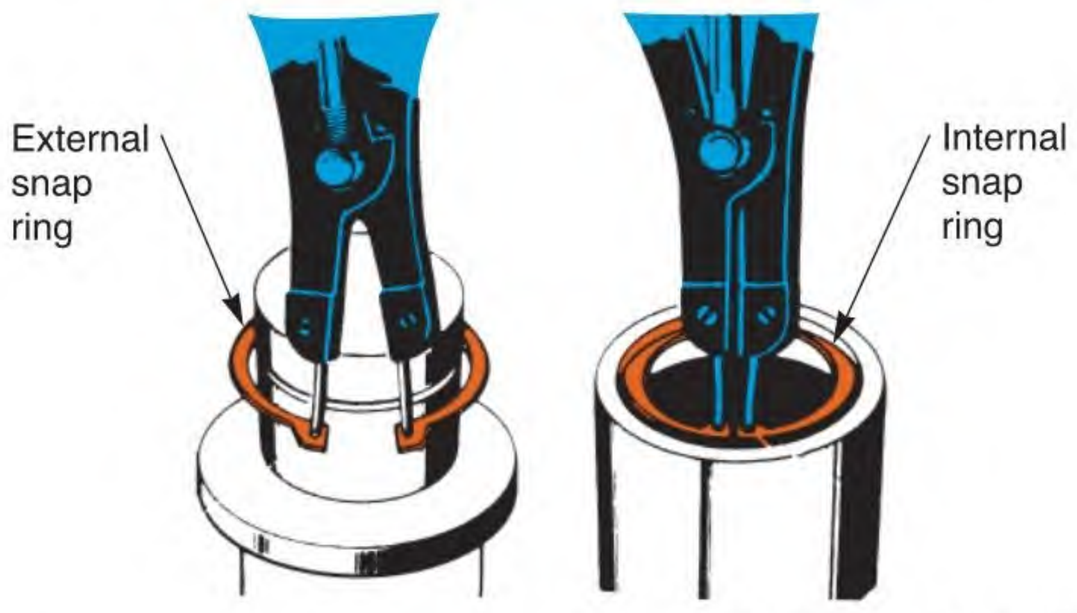
Keys and Set Screws

A metal ***key*** fits into a ***keyseat***, or slot, cut into a shaft and a ***keyway*** cut into the mating part, such as a gear, pulley, or collar. The key prevents the part from turning on its shaft. ***Set screws*** are normally used to lock a part onto a shaft. They can be used with or without a key. A set screw is a headless fastener normally designed to accept a hex (Allen) wrench or screwdriver. Refer to **Figure 8-10**.

Splines

Splines are a series of slots cut into a shaft and a mating part. Splines have an advantage over keys in that they allow a gear or collar to slide on a shaft but still not rotate. This sliding locking action is commonly used in manual transmissions, clutches, and drive shaft yokes. See **Figure 8-11**.

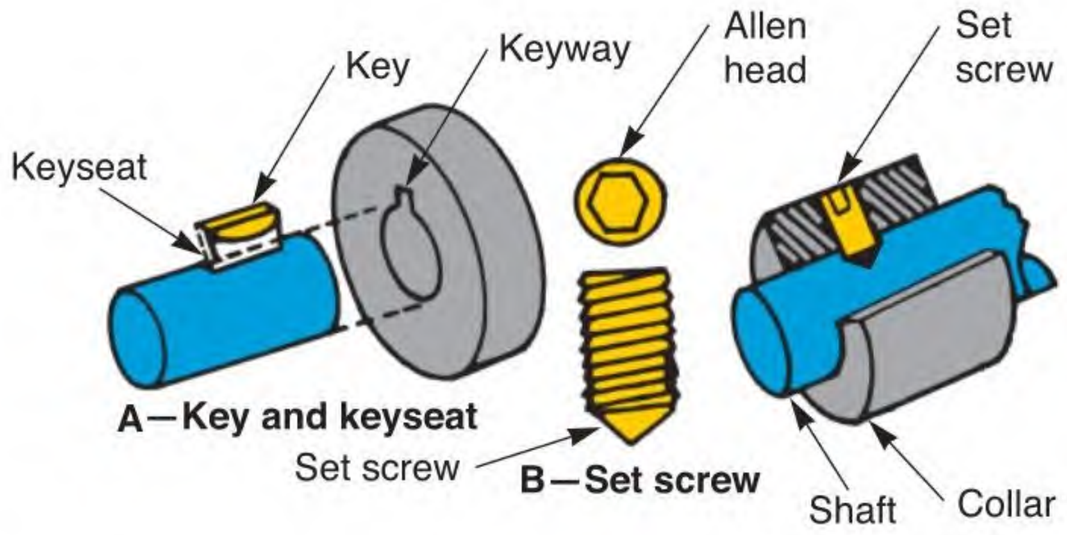




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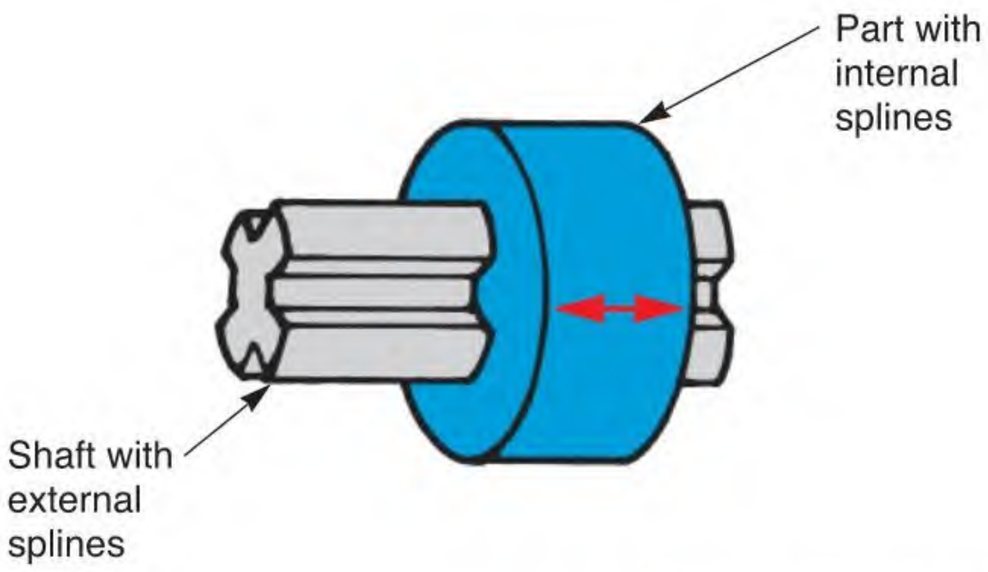
Figure 8-9. Compare different snap ring types. External snap rings fit into a groove on a shaft. Internal snap rings fit into a groove inside a hole.

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Figure 8-10. Keys and set screws are used to keep parts locked to shafts.



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Figure 8-11. Splines allow a part to slide on a shaft, but not turn on the shaft.

Adhesives

Adhesives are special glues widely used in vehicles. They hold body moldings, rubber weather stripping, and body emblems. Some adhesives are designed to stay soft and pliable; others dry hard. Some take hours to dry, while others dry in seconds. Observe all directions and safety precautions when using adhesives.

Torquing Bolts and Nuts

It is very important that bolts and nuts be tightened properly. This is called ***torquing***. If overtightened, a bolt will stretch and possibly break. The threads could also fail. If undertightened, a bolt may loosen and fall out. Part movement could also shear the fastener or damage a gasket, causing leakage.

Torque specifications are tightening values given by the auto manufacturer. Torque specifications are normally given for fasteners used in precision assemblies, such as engines, transmissions, and differentials. A general torque specification chart gives average bolt tightening values by fastener size and grade. It can be used when factory specifications are not available. Notice how bolt torque increases with bolt size and grade. Refer to **Figure 8-12**.

Service manuals sometimes recommend new bolts when certain parts are reassembled because of a torque-to-yield process. Discard the old bolts in such cases. ***Torque-to-yield*** is a bolt tightening method that requires the bolt to be tightened to a specific torque and then turned an additional number of degrees. After the fastener is torqued to specification, a degree wheel adapter is placed between the torque wrench and socket. The fastener is then turned until the

Caution
The torque specifications listed below are approximate guidelines only and may vary depending on conditions when used such as amount and type of lubricant, type of plating on bolt, etc.

SAE Standard / Foot-pounds

Grade of bolt	SAE 1 & 2	SAE 5	SAE 6	SAE 8		
Min. tensile strength	64,000 P.S.I.	105,000 P.S.I.	133,000 P.S.I.	150,000 P.S.I.		
Markings on head					Size of socket or wrench opening	
U.S. standard	Foot-pounds				U.S. regular	
Bolt diameter					Bolt head	Nut
1/4	5	7	10	10.5	3/8	7/16
5/16	9	14	19	22	1/2	9/16
3/8	15	25	34	37	9/16	5/8
7/16	24	40	55	60	5/8	3/4
1/2	37	60	85	92	3/4	13/16
9/16	53	88	120	132	7/8	7/8
5/8	74	120	167	180	15/16	1.
3/4	120	200	280	296	1-1/8	1-1/8

Metric Standard

Grade of bolt	5D	8G	10K	12K	
Min. tensile strength	71,160 P.S.I.	113,800 P.S.I.	142,200 P.S.I.	170,679 P.S.I.	
Grade markings on head	5D	8G	10K	12K	Size of socket or wrench opening
Metric	Foot-pounds				Metric
Bolt dia. / U.S. dec equiv.					Bolt head
6 mm .2362	5	6	8	10	10 mm
8 mm .3150	10	16	22	27	14 mm
10 mm .3937	19	31	40	49	17 mm
12 mm .4720	34	54	70	86	19 mm
14 mm .5512	55	89	117	137	22 mm
16 mm .6299	83	132	175	208	24 mm
18 mm .709	111	182	236	283	27 mm
22 mm .8661	182	284	394	464	32 mm

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Figure 8-12. Study the general bolt torque chart. Note how torque values increase as the bolt size and grade increase.

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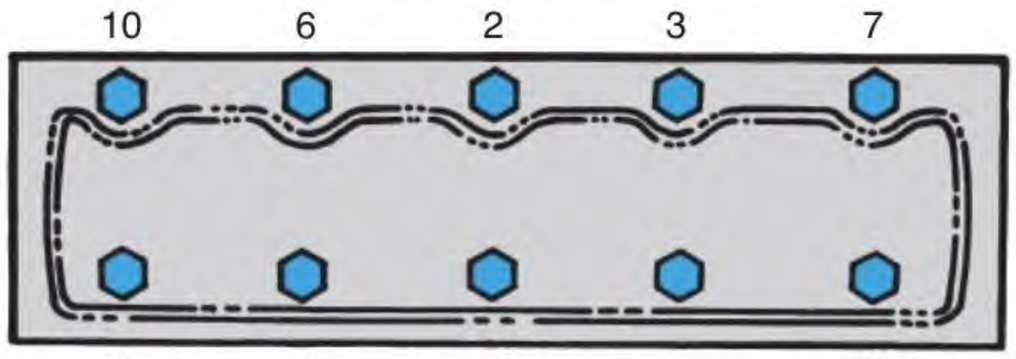
degree wheel reads as specified by the manufacturer. This stretches the bolt to its correct yield point and preloads the fastener for better clamping under varying conditions.

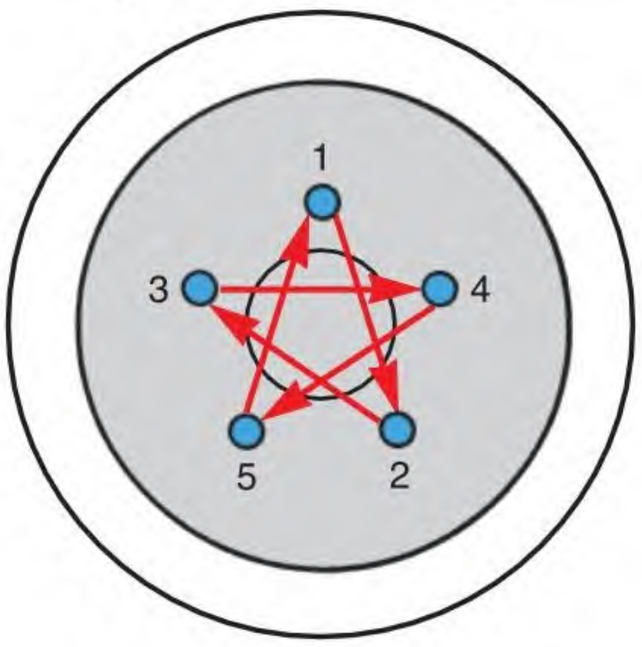
Torque stretch is determined by measuring bolt length change while torquing the bolt. For example, when building a racing engine, you can "mike" connecting rod bolts to measure the length before and after tightening. Too much stretch indicates bolt weakness. Not enough stretch may indicate thread problems affecting torque.

Bolt Tightening Sequence

A ***bolt tightening sequence***, or torque pattern, is used to make sure that parts are fastened evenly. An incorrect sequence can cause uneven tightening, leading to breaks, warping, leaks, and other problems. Generally, a group of fasteners on a part is tightened in a ***crisscross pattern***. This creates an even, gradual clamping force along the entire mating surface of the parts. A service manual will illustrate the proper sequence when even tightening is critical. Refer to **Figure 8-13**.

A—Pattern for engine cylinder head





B—Pattern for wheel lug nuts

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Figure 8-13. A crisscross pattern is recommended when multiple fasteners hold a part.

Tech Tip

When tightening engine covers and covers on other large assemblies, remember that "less is usually better." The most common mistake is to overtighten covers and damage or split the gasket or seal. It usually takes much less torque than you may think to make a new gasket seal properly.

Using a Torque Wrench

A ***torque wrench*** is used to apply the proper amount of torque when tightening a threaded fastener. Use the following basic rules.

- Keep a steady pull on the wrench. Do not use short, jerky motions.
- Clean fastener threads.
- When possible, avoid using swivel joints. They can affect torque wrench accuracy.
- When reading a torque wrench, look straight down at the scale. Viewing the scale from an angle can give a false reading.
- A general torque value chart should only be used when the manufacturer's specifications are not available.
- When the manufacturer's torque patterns are not available, use a general crisscross pattern for tightening fasteners.
- Pull only on the handle of the torque wrench. Do not allow the beam of a beam-type torque wrench to touch anything.
- Tighten bolts and nuts in four steps: one-half recommended torque, three-fourths torque, full torque, and full torque a second time.
- Retorque when required. On some assemblies, such as cylinder heads, intake manifolds, and exhaust manifolds, bolts may have to be retightened after operation and heating. This is because expansion and contraction due to temperature changes can cause the fasteners to loosen.

Caution

Many late-model parts are made of plastic or composite materials. These parts are more delicate than metal parts and are easily damaged from overtorquing.

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Thread Repairs

Threaded holes in parts can become damaged, requiring repairs. A technician must be capable of repairing damaged threads quickly and properly.

Minor Thread Repairs

Minor thread damage includes nicks, partial flattening, and other less serious problems with the fastener or part. Minor thread damage can usually be repaired with a thread chaser. A thread chaser "cleans up" slightly damaged internal and external threads. The chaser is run through or over the threads to restore them, **Figure 8-14**.

Major Thread Repairs

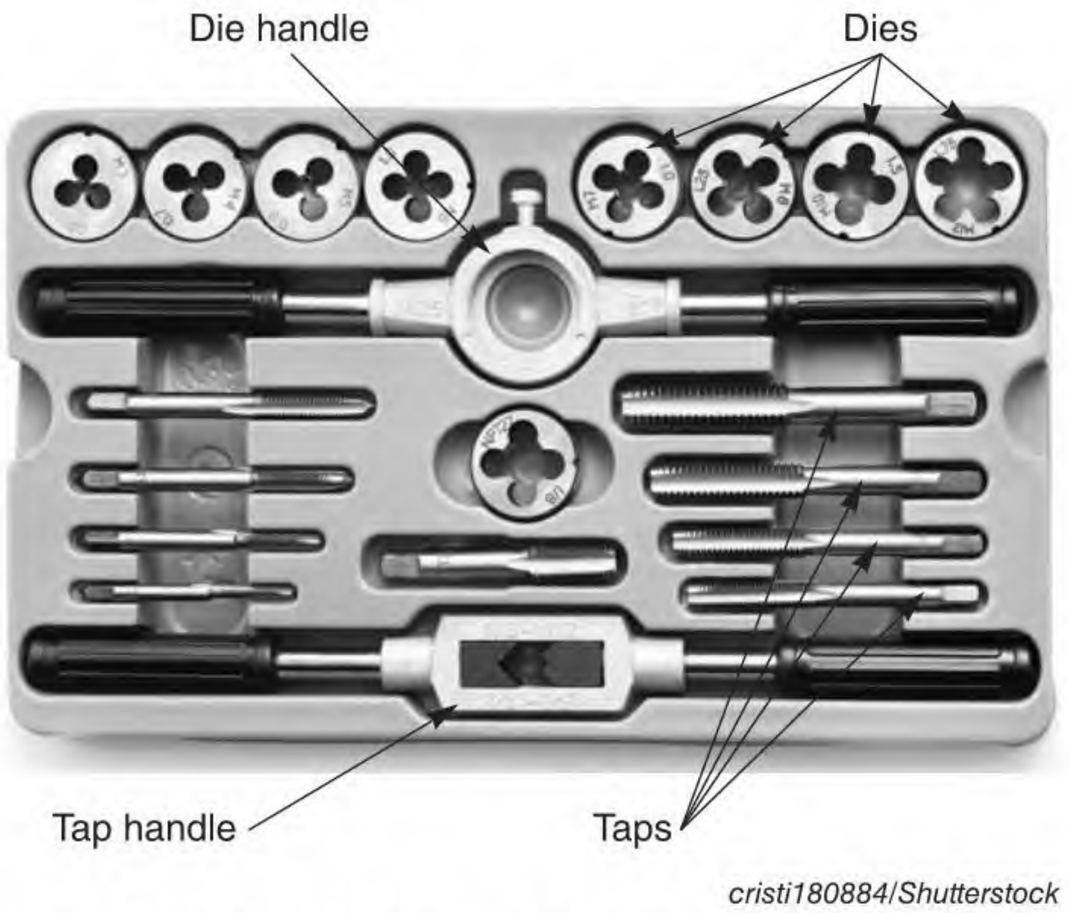
Major thread damage generally includes badly smashed or stripped threads. Sometimes, major thread damage is repaired with either a tap or die. A ***tap*** is a threaded tool for cutting internal threads in holes. Various tap shapes are available. Some are for starting the threads. Others are for cutting the threads all the way to the bottom of a hole. A ***die*** cuts external threads. It can be used to cut threads on metal rods, bolts, shafts, and pins. See **Figure 8-15**.

Taps and dies are mounted in special handles called tap handles or die handles. The tool must be held squarely while being rotated into the work, **Figure 8-16**. As soon as the tap or die begins to bind, back the tool off about a quarter turn. This clears away the metal cuttings. Then, the cut can be made another half turn deeper. Keep rotating the tool a half turn in and a quarter turn out until the cut is complete.



Snap-on Tool Corp.

Figure 8-14. Thread chasers can be used to clean up slightly damaged internal or external threads.



cristi180884/Shutterstock

Figure 8-15. Taps and dies can be used to repair major thread damage. They are often sold in sets that contain the tools needed to repair a variety of thread types.

Tap and Die Rules

- Never force a tap handle or the tool may break. Back off the handle to clean out metal shavings.
- Keep the tap and die well oiled to ease cutting.
- Always use the right size tap in the correct size hole.



smuay/Shutterstock

Figure 8-16. The tap or die fits into a special handle. The handle is held square as the tool is turned into the work. Back the handle off to clean metal out of the threads. A taper tap is used to start threads in a hole. Then, a plug tap and a bottoming tap are used to cut the threads to the bottom of the hole.

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- Use coarse threads when threading or tapping into soft metal, like aluminum. Coarse threads hold better than fine threads. Use fine threads on harder metals, like steel.

Tapping Oversize

When a thread chaser or tap cannot be used to clean up damaged threads, the hole can be drilled and tapped oversize. A drill and tap size chart is used to determine right size drill bit and tap, **Figure 8-17**. For example, a 27/64" drilled hole should have a 1/2" coarse tap used in it. First, drill the hole one diameter or size larger than the original hole. Then, cut new threads in the drilled hole with the correct size tap. A larger bolt can then be installed in the threaded hole.

Thread Repair Insert

A ***thread repair insert*** should be used when the use of an oversize hole and fastener is not acceptable. The insert takes the place of damaged internal threads and allows the use of the original-size bolt.

To use a thread repair insert, drill the hole oversize as described in the insert manufacturer's instructions. Then, tap the hole. Finally, screw the insert into the threaded hole. The inside of the insert contains threads that are the same size as those in the original hole. See **Figure 8-18**.

Removing Damaged Fasteners

An automotive technician must be able to remove broken bolts, screws, and studs, as well as fasteners with rusted or rounded-off heads. Certain tools and methods are needed for removing problem fasteners. Refer to **Figure 8-19**.

- ***Locking pliers*** can sometimes be used to remove fasteners with heads that are badly rusted and rounded off. Lock the pliers tightly on the bolt or nut for removal.
- A ***stud puller***, or stud wrench, can remove studs and bolts broken off above the surface of the part. This tool is also used to install studs. Position the stud puller so it will not clamp onto and damage the threads.
- In some cases, broken fasteners are too short to grasp with any tool. Either cut a slot in the fastener with a hacksaw or weld on another bolt head. Then use a screwdriver or wrench to unscrew the broken bolt.

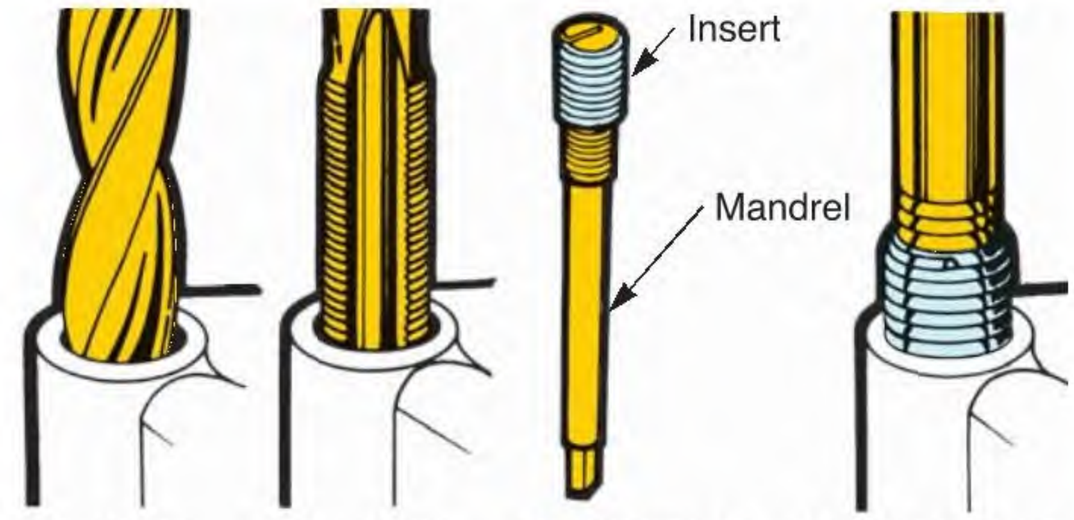
American National Screw Thread Pitches

Coarse Standard Thread (N.C.) Formerly U.S. Standard Thread				
Bolt or tap size	**Threads per inch**	**Outside diameter at screw**	**Drill sizes**	**Decimal equivalent of drill**
1	64	.073	53	0.0595
2	56	.086	50	0.0700
3	48	.099	47	0.0785
4	40	.112	43	0.0890
5	40	.125	38	0.1015
6	32	.138	36	0.1065
8	32	.164	29	0.1360
10	24	.190	25	0.1495
12	24	.216	16	0.1770
1/4	20	.250	7	0.2010
5/16	18	.3125	F	0.2570
3/8	16	.375	5/16	0.3125
7/16	14	.4375	U	0.3680
1/2	13	.500	27/64	0.4219
9/16	12	.5625	31/64	0.4843
5/8	11	.625	17/32	0.5312
3/4	10	.750	21/32	0.6562
7/8	9	.875	49/64	0.7656
1	8	1.000	7/8	0.8750
1 1/8	7	1.125	63/64	0.9843
1 1/4	7	1.250	1 7/64	1.1093
Fine Standard Thread (N.F.) Formerly S.A.E. Thread				
Bolt or tap size	**Threads per inch**	**Outside diameter at screw**	**Drill sizes**	**Decimal equivalent of drill**
0	80	.060	3/64	0.0469
1	72	.073	53	0.0595
2	64	.086	50	0.0700
3	56	.099	45	0.0820
4	48	.112	42	0.0935
5	44	.125	37	0.1040
6	40	.138	33	0.1130
8	36	.164	29	0.1360
10	32	.190	21	0.1590
12	28	.216	14	0.1820
1/4	28	.250	3	0.2130
5/16	24	.3125	I	0.2720
3/8	24	.375	Q	0.3320
7/16	20	.4375	25/64	0.3906
1/2	20	.500	29/64	0.4531
9/16	18	.5625	0.5062	0.5062
5/8	18	.625	0.5687	0.5687
3/4	16	.750	11/16	0.6875
7/8	14	.875	0.8020	0.8020
1	14	1.000	0.9274	0.9274
1 1/8	12	1.125	1 3/64	1.0468
1 1/4	12	1.250	1 11/64	1.1718

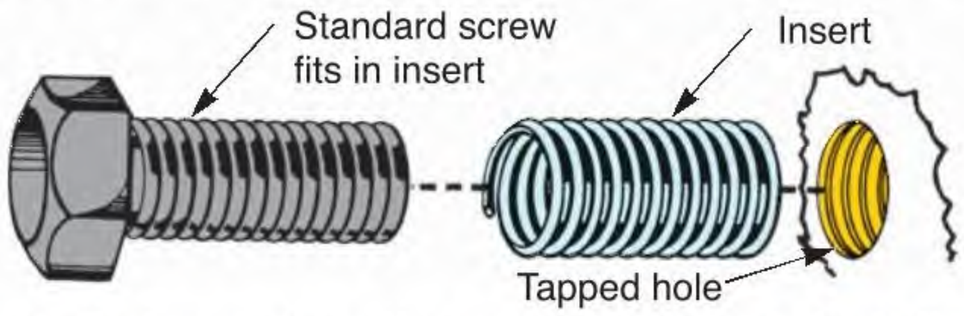
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Figure 8-17. A tap drill chart tells you what size hole should be drilled for different taps. The drill bit size is in two right columns. The tap or bolt size is in left column.

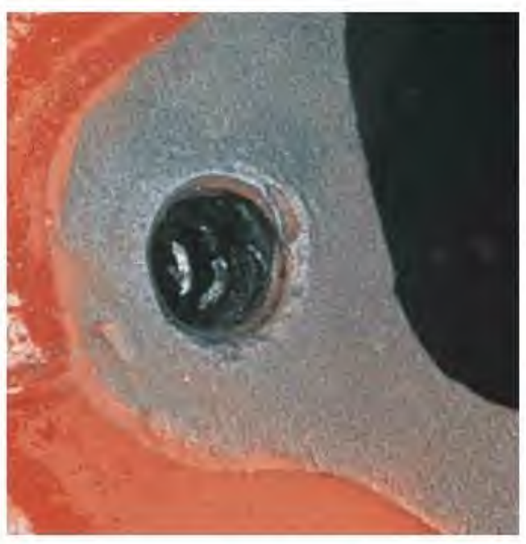
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A—First, drill the hole oversize. **B—Next, tap the hole oversize.** **C—Mount the insert on a mandrel.** **D—Thread the insert into the hole.**



E—The insert allows the use of the original-size bolt.



F—Damaged threads before a repair.



G—An installed insert.

Chrysler and The Eastwood Company

Figure 8-18. Basic method for using an insert to repair stripped threads.

- When the fastener is broken flush with the part surface, a hammer and punch can sometimes be used to remove it. Angle the punch so the blows from the hammer can drive out the broken fastener.
- A ***screw extractor***, or "easy-out," can also be used to remove bolts that are broken flush with or below the part surface. See **Figure 8-20**. To use a screw extractor, drill a hole in the center of the broken fastener. Then, lightly tap the extractor into the hole using a hammer. Finally, unscrew the broken bolt by turning the extractor with a wrench.
- On some broken bolts, you may have to drill a hole almost as large as the inside diameter of the threads. Then, use a tap or punch to remove the thread shell. The thread shell is the thin layer of threads remaining in the hole.

Caution

Be extremely careful not to break a tap or a screw extractor. They are hardened steel and cannot be easily drilled out of a hole. You will compound your problems if you break off one of these tools in a hole.

Tech Tip

If you accidentally break a tap off in a part, screw the broken piece back into the hole until the flutes, or grooves, in the two pieces of the tap align. Next, insert nails or pieces of cotter pin into the grooves and down through both pieces of the tap. You should then be able to unscrew both pieces of the broken tap from the hole. See **Figure 8-21**.

Rust Penetrant

Rust penetrant is a chemical that dissolves rust or corrosion. It is often applied to rusted fasteners to aid in their removal. The penetrant is sprayed or squirted on the rusty fastener and allowed to soak for a few minutes. This often helps free up the fastener, allowing it to be removed without breakage. See **Figure 8-22**.

Gaskets and Seals

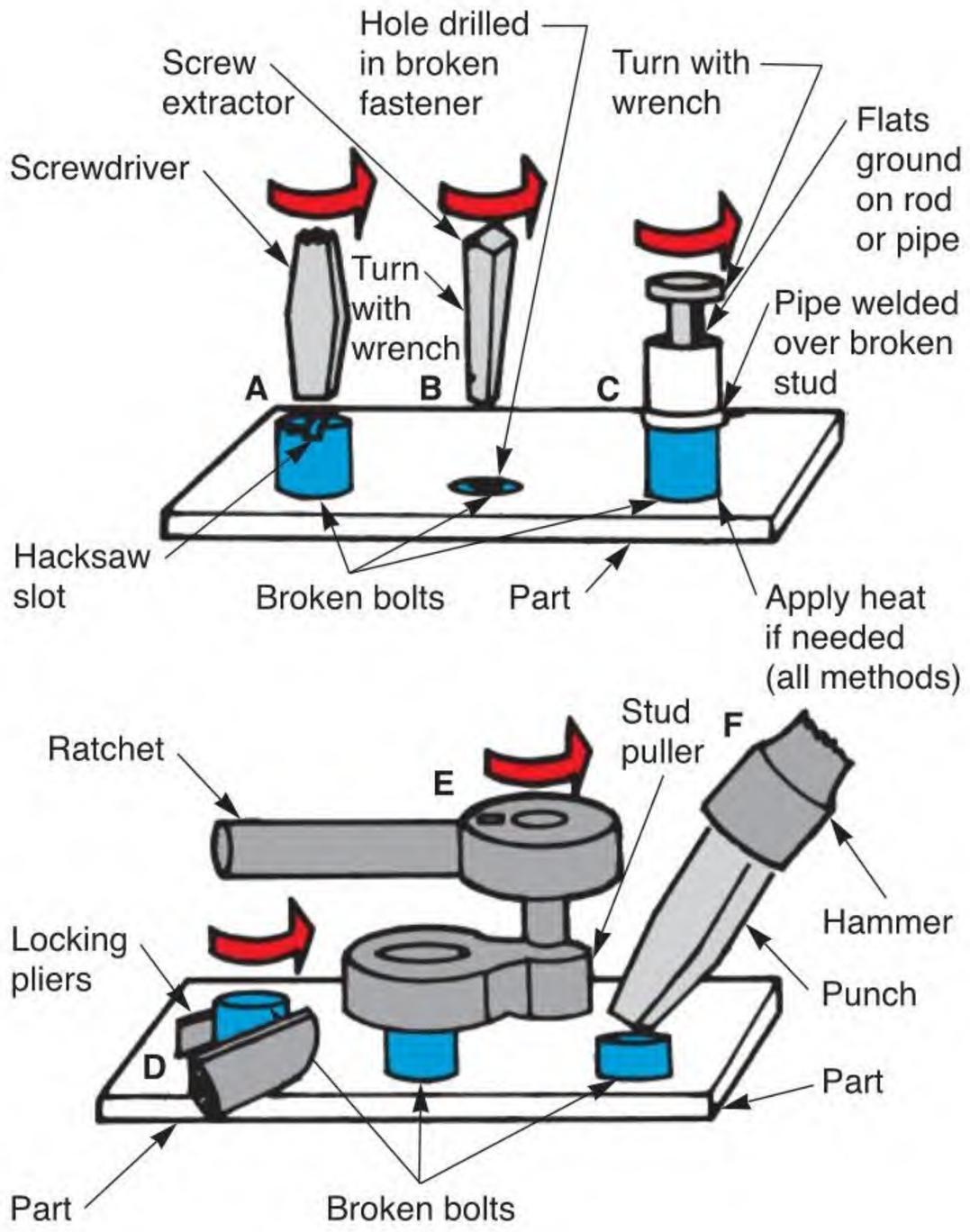
Gaskets and seals are used between parts to prevent leakage of engine oil, coolant, transmission oil, and other fluids. It is important to understand a few principles about gaskets and seals. If gaskets or seals are serviced improperly, customer complaints and serious mechanical failures can result.

Gaskets

A ***gasket*** is a soft, flexible material placed between parts to prevent leakage. It can be made of fiber materials, rubber, neoprene (synthetic rubber), cork, treated paper, or thin steel.

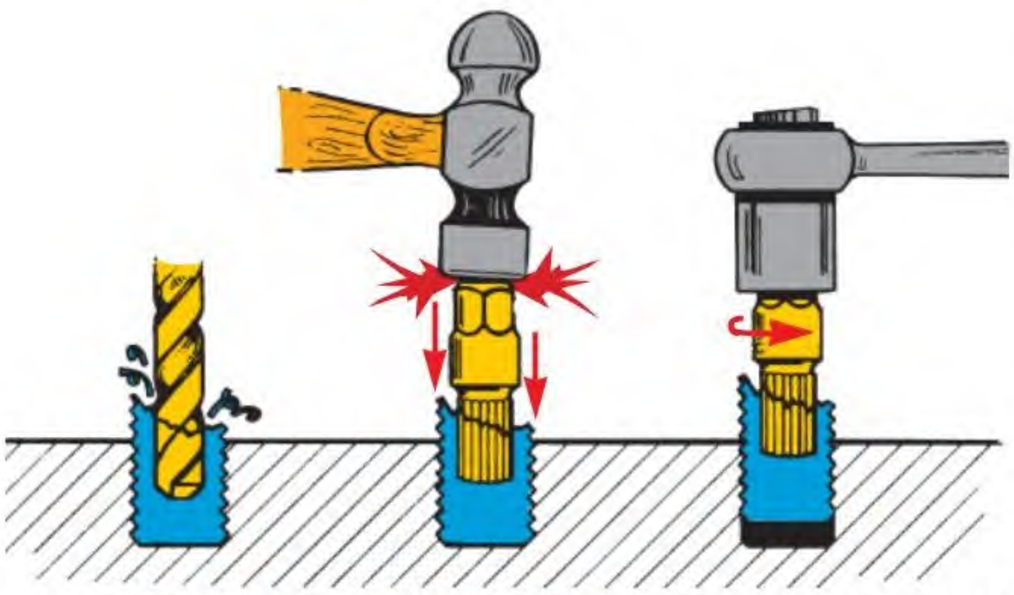
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A—Hacksaw a slot and turn with a screwdriver.
B—Drill a hole and use a screw extractor.
C—Weld a piece of slotted pipe onto the bolt and turn with a wrench.



D—Grasp and turn with locking pliers.
E—Use a stud extractor and ratchet.
F—Use a hammer and punch to rotate fasteners.

Figure 8-19. Study various ways to remove broken bolts.



A—First, drill a hole in the center of the broken bolt. **B—Next, tap the extractor into the hole.** **C—Finally, unscrew the extractor and the broken bolt with a wrench.**

Lisle Tools

Figure 8-20. A screw extractor will usually rotate and remove broken bolts.

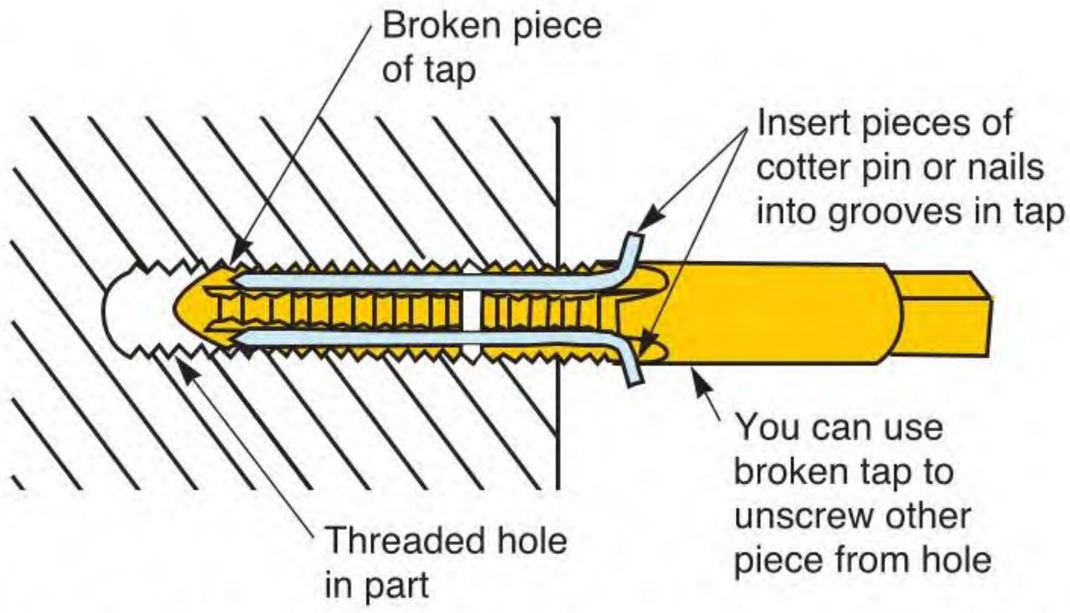


Figure 8-21. If you accidentally break a tap, try unscrewing it using nails or cotter pins to hold both pieces of the broken tap together.

When the parts are fastened tightly together, the gasket is compressed and deformed. This forces the gasket material to fill small gaps, scratches, dents, or other imperfections in the mating surfaces. A leakproof seal is produced. See **Figure 8-23**.

Using Gaskets

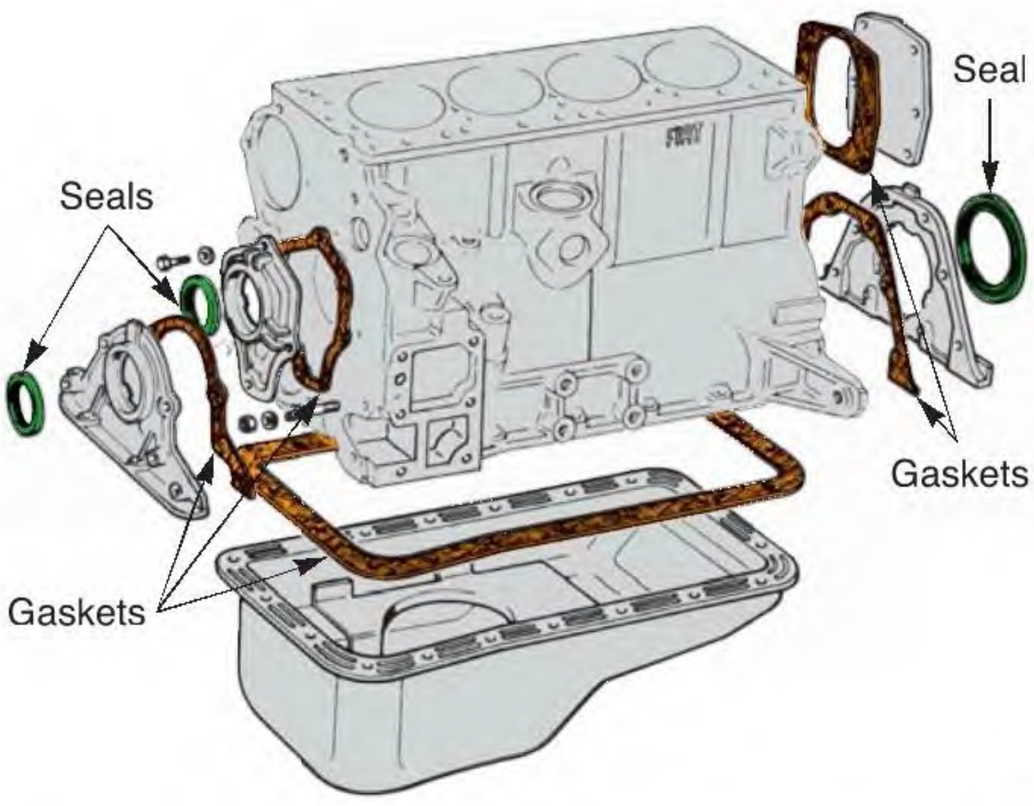
When using gaskets, you need to inspect for leaks before disassembly. If the two parts are leaking, the part surfaces should be inspected closely for problems. Also, be careful not to nick, gouge, or dent mating surfaces while removing parts. The slightest

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Fel-Pro Gaskets

Figure 8-22. On rusted threads, such as those on this brake bleed screw, use rust penetrant to help ease turning and prevent screw breakage.



Fiat

Figure 8-23. Gaskets prevent leakage between stationary parts. Seals prevent leakage between moving parts.

unevenness can cause leakage. While working with gaskets, remember the following:

1. Clean off old gaskets carefully. All the old gasket material must be scraped or wire brushed from the parts. Use care, especially on aluminum and brass. These soft metals are easily damaged. Use a dull scraper and wire brush lightly.
2. Wash and dry parts thoroughly using solvent. Blow them dry with compressed air. Then, wipe mating surfaces with a clean shop towel.
3. Compare the new gasket to the shape of the mating surface. All holes and sealing surfaces must match perfectly.
4. Use sealer if needed! Some gaskets require sealer. Sealer is normally used where two different gaskets come together. It will prevent leakage where gaskets overlap. Check a service manual for details. However, use sealer sparingly. Too much sealer could clog internal passages in the assembly.
5. After fitting the gasket and parts in place, screw all bolts in by hand. This will ensure proper part alignment and threading of fasteners. It also lets you check bolt lengths.
6. When more than one bolt is used to hold a part, use a crisscross tightening pattern and tighten the fasteners in steps. This will ensure even gasket compression and proper sealing. First, tighten all the bolts to about half of their torque specification. Next, tighten them to three-fourths torque. Then, tighten the fasteners to full torque. As a final precaution, retorque each fastener.

Caution

Do not overtighten fasteners. It is very easy to tighten the bolts enough to dent sheet metal parts and smash or break the gaskets. Apply only the specified torque.

Tech Tip

The trend in gasket design is to use large, synthetic-rubber O-ring-type gaskets instead of fiber or treated paper gaskets. These new gaskets can have a round, D-shaped, or odd-shaped cross-section to help seal with the cover design. Follow the manufacturer's instructions when installing these types of gaskets. See **Figure 8-24**.

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Figure 8-24. Many modern engines use synthetic O-ring-type gaskets. These specially shaped gaskets fit down into a small groove formed in the part.

Sealers

A gasket is commonly coated with a ***sealer*** to help prevent leakage and to hold the gasket in place during assembly. There are numerous kinds of sealers. They have different properties and are designed for different uses.

Hardening sealers are used on permanent assemblies, such as fittings and threads, and for filling uneven surfaces. They are usually resistant to heat and most chemicals.

Nonhardening sealers are for semipermanent assemblies, such as cover plates, flanges, threads, and hose connections. They are also resistant to most chemicals and moderate heat. Shellac is a nonhardening sealer. It is a sticky substance that remains pliable. It is frequently used on fiber gaskets as a sealer and to hold the gasket in place during assembly.

Always read the manufacturer's label and the service manual before selecting a sealer. See **Figure 8-25**.

Form-in-Place Gaskets

Form-in-place gaskets are special sealers used instead of conventional fiber or rubber gaskets. Two common types of form-in-place gaskets are room temperature vulcanizing (RTV) sealer and anaerobic sealer.

When selecting a form-in-place gasket, refer to a manufacturer's service manual. Scrape or wire brush all sealing surfaces to remove loose material. Check that all gasket flanges are flat. Using a shop towel and solvent, wipe off oil and grease. The sealing surfaces must be clean and dry before using a form-in-place gasket.

RTV sealer, also called silicone sealer, dries in contact with air. It is used to form a rubber-like gasket on thin, flexible flanges. RTV sealer normally comes in a tube, as shown in **Figure 8-26.**

Type	Temperature range	Use	Resistant to	Characteristics
shellac	–65° to 350° F (–54° to 177° C)	general assembly: gaskets of paper, felt, cardboard, rubber, and metal	gasoline, kerosene, grease, water, oil, and antifreeze mixtures	dries slowly sets pliable alcohol soluble
hardening gasket sealant	–65° to 400° F (–54° to 205° C)	permanent assemblies: fittings, threaded connections, and for filling uneven surfaces	water, kerosene, steam, oil, grease, gasoline, alkali, salt solutions, mild acids, and antifreeze mixture	dries quickly sets hard alcohol soluble
nonhardening gasket sealant	–65° to 400° F (–54° to 205° C)	semipermanent assemblies: cover plates, flanges, threaded assemblies, hose connections, and metal-to-metal assemblies	water, kerosene, steam, oil, grease, gasoline, alkali, salt solutions, mild acids, and antifreeze solutions	dries slowly nonhardening alcohol soluble

Fel-Pro Gaskets

Figure 8-25. Note the different uses and characteristics of various types of sealers.

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Fel-Pro Gaskets

Figure 8-26. RTV sealer is commonly recommended where two different gaskets join to avoid fluid leakage.

Tech Tip

Depending on the brand, an adhesive or sealer can have a shelf life from one year to two years. Always inspect the package for the expiration date before using the sealer. If too old, RTV sealer will not cure and seal properly, which could result in engine leaks and time-consuming, costly repairs.

RTV sealer should be applied in a continuous bead that is approximately 1/8" (3 mm) wide. All mounting holes must be circled. Locating dowels are often used to prevent the sealing bead from being smeared. If the continuous bead is broken, a leak may result. Uncured RTV can be removed with a rag. Components should be torqued in place while the RTV is still wet to the touch, usually within about 10 minutes of application.

Anaerobic sealer cures to a plastic-like substance in the absence of air and is designed for tightly fitting, thick parts. It is used between two smooth, true surfaces, not on thin, flexible flanges. The RTV-sealed section contacts the flexible engine oil pan. The anaerobic-sealed section touches the strong, machined engine block.

Anaerobic sealer should be applied sparingly. Use a 1/16"–3/32" (1.5 mm–2 mm) wide bead on one gasket surface. Be certain that the sealer surrounds each mounting hole. Typically, bolts should be torqued within 15 minutes of sealer application.

Tech Tip

A few gasket manufacturers sell precut gaskets designed to replace form-in-place gaskets. When working on an engine installed in a vehicle, it can be difficult to properly clean the sealing surfaces. It may also be impossible to fit a part on the engine without hitting and breaking the bead of sealant. When this is the case, a precut gasket might work better than a form-in-place gasket during an in-vehicle repair.

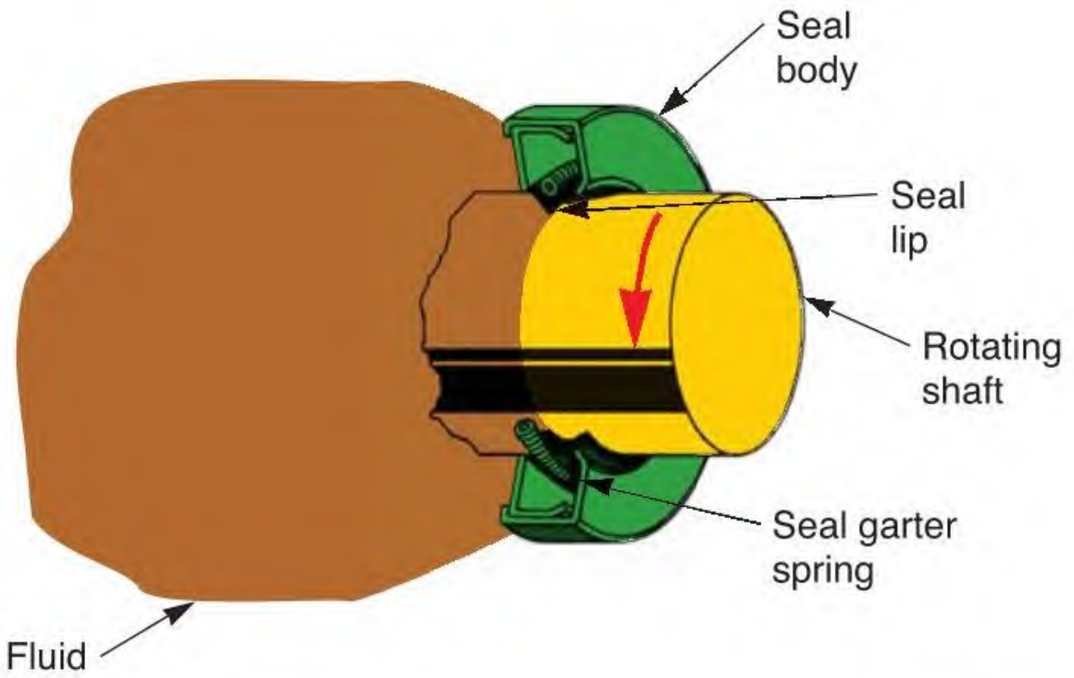
Seals

Seals prevent leakage between a stationary part and a moving part. They can be found in engines, transmissions, power steering units, and almost any part containing fluid and moving parts. A seal allows a shaft to spin or slide inside a nonmoving part without fluid leakage. Seals are normally made of synthetic rubber molded onto a metal body, **Figure 8-27**.

Seal Rules

There are several important procedures to remember when working with seals.

- Inspect the seal for leakage before disassembly. If a seal is leaking, there may be other problems besides a defective seal. Look for a bent shaft, misaligned seal housing, or damaged parts. Leakage requires close inspection after disassembly.



Caterpillar Tractor

Figure 8-27. This oil seal is mounted in a stationary part. The seal lip faces the fluid and keeps it inside the part. The shaft spins inside the seal with minimum wear because of the lubricating fluid inside the seal.

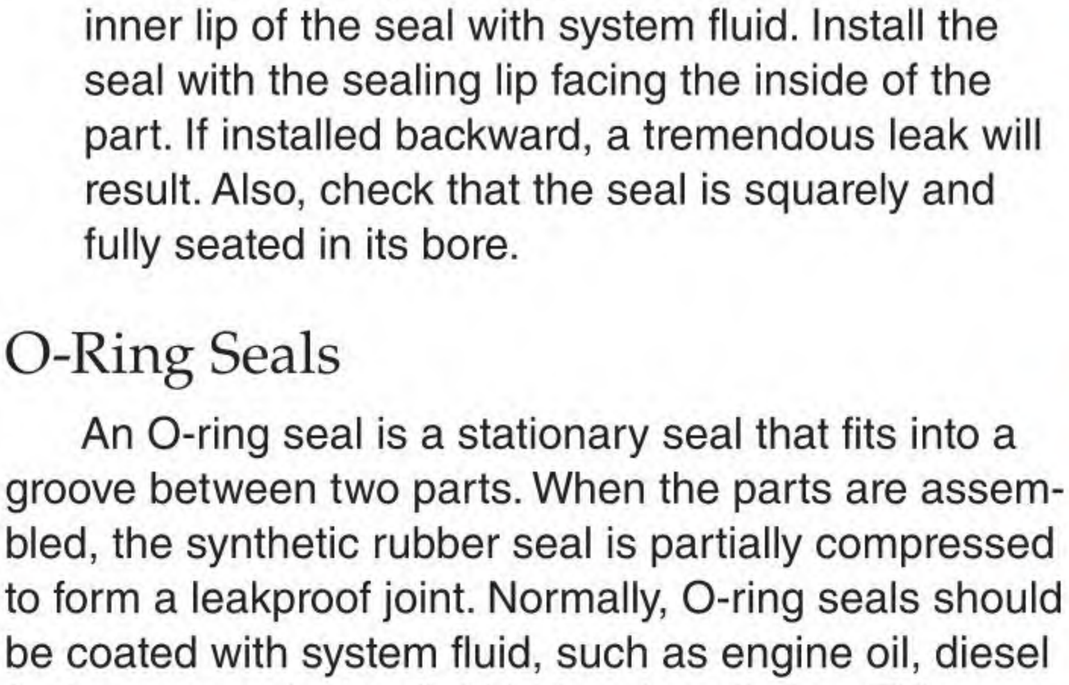
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- Remove the old seal carefully, without scratching the seal housing. Sometimes, a special puller is required for seal removal. This is discussed in later chapters.
- Inspect shafts for wear and burrs, **Figure 8-28**. Look at the shaft closely where it contacts the seal. It should be smooth and flat. File off any burrs that may cut the new seal. A badly worn shaft will require polishing, a shaft sleeve repair kit, or replacement.
- Compare the old seal to the new seal. Hold them next to each other. Both the inside diameter (ID) and the outside diameter (OD) must be the same. To double-check the ID, slip the seal over the shaft. It should fit snugly to prevent leakage.
- Install the new seal correctly. Coat the outside of the seal housing with approved sealer. Coat the inner lip of the seal with system fluid. Install the seal with the sealing lip facing the inside of the part. If installed backward, a tremendous leak will result. Also, check that the seal is squarely and fully seated in its bore.

O-Ring Seals

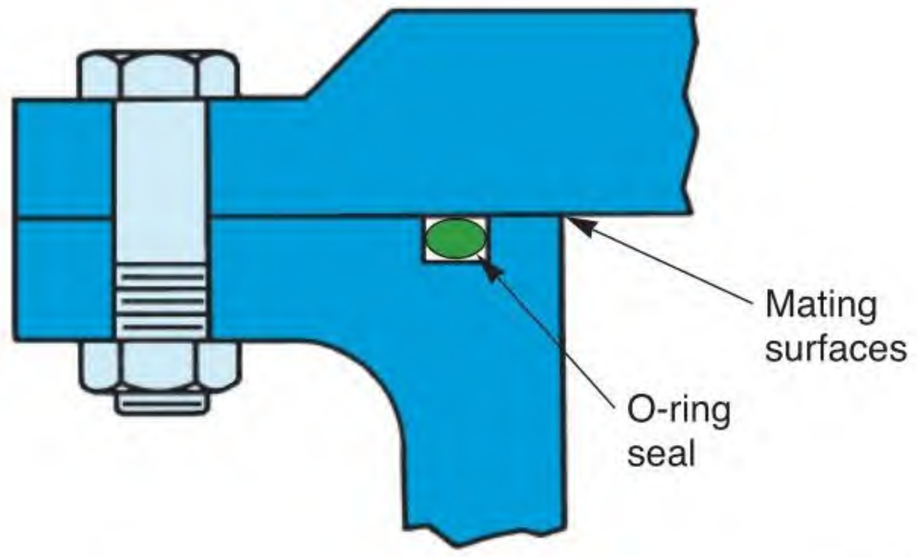
An O-ring seal is a stationary seal that fits into a groove between two parts. When the parts are assembled, the synthetic rubber seal is partially compressed to form a leakproof joint. Normally, O-ring seals should be coated with system fluid, such as engine oil, diesel fuel, or transmission fluid before installation. This helps the parts slide together without scuffing or cutting the seal. See **Figure 8-29**.

Usually, sealants are not used on O-ring type seals. When in doubt about any seal installation, refer to a shop manual.



Federal Mogul

Figure 8-28. Always inspect seals and shafts for damage. Even the smallest nicks or scratches could cause leakage.



Deere & Co.

Figure 8-29. O-ring seals prevent leakage by applying pressure to multiple surfaces, as shown. When the parts are bolted together, they partially compress and clamp the O-ring to form a good seal for air, coolant, or lubricant.

Other Information

Special gaskets and seals sometimes require other installation techniques. These special situations are discussed in later chapters.



Workplace Skills

One of the most serious and common mistakes in automotive service is not torquing wheel lug nuts properly. Improper wheel lug nut torque can warp the brake rotor or wheel, or allow the wheel nuts to loosen, which can lead to a very dangerous situation. To torque wheel lug nuts correctly, run the lug nuts down lightly with an air impact wrench and then tighten them to factory specifications with a torque wrench. If tightening the lug nuts in this way prevents even one problem per year, it was worth the extra time to do the job right.

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Summary

- Fasteners are devices that hold the parts of a vehicle together.
- When a high-quality bolt is threaded into a part without a nut, it can also be called a cap screw.
- Bolt size is a measurement of the outside diameter of the bolt threads.
- Tensile strength, or grade, refers to the amount of pull or stretch a fastener can withstand before breaking.
- A flat washer increases the clamping surface under the fastener.
- A lock washer prevents the bolt or nut from becoming loose under stress and vibration.
- It is very important that bolts and nuts are torqued properly.
- Torque specifications are tightening values given by the vehicle manufacturer.
- Generally, tightening a group of fasteners on a part follows a crisscross pattern.
- A torque wrench measures the twisting force applied when tightening a threaded fastener.
- A tap is a threaded tool for cutting internal threads in holes. A die cuts external threads.
- Machine screws are similar to bolts, but they normally have screwdriver-type heads.
- Numerous types of nonthreaded fasteners, such as snap rings, clips, and adhesives, are utilized in the assembly of a vehicle.
- Adhesives are widely used on most vehicles.
- A gasket is a soft, flexible material placed between stationary parts to prevent leakage.
- RTV sealer, also called silicone sealer, cures in the presence of air. It is used to form a rubber-like gasket on thin, flexible flanges.
- Seals prevent leakage between a stationary part and a moving part.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

adhesive
bolt
bolt head marking
bolt tightening sequence
cap screw
cotter pin
crisscross pattern
die
fastener
gasket
key
keyseat
keyway
locking pliers
machine screw
nonthreaded fastener
nut
rust penetrant
screw extractor
seal
sealer
set screw
sheet metal screw
snap ring
stud puller
tap
tapping screw
tensile strength
thread repair insert
torque specification
torque wrench
torque-to-yield
torquing
washer

Activities

1. Prepare a large chart for the shop showing how to read information given on a bolt.
2. Demonstrate the proper methods for repairing thread damage.

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Review Questions

Answer the following questions using the information provided in this chapter.

1. Define the terms *bolt* and *nut*.
2. How are bolts and nuts usually named in automotive terminology?
3. List and explain the four basic dimensions of a bolt.
4. Customary bolt heads are marked with _____ or _____ marks to indicate bolt strength. Metric bolts use a(n) _____ system to indicate bolt strength.
5. A(n) _____ is a safety device commonly used with a slotted nut.
6. Describe the difference between a flat washer and a lock washer.
7. What are torque specifications?
8. What is a bolt or nut tightening sequence?
9. Which of the following is *not* used for thread repair?
   (A) Tap.
   (B) Die.
   (C) Chaser.
   (D) Chisel.
10. A(n) _____ and _____ is needed to select the right size drill and tap.
11. How do you use a thread repair insert?
12. Describe six ways to remove broken fasteners.
13. Which of the following group of sealers is used on permanent assemblies?
   (A) Hardening.
   (B) Nonhardening.
   (C) Form-in-place.
   (D) All of the above.
14. Explain when RTV and anaerobic sealers are recommended.
15. Describe five rules for working with seals.

ASE-Type Questions

1. A broken bolt must be replaced. Technician A says that thread pitch is the same as thread coarseness. Technician B says that bolt head markings specify the tensile strength of a bolt. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Which of the following is a safety device that keeps a slotted nut from turning or coming off?
   (A) Lock tab.
   (B) Snap ring.
   (C) Cotter pin.
   (D) Thread pitch.
3. Snap rings hold and fit into grooves in:
   (A) pins.
   (B) gears.
   (C) shafts.
   (D) All of the above.
4. Set screws are headless fasteners designed to accept a(n):
   (A) hex wrench.
   (B) screwdriver.
   (C) Allen wrench.
   (D) All of the above.
5. Which of the following is determined by measuring bolt length change while torquing a bolt?
   (A) Torque stretch.
   (B) Torque-to-yield.
   (C) Torquing sequence.
   (D) Torque specification.
6. Fastener tightening generally follows a:
   (A) clockwise pattern.
   (B) crisscross pattern.
   (C) left-to-right pattern.
   (D) counterclockwise pattern.
7. Which of the following is *not* a basic rule to follow when using a torque wrench?
   (A) Avoid using swivel joints.
   (B) Pull only on the wrench handle.
   (C) Clean fastener threads.
   (D) Use short, jerky pull motions for accuracy.

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8. Which threaded tool is used for cutting internal threads in holes?
   (A) Tap.
   (B) Helicoil.
   (C) Thread chaser.
   (D) Thread repair insert.
9. Each of the following is a tool that can be used to help remove problem fasteners *except:*
   (A) hacksaw.
   (B) stud puller.
   (C) die.
   (D) screwdriver.
10. While installing gaskets, Technician A believes gaskets alone will produce leakproof seals. Technician B believes that some gaskets require sealer to further prevent leakage where gaskets overlap. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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Chapter 9
Vehicle Maintenance, Fluid Service, and Recycling

After studying this chapter, you will be able to:

- Check a car's fluid levels.
- Explain the importance of vehicle maintenance.
- Locate fluid leaks.
- Replace engine oil and filter.
- Change automatic transmission fluid and filter.
- Perform a grease job.
- Inspect for general problems with hoses, belts, idler pulleys, and other components.
- Demonstrate safe practices while working with vehicle fluids.
- Recycle or properly dispose of auto shop wastes.
- Correctly answer ASE certification test questions on fluid service and vehicle maintenance.

Vehicle fluids include engine oil, coolant, brake fluid, transmission fluid, power steering fluid, and other liquids. When working as a technician, you must be proficient with checking and changing vehicle fluids. Service station attendants, oil change technicians, and even master technicians must check, add, or replace fluids.

Your first job might involve working in an oil change shop or a tire specialty shop. Apprentice technicians "cut their teeth" doing fluid service, grease jobs, rotating and changing tires, and light mechanical repairs. Therefore, this chapter is extremely important to your future employment. It is your chance to learn basic service tasks essential to what may be your first job in an auto shop. Study this material carefully.

The last section of the chapter discusses recycling. To help save our environment, you should recycle as many automotive parts, fluids, and materials as possible. Used batteries, tires, antifreeze, and oil can all be recycled into new products while saving energy

Lubrication Service

Lubrication service is vital to keeping a vehicle in good working order. A technician must be familiar with all aspects of lubrication service, which include:

- Checking fluid levels and fluid condition.
- Changing engine oil and filter.
- Changing automatic transmission fluid.
- Lubricating (greasing) chassis parts that have grease fittings.
- Locating fluid leaks and other obvious problems.
- Following state regulations for recycling and disposal of waste fluids.

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Vehicle Maintenance

Vehicle maintenance includes any operation that will keep a vehicle in good operating condition. Without proper care, the life of an automobile may be reduced by thousands of miles. For example, fluids can become contaminated and change chemically after prolonged use. This can cause wear, corrosion, and mechanical failure of parts.

Tech Tip

A wise saying goes, "You can pay now or you can pay later." In the automotive field, this means that your customers can pay a little now for maintenance or pay a whole lot more later for repairs. A poorly serviced vehicle will wear out and break down much sooner than a well-maintained vehicle. In the long run, vehicle maintenance saves your customers money.

Fluid Service

A service manual contains detailed information on how to check fluid levels. The manual will usually describe:

- Location of all fluid checkpoints, **Figure 9-1**.
- Location of all fluid fill points.
- Correct interval (time or mileage) between fluid checks and changes.
- Correct type and quantity of fluids to be used.

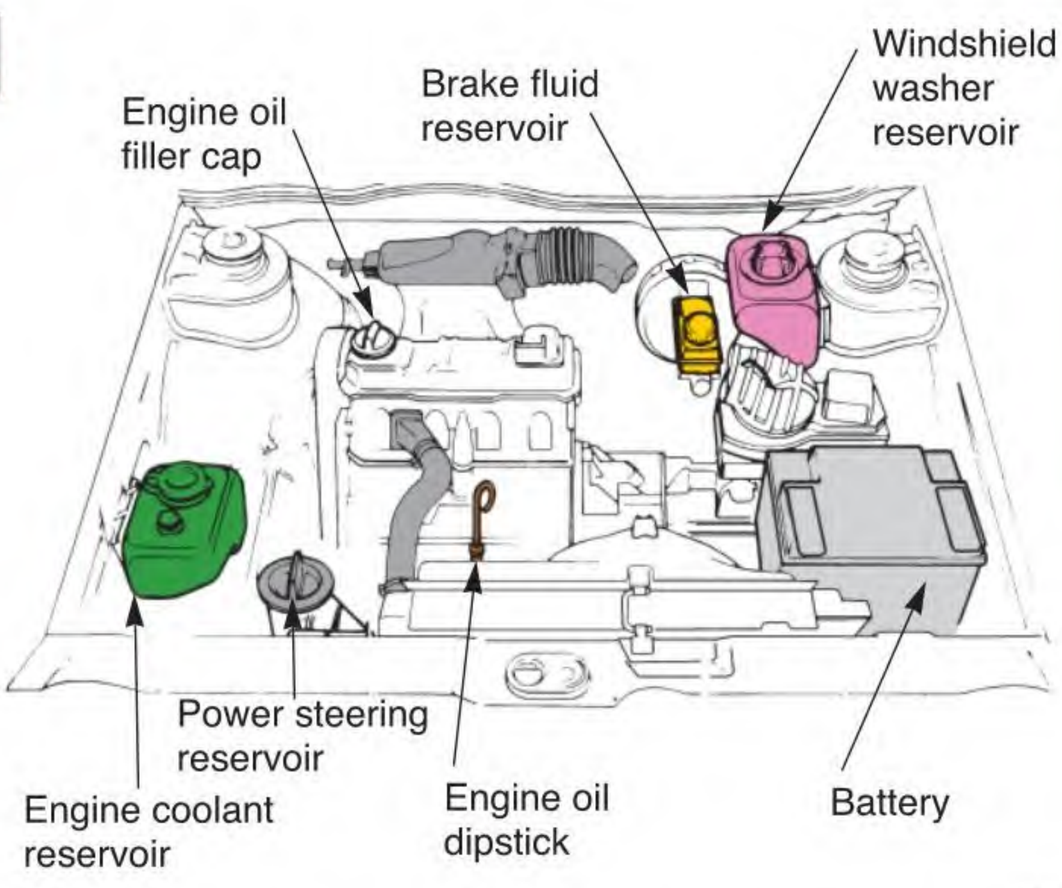


Figure 9-1. A service manual gives the locations of all fluid checkpoints. This illustration shows engine compartment fluid checkpoints.

This information varies by make and model of vehicle. For example, a diesel, supercharged, or turbocharged engine often requires more frequent oil changes than typical engines. Automatic transmission or transaxle fluids, differential lubricants, and other fluids can also vary slightly in chemical content to match the internal design of the assembly.

Tech Tip

A car's warranty may become void if incompatible fluids, incorrect service procedures, or improper intervals are used. For this reason, refer to the manufacturer's recommendations and specifications when servicing fluids.

Fluid capacity is the maximum amount of fluid a reservoir or assembly will hold. The vehicle manufacturer will list fluid capacities for the engine, transmission/transaxle, power steering system, and differential.

Checking Engine Oil

Service Procedure

To check engine oil:

1. Warm the engine to operating temperature.
2. Shut off the engine and allow it to sit for a few minutes.
3. Locate and remove the engine oil dipstick.
4. Wipe off the dipstick and replace it all the way into its tube.
5. Pull the dipstick back out and hold it over your shop rag.
6. Observe the highest point on the dipstick wet from oil. The oil level should be between the ADD (LOW) and FULL marks on the dipstick.

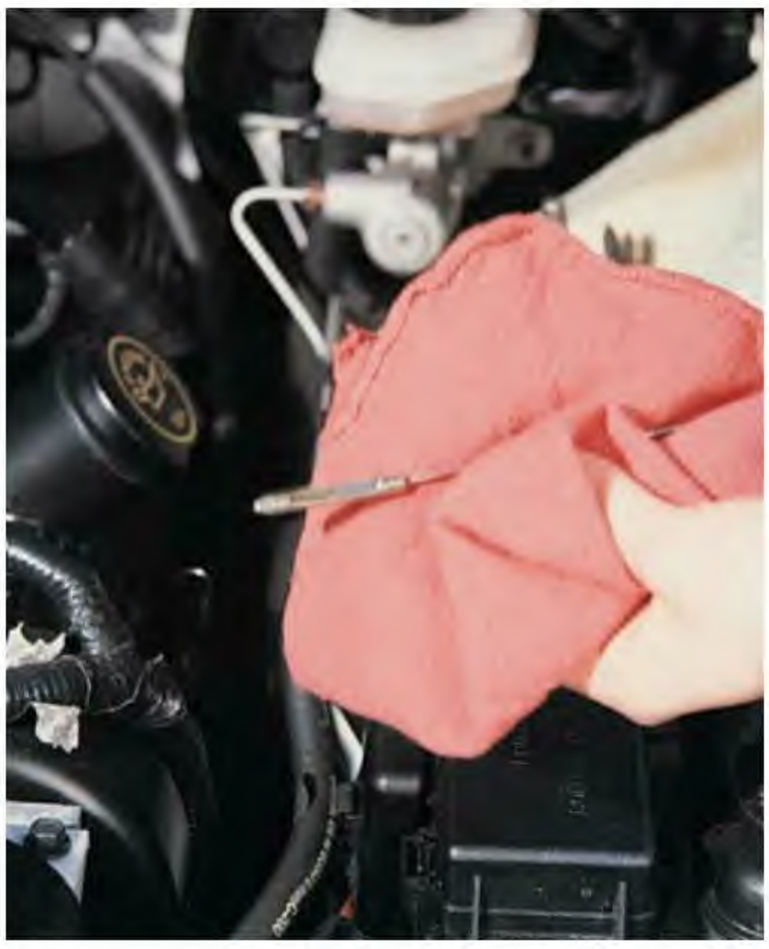
Before reinstalling the dipstick, inspect the condition of the oil. The oil should not be too thick or thin, smell like gasoline, or be too dirty.

If the oil level is low, you must add the correct amount and type of oil. If the oil level is down to the ADD mark, typically one quart is needed. If the dipstick reads halfway between ADD and FULL, you would need to add only one-half quart. See **Figure 9-2**.

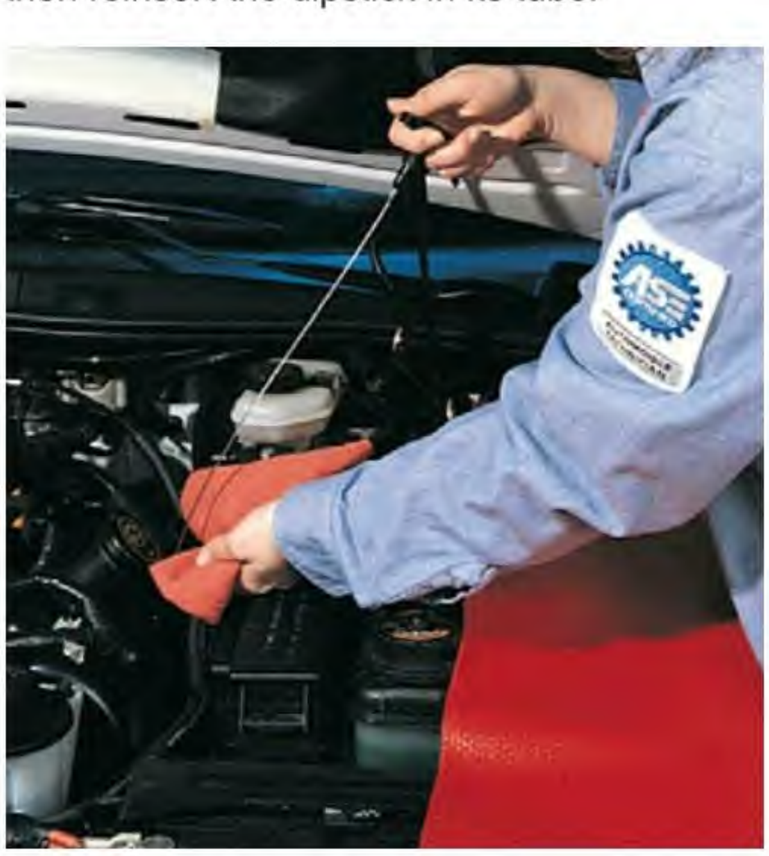
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A—Remove the dipstick.



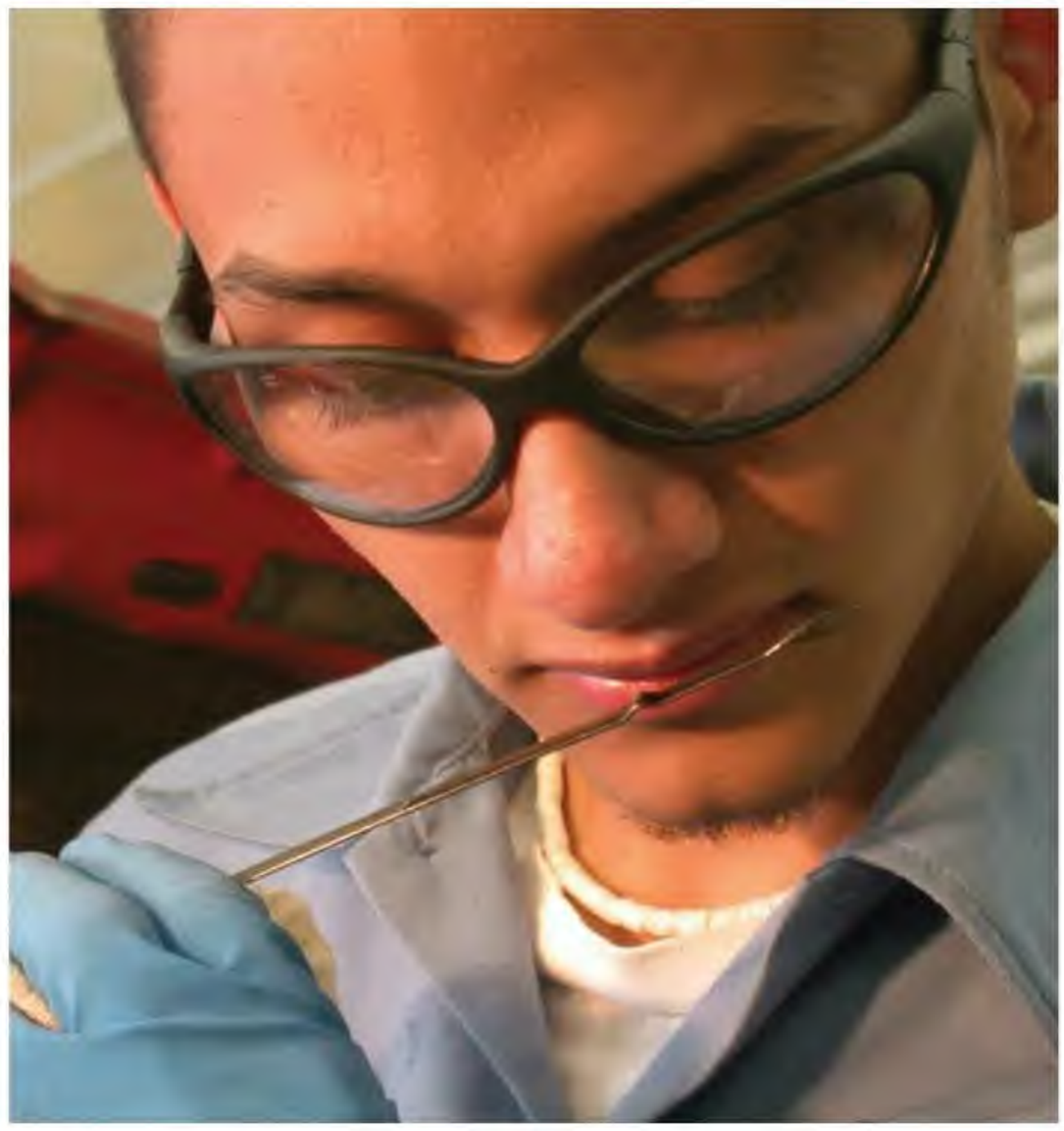
B—Wipe the oil from the dipstick; then reinsert the dipstick in its tube.



C—Remove the dipstick.



D—Look closely to see how far the oil goes up on the dipstick.



E—Determine if the oil smells burned or has turned black and is dirty.



F—Use the recommended type and weight of oil when adding oil to the engine.

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Figure 9-2. Check the amount of oil in the engine using the dipstick.

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Never add too much oil to an engine. Pour in only enough oil to reach the FULL mark. Overfilling can cause ***oil foaming*** (the oil absorbs air bubbles), which reduces the oil's lubricating ability.

Warning

Be careful when checking or changing vehicle fluids. At operating temperature, oil and other fluids can be hot enough to burn your hand, arm, and face. Wear a face shield and oil-resistant gloves when changing an engine's oil and filter.

Adding Engine Oil

Before adding engine oil, obtain the right kind of oil (weight, detergent, synthetic). Unless you have a very high mileage engine, use the same weight of oil that was installed during the last oil change. Use heavier or thicker oil in engines with very high mileage, especially if the engine is knocking, smoking, or has low oil pressure. Thicker oil will help raise oil pressure, cushion excessive bearing clearance, reduce light knocking, and help lower engine blow-by and smoking slightly. For example, some engines require zero weight oil when new. When these engines reach 200,000 miles, they will normally benefit from heavier oil.

To add oil to the engine, remove the oil cap, which is usually on the valve cover. Install a small, clean funnel into the engine opening. Without spilling, pour the oil slowly into the funnel and engine.

Changing Engine Oil and Filter

When changing engine oil, make sure the engine is warm and the vehicle is sitting level. This will ensure that more of the oil contaminants are suspended in the oil and are drained out of the engine. If the oil is cold, the oil will drain more slowly and debris will settle to the bottom of the oil pan and cylinder heads.

Service Procedure

To change the engine oil:

1. Warm the engine to operating temperature.
2. Put on eye or face protection and work gloves.
3. Raise the vehicle on a lift or place it on jack stands in a level position.
4. Place a catch pan under the oil drain plug.
5. Unscrew the drain plug by turning it counterclockwise. Be careful, as the oil is hot. Allow enough time for the oil to drain completely and stop dripping out of the pan. See **Figure 9-3**.



A—Warm engine to full operating termperature. Then unscrew oil drain plug in counterclockwise direction.



B—Be careful not to let hot oil burn your hand or arm. Allow all old oil to drain into catch pan for several minutes.

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Figure 9-3. Note the basic steps for draining old oil from an engine.

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6. Reinstall the drain plug without crossthreading. The threads in the pan and on the drain plug can strip easily. Torque the drain plug to minimum torque specifications. Apply only enough torque to draw the drain plug snug on its seal and prevent leakage.
7. Position your catch pan under the oil filter.
8. Using an oil filter wrench, as in **Figure 9-4**, unscrew the filter. Again, be careful that hot oil does not run down your arm and burn you.
9. Obtain the correct replacement filter. Compare the old and new filters. The threads and O-ring seals must be the same size.
10. Wipe some clean oil on the rubber O-ring and thread the new oil filter onto the engine. See **Figure 9-5**.
11. Tighten the oil filter by hand. Placing a clean shop rag over the filter before tightening will help you get a proper grip, **Figure 9-6**. Never use an oil filter wrench to install an oil filter, or you will have to cut the filter off the next time. Overtightening may also distort the O-ring and cause a severe oil leak.
12. Lower the car to the ground and add the correct amount and type of oil.
13. Start the engine and make sure the oil pressure light goes out.
14. Let the engine run while checking for leaks under the engine compartment.
15. Shut off the engine and check the oil level again.



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Figure 9-4. An oil filter wrench is needed to remove the oil filter. Rotate the wrench in a counterclockwise direction to unscrew the filter.



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Figure 9-5. When installing a new filter, coat the O-ring seal with clean oil and only hand tighten the filter.



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Figure 9-6. A clean, dry shop rag will help you snug down the new oil filter.

Automatic Transmission/Transaxle Fluid and Filter Service

Like engine oil, automatic transmission and transaxle fluid should be checked and changed at specified intervals. The fluid can become contaminated with metal, dirt, moisture, and friction material (nonmetallic, heat-resistant fibrous substance) from internal parts.

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This can cause rapid part wear and premature transmission failure.

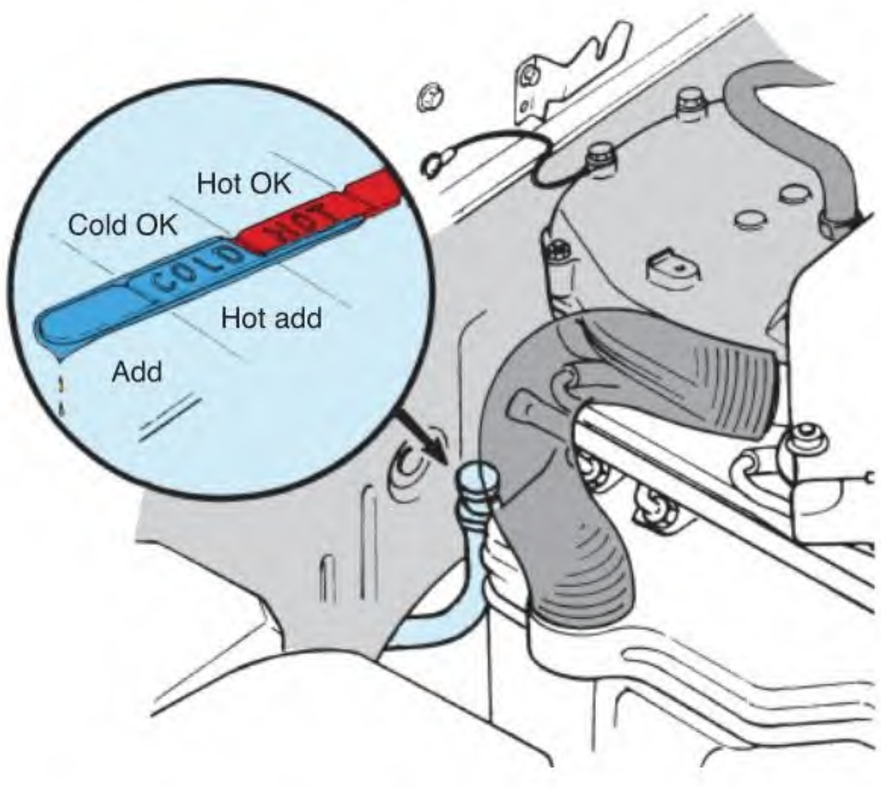
To check the fluid in an automatic transmission or transaxle, warm up the engine and move the gear selector through all positions. Apply the parking brake. Place the transmission in park and block the wheels. With the engine still running, locate the transmission dipstick. See **Figure 9-7**.

Tech Tip

Don't "go crazy" looking for the transmission dipstick on some new cars and trucks. You may not find one. Some transmissions and transaxles are sealed at the factory. They are designed to not require fluid changes and periodic checking of fluid level. Some manufacturers provide screw plugs on the side of the transmission case for checking and adding transmission fluid. The procedure is similar to that for a manual transmission.

Pull out the dipstick. Wipe it off and reinsert it into the tube. Remove the dipstick again and hold it over a shop rag. The fluid should read between the ADD and FULL marks. Also, inspect the fluid for discoloration and odor. If it smells burned or looks dirty, the fluid should be changed.

It is very easy to overfill an automatic transmission. Seldom do you have to add a full quart. Normally, if the dipstick reads ADD, only a fraction of a quart is needed to fill the transmission. Sometimes, instructions are written on the dipstick. If in doubt, check a shop or owner's manual.



Saab

Figure 9-7. Check automatic transmission fluid level with the engine running and the transmission in park. Compare the fluid level to the marks on the dipstick. If needed, add the correct amount and type of fluid.

Service Procedure

To change the fluid and filter in an automatic transmission or transaxle:

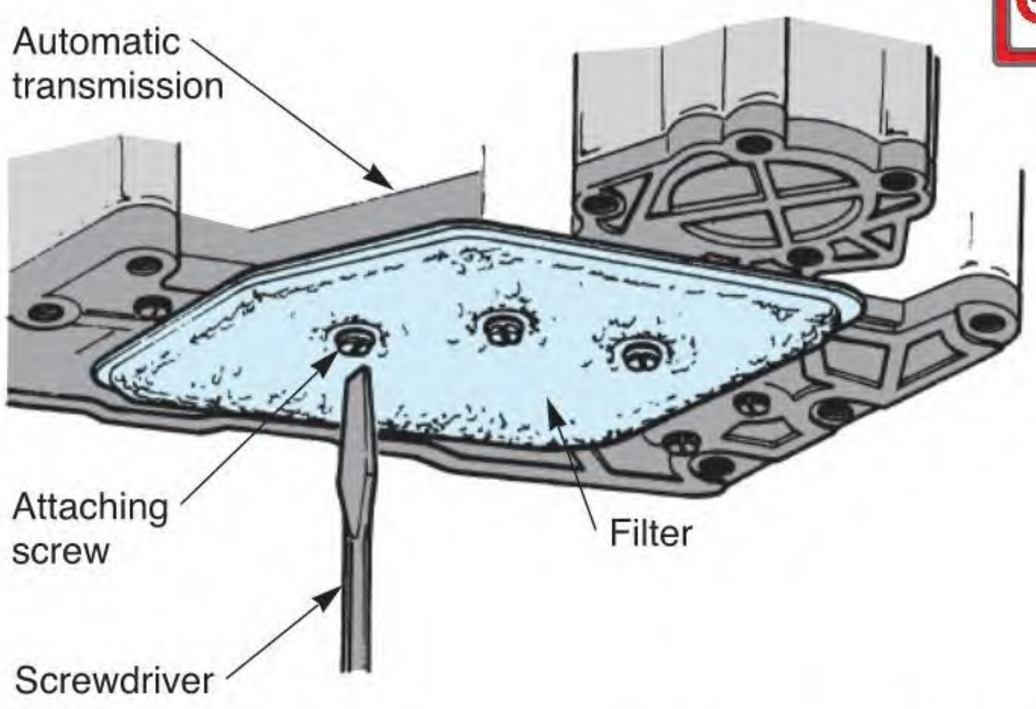
1. Warm the engine and transmission or transaxle to full operating temperature so the fluid will drain more fully.
2. Raise the vehicle on a lift or secure it on jack stands. If the transmission pan has a drain plug, remove it and allow the old fluid to drain into your catch pan. If the pan does not have a drain plug, remove the pan as outlined in steps 3-10.
3. Remove all but one of the bolts securing the transmission pan, **Figure 9-8**. Be careful not to spill the hot transmission fluid. It can cause painful burns!
4. Loosen but do not remove the last pan bolt while holding the pan in place with a shop rag.
5. Allow the pan to drop and let the fluid pour into a catch pan.
6. Unscrew the last pan bolt and remove the pan. If needed, replace or clean the transmission filter, **Figure 9-9**.
7. Scrape the old gasket off the transmission pan and housing.
8. Position the new pan gasket using an approved sealer. Use the sealer sparingly. You do not want any to squeeze out of the gasket and into the transmission or transaxle housing.
9. Start all the pan bolts with your fingers.
10. Tighten the pan bolts in a crisscross pattern to their recommended torque specification. Overtightening can split the gasket or distort the transmission pan.
11. If recommended, drain the torque converter (fluid coupling in front of the transmission). A drain plug may be located in the converter. It is usually under a rock shield on the front of the transmission housing.
12. Refill the transmission with the correct type and amount of transmission fluid. If required, check a service manual for details. In most cases, you must pour fresh fluid into the dipstick tube.
13. Start the engine and shift through the gears.
14. Check under the car for leaks and recheck the transmission fluid level.

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Subaru

Figure 9-8. Usually, the transmission pan must be removed to drain the fluid. A few pans, however, have a drain plug. Do not spill hot fluid on yourself.



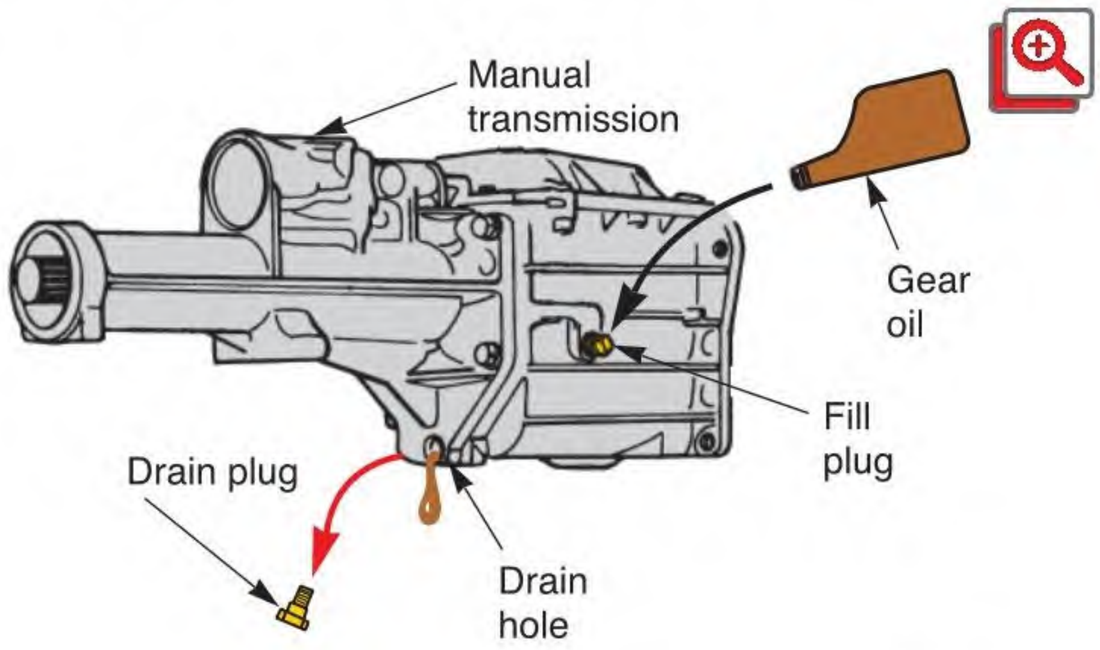
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Figure 9-9. Some manufacturers recommend periodic replacement of the automatic transmission filter. It is located inside the transmission pan. Tighten all fasteners to specs when assembling.

Manual Transmission Fluid Service

To check the fluid in a manual transmission, locate and remove the transmission fill plug, **Figure 9-10**. It is normally on one side of the transmission. Generally, warm fluid in a recently driven vehicle should be even with the fill hole. When the transmission fluid is cold, the fluid can be slightly below the fill hole.

Some manufacturers suggest that manual transmission fluid be changed periodically; others do not.



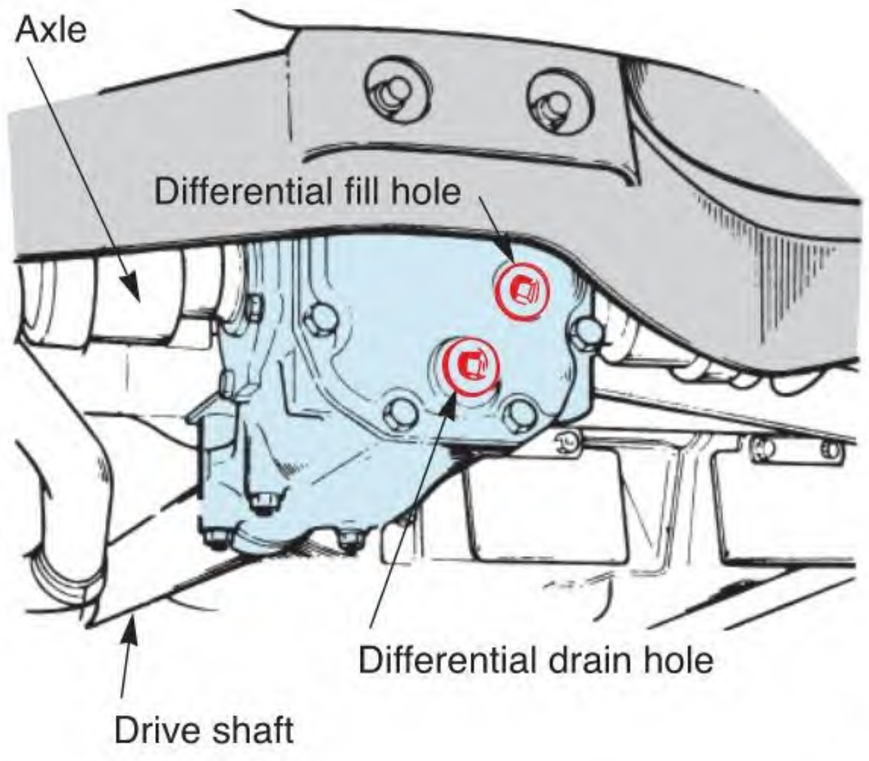
Chrysler

Figure 9-10. A manual transmission will have a fill plug for checking the fluid level. The fluid should be almost even with the hole when the fluid is warm. Check the service manual for details.

If a fluid change is needed, remove the drain plug on the bottom of the transmission case and allow all the fluid to pour into your catch pan. Replace the drain plug and install the right type and quantity of fluid. Lubricate the gearshift mechanism and clutch release as described in service literature.

Differential Fluid Service

To measure the fluid level in a differential (rear axle assembly), remove the fill plug. It will normally be on the front, back, or side of the differential. See **Figure 9-11**. The lubricant should be even with the fill hole when hot. When cold, it should be slightly below the fill hole.



Subaru

Figure 9-11. The differential fill hole allows for a check of the lubricant level. Do not accidentally remove the drain plug.

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At the manufacturer's recommended change interval, remove the drain plug. It will be on the bottom of the differential. After draining, reinstall the plug and fill the differential with the proper lubricant. If a drain plug is not provided, a special siphon (suction) gun can be used to draw out the old fluid.

Caution

Positive-traction, or limited-slip, differentials (both wheels turn for added traction) often require a special lubricant. Refer to the vehicle identification number and a service manual for details. If you install the wrong lubricant, differential action and traction can be adversely affected.

Checking Engine Coolant

Engine coolant (mixture of water and antifreeze) is used in an engine's cooling system. Engine coolant must be changed periodically. After prolonged use, the coolant will deteriorate. It can become very corrosive and filled with rust. This may result in premature water pump, thermostat, and radiator failure.

To check the coolant level, look at the side of the plastic overflow tank connected to the radiator. The coolant should be between the hot and cold marks on the side of the tank. See **Figure 9-12**.

When an overflow tank is used, the radiator cap does not need to be removed to check coolant level. However, some older cars do not use an overflow tank. In this case, the radiator cap must be removed to check the coolant level.

Warning

Never remove a radiator cap while the engine or radiator is hot. Extremely hot coolant can spray out of the radiator, causing serious burns.

The coolant should be about 1″ (25 mm) down in the radiator. Also, inspect the condition of the coolant. If rusty, the coolant should be drained and replaced. Watch for system leaks.



A—Plastic Reservoir Tank



B—Clean Funnel

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Figure 9-12. Do not remove the pressure cap when checking modern engine cooling systems. Only remove the non-pressurized plastic reservoir cap.

Checking Power Steering Fluid

Power steering fluid level should be checked regularly. The engine should not be running when checking power steering fluid. If the fluid is contained in a clear plastic reservoir, simply compare the fluid level to the markings on the side of the reservoir. See **Figure 9-13A**. In some vehicles, the level is checked by removing a dipstick from the power steering pump, **Figure 9-13B**. Inspect the fluid level on the dipstick closely. If low, inspect for and correct any leaks. Then add the correct type and amount of power steering fluid.

Burned power steering fluid has been overheated from pump wear or a clogged line or passage in the hydraulic system. It will smell like burned rubber. The old fluid must be flushed and replaced.

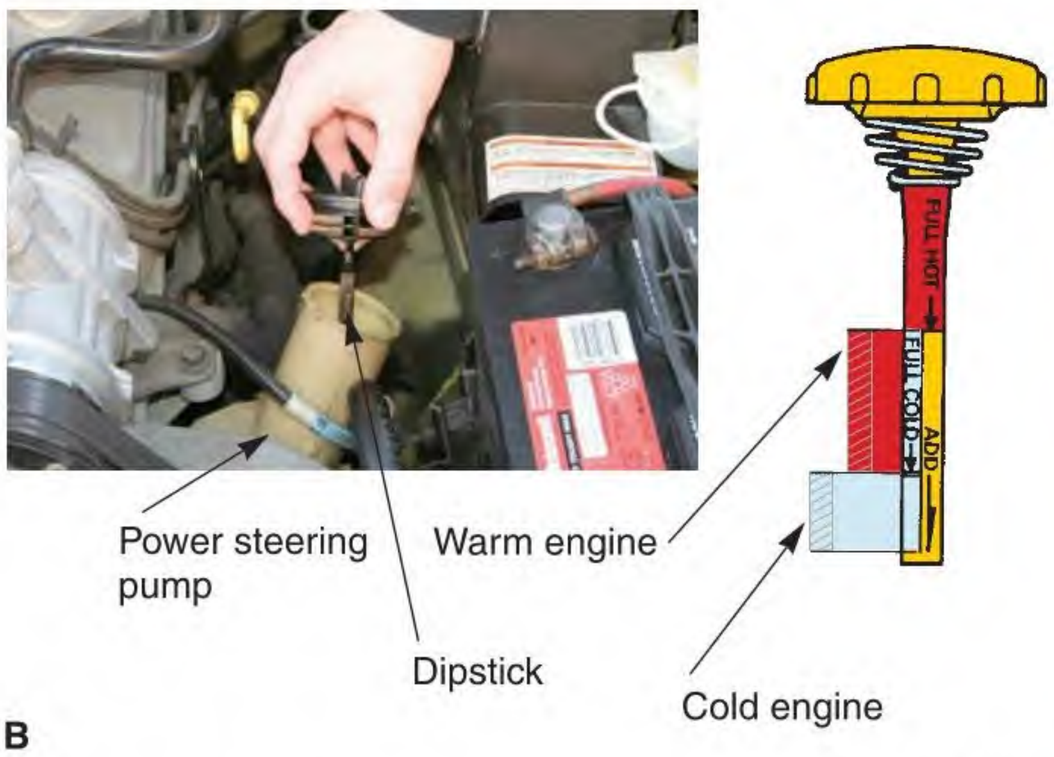
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Tech Tip

A common and troublesome mistake is accidentally overfilling the power steering system. If you add too much power steering fluid and fill the reservoir to the very top, the extra fluid will spray out all over the engine compartment. Remember that liquids cannot be compressed. If you overfill the reservoir, use a clean squeeze bulb to suck out the extra fluid.



A



B

Subaru

Figure 9-13. Note how to check the power steering fluid level. A—Compare fluid level markings on the side of the reservoir. B—On some vehicles, the power steering pump has a cap with a dipstick. Check the fluid with the engine off. Compare the fluid level to markings on the dipstick. Normally, you need to add only a fraction of a quart, not a whole quart.

Checking Brake Fluid

The amount of brake fluid in a master cylinder should be inspected at least twice a year. Look at **Figure 9-14**. The master cylinder is normally mounted on the firewall (body section between the engine and the passenger compartment). When the master cylinder reservoir is clear plastic, simply compare the fluid level to the markings on the reservoir. The fluid should be between the ADD and FULL marks. With some master cylinders, you must remove the reservoir cover to check the fluid. Generally, the fluid should be about 1/4″ (about 6 mm) down from the top of the reservoir. Add the recommended type of brake fluid as needed.

Caution

Never let anything (oil, grease, dirt) contaminate the brake fluid. Oil and grease, for example, will attack the rubber parts in the brake system. Major repairs would be needed and the vehicle could lose braking ability.

Checking Hydraulic Clutch Fluid

Some manual transmission clutches do not use mechanical linkage rods or cables. Instead, they use



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Figure 9-14. Check the brake fluid level at the master cylinder reservoir. The master cylinder is mounted on the firewall, in front of the driver. The maximum fluid level is often indicated on the side of the reservoir. If not, fluid should be slightly below the top of the reservoir.

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a hydraulic system to disengage the clutch. A clutch master cylinder, similar to a brake master cylinder, produces hydraulic pressure to activate the clutch release. The fluid in the clutch master cylinder should be checked. If the fluid level is low, add brake fluid to fill the reservoir almost full. Always watch for leaks.

Checking Manual Steering Fluid

Manual steering fluid is checked by removing either a fill plug or a designated bolt from the top of the box or rack. The lubricant should be almost even with the plug or bolt opening. If not, add the recommended amount and weight of fluid.

Checking Windshield Washer Solution

The windshield washer solution is normally visible through the side of the plastic storage tank. If low, add an approved washer solution. The solution will aid windshield cleaning and also prevent ice formation in cold weather.

Checking Battery

New cars use maintenance-free batteries, which do not require an electrolyte (acid) check. However, make sure that the battery terminals and case top are clean. A battery post and cable cleaning tool can be used on corroded connections. If the top of the battery is dirty, it can be cleaned with a solution of baking soda and water. See **Figure 9-15**.

Filter Service

Quite often, various filters used in a vehicle are replaced during lubrication service. Besides the engine oil and transmission filters, the technician may need to change or clean the air and fuel filters.

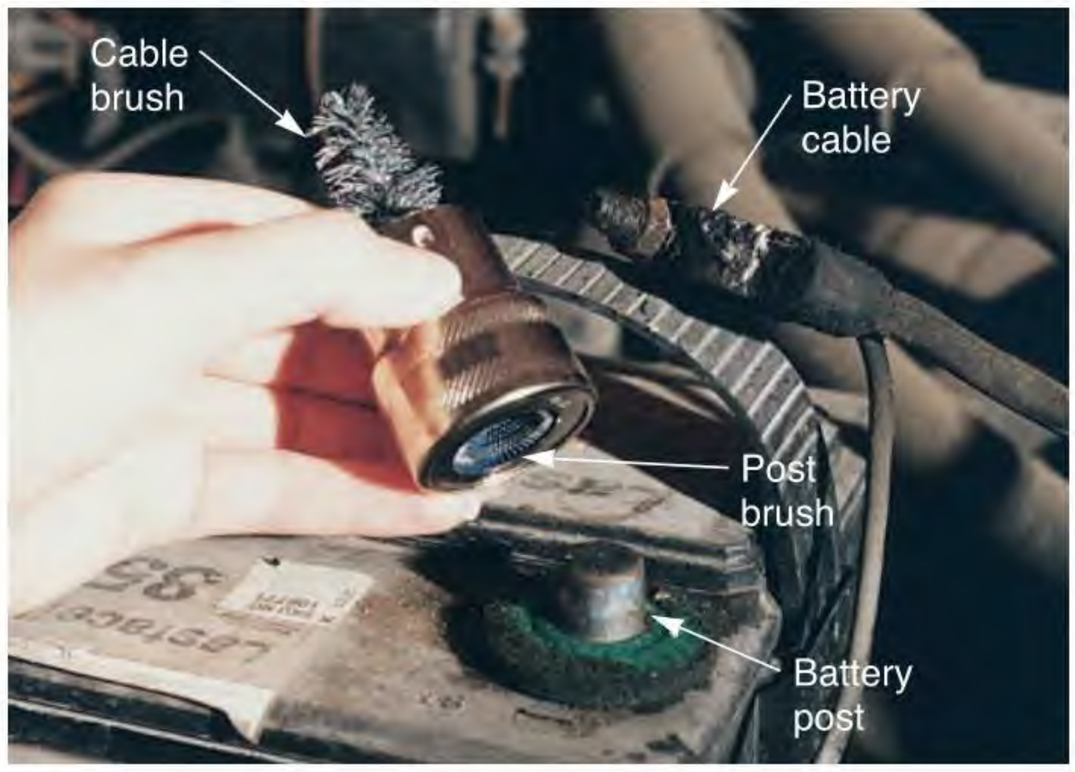
If an air filter is extremely dirty, it is normally replaced. However, some manufacturers permit light dirt and dust to be tapped from the filter. Special foam or oil-bath (oil-filled) air filters can be cleaned as described in a service manual.

Cabin filters are air filters that clean the air flowing into the passenger compartment. They are often high-density filters for blocking pollen and other airborne particles. Cabin filters are usually located and accessed under the right side of the dash.

Fuel filters can be located almost anywhere in the fuel circuit. Modern fuel systems often use inline fuel filters between the fuel tank and the engine. In older



A



B



C

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Figure 9-15. Checking battery condition is important to vehicle maintenance. Battery problems are the number one cause of engine "no start" problems. A—Dirty battery top will drain the battery. Corroded terminals can prevent charging and starting. B—Battery post cleaning tool will remove resistance-causing corrosion from the high current conducting surfaces. C—Wash the top of the battery with baking soda and secure terminals.

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systems, the fuel filter can be located at the inlet to the throttle body injector or in the carburetor. Most fuel systems also have a fuel strainer on the pickup tube in the fuel tank. Refer to the service manual for exact filter locations.

Warning

Wear a full face shield and work gloves when servicing fuel lines. Hold a shop rag around fuel line fittings when loosening them. The shop rag will keep fuel from spraying out due to any residual pressure, preventing a possible explosion and fire.

Chassis Lubrication

Chassis lubrication generally involves greasing high-friction points on the vehicle. It may also involve lubricating locks, hinges, latches, and other body parts. Chassis lubrication of control arms and ball joints is often done when the engine oil and filter are serviced.

Tech Tip

Control arms and ball joints are sealed on most passenger vehicles, so further lubrication may not be necessary anymore on these parts.

Grease Job

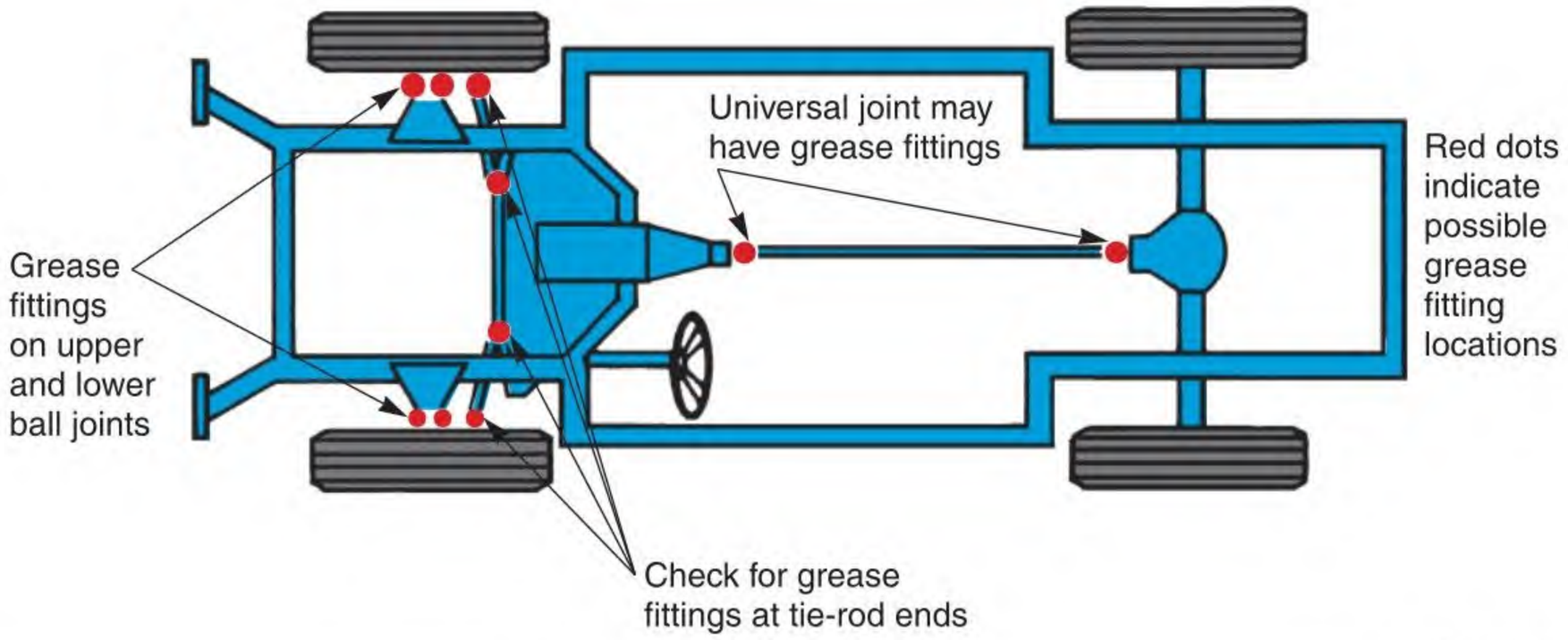
During a ***grease job***, you must lubricate high-friction pivot points on the suspension, steering, and drive train systems. Most service manuals illustrate which parts must be lubricated, **Figure 9-16**.

A ***grease gun***, **Figure 9-17**, is used to force lubricant (chassis grease) into small fittings. Inject only enough grease to fill the cavity in the part. Overgreasing can sometimes rupture the rubber boot surrounding the joint.



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Figure 9-17. This technician is using a power grease gun to lubricate fittings on a suspension system.



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Figure 9-16. A grease job involves lubricating the pivot points shown. Some cars have more grease fittings than others. Check closely on steering and suspension components, as well as on drive shafts.

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Tech Tip

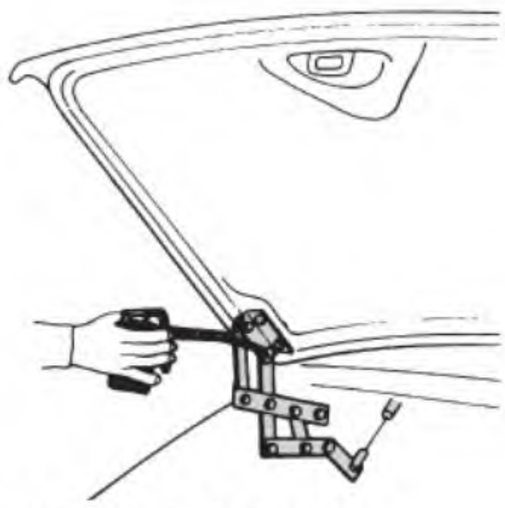
When doing any kind of lubrication service, protect the customer's vehicle from oil and grease damage. Use seat covers, paper floor mats, and fender covers to protect surfaces from oil and grease stains. A stained carpet or seat cover can be very expensive to replace!

Body Lubrication

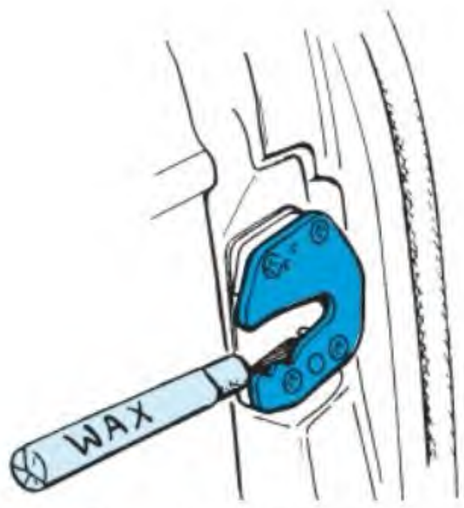
When performing a complete chassis lubrication job, you should also lubricate high-friction points on the body (hinges and latches on doors, hood, and trunk). This will help prevent squeaking doors, sticking hinges, and wear problems.

Always use the prescribed lubricant. Normally, rubber and plastic parts will deteriorate if exposed to petroleum-based lubricants (oils and grease). Silicone lubricant should be used on plastic and rubber components. See **Figure 9-18**. The most common types of body lubricants are:

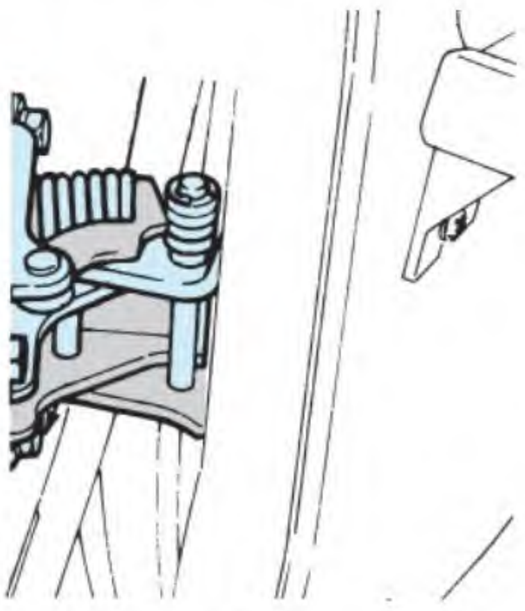
- ***Engine oil***—Engine oil is used on hard-to-reach high-friction points.
- ***Graphite***—Graphite is excellent for door and trunk locks. It will not collect dust and dirt, which could upset lock operation.
- ***Dry stick (wax) lubricant***—Dry stick lubricant is desirable on door latches and strikers (post that engages door latch). It will not stain clothing.
- ***Chassis grease***—Chassis grease is good all-around body lubricant. It can be used on easy-to-reach hinges and latches.
- ***Silicone lubricant***—Silicone lubricant often comes in a spray can. It is especially suited for rubber door weather stripping and windows. It is a dry lubricant that will not soil windows and clothing.



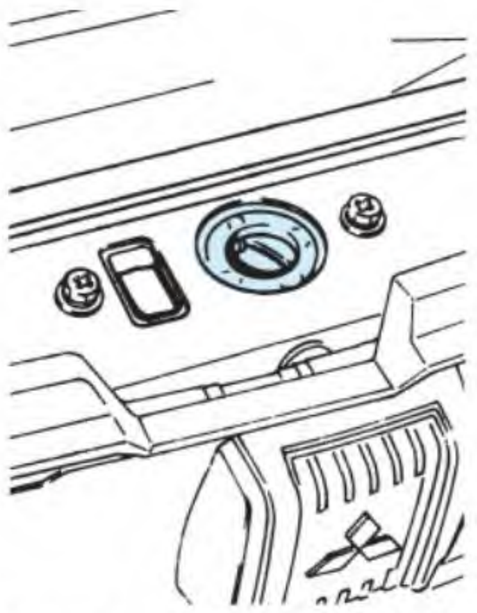
A—Lubricate hood and trunk hinges.



B—Use non-stain wax on door strikers.



C—Place a dab of grease on door hinges.



D—Lubricate the hood latch to prevent it from rusting.

Volvo

Figure 9-18. During lubrication service, lubricate body components to prevent squeaks and wear.

Checking Tires

Service Procedure

To check a vehicle's tires for safety:

1. Inspect the condition of the tire treads. Generally, all grooves in the tire should be at least 1/8" (3.2 mm) deep. If they are worn more than this, inform the shop foreman or vehicle owner. New tires are recommended to improve traction and prevent a dangerous tire failure or "tire blow out."
2. If tire tread wear is minimal, measure tire inflation pressure.
3. Remove the valve stem cap and press the tire gauge squarely over the valve stem.
4. Read and compare the air pressure indicated on the gauge with the vehicle manufacturer's inflation specifications, which are listed on

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the sticker that is generally located in the door jamb or on the fuel filler door. The air pressure listed on the tire's sidewall is maximum pressure, not the pressure recommended by the vehicle manufacturer.

5. If the tire pressure is low, add air. If the pressure is high, press in on the valve core pin to release air from the tire.
6. Recheck tire pressure with your gauge until correct.
7. Reinstall the valve stem cap and repeat on the other three tires.

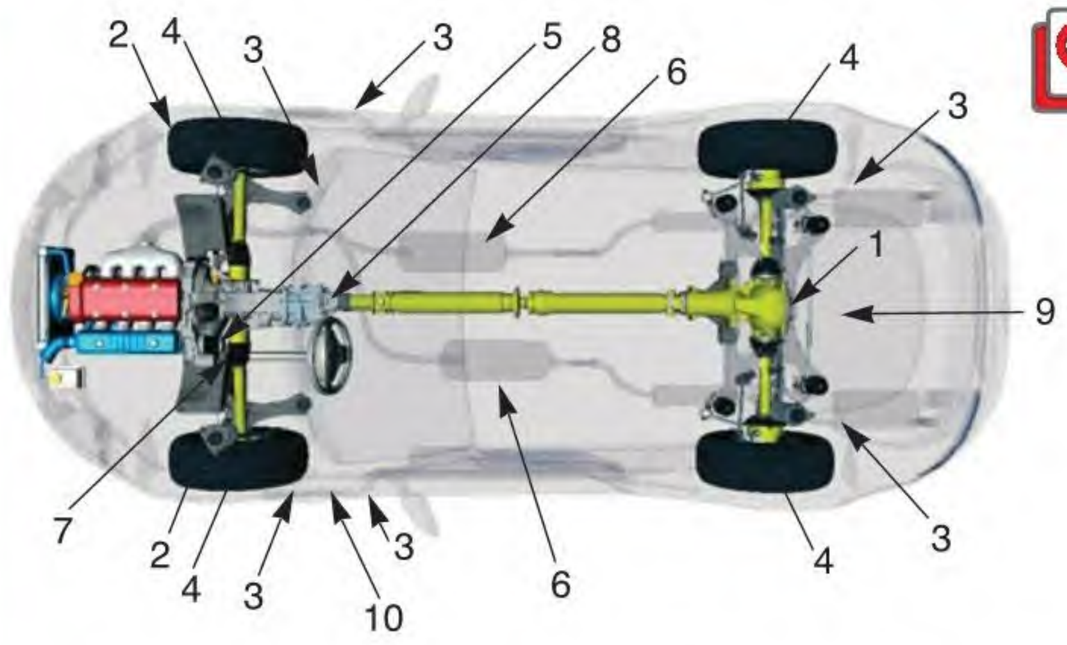
Tech Tip

Remember the tire inflation pressure on the sidewall is the maximum recommended pressure. The ideal tire pressure for the vehicle is given in the owner's manual. It can also be found on the sticker located on the door (B) pillar, door jamb, fuel filler door, deck lid, or other location. Ideal tire pressure depends on several variables, such as vehicle curb weight, suspension stiffness, and temperature.

Most tire manufacturers recommend a cold inflation pressure that is 1 psi (6.9 kPa) to 3 psi (21 kPa) below the maximum listed air pressure. This allows for tire heating, air expansion, and pressure increase without exceeding maximum pressure limits on the tire carcass.

Service Intervals

A service interval is the amount of time (in months) or the number of miles between recommended service checks or maintenance operations. The factory service manual will give exact intervals for the particular make, model, and year of vehicle. New vehicles tend to have longer intervals before service is required. Service manual recommendations for chassis maintenance vary slightly with the make of the vehicle. Note typical service intervals in **Figure 9-19**.



Component	Service	Interval
1. Axle differential		5000 mi (8 000 km)
		30,000 mi (48 000 km)
2. Bearings, front wheel	a.	30,000 mi (48 000 km)
3. Body lubrication	b.	15,000 mi (24 000 km)
4. Brake inspection	c.	15,000 mi (24 000 km)
5. Clutch lever		30,000 mi (48 000 km)
6. Exhaust system inspection	d.	15,000 mi (24 000 km)
7. Manual steering gear	e.	5000 mi (8 000 km)
8. Manual transmission	e.	5000 mi (8 000 km)
9. Spare tire	f.	7500 mi (12 000 km)
10. Stored service reminders	g.	15,000 mi (24 000 km)
		30,000 mi (48 000 km)

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Figure 9-19. Study the chassis maintenance information from a service manual. Recommendations for other parts of the car are also given.

Tech Tip

If a transmission has over 100,000 miles on it without a previous fluid change, the worst thing you can do is change the transmission fluid. The old transmission fluid is full of friction material that prevents band and clutch slippage. If you install "fresh slippery oil" in the worn automatic transmission, it will slip and fail quickly. You or the shop could be liable since the transmission worked fine before the fluid change.

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General Inspection and Problem Location

As you perform lubrication service or any kind of auto repair, always watch for mechanical problems. Visually inspect the vehicle for any signs of wear, deterioration, loose parts, or leaks. Check the condition of fan belts, water hoses, fuel hoses, vacuum hoses, and wiring. This can be done as you are working.

- ***Hose inspection***—This type of inspection includes checking for hardening, softening, cracking, splitting, or other signs of impending failure. Squeeze all the hoses. If the hoses are deteriorating (hard or soft), inform the customer or shop supervisor of the problem. See **Figure 9-20**.
- ***Drive belt inspection***—Drive belt inspection includes looking for splits, tears, cuts, and wear. If worn or wear hardened, the belt may slip and squeal. Refer to **Figure 9-21**.
- ***Wiring inspection***—This type of inspection involves looking for improper routing, cracked or brittle insulation, or other obvious problem signs. Make sure wires are away from all moving or hot parts.
- ***Tire inspection***—Tire inspection is performed by looking for excessive wear, improper inflation, or physical damage. Tire maintenance is very important from a safety standpoint. Badly worn tires can blow out, causing you to lose control of the vehicle and resulting in collisions, injuries, or even death.
- ***Steering system inspection***—Steering system inspection includes checking for excessive wear and play in moving parts. The steering wheel should not move more than about 1″ (25 mm) without causing front wheel movement. If it does, wear in the steering mechanism is indicated.
- ***Exhaust system inspection***—This type of inspection involves looking for damaged, rusted, or leaking parts. The exhaust system should be inspected any time a vehicle is raised on a lift. A leaking exhaust system can be very dangerous, as it may allow poisonous exhaust gases to enter the vehicle's passenger compartment. Look for rust holes in the pipes, muffler, and other parts.
- ***Brake inspection***—Brake inspection involves removing the wheels and tires so you can visually examine the brake pads and rotors. If they are damaged or worn, your shop should inform the customer of the need for brake repairs.

When working on a vehicle, be alert for these kinds of problems. This will show the shop supervisor and the customer that you are a concerned, competent technician.



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Figure 9-20. Check the condition of all hoses. Feel hoses for hardening or softening. Look for leaks during hose inspection.



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Figure 9-21. Inspect belts for glazing, cracking, and fraying. Most modern belts use a spring-loaded tensioner, so belt adjustment is no longer necessary.

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Fluid Leaks

Fluid leaks result from bad gaskets, seals, or hoses; cracks in parts; and similar troubles. Leaks are very common problems that should be corrected. See **Figure 9-22**. To become good at leak detection and correction, you should:

- Become familiar with the *color*, *smell*, and *feel* (texture) of the different fluids. Then, you will be able to quickly identify a fluid leak. Does the fluid feel more like water or oil? Dab a white paper towel into a puddle of fluid to show its color more accurately. Oil will be slippery to the touch and will be dark brown or black if used for an extended period of time. If the fluid is clear or brown and feels "squeaky" when rubbed between your fingers, it is probably brake fluid or hydraulic clutch fluid. Antifreeze can be green, orange, or rust colored and will feel slick. Automatic transmission fluid can be dark brown, red, or dark green. Power steering fluid can be amber, red, or clear and will feel like transmission fluid.
- Fluid leaks tend to flow downward and to the rear of the vehicle. For this reason, look for leaks above and slightly in front of where you find fluid dripping off the vehicle.
- If multiple leaks are indicated, fix the leak located the highest and farthest forward on the vehicle. Then, repair other leaks.
- If the leaking part is badly soiled, clean the area thoroughly. Then it will be easier to see fresh fluid leaking out of the part.
- The most frequent cause of fluid leakage is broken gaskets and worn seals. Replacement will usually correct the problem. However, you should always check the parts for warpage, cracks, and dents.



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Figure 9-22. When working under a vehicle, always look for signs of fluid leakage and other obvious problems. Inspect rubber boots and hoses for signs of damage.

Noise Detection and Location

Abnormal noises are unwanted sounds that indicate part wear or other mechanical problems. They are common to almost all systems of a vehicle. When test-driving or idling the engine in the shop, listen for unusual sounds (knocks, clunks, rattles, clicks, and hisses). Locating the source of these sounds will help you identify problems that might not trip a trouble code.

A stethoscope (similar to that used by a doctor to listen to a patient's heart) is commonly used by an auto technician. It will help the technician pinpoint the source of internal part noises. To use the stethoscope, touch the probe on the component near the unwanted sound. Move the stethoscope around until the sound is the loudest, **Figure 9-23**.

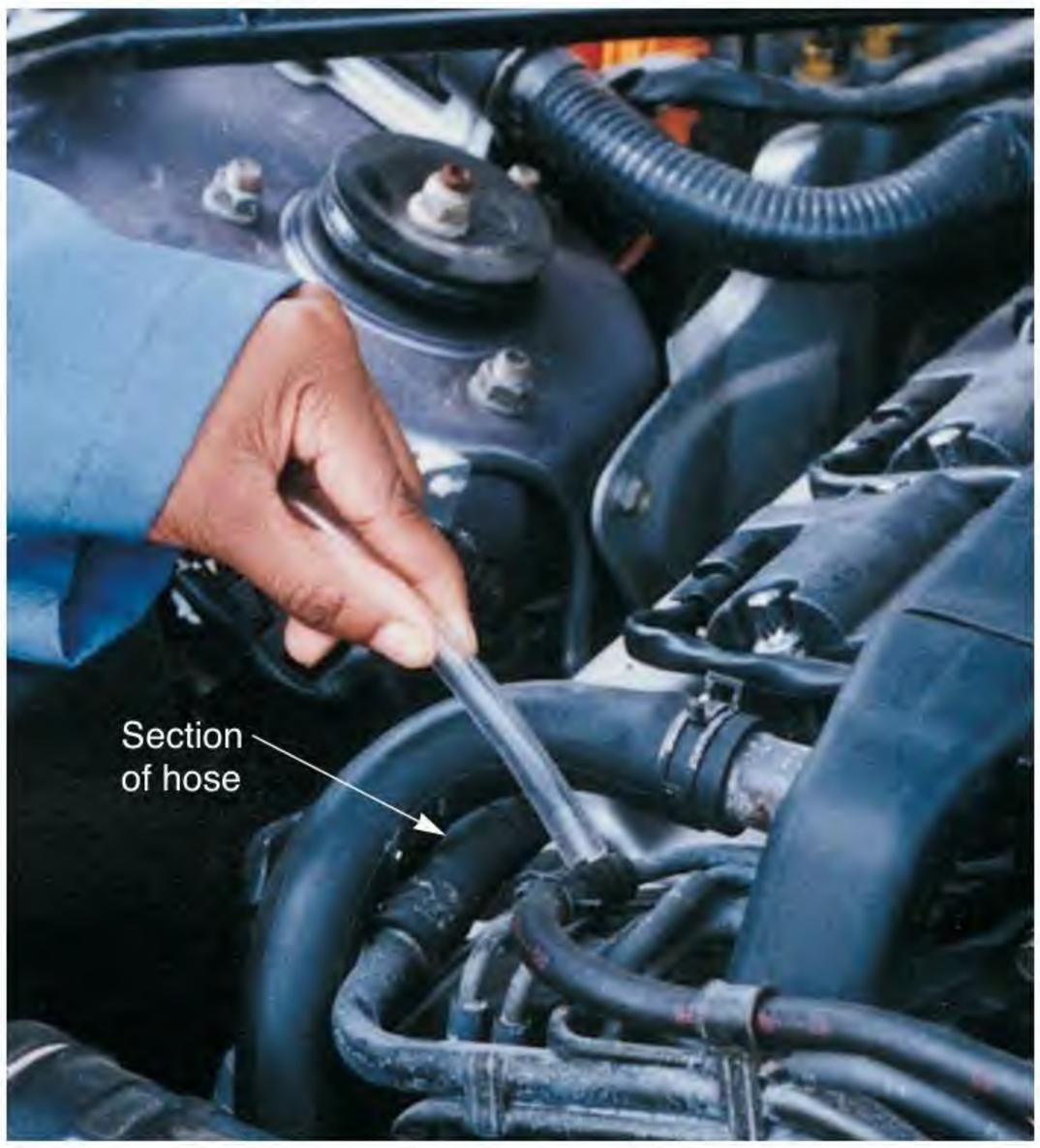
A long screwdriver can be used in place of a stethoscope. Place the tip of the screwdriver on the part. Place the handle next to your ear. Sound will travel through the screwdriver and permit noise diagnosis. Make sure you keep the screwdriver away from moving parts or you could be injured.

A section of vacuum hose is a handy device for finding sounds not coming from internal parts. The hose is useful for locating hissing sounds, rattles, whines, and squeaks. Place one end of the hose to your ear. Then, move the other end around the area of the sound. When the sound becomes the loudest, you have pinpointed the problem. Again, keep the hose away from moving or hot parts. By removing the metal end from a stethoscope, you can also listen for these kinds of noises, especially hissing vacuum leaks.

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A



B

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Figure 9-23. You must often listen to the sounds outside and inside an assembly to find the source of the problem. A—A stethoscope can be used to quickly find knocks and rattles inside components. Move the tip around on parts. When noise becomes the loudest, you have found the source of the problem. B—A piece of vacuum hose can be used like a stethoscope to find external noises. It will help you find vacuum leaks, squeaks, wind noise, and other abnormal sounds.

Recycling and Disposal of Auto Shop Wastes

Recycling and the proper disposal of auto shop wastes are needed to help save our planet's natural resources and reduce the amount of materials being sent to landfills. Laws have been passed that require specific procedures when handling and discarding potentially harmful materials.

Auto Shop Wastes

Automotive maintenance may generate hazardous wastes that come under the requirements of the Resource Conservation and Recovery Act. This federal act covers businesses that generate, transport, and manage hazardous wastes. Any business that maintains or repairs vehicles, heavy equipment, or farm equipment is classified as a vehicle maintenance facility by this act.

Vehicle maintenance fluid and solid wastes include:

- Used motor oil (can be combustible and may contain toxic chemicals).
- Other discarded lubricants, such as transmission and differential fluids (may contain toxic chemicals).
- Used parts.
- Cleaners and degreasers that are contaminated from parts-cleaning operations.
- Fuel injection system cleaners (flammable and may contain toxic chemicals).
- Rust removers (may contain strong acidic or alkaline solutions).
- Paint thinners or reducers (may be ignitable or contain toxic additives).
- Worn out batteries contain lead and sulfuric acid).
- Tires and catalytic converters.

Repair and maintenance facilities (service stations, automotive dealerships, independent auto repair shops, etc.) that generate 220 lb. (100 kg) of hazardous waste monthly must file a Uniform Hazardous Waste Manifest before removing the wastes. The manifest must list the proper Department of Transportation (DOT) shipping descriptions for a number of wastes. Tables listing these descriptions are available from each state's hazardous waste management agency or a regional EPA office.

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However, EPA regulations also state that no manifest is needed for used oil or lead-acid batteries if they are sent for recycling. In such cases, the material is not regarded as hazardous. Your state may have its own requirements; check with your state hazardous waste management agency.

Unless recycled for scrap metal, used oil filters are considered hazardous waste. If not recycled, they must be listed on the monthly manifest as hazardous. Before disposal, filters should be gravity drained so they do not contain free-flowing oil. Store them uncrushed in a closed, labeled container for pickup by a recycler.

Recycling Motor Oil

Used motor oil is considered hazardous waste unless it is destined to be recycled. The old oil should be stored in an approved container for recycling. One gallon of used motor oil can be refined into two and one-half quarts of high-quality motor oil. It takes about 40 gallons of crude oil to produce this much motor oil. Recycling old oil not only saves our environment from pollution, but it also helps save our natural resources. Always send used motor oil to a recycling center! Put the oil in an approved container. Some recycling companies provide a pickup service, while others require you to take the old oil to their facility.

Recycling Coolants

Antifreeze has been classified as a hazardous waste due to heavy metal and chlorinated solvents that it picks up circulating through cooling systems. It should never be mixed with used oil. The entire mixture would then be classified as a hazardous waste, even though the used oil may not be, under federal regulations.

Regulations require that spent antifreeze solutions be collected by a registered hazardous waste hauler. Several major companies offer pickup and recycling services.

Recycling Refrigerants

Refrigerants, such as R-134a, removed from automotive air conditioning systems during servicing should not be vented to the atmosphere. State regulations require that refrigerants be recovered and recycled.

As you will learn in later chapters, systems are now available for recovering, cleaning, and recycling air conditioning refrigerants.

Other Automotive Recyclables

Other recyclable materials that are commonly removed from service during maintenance and repair of vehicles include:

- Catalytic converters, which contain platinum.
- Worn tires, which can be sold to a retreader company (if the carcass is sound) or to a shredder. Shredded rubber is an ingredient in road resurfacing materials and other products that give the rubber a second use.
- Batteries can be recycled and used to make new batteries. This prevents lead, acid, and other materials from adding to our waste disposal problems.
- Brake shoes can be recycled and sold as cores for making reconditioned brake shoes.
- Many small assemblies (alternators, starters, master cylinders, etc.) can be recycled and made into rebuilt assemblies.
- Plastic bumpers and other body parts can be recycled into a variety of new products.



Diagnostic Case Study

Concern: Ms. Jones brought her 2012 KIA in for repair because she noticed a puddle of fluid on her garage floor.

Cause: Duff, the shop owner, questions Ms. Jones to find out more about what is wrong with the vehicle. He asks her about unusual sounds and odors. He also asks if she knows approximately where the fluid is leaking from (front of engine, back of engine, right side, left side, etc.). Ms. Jones says the puddle seems to be coming from the left front corner of the vehicle and that she often hears a growling noise when driving around corners. After listening carefully to Ms. Jones, Duff suspects that the power steering system might be leaking and that the growling noise may be caused by air in the power steering system. Duff then turns the repair over to the shop's suspension and steering technician. Duff discusses the symptoms with her and tells her what he thinks the problem is.

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The technician checks for dripping under the engine compartment and finds a small fresh puddle that looks and smells like power steering fluid. She then opens the hood and looks for the source of the leak. As she feels around the power steering pump and hoses, she finds a leak at the hose behind the power steering pump. She then starts the engine and uses a mirror to observe the fluid dripping from the crimped metal fitting on the hose.

Correction: The technician orders and installs a new power steering hose. She then fills the system with fluid, starts the engine, and rotates the steering wheel back-and-forth between the stops to purge air from the system. After test-driving the vehicle, she lets it run for approximately 15 minutes and then rechecks the system for leaks. After verifying that the problem has been corrected, the technician rechecks the power steering fluid level and releases the vehicle to the customer.

Summary

- Vehicle fluids include engine oil, coolant, brake fluid, transmission fluid, power steering fluid, and other liquids.
- Vehicle maintenance includes any operation that will keep a vehicle in good operating condition.
- A car's warranty can become void if improper fluids or incorrect service procedures or intervals are used.
- Be careful! Oil and other fluids at operating temperature can be hot enough to burn.
- EPA (Environmental Protection Agency) guidelines and state regulations affect how you must handle and dispose of used fluids, solvents, and other shop chemicals.
- Never remove a radiator cap while the engine or radiator is hot. Boiling coolant can spray out of the radiator, causing serious burns.
- Hold a shop rag around fuel line fittings when loosening. This will keep fuel from spraying or leaking out, preventing a possible explosion and fire.
- During a grease job, you must lubricate high-friction pivot points on the suspension, steering, and drive train systems.
- As you perform a lubrication job or any kind of auto repair, always watch for mechanical problems. Visually inspect the vehicle for any signs of wear, deterioration, loose parts, or leaks.
- A stethoscope (similar to that used by a doctor to listen to a patient's heart) is commonly used by a technician.
- A section of vacuum hose can be used as a handy device for finding sounds not coming from inside parts.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

brake inspection
chassis grease
chassis lubrication
drive belt inspection
dry stick (wax) lubricant
engine oil
exhaust system inspection
fluid leak
graphite
grease gun
grease job
hose inspection
lubrication service
oil foaming
silicone lubricant
steering system inspection
tire inspection
vehicle fluid
vehicle maintenance
wiring inspection

Activities

1. On a vehicle chosen by your instructor, determine the capacity of the cooling system. Then determine the amounts of water and antifreeze needed to produce a 50/50 mixture.
2. Survey the motor oils offered for sale at a local outlet. Determine the cost to change the motor oil in a vehicle. Add labor cost at $36/hour.
3. Change the oil and filter on a vehicle designated by your instructor.

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Review Questions

Answer the following questions using the information provided in this chapter.

1. List the six aspects of lubrication service.
2. _____ includes any operation that will keep the car in good operating condition.
3. When checking engine oil, allow the engine to cool completely. True or False?
4. What can happen when too much oil is added in an engine?
5. Which of the following should *not* be done when changing an engine's oil and filter?
   (A) Torque the drain plug only enough to prevent leaking and loosening.
   (B) Use an oil filter wrench to remove the old filter.
   (C) Wipe clean engine oil on the new filter O-ring seal.
   (D) Use an oil filter wrench to tighten the new oil filter.
6. The automatic transmission dipstick is normally located in front of the engine. True or False?
7. Check automatic transmission or transaxle fluid with the engine running. Check engine oil with the engine off. True or False?
8. Explain how to check the following:
   (A) Engine coolant level and condition.
   (B) Power steering fluid.
   (C) Brake fluid.
   (D) Manual steering fluid.
   (E) Battery condition.
9. A(n) _____ involves lubricating the steering, suspension, and drive train of a vehicle.
10. List and explain the use of five lubricants.
11. A(n) _____ is the amount of time between recommended service or maintenance operations.
12. Describe six general inspection points that should be checked during vehicle maintenance.
13. Which of the following should be done to help with leak detection and troubleshooting skills?
    (A) Become familiar with the color and smell of different fluids.
    (B) Trace the problem to the highest point of wetness or leakage.
    (C) Clean the area around the leak if the leak is difficult to isolate.
    (D) All of the above.
14. A(n) _____ is commonly used to find the source of noises inside parts.
15. List four automotive items that should be recycled.

ASE-Type Questions

1. During a complete lubrication service, all of the following are done *except:*
   (A) change engine oil.
   (B) change oil filter.
   (C) check all fluid levels.
   (D) check ride height.
2. During an oil change, Technician A says to use an oil filter wrench to remove the old oil filter. Technician B says to apply a little oil to the seal on the new filter to aid installation. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   D) Neither A nor B.
3. When changing engine oil, Technician A says the engine oil should be cool. Technician B says the oil should be warm. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. When checking automatic transmission fluid, the following should be done.
   (A) Engine off, transmission in park.
   (B) Engine running, transmission in park.
   (C) Engine off, transmission in neutral.
   (D) Engine on, transmission in neutral.

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5. Engine coolant consists of:
   (A) water and antifreeze.
   (B) oil and antifreeze.
   (C) water and stop leak.
   (D) water only.
6. A vehicle with an automatic transaxle enters the shop with 150,000 miles on its odometer. Technician A tells the customer that she should change the transmission fluid. Technician B says this could be a big mistake because the loss of friction material in the old fluid could make the worn bands and clutches slip, stopping the car "dead in its tracks." Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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Chapter 10
Career Success

After studying this chapter, you will be able to:

- List the traits employers look for in their employees.
- Summarize the different systems used to pay technicians.
- Explain the types of repair facilities.
- Explain how to find job openings in the automotive field.

This chapter briefly covers factors that can determine your degree of success when employed as an automotive technician. There is more to being a good technician than just being able to work on vehicles. There are many simple things you can do to help you succeed in the auto repair shop.

Traits of Desirable Employees

There are several common traits that most employers look for in their employees. Good employees are dependable, cooperative, curious, efficient, professional, and honest. They are also good leaders and communicators. To be a successful technician, you should strive to excel in all these areas.

Dependability

Dependability is the capability to be relied on in the workplace. This trait is critical to career success. Failure to report to work on time, leaving early, or taking too many days off can have a detrimental effect on both your fellow technicians and your customers. The shop owner or service writer is responsible for scheduling repair work based on a certain number of technicians. If one or more technicians do not report to work, this schedule is useless and customers may have to wait for their vehicles longer than planned.

If customers are unhappy about being inconvenienced, they will not return to the shop. The technicians will have less work and the shop will not be as profitable. Everyone can suffer when a technician is constantly absent from or late for work. The number one reason technicians are fired is lack of dependability.

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Cooperativeness and Initiative

Cooperativeness is the ability to work with others to achieve a goal. Technicians must cooperate with other employees in the shop. In other words, they must be able to work as part of a team. Cooperativeness also involves following directions. Failure to follow directions can lead to improper repairs and, in some cases, unsafe actions. Refer to **Figure 10-1.**

If technicians do not get along and do not cooperate, morale and work output suffer. There are times when employees and employers must negotiate on a task or work-related issue. Negotiation is the process of agreeing to an issue that requires all parties to give and take. The goal is a "win-win" solution in which both parties get some or all of what they are seeking. ***Negotiation*** begins with trying to understand the other party's interests. Possible solutions that meet their mutual concerns can be developed. Often the best solution becomes clear when both parties have ample time to explain what they are trying to accomplish.

Taking ***initiative*** means that you start activities on your own without being told. When you finish one task, you should not wait to hear what to do next. If you do not have a vehicle to work on, offer to assist another technician who is completing a job. He or she may be willing to return the favor at a later date. As a result, you will make more money and so will the other employees.



ASE

Figure 10-1. Automotive technicians sometimes work together when diagnosing difficult problems.

Leadership

Leadership is the ability to guide and motivate others to complete tasks or achieve goals. It involves communicating well with others, accepting responsibility, and making decisions with confidence. Leaders often seem to carry the most responsibility in a group. Other group members look to them for answers and direction.

The most important role of leaders is to keep the team advancing toward its goal. Leaders do this by inspiring their groups and providing the motivation to keep everyone working together. Good leaders encourage teamwork, because a team that is working well together is more likely to reach goals. Leaders also want to set a good example by doing a fair share of the work. In these ways, leaders cultivate a sense of harmony in the group.

Curiosity

Curiosity is the desire to learn. Automotive technology is changing at a frantic pace. To be successful in automotive repair, you must want to learn about new technologies and repair techniques.

To keep up with changes in technology, read service manuals, service bulletins, automotive magazines, and other literature. Continuing education is another way to stay abreast of new and changing engine technologies. Try to learn something new each day.

Efficiency

Efficiency is the ability of a technician to produce high quality work quickly. A primary concern of any engine technician, shop owner, or customer is work quality. Repairs must be done correctly following factory specifications.

It is tempting for a technician to work too fast in an attempt to make more money. This strategy usually backfires. When a technician works too quickly, comebacks increase. A ***comeback*** is a repair that must be done over because it was done incorrectly the first time. Comebacks are an indication of poor work quality.

When customers return unsatisfied with the repairs done to their vehicles, the technician must do the repairs again, this time without charging the customer. The technician loses money on lost work time, the shop owner loses money on wasted stall time, and the owner of the vehicle loses because the vehicle had to be returned to the shop.

While working too fast may lead to poor work quality, work speed is still very important to the automobile technician. For those working on a commission basis, income will depend on the amount of work completed each week.

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To increase work speed without affecting work quality, constantly think about new methods to increase work efficiency. Consider a new tool or technique that will save time without lowering the quality of the repair. This kind of mental attitude will help you improve your skills. As a result, you will become more productive each day.

Professionalism

Professionalism involves presenting yourself in an appropriate manner in the workplace. You must always project a professional image. Your work clothes reflect your mechanical abilities and work attitudes. If you look dirty and sloppy, customers will suspect that your work may be less than desirable. See **Figure 10-2**.

In addition to a professional appearance, the technician must act professionally. Be courteous when addressing customers and other technicians.

Honesty

Employers demand that their employees be honest and ethical. ***Ethical behavior*** on the job means conforming to accepted standards of fairness and good conduct. It is based on a person's sense of what is right to do. Individuals and society as a whole regard ethical behavior as highly important. Integrity, confidentiality, and honesty are crucial aspects of ethical workplace behavior. Integrity is firmly following your moral beliefs.

For example, intentionally failing to install a couple hard-to-reach bolts is unethical and dishonest. It may cause the repair to fail prematurely, and you have not properly completed the repair the customer is paying for.

Most shops have a set of workplace policies that employees are expected to follow. For example, all shops support a drug-free workplace and many require their employees to have a clean driving record. Employees who do not comply with these policies may be disciplined or dismissed. In cases of criminal behavior, employees may lose their jobs and be arrested. If proven, the charge of criminal behavior stays on the employee's record. Such an employee will have a difficult time finding another job.



ASE

Figure 10-2. A technician must maintain a professional appearance. To your customers, your appearance reflects your abilities and attitudes.

Strong Communication Skills

Communicating effectively with others is important for success as an automotive technician. Being a good communicator means that you can share information well with customers and co-workers. It also means you are a good listener.

Good communication is central to a smooth operation of any business. Communication is the process of exchanging ideas, thoughts, or information. Poor communication is costly to an employer, as when time is lost because a work order was filled out incorrectly or the wrong parts were ordered. Poor communication can result in lost customers, too.

There are two primary forms of communication: verbal and nonverbal. Verbal communication includes writing, reading, speaking, and listening. You must be able to write clearly to describe symptoms and report repairs on work orders. You must be able to read and comprehend service information and procedures. You must be able to prepare and deliver effective oral presentations, such as service training, and speak clearly in casual conversation, as when describing a proposed repair to a customer. Listening is also an important part of verbal communication. If you do not understand something that is said, ask questions.

Nonverbal communication is the sending and receiving of messages without words. It includes facial expressions and body language. For example, leaning forward while a person is talking signals interest and keen listening. Slouching back in a chair and yawning give the opposite signal—that you are bored and uninterested.

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The message you convey in telephone communication involves your promptness, tone of voice, and attitude. Answering the phone quickly with a pleasant tone conveys a positive image for the company. Learning to obtain accurate information from the caller without interrupting that person's message is important.

Communication tools have advanced with the development of new technologies. To be an effective employee, you must know how to communicate well with the common tools of your workplace. For example, when sending e-mail communications, remember to think through each message before sending it. Often, messages are sent quickly without thought of how the recipient may interpret them. The same is true of voice mail.

It is not uncommon to encounter customers from different cultures in the automotive repair shop. When communicating with non-native English speakers, do not assume that they fully understand you. Make sure your message is clear and to the point. Also, be aware that individuals from different cultures may have different business customs. Practices common in the U.S. are not necessarily accepted worldwide and may be interpreted as impolite or even offensive. For example, in some cultures, a firm handshake is considered rude.

Earnings

There are three basic methods shops use to pay their technicians. These are hourly rate, commission, and commission plus parts.

Hourly Rate

The ***hourly rate*** is simply a stated amount of pay given for each hour worked. This pay method may be desirable if you do not like the pressure of producing a specific quantity of work each week. However, you may make less money per year being paid an hourly rate than with other pay systems.

Commission

When you earn a ***commission***, you obtain a set percentage of the amount charged to the customers. For example, with a 50% commission on a $300 job, you would get $150 when the work is completed.

The flat-rate manual is a book that states how long each repair should take. If you are fairly quick and can match or beat the repair times listed in a flat-rate manual, you can earn a good wage. However, if you are slow or if there is not enough work to keep you busy, your income could be as low or lower than a technician paid an hourly rate.

Commission Plus Parts

Some technicians earn ***commission plus parts***. This is a variation of the commission system. In this pay system, a technician being paid on commission also receives a small commission for the parts installed during a repair.

Types of Shops

There are several different types of repair shops in which you can find employment. Each type of shop has advantages and disadvantages.

Dealerships

Large auto ***dealerships*** usually pay well and have a large volume of work to be done. Generally, dealerships also offer good benefits. In addition, since a dealership is aligned with a vehicle manufacturer, specialized training may be available for the types of vehicles you will be servicing. If you are fairly experienced and fast, a large dealership may be a good place to seek employment.

However, dealerships are required to perform warranty work. Warranty work consists of repairs done on vehicles that are still under warranty. The rate of pay for warranty work is considerably lower than that for customer-pay work. Refer to **Figure 10-3**.

Independent Shops

An ***independent shop*** is a service facility that is not affiliated with a vehicle manufacturer, retail store, or franchise operation. This type of shop can also be an excellent place to work. The pay is normally good and independent shops do not perform warranty work. The shop owner controls the work atmosphere and conditions for the technicians. If you want to work in an independent shop, locate a reputable shop that has plenty of volume to keep you busy. The shop should encourage ASE certification. Inquire about insurance and other benefits; many independent shops offer these.

Service Stations

A ***service station*** that has a repair area (not a gas station) may be an excellent place to work, especially

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when you are a beginner. Much of the work will be quick service repairs that only take an hour or two. You will replace belts, hoses, water pumps, thermostats, tires, and other items. Many service stations offer a parts percentage incentive, which can increase your earnings. You can learn much about vehicle repair in a service station.

Specialty Shops

A ***specialty shop*** specializes in one type of work. Many specialty shops are franchise operations. The drawback to a specialty shop is a lack of variety.

An example of a specialty shop is a muffler shop. This type of shop will have specialized tubing benders and pipe cutting equipment for exhaust pipe fabrication. See **Figure 10-4**.

Getting a Job as an Automobile Technician

Normally, it is not difficult to find a job as an automobile technician. Job openings are available in service stations, specialty shops, independent shops, and large dealerships. You must match your training and experience to the openings available.

Preparing a Résumé

The first step in any job search should be to prepare a detailed résumé. A ***résumé*** is a document that summarizes your qualifications for a position. Even if employers do not require a résumé, preparing this document will help you assess your qualifications for the types of jobs you are seeking. It will also help you review your skills in preparation for interviews with potential employers.

The résumé should include your contact information (name, address, phone number, and e-mail address), an objective identifying the type of job you are seeking, and a summary of your education, skills, and work experience.

Be sure to include the names and telephone numbers of two or three people who can provide a recommendation. Examples of good references include previous employers, supervisors, or instructors. A sample résumé is given in **Figure 10-5**.

The Internet is a good resource of information to help you develop an effective résumé. Public libraries have many references available to assist in résumé preparation. There are also computer software packages designed for writing a résumé.

Job Application Forms

A prospective employer may ask you to complete a job application form before having an interview. The job application form highlights the information the employer needs to know about you, your education, and your prior work experience. Employers often use these forms to screen applicants for the skills needed on the job. You might complete a form in a personnel or employment office. Sometimes you may get the form by mail.



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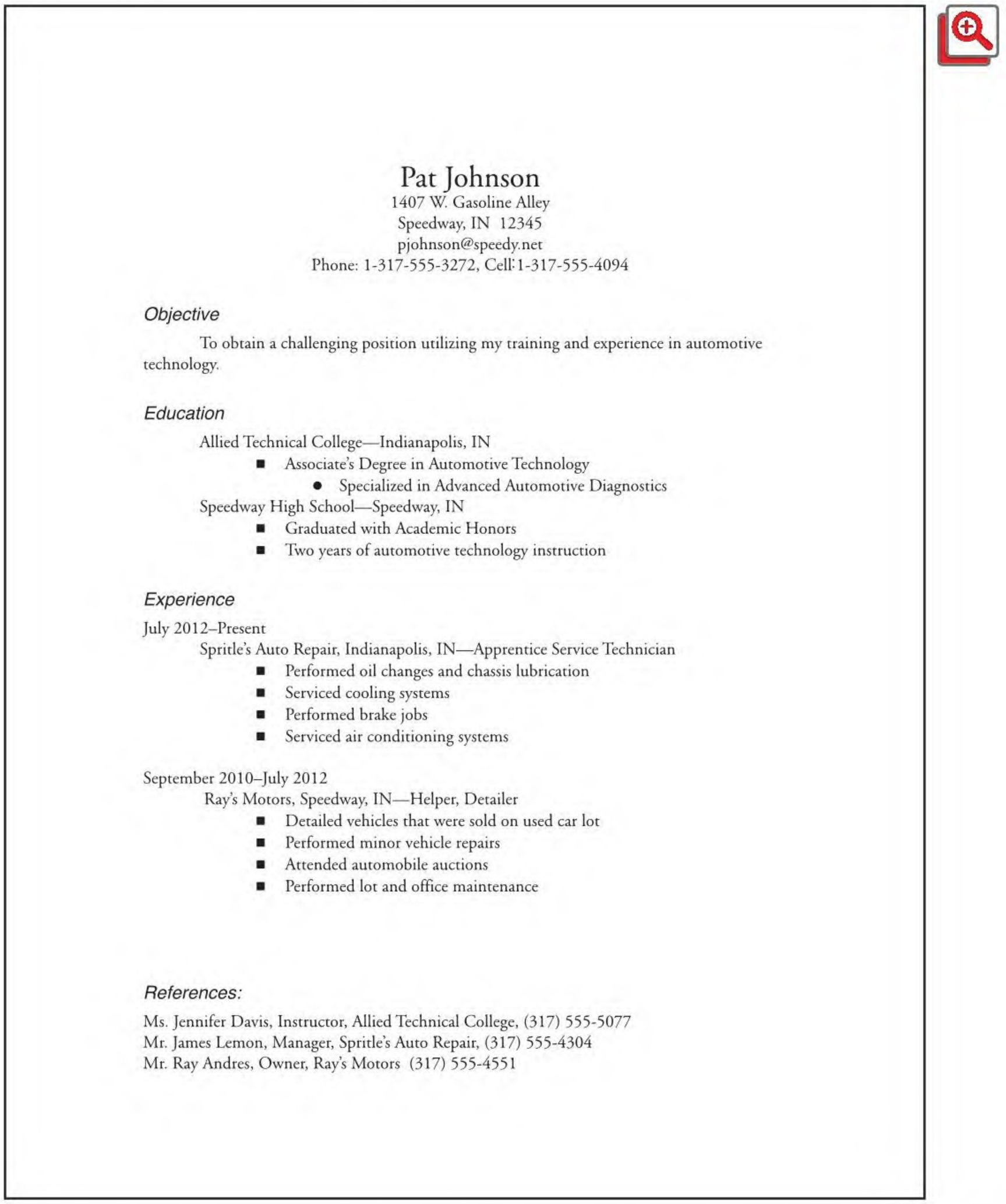
Figure 10-3. Automobile dealerships provide many opportunities for competent technicians.



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Figure 10-4. This specialty shop performs repairs in only a few areas.

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Pat Johnson
1407 W. Gasoline Alley
Speedway, IN 12345
pjohnson@speedy.net
Phone: 1-317-555-3272, Cell: 1-317-555-4094

Objective

To obtain a challenging position utilizing my training and experience in automotive technology.

Education

Allied Technical College—Indianapolis, IN
- Associate's Degree in Automotive Technology
  - Specialized in Advanced Automotive Diagnostics

Speedway High School—Speedway, IN
- Graduated with Academic Honors
- Two years of automotive technology instruction

Experience

July 2012–Present
Spritle's Auto Repair, Indianapolis, IN—Apprentice Service Technician
- Performed oil changes and chassis lubrication
- Serviced cooling systems
- Performed brake jobs
- Serviced air conditioning systems

September 2010–July 2012
Ray's Motors, Speedway, IN—Helper, Detailer
- Detailed vehicles that were sold on used car lot
- Performed minor vehicle repairs
- Attended automobile auctions
- Performed lot and office maintenance

References:

Ms. Jennifer Davis, Instructor, Allied Technical College, (317) 555-5077
Mr. James Lemon, Manager, Spritle's Auto Repair, (317) 555-4304
Mr. Ray Andres, Owner, Ray's Motors (317) 555-4551

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Figure 10-5. A résumé should provide potential employers with a summary of your qualifications.

The appearance of the application form can give an employer the first opinion about you. Fill out the form accurately, completely, and neatly. How well you accomplish that can determine whether you get the job. When asked about salary, write open or negotiable. This means you are willing to consider offers.

Finding Job Openings

You may want to begin your job search by looking through the help-wanted ads in your local newspaper. If you are a student, ask your automotive instructors if they know of any job openings. Often, local repair facilities will contact instructors when looking for new employees.

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You can also search the Internet for leads. This is especially helpful if you plan to relocate to a new city. Visit websites that post job opportunities and allow you to post your résumé. See **Figure 10-6**. You can also use social networking sites, such as www.linkedin.com, to connect with prospective employers.

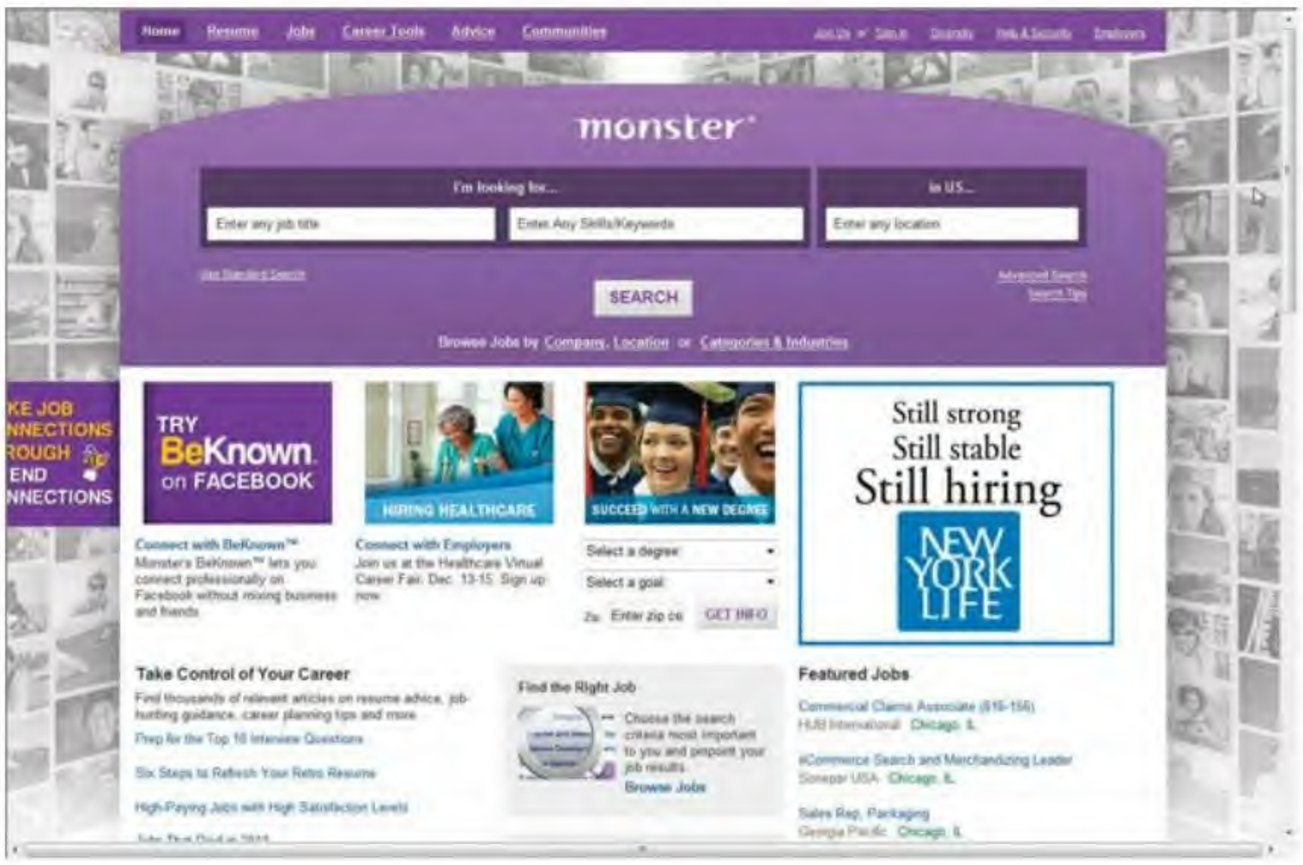
State and local governments operate employment agencies that can help you identify job openings. Check the local telephone directory to locate the agency in your area. Private employment agencies are also an option. However, do not enter into a contract with a private agency until you fully understand the services they provide and the fees they charge. Also, make sure the agency works with employers offering the types of jobs you are seeking.

If you cannot find job openings, look in the yellow pages of your local phone book. Instead of calling, go to each shop or garage. Ask if you can fill out an application. Then, even if there are no openings at that time, you will be on record if the shop needs someone to fill a position. When going to shops to apply for a position, take your résumé with you. At the very least, it will help you fill out any application required by the potential employer. In many cases, you can leave a copy of your résumé with the completed employment application. When visiting shops, dress appropriately. If you look and talk like a professional, your chances of getting a job will increase tremendously.

Interviewing

In some cases, a potential employer will ask you to come in for an interview. An ***interview*** is a meeting between a job candidate and an employer that allows the employer to more thoroughly evaluate the candidate's qualifications. It also gives the candidate the opportunity to ask questions about the job opening.

Be sure to arrive at the interview site a few minutes early. This will indicate that you are a punctual person. If necessary, drive to the interview site the day before the scheduled interview so you know how long it will take to get there. Dress neatly for the interview. This shows your professionalism. During the interview, sit upright in the chair, and talk slowly and plainly. Maintain eye contact with the person asking the questions and answer all questions thoroughly and honestly. Don't be afraid to ask questions about the job opening or to emphasize your qualifications. However, do not brag or act like you know everything there is to know about automotive technology. A good technician is willing to continue his or her education, even on the job. If you have passed ASE certification tests, be sure to mention this during the interview. At the conclusion of your interview, thank the interviewer for taking the time to meet with you. It is a good idea to send a follow-up letter thanking the interviewer for the opportunity to interview and offering to answer any additional questions that may arise. Be sure to include your contact information on the follow-up letter.



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Figure 10-6. Visit various websites to search for jobs in your area and to post your résumé.

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Accepting an Offer of Employment

If you are offered a job, make sure you know the terms of employment before accepting. Ask about the work hours, responsibilities, wages, benefits, and company policies. In many cases, you will be expected to provide your own tools. In other instances, tools will be provided for you. Before accepting a job, ask the potential employer when you would be expected to start work. Once you have worked out all the details and are comfortable with the terms of employment, you can formally accept the employment offer.



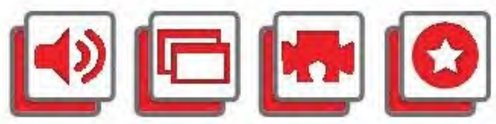
Workplace Skills

When applying for a position at an automotive shop, be sure to submit a resume, even if it is not required. It will give your prospective employer information about your qualifications, such as your education and work experience. For the interview, be sure to dress appropriately and have a positive attitude. Remember that the employer is looking not only at what you know, but also at your potential for learning on the job.

Summary

- Good employees are dependable, cooperative, curious, efficient, and professional.
- Failure to report to work on time, leaving early, or taking too many days off can have a detrimental effect on both your fellow technicians and your customers.
- All employees should work together to make the service facility a safe, enjoyable, and efficient operation.
- Efficiency is the ability of a technician to produce high quality work quickly.
- An hourly rate is a stated amount of pay given for each hour worked.
- When you earn a commission, you obtain a percentage of the flat rate charged to the customers.
- In the commission plus parts pay system, a technician is paid on commission but also receives a small commission for the parts installed during a repair.
- Large auto dealerships usually pay well and have a large volume of work to be done. They also offer good benefits and specialized training for the types of vehicles you will be servicing.
- Warranty work consists of repairs done on vehicles that are still under warranty. The rate of pay for warranty work is considerably lower than that for customer-pay work.
- A specialty shop specializes in one type of work. For example, engine machine shops will rebuild or overhaul engines.
- The first step in getting any job should be to prepare a detailed resume.
- A good way to begin your job search is to look through the help-wanted ads in your local newspaper or at various job-related websites. Additionally, state and local governments operate employment agencies that can help you identify job openings.
- If you are offered a job, make sure you know the terms of employment before accepting.

Technical Terms



Write the definitions for the following terms on a separate sheet of paper.

comeback
commission
commission plus parts
cooperativeness
curiosity
dealership
dependability
efficiency
ethical behavior
hourly rate
independent shop
initiative
interview
leadership
negotiation
professionalism
résumé
service station
specialty shop

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Activities

1. Write a résumé and have your instructor review it.
2. Schedule a visit to a local garage. Ask permission to watch the workers do their jobs. Write a report on what you observed.
3. Do a practice interview with a friend or relative.

Review Questions

Answer the following questions using the information provided in this chapter.

1. Briefly explain why *dependability* is important to career success.
2. Why is it important to be able to work cooperatively with other technicians?
3. Why is *leadership* an important trait in a technician?
4. Name three crucial aspects of ethical workplace behavior.
5. What issues should be taken into consideration when communicating with customers from different cultures?
6. Explain three ways in which you can be paid as an engine technician.
7. This would be used to determine how long a specific repair should take.
   (A) Service manual.
   (B) Service bulletin.
   (C) Commission manual.
   (D) Flat-rate manual.
8. A(n) _____ shop performs one type of work.
9. What information should be contained in a résumé?
10. What is the purpose of an interview?

ASE-Type Questions

1. The number one reason a technician is usually fired is due to lack of _____.
   (A) mechanical skills
   (B) dependability
   (C) education
   (D) productivity
2. Which of the following determine(s) the success of a technician?
   (A) Efficiency.
   (B) Dependability.
   (C) Professionalism.
   (D) All of the above.
3. Technician A says that some shops pay their technicians on an hourly rate basis. Technician B says that some shops pay their technicians on a commission basis. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. Which of the following is typical of the work normally performed at a service station?
   (A) Water pump replacement.
   (B) Serpentine belt replacement.
   (C) Thermostat replacement.
   (D) All of the above.
5. Technician A says you should arrive at an interview a little early to show that you are punctual. Technician B says that you should never ask questions of a potential employer during an interview. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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Section 2

Engine Technology

Chapter 11
Engine Fundamentals

Chapter 12
Engine Design Classifications

Chapter 13
Engine Top End Construction

Chapter 14
Engine Bottom End Construction

Chapter 15
Engine Front End Construction

Chapter 16
Engine Size and Performance Measurements

The engine is the "power plant" that produces the energy needed to propel the vehicle and operate other systems. It converts the heat energy of a fuel (gasoline, diesel oil, alcohol, etc.) into movement. If you know how an engine is constructed and how it is designed to operate, you will be better prepared to diagnose problems when it malfunctions.

Section 2 details the construction and operation of late-model automotive engines. It explains the four-stroke cycle, describes the function and location of major engine parts, details engine design variations, and summarizes engine size and performance measurements.

The information presented in this section will help you pass ASE Test A1, Engine Repair, and will also help you prepare for later chapters on engine diagnosis, service, and repair.



Chapter 11
Engine Fundamentals

After studying this chapter, you will be able to:

- Identify the major parts of a typical automotive engine.
- Describe the four-stroke cycle.
- Define common engine terms.
- Explain the basic function of the major parts of an automotive engine.
- Cite and demonstrate safe working practices related to engines.
- Correctly answer ASE certification test questions that require knowledge of the basic operation of piston engines.

In the first chapter, you learned a little about how an engine operates. This chapter will build on that information by explaining each engine part in more detail. It will help you understand the information on engine types, engine construction, engine diagnostics, and engine service, presented in later chapters.

Engine Operation

The ***engine*** is the source of power for the vehicle. For this reason, it is sometimes called a power plant. An energy source, or ***fuel*** (usually gasoline, gas/alcohol mix, or diesel oil), is burned inside the engine's ***combustion chamber*** (hollow area between the top of the piston and the bottom of the cylinder head). This burning, or combustion, produces heat. The heat causes ***expansion*** (enlargement) of the gases in the engine.

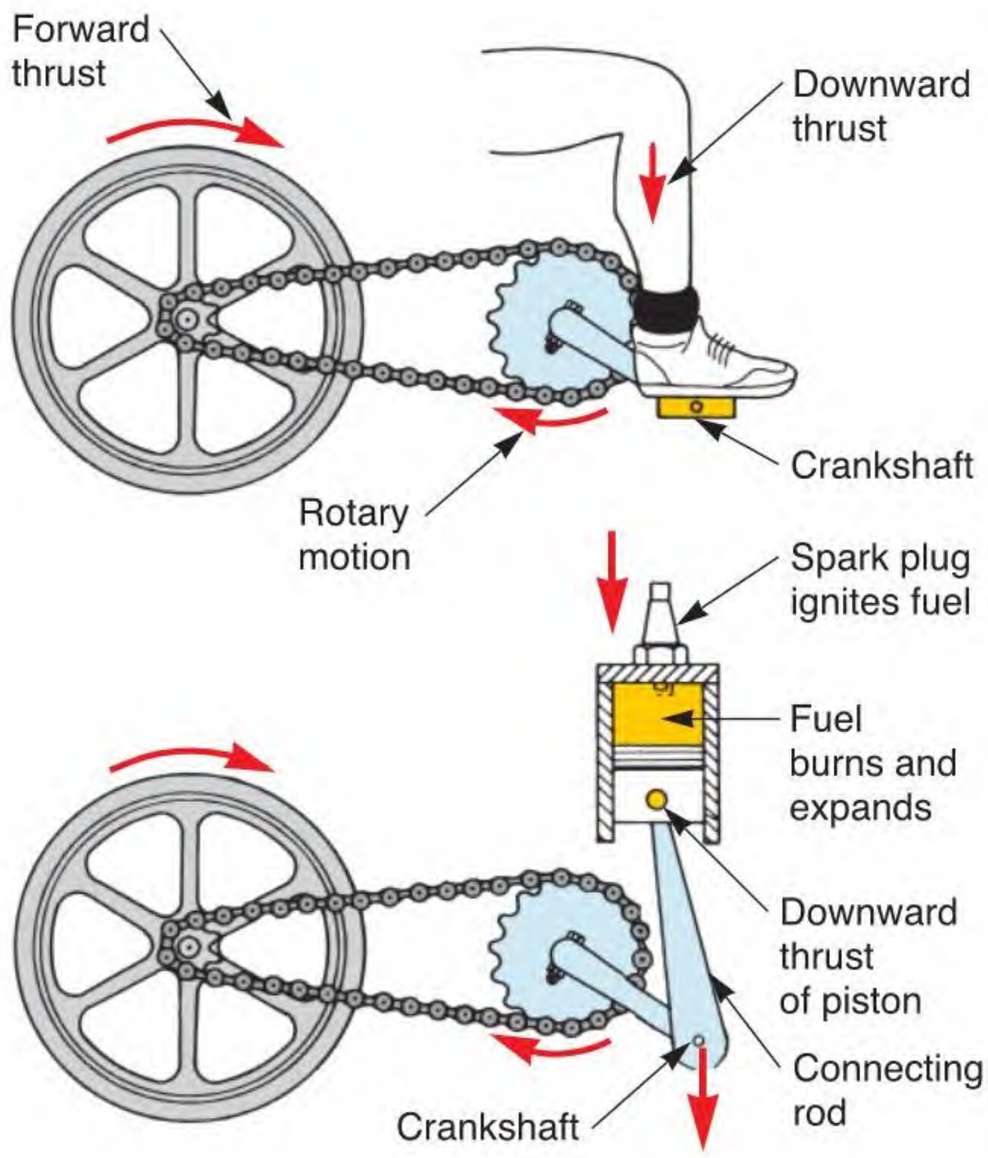
The burning and expansion of the gases in the combustion chamber produces pressure. The engine piston, connecting rod, and crankshaft convert this pressure into motion for moving the car and operating its other systems. See **Figure 11-1**.

Combustion pressure forces the piston down. By linking the piston to the crankshaft, an engine can produce a powerful rotating motion. The rotating crankshaft can be used to drive gears, chains and sprockets; belts and sprockets; and other drive mechanisms.

Piston Travel (TDC, BDC)

The distance the piston can travel up or down in the cylinder is limited by the crankshaft. When the piston is at the *highest point* in the cylinder, it is at ***top dead center (TDC)***. When the piston slides to its *lowest point* in the cylinder, it is at ***bottom dead center (BDC)***.

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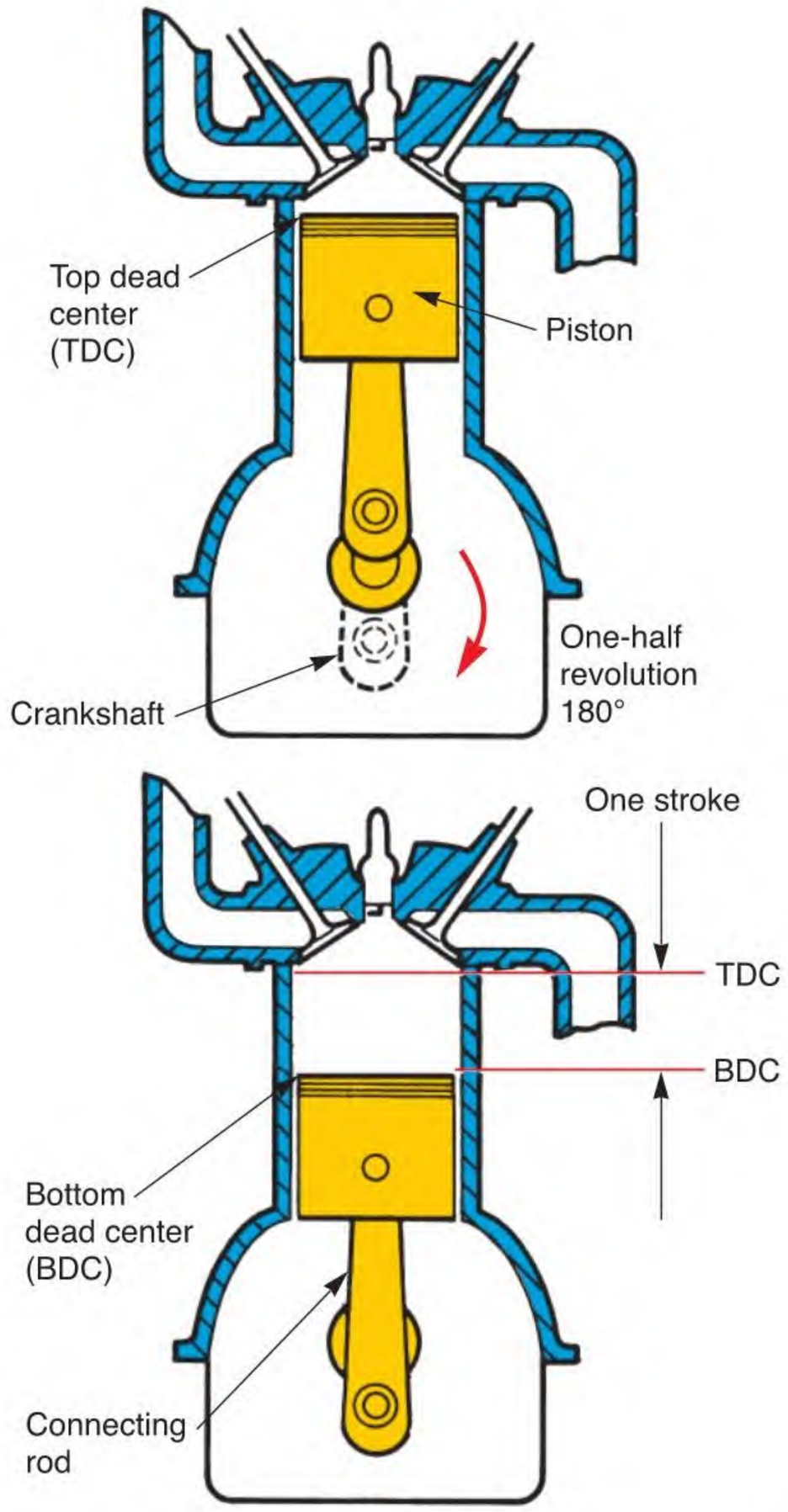
Figure 11-1. A crankshaft converts the downward thrust of the piston into useful rotating motion. The rotating motion can be used to operate the drive mechanism.

Piston stroke is the distance the piston slides up or down from TDC to BDC. The crankshaft rotates 180° (one-half turn) during one piston stroke. Refer to **Figure 11-2**.

Four-Stroke Cycle

The ***four-stroke cycle*** requires four piston strokes to complete one cycle (complete series of events). Every four strokes, the engine produces one power stroke (useful energy). Almost all automobiles use four-stroke-cycle engines.

The ***intake stroke*** of a direct injection engine draws air into the combustion chamber. During this stroke, the intake valve is open and the exhaust valve is closed. The piston slides down and forms a low-pressure area, or vacuum, in the cylinder. Atmospheric pressure then pushes the air past the open intake valve and down into the cylinder. Fuel is often injected into the cylinder during the intake stroke.



Ford

Figure 11-2. TDC means the piston is at the top of its stroke. BDC means the piston is at the bottom of its stroke. A stroke is one piston movement.

Tech Tip

Many engines still use multiport fuel injection systems. In these engines, fuel is injected into the intake manifold rather than into the cylinder. Therefore, the engine must pull both air and fuel into the combustion chamber during the intake stroke.

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During the ***compression stroke,*** the piston slides up with both valves closed. This squeezes the air-fuel mixture to prepare it for combustion (burning). The air-fuel mixture becomes hotter when pressurized.

Tech Tip

Injection timing in a direct gasoline injection engine depends on operating conditions. During moderate or heavy load operation, fuel is injected during the intake stroke. Under light load conditions, fuel is injected during the compression stroke. This will be covered in detail in later chapters.

During the ***power stroke***, the air-fuel mixture burns and pushes the piston down with tremendous force. This is the only stroke that does not consume energy—it produces energy. When the spark plug fires (gasoline engine), it ignites the air-fuel mixture. Since both valves are still closed, pressure forms on the top of the piston. The piston is forced down, spinning the crankshaft.

The ***exhaust stroke*** removes the burned gases from the engine and readies the cylinder for a fresh charge of air and fuel. During this stroke, the piston moves up. The intake valve is closed and the exhaust valve is open. The burned gases are pushed out the exhaust port and into the exhaust system.

The crankshaft must rotate two complete revolutions to complete the four-stroke cycle. With the engine running, this series of events happens over and over very quickly. Look at **Figure 11-3**.

Engine Bottom End

The term ***engine bottom end*** generally refers to the block, crankshaft, connecting rods, pistons, and related components. Another name for engine bottom end is the short block. It is an assembled engine block with the cylinder heads, intake manifold, exhaust manifold, and other external parts removed.

Engine Block

The ***engine block***, also called cylinder block, forms the main body of the engine. Other parts bolt to or fit inside the block. Refer to **Figure 11-4**.

The ***cylinders***, also known as the cylinder bores, are large, round holes machined through the block from top to bottom. The ***pistons*** fit into the cylinders. The cylinders are slightly larger than the pistons. This lets the pistons slide up and down freely.

The ***deck***, or deck surface, is the top of the block surrounding the cylinders. It is machined perfectly flat. The cylinder head bolts to the deck. Oil and coolant passages through the deck surface allow lubrication and cooling of the cylinder head parts.

Water jackets are coolant passages through the block. They allow a solution of water and antifreeze to cool the cylinders.

Core plugs, or freeze plugs, are round, metal plugs on the outside of the block. They seal holes left in the block after casting (manufacturing in a foundry). The plugs prevent coolant leakage out of the water jackets. Some new engines do not have freeze plugs.

The ***main bearing bores*** are holes machined in the bottom of the block to hold the crankshaft. Removable ***bearing inserts*** fit into these bores.

Main caps bolt to the bottom of the block and hold the crankshaft and main bearing inserts in place. Two or four large bolts normally secure each cap to the block. The caps and the block together form the main bearing bores.

An ***engine bedplate*** is a large metal girdle that replaces all the main bearing caps. It is a large, one-piece casting that has the lower half of the main bores machined into it to accept the main bearing inserts. A bedplate strengthens the bottom of the block, allowing the engine to develop more power without bearing failure.

The crankcase is the lowest portion of the block. The crankshaft rotates inside the crankcase.

Crankshaft

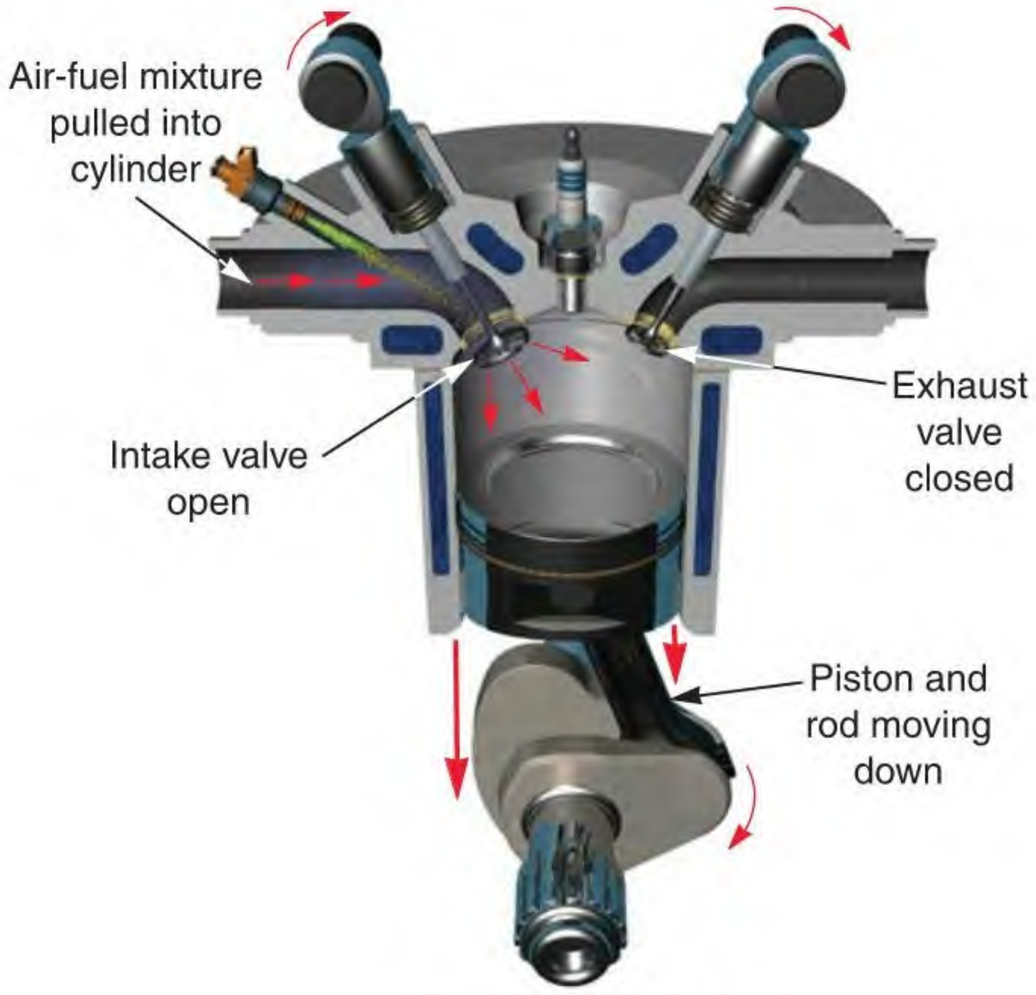
The ***crankshaft*** harnesses the tremendous force produced by the downward thrust of the pistons. It changes the up-and-down motion of the pistons into a rotating motion. The crankshaft fits into the bottom of the engine block.

The crankshaft main journals are surfaces that are precisely machined and polished. They fit into the block's main bearings.

The crankshaft rod journals are also machined and polished surfaces, but they are offset from the main journals. The connecting rods bolt to the rod journals. With the engine running, the rod journals revolve around the centerline of the crankshaft, **Figure 11-5**.

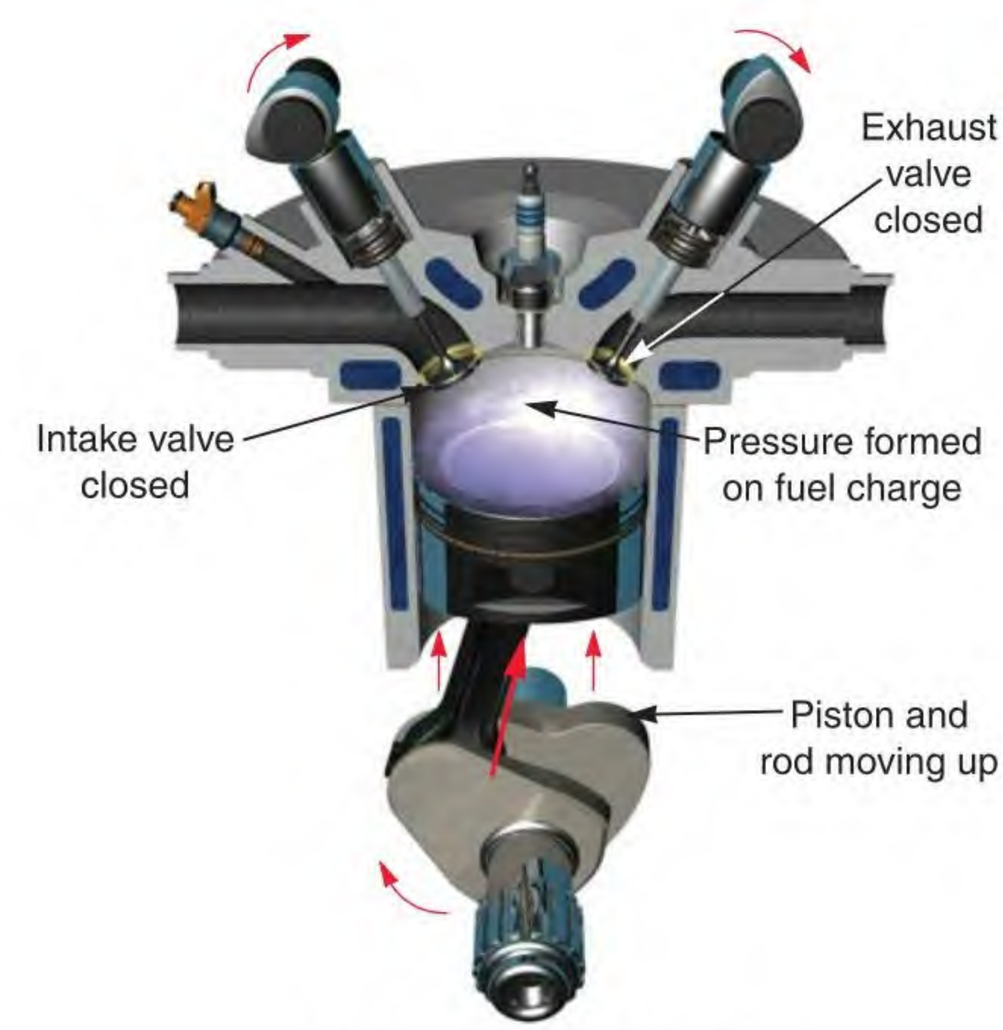
Counterweights are formed on the crankshaft to prevent vibration. These weights counteract the weight of the connecting rods, pistons, rings, and rod journal offset.

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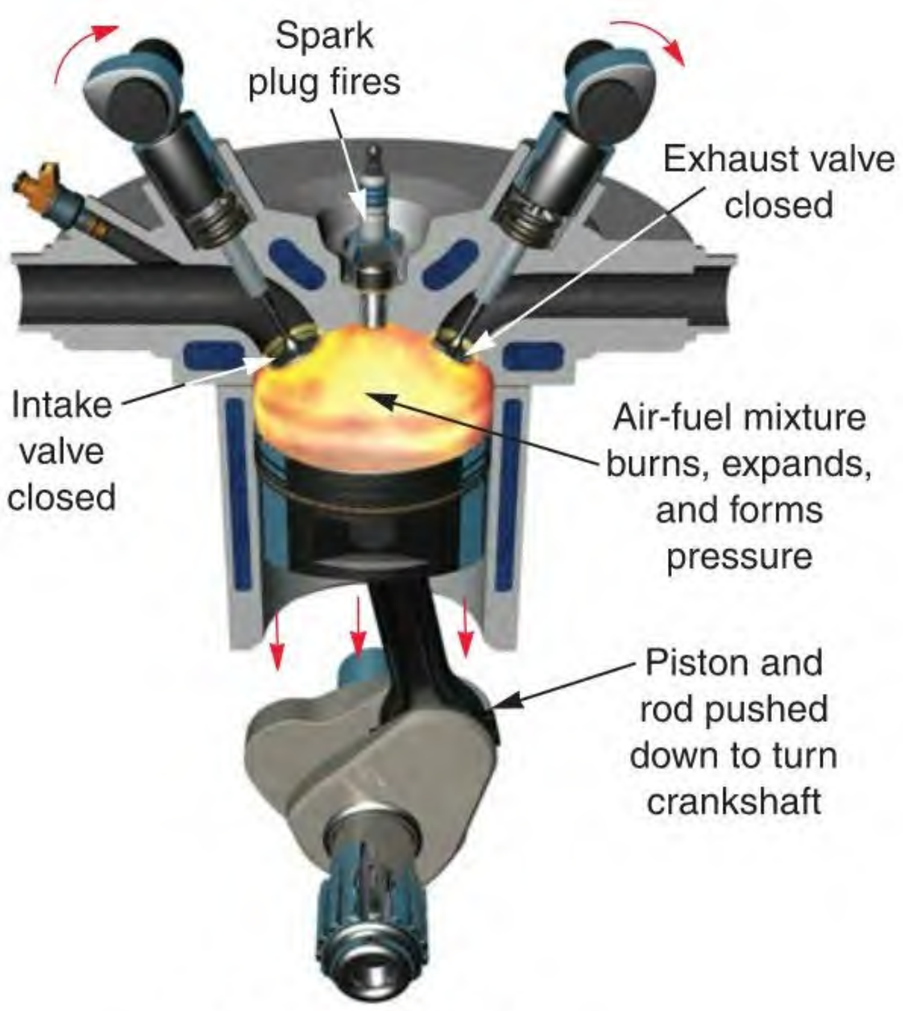
A—Intake Stroke

The piston slides down with the intake valve open and the exhaust valve closed. The air-fuel charge is pulled into the cylinder.



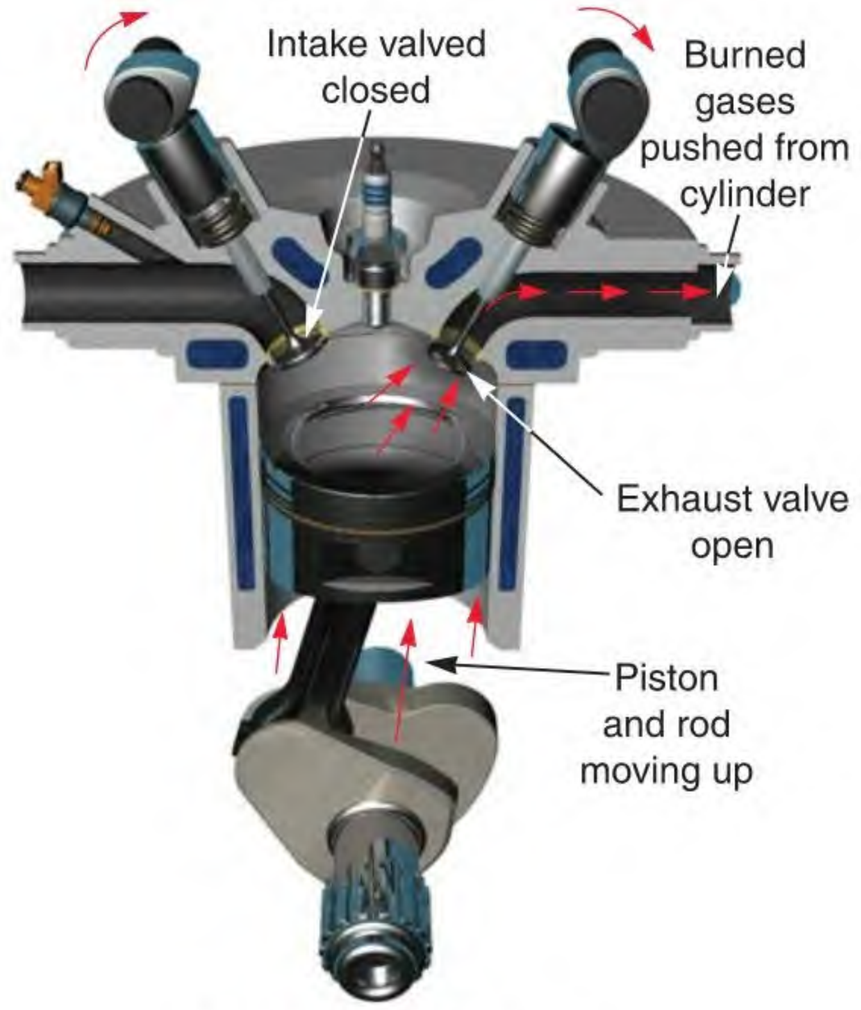
B—Compression Stroke

Both valves are closed and the piston slides up. This compresses the air-fuel charge and prepares it for combustion.



C—Power Stroke

The spark plug fires and the fuel begins to burn. The heat of combustion causes expansion of the gases and creates pressure. This pushes the piston down with tremendous force to spin the crankshaft.



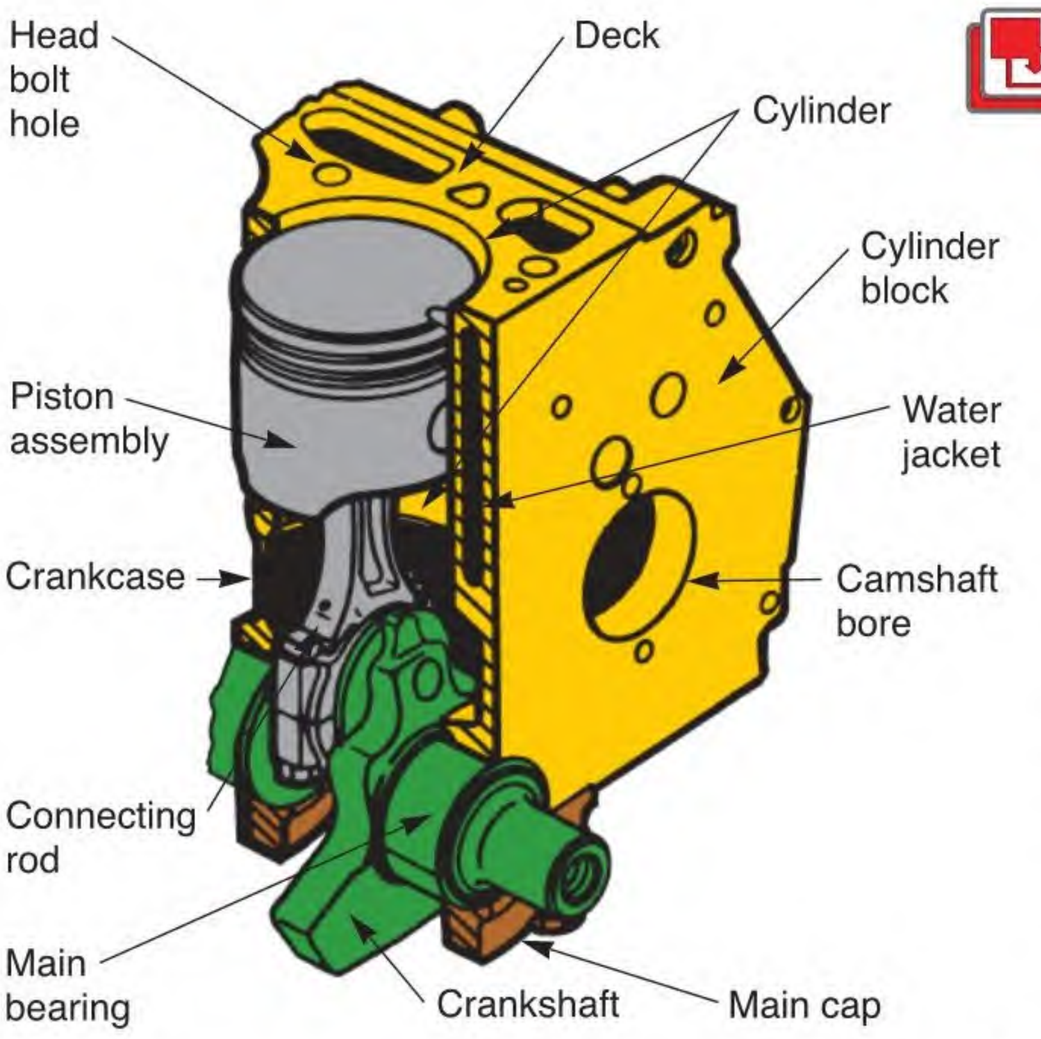
D—Exhaust Stroke

The piston slides up with the intake valve closed and the exhaust valve open. This pushes the exhaust gases out of the cylinder so a fresh charge can enter.

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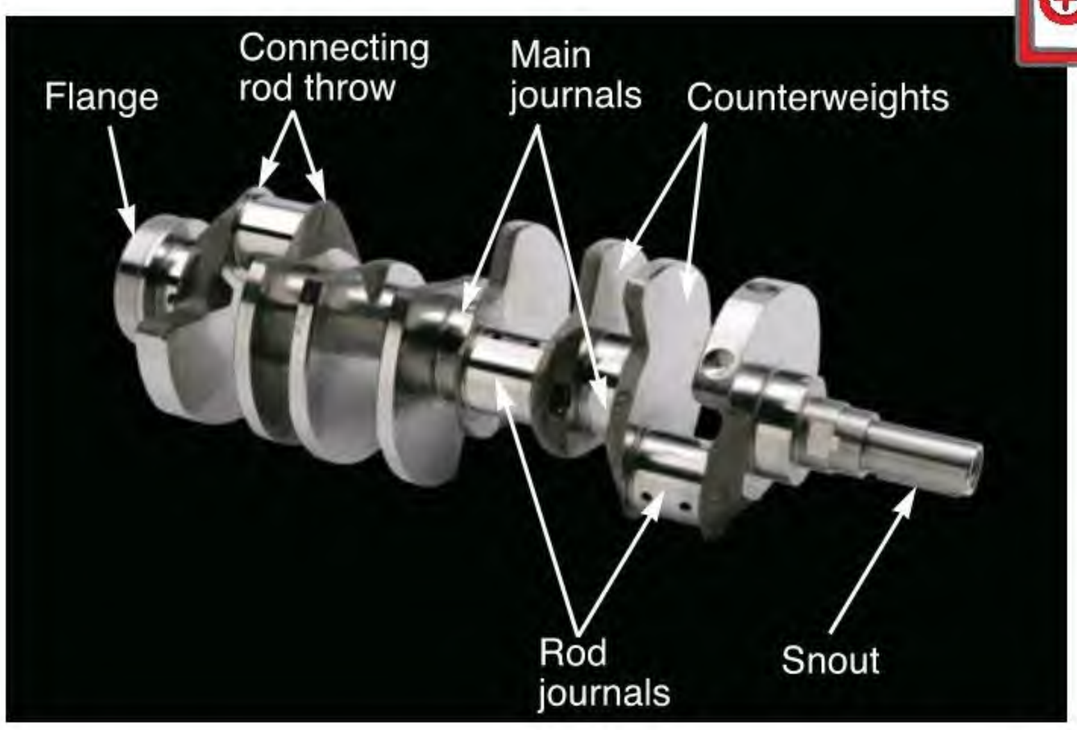
Figure 11-3. Study the phases of the four-stroke cycle.

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Ford

Figure 11-4. The block is the main supporting member of the engine. Note how the other parts fit into the block. The crankshaft fits into the bottom of the block.



Ford

Figure 11-5. Study the basic parts of a crankshaft. Journals are very smooth surfaces for the bearings.

The crankshaft snout sticks through the front of the block. It provides a mounting place for the camshaft drive mechanism, front damper, and fan belt pulleys.

A crankshaft flange holds the flywheel. The flywheel bolts to this flange. The center of the flange has a pilot hole or bushing for the transmission torque converter or input shaft.

Automobile engines can have 2, 3, 4, 5, 6, 8, 10, or 12 cylinders. The crankshaft rod journals are arranged so there is always at least one cylinder on a power stroke. As a result, force is always being transmitted to the crankshaft to smooth engine operation.

Engine Main Bearings

The ***engine main bearings*** fit between the block main bores and the crankshaft main journals. Each engine main bearing consists of two removable inserts. The upper main bearing insert fits into the cylinder block. The lower main bearing insert fits into the main caps or the bedplate.

Oil holes in the upper main bearing inserts line up with oil holes in the block. This allows oil to flow through the block and main bearings, and into the crankshaft. The oil flows through the crankshaft to lubricate the main bearings and the connecting rod bearings. This prevents metal-to-metal contact.

A main thrust bearing limits the distance the crankshaft can slide forward or rearward in the block. Flanges are formed on the main thrust bearing. These flanges almost touch the thrust surfaces on the crankshaft. This limits crankshaft end play (front-to-rear movement). Normally, only one of the main bearings serves as a thrust bearing.

Main bearing clearance is the space between the crankshaft main journal and the main bearing insert. Clearance allows lubricating oil to enter and separate the journal and bearing. This allows the journal to rotate without rubbing on the bearing and causing excess wear. Refer to **Figure 11-6**.

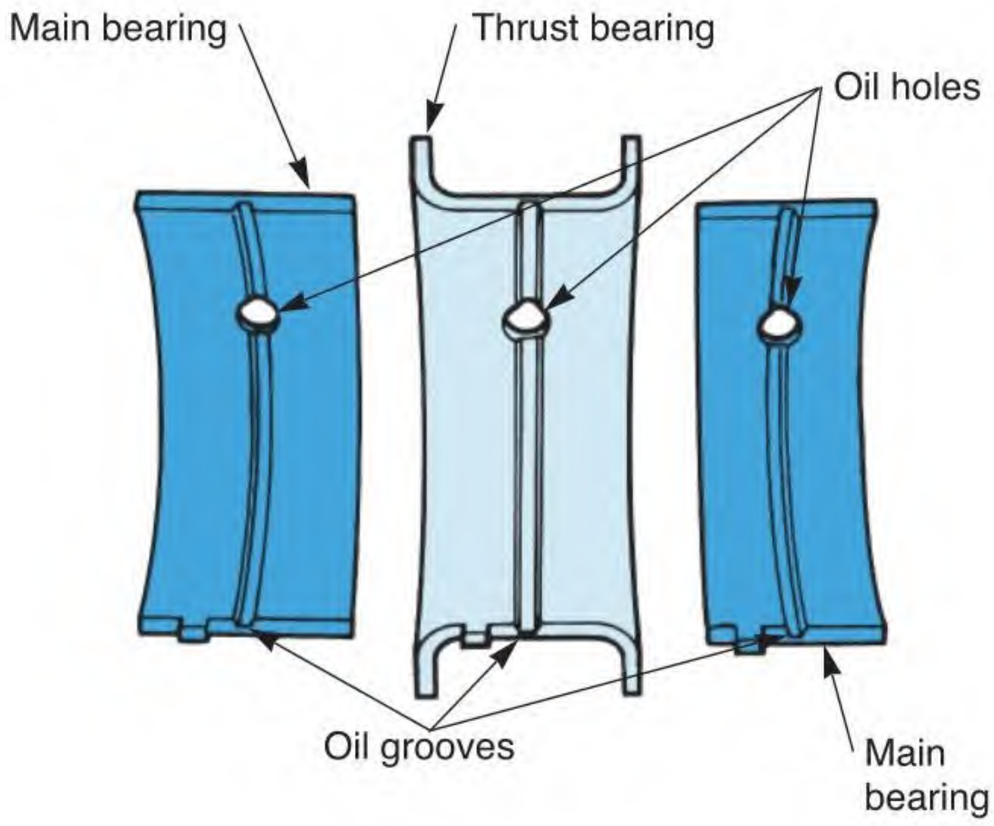
Crankshaft Oil Seals

Crankshaft oil seals keep oil from leaking from the front and rear of the engine. The oil pump forces oil into the main and rod bearings. This causes oil to spray out of the bearings. Seals are placed around the front and rear of the crankshaft to contain this oil.

The ***rear main oil seal*** fits around the rear of the crankshaft to prevent oil leakage. It can be a one- or two-piece seal. The seal lip rides on a machined and polished surface on the crankshaft.

The front seal prevents oil leakage around the crankshaft snout. It is normally a one-piece seal that is pressed into the engine's front cover (metal housing that bolts to the front of the engine). The seal lip may contact the crankshaft directly, or it may contact a sleeve that fits over the crankshaft snout.

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Federal Mogul

Figure 11-6. Main bearing inserts fit between the crankshaft main journals and the block. One bearing has thrust surfaces to control crankshaft end play. Oil holes and grooves allow oil to lubricate the bearings.

Flywheel

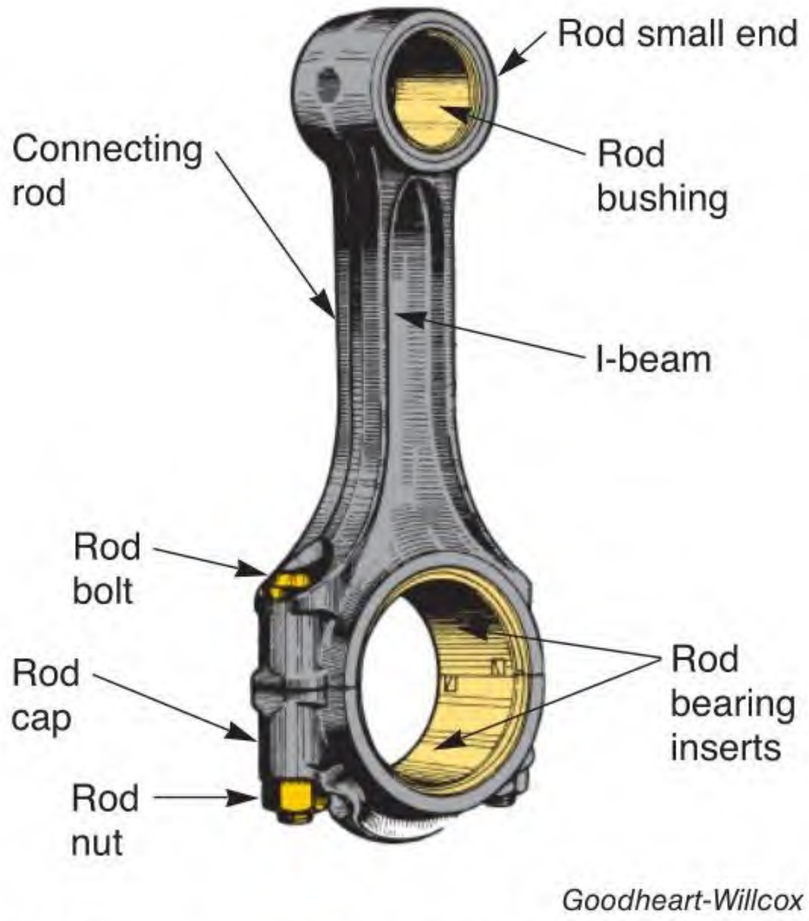
A ***flywheel*** is a large metal disk mounted on the rear of the crankshaft. A flywheel can have several functions:

- The flywheel connects the engine crankshaft to the transmission or transaxle. Either the manual clutch or the automatic transmission torque converter bolts to the flywheel.
- The flywheel for a vehicle with a manual transmission is very heavy and can help smooth engine operation.
- The flywheel generally contains a large ***ring gear***, which is used to start the engine. A small gear on the starting motor engages the flywheel ring gear and turns the flywheel.

Connecting Rod

The ***connecting rod*** fastens the piston to the crankshaft. It transfers piston movement and combustion pressure to the crankshaft rod journals. The connecting rod also causes piston movement during the non-power-producing strokes (intake, compression, and exhaust). Refer to **Figure 11-7**.

The connecting rod small end, or top end, fits around the piston pin. Also called the upper end, it contains a one-piece bushing. The bushing is pressed into the rod small end.



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Figure 11-7. The connecting rod is the link between the piston and crankshaft.

The connecting rod I-beam is the center section of the rod. The I-beam shape provides a very high strength-to-weight ratio. It prevents the rod from bending, twisting, and breaking.

The connecting rod cap bolts to the bottom of the connecting rod body. The connecting rod big end, or lower end, is a hole machined in the rod body and cap. The connecting rod bearing fits into the big end.

Connecting rod bolts and nuts clamp the rod cap and rod together. They are special high tensile strength fasteners. Some rods use cap screws without a nut. The cap screws thread into the rod itself. This design reduces rod weight.

Connecting Rod Bearings

The ***connecting rod bearings*** ride on the crankshaft rod journals. They fit between the connecting rods and the crankshaft. Like main bearings, the rod bearings are removable inserts.

Rod bearing clearance is the small space between the rod bearing and crankshaft journal. As with main bearing clearance, it allows oil to enter the bearing. The oil prevents metal-to-metal contact that would wear out the crank and bearings.

Piston

The piston transfers the pressure of combustion (expanding gas) to the connecting rod and crankshaft. It must also hold the piston rings and piston pin while operating in the cylinder.

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The piston head is the top of the piston and is exposed to the heat and pressure of combustion. This area must be thick enough to withstand these forces. It must also be shaped to match and work with the shape of the combustion chamber for complete combustion. Study **Figure 11-8**.

Piston ring grooves are slots machined in the piston for the piston rings. The upper two grooves hold the compression rings. The lower groove holds the oil ring.

Piston oil holes in the bottom ring groove allow the oil to flow through the piston and onto the cylinder wall. The oil then drains back into the crankcase.

The piston ring lands are the areas between and above the ring grooves. They separate and support the piston rings as they slide on the cylinder.

The piston skirt is the side of the piston below the last ring. It keeps the piston from tipping in its cylinder. Without a skirt, the piston could cock and jam in the cylinder.

The piston boss is a reinforced area around the piston pin hole. It must be strong enough to support the piston pin under severe loads.

A piston pin hole is machined through the pin boss for the piston pin. It is slightly larger than the piston pin.

Piston clearance is the amount of space between the sides of the piston and the cylinder wall. Clearance allows a lubricating film of oil to form between the piston and the cylinder. It also allows for expansion when the piston heats up. The piston must always be free to slide up and down in the cylinder block.

Piston Pin

The ***piston pin***, also called wrist pin, allows the piston to swing on the connecting rod. The pin fits through the hole in the piston and the connecting rod small end. This is pictured in **Figure 11-9**.

Piston Rings

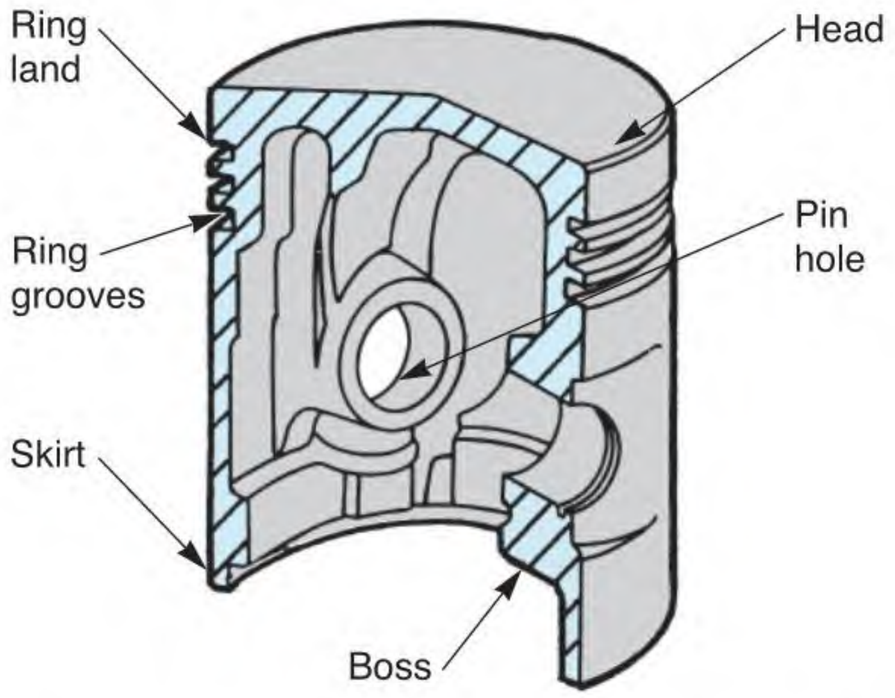
The ***piston rings*** seal the clearance between the outside of the piston and the cylinder wall. They must keep combustion pressure from entering the crankcase. They must also keep oil from entering the combustion chambers.

Most pistons use three rings: two upper compression rings and one lower oil ring. Note piston ring locations in **Figure 11-10**.

The ***compression rings*** prevent blowby (combustion pressure leaking into engine crankcase). **Figure 11-11** shows how compression rings function in an engine. On the compression stroke, pressure is trapped between the cylinder and piston grooves by the compression rings. Combustion pressure pushes the compression rings down in their grooves and out against the cylinder wall. This produces an almost leakproof seal.

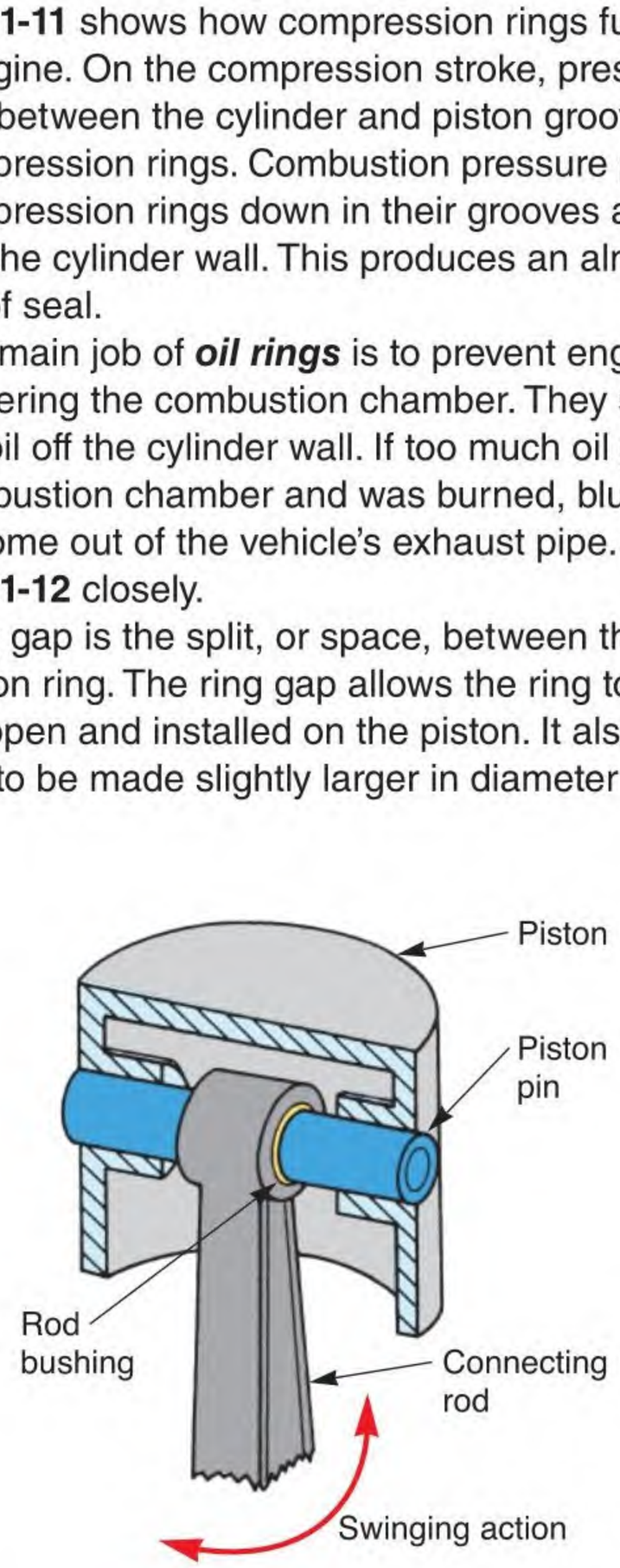
The main job of ***oil rings*** is to prevent engine oil from entering the combustion chamber. They scrape excess oil off the cylinder wall. If too much oil got into the combustion chamber and was burned, blue smoke would come out of the vehicle's exhaust pipe. Study **Figure 11-12** closely.

Ring gap is the split, or space, between the ends of a piston ring. The ring gap allows the ring to be spread open and installed on the piston. It also allows the ring to be made slightly larger in diameter than the



Deere & Co.

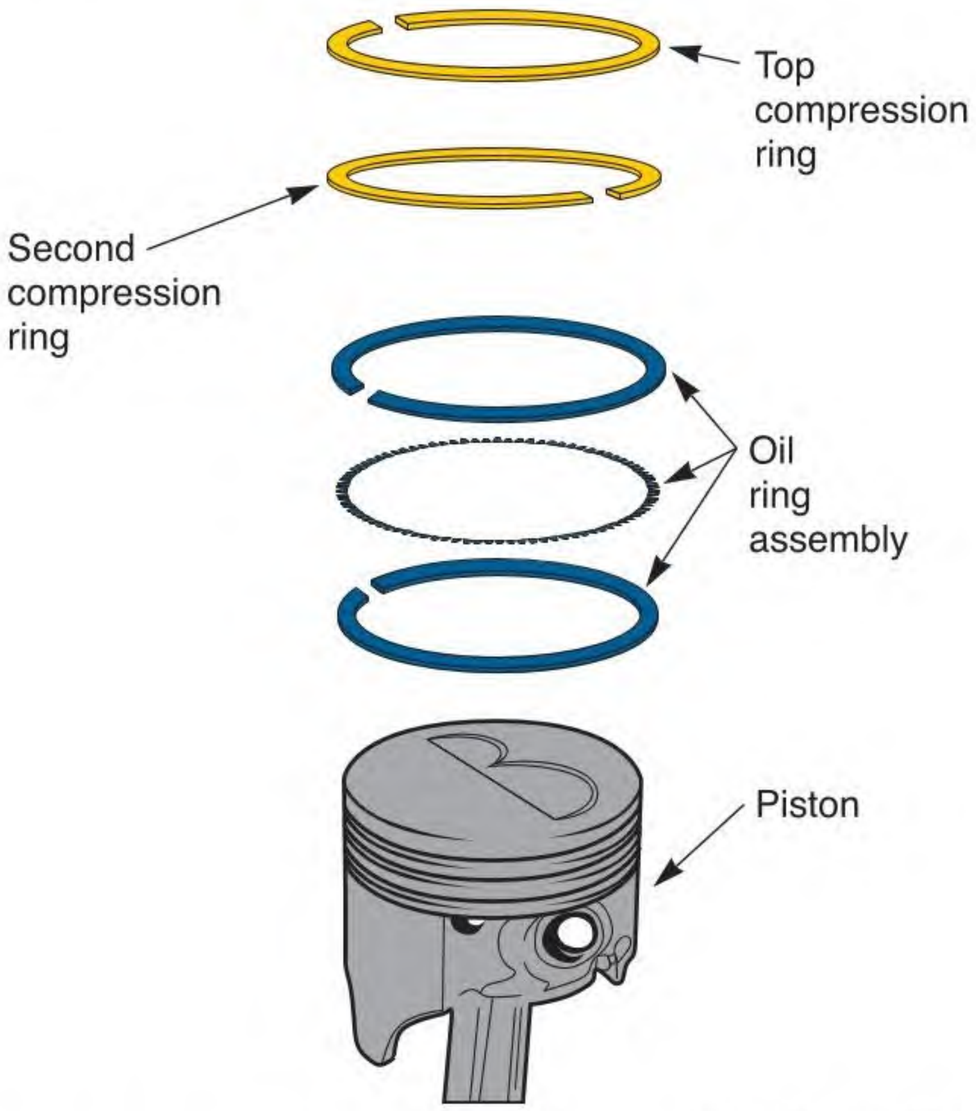
Figure 11-8. The piston rides in the cylinder and is exposed to the combustion flame. It must be light and strong.



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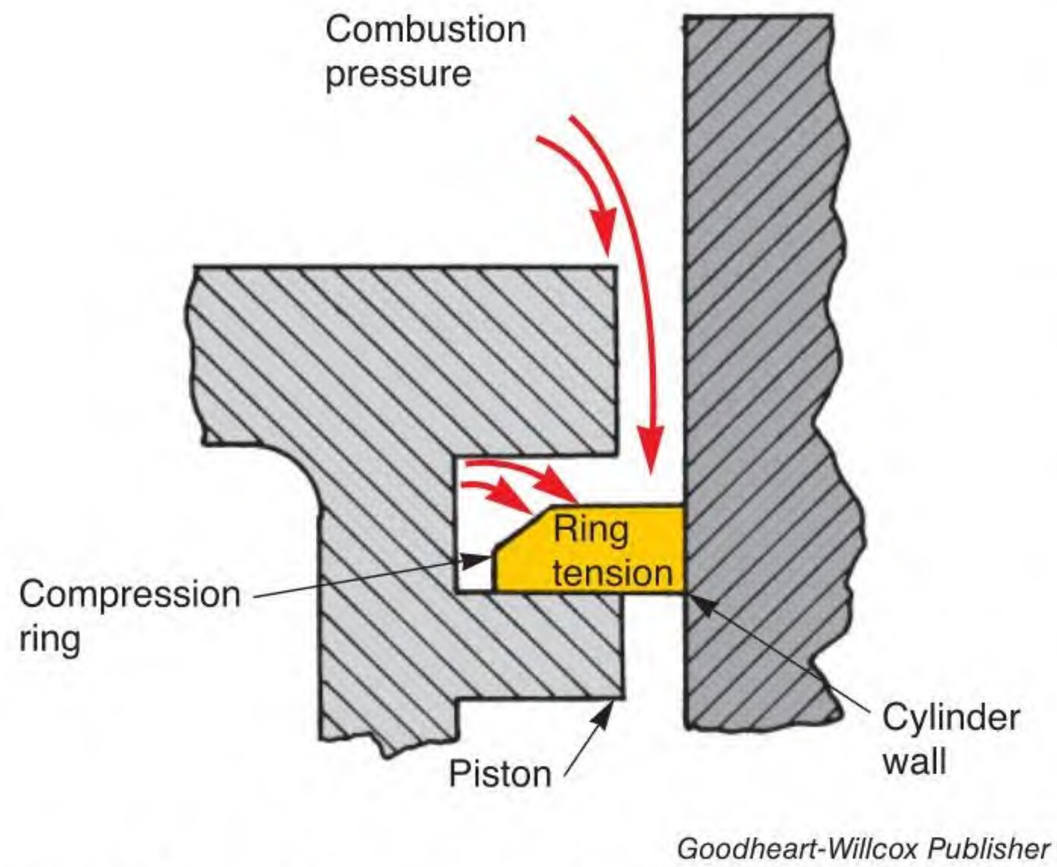
Figure 11-9. The piston pin allows the connecting rod to swing in the piston. This allows crankshaft and rod bottom end movement.

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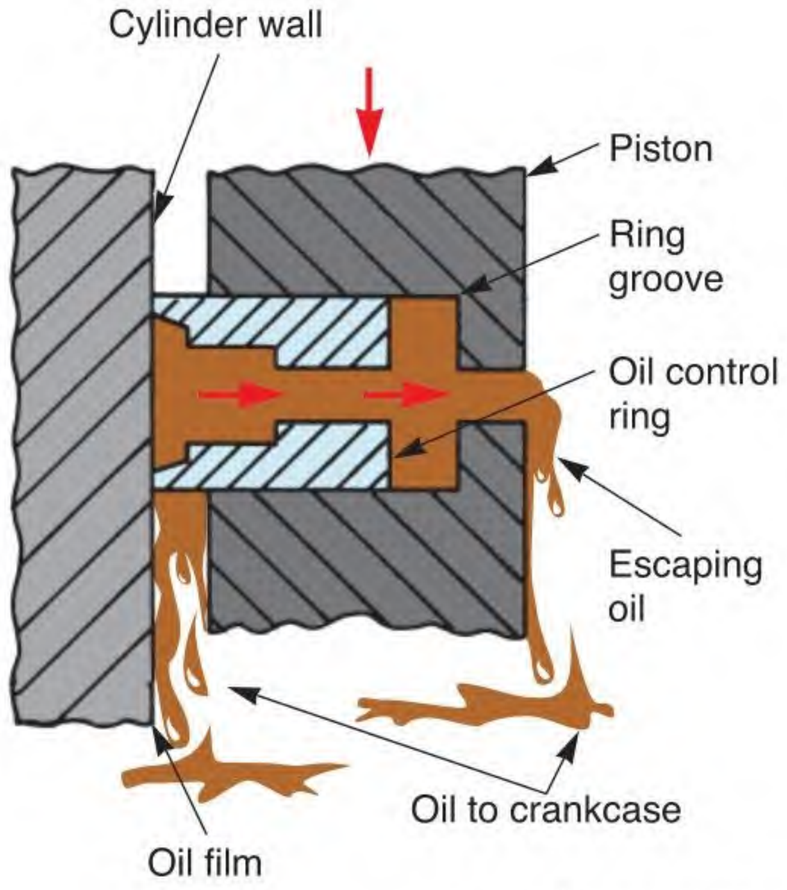
Figure 11-10. The two top piston rings are compression rings. The bottom ring is an oil ring. They fit into grooves cut in the piston.



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Figure 11-11. The compression ring must prevent combustion pressure from leaking between the piston and cylinder wall. Pressure actually helps push the ring against the cylinder to aid sealing.

cylinder. When squeezed together and installed in the cylinder, the ring spreads outward and presses on the cylinder wall. This aids ring sealing.



Goodheart-Willcox Publisher

Figure 11-12. The oil control ring scrapes excess oil off the cylinder wall. If this oil entered the combustion chamber, the engine would emit blue smoke.

Engine Top End

The term ***engine top end*** generally refers to the cylinder heads, valves, camshaft, and other related components. These parts work together to control the flow of air and sometimes fuel into the engine cylinders. They also control the flow of exhaust out of the engine. See **Figure 11-13**.

Cylinder Head

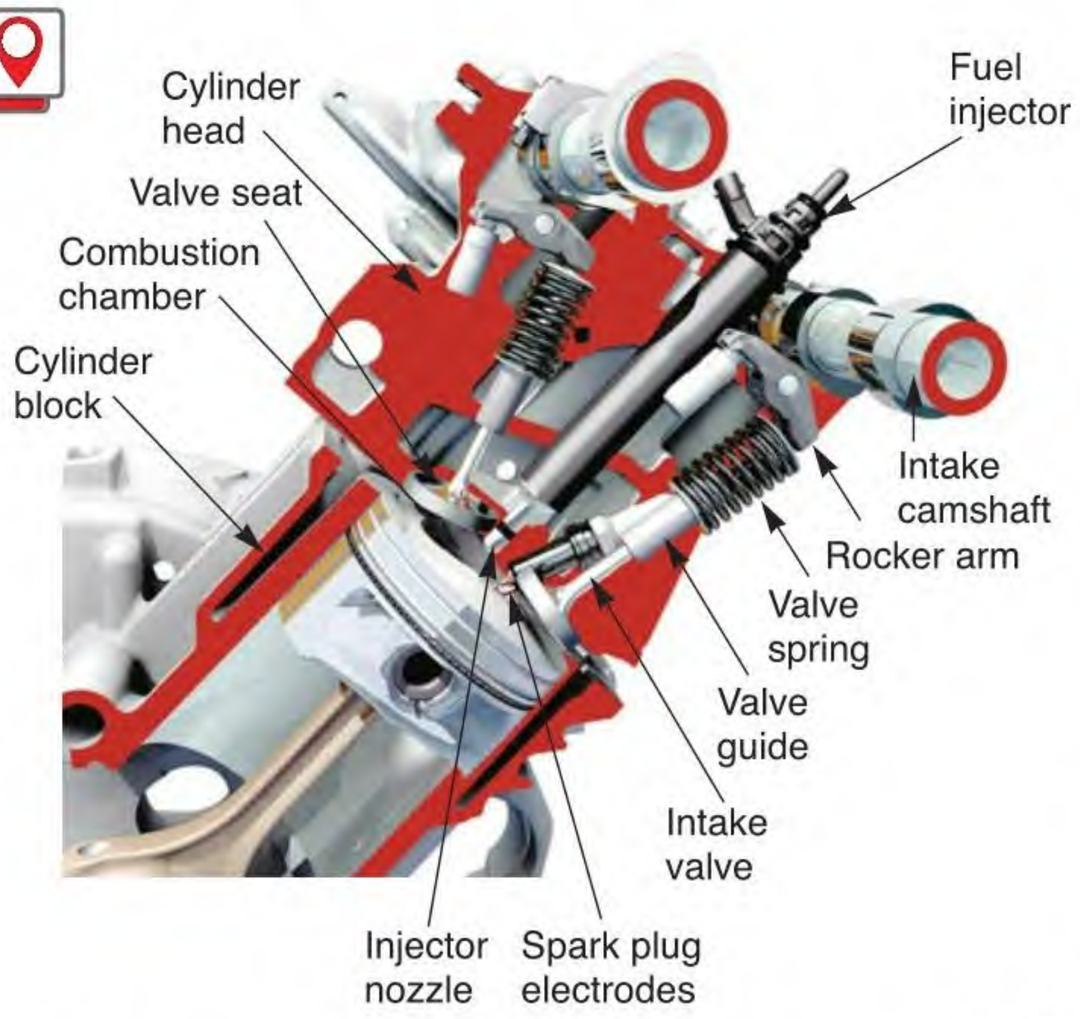
The ***cylinder head*** bolts to the deck of the cylinder block. It covers and encloses the top of the cylinders. See **Figure 11-14**.

Combustion chambers are small pockets formed in the cylinder heads. The combustion chambers are located directly over the cylinders. Combustion occurs in these areas of the cylinder head. Spark plugs (gasoline engine) and fuel injectors (direct injection engine) are mounted in holes in the cylinder head and protrude into the combustion chambers. See **Figure 11-15**.

Intake and exhaust ports are cast into the cylinder head. The ***intake ports*** route air (direct injection) or air and fuel (port injection) into the combustion chambers. The ***exhaust port*** routes burned gases out of the engine.

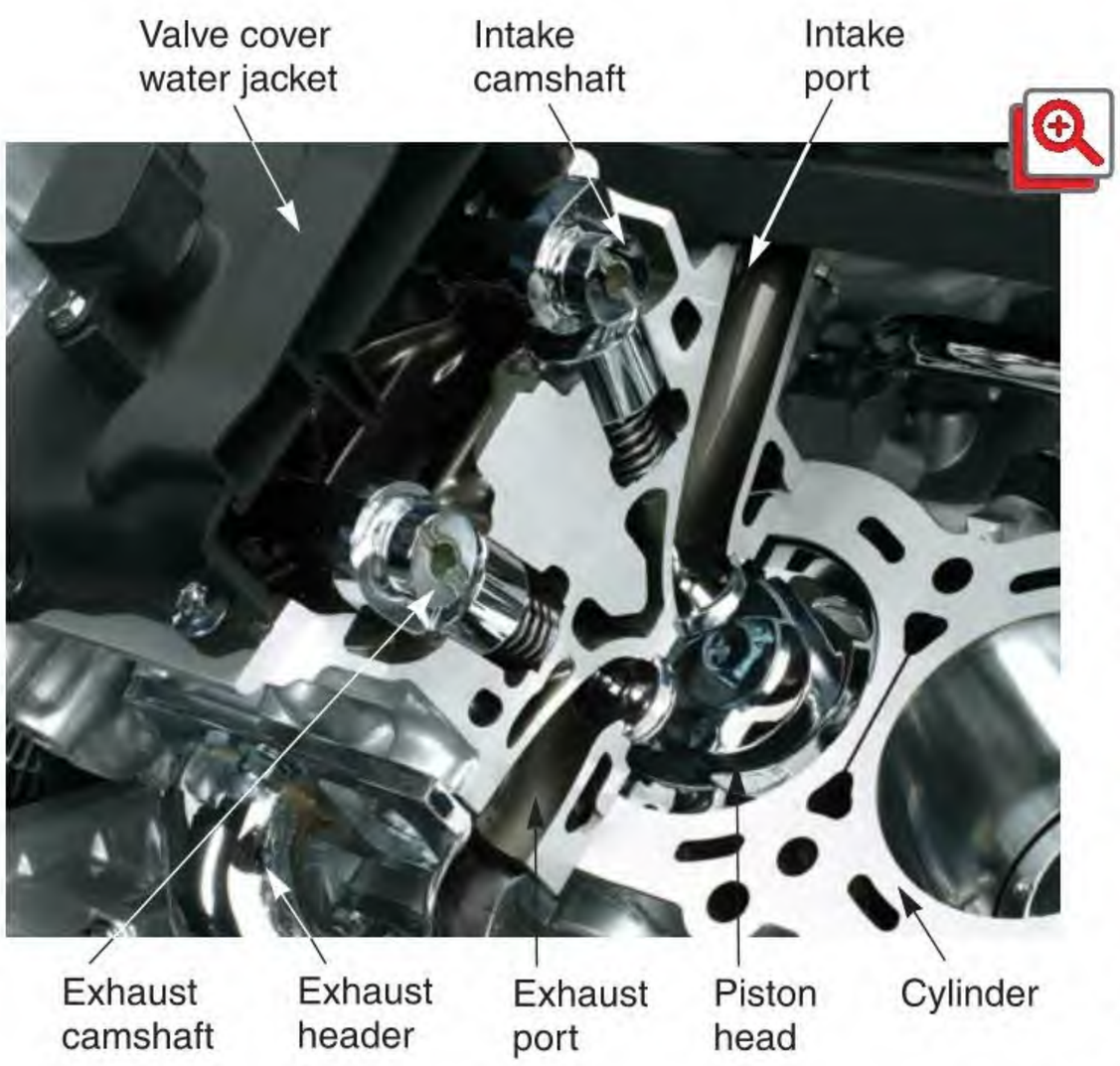
Valve guides are small holes machined through the cylinder head for the valves. The valves fit into and slide in these guides.

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Chrysler

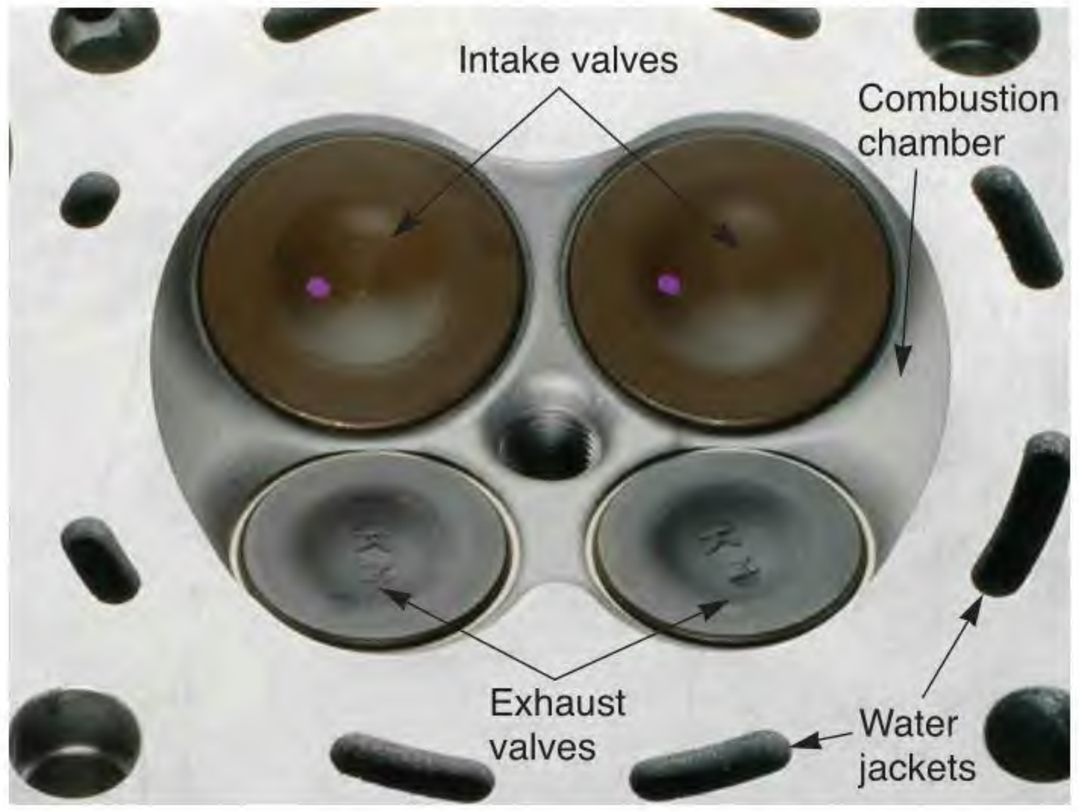
Figure 11-13. The engine top end controls the flow of the air or air-fuel mixture into the cylinder. It also controls the flow of exhaust out of the cylinder.



Nissan

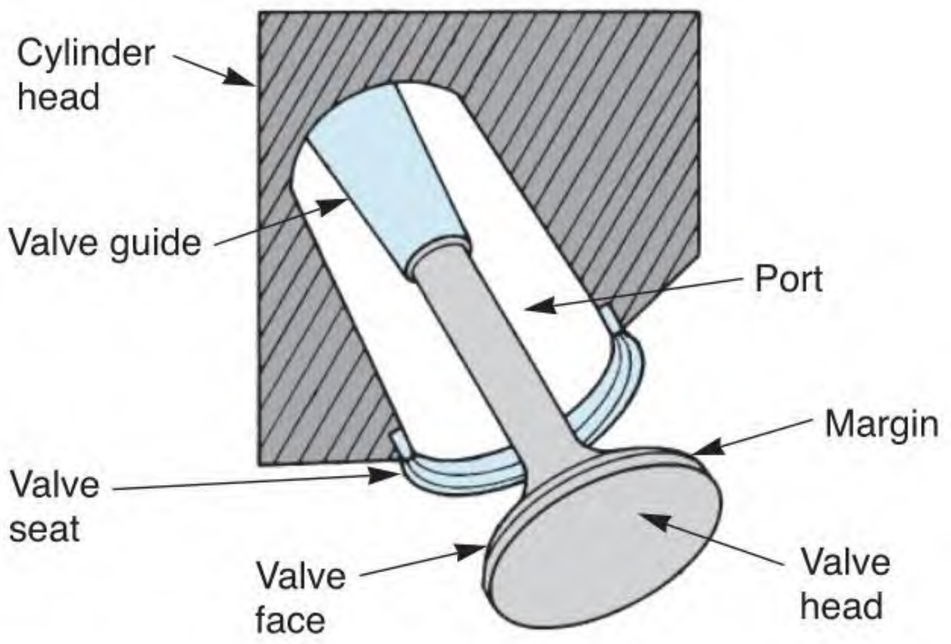
Figure 11-14. Study the basic engine top end components. The cylinder head is the foundation for these parts.

Valve seats are round, machined surfaces in the combustion chamber port openings. When a valve is closed, it seals against the valve seat, **Figure 11-16**.



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Figure 11-15. The combustion chamber is formed in the cylinder head.



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Figure 11-16. A valve slides up and down in the guide during operation. When the valve is closed, it seals against the valve seat to close off the port.

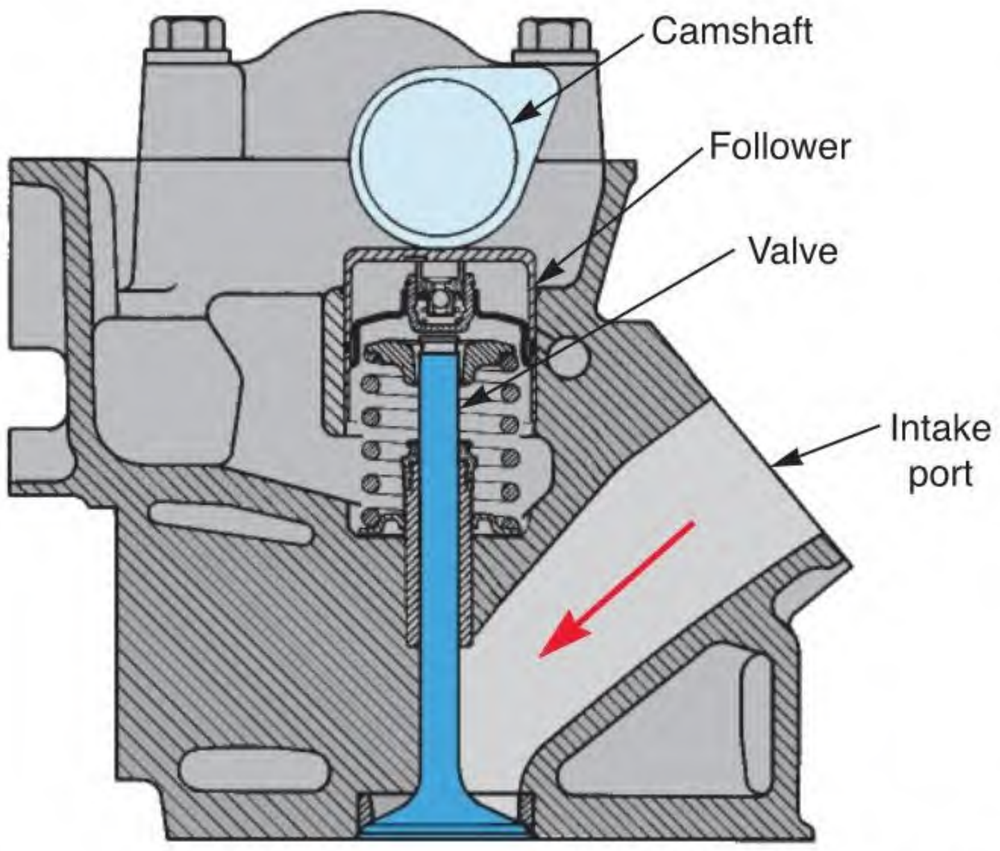
Valve Train

The ***engine valve train*** consists of the valves and the parts that operate them. These include the camshaft, lifters, push rods, rocker arms, valves, and valve spring assemblies. The valve train must open and close the valves at the correct time. Look at **Figure 11-17**. **Figure 11-18** illustrates basic valve train action.

Camshaft

The ***camshaft*** has lobes that open each valve. It can be located in the engine block or in the cylinder head.

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Mercedes-Benz

Figure 11-17. The valve train operates the engine valves. In this particular arrangement, the camshaft is located in the cylinder head, above the valve. As the camshaft lobe turns, it pushes downward on the follower to open the valve.

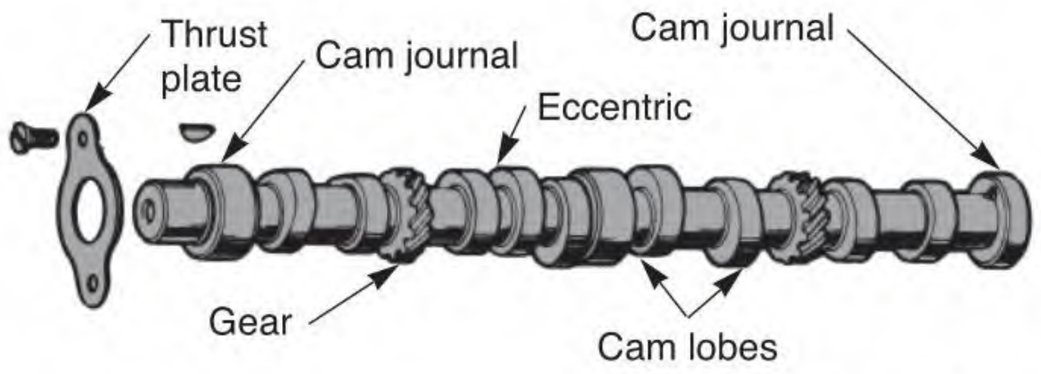
The cam lobes are egg-shaped protrusions (bumps) machined on the camshaft. One cam lobe is provided for each engine valve. Assuming the engine has two valves per cylinder, a 4-cylinder engine camshaft would have 8 cam lobes; a 6-cylinder, twelve lobes; etc.

An eccentric (oval) may be machined on the camshaft to operate a mechanical (engine-driven) fuel pump. This feature can be found on camshafts used in older engines or some diesel engines, as well as many direct gasoline injection engines with a high-pressure mechanical fuel pump. It is similar to a cam lobe but is more round.

Camshaft journals are precisely machined and polished surfaces for the cam bearings. Like the crankshaft, the camshaft rotates on its journals. Oil separates the cam bearings and cam journals. A camshaft is illustrated in **Figure 11-19**.

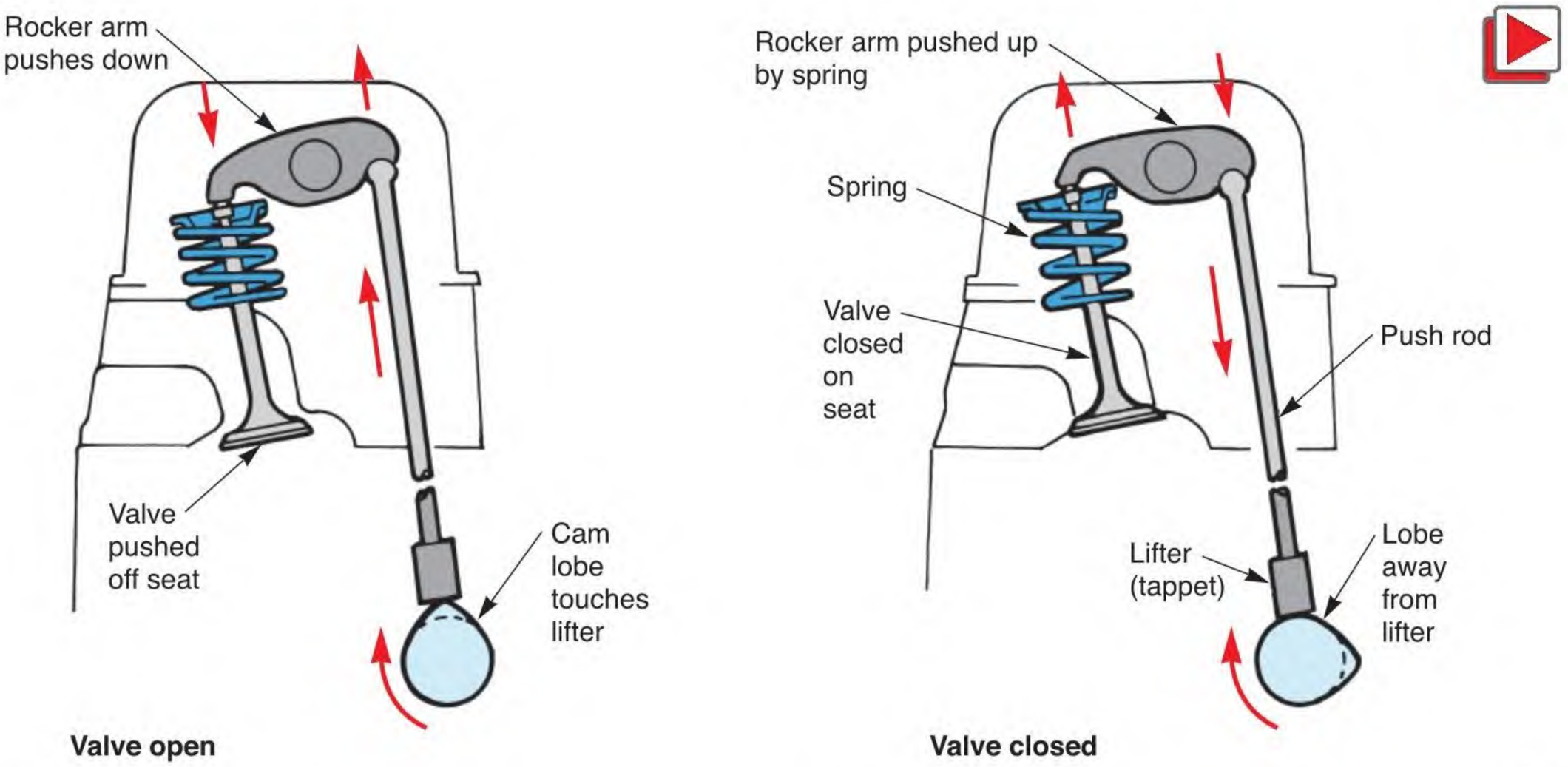
Valve Lifters

A ***valve lifter***, also called a ***tappet***, usually rides on the cam lobes and transfers motion to the rest of the valve train. The lifters can be located in the engine



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Figure 11-19. The camshaft is a long metal shaft with lobes, journals, and sometimes, an eccentric and gears.



Ford

Figure 11-18. In this valve train arrangement, the camshaft is located in the engine block. When the camshaft lobe turns into the lifter, the valve is pushed open. When the lobe rotates away from the lifter, the valve spring pushes the valve closed.

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block or cylinder head. They fit into lifter bores, which are machined holes in the block or head.

When the cam lobe moves toward the lifter, the lifter is pushed up in its bore. This opens the valve. Then, when the lobe rotates away from the lifter, the lifter is pushed down in its bore by the valve spring. This keeps the lifter in constant contact with the camshaft.

Push Rods

Push rods transfer motion between the lifters and the rocker arms. They are needed when the camshaft is located in the cylinder block. They are not needed when the camshaft is in the cylinder head.

A push rod is a hollow metal tube with a ball or socket formed on each end. One end of the push rod fits into the lifter. The other end fits against the rocker arm. In this way, when the lifter slides up, the push rod moves the rocker arm.

Rocker Arms

Rocker arms can be used to transfer motion to the valves. They mount on top of the cylinder head. A pivot mechanism allows the rocker arms to rock back and forth, opening and closing the valves.

Valves

Engine valves open and close the ports in the cylinder head. In the past, only two valves were used per cylinder: one intake valve and one exhaust valve. To improve efficiency, many late-model engines are equipped with four valves per cylinder: two intake valves and two exhaust valves.

The ***intake valve*** is larger than the exhaust valve. It controls the flow of the fuel mixture (gasoline engine) or air (direct injection and diesel) into the combustion chamber. The intake valve fits into the port leading from the intake manifold.

The ***exhaust valve*** controls the flow of exhaust gases out of the cylinder. It is smaller than the intake valve. The exhaust valve fits into the port leading to the exhaust manifold.

The valve head is the large, disc-shaped surface exposed to the combustion chamber. Its outside diameter determines the size of the valve.

The valve face is a machined surface on the back of the valve head. It touches and seals against the seat in the cylinder head.

The valve margin is the flat surface on the outer edge of the valve head. It is located between the valve head and face. The margin is needed to allow the valve to withstand the high temperatures of combustion. Without a margin, the valve head would melt and burn.

The valve stem is a long shaft extending out of the valve head. The stem is machined and polished. It fits into a guide located in the cylinder head.

Keeper grooves, or lock grooves, are machined into the top of the valve stem. They accept small keepers, or locks, that hold the retainer and spring on the valve, **Figure 11-20**.

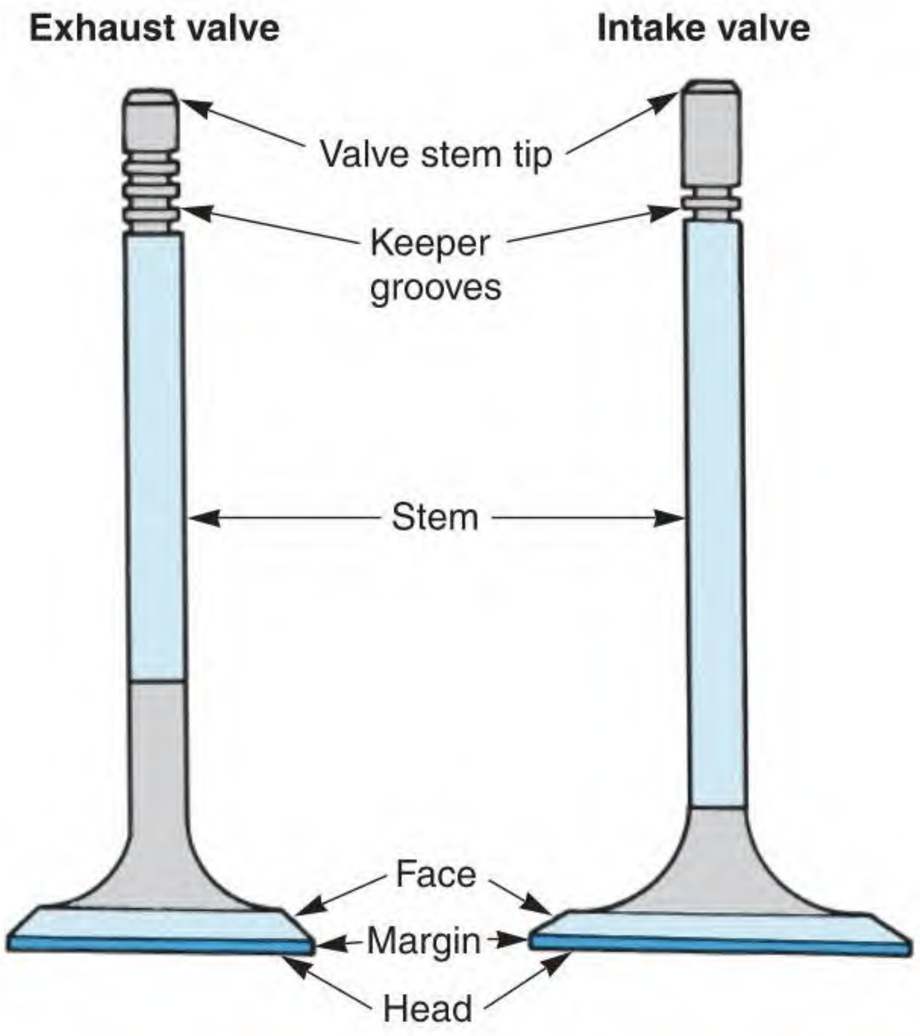
Valve Seals

Valve seals prevent oil from entering the combustion chambers through the valve guides. The valve seals fit over the valve stems and keep oil from entering through the clearance between the stems and guides.

Without valve seals, oil could be drawn into the engine cylinders and burned during combustion. Oil consumption and engine smoking could result. This is illustrated in **Figure 11-21**.

Valve Spring Assembly

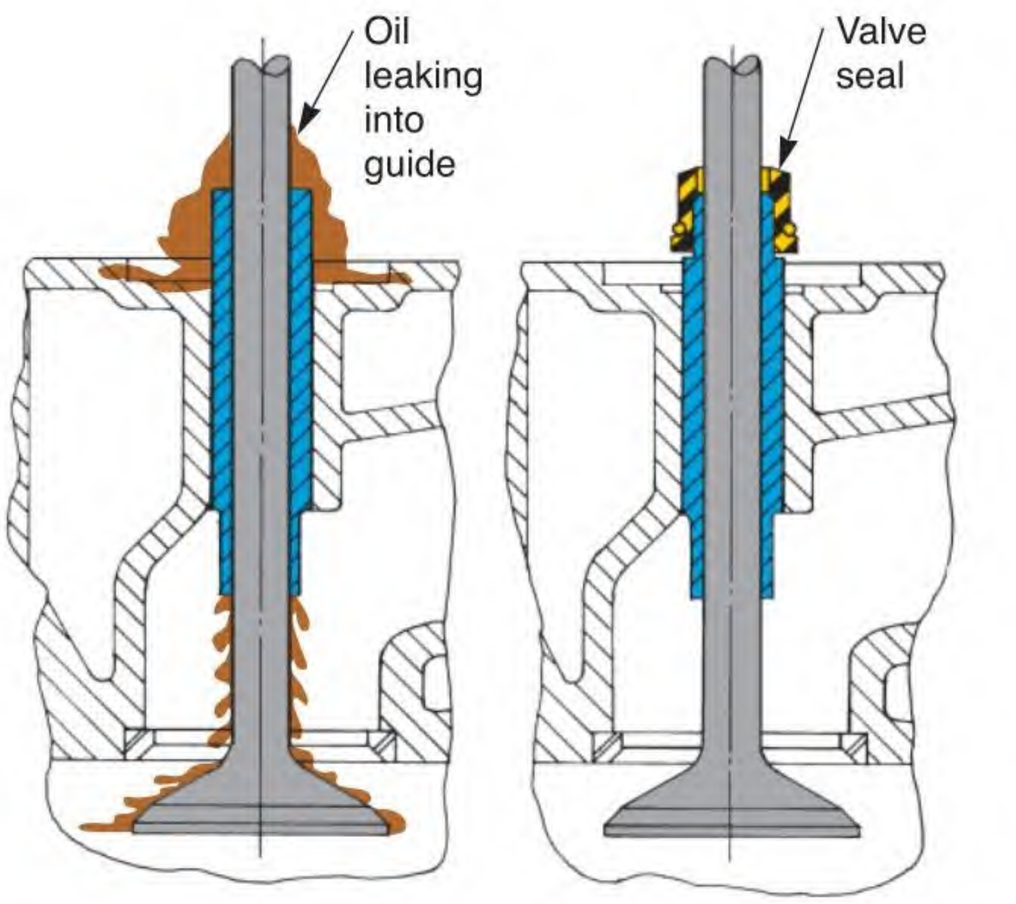
The ***valve spring assembly*** is used to close the valve. It basically consists of a valve spring, a retainer, and two keepers. The ***keepers*** fit into the grooves cut in the valve stem. This locks the retainer and spring on the valve. See **Figure 11-22**.



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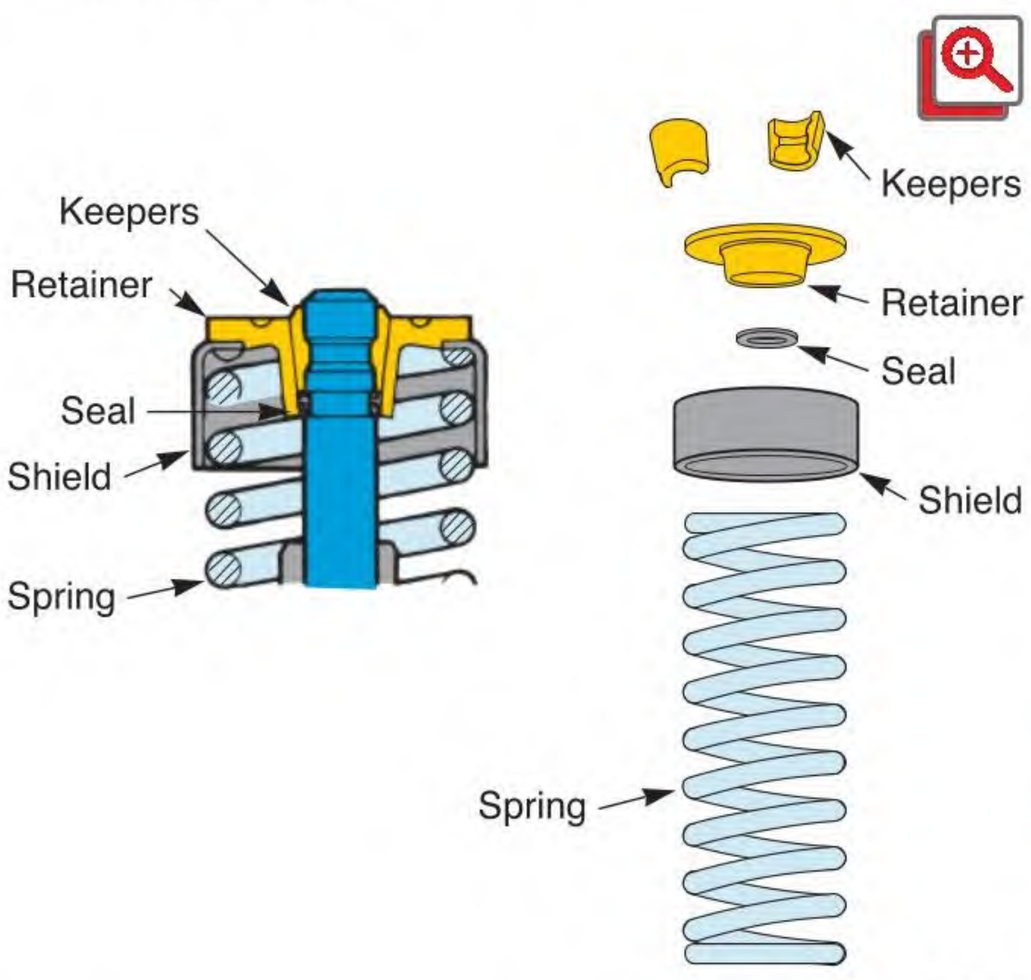
Figure 11-20. The intake valve is larger than the exhaust valve. Note the parts of each valve.

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American Hammered Piston Rings

Figure 11-21. A valve seal keeps oil from entering the guide and combustion chamber.



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Figure 11-22. The valve spring assembly basically consists of a spring, retainer, keepers, and sometimes, a shield. Note how this type of seal fits on the valve stem.

Intake Manifold

The ***intake manifold*** bolts to the side or top of the cylinder head(s). On modern engines, the intake manifold is often made of plastic or aluminum. The throttle body bolts to the inlet of the intake manifold. A large-volume plenum is formed in the middle of the manifold. Runners connect the plenum to the cylinder head intake ports. Seals fit around each port to seal against the cylinder head to prevent vacuum or pressure leakage. With modern direct gasoline injection or diesel injection, only air passes through the engine's intake manifold because the fuel injector nozzles extend directly into the combustion chambers.

Exhaust Manifold

The ***exhaust manifold*** fastens over the exhaust ports to carry burned gases into the exhaust system. During the exhaust strokes, hot gases blow into this manifold before entering the rest of the exhaust system. An exhaust manifold can be made of heavy cast iron or lightweight aluminum or stainless steel tubing. The trend is toward lighter designs.

Valve Cover

The ***valve cover***, also called the rocker cover, is a thin metal or plastic lid over the top of the cylinder head. It simply keeps valve train oil spray from leaking out of the engine. Look at **Figure 11-23**.

Engine Front End

The ***engine front end*** includes all the parts attached to the front of the engine. It consists of the camshaft drive, a front cover, an oil seal, and a crank damper. It may contain the oil pump, water pump, chain or belt tensioners, auxiliary drives or sprockets, and engine sensors.

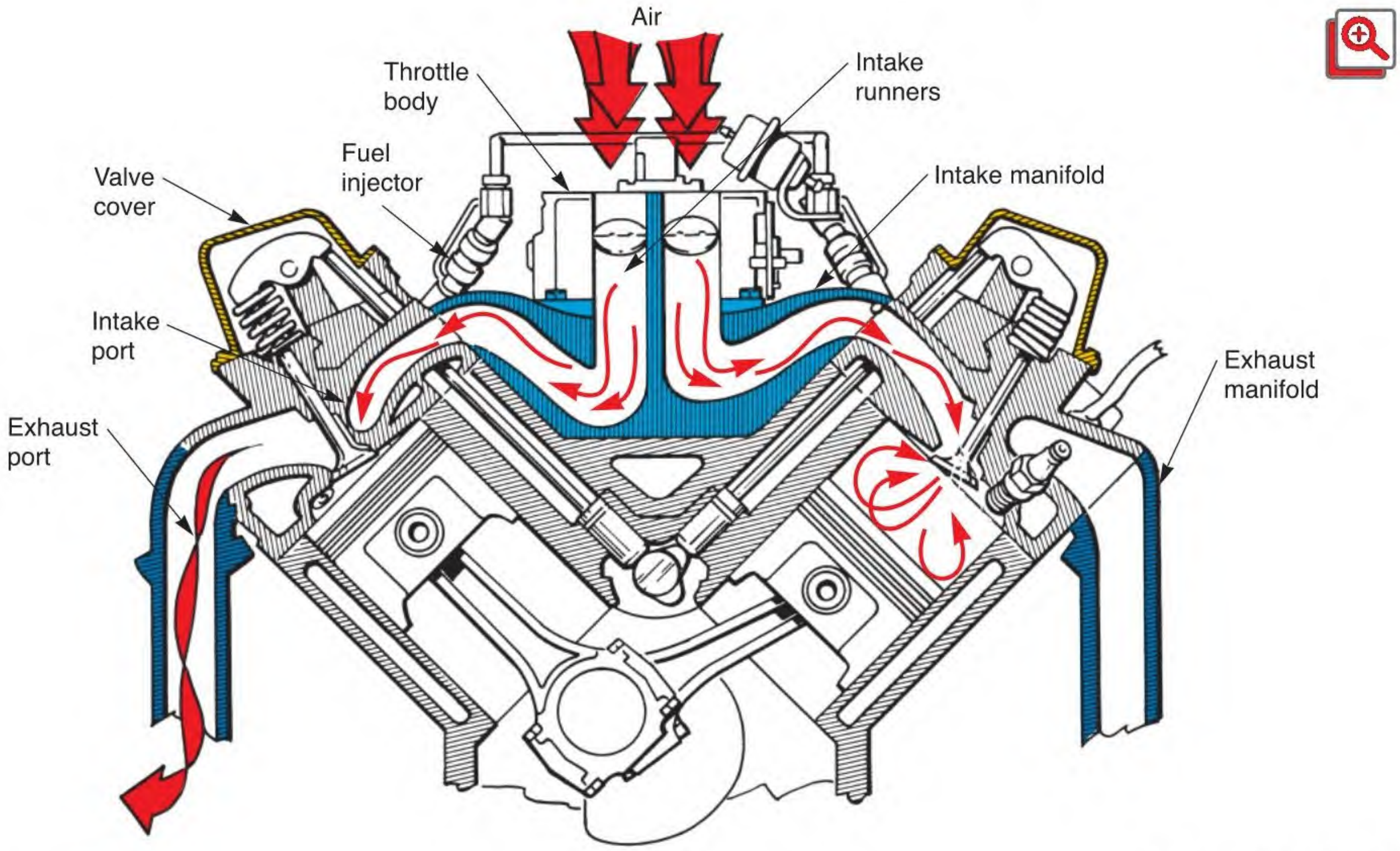
Tech Tip

Engine front end assemblies are much more complicated than in the past. With today's dual overhead cam engines, the cam drive mechanism can be difficult to comprehend. Carefully study all the illustrations in this book to compare front end design differences. This will prepare you to work on various engines.

Camshaft Drive

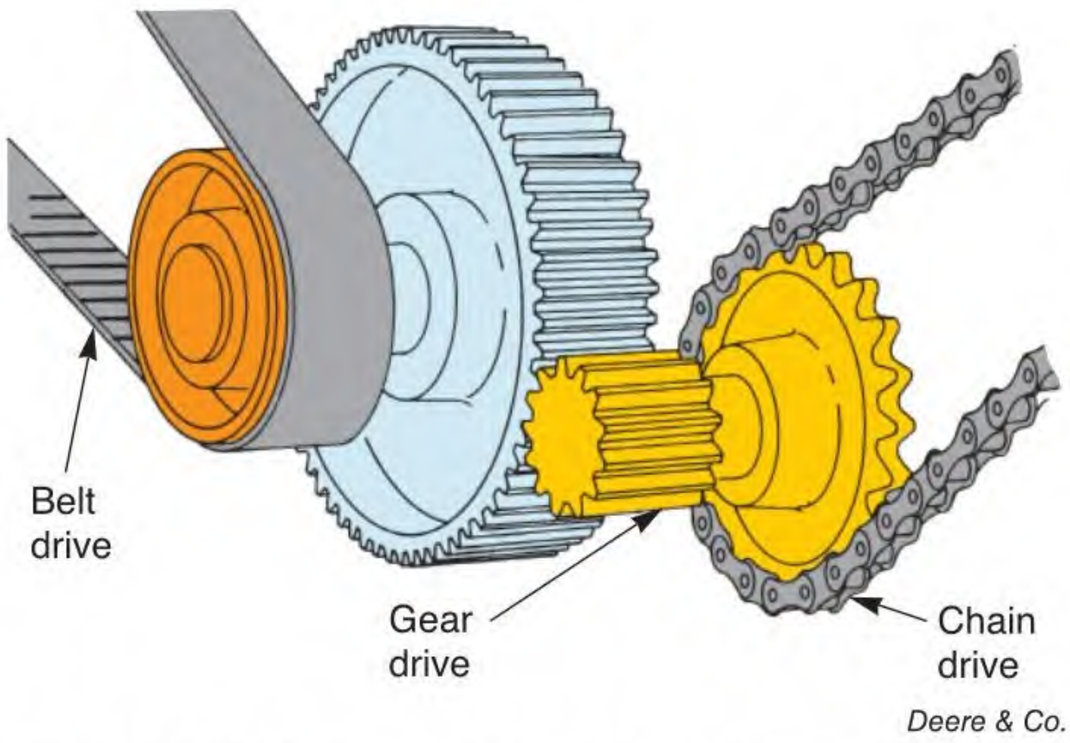
A ***camshaft drive*** is needed to turn the camshaft at one-half engine speed. A belt and sprockets, gears, or a chain and sprockets can be used to turn the camshaft. Look at **Figure 11-24**.

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Figure 11-23. Intake and exhaust manifolds bolt to the cylinder head. The intake manifold contains runners that route the fuel mixture into the cylinder heads. The exhaust manifolds route burned gases into the exhaust system.



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Figure 11-24. The camshaft can be turned by one of three drive mechanisms: a belt drive, a gear drive, or a chain drive.

These parts are often called the timing belt, timing gears, or timing chain because they time the camshaft with the crankshaft. The camshaft is designed to turn at one-half engine speed. As a result, each valve will open only once for every two crankshaft revolutions.

For instance, the intake valve must open only on the intake stroke, not the compression, power, or exhaust strokes. To do this, the camshaft gear or sprocket is twice as big as the gear or sprocket on the crankshaft. See **Figure 11-25**.

Front Cover

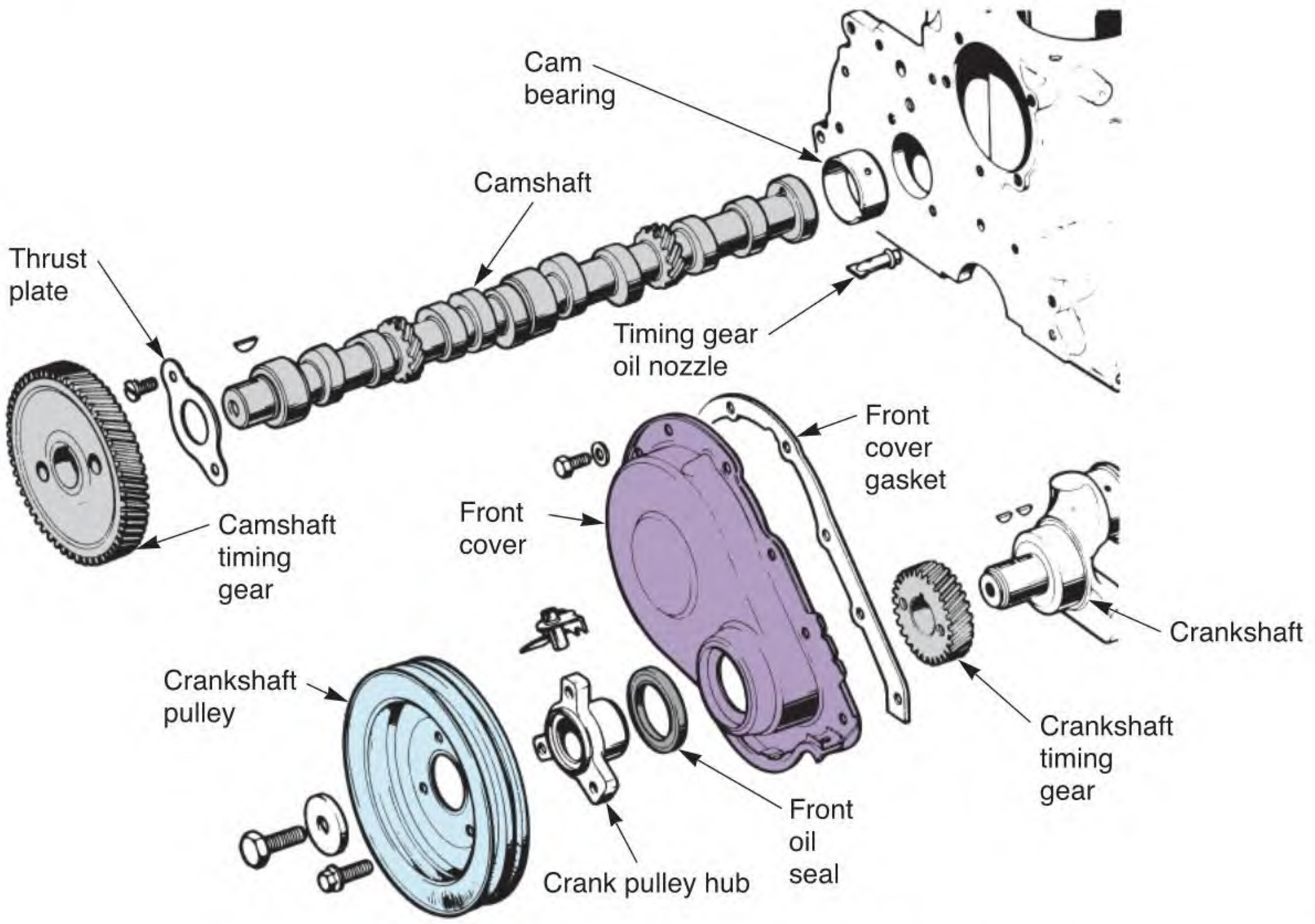
The ***front cover*** bolts over the crankshaft snout. It holds an oil seal that seals the front of the crankshaft.

When the engine uses a gear- or chain-type camshaft drive, the front cover can also be called the timing cover. With a belt drive, this cover does not enclose the cam drive or timing mechanism. A second cover is installed over the belt. Refer to **Figures 11-26** and **11-27**.

Crank Damper

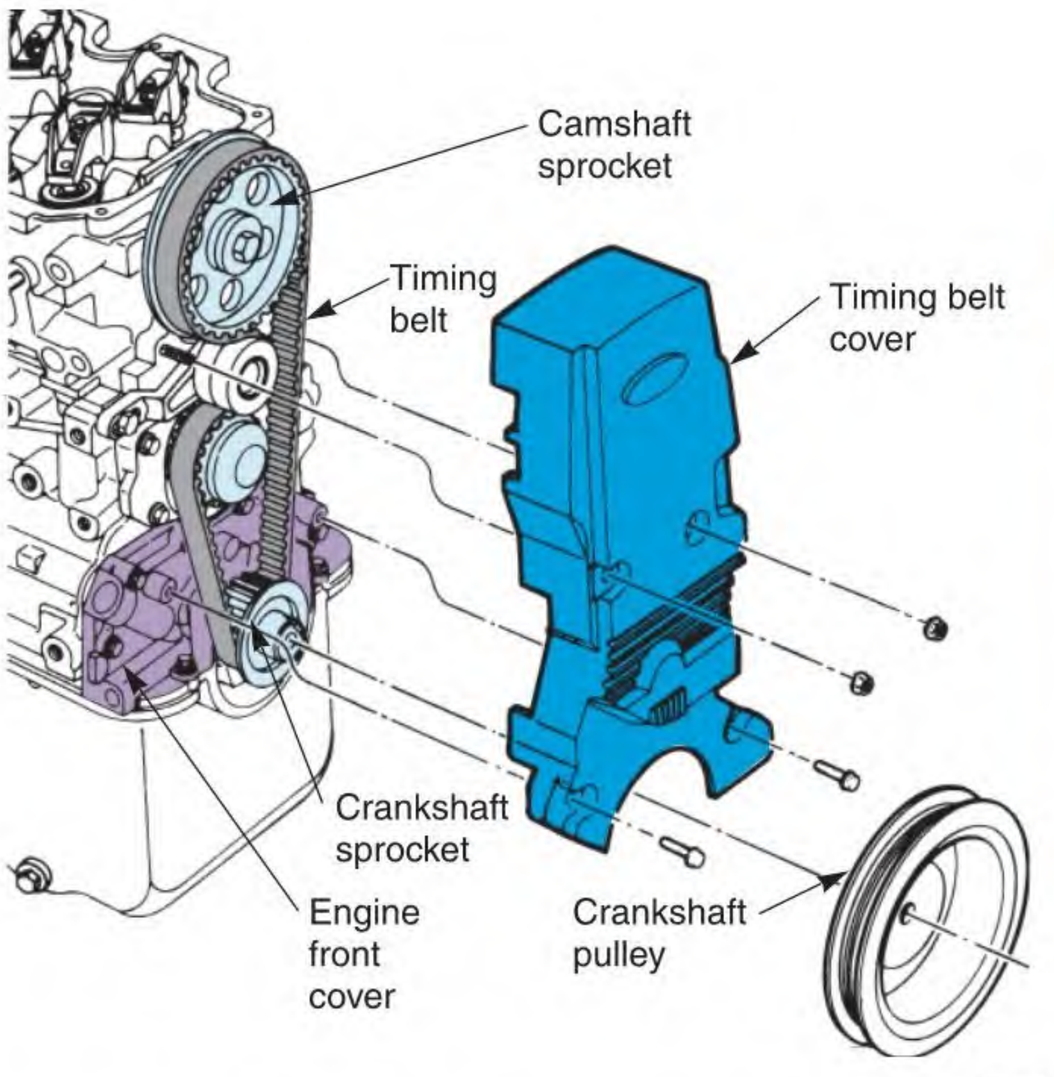
A ***crank damper*** is a heavy wheel on the crankshaft snout. It is mounted in rubber and helps prevent crankshaft vibration and damage. This damper is also called the harmonic balancer or vibration damper.

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Figure 11-25. The engine front end components primarily operate the engine camshaft. This engine uses timing gears to drive the camshaft at one-half engine speed. The front cover encloses the gears. The front seal prevents leakage around the crankshaft snout.



Ford

Figure 11-26. The crankshaft sprocket turns the timing belt. The timing belt turns the camshaft sprocket and camshaft. The front cover simply houses the front oil seal. The timing cover fits over the belt.

A cutaway view of a modern V-8 engine is shown in **Figure 11-27**. How many engine parts can you identify from memory?

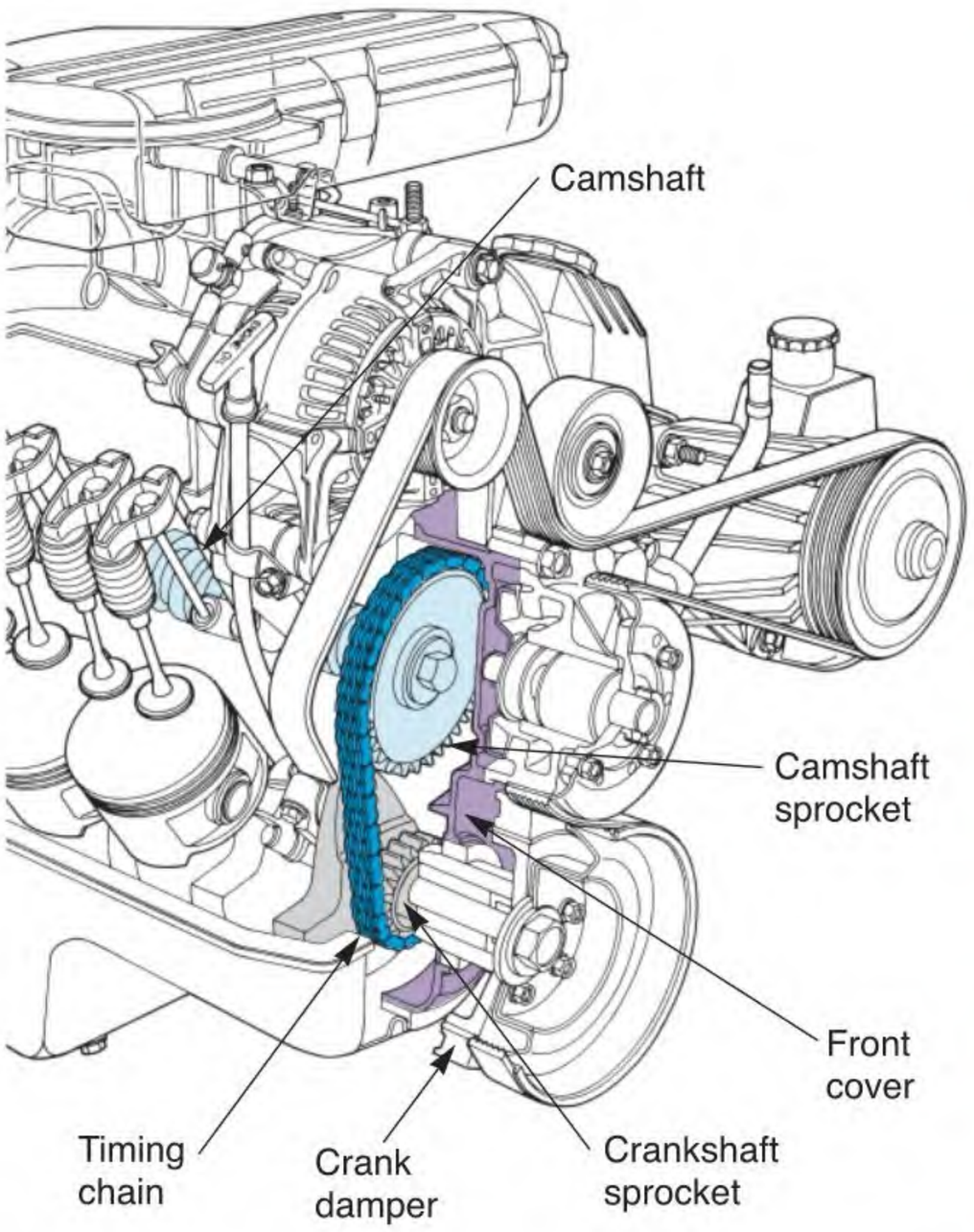


Workplace Skills

Teamwork is the key to success in the automotive shop. Smart technicians "talk shop," exchanging information about new tools and repair methods. They also help each other with diagnosis and heavy work.

Working as part of a team will increase your job satisfaction and productivity. You will spend a large portion of your life working. Why not enjoy it?

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Figure 11-27. The timing chain and sprockets operate the camshaft in this engine.

Summary

- The engine is the source of power for the vehicle. For this reason, it is also called a power plant.
- When the piston is at its highest point in the cylinder, it is at TDC (top dead center). When the piston slides to its lowest point in the cylinder, it is at BDC (bottom dead center).
- The term engine bottom end generally refers to the block, crankshaft, connecting rods, pistons, and related components.
- The crankshaft harnesses the tremendous force produced by the downward thrust of the pistons.
- The engine main bearings are removable inserts that fit between the block main bore and crankshaft main journals.
- Main bearing clearance is the space between the crankshaft main journal and the main bearing insert.
- Crankshaft oil seals keep oil from leaking out the front and rear of the engine.
- The connecting rod fastens the piston to the crankshaft. It transfers piston movement to the crankshaft rod journals.
- The engine piston transfers the pressure of combustion (expanding gas) to the connecting rod and crankshaft.
- Piston clearance is the amount of space between the sides of the piston and the cylinder wall.
- The piston rings seal the clearance between the outside of the piston and the cylinder wall.
- The compression rings prevent blowby (combustion pressure leaking into engine crankcase).
- The main job of oil rings is to prevent engine oil from entering the combustion chamber.
- The term engine top end generally refers to the cylinder heads, valves, camshaft, and related components.
- The camshaft has lobes that open the valves.
- A valve lifter usually rides on the cam lobes and transfers motion to the rest of the valve train.
- Engine valves open and close the ports in the cylinder head.
- The valve spring assembly is used to close the valve.
- The engine front end operates the engine camshaft and, sometimes, the oil pump, water pump, engine sensors, and diesel injection pump.
- A crank damper is a heavy wheel on the crankshaft snout. It is mounted in rubber and helps prevent crankshaft vibration and damage.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

bearing insert
bottom dead center (BDC)
camshaft
camshaft drive
combustion chamber
compression ring
compression stroke
connecting rod
connecting rod bearing
core plugs
crank damper
crankshaft
crankshaft oil seal
cylinder
cylinder head
deck
engine
engine bedplate

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engine block
engine bottom end
engine front end
engine main bearings
engine top end
engine valve train
exhaust manifold
exhaust port
exhaust stroke
exhaust valve
expansion
flywheel
four-stroke cycle
front cover
fuel
intake manifold
intake port
intake stroke
intake valve
keeper
main bearing bore
main cap
oil ring
piston
piston pin
piston ring
piston stroke
power stroke
push rod
rear main oil seal
ring gear
rocker arm
tappet
top dead center (TDC)
valve cover
valve guide
valve lifter
valve seal
valve seat
valve spring assembly
water jacket

Activities

1. A camshaft changes rotary motion to up-and-down motion. Find and describe or sketch at least three other examples of ways that a mechanical system changes the type, direction, or force of a motion.
2. If possible, obtain from a repair shop a bearing or other engine part that shows severe wear. Clean the part so the wear can be seen easily and pass it around to your classmates. Discuss how the wear was caused.
3. Make a chart showing the position (open or closed) of the intake valve and the exhaust valve during each stroke of the four-stroke cycle.

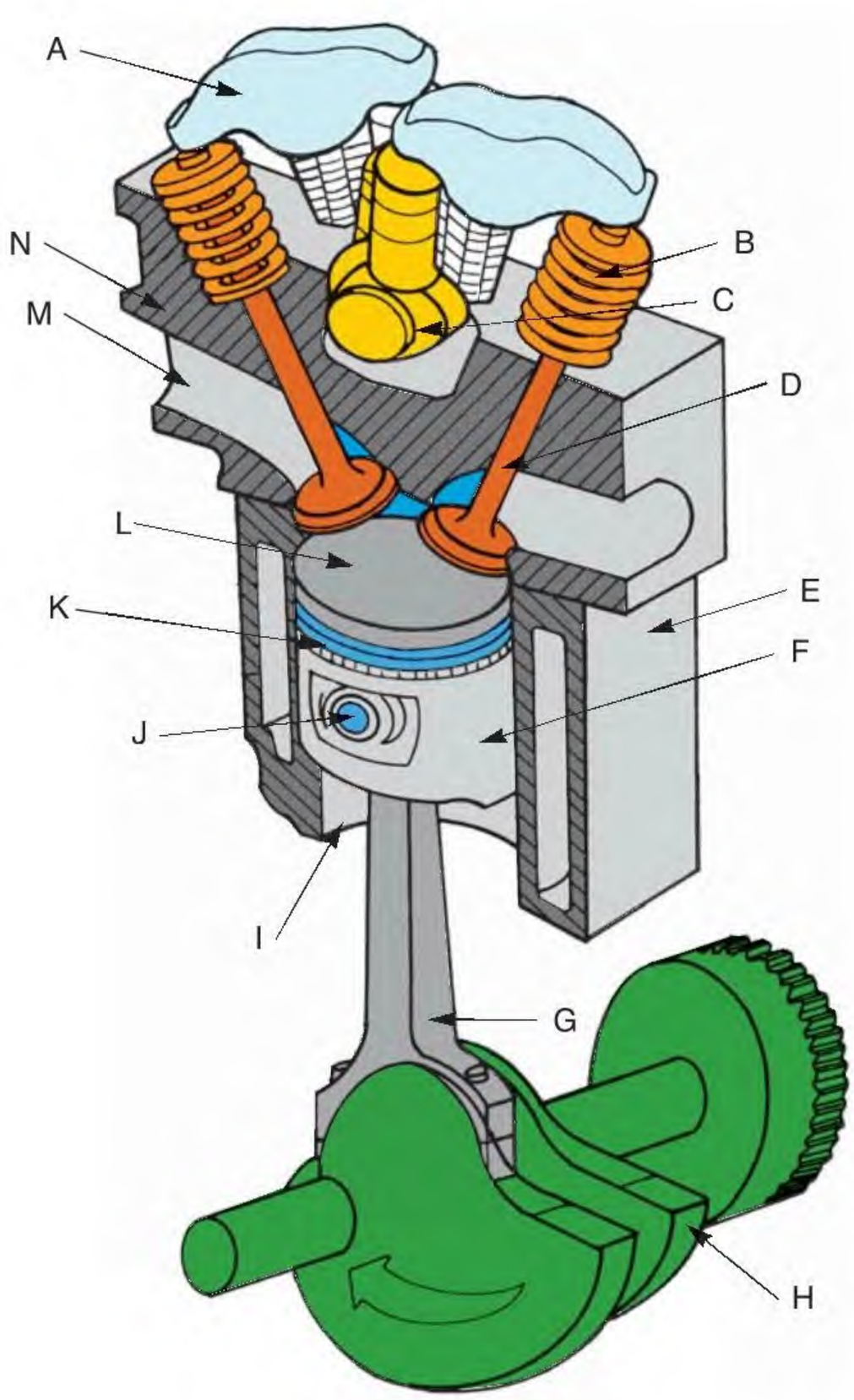
Review Questions

Answer the following questions using the information provided in this chapter.

1. Usually, _____ or _____ is burned inside the engine to produce heat, expansion, and resulting pressure.
2. What do TDC and BDC mean?
3. Every four strokes, the engine produces two power strokes. True or False?
4. Explain the intake stroke.
5. Explain the compression stroke.
6. Explain the power stroke.
7. Explain the exhaust stroke.
8. _____ bolt to the bottom of the block and hold the crankshaft in place.
9. The crankcase is the highest portion in the block. True or False?
10. The crankshaft changes the up-and-down motion of the piston into a useful _____ motion.
11. What is the function of crankshaft counterweights?
12. Describe the function of the main thrust bearing.
13. The _____ transfers piston movement to the crankshaft.
14. The distance from the centerline of the crankshaft to the centerline of a rod journal is 3″ (76 mm). What is the total vertical distance that the piston will travel in the cylinder (from TDC to BDC)?
15. Which of the following is *not* part of a connecting rod?
    (A) I-beam.
    (B) Lobe.
    (C) Cap.
    (D) Bushing.
16. Why is rod bearing clearance needed?
17. Explain the function of compression and oil rings.
18. Which of the following is part of the cylinder head?
    (A) Combustion chambers.
    (B) Intake and exhaust ports.
    (C) Valve guides.
    (D) All of the above.
19. List and explain the basic parts of a camshaft.
20. _____ open and close the ports in the cylinder head.

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21. The intake valves are larger than the exhaust valves. True or False?
22. Describe the five basic parts of an engine valve.
23. What do valve seals do and what would happen without valve seals?
24. Explain the function of the following parts.
    (A) Intake manifold.
    (B) Exhaust manifold.
    (C) Valve cover.
25. Identify the engine parts in the following illustration. Write A through N on your paper. Then write the name of the part next to each letter.



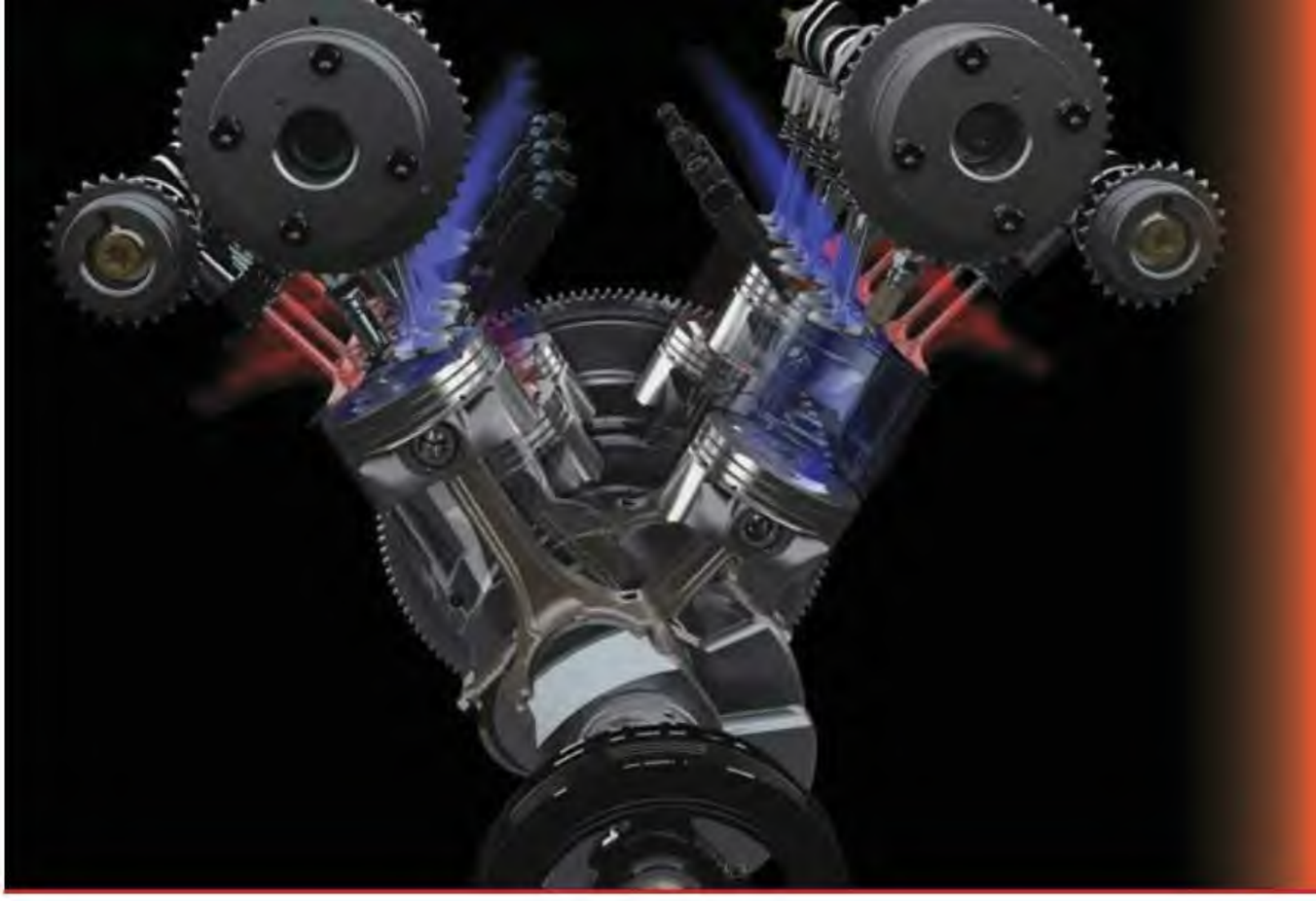
ASE-Type Questions

1. Technician A says the engine camshaft converts reciprocating motion of the piston into rotary motion for power output. Technician B disagrees and says the crankshaft performs this function. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. The distance a piston travels up or down in a cylinder is limited by the:
   (A) flywheel.
   (B) camshaft.
   (C) crankshaft.
   (D) valve train.
3. The air-fuel mixture is actually burned during the:
   (A) power stroke.
   (B) intake stroke.
   (C) exhaust stroke.
   (D) compression stroke.
4. How many crankshaft rotations are needed to complete the four-stroke cycle?
   (A) One.
   (B) Two.
   (C) Three.
   (D) Four.
5. Automobile engines normally have:
   (A) four cylinders.
   (B) six cylinders.
   (C) eight cylinders.
   (D) All of the above.
6. A flywheel performs each of these functions *except:*
   (A) contains a gear used for engine starting.
   (B) smoothes engine operation.
   (C) provides lubrication to parts.
   (D) connects crankshaft to transmission.
7. Which of the following causes piston movement during non-power-producing strokes?
   (A) Flywheel.
   (B) Connecting rod.
   (C) Counterweights.
   (D) Main thrust bearing.

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8. Which of the following components transfers combustion pressure to the crankshaft and connecting rods?
   (A) Piston.
   (B) Camshaft.
   (C) Valve train.
   (D) Thrust bearing.
9. Which of the following keeps a piston from tipping in its cylinder?
   (A) Piston pin.
   (B) Piston boss.
   (C) Piston skirt.
   (D) Piston head.
10. An engine has been diagnosed with blowby. Technician A says the engine could have a cracked flywheel. Technician B says the compression rings could be worn. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
11. Which of the following components is *not* part of the valve train?
   (A) Camshaft.
   (B) Crankshaft.
   (C) Rocker arms.
   (D) Valve springs.
12. While discussing camshaft operation, Technician A states that cam lobes open each valve in the engine. Technician B states that the camshaft journals operate engine valves. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
13. The valve train parts that transfer motion to the rest of the valve train are the:
   (A) lifters.
   (B) tappets.
   (C) Both A and B.
   (D) Neither A nor B.
14. Which of the following is used to turn the camshaft at one-half engine speed?
   (A) Timing belt.
   (B) Timing chain.
   (C) Timing gears.
   (D) All of the above.
15. Which of the following helps prevent crankshaft vibration and damage?
   (A) Crank damper.
   (B) Vibration damper.
   (C) Harmonic balancer.
   (D) All of the above.

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Chapter 12
Engine Design Classifications

After studying this chapter, you will be able to:

- Describe basic automotive engine classifications.
- Compare gasoline and diesel engines.
- Contrast combustion chamber designs.
- Discuss alternative engine types.
- Compare two- and four-stroke cycle engines.
- Correctly answer ASE certification test questions that require a knowledge of engine classifications and design differences.

In previous chapters, you learned about the basic parts of an engine. Now you are ready to learn about the various engine types, designs, and classifications used in automobiles and light trucks.

An experienced engine technician can glance into an engine compartment and "rattle off" dozens of engine facts. For example, you might hear a technician say, "This is an inline, 4-cylinder, 16-valve, overhead-cam turbo engine." You must understand these kinds of terms when troubleshooting and repairing engines. Study this chapter carefully. It will help you learn the "language" of an engine service technician.

Engine Classifications

Even though basic engine parts are the same, design differences can change the way engines operate and how they are repaired. For this reason, you must be able to classify engines.

Some common engine classifications include:

- Cylinder arrangement.
- Number of cylinders.
- Cooling system type.
- Valve location.
- Camshaft location.
- Combustion chamber design.
- Type of fuel burned.
- Type of ignition.
- Number of strokes per cycle.
- Number of valves per cylinder.
- Type of aspiration.

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Cylinder Arrangement

Cylinder arrangement refers to the position of the cylinders in relation to the crankshaft. There are four basic cylinder arrangements: inline, V-type, W-type, and opposed. Refer to **Figure 12-1**.

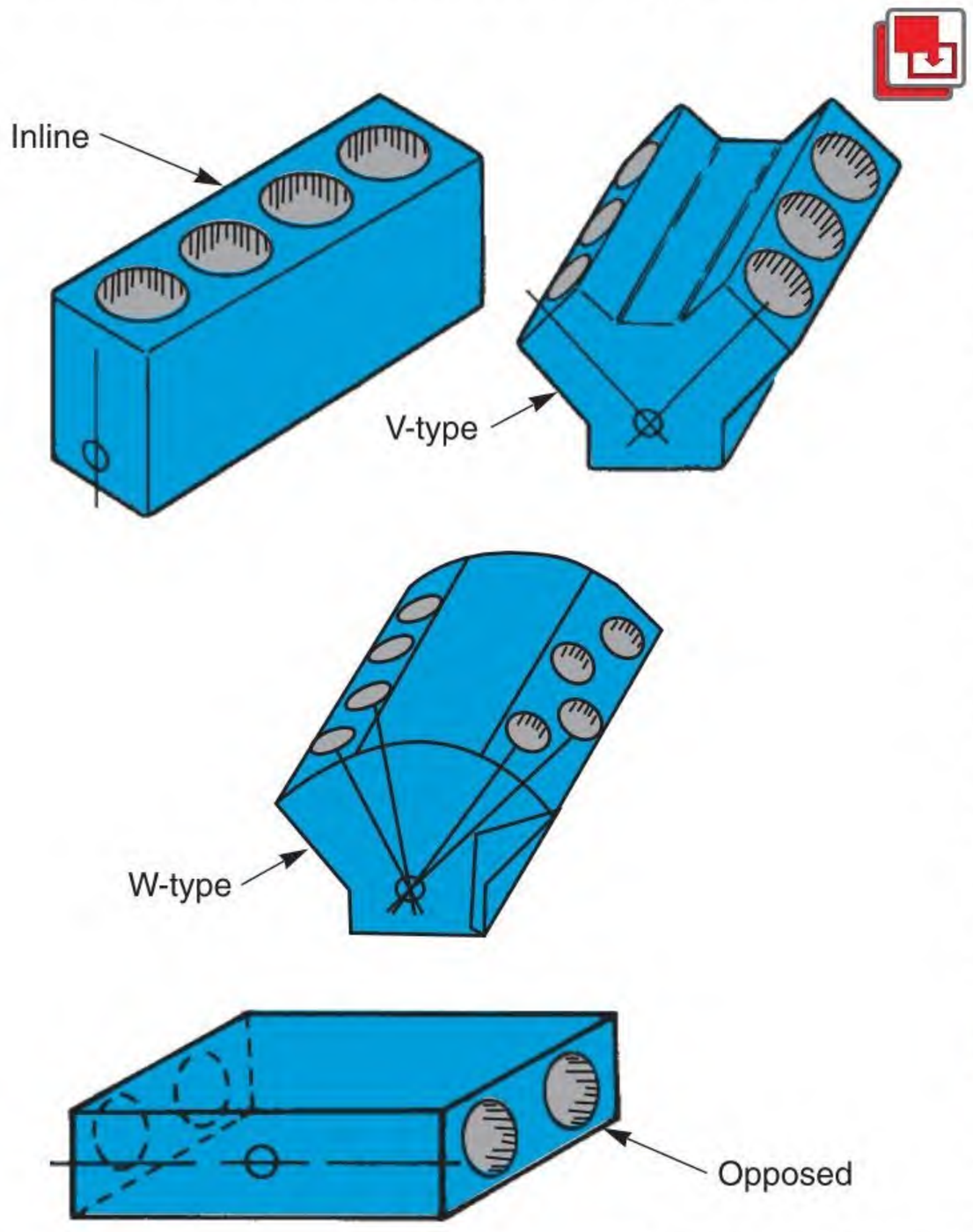
In an ***inline engine***, the cylinders are lined up in a single row. Each cylinder is located in a straight line that is parallel to the crankshaft. Four-, five-, and six-cylinder engines are commonly inline engines.

Viewed from either end, a ***V-type engine*** looks like the letter "V." The two banks of cylinders lie at an angle to each other. This arrangement reduces the length and the height of the engine.

Like a V-type engine, the ***W-type engine*** consists of two cylinder banks that form a "V." However, the cylinders in each bank of the W-type engine are offset, forming a second, very narrow "V" (V+V=W). This compact design allows manufacturers to increase engine displacement without increasing engine size.

Cylinders of an ***opposed engine*** lie flat on either side of the crankshaft. Because of its appearance, this type of engine is sometimes called a "pancake engine" or "boxer engine." An opposed engine may be found in older Volkswagens and a few late-model foreign sports cars (Porsche and Subaru, for example).

One advantage of an "opposed engine" is that it minimizes frictional horsepower loss at the main bearings. Inline and V-type engines produce a downward thrust on the crankshaft that causes a small but unwanted power loss. In an opposed engine, the pistons move right and left against each other to prevent a downward thrust on the main bearings. This type of engine also has a much lower center of gravity than other car and truck engines. This can be an advantage with a sports car or racing car, where a low center of gravity increases cornering ability.



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Figure 12-1. Engines can be classified by the way the cylinders are arranged in the block and around the crankshaft. The four basic cylinder arrangements used in automobiles are shown.

Number of Cylinders

Normally, car and truck engines have 4, 6, or 8 cylinders. A few automotive engines have 3, 5, 10, 12, or 16 cylinders.

A greater number of cylinders generally increases engine smoothness and power. For instance, an 8-cylinder engine produces twice as many power strokes per crank revolution as a 4-cylinder engine. This reduces power pulsations and roughness (vibrations) at idle. Four-cylinder engines usually have inline, slant, or opposed cylinder arrangements. Six-cylinder engines can have inline, slant, or V-type arrangements. Five-cylinder engines are normally inline engines. Eight-, 10-, and 12-cylinder engines are commonly V-type engines.

Engine manufacturers number each engine cylinder to help technicians make repairs. The service manual will provide an illustration showing the number of each cylinder.

Cylinder numbers are normally stamped on the connecting rods. Sometimes, they are cast into the intake manifold. Cylinder numbering varies from one manufacturer to another. You should keep this in mind when referring to engine classifications. Two V-6 engines, for example, can have completely different cylinder numbering systems.

Cooling System Type

There are two types of cooling systems: liquid cooling systems and air cooling systems. The liquid cooling system is the most common.

The ***liquid cooling system*** surrounds the cylinder with coolant (water and antifreeze solution). The coolant carries combustion heat out of the cylinder head and engine block to prevent engine damage.

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An ***air cooling system*** circulates air over cooling fins on the cylinders. This removes heat from the cylinders to prevent overheating. Air-cooled or air-oil cooled engines are seldom used in passenger cars. They can be found on motorcycles, lawnmowers, and a few high-performance cars. See **Figure 12-2**.

Fuel Type

An engine is also classified by the type of fuel it burns. A gasoline engine burns gasoline. A diesel engine burns diesel fuel. These are the most common types of fuel for vehicles.

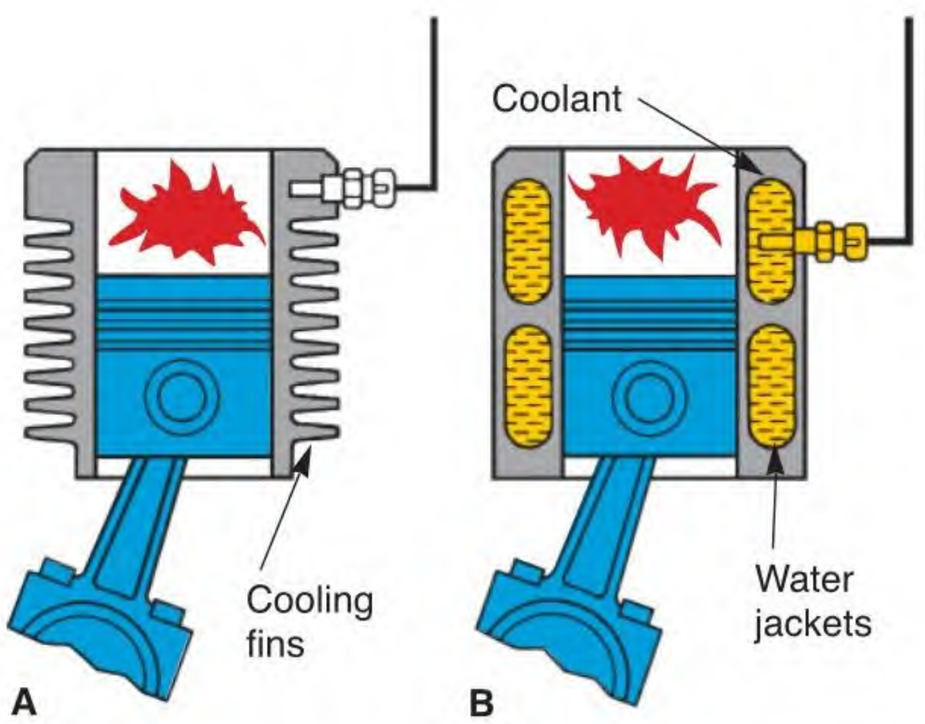
Liquefied petroleum gas (LPG), gasohol (10% alcohol, 90% gasoline), and pure alcohol can also be used to power an engine. These fuels are used in limited quantities.

Ignition Type

Two basic methods are used to ignite the fuel in an engine combustion chamber: spark ignition (spark plug) and compression ignition (compressed air).

A ***spark ignition engine*** uses an electric arc at the spark plug to ignite the fuel. The arc produces enough heat to start the fuel burning. Gasoline engines use spark ignition.

A ***compression ignition engine*** squeezes the air in the combustion chamber until it is hot enough to ignite the fuel. A diesel engine is a compression ignition engine. No spark plugs are used.



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Figure 12-2. These are cooling systems. A—Air cooling systems use large fins around the cylinders to remove heat. B—Liquid cooling systems are commonly used in automobiles. Motorcycles and lawnmowers use air cooling systems.

Valve Location

Another engine classification can be made by comparing the location of the valves, given in **Figure 12-3**.

An ***L-head engine*** has both the intake and exhaust valves in the block. Also called a ***flat head engine***, its cylinder head simply forms a cover over the cylinders and valves. The camshaft is in the block and pushes upward to open the valves. Some four-stroke lawnmower engines are L-head types. Automotive engines are no longer L-head types.

An ***I-head engine*** has both valves in the cylinder head. Another name for this design is the ***overhead valve (OHV) engine***. Numerous variations of the overhead valve engine are now in use.

Other valve configurations have been used in the past. However, they are so rare that their mention is not important.

Camshaft Location

There are two basic locations for the engine camshaft: in the block and in the cylinder head. Both locations are common.

A cam-in-block engine uses push rods to transfer motion to the rocker arms and valves. The term overhead valve (OHV) is sometimes used when referring to a cam-in-block engine.

In an ***overhead cam (OHC) engine***, the camshaft is located in the top of the cylinder head. Push rods are not needed to operate the rockers and valves. This type of engine is a refinement of the overhead valve engine.

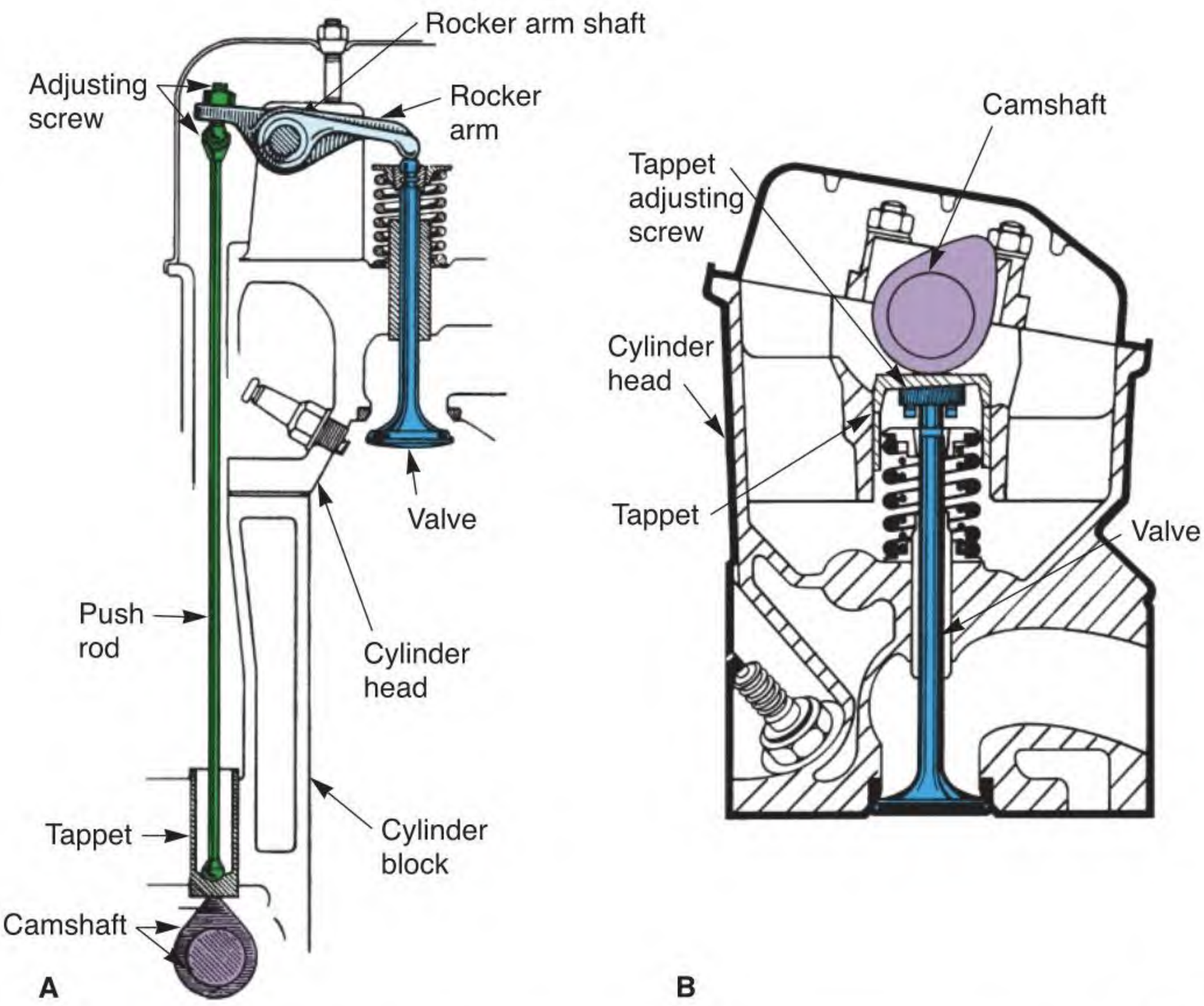
With the camshaft in the head, the number of valve train parts is reduced. This cuts the weight of the valve train. Also, the valves can be placed at an angle to improve breathing (airflow through cylinder head ports).

OHC engines were first used in race cars to improve their high-rpm (revolutions per minute) efficiency. Now all types of engines commonly use this configuration. With lower valve train weight, improved valve positioning, and no push rods to flex, the OHC engine is becoming very popular.

A ***single overhead cam (SOHC) engine*** has only one camshaft per cylinder head. The cam may act directly on the valves, or rocker arms may be used to transfer motion to the valves.

A ***dual overhead cam (DOHC) engine*** has two camshafts per cylinder head. One cam operates the intake valves; the other operates the exhaust valves.

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Black & Decker and Chrysler

Figure 12-3. Study the two common valve-camshaft locations. A—The cam-in-block engine, also called the overhead valve or I-head engine, is common. B—The overhead cam engine is another form of the I-head engine. It is also very common in today's vehicles.

The dual overhead cam arrangement is frequently used in engines equipped with four-valve combustion chambers. A DOHC engine will be shown later in the chapter.

Tech Tip

Subscribe to and read a variety of automotive magazines. They often contain technical information on the latest engine designs. This will give you valuable information when working on new vehicles.

Combustion Chamber Shape

The shape of the combustion chamber provides still another method of classifying an engine. The four basic combustion chamber shapes for gasoline engines are pancake, wedge, hemispherical, and pent-roof.

The ***pancake combustion chamber***, also called the bathtub chamber, has valve heads that are almost parallel to the top of the piston. The chamber forms a flat pocket over the piston head, **Figure 12-4A**.

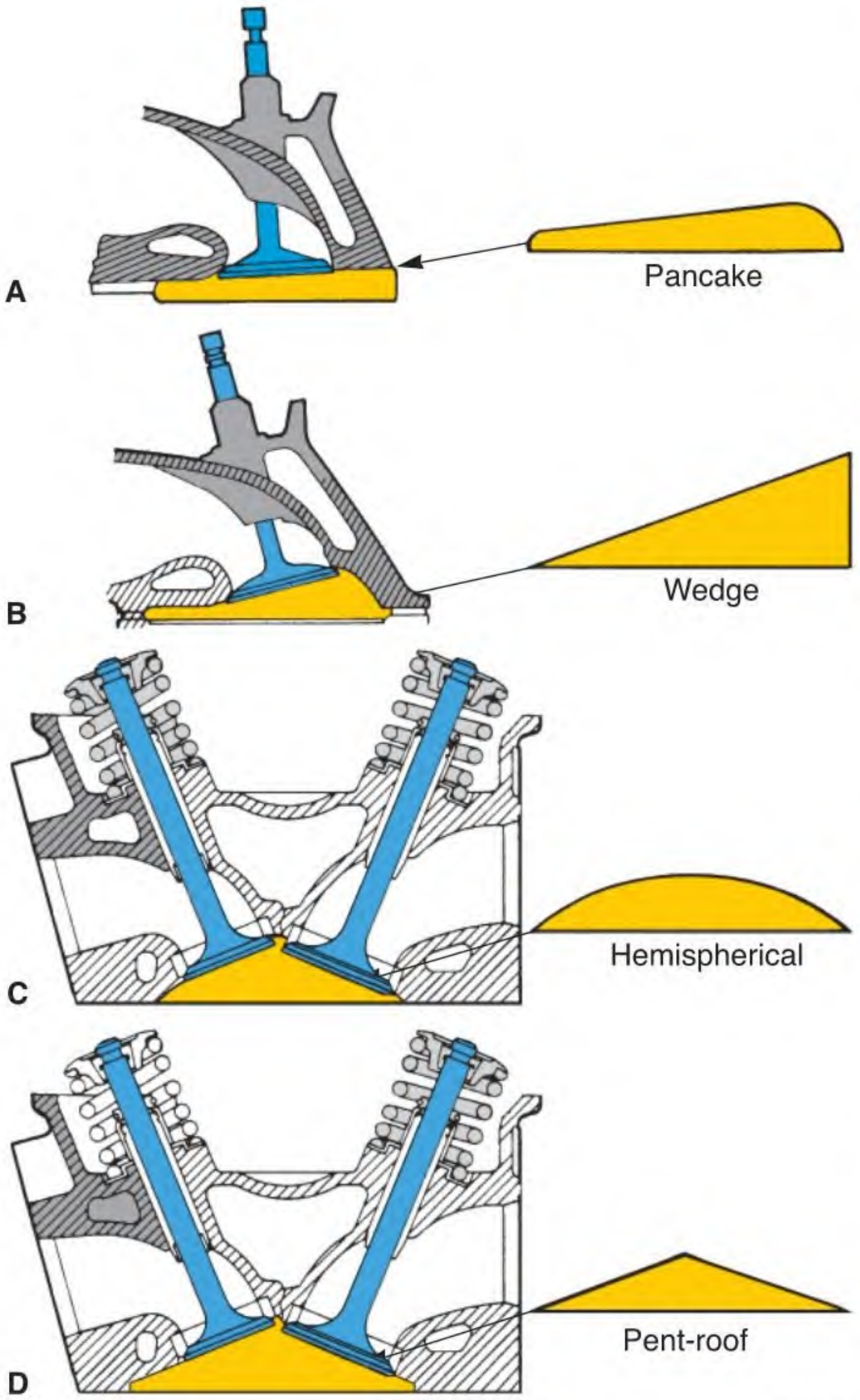
A ***wedge combustion chamber***, or wedge head, is shaped like a triangle, or a wedge, when viewed from the side. Valves are placed side-by-side, and the spark plug is located next to the valves, **Figure 12-4B**.

A ***squish area*** is commonly formed inside a wedge combustion chamber. When the piston reaches TDC, it comes very close to the bottom of the cylinder head. This squeezes the air-fuel mixture in that area and causes it to squirt, or squish, out into the main part of the chamber. A squish area can be used to improve air-fuel mixing at low engine speeds.

A ***hemispherical combustion chamber***, nicknamed hemi-head, is shaped like a dome. The valves are canted (tilted) on each side of the combustion chamber. The spark plug is located near the center of the chamber. A hemi-head is shown in **Figure 12-4C**.

A hemispherical combustion chamber is extremely efficient. There are no hidden pockets, minimizing the chances of incomplete combustion. The surface area is very small, reducing heat loss from the chamber.

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Chrysler

Figure 12-4. There are four basic combustion chamber shapes. A—In a pancake combustion chamber, the valves are almost parallel with the top of the piston. B—In the wedge combustion chamber, the valves are at an angle to the top of the piston. C—The valves are at an angle to each other in a hemispherical combustion chamber. D—In a pent-roof combustion chamber, the valves are located on flat, angled surfaces.

The centrally located spark plug produces a very short flame path for combustion. The canted valves help increase breathing ability.

The hemi-head was first used in high-horsepower racing engines. It is now used in many OHC passenger car engines. It allows the engine to operate at high rpm and makes it very fuel efficient. It also produces complete burning of the fuel to reduce emissions.

The ***pent-roof combustion chamber*** is similar to the hemispherical chamber, but it has flat, angled surfaces rather than a domed surface. This design improves volumetric efficiency and reduces emissions. See **Figure 12-4D**.

Combustion Chamber Types

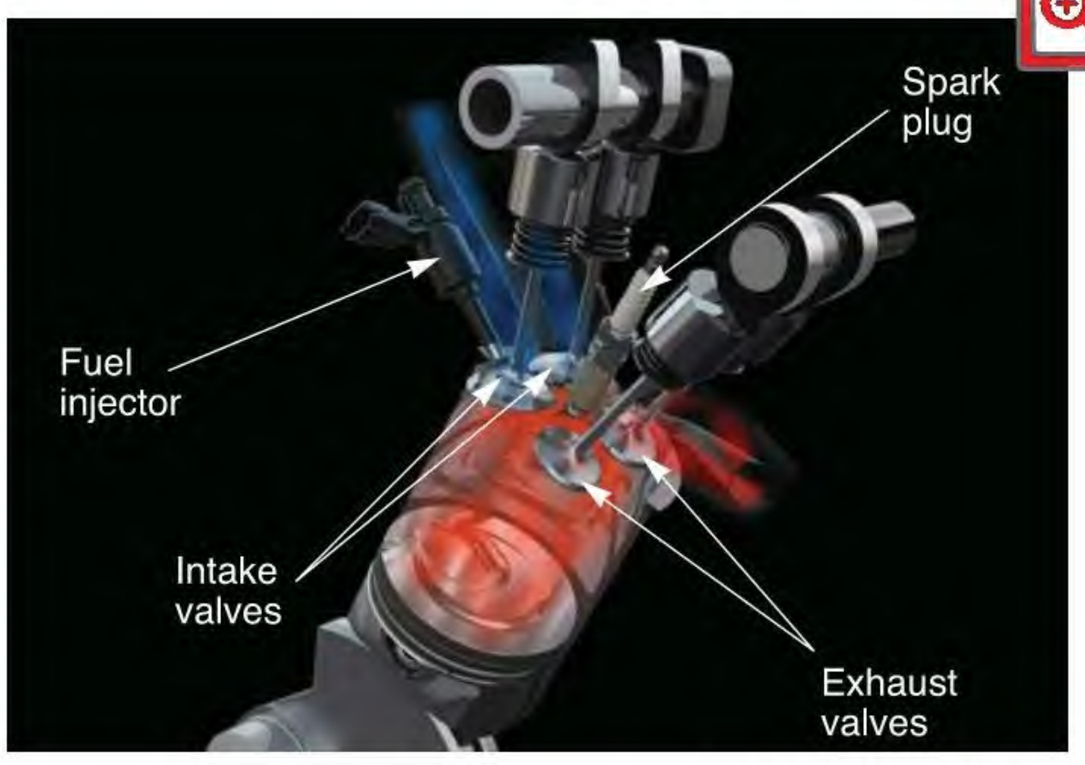
Besides the four shapes just covered, there are several other combustion chamber classifications. Each type is designed to increase combustion efficiency, gas mileage, and power while reducing exhaust pollution.

A ***swirl combustion chamber*** is designed to cause the air-fuel mixture to swirl, or spin, as it enters from the intake port. This causes the air and fuel to mix into a finer mist that burns better.

A ***four-valve combustion chamber*** uses two exhaust valves and two intake valves. The extra valves increase flow in and out of the combustion chamber. This setup is now used on many modern passenger car engines. This is illustrated in **Figure 12-5**.

In some four-valve combustion chambers, one of the intake valves is opened farther than the other. This produces a swirling action on the air-fuel mixture entering the combustion chamber. The swirling action helps reduce low-speed emissions.

A ***three-valve combustion chamber*** has two intake valves and one exhaust valve. The two intake valves allow ample airflow into the combustion chamber on the intake stroke. The single exhaust valve provides enough surface area to handle exhaust flow. This is a relatively new design and is used by only a couple manufacturers. The three-valve combustion chamber provides almost as much performance gain as a four-valve chamber, but it has fewer moving parts. This reduces cost and increases reliability.



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Figure 12-5. Two exhaust valves and two intake valves increases flow in and out of the combustion chamber.

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A ***stratified charge combustion chamber*** uses a small combustion chamber flame to ignite and burn the fuel in the main, large combustion chamber. A very lean mixture (high ratio of air to fuel) is admitted into the main combustion chamber. The mixture is so lean that it will not ignite and burn easily. A richer mixture (higher ratio of fuel to air) is admitted into the small chamber by an extra valve. When the fuel mixture in the small chamber is ignited, flames blow into the main chamber and ignite the lean mixture.

The stratified charge chamber allows the engine to operate on a lean, high-efficiency air-fuel ratio. Fuel economy is increased, and exhaust emission output is reduced.

An ***air jet combustion chamber*** has a single combustion chamber fitted with an extra air valve. During the intake stroke, the engine camshaft opens both the conventional intake valve and the jet valve. This allows the fuel mixture to flow past the conventional intake valve and into the cylinder. At the same time, a stream of air flows into the cylinder through the jet valve.

The jet valve action causes the fuel mixture in the cylinder to swirl and mix. This increases combustion efficiency by causing more of the fuel to burn during the power stroke.

The jet valve only works at idle and low engine speeds. At higher rpm, normal air-fuel mixing is adequate for efficient combustion.

A ***precombustion chamber*** is commonly used in automotive diesel engines. It is similar in shape to the stratified charge chamber used in gasoline engines. Also called a ***diesel prechamber***, the precombustion chamber is used to quiet engine operation and to allow the use of a glow plug (heating element) to aid cold weather starting.

During combustion, diesel fuel is injected into the prechamber. If the engine is cold, the glow plug heats the air in the prechamber. This heat, along with the heat produced by compression, causes the fuel to ignite and burn. As the fuel burns, the flame expands and moves into the main chamber to burn the remaining diesel fuel to produce a power stroke.

Alternative Engines

As you have learned, vehicles generally use internal combustion, 4-stroke cycle, reciprocating piston engines. However, there are several alternative engine designs in production or development. Some of these designs are variations of the 4-stroke cycle, piston engine. Other designs have a completely different operational design. This section describes several alternative engine designs.

Variable Displacement Engine

A ***variable displacement engine*** can deactivate cylinders so the engine conserves fuel and reduces emissions. During acceleration, all the cylinders function normally. However, when cruising speed is reached and there is a reduced demand for power, the computer disables cylinders to improve efficiency.

Most variable displacement engines shut off the fuel injectors in certain cylinders. Some also disable the valve train of the deactivated cylinders.

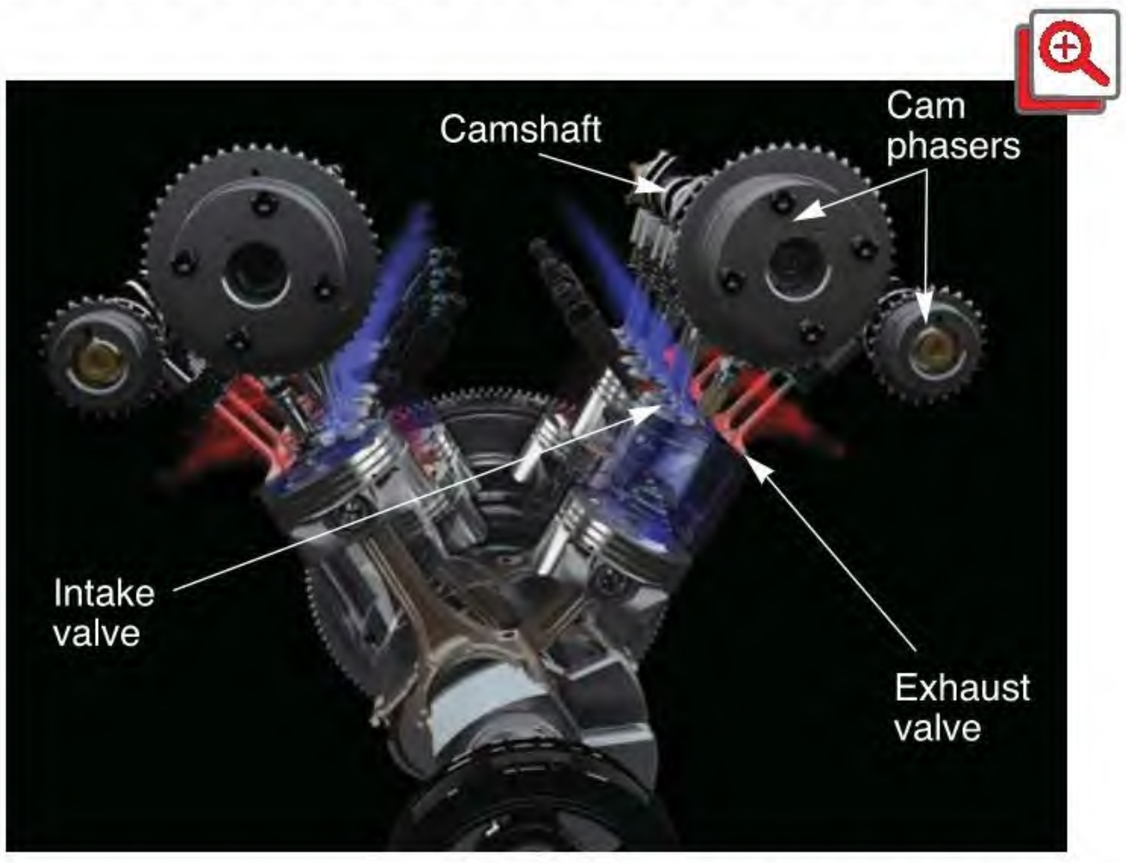
Tech Tip

In most systems, the spark plugs continue to fire in deactivated cylinders. This helps prevent spark plug temperature loss and minimizes fouling caused by incomplete combustion during cylinder reactivation.

Variable Valve Timing Engine

A ***variable valve timing engine*** can alter valve opening and closing independent of crankshaft rotation. This also improves engine efficiency compared to conventional engines that fix valve action with each degree of crankshaft rotation.

In some systems, a rotating camshaft gear called a cam phaser is used to change valve timing. See **Figure 12-6**. However, other variable valve timing designs rely on electro-hydraulically operated rocker arms to alter valve operation. An advantage of this

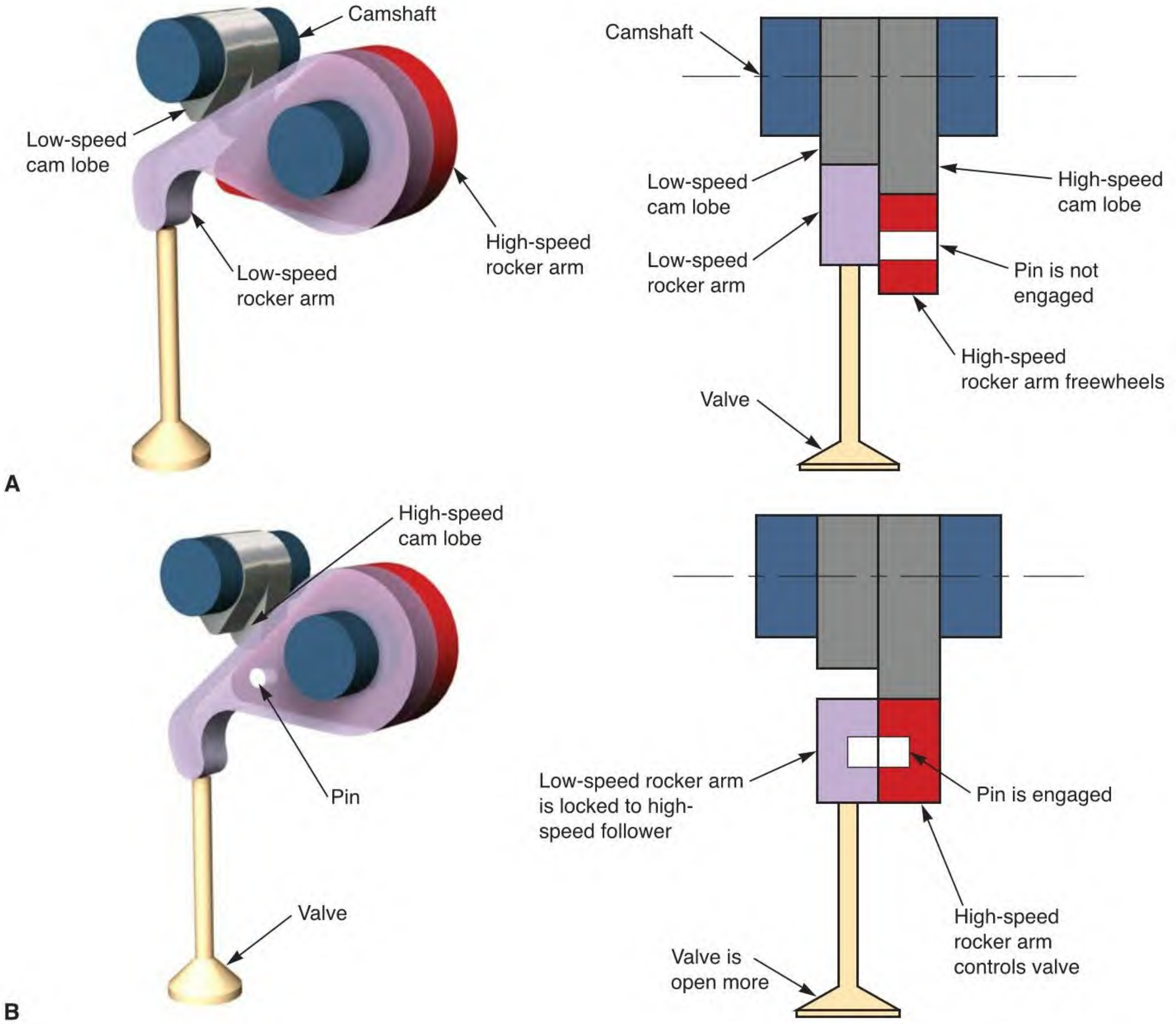


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Figure 12-6. This high efficiency engine uses electro-hydraulic cam phasers to advance or retard valve timing with engine speed and load.

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design is that in addition to altering valve timing, it can match valve lift (distance the valve opens) and duration (amount of time valve remains open) to engine speed and load for improved power and lower exhaust emissions. These systems use two different camshaft lobes and two rocker arms for each valve. One lobe is designed for optimal performance at low engine speeds. The second lobe is designed for optimal performance at high engine speeds. At low engine speeds, the low-speed cam lobe acts on the low-speed rocker arm to open the valve. The high-speed cam lobe acts on the high-speed rocker arm, but the rocker arm "freewheels" and does not act on any other component. However, once the engine reaches a certain speed, the computer opens a valve to allow oil pressure to push a pin through both the low- and high-speed rocker arms. Since the rocker arms are now locked together, the high-speed cam lobe controls the opening of the valve. See **Figure 12-7**.



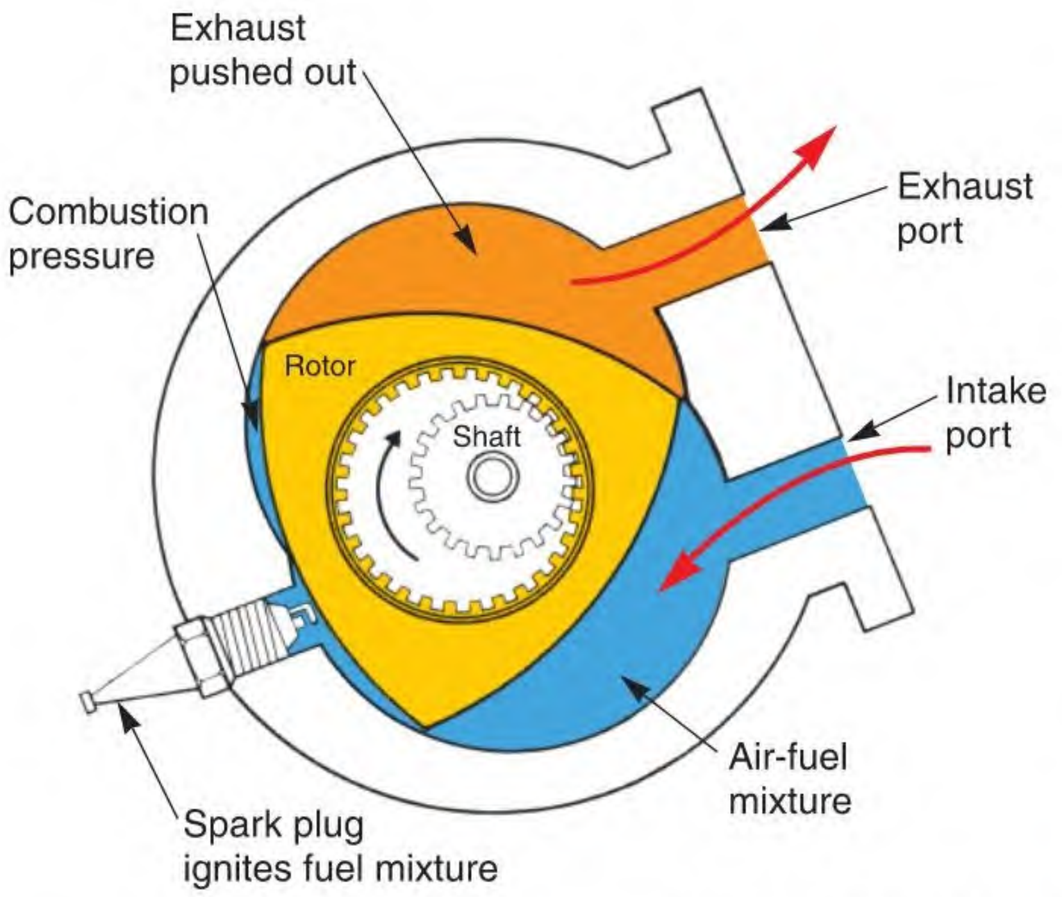
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Figure 12-7. This variable valve timing engine uses two camshaft lobes per cylinder to alter valve timing. A—At low engine speeds, the low-speed cam lobe and rocker arm control the valve action. B—At high engine speeds, the pin locks the low- and high-speed rocker arms together and the high-speed cam lobe controls valve action.

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Rotary Engine

A ***rotary engine***, also known as a Wankel engine, uses a spinning triangular rotor instead of conventional pistons. The rotor turns inside a specially shaped chamber, as shown in **Figure 12-8**.



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Figure 12-8. Study the parts of a rotary automotive engine. The rotor spins inside the housing for smooth operation. There are no reciprocating pistons in this design.

While turning in the chamber, the rotor orbits around a mainshaft. This eliminates the reciprocating (up-and-down) motion found in piston engines.

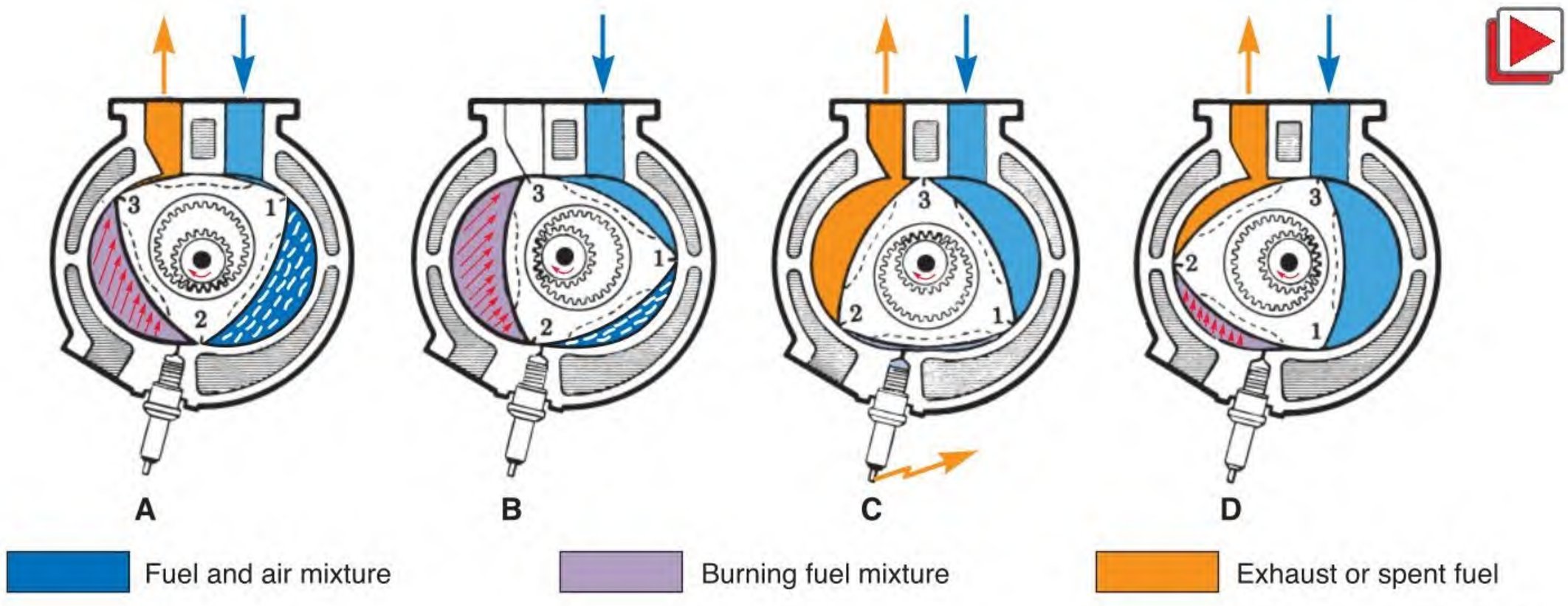
Three complete power-producing cycles take place during every revolution of the rotor: three rotor faces produce three intake, compression, power, and exhaust events per revolution, as shown in **Figure 12-9**.

A rotary engine is very powerful for its size. Also, because it spins—rather than moving up and down—engine operation is very smooth and vibration free.

In the past, a complicated emission control system was needed to make the rotary engine pass emissions standards. This has limited the use of the traditional rotary engine. The newest rotary engine, called the Renesis design, has intake and exhaust ports in the engine endplates and to the side of the rotor housing. The ports are no longer in the periphery of the rotor housing. This helps reduce exhaust emissions because it eliminates the intake/exhaust port overlap of the older design, which contributed to higher emissions. See **Figure 12-10**.

Two-Stroke-Cycle Engine

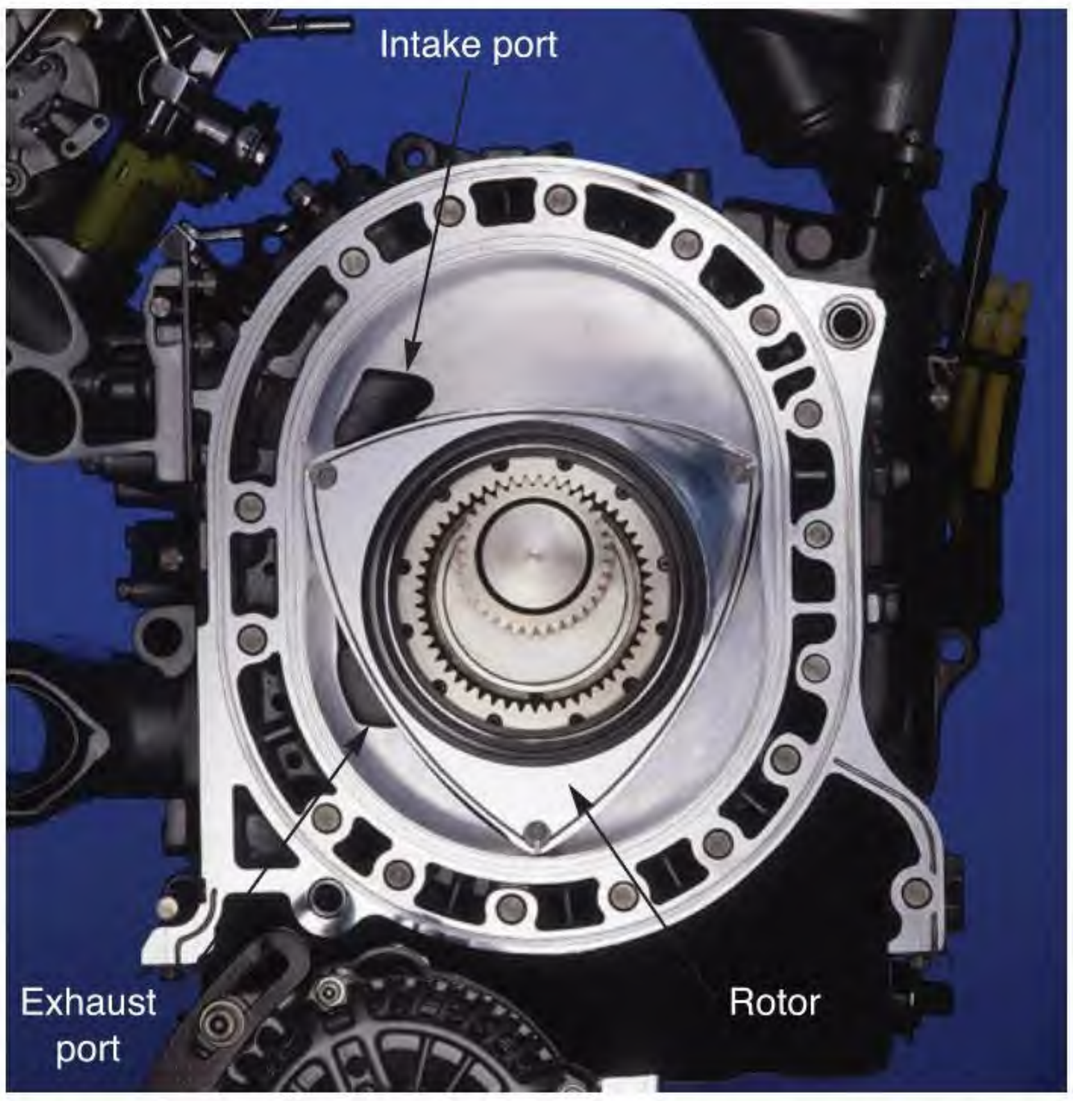
A ***two-stroke-cycle engine*** is similar to a four-stroke-cycle engine, but it requires only one revolution of the crankshaft for a complete power-producing cycle. Two piston strokes (one upward and one



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Figure 12-9. The sequence of events in a rotary engine. A—Intake is starting between points 1 and 3, compression is occurring between points 1 and 2, power is being produced between points 2 and 3, and exhaust is finishing between points 3 and 1. B—Intake continues between points 1 and 3, compression continues between points 1 and 2, and power is finishing between points 2 and 3. C—Intake continues between points 1 and 3, spark occurs between points 1 and 2 (power begins), and exhaust begins between points 2 and 3. D—Intake is finished between points 1 and 3, power is being produced between points 1 and 2, and exhaust is continuing between points 2 and 3.

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Figure 12-10. In this rotary engine design, the intake and exhaust ports are located in the endplates. This reduces emissions considerably.

downward) complete the intake, compression, power, and exhaust events. Look at **Figure 12-11**.

As the piston moves up, it compresses the air-fuel mixture in the combustion chamber. At the same time, the vacuum created in the crankcase by the piston movement draws fuel and oil into the crankcase. Either a ***reed valve*** (flexible metal flap valve) or a ***rotary valve*** (spinning disc-shaped valve) can be used to control flow into the crankcase.

When the piston reaches the top of the cylinder, ignition occurs and the burning gases force the piston downward while spinning in the crankshaft.

As the piston moves down in the cylinder, it uncovers an exhaust port in the cylinder wall. Burned gases leave the engine through the exhaust port.

As the piston continues downward, it uncovers the transfer port. Pressure in the crankcase causes a fresh fuel charge to flow through the transfer port and into the cylinder. Upward movement of the piston again covers the transfer and exhaust ports, compression begins, and the cycle is repeated.

Since the crankcase is used as a storage chamber for each successive fuel charge, the fuel and lubricating oil are pre-mixed and introduced into the engine through the carburetor.

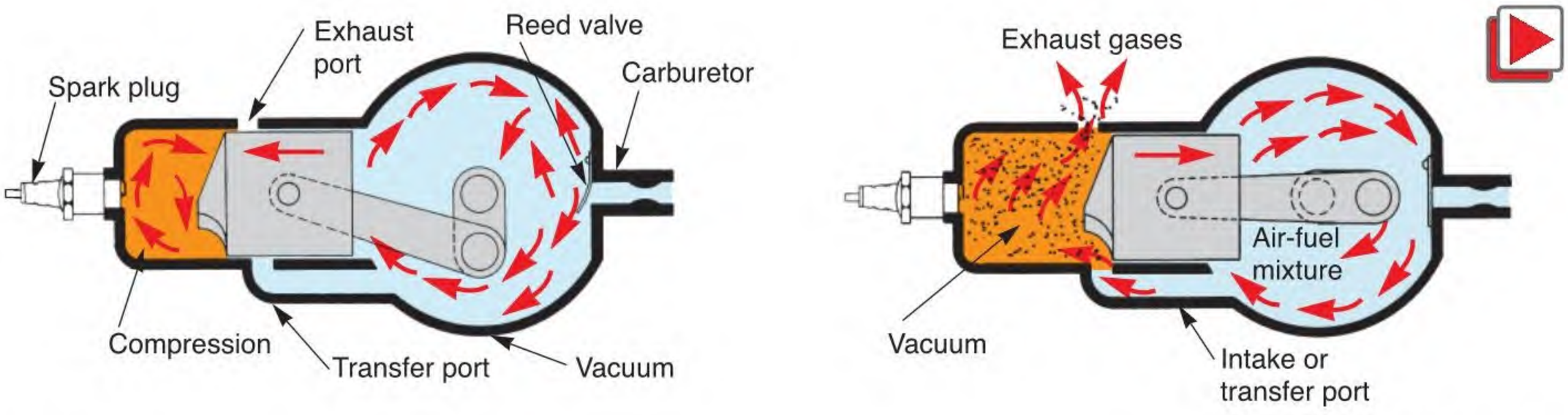
Inside the crankcase, some of the oil separates from the gasoline. The oil mist lubricates and protects the moving parts inside the engine.

Generally speaking, two-stroke-cycle engines are not used in vehicles because they:

- Produce too much exhaust pollution.
- Have poor power output at low speeds.
- Require more service than a four-stroke engine.
- Must have motor oil mixed into the fuel.
- Are not as fuel efficient as a four-stroke engine.

Miller-Cycle Engine

A ***Miller-cycle engine*** uses a modified four-stroke cycle. This engine is designed with a shorter compression stroke and a longer power stroke to increase efficiency. The intake valve remains open longer to delay compression. Because the intake valve remains open for a relatively long time, the air-fuel charge wants to



Ethyl Corporation

Figure 12-11. The two-stroke-cycle engine completes all four events in two piston movements.

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Mazda

Figure 12-12. Cutaway view of a Miller-cycle engine. It is similar to a conventional four-stroke piston engine. However, the opening and closing of the intake valves is modified to increase the duration of power stroke. Note the supercharger, which is needed to prevent backflow of the fuel charge into the intake manifold.

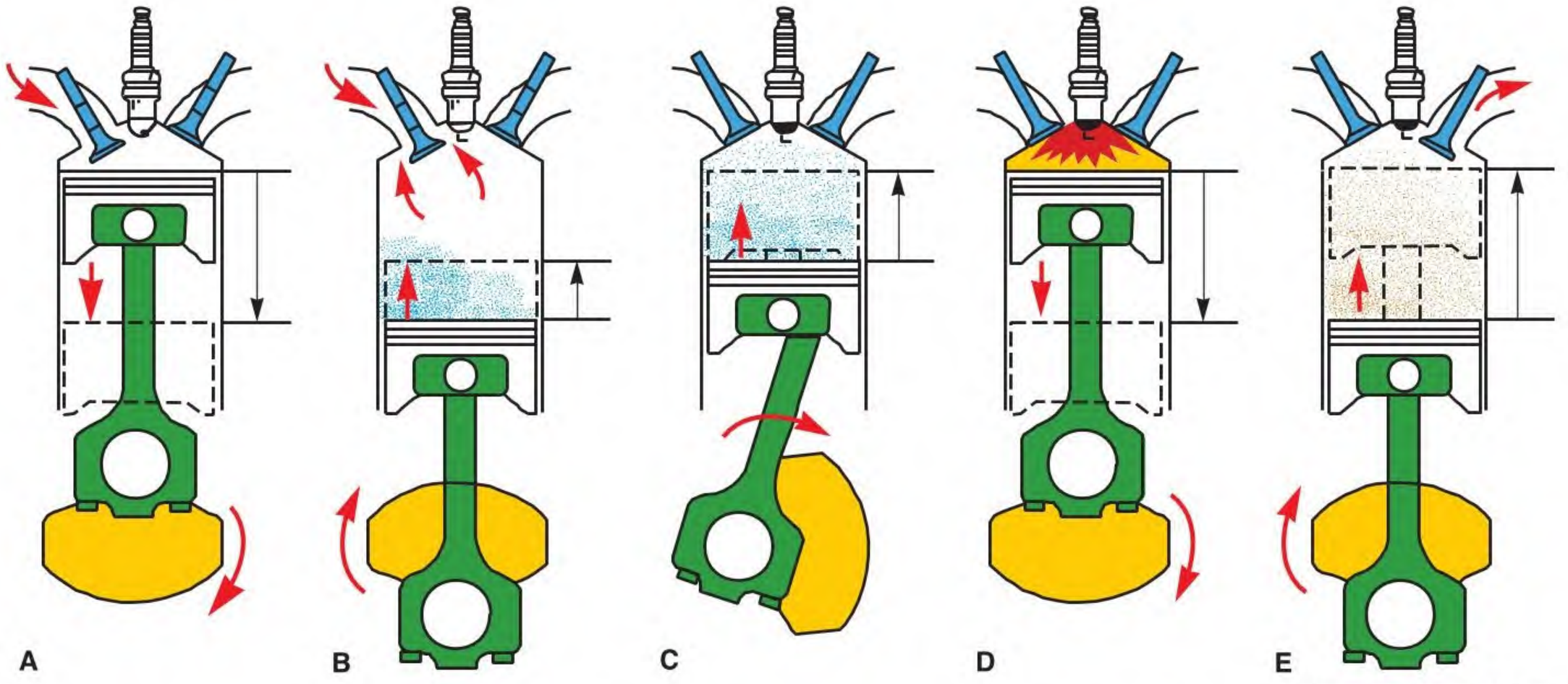
be pushed back out the intake port. To compensate for this reverse flow, a supercharger is normally used to pressurize the intake manifold and block or reverse airflow, **Figures 12-12** and **12-13**.

Today, an Atkinson cycle engine modifies the four-stroke-cycle engine to have a short intake stroke and a very long power stroke. This allows the engine to pull more heat energy out of the burning fuel. Variable cam and valve timing can cause the compression stroke to occur more quickly and power stroke to take more time in degrees of crankshaft rotation. A small cylinder bore and long stroke will also help thermal efficiency.

Theoretically, a Miller-cycle engine can produce more power and is more economical than a conventional four-stroke-cycle engine of equal size. However, the engine is more complex to produce and maintain because of the supercharger. One auto manufacturer is now successfully using a Miller-cycle engine in its passenger cars.

Workplace Skills

An apprentice technician gave a customer a quote for a valve job on a passenger car engine. The apprentice failed to recognize that the customer's vehicle was equipped with a four-valve engine. When the bill came back from the machine shop for grinding the valves and cylinder head seats, it was twice as much as estimated. Instead of 16 valves, the heads had 32 valves and 32 seats, doubling the parts and labor needed to recondition the heads.



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Figure 12-13. Illustrations show Miller-cycle engine operation. A—The piston slides down with the intake valve open. B—The intake valve remains open as the piston slides up. Supercharger pressure prevents backflow into the intake port. C—Piston travels with both valves closed. D—Power stroke. E—Exhaust stroke.

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The apprentice tried to explain to the customer why the final bill for the repair was higher than originally estimated. The customer paid the bill, but he left the shop angry, taking his business elsewhere after that.

If the apprentice had taken the time to learn about various engine classifications, he would not have given the low quote and the customer would have been satisfied with the repair. If you are not sure about something, research it.

Summary

- Although basic engine parts are the same, design differences can change how engines operate and how they are repaired.
- Cylinder arrangement refers to the position of the cylinders in relation to the crankshaft.
- The liquid cooling system surrounds the cylinder with coolant (water and antifreeze solution).
- A spark ignition engine uses an electric arc at the spark plug to ignite the fuel.
- A compression ignition engine squeezes the air in the combustion chamber until it is hot enough to ignite the fuel.
- A cam-in-block engine uses push rods to transfer motion to the rocker arms and valves.
- In an overhead cam (OHC) engine, the camshaft is located in the top of the cylinder head.
- A four-valve combustion chamber uses two exhaust valves and two intake valves per cylinder.
- A stratified charge combustion chamber uses a small combustion chamber flame to ignite and burn the fuel in the main combustion chamber.
- A precombustion chamber is commonly used in automotive diesel engines.
- A variable displacement engine can deactivate cylinders so the engine conserves fuel and produces fewer emissions.
- A variable valve timing engine can alter valve opening and closing independent of crankshaft rotation.
- A two-stroke-cycle engine is similar to a four-stroke-cycle engine, but it requires only one revolution of the crankshaft for a complete power-producing cycle.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

air cooling system
air jet combustion chamber
compression ignition engine
cylinder arrangement
cylinder numbers
diesel prechamber
dual overhead cam (DOHC) engine
flat head engine
four-valve combustion chamber
hemispherical combustion chamber
I-head engine
inline engine
L-head engine
liquid cooling system
Miller-cycle engine
opposed engine
overhead cam (OHC) engine
overhead valve (OHV) engine
pancake combustion chamber
pent-roof combustion chamber
precombustion chamber
reed valve
rotary engine
rotary valve
single overhead cam (SOHC) engine
spark ignition engine
squish area
stratified charge combustion chamber
swirl combustion chamber
three-valve combustion chamber
two-stroke-cycle engine
variable displacement engine
variable valve timing engine
V-type engine
wedge combustion chamber
W-type engine

Activities

1. Make a poster that shows the four types of engine cylinder arrangements. Label the arrangements.
2. Visit vehicle manufacturer websites and identify the different engine types offered as standard across the range of automobile models under a single brand name (Ford, Honda, Chrysler, Volvo, etc.). Write a short report on your findings.

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3. Research the Stanley Steamer or another steam-driven automobile on the Internet. Describe to the class how its engine worked. Show a drawing or photograph, if possible.

Review Questions

Answer the following questions using the information provided in this chapter.

1. List ten ways to classify an automotive engine.
2. Normally, car engines have _____, _____, or _____ cylinders.
3. Why are cylinders numbered?
4. Cylinder numbering varies from one manufacturer to another. True or False?
5. Most car engines have air cooling systems. True or False?
6. Explain the difference between spark ignition and compression ignition.
7. Where are the two typical locations for the engine camshaft?
8. Which of the following does not refer to camshaft location and design?
   (A) OHC.
   (B) SOHC.
   (C) DOHC.
   (D) UHC.
9. A hemi-head combustion chamber is flat. True or False?
10. Explain the operation of a diesel precombustion chamber.
11. A(n) _____ engine does *not* use pistons that slide up and down.
12. Some variable valve timing engines use electro-hydraulically controlled _____ to alter valve operation.
13. Three complete power-producing cycles occur during every revolution of a rotary engine's rotor. If an engine has three rotors and each completes one revolution, how many complete cycles are produced?
   (A) 4.
   (B) 3.
   (C) 6.
   (D) 9.
14. Which of the following refers to a two-stroke-cycle engine?
   (A) One crankshaft revolution completes a power-producing cycle.
   (B) Two strokes complete all four events.
   (C) Uses reed valves or rotary valves.
   (D) All of the above.
15. In a Miller-cycle engine, a supercharger is used to _____ the intake manifold.

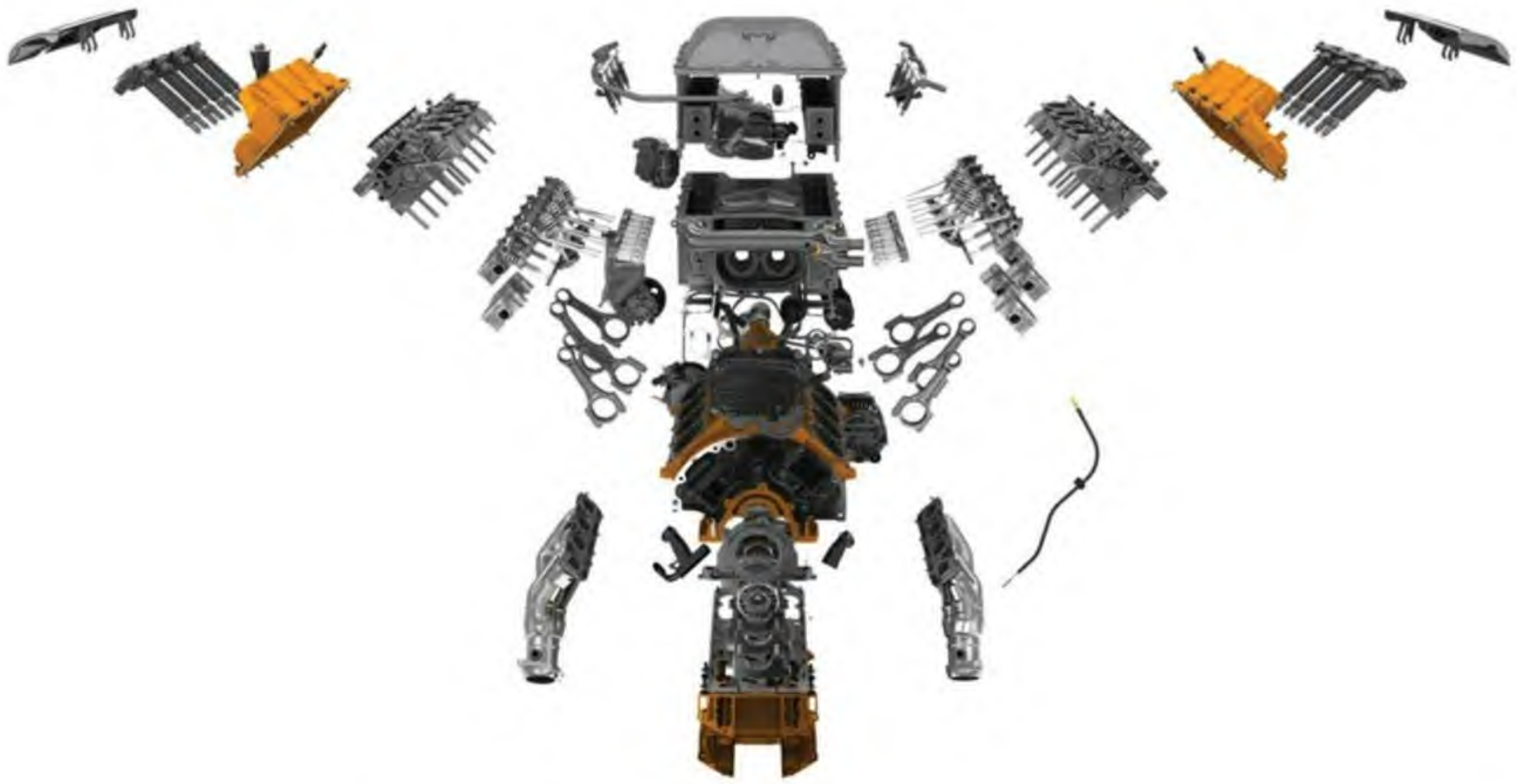
ASE-Type Questions

1. Vehicle engine classifications include each of the following *except:*
   (A) valve location.
   (B) type of ignition.
   (C) number of cylinders.
   (D) type of drive mechanism.
2. Which of the following is *not* a basic cylinder arrangement?
   (A) Opposed.
   (B) Inline.
   (C) U-type.
   (D) V-type.
3. Technician A says gasoline engines are compression ignition engines. Technician B says compression ignition engines use spark plugs to ignite the fuel. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. The type of engine that has both an intake and exhaust valve in its cylinder head is called a(n):
   (A) I-head engine.
   (B) L-head engine.
   (C) flat head engine.
   (D) All of the above.
5. In cam-in-block engine, push rods are needed to operate the:
   (A) rockers and valves.
   (B) camshaft and valves.
   (C) camshaft and rockers.
   (D) All of the above.

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6. The combustion chamber shape in which the valve heads are almost parallel with the top of the piston is called the:
   (A) swirl chamber.
   (B) wedge chamber.
   (C) pancake chamber.
   (D) stratified chamber.
7. Which of the following combustion chambers allows the use of a glow plug in automotive diesel engines?
   (A) Precombustion chamber.
   (B) Swirl chamber.
   (C) Air jet chamber.
   (D) Stratified charge chamber.
8. The engine type that uses a triangular rotor instead of conventional pistons is called a(n):
   (A) rotary engine.
   (B) opposed engine.
   (C) cam-in-block engine.
   (D) spark ignition engine.
9. A two-stroke-cycle engine requires how many crankshaft revolutions per power cycle?
   (A) One.
   (B) Two.
   (C) Four.
   (D) None of the above.
10. While discussing engines, Technician A says two-stroke-cycle engines are not used in vehicles because they have poor power output at low speeds. Technician B says two-stroke engines are not used in vehicles because they produce too much exhaust pollution. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

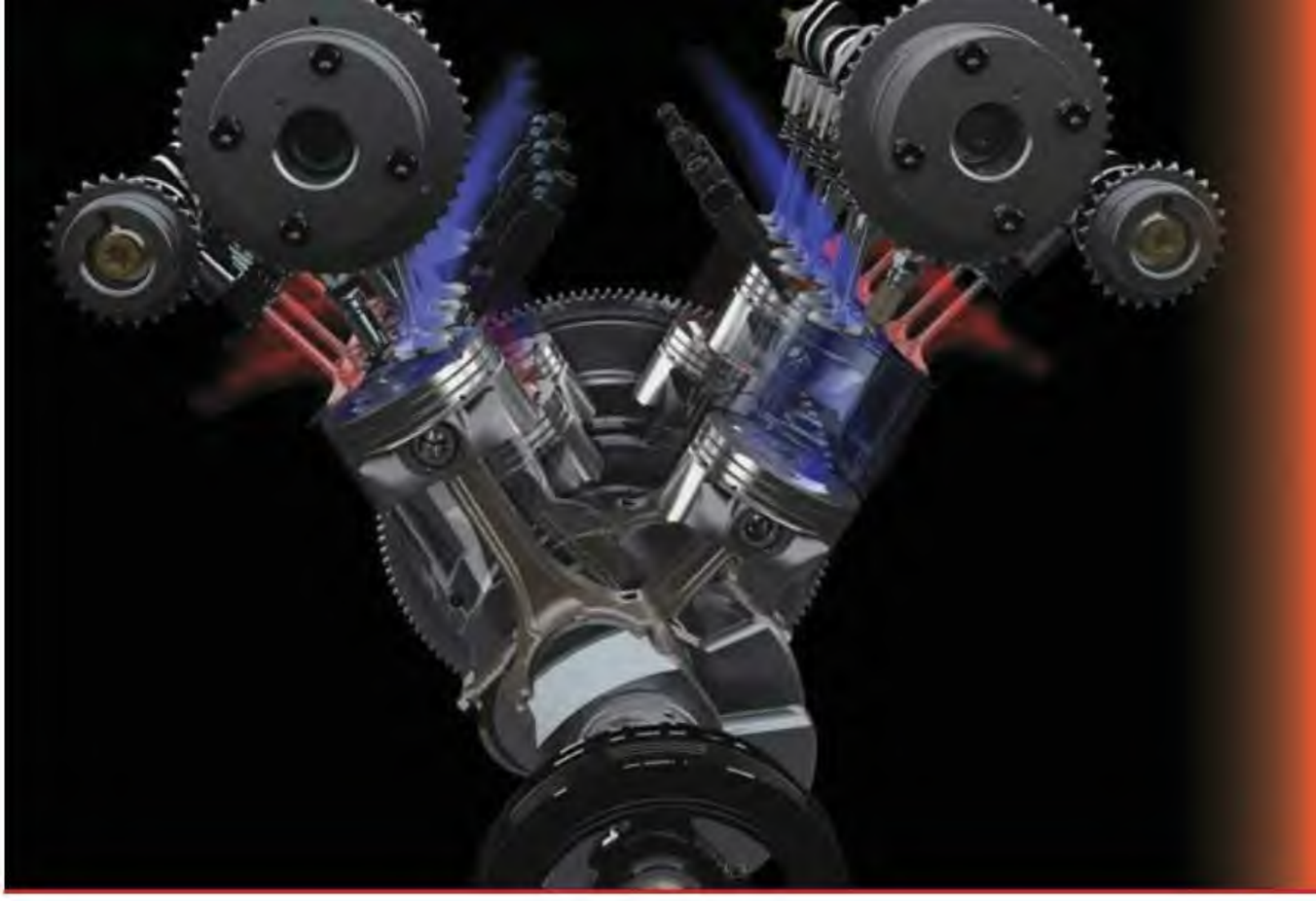
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(Chrysler)

How many engine components can you identify in this exploded view?

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Chapter 13

Engine Top End Construction

After studying this chapter, you will be able to:

- Describe the design and construction of an engine cylinder head.
- Explain umbrella and O-ring valve seals.
- Explain the purpose of valve spring shims, rotators, stem caps, and spring shields.
- Describe the construction and operation of a camshaft.
- Explain hydraulic and mechanical lifters.
- Describe different types of rocker arm assemblies.
- Explain the construction and design of intake and exhaust manifolds.
- Describe safety practices used when working on engine top end components.
- Answer ASE certification test questions that require a knowledge of engine top end construction.

An ***engine top end*** basically includes the cylinder head assembly, valve train, valve cover, and intake and exhaust manifolds. Understanding the construction of an engine top end helps improve your ability to troubleshoot and repair an engine. This chapter explains the engine top end and each of its components, **Figure 13-1**.

Cylinder Head Construction

A ***bare cylinder head*** is a complex metal casting with all of its parts removed. These parts include the valves, keepers, retainers, springs, seals, and rocker arms. A bare cylinder head is commonly made of cast iron or aluminum.

If a cylinder head becomes badly damaged, the technician may need to install a new bare head. All the old, reusable parts (valves, keepers, retainers, etc.) can be removed and installed in the new head.

The construction of a cylinder head varies with engine design and type. It is critical that you understand the most important cylinder head variations. See **Figures 13-2** and **13-3**.

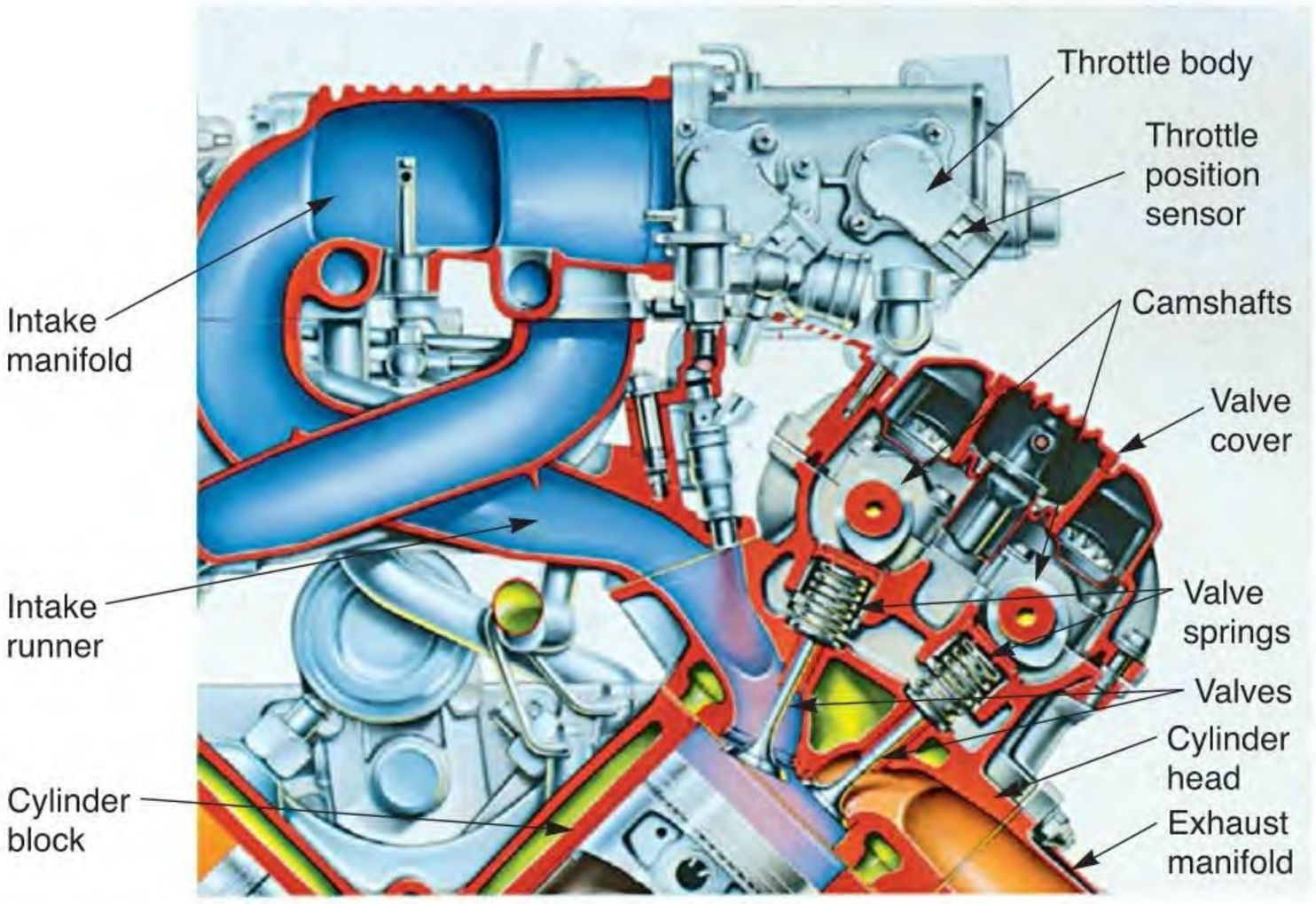
For example, some engines have a drain hole at the rear of the cylinder head. This allows the oil from the valve train to flow back down through the engine and into the sump. With this design, the engine may be mounted in the vehicle at a slight angle.

Valve Guide Construction

There are two basic types of valve guides: integral guides and pressed-in guides. Both types are used in modern engines.

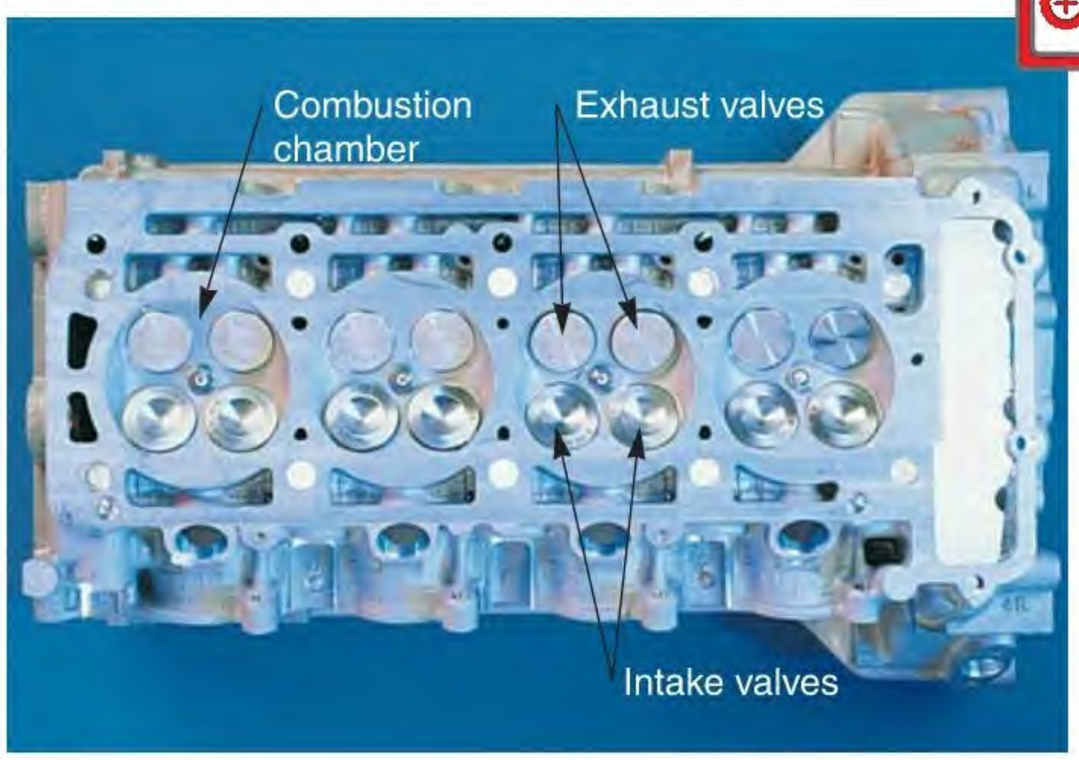
An ***integral valve guide*** is part of the cylinder head casting. An integral guide is simply a hole machined

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Honda

Figure 13-1. Generally, an engine top end includes parts that fasten to the top of the cylinder block. These include the head, valve train, intake manifold, exhaust manifold, and valve cover.



Chrysler

Figure 13-2. The cylinder head assembly has the valves and springs still installed. This cast aluminum cylinder head has four-valve combustion chambers.

through the cylinder head. This type of guide is very common because of its low production cost.

A ***pressed-in valve guide*** is a separate sleeve forced into a hole machined in the cylinder head. It can be made of cast iron or bronze. Friction from the press fit holds the valve guide in the cylinder head. A pressed-in valve guide simplifies guide repair. See **Figure 13-4**.

A worn guide can be pressed out and a new guide can be quickly pressed in. This eliminates some of the machining needed when replacing a badly worn integral valve guide.

Valve Seat Construction

Like valve guides, valve seats can be integral or pressed-in. Both are commonly used in modern engines.

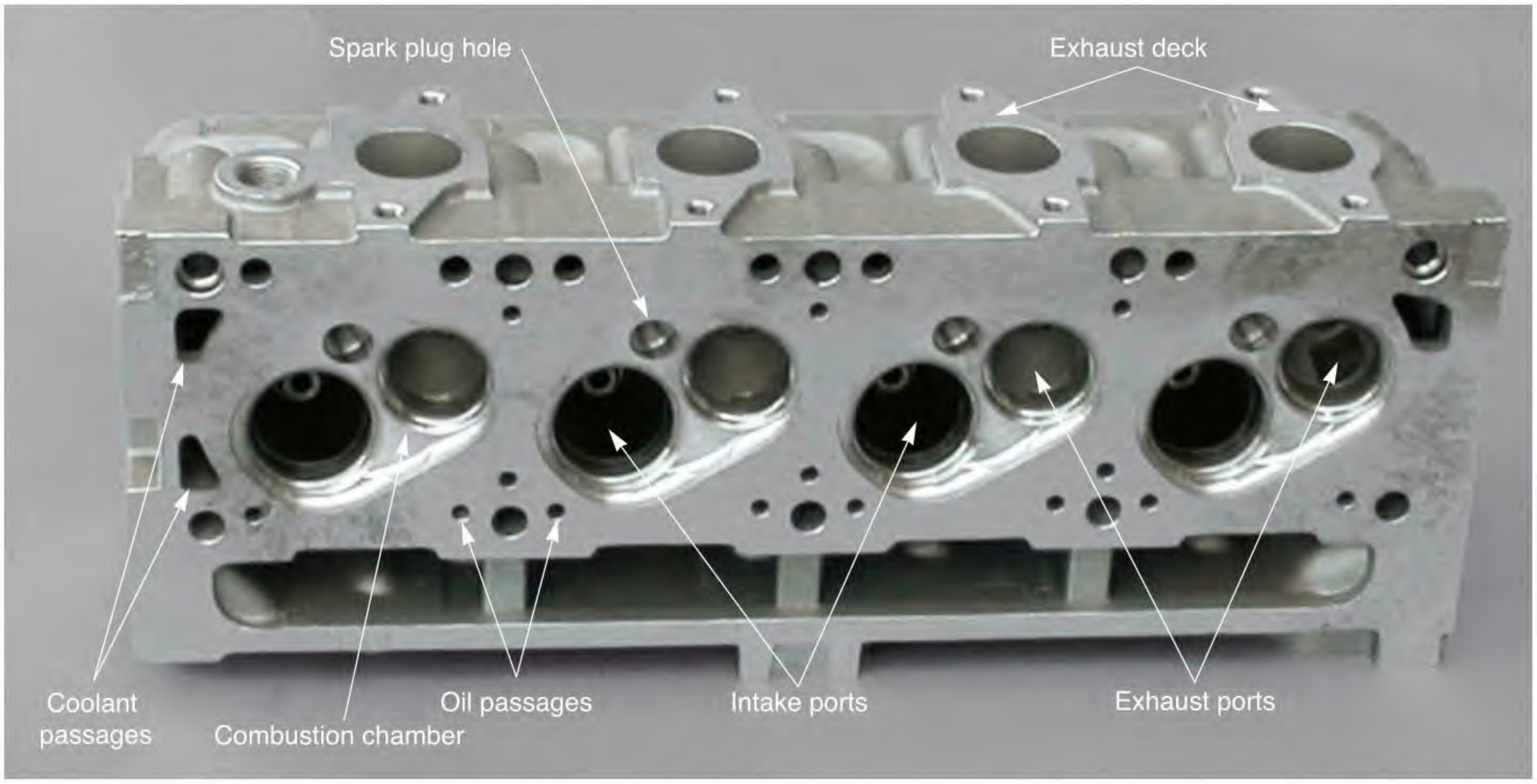
An ***integral valve seat*** is simply a machined portion of the cylinder head casting. Different cutters are used to machine a precise face on the valve port opening.

A ***pressed-in valve seat***, also called a seat insert, is a separate part that is forced into a recess cut into the head. Steel pressed-in valve seats are commonly used in aluminum cylinder heads. Steel is needed to withstand the extreme heat produced during engine operation. A pressed-in valve seat is shown in **Figure 13-4**.

The ***valve seat angle*** is the angle formed by the face of the seat. A 45° angle is commonly used on passenger car engines. However, some high-performance engines have seat angles of 30°.

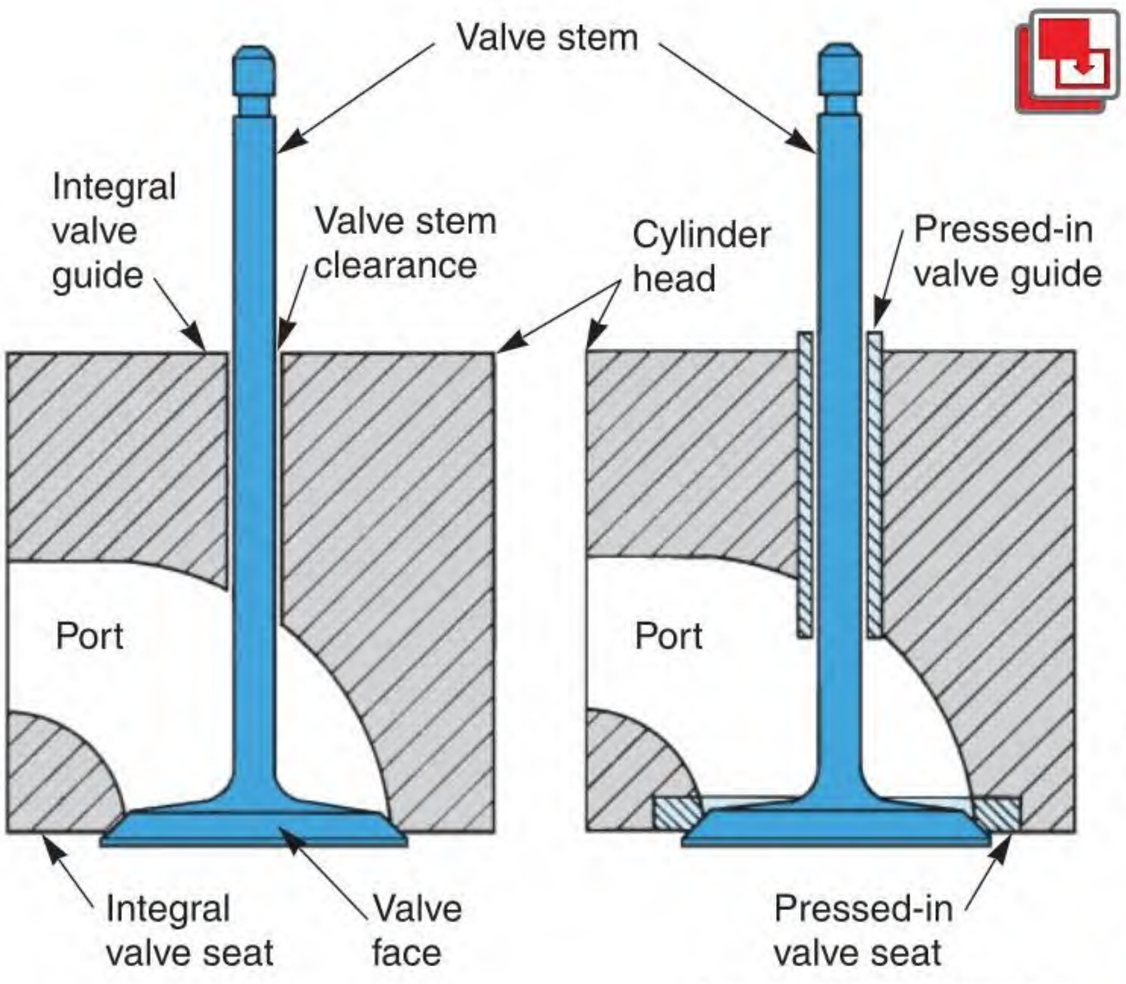
An ***interference angle*** is a 1/2°–1° difference between the valve seat face angle and the angle of the valve face. The interference angle reduces

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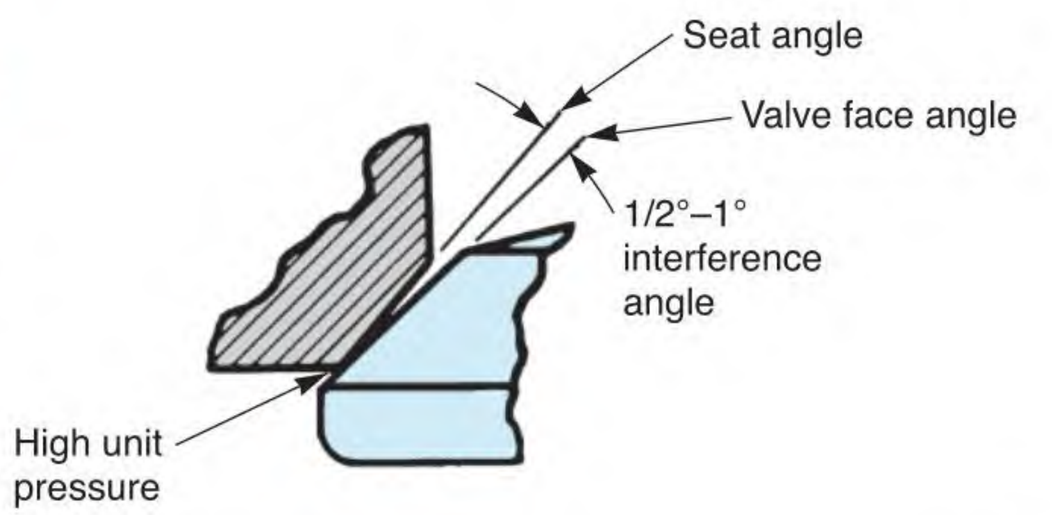
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Figure 13-3. A bare cylinder head is a head casting with the components removed. Note the location and names of the parts. Cylinder heads can be cast from iron or aluminum. This bare cylinder head has a two-valve combustion chamber.



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Figure 13-4. Valve guides and seats can be made as an integral part of the head or as separate inserts.



TRW

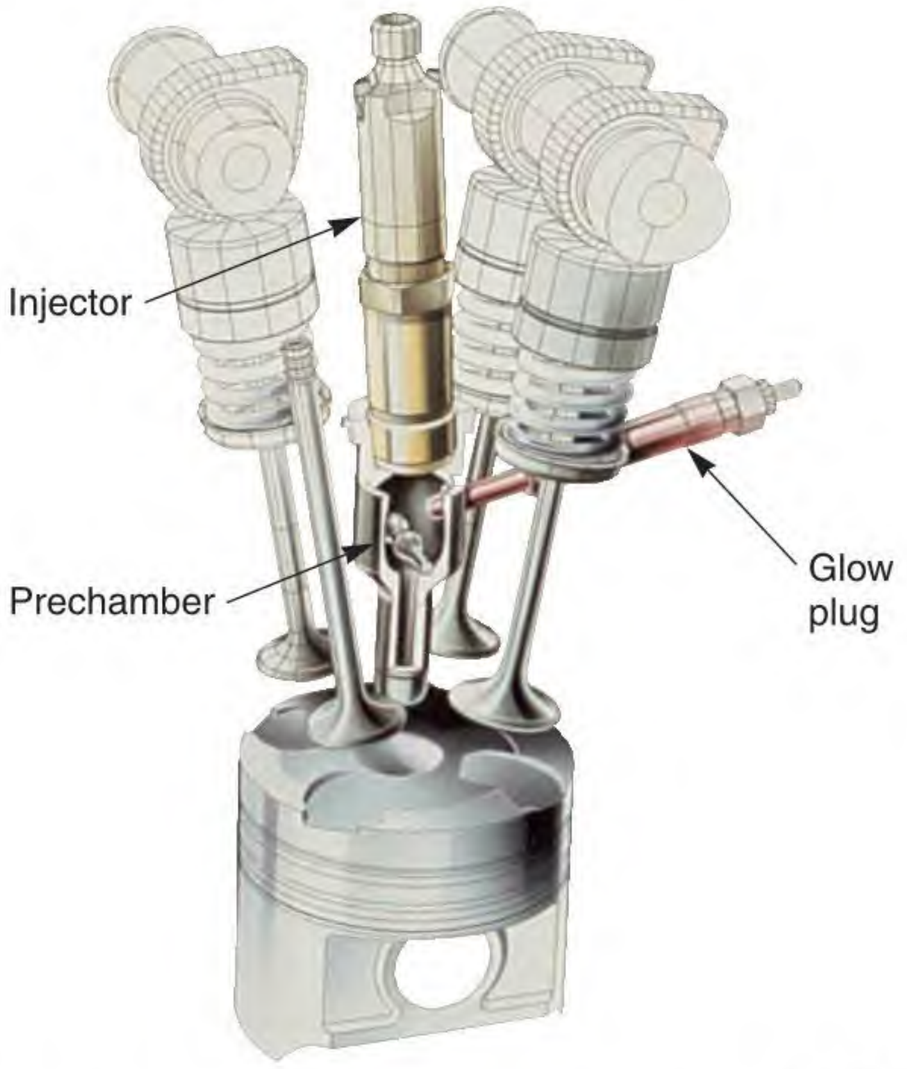
Figure 13-5. Common valve and seat angles are 30° and 45°. The interference angle is the 1° difference between the valve and seat angles to increase sealing pressure and to speed seating, or break-in.

the contact area between the seat and valve. This increases pressure between the two and speeds valve seating (sealing) during engine operation, **Figure 13-5**.

Prechamber Cup

A ***prechamber cup*** is pressed into the cylinder head of some diesel engines. Holes are precisely machined into the cylinder head deck surface. The prechamber cups are force-fit into these holes. Each prechamber cup forms an enclosure around the tip of an injector and glow plug. This area is heated by the glow plug for better cold starting. Refer to **Figure 13-6**.

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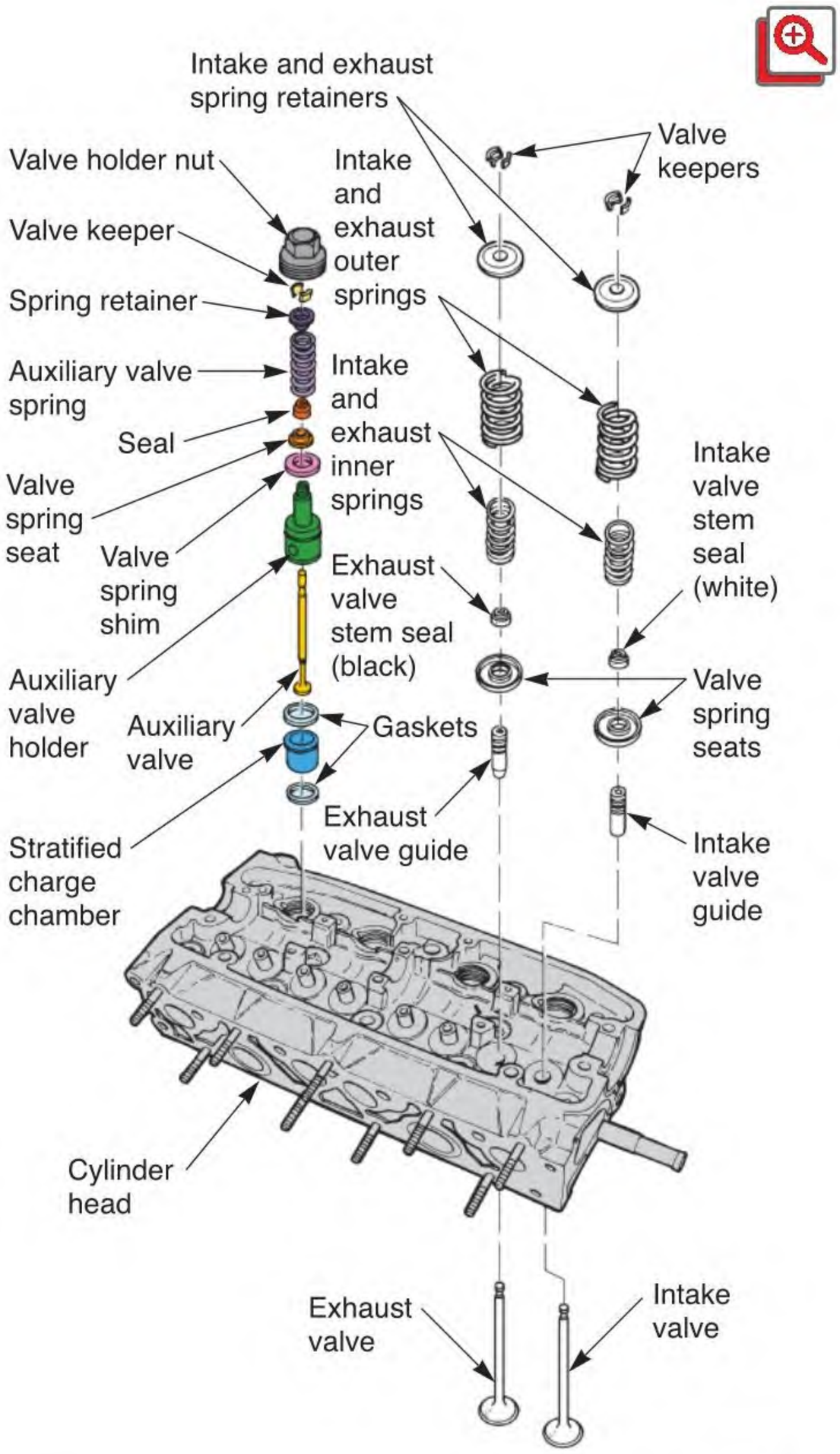


General Motors

Figure 13-6. A diesel cylinder head normally has pressed-in prechamber cups. They form the precombustion chambers for the tips of glow plugs and injectors.

Stratified Charge Chamber

A stratified charge chamber also fits into the cylinder head casting. It is found in gasoline engines that are designed to use a rich fuel mixture in the auxiliary chamber to ignite a lean mixture in the main combustion chamber. **Figure 13-7** shows how the stratified charge chamber and related components are assembled in the cylinder head. Study it closely.



Honda

Figure 13-7. This is a gasoline engine cylinder head with stratified charge auxiliary chambers. Note how the chamber and extra intake valve are assembled.

Valve Train Construction

The valve train controls the opening and closing of the cylinder head ports. Although the basic function of all valve trains is the same, valve train construction will vary with engine design. To be able to work on any type of valve train, you must understand these differences.

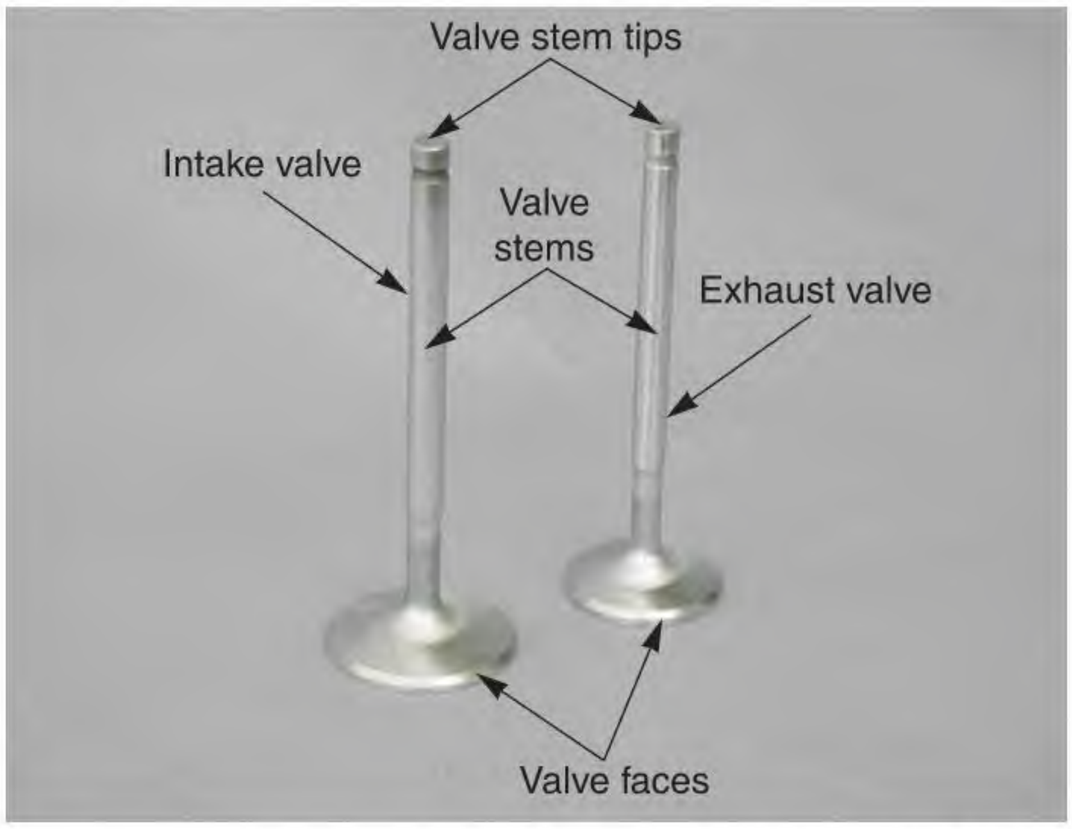
Valve Construction

Automotive engines commonly use ***poppet valves***, or ***mushroom valves***. These terms come from the valve's shape and action. The valve is shaped something like a mushroom and it "pops" open. Actual engine valves are shown in **Figure 13-8**.

Almost every surface of a valve is machined. The stem must accurately fit the guide. Some engine valve stems are chrome plated to better resist wear. The face must contact the seat perfectly. The margin must be thick enough to prevent valve burning. Grooves are cut into the valve stem tops for the keepers.

The ***valve face angle*** is the angle formed between the valve face and valve head. Normal valve face angles are 45° and 30°. The exhaust valve is exposed to higher temperatures than the intake valve—the intake valve has cooler outside air flowing

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Figure 13-8. Typical poppet, or mushroom, valves. The intake valve is normally larger than the exhaust valve.

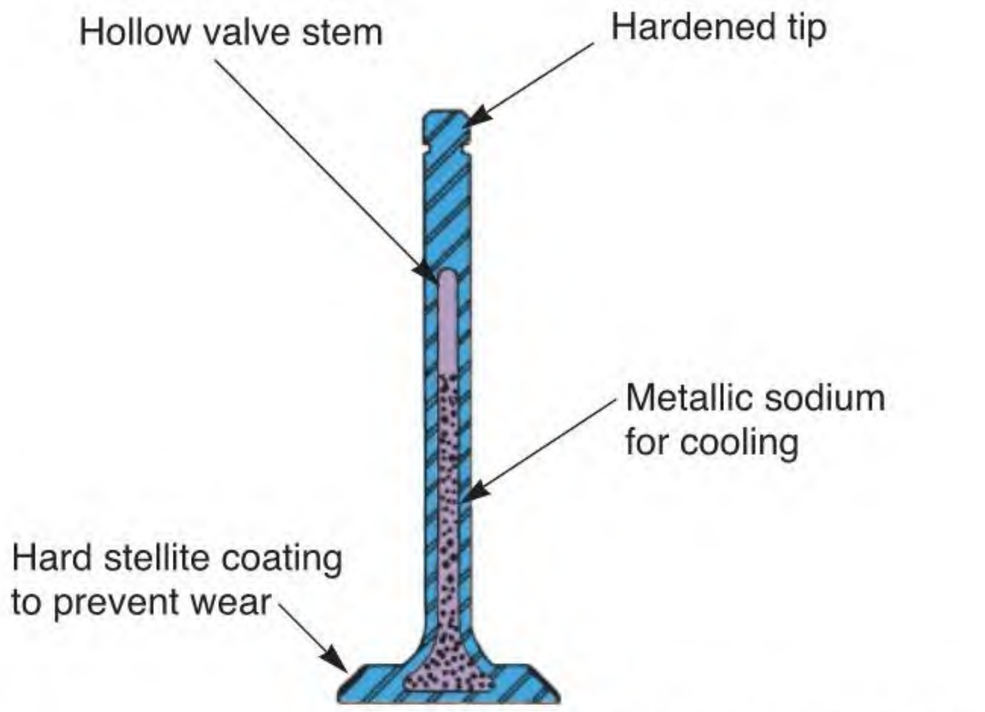
over it, while hot combustion gases flow over the exhaust valve. If the exhaust valve does not transfer heat into the cylinder head, it will burn.

Hollow-stem, sodium-filled valves are used when extra valve cooling action is needed. During engine operation, the sodium inside the hollow valve melts. When the valve is pressed down, or opened, the sodium splashes down into the valve head and collects heat. Then, when the valve is released, or closed, the sodium splashes up into the valve stem. Heat transfers out of the sodium and into the stem, valve guide, and engine coolant. In this way, the valve is cooled.

Warning

Sodium-filled valves are used in a few high-performance engines. They are very light and allow high engine rpm for prolonged periods. However, they can explode if placed in a fire and, therefore, must be disposed of properly.

A stellite valve has a stellite (very hard metal alloy) coating on its face. A stellite coating is often used in engines designed to burn unleaded fuel. Older engines did not require the use of stellite valves, because leaded fuel (now phased out) helped lubricate the valve and seat faces. Look at **Figure 13-9**.



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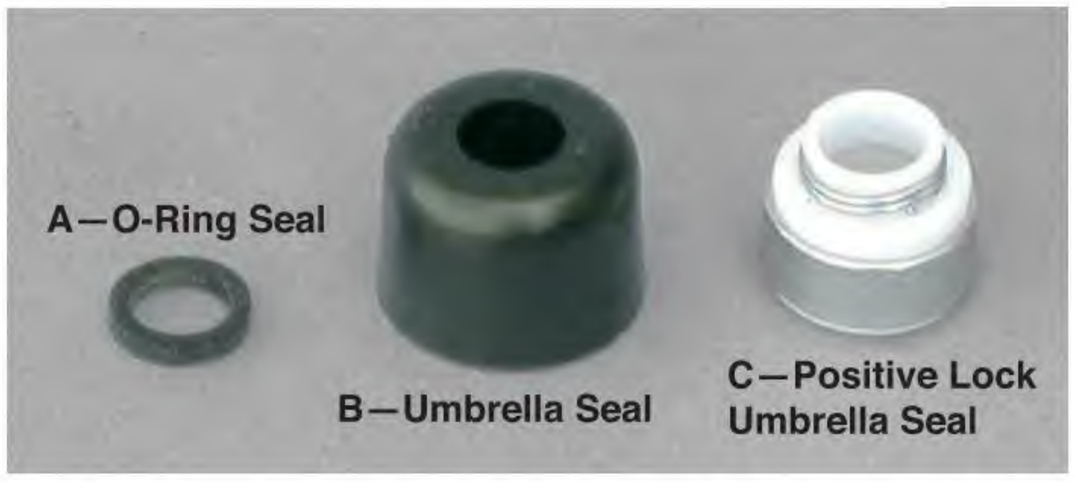
Figure 13-9. Stellite coating on the valve face retards wear and allows the use of unleaded fuel.

Valve Seal Construction

Valve seals come in two basic types. These types are umbrella and O-ring. Both are common on modern engines. See **Figure 13-10**.

An ***umbrella valve seal*** is shaped like a cup and can be made of neoprene rubber or plastic. An umbrella valve seal slides down over the valve stem before the spring and retainer. It covers the small clearance between the valve stem and guide. This keeps oil from being drawn into the cylinder head port and combustion chamber.

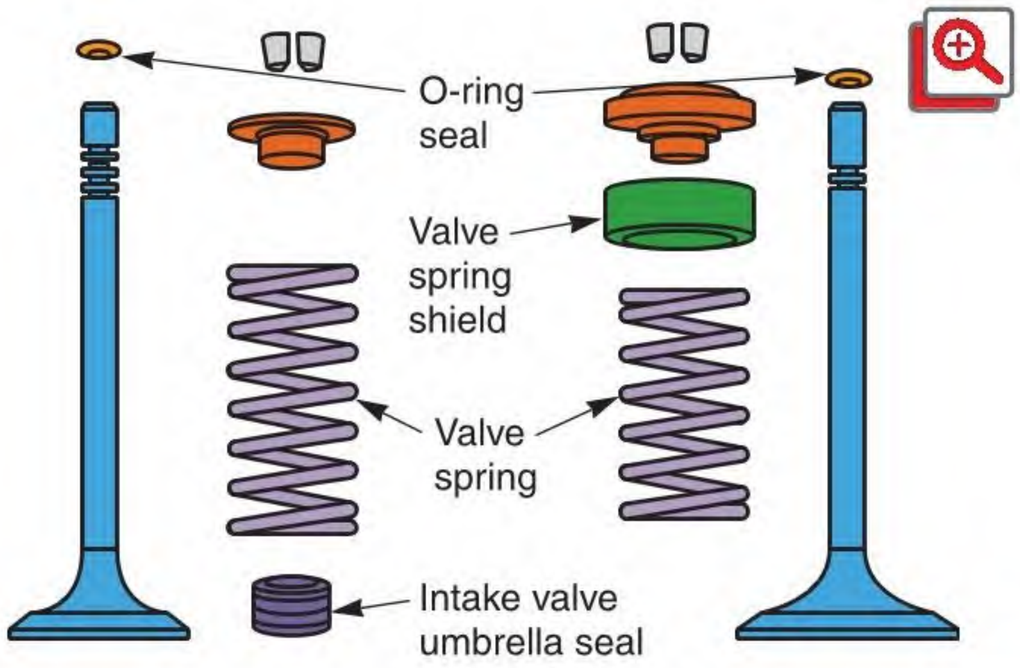
An ***O-ring valve seal*** is a small round seal that fits into an extra groove cut in the valve stem. Unlike the umbrella type, it seals the gap between the retainer and valve stem, not the guide and stem. It stops oil from flowing through the retainer, down the stem, and into the guide. An O-ring valve seal fits onto the valve stem after the spring and retainer. It is made of soft synthetic rubber that allows it to be stretched over the valve stem and into place. Look at **Figure 13-11**.



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Figure 13-10. Three types of valve seals are shown.

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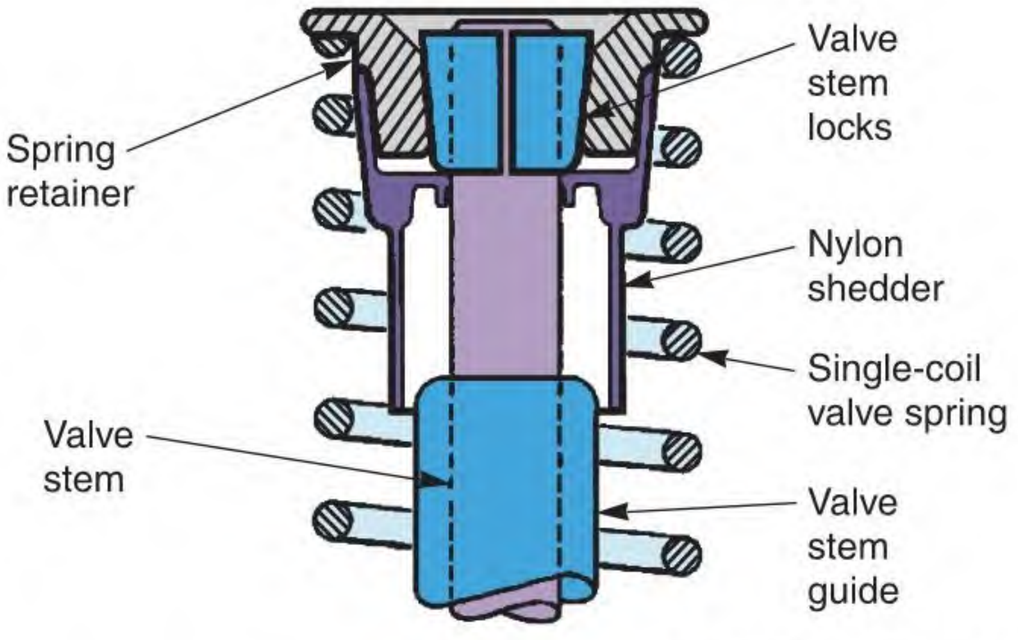
Figure 13-11. An O-ring valve seal fits into an extra groove cut in the valve stem. To prevent seal damage, the spring and retainer must be installed before the seal. This valve spring assembly uses both an O-ring seal and an umbrella seal on the intake valve.

A ***valve spring shield*** is normally used with an O-ring valve seal. The shield surrounds the top and upper sides of the spring and helps keep oil off the valve stem.

A nylon shedder can also be used to limit the amount of oil that splashes on the valve stem and guide opening. The shedder is a cross between a conventional oil seal and a valve spring shield. It seals against the valve stem like a seal and encircles the upper spring like a shield. One is illustrated in **Figure 13-12**.

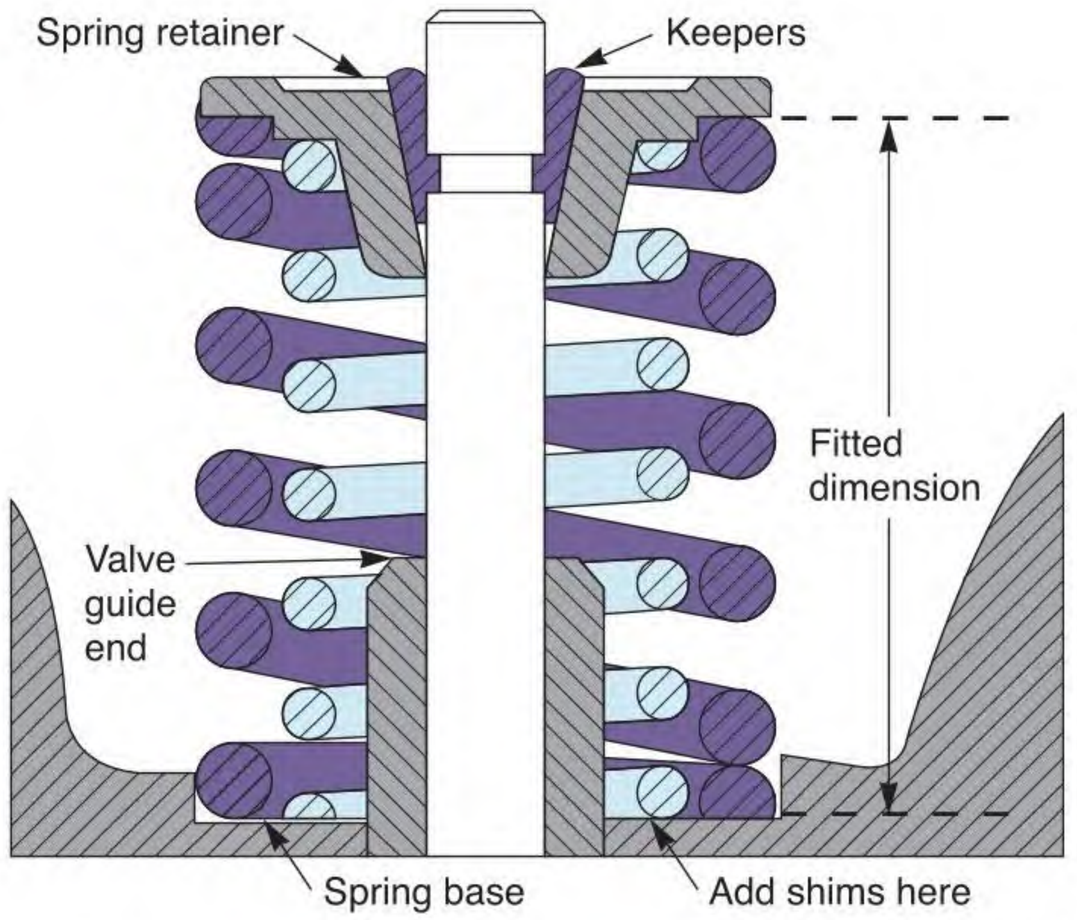
Valve Spring Construction

Valve spring construction is basically the same for all engines. However, the number and type of coils can vary. See **Figures 13-13** and **13-14**.



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Figure 13-12. A nylon shedder functions as both an O-ring seal and a shield to keep oil out of the valve guide.

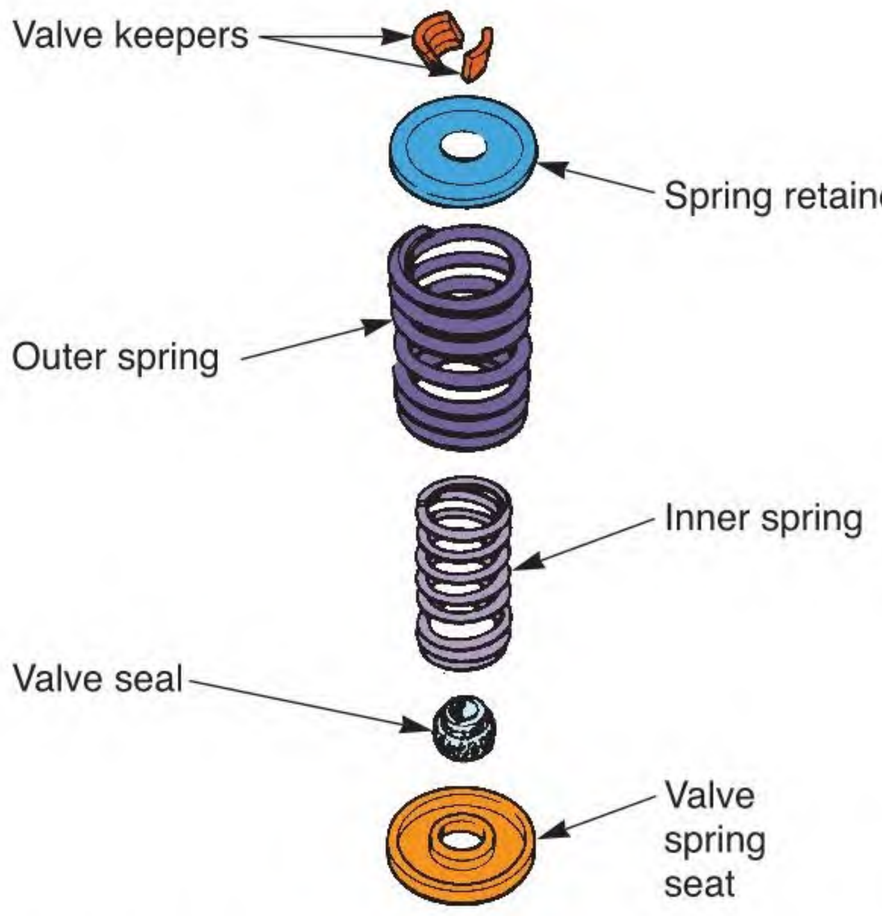


Ford

Figure 13-13. A dual-coil valve spring increases the valve closing pressure. Also notice the other parts.

Spring tension refers to the stiffness of a valve spring measured in pounds or kilograms. Spring tension is usually stated for both opened and closed valve positions. The service manual will give the tension specifications for specific compressed lengths.

Spring free length is the length of the valve spring when removed from the engine. ***Spring open length*** is the spring's length when installed on the



Honda

Figure 13-14. A valve spring assembly using a spring seat. The seat keeps the bottom of the spring in alignment with the stem.

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engine with the valve fully open. ***Spring closed length*** is the length of the valve spring when installed on the engine with the valve closed. Both open length and closed length are measured from the bottom of the spring to the bottom of the spring retainer.

Spring specifications are important. They affect valve action. Low spring tension can cause valve float. ***Valve float*** occurs when the valve fails to close entirely at high rpms because the spring is too weak.

Valve Spring Shim

A ***valve spring shim*** is a very thin, accurately machined washer used to increase spring tension. When a shim is placed under a spring, the open and closed lengths of the valve spring are reduced. This compresses the spring to increase closing pressure. A used valve spring may weaken and lose some of its tension. Valve spring shims provide a means of restoring full spring tension and pressure without spring replacement.

Valve Retainers and Keepers

Valve retainers and ***keepers*** lock the valve spring onto the valve. The retainer is a specially-shaped washer that fits over the top of the valve spring. The keepers fit into the valve stem grooves. This holds the retainer and spring in place.

Valve Spring Seat

A ***valve spring seat*** is a cup-shaped washer installed between the cylinder head and the bottom of the valve spring. It provides a smooth, machined surface or pocket to hold the bottom of the valve spring.

Valve Rotators

A ***valve rotator*** turns the valve to prevent carbon buildup and hot spots on the valve face. A valve rotator may be located under or on top of the valve spring. If under the seat, it is called a seat-type rotator. If on top of the valve spring, it is called a retainer-type rotator. Rotators are commonly used on engine exhaust valves, which are exposed to more heat than intake valves.

Valve Stem Cap

A ***valve stem cap*** may be placed over the end of the valve stem. It helps prevent stem and rocker arm wear. A valve stem cap is free to turn on the valve stem. This serves as a bearing that reduces friction. Some valve stem caps are used to adjust the clearance in the valve train. Different cap thicknesses are available. Caps can be changed to alter the clearance between the rocker arm and the valve stem.

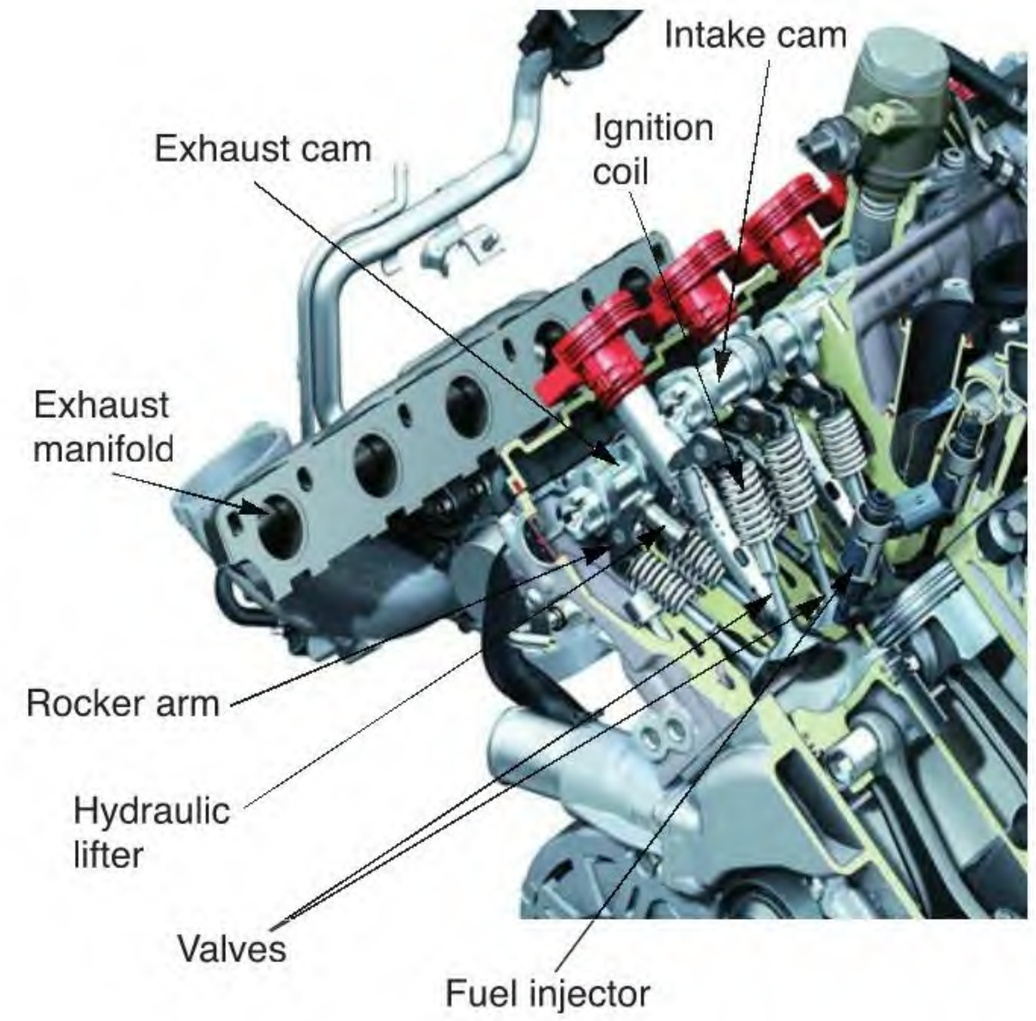
Camshaft Construction

A ***camshaft*** controls when the valves open and close. It can be driven by gears, a chain, or a belt. The number of lobes on a camshaft depends on the number of valves in the combustion chambers and the number of cylinders in the engine. Many engines only use one camshaft. However, others use two or more, **Figure 13-15**.

With dual overhead cam engines, there are two camshafts per cylinder head. One is the intake camshaft and the other is the exhaust camshaft. The intake camshaft operates all the intake valves in the cylinder head. The exhaust camshaft operates all the exhaust valves.

Cam Lobes

The ***cam lobes*** are precision-machined and polished surfaces on the camshaft. Each cam lobe consists of a nose, flank, heel, and base diameter.



Audi

Figure 13-15. In a dual overhead cam engine, separate camshafts control the intake and exhaust valves. The shape of the cam lobes determines when the valves open, how far they open, and how long they remain open.

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Variations in lobe shape control:

- When each valve opens in relation to piston position.
- How long each valve stays open.
- How far each valve opens.

Camshaft lift is the distance the valve opens. Camshaft lift is found by subtracting the cam base diameter from the height of the cam lobe.

Camshaft duration determines how long the valve stays open. The shape of the cam lobe nose and flank regulates camshaft duration. For instance, a pointed cam lobe has a shorter duration than a rounded lobe. See **Figure 13-16**.

Valve timing refers to valve opening and closing in relation to the position of the pistons in the cylinders. Valve timing is designed into the camshaft and drive sprockets or gears by the manufacturer.

Valve overlap is the time when both the intake and exhaust valves in the same cylinder are open. Valve overlap is used to help draw burned gases out of the cylinder. It also helps pull a fresh fuel charge into the cylinder. With both the intake and exhaust valves open, there is more flow into and out of the combustion chamber. The added flow of air-fuel mixture and exhaust gases increases engine power. Valve overlap helps engine breathing, especially at higher engine speeds. Look at **Figure 13-17**.

Some camshafts are machined with dual cam lobes that have two different profile shapes. One cam lobe is designed for good low-speed efficiency. The other is a high-speed profile for high engine rpm power. The driveline control module operates a solenoid valve that controls oil flow to shift the rocker arms from one lobe profile to the other.

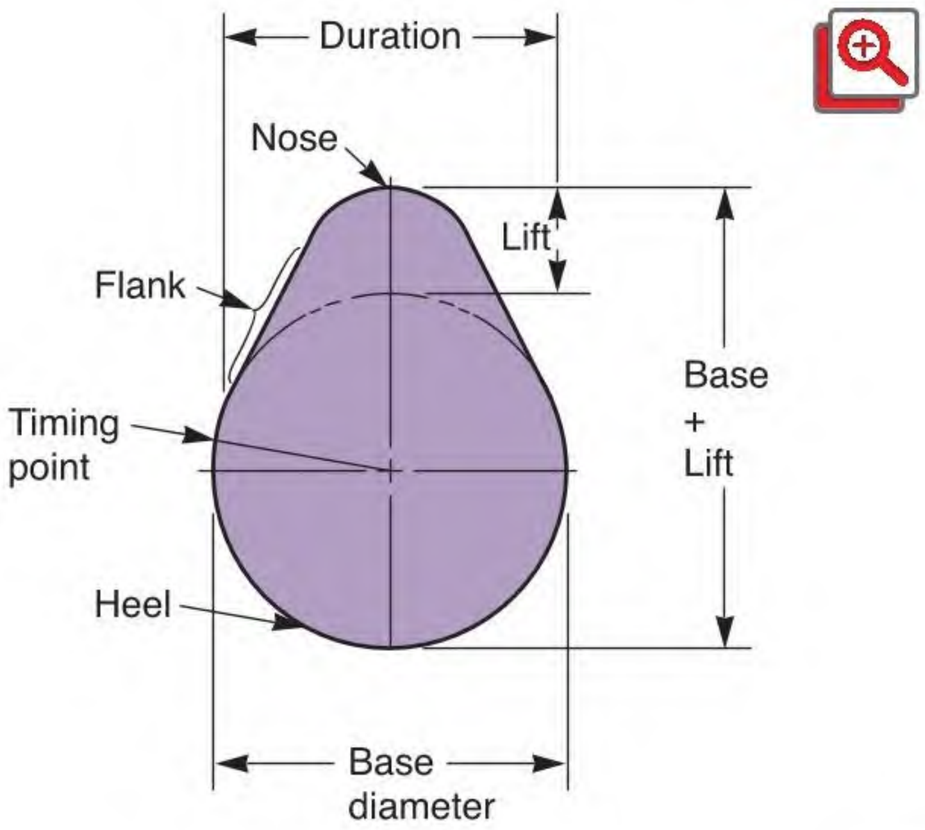
Hollow camshafts can have their lobes pressed onto the shaft. To lock the splined lobes in place, an oversize steel ball is forced down through the center of the hollow shaft. Some new engines use hollow composite camshafts to lighten the valve train for quicker engine acceleration.

Camshaft Thrust Plate

A ***camshaft thrust plate*** is used to limit camshaft end play. End play is the front-to-rear movement. The thrust plate bolts to the front of the block or cylinder head. When the drive gear or sprocket is bolted in place, the thrust plate sets up a predetermined camshaft end play.

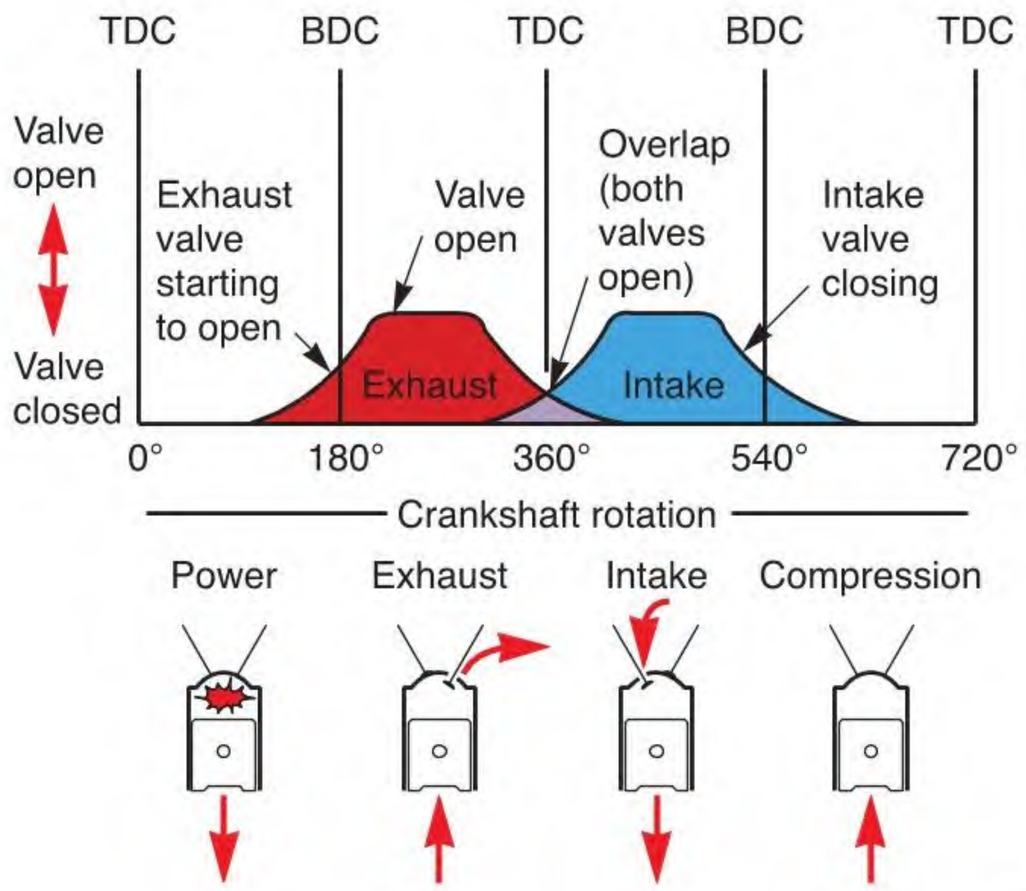
Cam Bearings

Cam bearings are usually one-piece inserts pressed into the block or cylinder head. See **Figure 13-18**. Two-piece inserts are sometimes used when the camshaft is mounted in the head. The camshaft journals ride in the cam bearings. Cam bearings are usually constructed like engine main and connecting rod bearings.



TRW

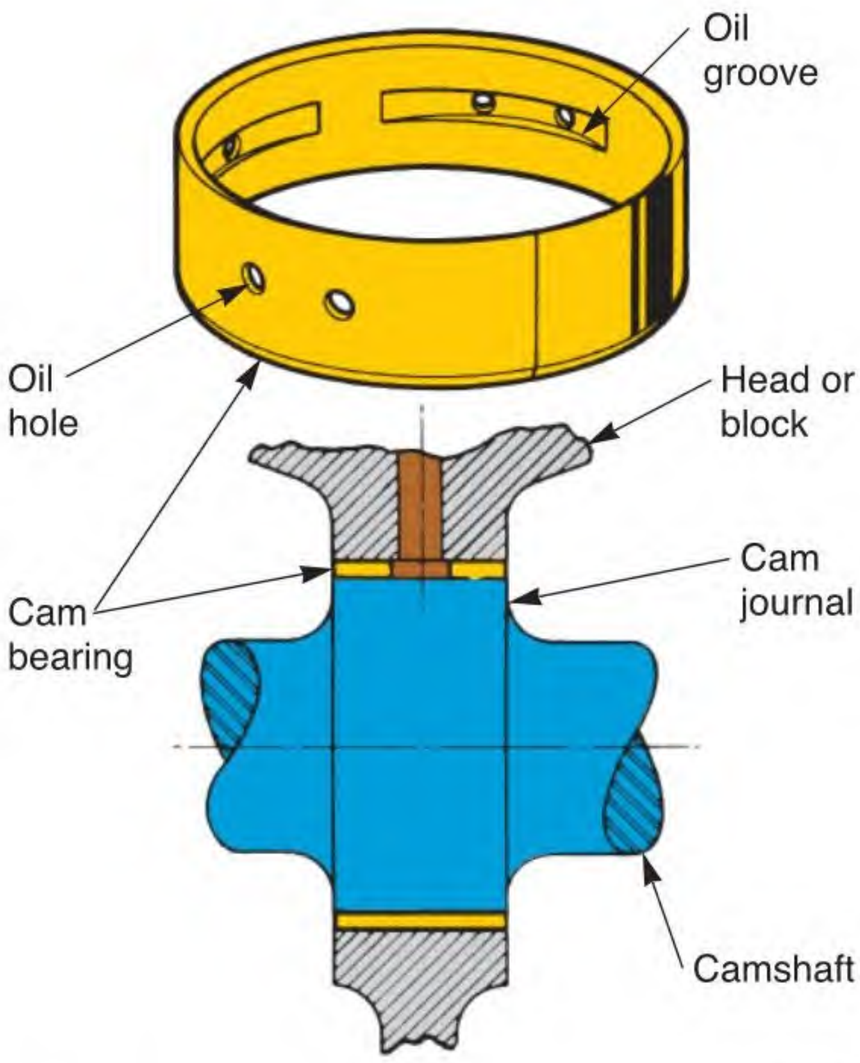
Figure 13-16. The basic parts and shape of a cam lobe. The height of the nose compared to base circle determines the amount of valve opening. The width or roundness of the nose determines how long the valve stays open.



VW

Figure 13-17. Valve timing is the measurement of when valves open in relation to the piston position in the cylinder. Valve overlap is the period where both the intake and exhaust valves in the same cylinder are open.

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Federal Mogul

Figure 13-18. Camshaft journals ride in cam bearings. Cam bearings may be pressed into the block or cylinder head bore.

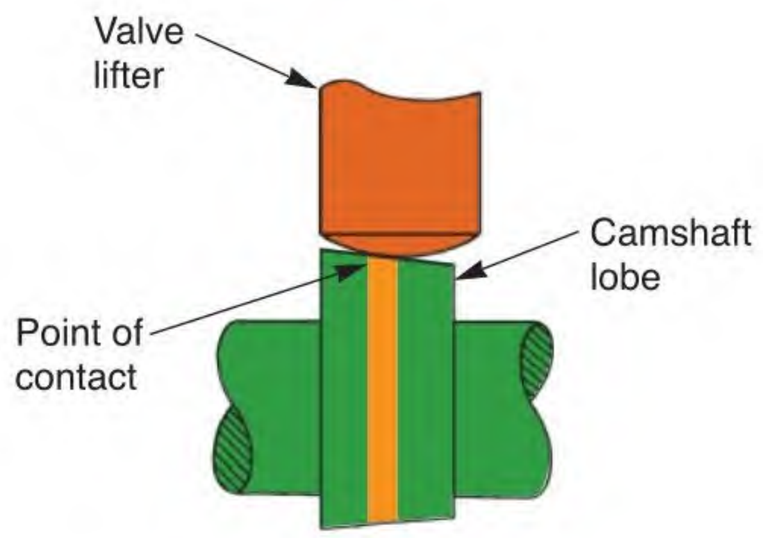
Cam Housing and Cam Cover

Some cam or valve covers are acoustically dampened by making them out of two sheets of steel formed around a center layer of sound-dampening material. A ***cam housing*** is a casting that bolts to the top of the cylinder head to hold the engine camshaft. It is used in some overhead cam engine designs. A ***cam cover*** is a lid over the top of the cam housing. It serves the same purpose as a valve cover on an overhead valve engine. Acoustically dampened construction means the part is designed to help reduce the transmission of sound.

Valve Lifters

Valve lifters, or tappets, ride on the camshaft lobes and transfer motion to the other parts of the valve train. Look at **Figure 13-19**. The bottom of a lifter is crowned, or slightly curved. The camshaft lobe is also not perfectly square with the lifter base. As a result, one side of the lifter touches the cam lobe. This tends to rotate the lifter in its bore to reduce wear. There are four basic types of lifters. These are hydraulic, mechanical, roller, and OHC follower.

Hydraulic valve lifters are common because they operate *quietly* by maintaining zero valve clearance. Zero valve clearance means that there is no space

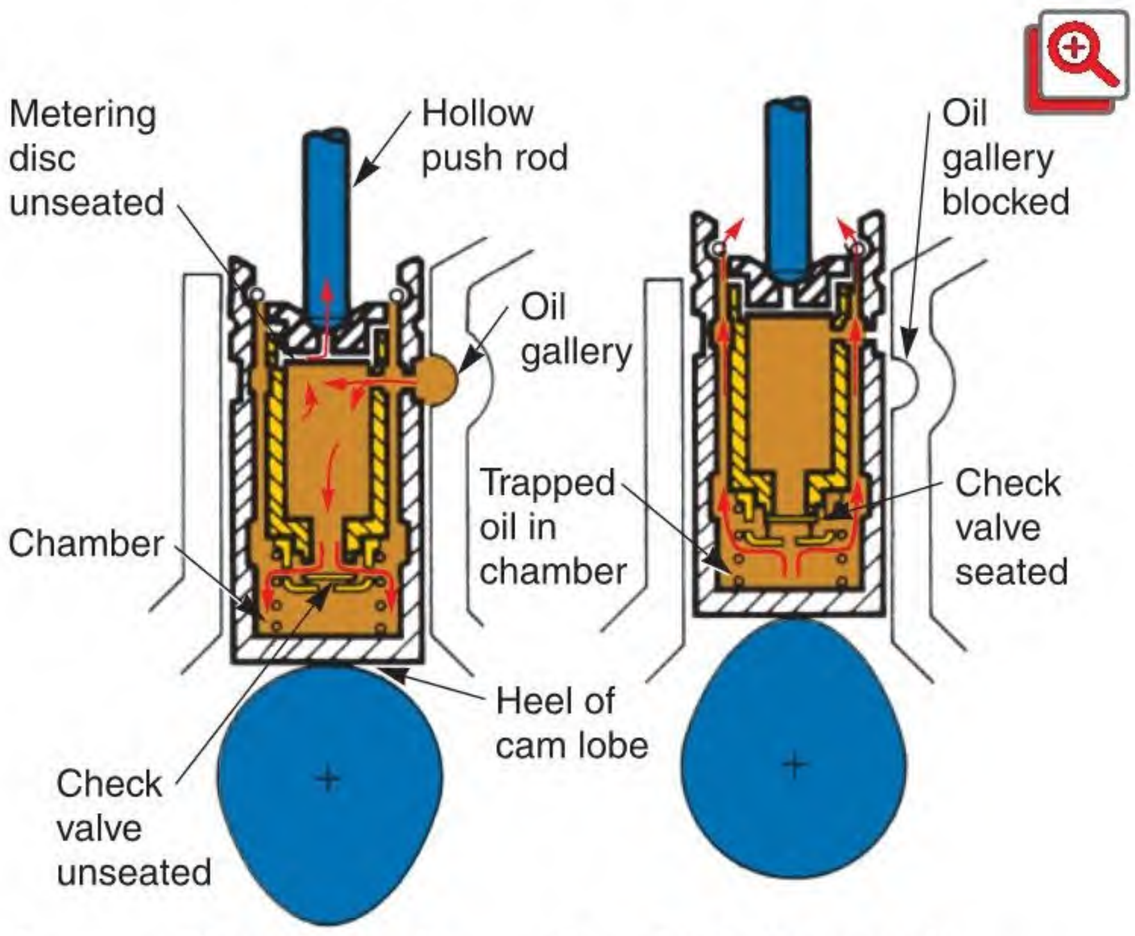


Dana

Figure 13-19. The bottom of a lifter is crowned and the cam lobe is tapered. This causes the rotating cam lobe to turn the lifter in its bore, reducing wear.

between valve train parts. With zero clearance, the valve train does not clatter when the engine is running. The hydraulic lifter adjusts automatically with temperature changes and part wear.

During engine operation, oil pressure fills the inside of the hydraulic lifter with motor oil. The pressure pushes the lifter plunger up in its bore until all the play is out of the valve train. As the camshaft pushes on the lifter, the lifter check valve closes to seal oil inside the lifter. Since oil is not compressible, the lifter acts as a solid unit to open the valve, **Figure 13-20**.



Chrysler

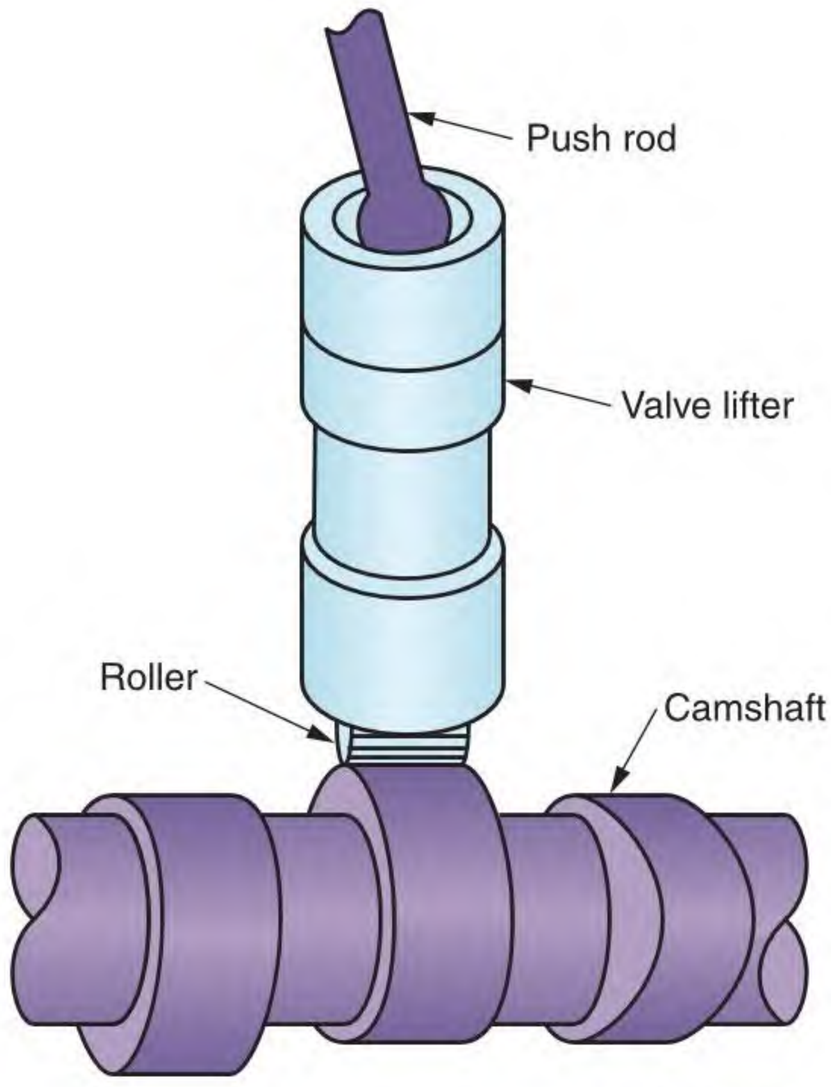
Figure 13-20. Note lifter action. A—When the valve closes, oil rushes into the lifter, pushing up on the disc or plunger to maintain zero clearance. B—When the cam acts on the lifter, oil is trapped in the lifter by a check valve. The lifter acts as a solid unit to push the valve open.

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Mechanical lifters, also called solid lifters, do not contain oil. They simply transfer cam lobe action to the push rod. Mechanical lifters are not self-adjusting and require periodic adjustment. An adjustment screw is normally provided at the rocker arm when solid lifters are used. Turning the adjustment screw down reduces any "play" in the valve train. Unscrewing, or backing off, the rocker arm adjustment increases clearance. The small clearance needed with solid lifters causes valve train noise. A clattering or clicking noise is produced as the valves open and close.

A ***roller lifter*** has a small roller that rides on the camshaft lobe, **Figure 13-21**. This type of lifter can be either mechanical or hydraulic. The point where the lifter touches the camshaft is one of the highest friction points in the engine. The roller helps reduce this friction and wear. A roller lifter is also used to reduce frictional losses of power.

An ***OHC follower*** fits between the camshaft and valve. The follower slides up and down in a bore machined in the head. Either an adjusting screw in the follower or shims of different thicknesses can be used to adjust valve clearance, **Figure 13-22**.



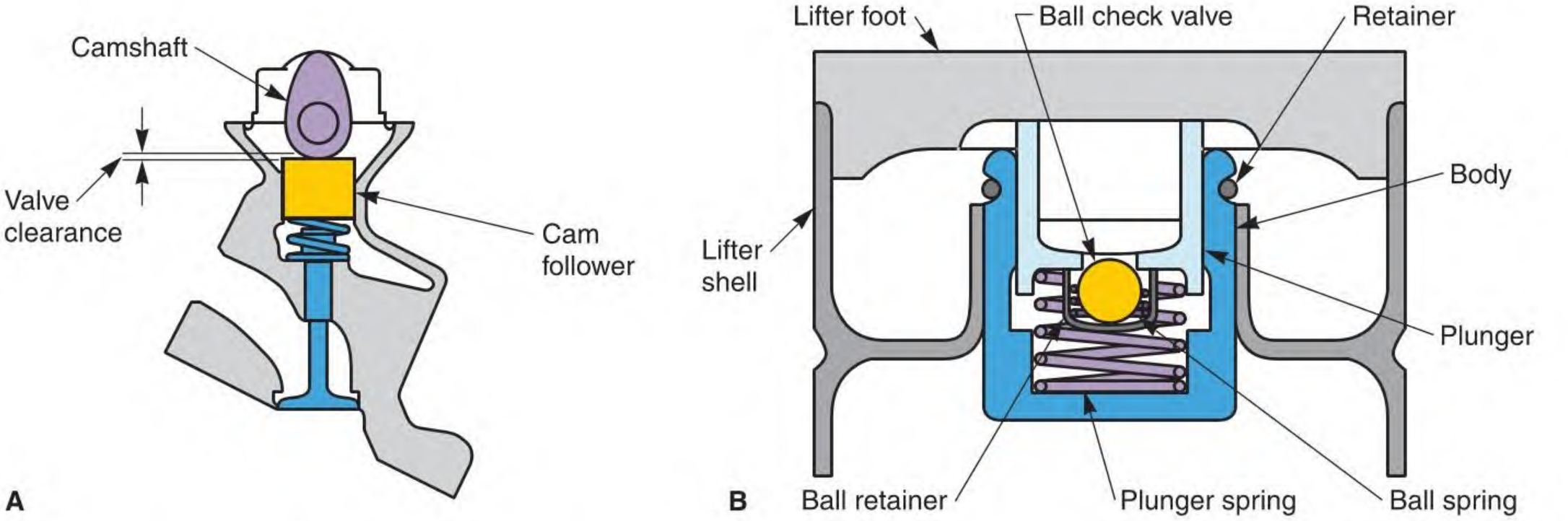
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Figure 13-21. A roller lifter is commonly used in diesel engines to reduce friction. The roller spins as the camshaft rotates.

Push Rod Construction

Push rods are metal tubes or rods with specially formed ends. They are used in cam-in-block engines to transfer motion from the lifters to the rocker arms. Some push rods have a ball on each end. Others have a ball on one end and a female socket on the other end. Some hollow push rods have holes in the ends to feed oil from the lifter to the rocker arms. This prevents wear on the tip of the push rod and on the rocker arm.

In some engines, ***push rod guide plates*** are used to limit side movement of the push rods. The guides hold the push rods in alignment with the rocker arms. When the push rods pass through holes in the cylinder head or intake manifold, guide plates are not needed.



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Figure 13-22. Study OHC cam followers. A—An overhead cam follower fits directly between the camshaft and valve stem. The follower slides up and down in a bore machined in the head. Either a spacer washer or a screw is used to adjust valve clearance. B—A cutaway of a cam follower.

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Rocker Arm Construction

Rocker arms transfer valve train motion to the valve stem tips. In OHC engines, the camshaft may act directly on the rocker arm. Then, the rocker acts on the valve. Some rocker arms are forked so that they can actuate two valves at once. In a push rod engine, the push rod acts on the rocker. Then, the rocker transfers the motion to the valve. See **Figure 13-23**. Rocker arms are usually made of either cast iron or steel.

Various methods are used to support the rocker arms on the cylinder head. Individual pivot balls or stands can be used to hold the rocker arm in place over the valve. **Figure 13-24** shows one such arrangement.

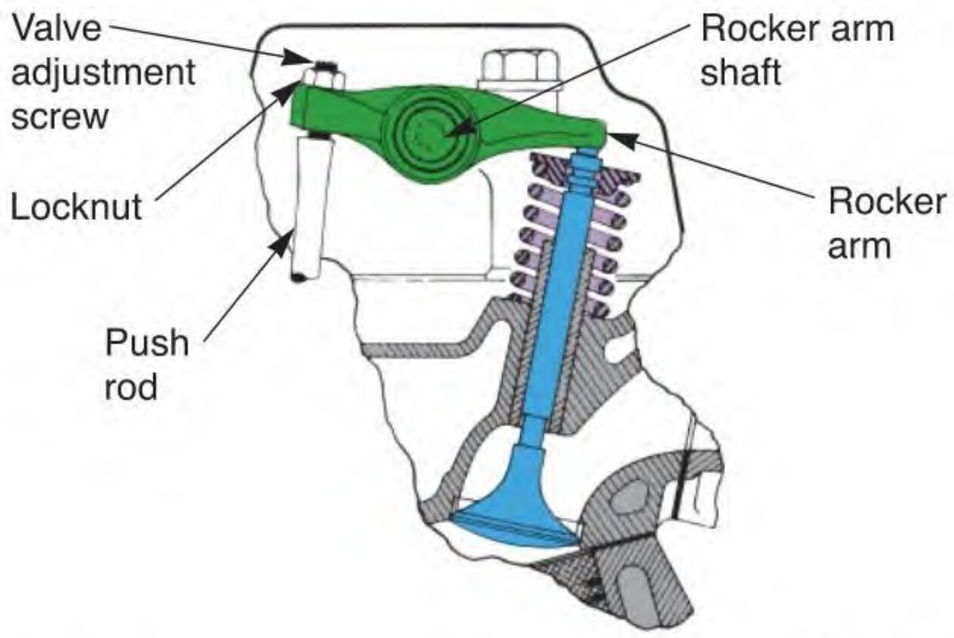
Adjustable rocker arms are used to change the valve train clearance. Either a screw is provided on the rocker arm or the rocker arm pivot point can be changed. Adjustable rocker arms must be used with mechanical lifters. Nonadjustable rocker arms have no means of changing the valve clearance. They are used only with some hydraulic lifters. The rocker arm assembly is tightened to a specific torque. This presets the lifter plunger halfway in its travel. Then, during engine operation, the hydraulic lifter automatically maintains zero clearance. Push rod length can be changed for clearance adjustments when using nonadjustable rocker arms.

Variable Valve Timing System

A ***variable valve timing system*** alters valve timing as engine speed changes. This is done to optimize engine power and efficiency at all operating speeds. Generally, the valves in these systems function with a normal duration at low engine speeds. As speed increases, however, the variable timing mechanism engages to hold the valves open longer, increasing volumetric efficiency.

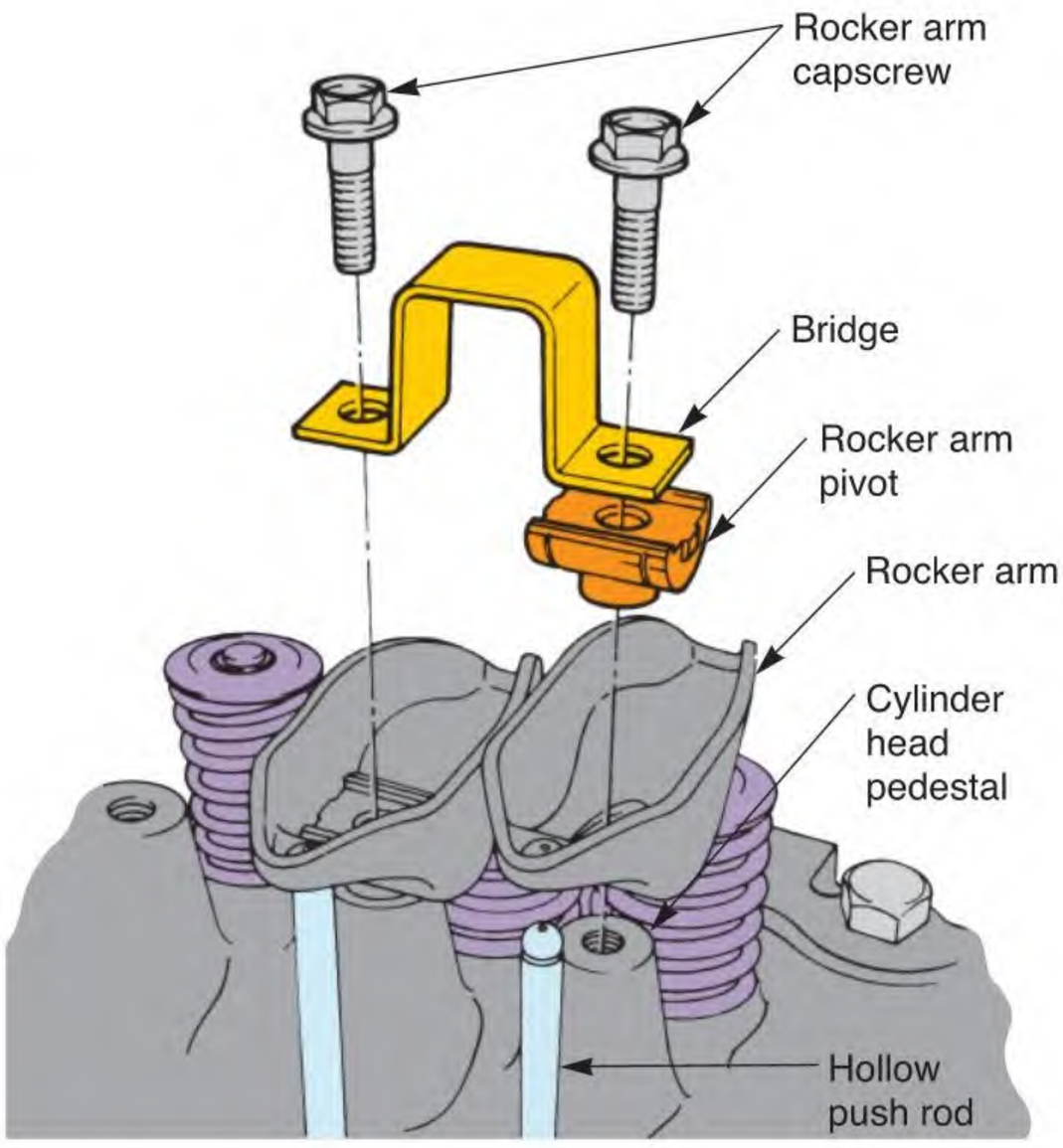
There are several ways of creating variable valve timing that have been explored. However, there are basically two common methods used in late-model engines. One method has electro-hydraulically operated rocker arms and two different camshaft profiles for each valve. The second method uses a camshaft gear that can rotate on the camshaft.

The system shown in **Figure 13-25** contains two intake valves and two exhaust valves per cylinder. A small hydraulic piston in the rocker arm shaft is used to engage and disengage the rocker arm assembly components. At low engine speeds, only one intake valve is fully opened per cylinder. The other intake rocker arm for that cylinder only slightly opens its intake valve. This slight opening is needed to prevent fuel accumulation behind the valve face. By fully opening only one of the two intake valves, air velocity through the intake port is increased. This, in turn, improves atomization and mixing of the fuel charge for improved combustion efficiency at low engine speeds.



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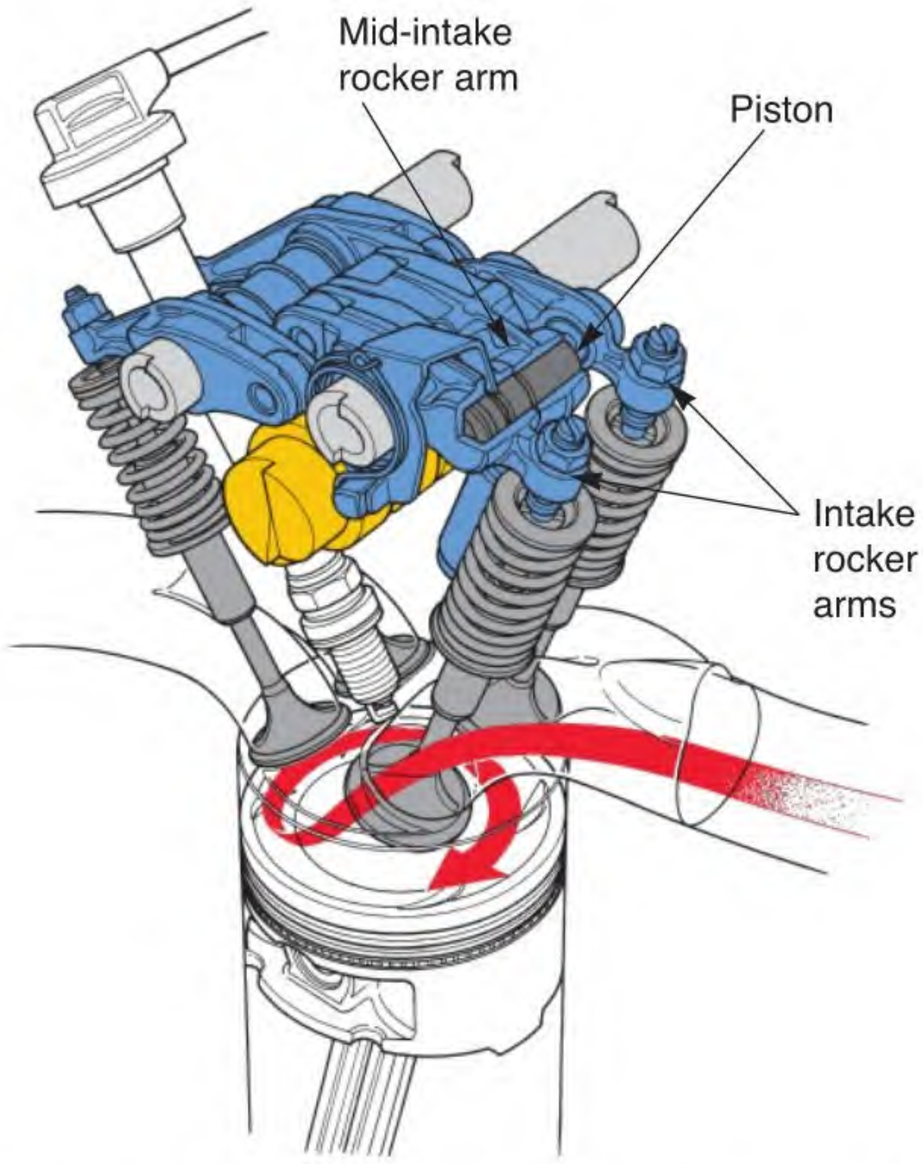
Figure 13-23. A rocker arm shaft holding the rocker arms in position. This rocker arm has an adjustment screw and locknut for changing valve clearance. The rocker is cast iron.



Chrysler

Figure 13-24. This engine uses rectangular rocker arm pivots. A bridge helps hold the rockers in position over the valve stems. These rockers are made of stamped steel.

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Honda

Figure 13-25. This engine uses small hydraulic pistons acting on the rocker arm assembly to alter valve lift and duration.

At high engine speeds, the two intake rocker arms are locked to a mid-intake rocker arm, which provides very high valve lift and longer duration. The mid-rocker arm rides on a high-speed camshaft lobe. This allows a larger, more powerful air-fuel charge to enter the combustion chambers.

The system that uses a rotating camshaft gear cannot alter lift or duration, only timing. However, the system has the advantage of being somewhat less complex. The camshaft gear consists of two halves with a rotor contained inside. One-half of the camshaft gear is attached to the rotor and the camshaft. The other half is driven by the crankshaft.

Tech Tip

In some dual overhead cam designs, the outer half of the gear is driven by the adjacent camshaft rather than the crankshaft.

Oil pressure inside the camshaft gear locks the two halves together. The computer controls the oil pressure inside the gear based on engine operating conditions. By shifting oil pressure from one side of the rotor to the other, the two halves of the gear move in relation to each other and valve timing is advanced or retarded. A variation of this system uses a shaft with helical splines instead of a rotor. As the camshaft gear slides along the splined shaft, the valve timing is adjusted.

Tech Tip

Some variable valve timing systems that have a rotating camshaft gear also have an additional system that allows the lift and duration to be altered.

Intake Manifold Construction

An ***intake manifold*** holds the throttle body and has passages, called runners, going to each cylinder head port. The manifold usually contains water jackets for cooling. It can be cast of iron, aluminum, or plastic.

Manifold runners are internal passages formed in the intake manifold to carry either the air-fuel mixture or air to the cylinder head ports. See **Figure 13-26**.

Intake manifolds can also be made of glass-filled nylon or plastic. These can weigh half as much as aluminum and several times less than iron. The inside of the plastic runners is also smoother than metal to improve airflow into the engine for more power. With plastic manifolds, brass thread inserts are pressed into the plastic. This allows additional parts, such as sensors and vacuum fittings, to be bolted to the plastic part without thread damage.

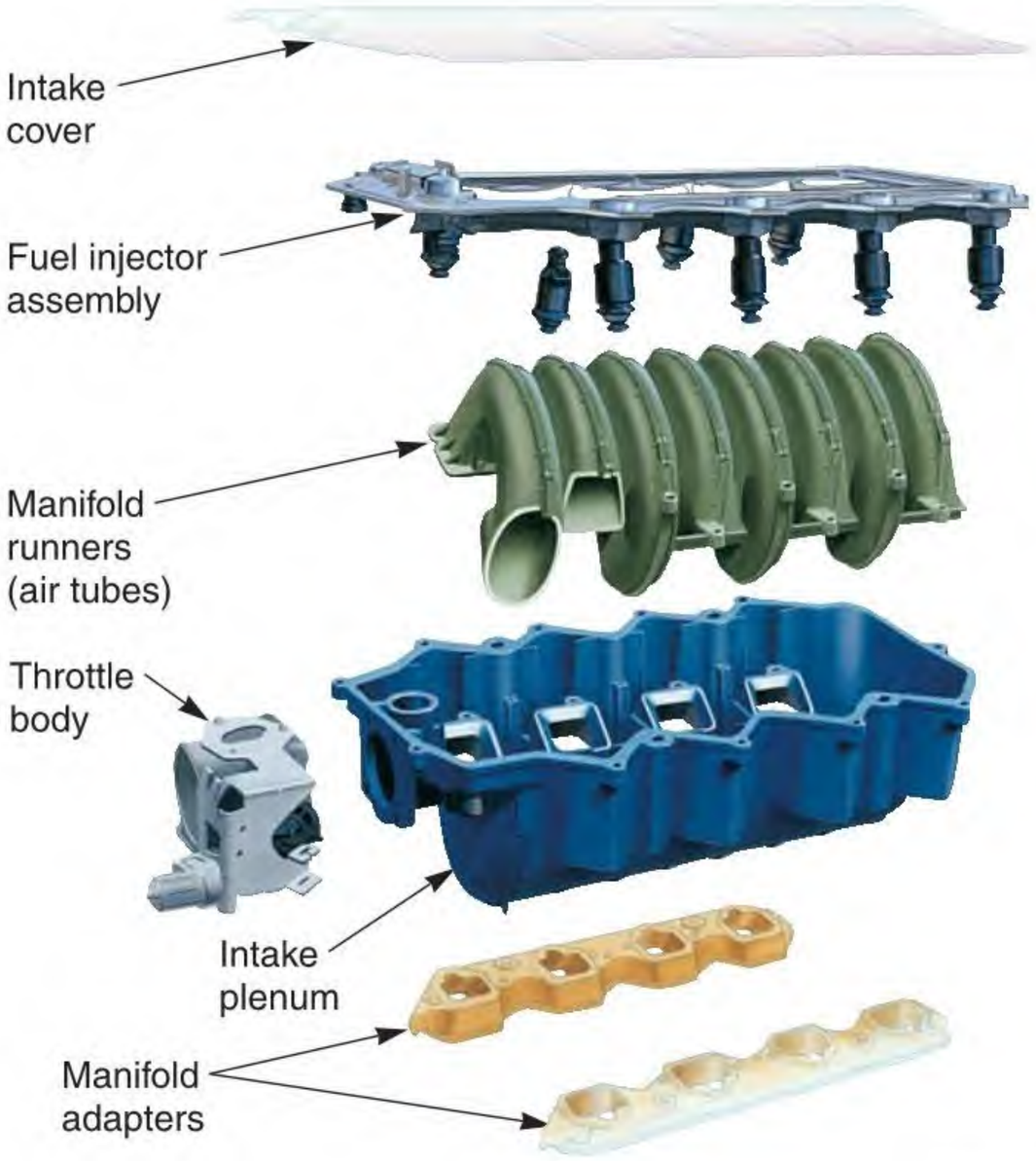
Compression limiters are metal inserts that limit the deformation around bolt holes in plastic parts. They allow enough bolt torque to provide good sealing without cracking or deforming the soft plastic.

A ***flame arrester*** is sometimes located before the engine intake manifold to prevent backfire damage to the air filter. It is made of metal mesh to prevent the flame of an engine backfire from entering the air filter housing. It should periodically be removed and cleaned in solvent for best engine performance.

Variable Induction System

A ***variable induction system*** has two sets of intake runners controlled by butterfly valves to aid engine efficiency and performance. A variable

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Cadillac

Figure 13-26. A multi-piece "ram manifold" assembly takes the place of a traditional intake manifold on some high-performance engines. Individual tubes supply air to each cylinder.

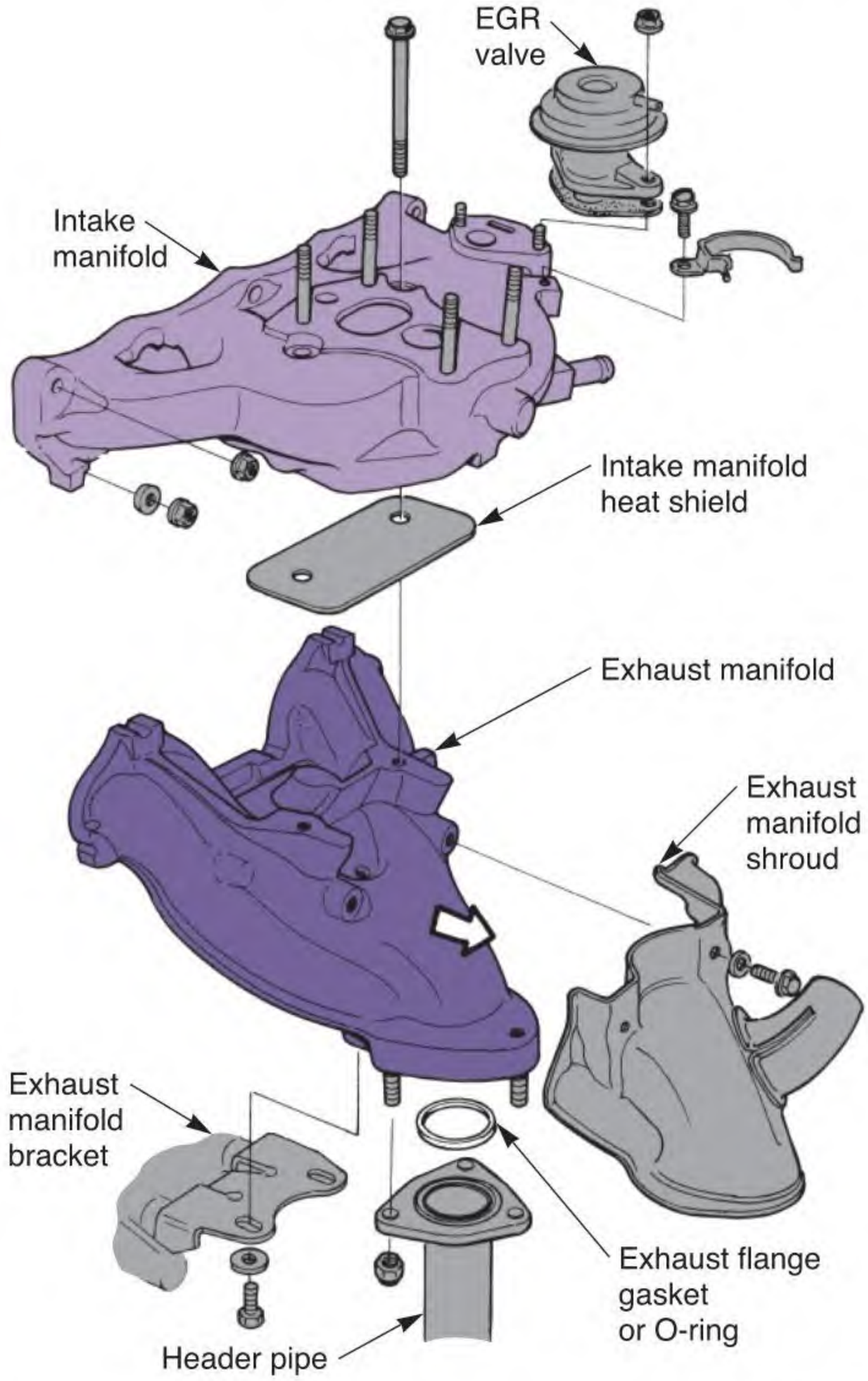
induction system is like having two intake manifolds in one—one is for low-speed torque and another for high-speed power.

At low engine speeds, the system uses long intake runners to "ram" more air and fuel into the cylinders for increased torque. Then, when a specific engine speed is reached, the computer opens the butterfly valves over shorter intake runners. The short runners increase airflow at high rpm for added power.

Exhaust Manifold Construction

An ***exhaust manifold*** routes burned exhaust gases from the cylinder head exhaust port to the exhaust pipe. Because of the high operating temperatures, the exhaust manifold is usually made of cast iron.

A few high-performance or sports car engines use lightweight, free-flowing steel tubing exhaust manifolds called headers. **Figure 13-27** shows both intake and exhaust manifolds for one particular engine.



Honda

Figure 13-27. Intake and exhaust manifolds shown with their related components.

Workplace Skills

Today's thin cast aluminum heads are less tolerant of overheating than older, thicker cast iron heads. If you experience engine overheating, do not keep driving the vehicle. Shut the engine off as soon as possible and allow it to cool. Repair the causes of the overheating problem right away. If the problem is not repaired soon enough, the aluminum head may be warped and cracked from the engine overheating.

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Summary

- An engine top end basically includes the cylinder head, valve train, valve cover, and the intake and exhaust manifolds.
- A bare cylinder head is a head with all its parts removed.
- An integral valve guide is part of the cylinder head casting. A pressed-in valve guide is a separate sleeve forced into a hole machined in the head.
- The valve seat angle is the angle formed by the face of the seat.
- An interference angle is a 1/2° to 1° difference between the valve seat face angle and the angle of the valve face.
- The valve face angle is the angle formed between the valve face and valve head.
- An umbrella valve seal is shaped like a cup and can be made of neoprene rubber or plastic.
- An O-ring valve seal is a small round seal that fits into an extra groove cut in the valve stem.
- Spring tension refers to the stiffness of a valve spring.
- A valve spring shim is a very thin and accurately machined washer used to increase spring tension.
- Valve retainers and keepers lock the valve spring on the valve.
- A valve rotator turns the valve to prevent carbon buildup and hot spots on the valve face.
- With dual overhead cam engines, there are two camshafts—the intake camshaft and the exhaust camshaft. The intake camshaft operates all the intake valves in the cylinder head. The exhaust camshaft operates all the exhaust valves.
- Camshaft lift is the amount of valve lift produced by the cam lobe.
- Camshaft duration determines how long the valve stays open.
- Valve timing refers to valve opening and closing in relation to the position of the pistons in the cylinders.
- Valve overlap is the time when both of the intake and exhaust valves in the same cylinder are open.
- Valve lifters, or tappets, ride on the camshaft lobes and transfer motion to the other parts of the valve train.
- Push rods are metal tubes with specially formed ends.
- Rocker arms transfer valve train motion to the valve stem tips.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

bare cylinder head
cam bearing
cam cover
cam housing
cam lobe
camshaft
camshaft duration
camshaft lift
camshaft thrust plate
compression limiter
engine top end
exhaust manifold
flame arrester
hydraulic valve lifter
intake manifold
integral valve guide
integral valve seat
interference angle
keeper
manifold runner
mechanical lifter
mushroom valve
OHC follower
O-ring valve seal
poppet valve
prechamber cup
pressed-in valve guide
pressed-in valve seat
push rod
push rod guide plate
rocker arm
roller lifter
spring closed length
spring free length
spring open length
spring tension
umbrella valve seal
valve face angle
valve float
valve lifter
valve overlap
valve retainer
valve rotator
valve seat angle
valve spring seat
valve spring shield
valve spring shim
valve stem cap
valve timing
variable induction system
variable valve timing system

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Activities

1. The rocker arm is a form of lever. Do research to find out what class of lever it is. Construct simple models of the three classes of levers and describe for the class how they work.
2. Make a sketch of a cam lobe, like the one shown in **Figure 13-16**. Assume that TDC is 0°. Use a protractor to mark points for a 90°, 180°, and 270° rotation. Using pencils or pens of different colors, draw the cam lobe in each of these positions.
3. If a disassembled engine is available, examine the head to determine whether integral or pressed-in valve guides and valve seats are used.

Review Questions

Answer the following questions using the information provided in this chapter.

1. What is a bare cylinder head?
2. A(n) _____ type valve guide is part of the cylinder head.
3. A(n) _____ valve guide is a separate sleeve forced into a hole in the cylinder head.
4. Cylinder heads use _____ or _____ valve seats.
5. What is the function of an interference angle on the valve face and seat?
6. This part is pressed into the cylinder head on some diesel engines.
   (A) Stratified charge chamber.
   (B) Glow plug.
   (C) Injector nozzle.
   (D) Prechamber cup.
7. Engines use poppet valves, which are also called _____ valves.
8. Define the term "valve face angle."
9. Why are some valves filled with sodium?
10. Stellite valves are used in engines designed to burn _____.
11. Describe the two basic types of valve seals.
12. Which of the following does *not* pertain to valve springs?
    (A) Free length.
    (B) Tension.
    (C) Tensile strength.
    (D) Closed length.
13. What is the function of a valve spring shim?
14. What is used to lock the valve spring on the valve?
15. A(n) _____ can be used to turn the valve and prevent hot spots on the valve face.
16. Variations in camshaft lobe shape control _____.
    (A) when each valve opens
    (B) how long each valve stays open
    (C) how far or wide each valve opens
    (D) All of the above.
17. Explain the term *camshaft lift*.
18. Why are hydraulic valve lifters used more than solid or mechanical lifters?
19. _____ lifters reduce friction and are frequently used in diesel or high-performance applications.
20. The cam base circle diameter of a camshaft is 3/4″. The camshaft's cam lobe height is 1 1/2″. What is the approximate camshaft lift of this engine?
    (A) 3/8″.
    (B) 1/4″.
    (C) 1/2″.
    (D) None of the above.

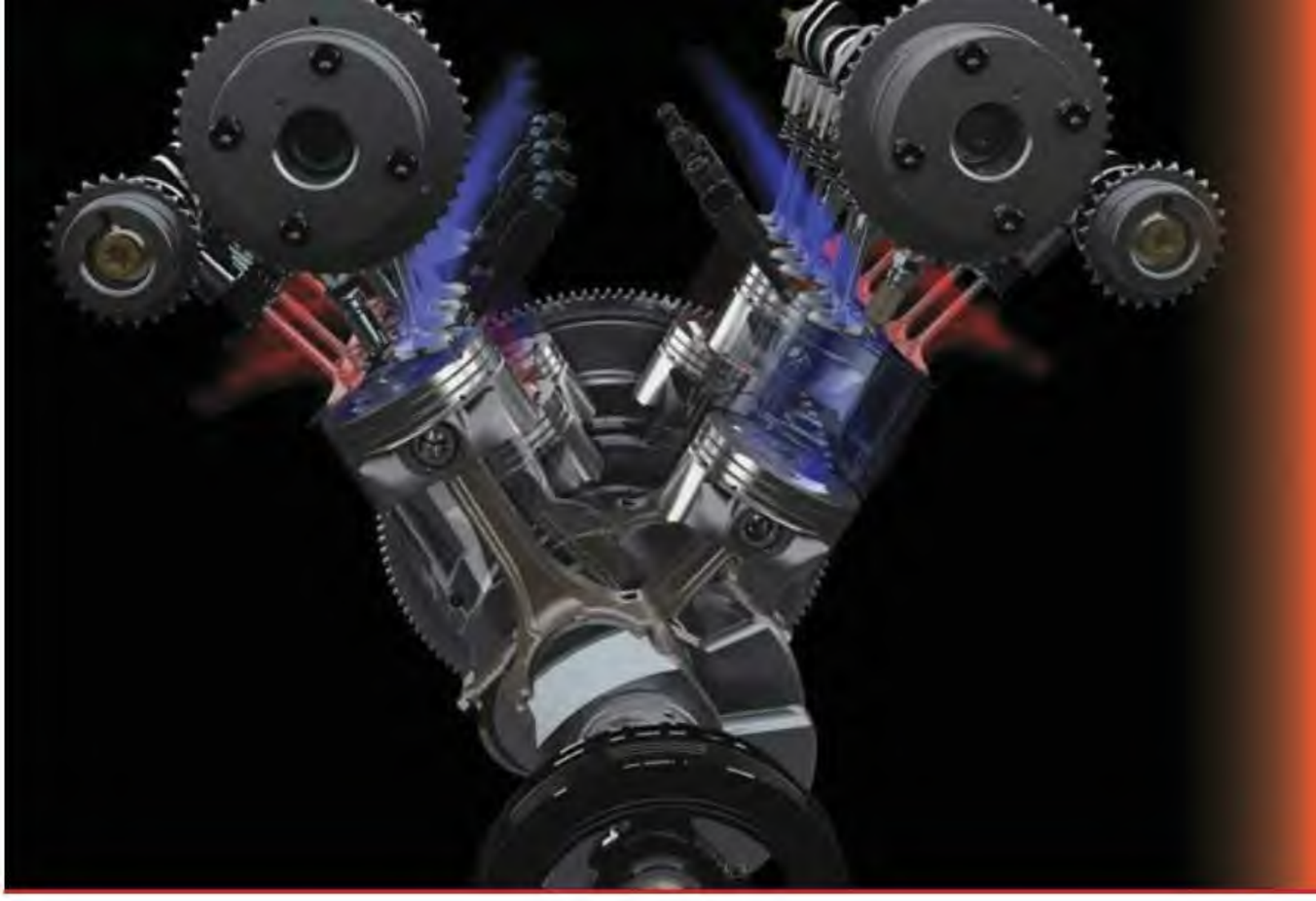
ASE-Type Questions

1. An engine top end typically consists of each of these *except:*
   (A) valve train.
   (B) connecting rod.
   (C) cylinder head.
   (D) intake manifold.
2. Which of the following is a hole machined through the cylinder head?
   (A) Stellite face.
   (B) Valve seat insert.
   (C) Integral valve guide.
   (D) Pressed-in valve guide.

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3. Common passenger car engines have a valve seat angle of:
   (A) 10°.
   (B) 20°.
   (C) 25°.
   (D) 45°.
4. Which of the following is a cross between an oil seal and a valve spring shield?
   (A) Nylon shedder.
   (B) O-ring valve seal.
   (C) Valve spring shim.
   (D) Umbrella valve seal.
5. Low valve spring tension can cause:
   (A) valve float.
   (B) valve rotation.
   (C) valve spring shim.
   (D) mushroomed valves.
6. Which of the following is used to lock a valve spring on a valve?
   (A) Retainer.
   (B) Keeper.
   (C) Seal.
   (D) Both A and B.
7. Which of the following is *not* a method by which a camshaft can be driven?
   (A) Belt.
   (B) Chain.
   (C) Gears.
   (D) Rotator.
8. A cam lobe consists of each of these *except:*
   (A) heel.
   (B) nose.
   (C) head.
   (D) flank.
9. The device used to limit camshaft endplay is the:
   (A) cam cover.
   (B) thrust plate.
   (C) cam bearings.
   (D) valve overlap.
10. Which type of valve lifter is filled with oil?
    (A) Solid.
    (B) Hydraulic.
    (C) Mechanical.
    (D) All of the above.

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Chapter 14
Engine Bottom End Construction

After studying this chapter, you will be able to:

- Compare the construction of different types of cylinder blocks.
- Explain how piston construction affects engine operation.
- Describe piston ring variations.
- Explain the construction of engine bearings.
- Compare design variations of different engine bottom end components.
- Explain safe practices when working with engine bottom end components.
- Correctly answer ASE certification test questions on engine bottom end construction.

As you have learned, the major parts of an ***engine bottom end*** are the cylinder block, crankshaft, connecting rods, rod bearings, main bearings, piston pins, piston rings, and pistons.

This chapter details the various designs and construction methods used by major auto manufacturers. This information will help you understand how to properly repair any make or model engine bottom end assembly. Refer to **Figure 14-1**.

Cylinder Block Construction

Engine cylinder blocks are normally made of cast iron or aluminum. A ***cast iron cylinder block*** is very heavy and strong. Nickel is sometimes added to the iron to improve strength and wear resistance. They are stronger than aluminum and withstand high loads found in turbo-boost applications in gas and diesel engines designed for higher horsepower.

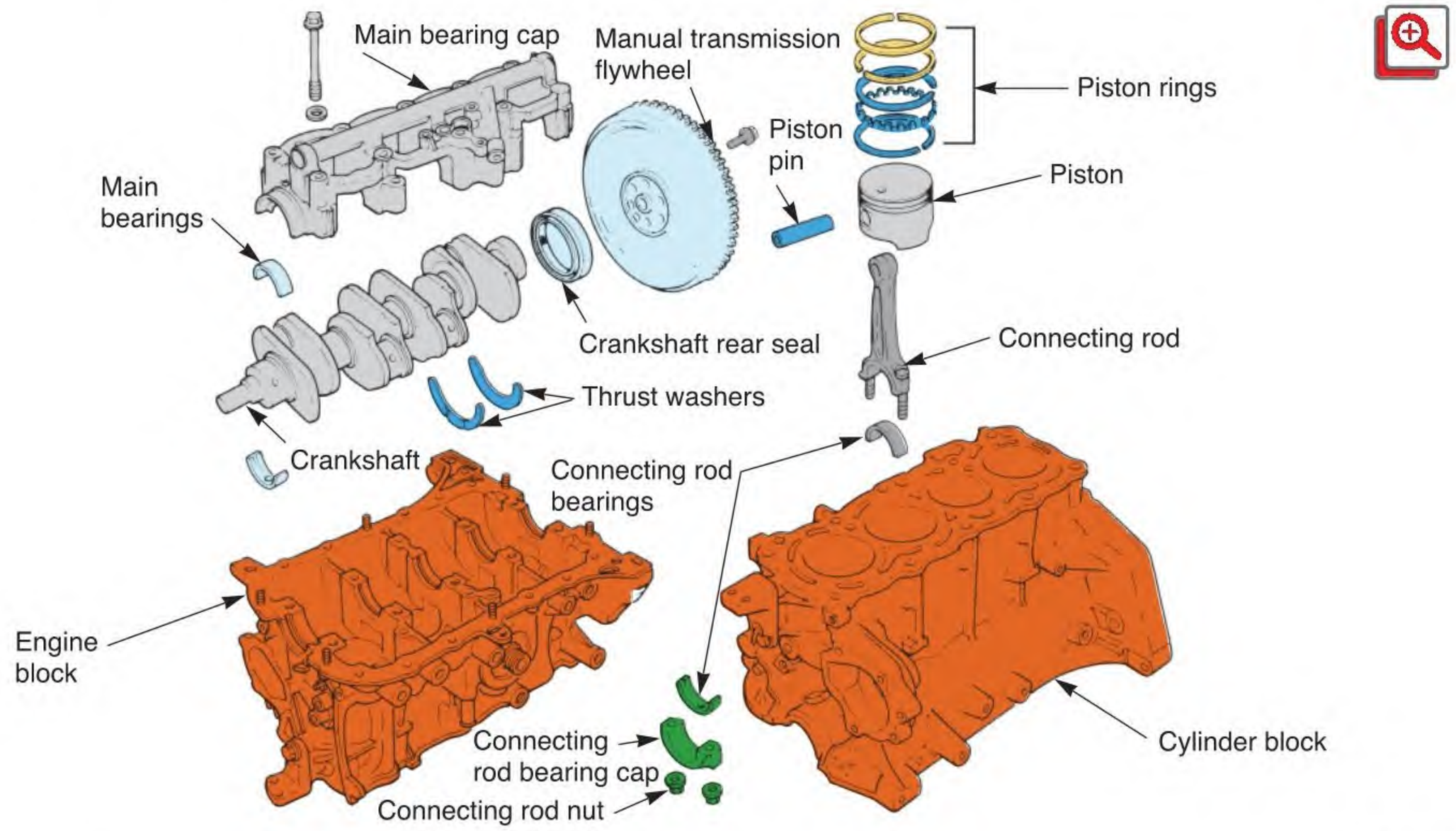
An ***aluminum cylinder block*** is much lighter than cast iron, yet almost as strong. See **Figure 14-2**. An aluminum block also dissipates heat better than a cast iron block. Many late-model vehicles use aluminum blocks to reduce weight and increase fuel economy.

Cylinder Sleeves

Cylinder sleeves, or liners, are metal, pipe-shaped inserts that fit into the cylinder block. They act as cylinder walls for the piston to slide up-and-down on without cylinder block wear.

Cast iron sleeves are commonly used in aluminum cylinder blocks. Sleeves can also be installed to repair badly damaged cylinder walls in cast iron blocks. There are two basic types of cylinder sleeves—dry sleeves and wet sleeves. Look at **Figure 14-3**.

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Figure 14-1. The engine bottom end assembly consists of the block, crank, rods, pistons, and rings. Understanding the construction of these components is very important to service and repair operations.

A ***dry sleeve*** is pressed into a cylinder that has been bored, or machined, oversize. Look at **Figure 14-4A**. A dry sleeve is relatively thin and is not exposed to engine coolant. The outside of a dry sleeve touches the walls of the cylinder block. This provides support for the sleeve.

When a cylinder becomes badly worn or is damaged, a dry sleeve can be installed. The original cylinder must be bored almost as large as the outside diameter of the sleeve. Then, the sleeve is pressed into the oversized hole. Next, the inside of the sleeve is machined to the original bore diameter. This allows the use of the original piston size.

A ***wet sleeve*** is exposed to the engine coolant. It must withstand combustion pressure and heat without the added support of the cylinder block. Therefore, it must be thicker than a dry sleeve. Refer to **Figure 14-4B**.

A wet sleeve will generally have a flange at the top. When the cylinder head is installed, the clamping action pushes down on the sleeve and holds it in position. The cylinder head gasket keeps the top of the sleeve from leaking. A rubber or copper O-ring is used at the bottom of a wet sleeve to prevent coolant leakage into the crankcase. The O-ring seal is pinched between the block and the sleeve to form a leakproof joint.

Many vehicles use aluminum cylinder blocks with cast iron, wet sleeves. The light aluminum block reduces weight for increased fuel economy. The cast iron sleeves wear very well, increasing engine service life. Refer to **Figure 14-5**.

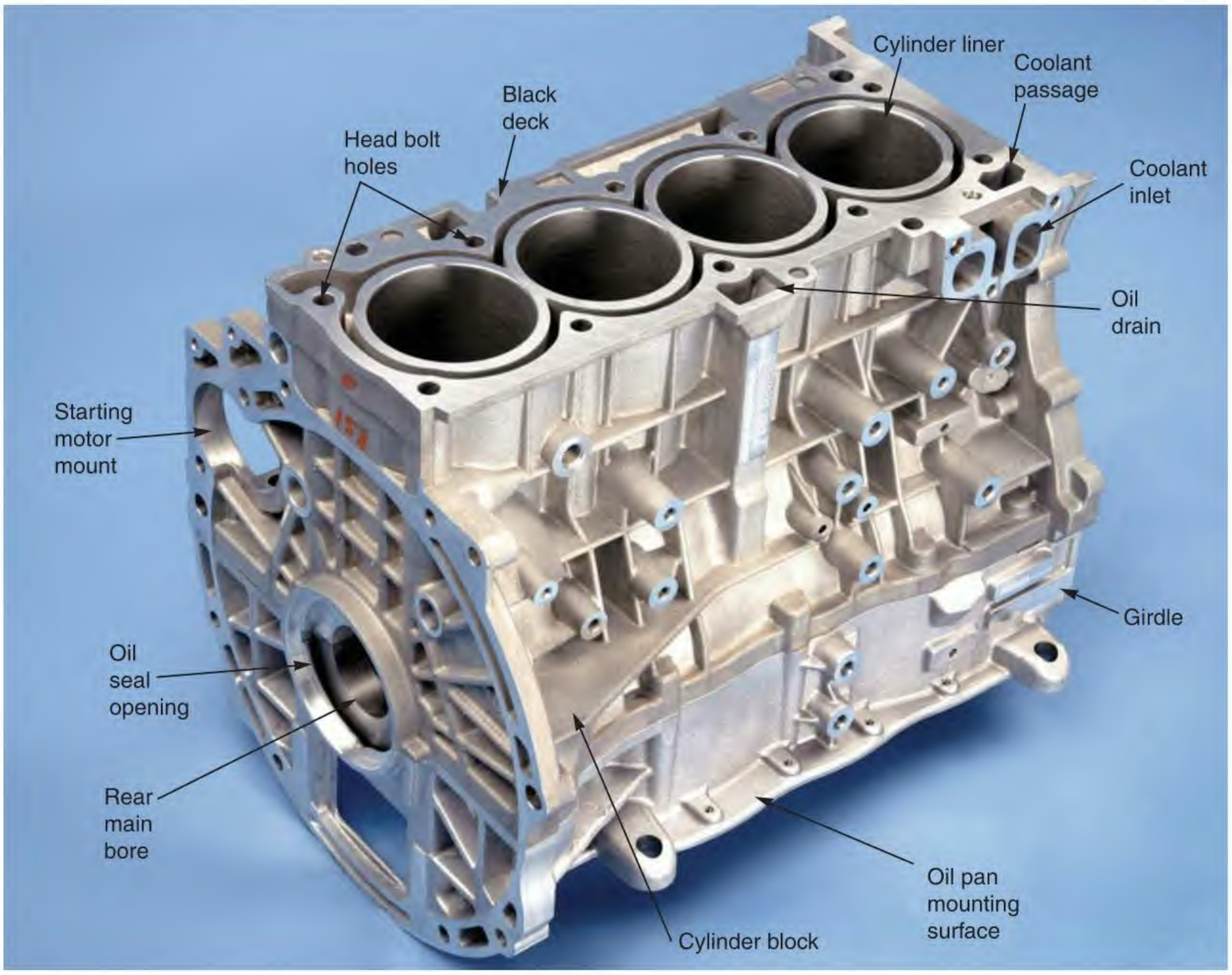
Line Boring

The term ***line boring*** refers to a machining operation that cuts a series of holes through the block for the crankshaft main bearings. A block may also be line bored for the camshaft bearings. The holes must be in perfect alignment for the crankshaft or camshaft to turn freely. Line boring can also be done to an OHC cylinder head.

Two- and Four-Bolt Mains

A ***two-bolt main block*** uses two cap screws to secure each main bearing cap to the cylinder block. A ***four-bolt main block*** has four cap screws holding each main cap. Four-bolt mains are used on high-performance engines. A few engines use six-bolt main blocks. With extra bolts, the block can withstand more crankshaft downward pressure without part failure.

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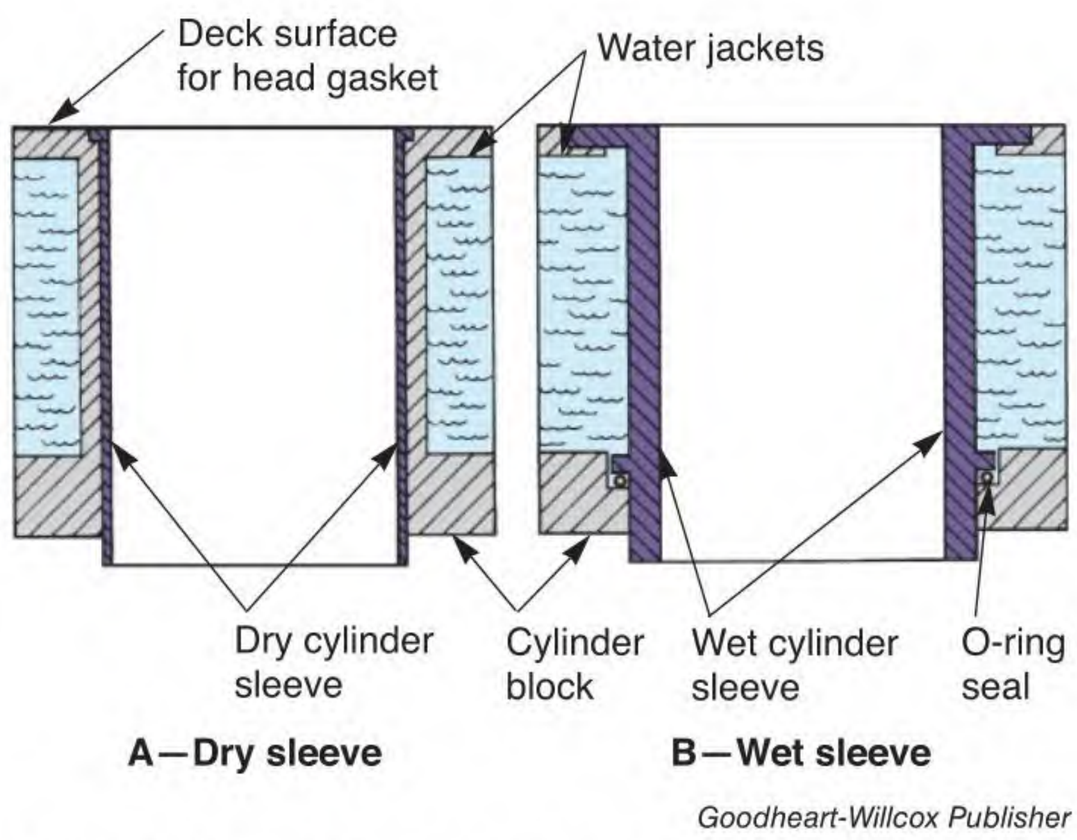
Chrysler

Figure 14-2. A cylinder block may be cast from iron or aluminum. This particular block is aluminum.



Dana Corp.

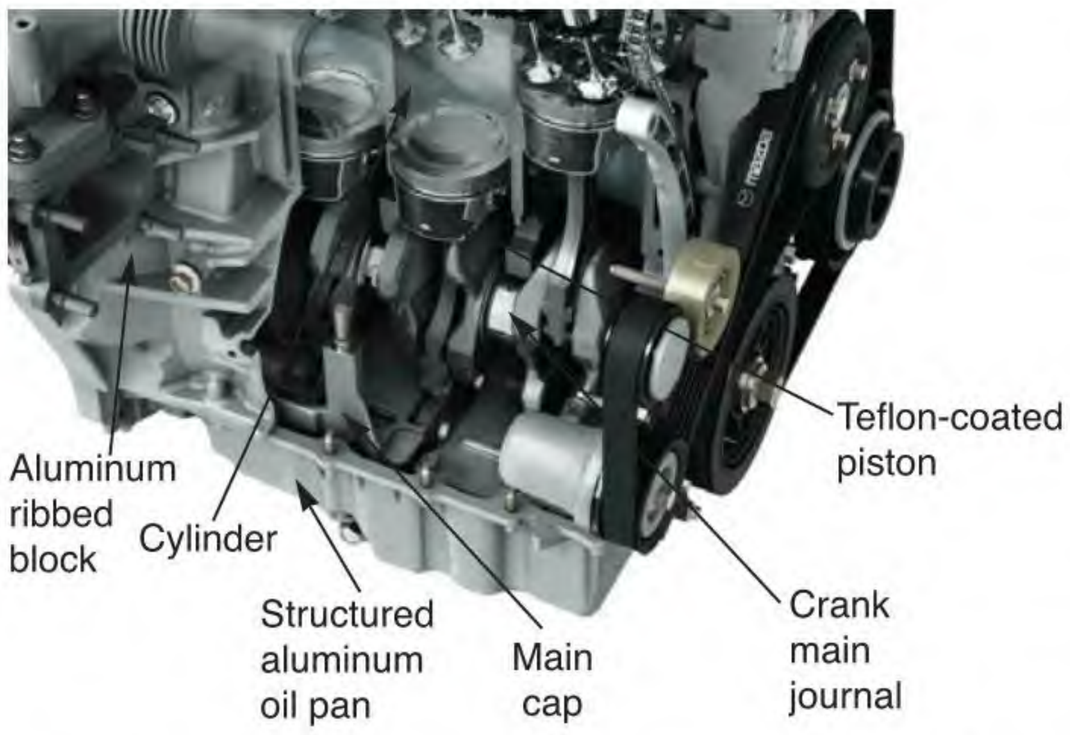
Figure 14-3. Notice the difference between the two wet sleeves and the one dry sleeve.



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Figure 14-4. Note the basic types of engine cylinder sleeves.

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Mazda

Figure 14-5. Modern cylinder blocks are frequently made of aluminum with pressed-in, cast iron wet sleeves.

A ***crossbolted block*** has extra cap screws going in through the sides of the block and main caps for added strength. This design is often used on high-performance engines.

Block Girdle

A ***block girdle***, or main bearing bedplate, is a large one-piece cap that fits over the entire bottom of the block. Also called a unit main cap, it secures the main bearings. All the main caps are formed as one piece to increase strength and block stiffness. The bedplate can also hold any balancer shafts. Gears on the crankshaft are used to drive the balancer shafts.

Tech Tip

Avoid using rings with hard coatings when rebuilding a passenger car engine. The hard rings are more difficult to seat than softer rings. Soft rings are more forgiving of cylinder wall imperfections. Engine smoking problems are more common in rebuilt engines when rings with hard coatings are used, because the rings take much longer to seat.

Piston Construction

Engine pistons are normally cast or forged from an aluminum alloy. Cast pistons are relatively soft and are used in slow-speed, low-performance engines. Forged pistons are commonly used in today's fuel-injected, turbocharged, and diesel engines. These engines expose the pistons to much higher stress loads, which could break cast aluminum pistons.

Since aluminum is very light and relatively strong, it is an excellent material for engine pistons. When an engine is running at highway speeds, the piston must withstand tremendous loads. A piston may accelerate from zero to 60 mph and then back to zero, all in about four inches of piston travel. A heavy piston could break the connecting rod. A weak piston could fall apart under these loads.

The design of a piston must provide maximum strength and minimum weight. The piston is thicker at stress points. The top of the piston is exposed to combustion and tremendous heat. It can reach operating temperatures as high as 650°F (345°C). Several design methods are used to provide dependable, quiet piston operation.

Piston Parts

The ***piston head***, or crown, is the top of the piston. It is exposed to the heat and pressure of combustion and must be thick enough to withstand these forces. The head must also be shaped to match and work with the shape of the combustion chamber for complete combustion.

Piston ring grooves are three slots machined in the piston for the piston rings. The upper two grooves hold the compression rings. The lower piston groove holds the oil ring. Oil holes in the lower groove allow the oil to pass through the piston. The oil then drains back into the crankcase.

The ***ring lands*** are the areas between and above the ring grooves. They separate and support the piston rings as they slide on the cylinder. See **Figure 14-6**.



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Figure 14-6. Study the major parts of a piston.

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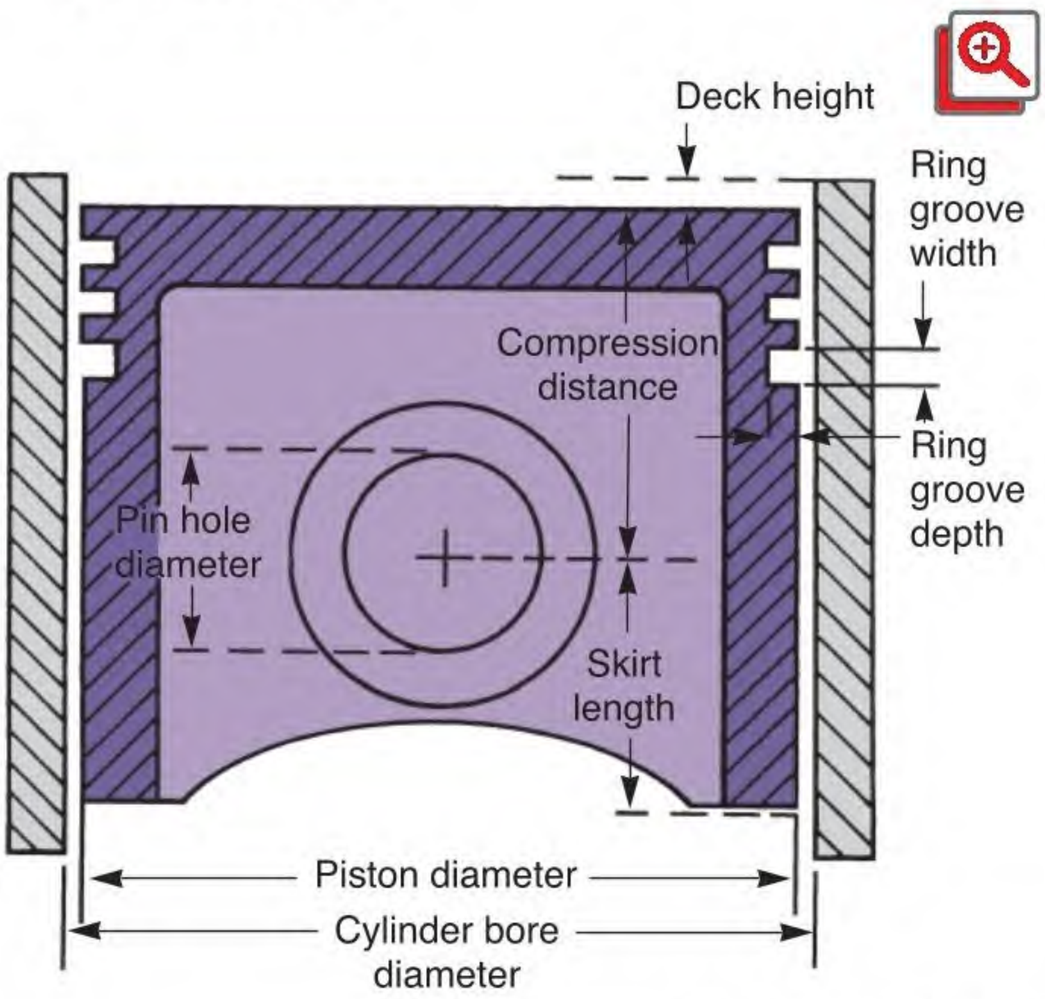
A ***piston skirt*** is the side of the piston below the last ring. It keeps the piston from tipping in its cylinder. Without a skirt, the piston could cock and jam in the cylinder. A slipper skirt is produced when portions of the piston skirt below the piston pin ends are removed. The slipper skirt provides clearance between the piston and the crankshaft counterweights. This allows the piston to slide farther down in the cylinder without hitting the crankshaft. A straight skirt is flat across the bottom. This style is no longer common in automotive engines.

A ***piston pin hole*** is machined through the piston to accept the piston pin. It is slightly larger than the pin. The ***piston boss*** is a reinforced area around the piston pin hole. It must be strong enough to support the piston pin under severe loads.

Piston Dimensions

Figure 14-7 illustrates several piston dimensions. These dimensions affect how the piston functions in the cylinder. These dimensions are explained as follows.

- ***Piston diameter***—The distance measured across the sides of the piston is piston diameter.
- ***Pin hole diameter***—Pin hole diameter is the distance measured across the inside of the piston pin hole.
- ***Ring groove width***—The distance measured from the top to the bottom of the ring groove is ring groove width.
- ***Ring groove depth***—Ring groove depth is the distance measured from the ring land to the back of the ring groove.
- ***Skirt length***—Skirt length is the distance from the bottom of the skirt to the centerline of the piston pin hole.
- ***Compression distance***—The distance from the centerline of the piston pin hole to the top of the piston is compression distance.



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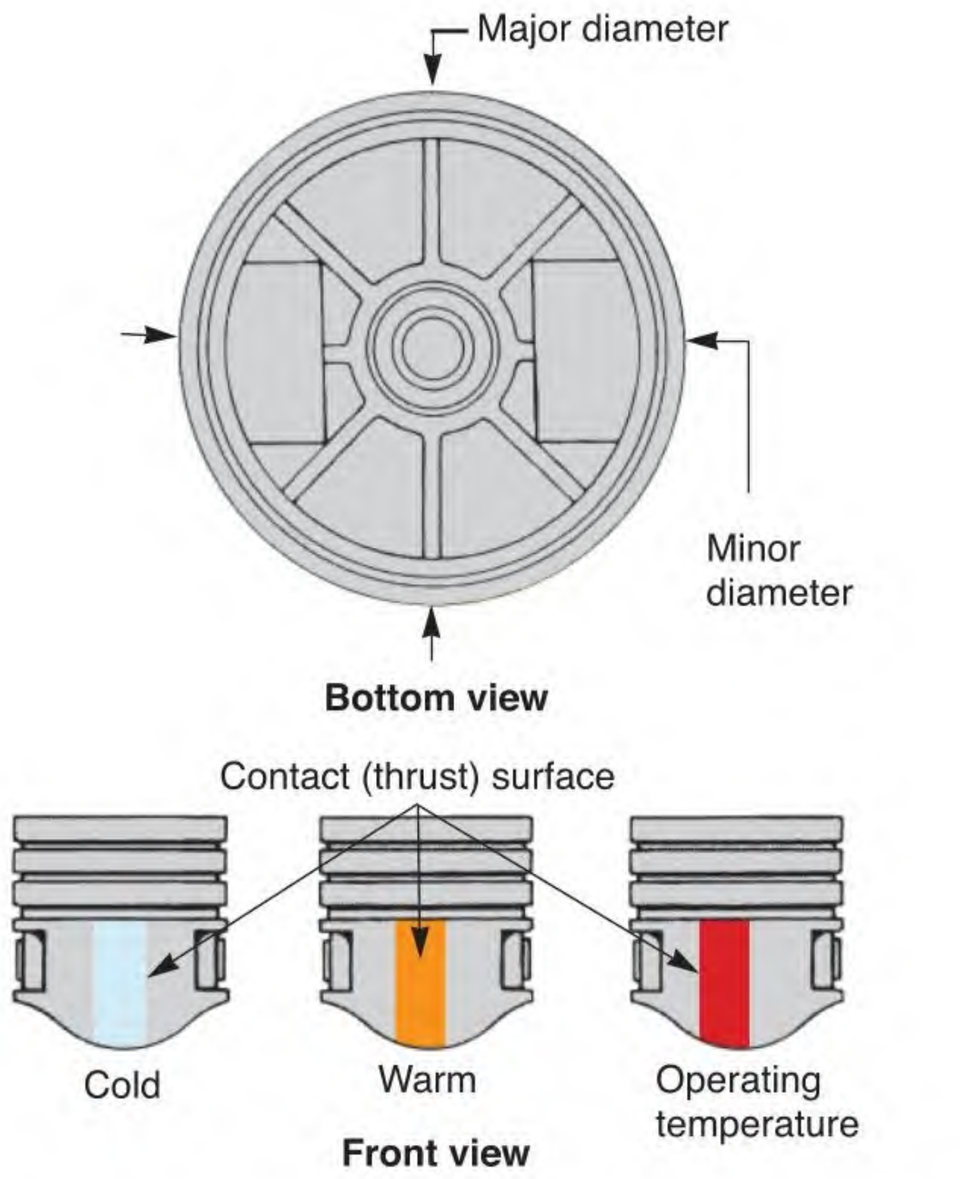
Figure 14-7. Note the basic dimensions of a piston.

Cam-Ground Piston

A ***cam-ground piston*** is slightly out of round when viewed from the top. The piston is machined a few thousandths of an inch larger in diameter perpendicular to the piston pin centerline.

Cam grinding is done to compensate for different rates of piston expansion due to differences in metal wall thickness. As the piston is heated by combustion, the thicker area around the pin boss causes the piston to expand more parallel to the piston pin. The oval-shaped piston becomes round when hot, and there is still enough clearance parallel to the piston pin. See **Figure 14-8**.

A cold cam-ground piston has acceptable piston-to-cylinder clearance. The unexpanded piston will not



Ford

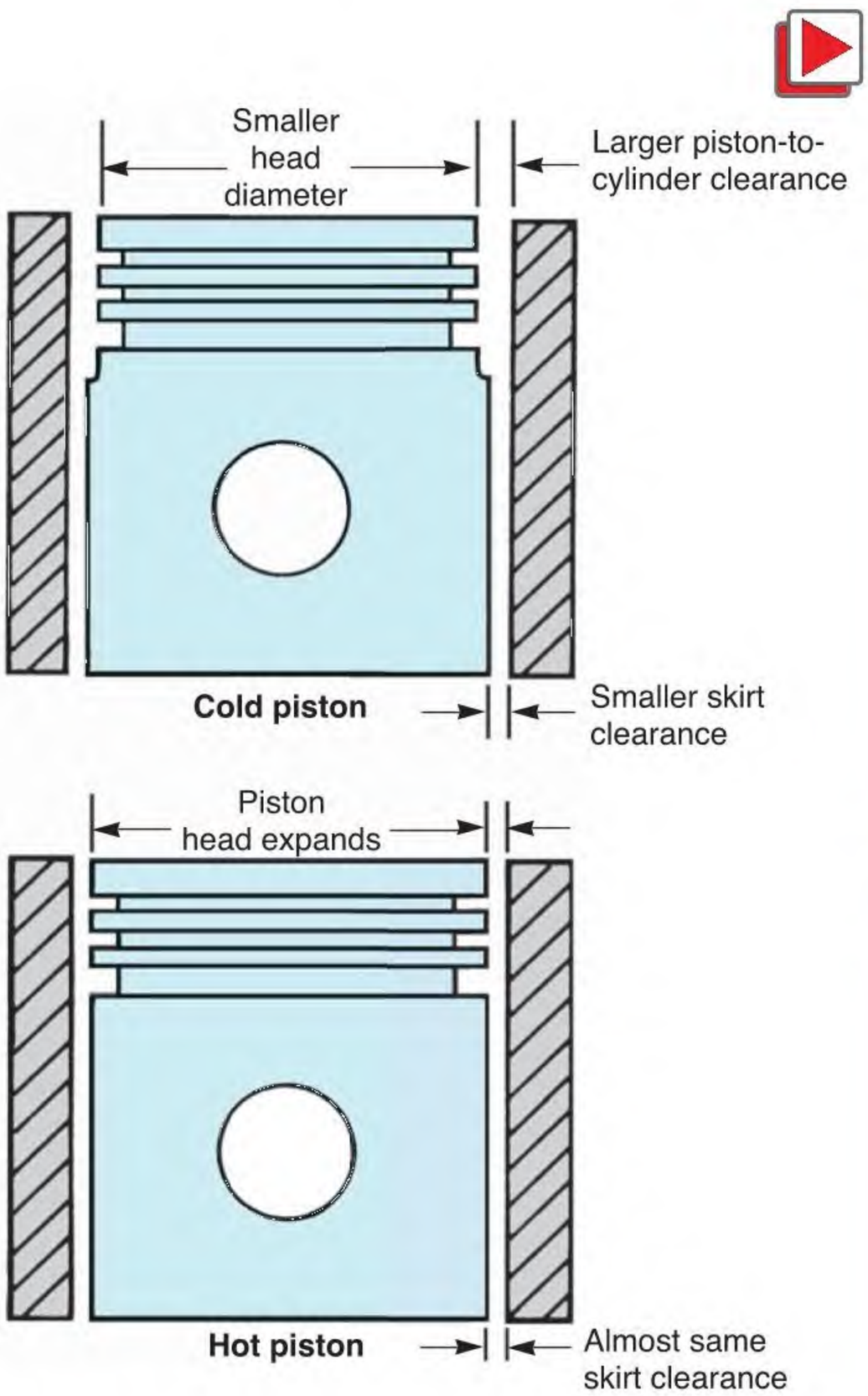
Figure 14-8. A cam-ground piston compensates for different rates of expansion. The piston is larger across the major diameter. The piston expands more across the minor diameter when heated. This causes the piston to become round when at full operating temperature.

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slap, flop sideways, and knock in the cylinder because of too much clearance. When heated to full operating temperature, the cam-ground piston expands for optimal piston-to-cylinder clearance. It will not become too tight in the cylinder.

Piston Taper

Piston taper is also used to maintain the correct piston-to-cylinder clearance. The top of the piston is machined slightly smaller than the bottom, **Figure 14-9**. Since the piston head gets hotter than the skirt, it expands more. The piston taper makes the piston almost equal in size at the top and bottom at operating temperature.

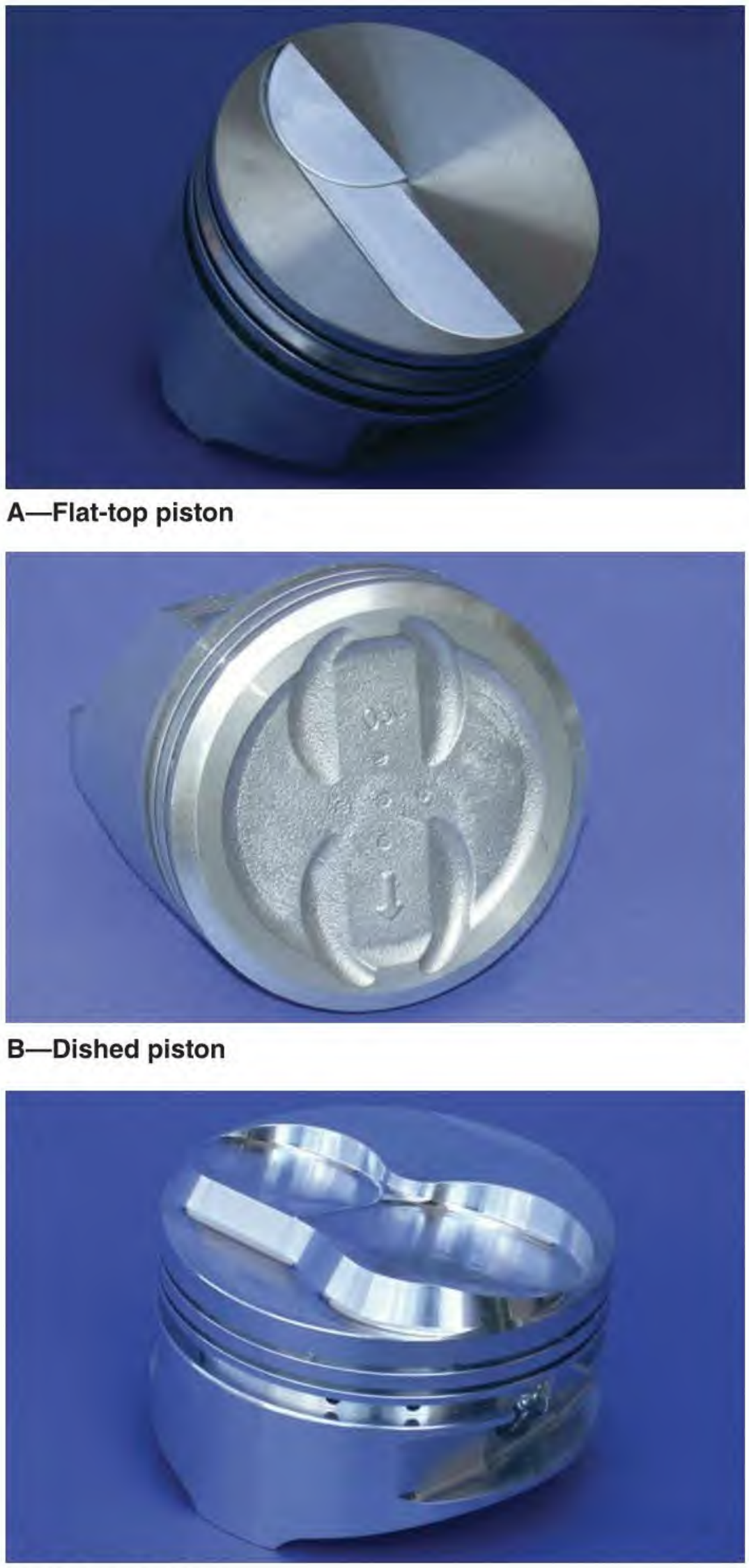


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Figure 14-9. Piston taper compensates for more expansion around the piston head. The head becomes hotter than the skirt and expands more. By machining the head smaller, the piston diameter becomes almost equal at the top and bottom when hot.

Piston Head Shape

Piston head shape generally refers to the contour of the piston top. Usually, a piston head is shaped to match and work with the shape of the cylinder head combustion chamber. See **Figure 14-10**.



A—Flat-top piston

B—Dished piston

C—Domed piston

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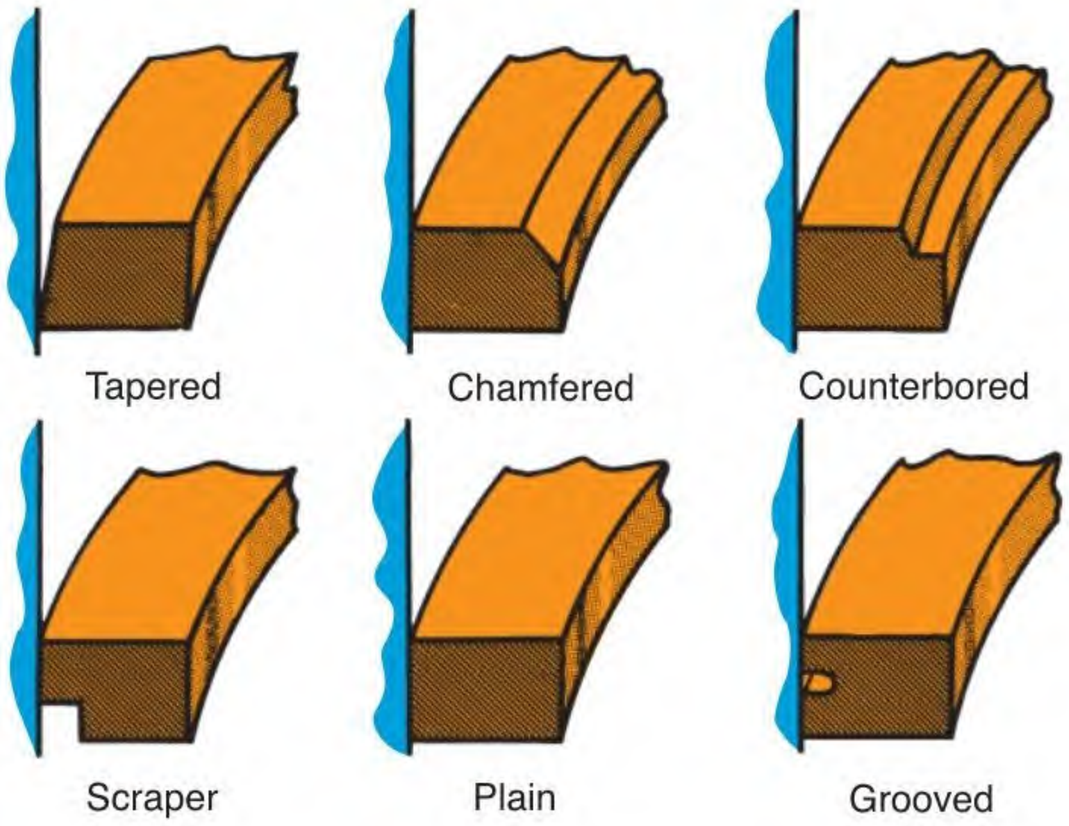
Figure 14-10. Compare common piston shapes.

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As its name implies, a flat-top piston, **Figure 14-10A**, has a flat head that is parallel to the block's deck surface. This type of piston is often used in engines with wedge- or pancake-type cylinder heads. Valve reliefs are cut into the head of this type of piston. Valve reliefs are small indentations either cast or machined into the piston crown to provide ample piston-to-valve clearance. Without valve reliefs, the valve heads could strike the piston.

A dished piston, **Figure 14-10B**, has a head that is sunken, or recessed. This type of piston can be used to lower compression pressure in a turbocharged or supercharged engine.

A domed piston, or pop-up piston, has a head that is convex, or curved upward. See **Figure 14-10C**. This type is normally used with a hemi-type cylinder head and some four-valve heads. The piston head fills the domed combustion chamber and produces enough compression pressure.



Ford

Figure 14-12. Various compression ring shapes are available. Each type is designed to help the ring prevent combustion pressure from leaking into the crankcase.

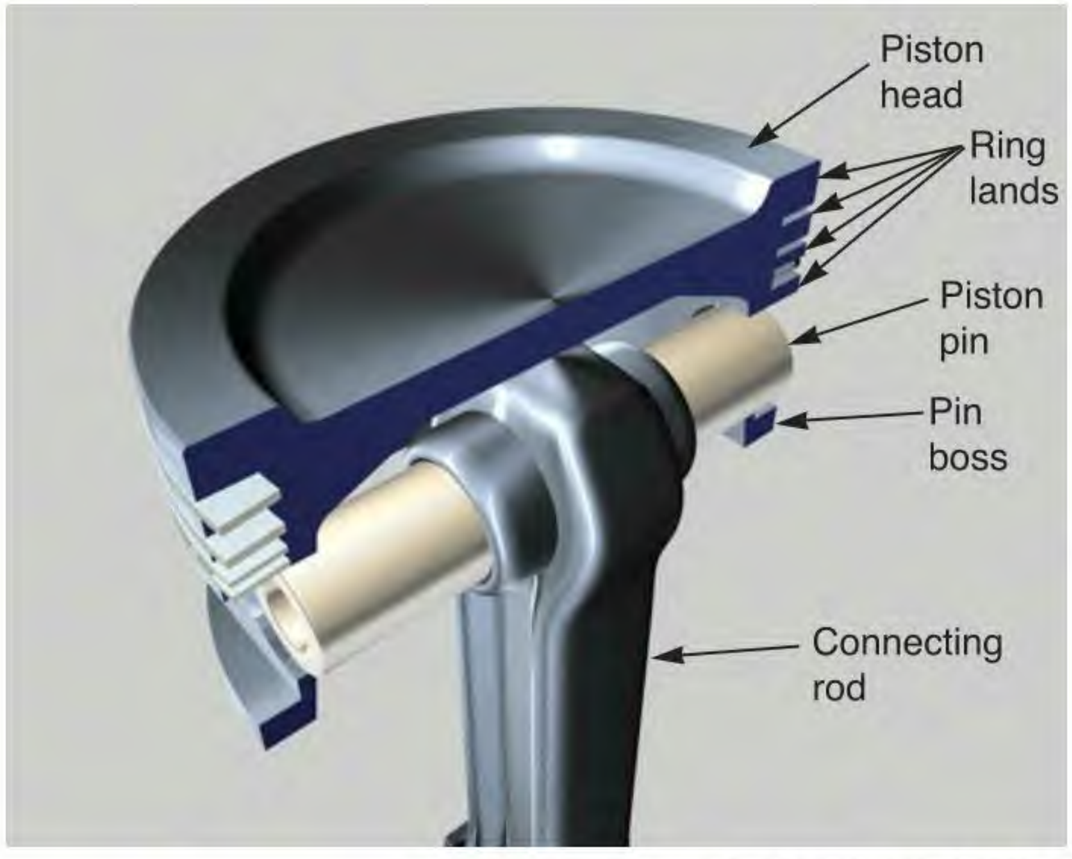
Piston Ring Construction

Automotive pistons normally use three rings—two compression rings and one oil ring. Refer to **Figure 14-11**. It is important for you to understand how variations in ring construction provide different operating characteristics.

The ***compression rings*** prevent pressure leakage into the crankcase. They also wipe some of the oil from the cylinder walls. To accomplish these functions, ring shapes vary, as shown in **Figure 14-12**. These shapes help seal combustion pressure and remove oil from the cylinder wall so oil is not burned with the fuel.

Compression rings are usually made of cast iron. An outer layer of chrome or other metal may be used to increase wear resistance. The face of compression rings may also be grooved to speed ring seating. ***Ring seating*** is the initial ring wear that makes the ring perfectly match the surface of the cylinder.

Oil rings are available in two basic designs: rail-spacer type and one-piece type, **Figure 14-13**. The primary function of oil rings is to keep crankcase oil out of the combustion chambers. A three-piece oil ring consisting of two rails, or scrapers, and an expander-spacer is the most common. The ***ring expander-spacer*** holds the two steel oil ring rails apart and helps push them outward, **Figure 14-13A**. A ***ring expander*** can be placed behind a one-piece oil ring to increase ring tension, **Figure 14-13B**. It can also be used behind the second compression ring. The expander helps push the ring out against the cylinder wall, increasing the ring's sealing action.



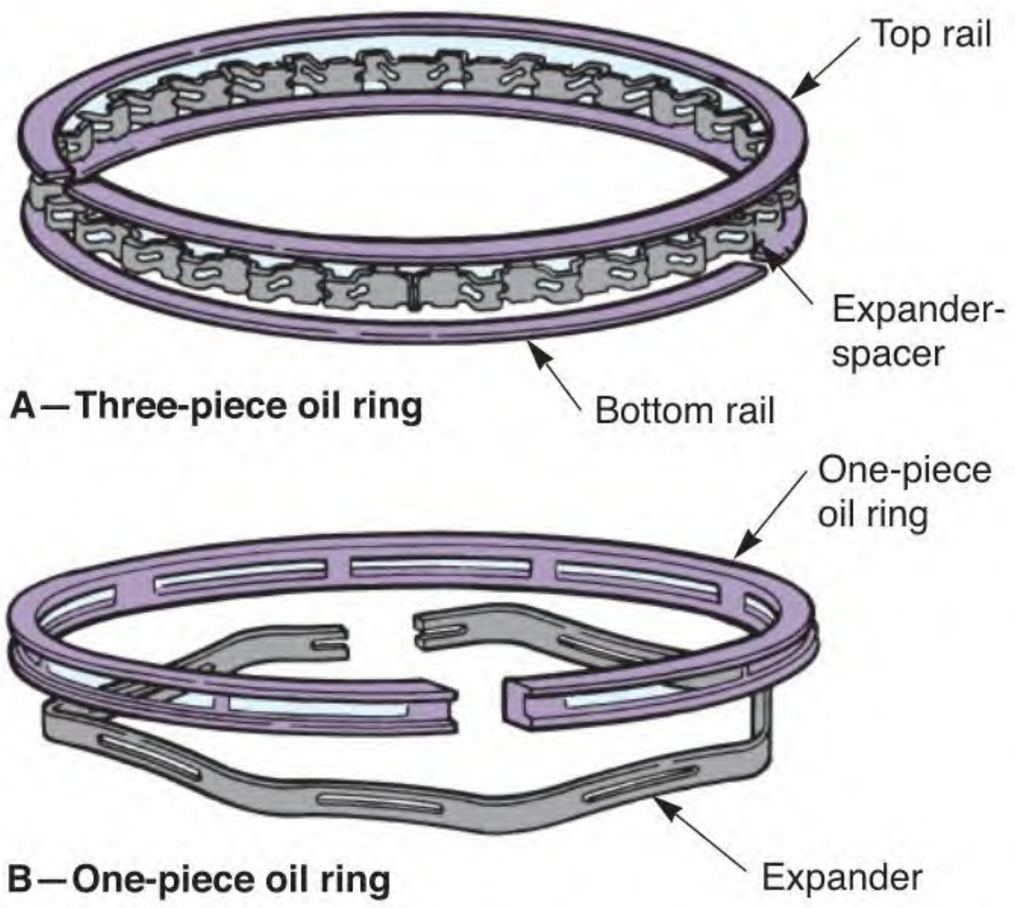
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Figure 14-11. Study the basic parts of a typical piston and rod assembly. This piston pin is press fit in the connecting rod.

Piston Ring Dimensions

Basic piston ring dimensions include the width, radial wall thickness, and gap. Refer to **Figure 14-14**. These dimensions affect the operation of the engine. Ring side and back clearances are also very important. They must be within factory specifications or poor engine performance could result.

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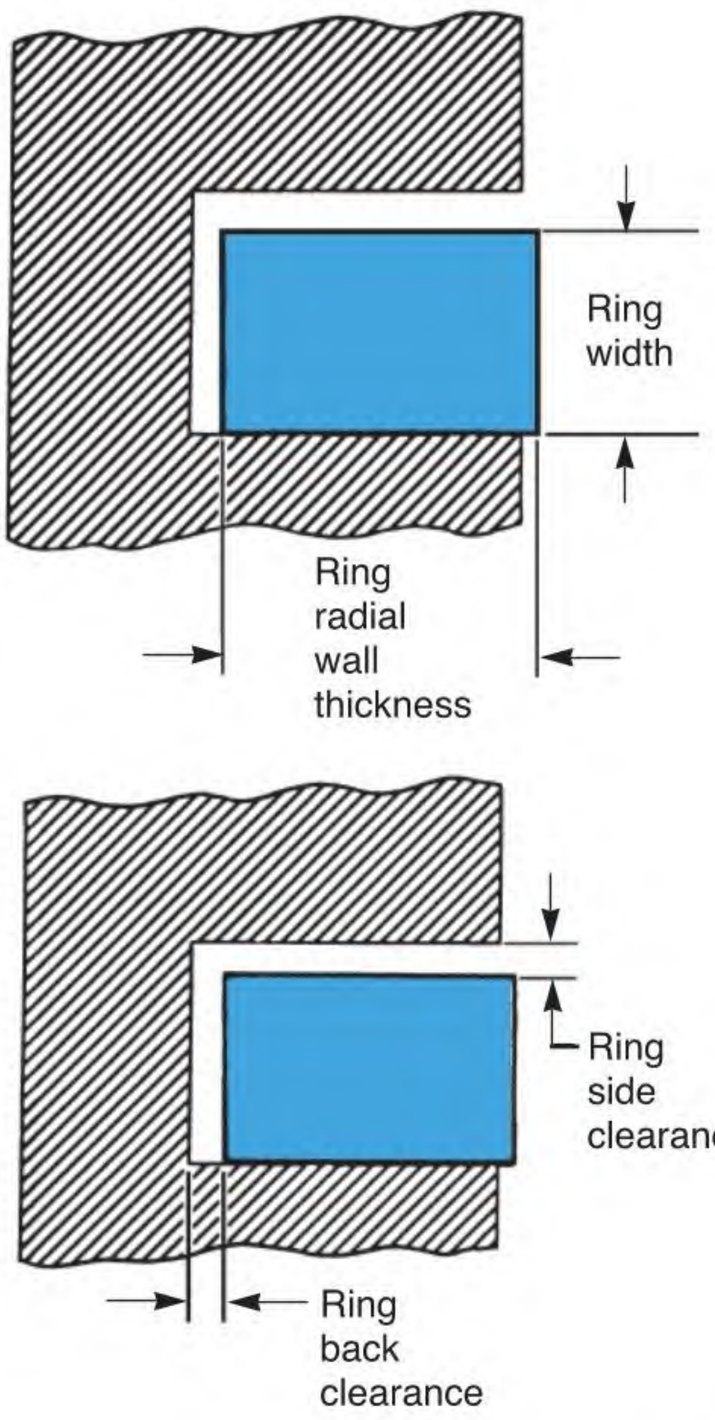


A—Three-piece oil ring

B—One-piece oil ring

Ford

Figure 14-13. An oil ring must wipe excess oil off the cylinder wall.



Perfect Circle

Figure 14-14. Ring width, ring groove depth, ring radial wall thickness, and ring groove height determine the ring back and side clearances.

The ***piston ring width*** is the distance from the top of the ring to the bottom of the ring. The difference between the ring width and the width of the piston ring groove determines the ***ring side clearance***.

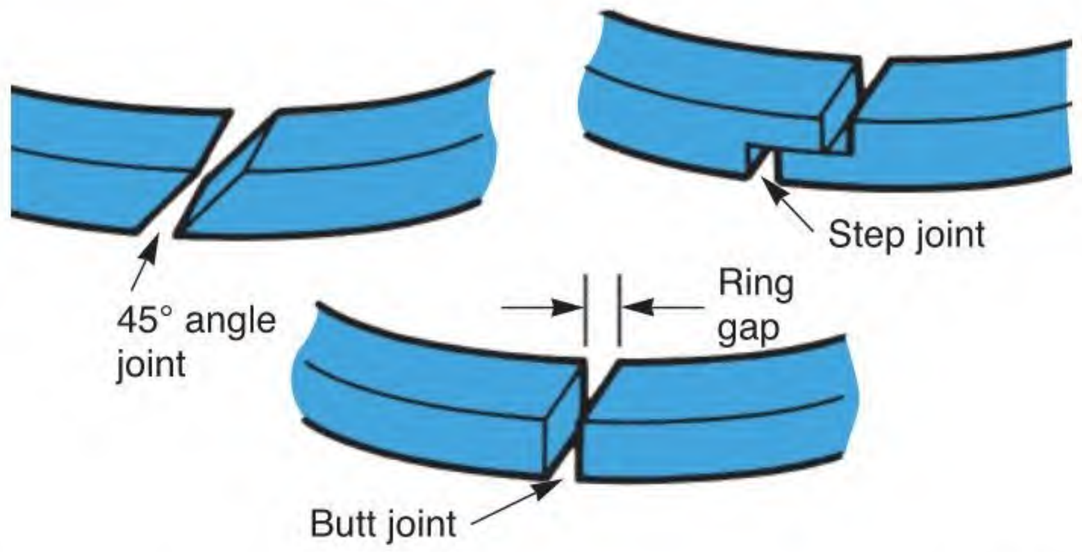
The ***piston ring radial wall thickness*** is the distance from the face of the ring to its inner wall. The difference between the piston ring radial wall thickness and ring groove depth determines the ***ring back clearance***.

The ***piston ring gap*** is the distance between the ends of the ring when the ring is installed in the cylinder. This is pictured in **Figure 14-15**. The ring gap allows the ring to be installed on the piston and to "spring outward" in its cylinder. The gap also allows the ring to conform to any variation in the cylinder diameter due to wear.

Piston Ring Coatings

Soft ring coatings of porous metal, usually iron, help the ring wear in quickly, forming a good seal. The soft outer surface will wear away rapidly so the ring conforms to the shape of the cylinder. Rings with these coatings, often called quick seal rings, are commonly recommended for used cylinders that are slightly worn.

Hard ring coatings, such as chrome or moly, are used to increase ring life and reduce friction. Rings with these coatings are used in new or freshly machined cylinders that are perfectly round and not worn. To aid break-in, chrome-plated rings usually have ribbed faces. The ribs hold oil and wear quickly to produce a good seal.



Ford

Figure 14-15. The ring gap is the small space between the ends of the ring when it is installed on the piston and the piston is in the cylinder. Most modern piston rings use a butt joint.

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Tech Tip

Avoid using rings with hard coatings when rebuilding a passenger car engine. The hard rings are more difficult to seat than softer rings. Soft rings are more forgiving of cylinder wall imperfections. Engine smoking problems are more common in rebuilt engines when rings with hard coatings are used, because the rings take much longer to seat.

Piston Pin Construction

Piston pins are normally made of case-hardened steel. Case-hardening is a heating and cooling process that increases the wear resistance of the piston pin. It hardens the outer layer of metal on the pin. The inner metal remains unhardened so the pin is not too brittle. The hollow piston pin is also machined and polished to a very precise finish. Piston pins are held in the piston by one of two means—a press-fit or snap rings.

A ***press-fit piston pin*** is forced tightly into the connecting rod's small end. It can rotate freely in the piston pin hole. However, the pin is not free to move in the connecting rod, **Figure 14-16A**. This holds the pin inside the piston and prevents it from sliding out and rubbing on the cylinder wall. The press-fit is a very dependable piston pin design. It is also inexpensive to manufacture.

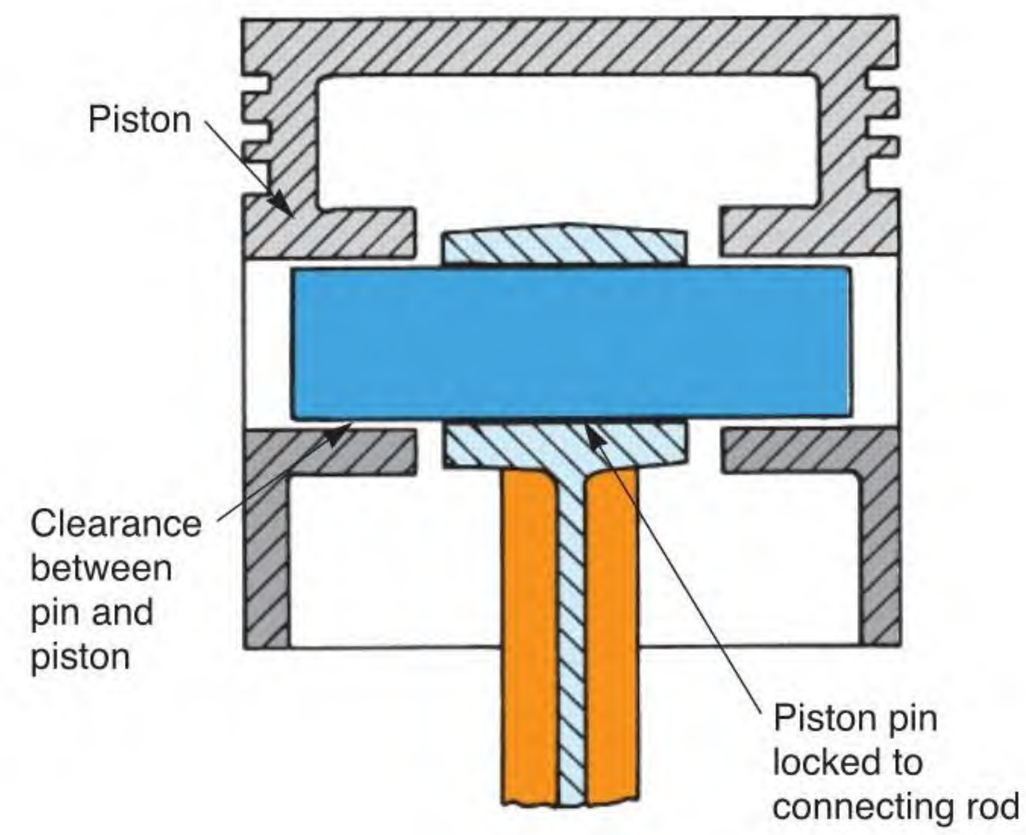
A ***full-floating piston pin*** is secured by snap rings and is free to rotate in both the rod and piston. Look at **Figure 14-16B**. The pin is free to "float" in both the piston pin bore and the connecting rod small end.

Full-floating piston pins are better than press-fit pins because they reduce friction and wear. A bronze bushing is usually used in the connecting rod. The piston pin hole serves as the other bearing surface for the pin. The snap rings fit into grooves machined inside the piston pin hole. See **Figure 14-17**.

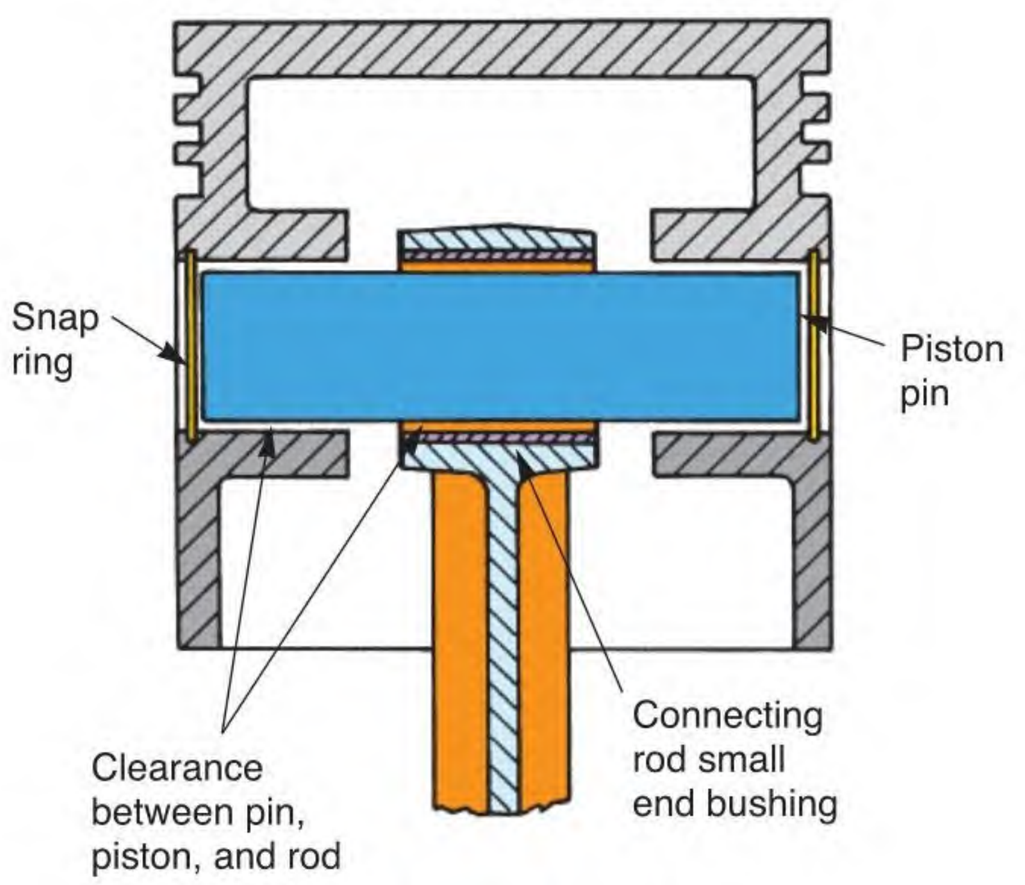


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Figure 14-17. A full-floating piston pin is held in place by snap rings that fit into grooves in the piston.



A—Press-fit piston pin



B—Full-floating piston pin

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Figure 14-16. Compare piston pin and piston boss designs.

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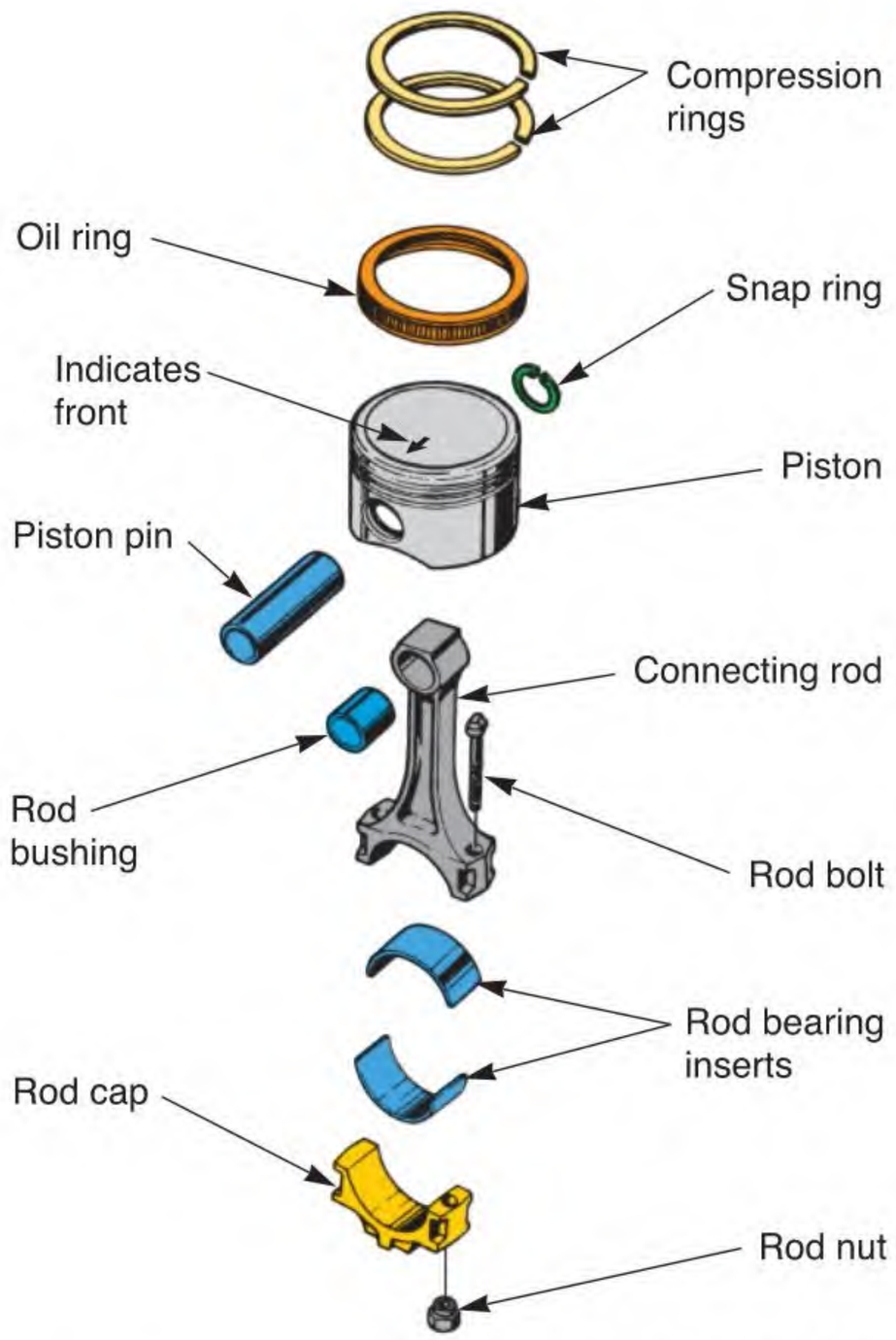
Piston Pin Offset

A ***piston pin offset*** locates the piston pin hole slightly to one side of the piston centerline. This helps quiet the piston during use. The piston pin hole is moved toward the piston's major thrust surface. This is the surface of the piston that is pushed tightly against the cylinder wall during the power stroke.

If the piston pin hole were centered in the piston, the piston could slap or knock in the cylinder. As the piston moves up in the cylinder, it could be positioned opposite the major thrust surface. Then, during combustion, the piston could be rapidly pushed to the opposite side of the cylinder, producing a knocking sound. With the piston pin offset, the piston tends to be pushed against its major thrust surface. This reduces its tendency to slap sideways in the cylinder.

A piston notch or other marking on the head of the piston is frequently used to indicate piston pin offset and the front of the piston. The piston may also have the word "front" or an arrow stamped on it. This information lets you know how to position the piston in the block for correct location of the piston pin offset.

Figure 14-18 shows an exploded view of a piston and connecting rod assembly. Note how the parts are assembled.



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Figure 14-18. An exploded view of a piston and rod assembly. This piston has a full-floating piston pin.

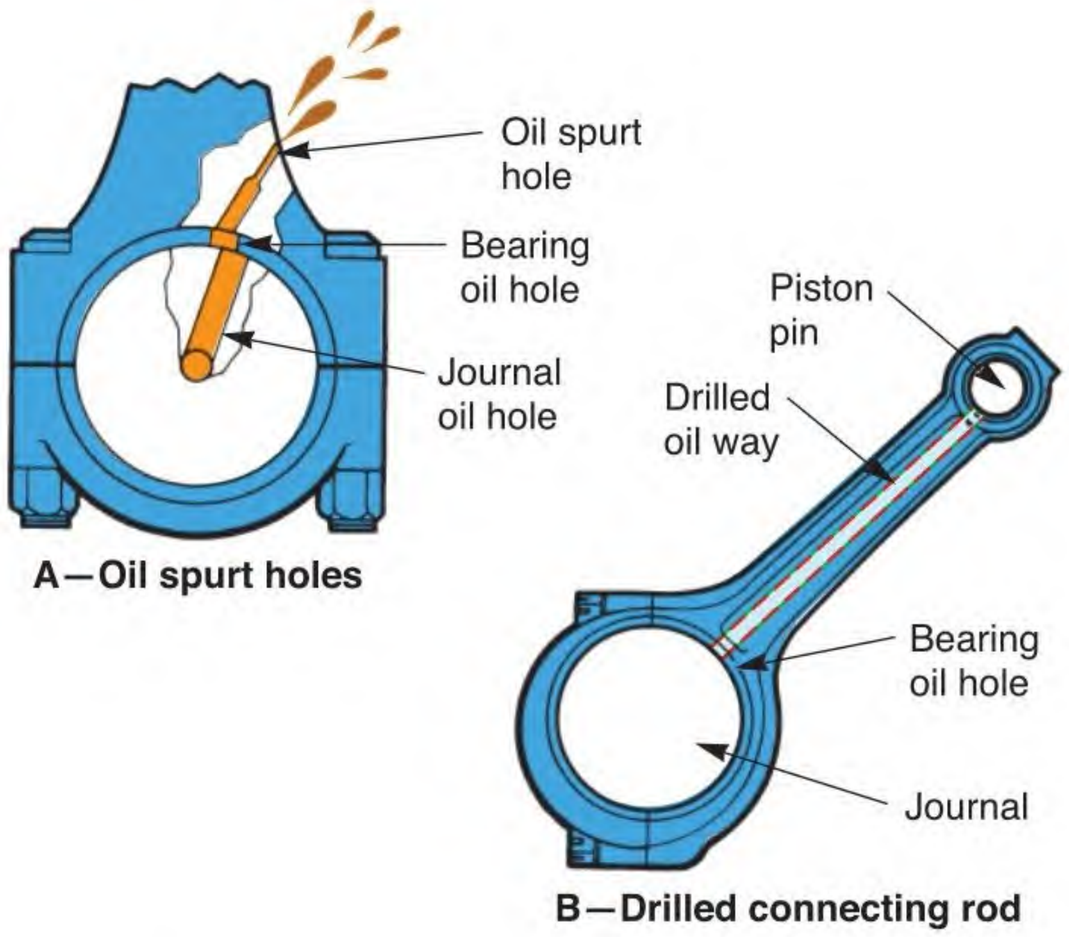
Connecting Rod Construction

Most connecting rods are made of steel. The rod must withstand tons of force as the piston moves up and down in the cylinder. Connecting rods normally have an I-beam shape. This shape has a high strength-to-weight ratio.

Connecting rods must be very strong, but as light as possible for low inertia forces from their changes in direction at top dead center (TDC) and bottom dead center (BDC). Low-inertia parts are light parts that will accelerate quickly.

Some connecting rods have an ***oil spurt hole*** that provides added lubrication for the cylinder walls, piston pin, and other surrounding parts. See **Figure 14-19**. Oil pressure forces oil out when the holes in the crankshaft journal and bearing align with the spurt hole. A ***drilled connecting rod*** has a machined hole through its entire length. The purpose of this hole is to supply oil to the piston pin.

Connecting rod numbers are used to ensure proper location of each connecting rod in the engine. They also ensure that the rod cap is installed on the rod body correctly.



Federal Mogul

Figure 14-19. Oil passages are machined through the crankshaft to lubricate rod bearings. Some connecting rods are drilled to also feed the oil up to the piston pin.

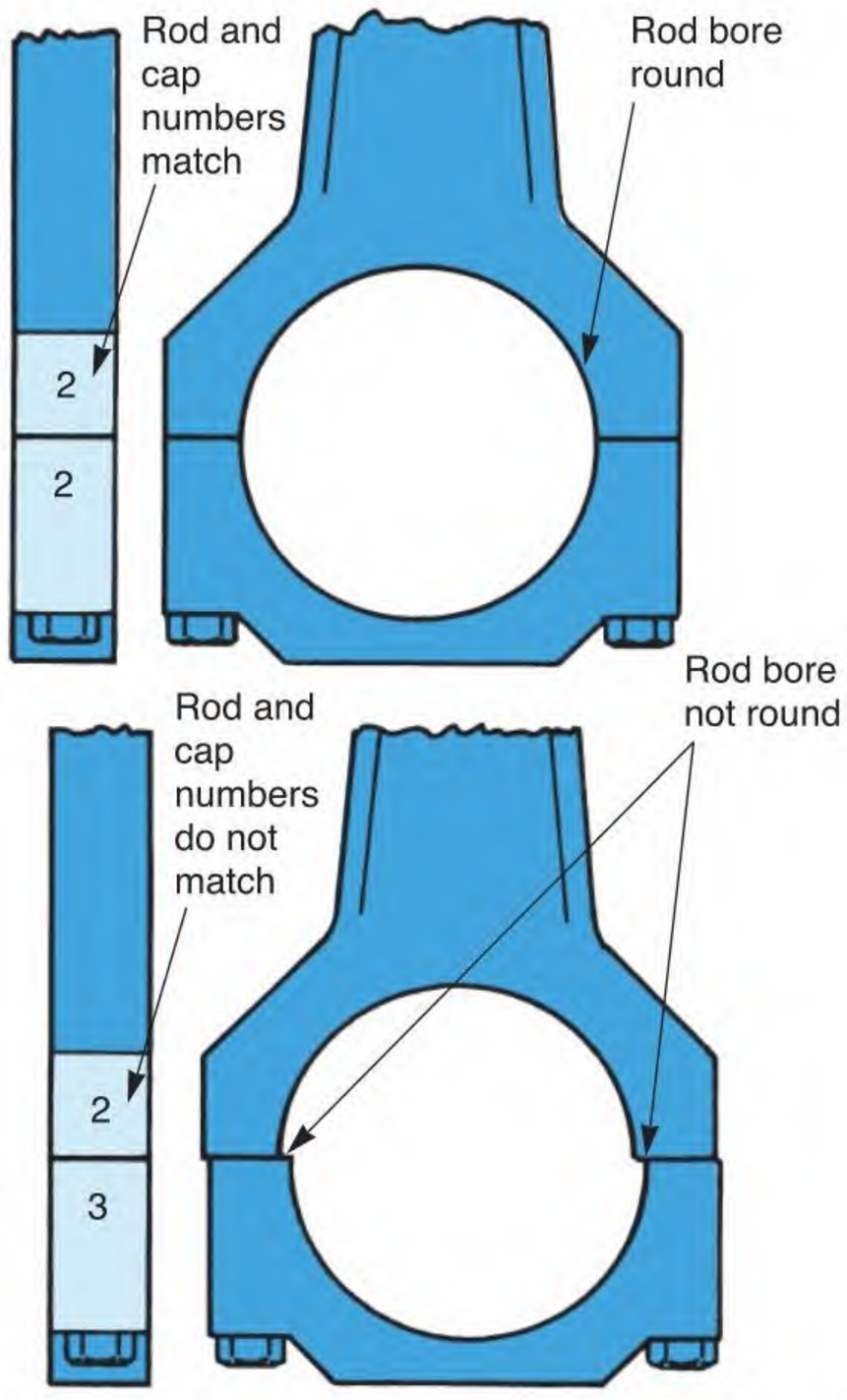
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During manufacture, connecting rod caps are bolted to the connecting rods. Then, the crank holes are machined in the rods. Since these holes may not be perfectly centered, rod caps must not be mixed up or turned around. If the cap is installed without the rod numbers in alignment, the bore will not be perfectly round. Severe rod, crankshaft, and bearing damage will result. Look at **Figure 14-20**.

A ***broken-surface rod*** is scribed and broken off when manufactured to produce a rough, irregular mating surface between the rod body and cap. This is done to help lock the rod and cap into alignment. The broken, irregular surfaces match perfectly to prevent the rod and cap from shifting during engine operation. This type of rod cannot be rebuilt. However, oversize rod bearings can still be installed during an engine rebuild.

Powdered metal forging refers to a process that forms the rough shape of a part out of metal powder before final shaping in a powerful forge. Some connecting rods are powdered metal forged to help control the shape and weight while reducing machining.

Machined block forging involves initial turning in a lathe to bring the blank of metal to size before forming it in a drop or press forge. This process helps eliminate flashing. Flashing is the small lip of rough metal produced when the two halves of the forge come together to "smash" the metal into shape. By reducing flashing, a step is removed from the manufacturing process.



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Figure 14-20. A rod cap must be installed on the rod correctly. If rod caps are mixed up or turned, the bore for the bearing may not be round. The bearing could be crushed into the crankshaft journal, damaging both.

Crankshaft Construction

Engine crankshafts are usually made of cast iron or forged steel. Forged steel crankshafts are needed for heavy-duty applications, such as turbocharged or diesel engines. A forged steel crankshaft is stiffer and stronger than a cast iron crankshaft. It will withstand greater forces without flexing, twisting, or breaking.

Oil passages leading to the rod and main bearings are either cast or drilled in the crankshaft, **Figure 14-21**. Oil enters the crankshaft at the main bearings and passes through holes in the main bearing journals. It then flows through passages in the crankshaft and out to the connecting rod bearings.

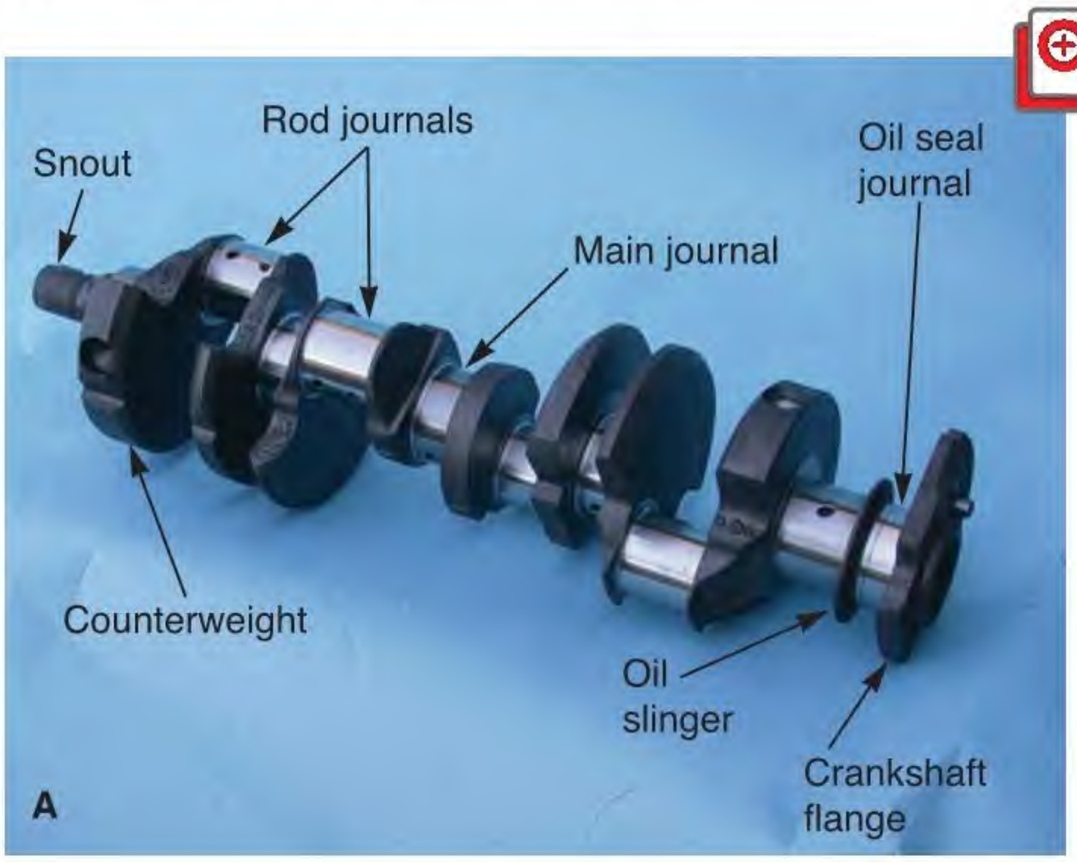
With an inline engine, only one connecting rod fastens to each rod journal, or ***crankpin***. With a V-type engine, two connecting rods bolt to each rod journal. The amount of rod journal offset controls the stroke of the piston. The journal surfaces are precision machined and polished to very accurate tolerances.

A ***fully counterweighted crankshaft*** has weights formed opposite every rod journal. A ***partially counterweighted crankshaft*** has weights formed opposite the journals in the center portion of the shaft only. A fully counterweighted crankshaft will operate with less vibration than a partially counterweighted crankshaft.

Engine Bearing Construction

There are two types of engine bearings: sleeve-type bearings and split-type bearings. ***Sleeve-type bearings***, or one-piece bearings, are press fit into the block or head. If the bearing has an oil hole, it must be aligned with the corresponding oil hole in the block or head. ***Split-type bearings*** are often called two-piece bearings because they consist of two halves. One half fits into the block or head, and the other half fits into a removable cap. Engine bearings include connecting rod bearings, crankshaft main bearings, and camshaft bearings. See **Figure 14-22**.

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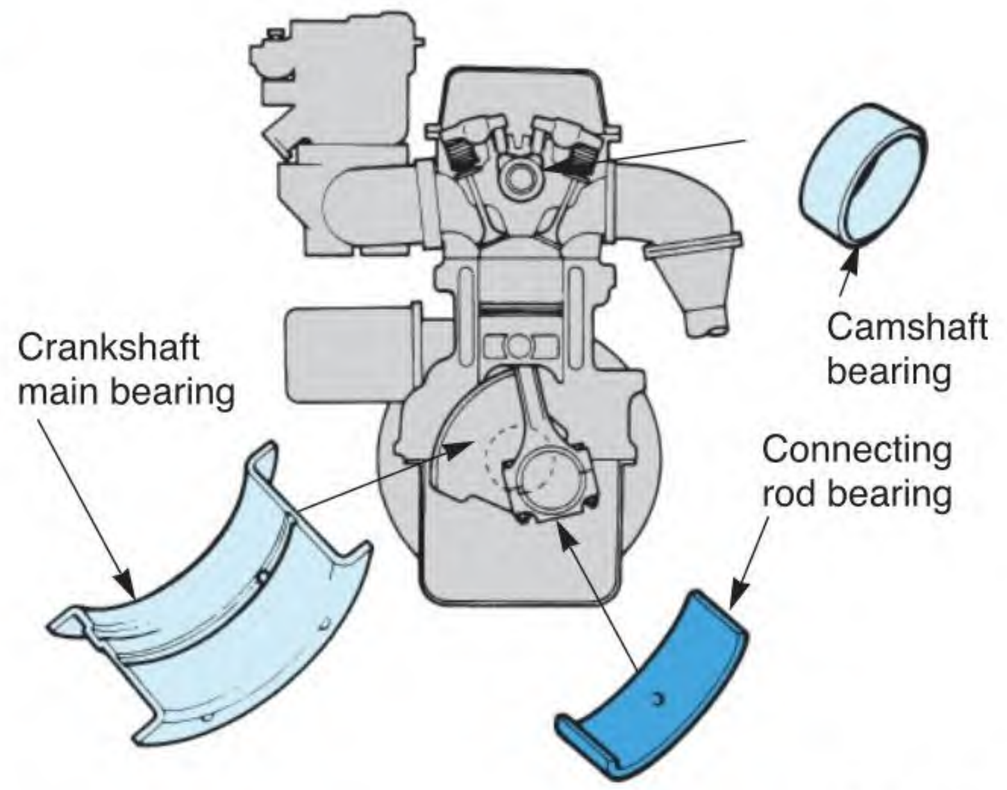


Ford

Figure 14-21. Study crankshaft construction. A—The crankshaft is often made of steel and is precision-balanced to prevent vibration damage. B—A crankshaft has internal passages to supply oil to the connecting rod bearings.

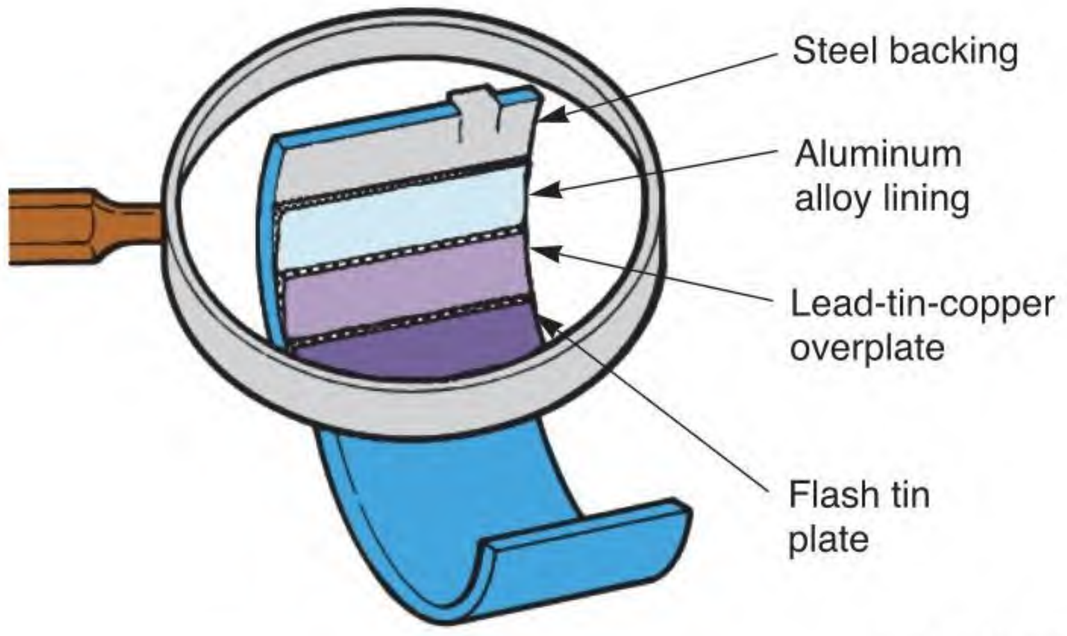
Steel is normally used for the bearing body, or backing, which contacts the stationary part of the engine. Softer alloys are bonded over this backing to form the bearing surface.

Any one of three metal alloys can be plated over the steel backing. These are babbitt (a lead-tin alloy), copper, or aluminum. These three metals may be used in different combinations to design bearings for use in light-, medium-, heavy-, or extra-heavy-duty applications. See **Figure 14-23**.



Federal Mogul

Figure 14-22. The three basic types of engine bearings are crankshaft main bearings, connecting rod bearings, and camshaft bearings.



Federal Mogul

Figure 14-23. Note the typical construction of an engine bearing. Steel backing forms the body of the bearing. Other alloys are plated over the backing to provide better operating characteristics.

Bearing Characteristics

Engine bearings must operate under tremendous loads, severe temperature variations, abrasive conditions, and corrosive surroundings. Essential bearing characteristics are described in this section. It is important to understand each of these.

Bearing load strength is the bearing's ability to withstand pounding and crushing during engine operation. The piston and rod can produce several tons of force. The bearing must not fail under these loads. If bearing load resistance is too low, the bearing can smash, spin, or split. This can ruin the bore or journal.

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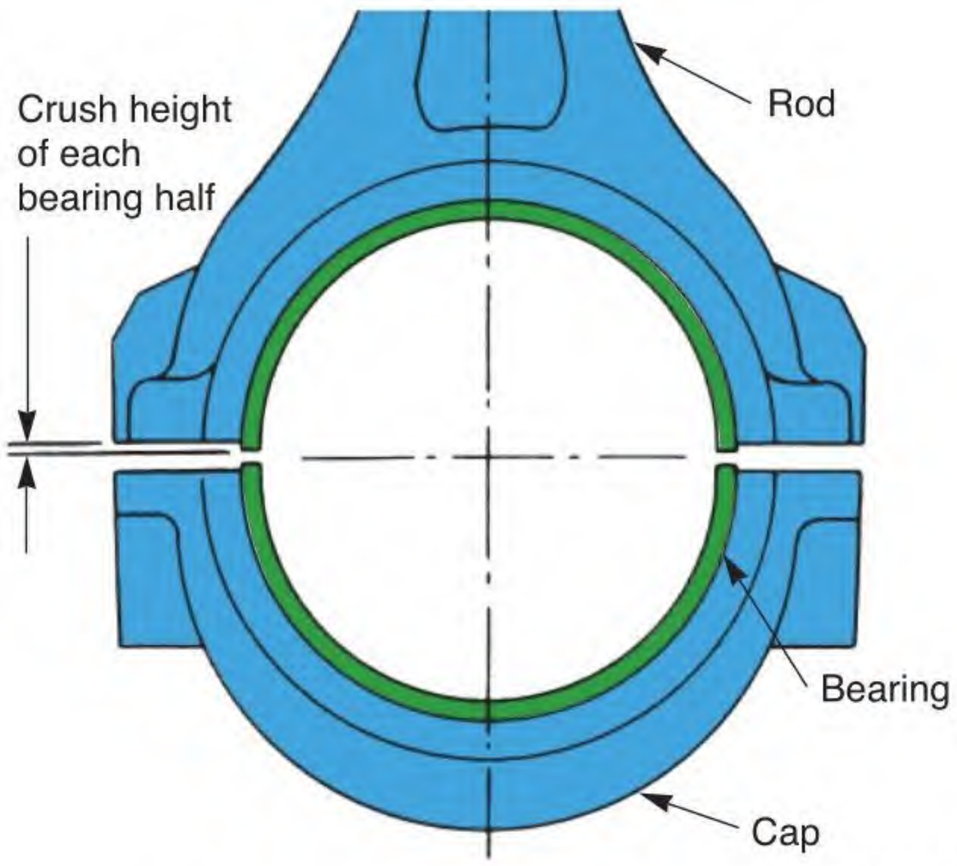
Bearing conformability is the bearing's ability to adjust to imperfections in the journal surface. Usually, a soft metal is plated over a hard steel backing. This lets the bearing conform to any defects in the journal.

Bearing embedability refers to the bearing's ability to absorb dirt, metal, or other hard particles. Dirt or metal is sometimes carried into the bearings. The bearing should allow the particles to sink into the bearing material. This prevents the particles from scratching, wearing, and damaging the surface of the crankshaft or camshaft journal.

Bearing corrosion resistance is the bearing's ability to withstand being acted on by acids, water, and other impurities in the engine oil. Combustion blowby gases cause oil contamination that can also corrode the engine bearings. Aluminum-lead and other alloys are commonly used because of their excellent corrosion resistance.

Bearing Crush

Bearing crush is used to help prevent a split-type bearing from spinning inside its bore during engine operation. Each bearing is made slightly larger than the bearing bore. The ends of the bearing extend slightly above the bore. When the rod or main cap is tightened, the bearing ends press against each other. This jams the back sides of the bearing inserts tightly against the bore, locking them in place. Bearing crush is illustrated in **Figure 14-24**.



Deere & Co.

Figure 14-24. Bearing crush is produced when bearings are made slightly larger than the bearing bore. When the cap is bolted down, the bearing is forced into the bore. This keeps the bearing from turning with the crankshaft.

Bearing Spread

Bearing spread is used on a split-type engine bearing to hold the bearing in place during assembly. The distance across the parting line of the bearing is slightly wider than the bearing bore. This causes the bearing insert to stick in its bore when pushed into place with your fingers. Tension from bearing spread keeps the bearing from falling out of its bore as you assemble the engine.

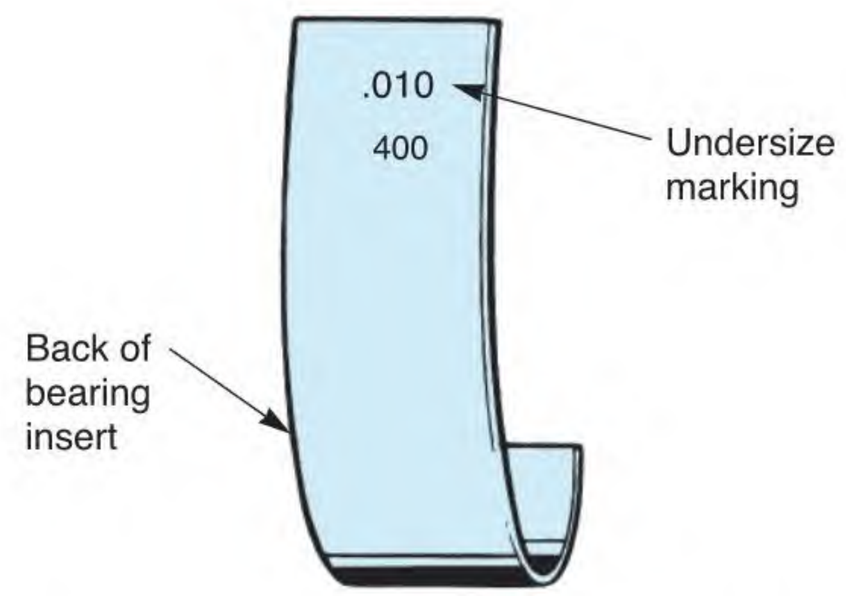
Standard and Undersize Bearings

A ***standard bearing*** has the original dimensions specified by the engine manufacturer for a new, unworn, or unmachined crankshaft. A standard bearing may have the abbreviation "STD" stamped on its back.

An ***undersize bearing*** is designed to be used on a crankshaft journal that has been machined to a smaller diameter. If the crankshaft journals have been worn or damaged, they can be ground undersize by a machine shop. Then, undersize bearings are needed. Connecting rod and main bearings are available in undersizes of 0.010″, 0.020″, 0.030″, and sometimes 0.040″. The undersize is normally stamped on the back of the bearing. The crankshaft may also have an undersize number stamped on it by the machine shop. Undersize bearings are illustrated in **Figure 14-25**.

Bearing Locating Lugs and Dowels

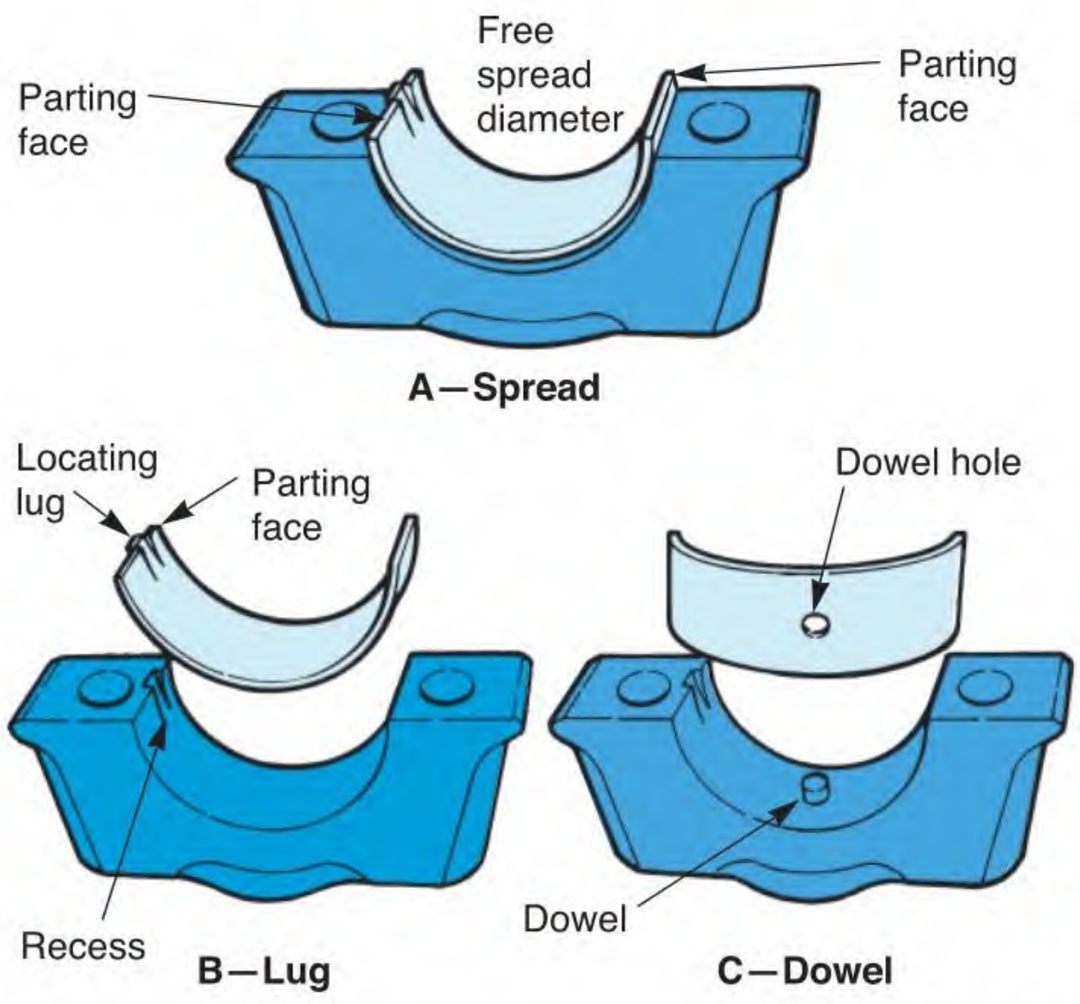
Bearing locating lugs and ***dowels*** position split bearings in their bores. Look at **Figure 14-26**. The bearing usually has a lug that fits into a recess



Buick

Figure 14-25. The bearing undersize is stamped on the back of the bearing. An undersize marking of 0.010″, for example, means that crankshaft journal has been ground 0.010″ smaller in diameter. Undersize bearings are needed to maintain correct bearing clearance.

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Federal Mogul

Figure 14-26. Bearing locating lugs or dowels can be used to position engine bearings in their bore.

machined in the bearing bore or cap. Sometimes a dowel in the cap or bore fits in a hole in the bearing insert. Either method helps keep the insert from shifting or turning during crankshaft rotation.

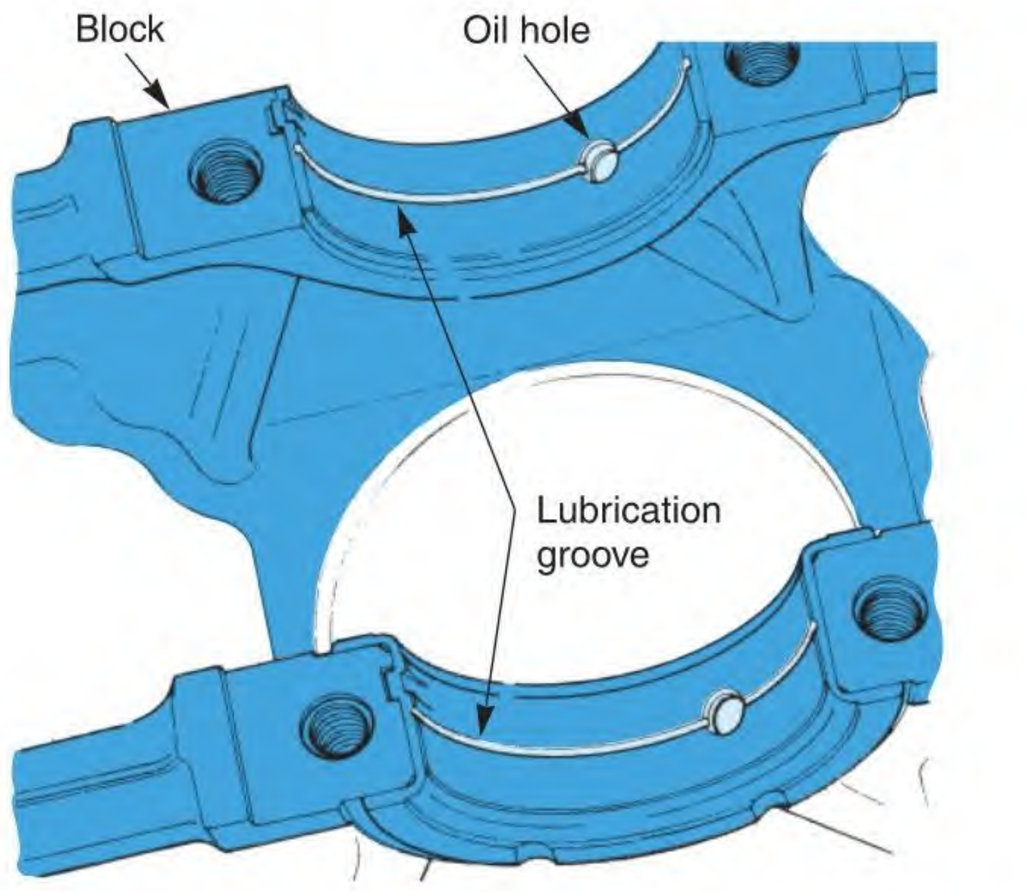
Bearing Oil Holes and Grooves

Bearing oil holes and ***grooves*** in the engine bearings permit bearing lubrication. The holes allow oil to flow through the block and into the clearance between the bearing and the journal. The grooves provide a channel so oil can completely encircle the bearing before flowing over and out of it. See **Figure 14-27**.

Main Thrust Bearings, Thrust Washers

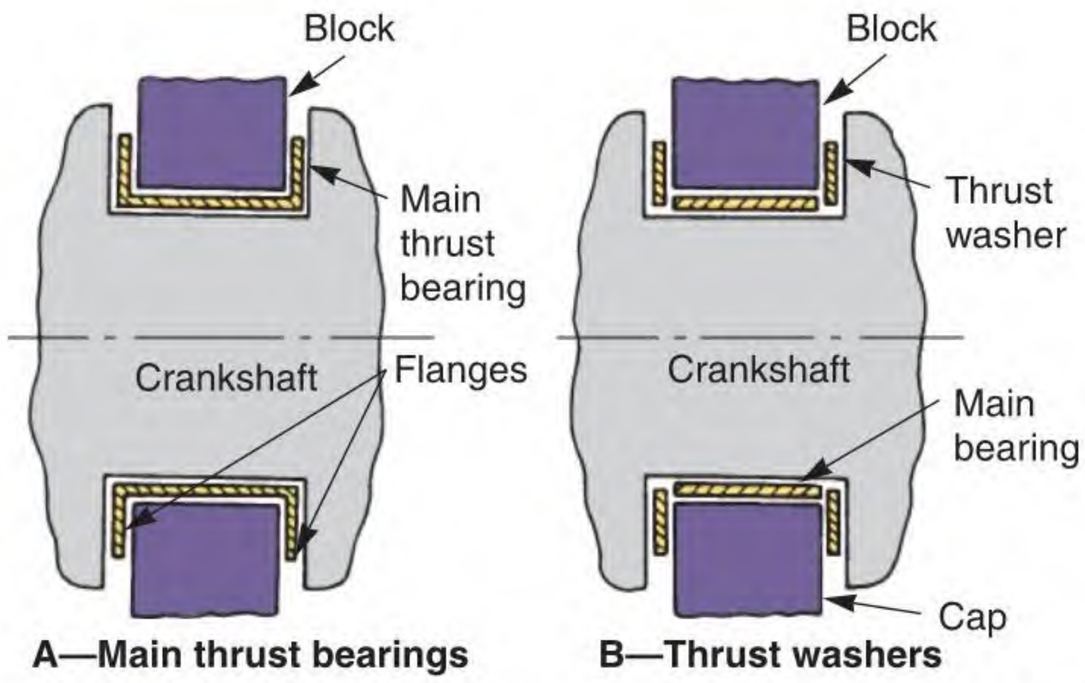
A ***main thrust bearing*** limits crankshaft end play. ***Crankshaft end play*** is the forward and rearward movement of the crankshaft. Thrust flanges are formed on the main bearing sides. These flanges almost touch the thrust surfaces machined on the crankshaft. Shown in **Figure 14-28A**, this keeps the crankshaft from sliding back and forth in the block.

Thrust washers are sometimes used instead of thrust bearings to limit crank end play. The thrust washers are separate parts from the main bearing. They slide down into the space between the crankshaft and block, as pictured in **Figure 14-28B**.



Chrysler

Figure 14-27. Main bearings have holes that let oil enter the bearing clearance. Grooves allow oil to circle the bearing to evenly distribute lubricating oil.



Deere & Co.

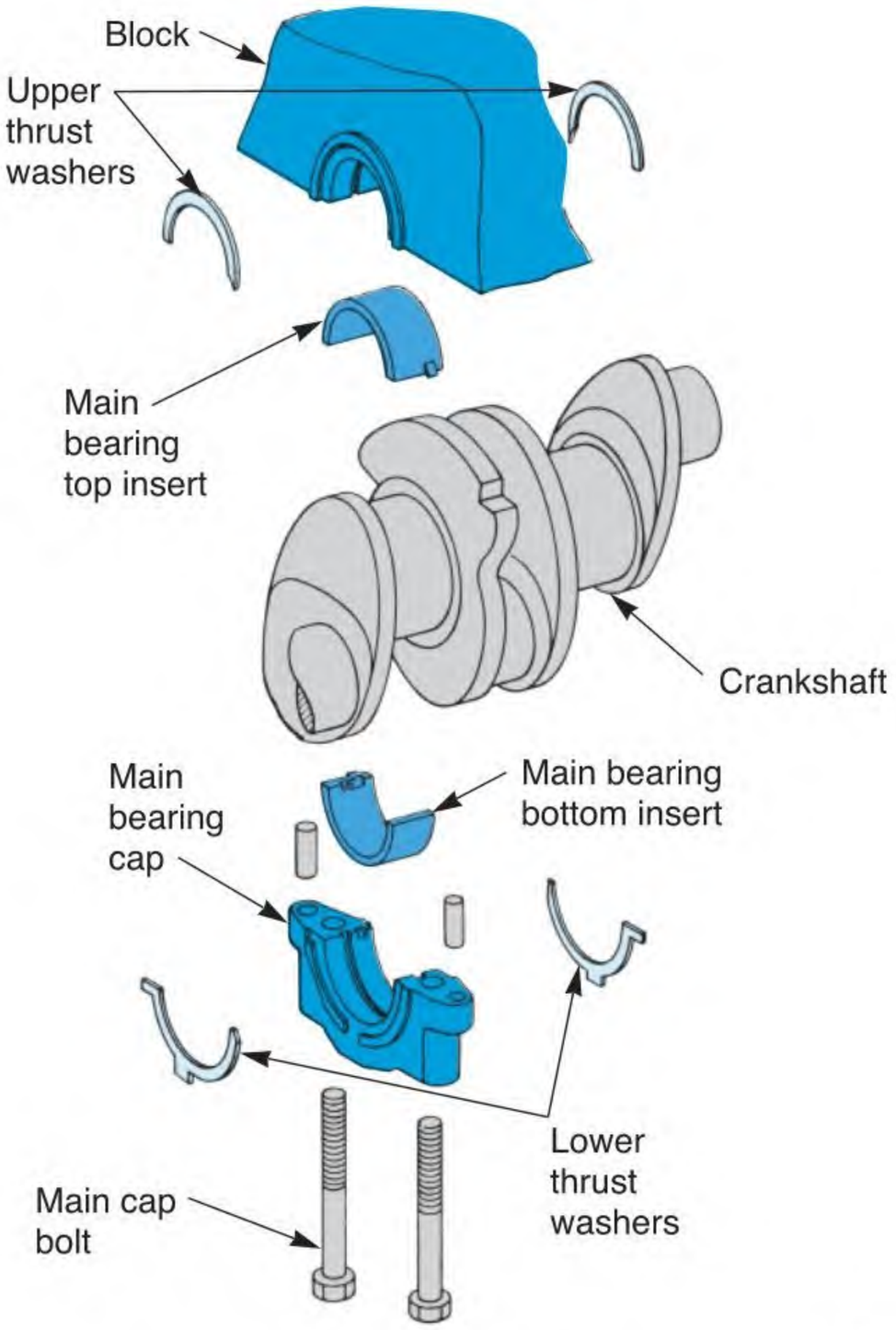
Figure 14-28. Thrust bearings or washers limit crankshaft end play.

Figure 14-29 shows how a main bearing, thrust washers, main cap, and related components assemble to the block.

Rear Main Bearing Oil Seal Construction

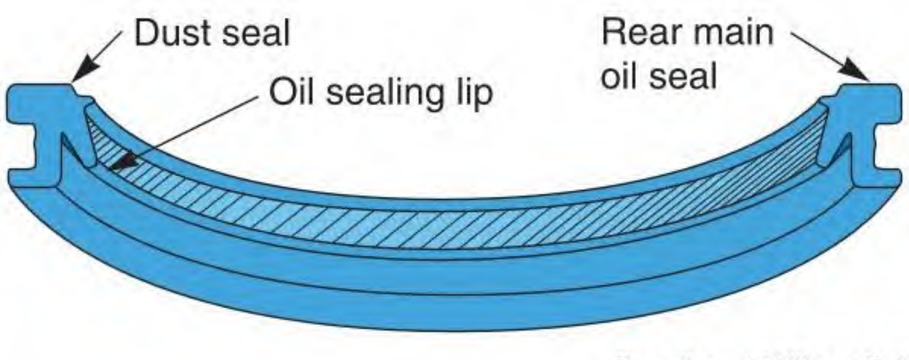
The engine ***rear main bearing oil seal*** prevents oil leakage around the back of the crankshaft. There are several different types of rear oil seals. These include a two-piece neoprene seal, a one-piece neoprene seal, and a wick or rope seal. Refer to **Figure 14-30**.

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Figure 14-29. Note how the main bearing, thrust washers, crankshaft, and cap fit together.

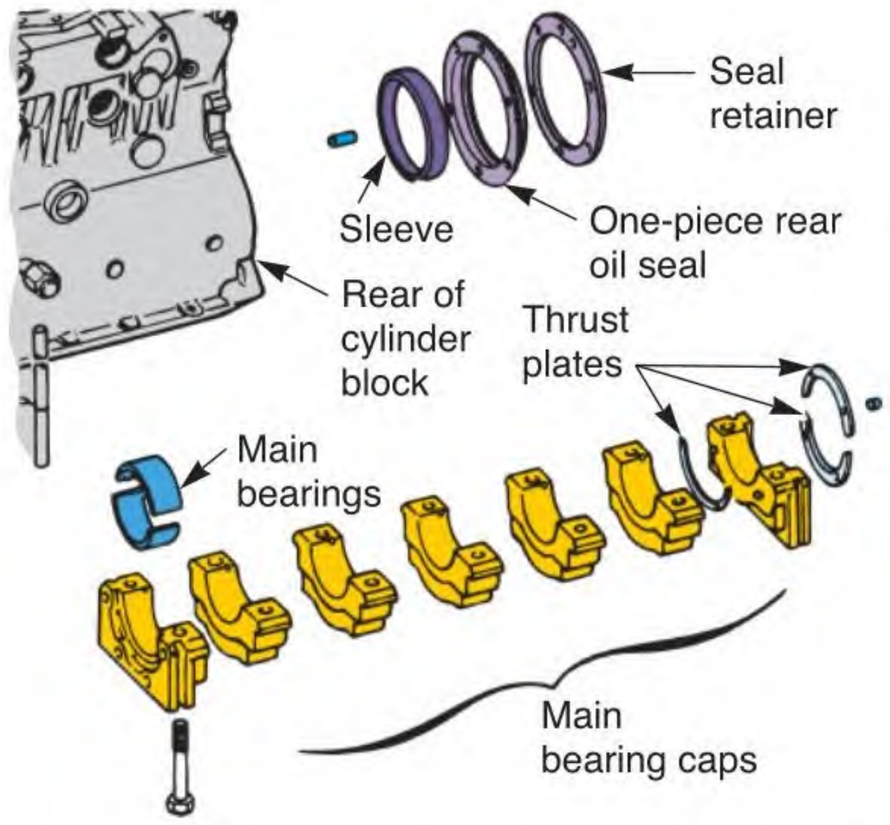


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Figure 14-30. A rear main oil seal has a sealing lip that must face the inside of the engine. The dust seal faces the outside of the engine.

A two-piece neoprene rear oil seal usually fits into a groove cut into the block and rear main cap. The seal has a lip that traps oil and another lip that keeps dust and dirt out of the engine. The sealing lips ride on a machined surface of the crankshaft. Spiral grooves may be used on the crank surface to help throw oil inward, preventing leakage.

A one-piece neoprene rear oil seal fits around the rear flange on the crankshaft. **Figure 14-31** shows how a retainer may be used to hold the seal on the rear of the



Chrysler

Figure 14-31. Some rear oil seals are one piece. They assemble into the rear of the block around the crankshaft flange.

engine. The one piece rear seal has sealing lips that are similar to those on a two-piece neoprene seal.

A rope, or wick, rear oil seal is simply a woven rope filled with graphite. One piece of the rope seal fits into a groove in the block. Another piece fits in a groove in the main cap. This type seal was used on antique cars and trucks.

Select-Fit Parts

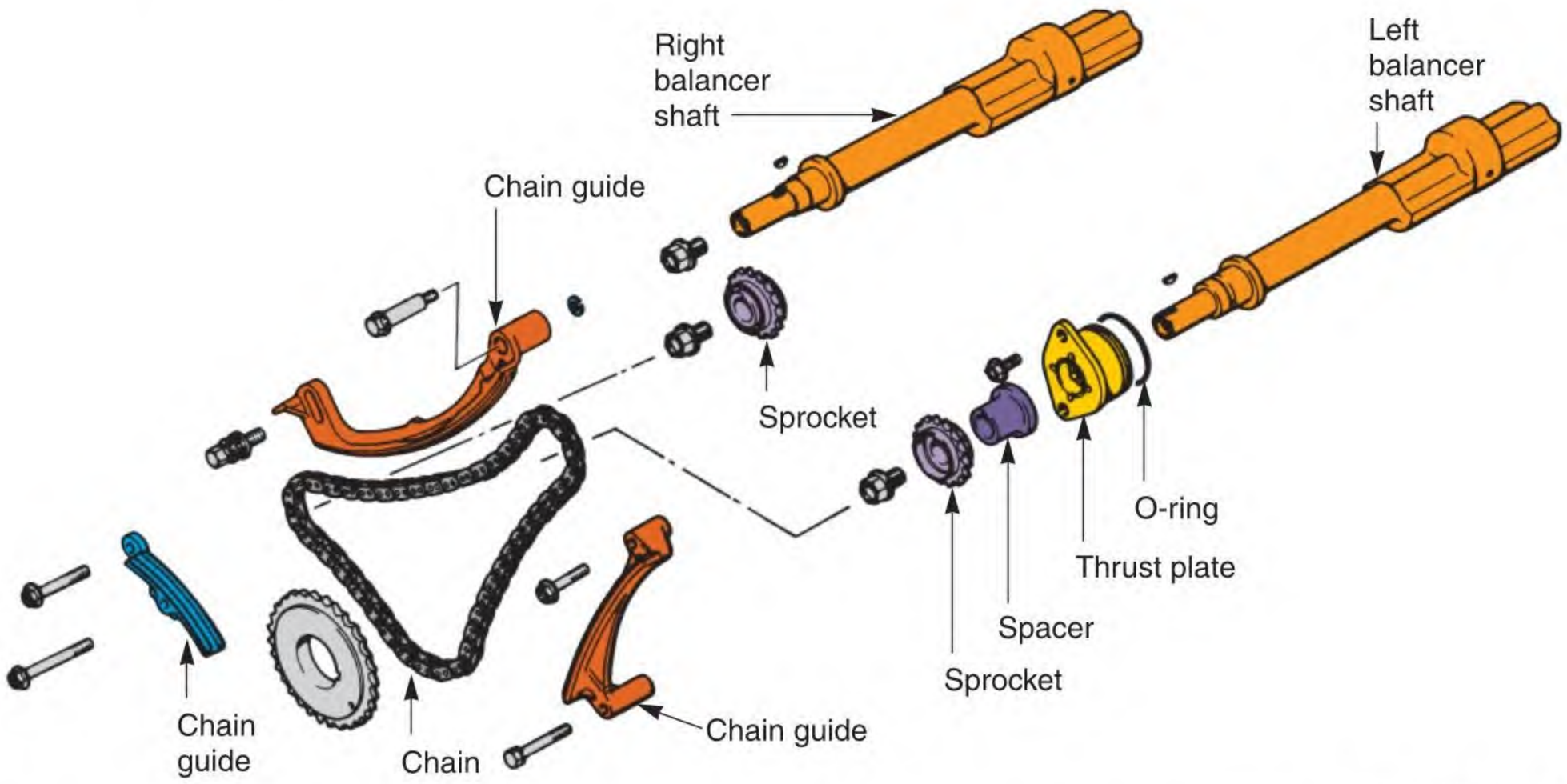
Select-fit means that some engine parts are selected and installed in a certain position to improve the fit or clearance between parts. For example, pistons are commonly selected to fit precisely into their cylinders. To do so, the engine manufacturer measures the diameter of the cylinders. If one cylinder is machined slightly larger than another, a slightly larger piston is installed. Because of select-fit parts, it is important that you reinstall parts in their original locations whenever possible.

Balancer Shafts

Balancer shafts are used in some engines to cancel the vibrating forces produced by crankshaft, piston, and rod movement. They are usually found on 4- and 6-cylinder engines. **Figure 14-32** shows the balancer shafts used in one particular engine.

The balancer shafts, also called silencer shafts, are installed in the right and left sides of the cylinder block on V-type engines. Usually, a chain is used to spin the shafts at twice crankshaft rpm. The shafts are supported on bearings fitted in a bore machined in the block. Oil is pressure-fed to these bearings to provide lubrication.

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Figure 14-32. Balancer shafts are turned by a chain, sprockets, and the engine crankshaft. They counteract any vibration produced by the crankshaft, pistons, and rods.

Workplace Skills

Reliability consists of being at work every day, arriving to work on time, and doing the job right. Reliability is your most important personality trait to an employer. Without it, you will have a difficult time keeping a good job and earning a good living as an auto repair technician.

Summary

- The basic parts of an engine bottom end are the block, crankshaft, connecting rods, and piston assemblies.
- Cylinder sleeves, or liners, are metal, pipe-shaped inserts that fit into the cylinder block.
- Line boring refers to a machining operation that cuts a series of holes through the block for the crankshaft bearings.
- A two-bolt main block only uses two bolts to secure each main bearing cap to the cylinder block. A four-bolt main block has four bolts holding each main cap.
- A main bearing bedplate is a large part that fits over the whole bottom of the block.
- A cam-ground piston is slightly out-of-round when viewed from the top.
- Piston taper is normally used to maintain the correct piston-to-cylinder clearance.
- A slipper skirt is produced when the portions of the piston skirt below the piston pin ends are removed.
- Piston ring width is the distance from the top of the ring to the bottom of the ring.
- Piston ring gap is the distance between the ends of the ring when it is installed in the cylinder.
- Case-hardening is a heating and cooling process that increases the wear resistance of the piston pin.
- A full-floating piston pin is secured by snap rings and is free to rotate in both the rod and piston.
- A press-fit piston pin is forced tightly into the connecting rod's small end.
- Piston pin offset locates the piston pin hole slightly to one side of the piston centerline to quiet piston operation.
- Connecting rod numbers are used to ensure proper location of each connecting rod in the engine.
- A broken surface rod is scribed and broken off when manufactured to produce a rough, irregular mating surface between the rod body and cap.
- A standard bearing has the original dimensions specified by the engine manufacturer and is used for a new, unworn, or unmachined crankshaft.

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- An undersize bearing is designed to be used on a crankshaft journal that has been machined to a smaller diameter.
- A main thrust bearing limits crankshaft end play.
- Select fit means that some engine parts are selected and installed in a certain position to improve the fit between parts.
- Balancer shafts are used in some engines to cancel the vibrating forces produced by crankshaft, piston, and rod movement.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

aluminum cylinder block
balancer shaft
bearing crush
bearing locating lug
bearing oil hole
bearing spread
block girdle
broken-surface rod
cam-ground piston
cast iron cylinder block
compression distance
compression ring
connecting rod number
crankpin
crankshaft end play
crossbolted block
cylinder sleeve
dowel
drilled connecting rod
dry sleeve
engine bottom end
four-bolt main block
full-floating piston pin
fully counterweighted crankshaft
grooves
hard ring coating
line boring
main thrust bearing
oil spurt hole
partially counterweighted crankshaft
pin hole diameter
piston boss
piston diameter
piston head
piston head shape
piston pin hole
piston pin offset
piston ring gap
piston ring groove
piston ring radial wall thickness
piston ring width
piston skirt
piston taper
press-fit piston pin
rear main bearing oil seal
ring back clearance
ring expander
ring expander-spacer
ring groove depth
ring groove width
ring land
ring seating
ring side clearance
select-fit
skirt length
sleeve-type bearings
soft ring coating
split-type bearings
standard bearing
thrust washer
two-bolt main block
undersize bearing
wet sleeve

Activities

1. Use inside and outside micrometers to measure the diameter of a piston and the engine cylinder bore. Then, find the amount of piston clearance by subtracting the piston diameter from the bore measurement.
2. If a number of pistons are available, determine whether any are cam ground. Do this by measuring the diameter parallel to the piston pin, and then measuring the diameter perpendicular (at a 90° angle) to the piston pin. If the piston is cam ground, the measurement perpendicular to the pin will be larger by a few thousandths of an inch.
3. Disassemble a rod cap from its connecting rod, turn it end-for-end so the numbers no longer align, and fit it into place. Can you visually detect an "out-of-round" rod bore? If not, try to think of a way to determine whether the bore is perfectly round. When finished with this activity, reassemble the rod and cap properly.

Review Questions

Answer the following questions using the information provided in this chapter.

1. Cylinder blocks can be made of _____ or _____.
2. Explain the difference between wet sleeves and dry sleeves.
3. Aluminum blocks commonly use _____, _____ sleeves.
4. List and define six piston dimensions.
5. A(n) _____ piston is machined slightly out-of-round to compensate for different rates of piston _____.
6. When the top of the piston outside diameter is machined slightly smaller than the bottom, it is called a _____.
   (A) pop-up piston
   (B) dished piston
   (C) cam-ground piston
   (D) piston taper
7. _____ are small indentations either cast or machined in the piston top.
8. What is a *ring expander-spacer*?

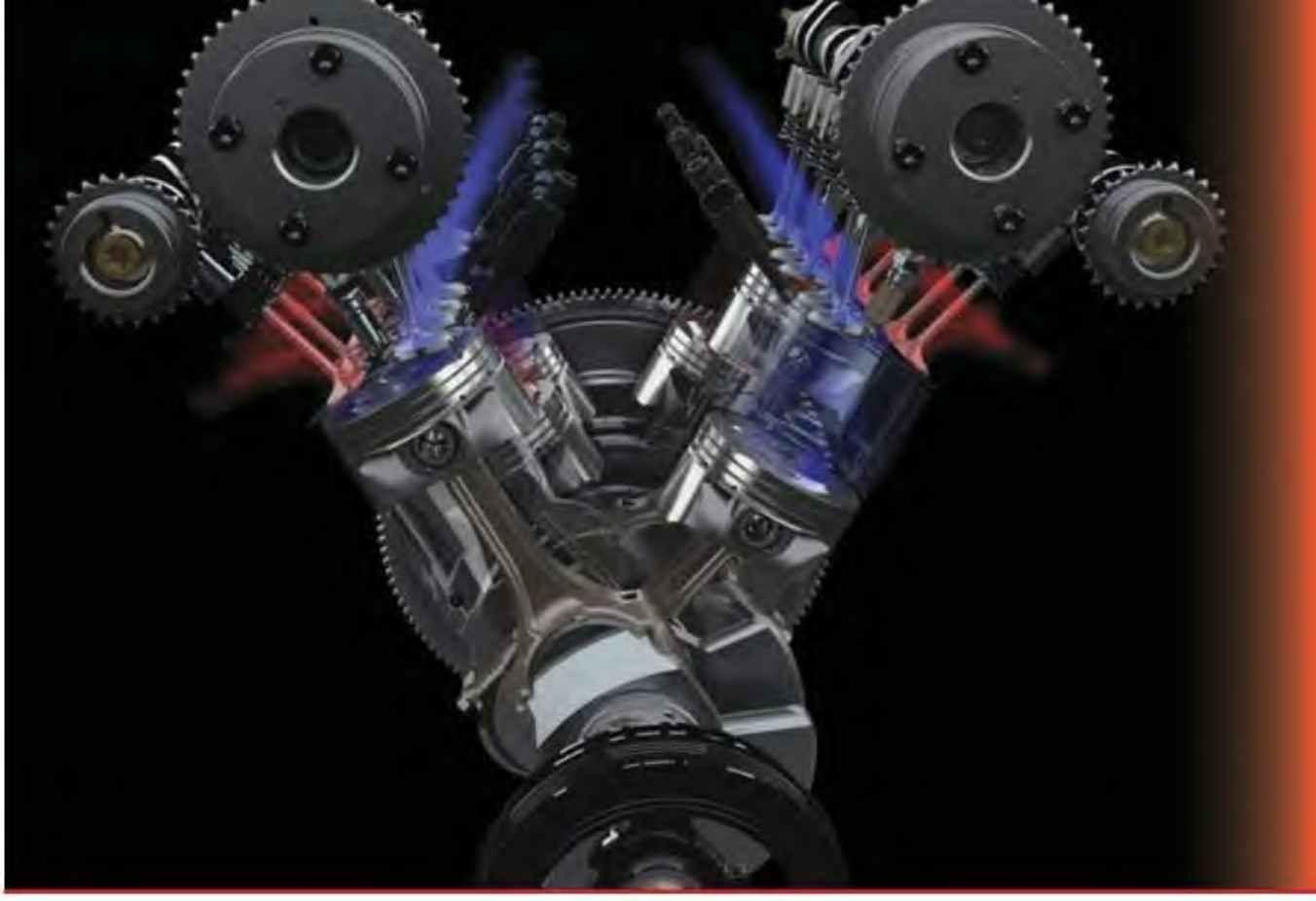
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9. The difference between the ring width and the width of the piston ring groove determines _____.
10. The difference between the ring wall thickness and ring groove depth determines _____.
11. Define *ring gap*.
12. When should you use piston rings with soft coatings?
13. Explain why some parts are case hardened.
14. Which of the following does *not* relate to modern piston assemblies?
    (A) Full-floating pin.
    (B) Press-fit pin.
    (C) Bolted piston pin.
    (D) Offset piston pin.
15. Describe *piston slap* and *piston pin offset*.
16. A(n) _____ on the head of a piston is used to indicate piston pin offset.
17. Name two reasons connecting rod numbers are used.
18. Engine crankshafts are usually made of _____ or _____.
19. How does lubricating oil get to the connecting rod bearings?
20. Which of the following does not pertain to engine bearings?
    (A) Load strength.
    (B) Lubrication absorption.
    (C) Conformability.
    (D) Embedability.
21. Explain *bearing crush*.
22. Explain *bearing spread*.
23. A(n) _____ bearing has the original dimensions specified by the manufacturer for a new, unworn, or unmachined crankshaft.
24. A(n) _____ bearing is designed to be used on a crankshaft journal that has been machined to a smaller diameter.
25. Describe three rear main oil seal variations.

ASE-Type Questions

1. Which of the following is *not* a basic part of an engine bottom end?
   (A) Block.
   (B) Valve train.
   (C) Crankshaft.
   (D) Connecting rods.
2. A piston head can reach operating temperatures as high as:
   (A) 450°F.
   (B) 500°F.
   (C) 650°F.
   (D) 700°F.
3. Which of the following provides clearance between the piston and crankshaft counterweights?
   (A) Slipper skirt.
   (B) Piston taper.
   (C) Valve reliefs.
   (D) Compression rings.
4. The distance from the piston pin hole centerline to the piston top is called:
   (A) skirt length.
   (B) piston diameter.
   (C) pin hole diameter.
   (D) compression distance.
5. The piston type commonly used with a wedge-type cylinder head is:
   (A) concave.
   (B) pop-up.
   (C) flat-top.
   (D) All of the above.
6. The most common oil rings consist of:
   (A) two rails and a spacer.
   (B) ten slots and a spacer.
   (C) three rails and an expander.
   (D) seven slots and an expander.
7. The difference between piston ring width and ring groove width determines:
   (A) ring gap.
   (B) ring side clearance.
   (C) ring wall thickness.
   (D) ring back clearance.
8. The purpose of a drilled connecting rod is to:
   (A) rotate the piston pin.
   (B) create piston pin offset.
   (C) prevent pressure leakage.
   (D) supply oil to the piston pin.
9. How many connecting rods bolt to each crankshaft journal in a V-type engine?
   (A) One.
   (B) Two.
   (C) Three.
   (D) Four.
10. Basic types of engine bearings include each of these *except:*
    (A) piston bearings.
    (B) camshaft bearings.
    (C) crankshaft bearings.
    (D) connecting rod bearings.

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Chapter 15
Engine Front End Construction

After studying this chapter, you will be able to:

- Explain the function and construction of a vibration damper.
- Compare the three types of camshaft drives.
- Explain the construction of a timing gear, timing chain, and timing belt assembly.
- Summarize the construction of engine front covers, oil slingers, and other related components.
- Describe safety practices related to working on engine front end components.
- Correctly answer ASE certification test questions on engine front end construction.

The typical engine front end assembly consists of the parts that attach to the front of the engine. These parts include the camshaft drive mechanism, front cover-mounted oil pump, water pump, auxiliary shafts, supercharger, etc.

Tech Tip

As automotive engineers design more compact, lighter, and more powerful engines, many of the auxiliary units that were traditionally mounted on the front of the engine and driven off the front of the camshaft are now mounted elsewhere on the engine and are driven off the rear or even the center of the crankshaft.

This chapter explains the construction and operation of engine front end assemblies. Study it carefully. It will help you understand later chapters on service and repair. Refer to **Figure 15-1**.

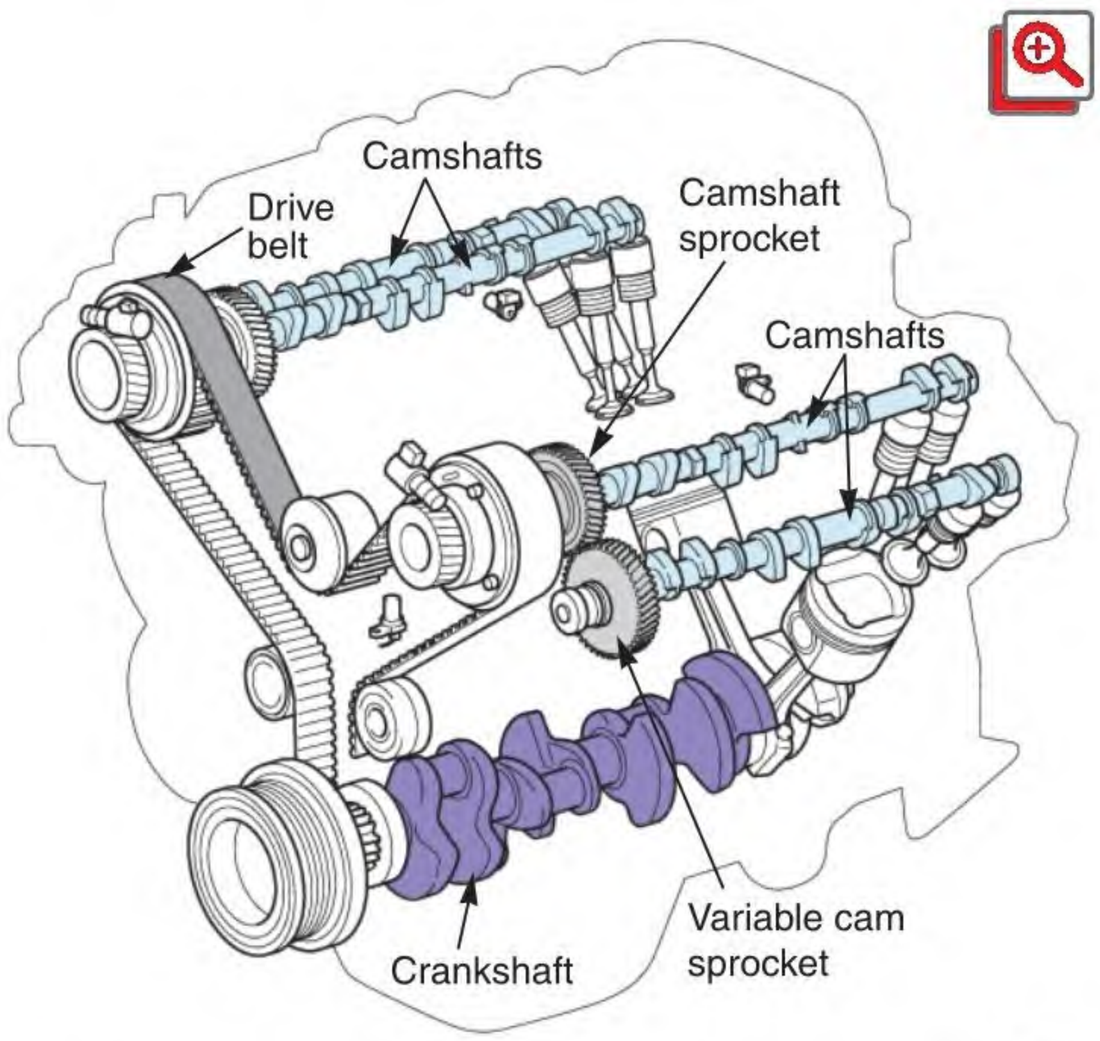
Tech Tip

Oil pumps, water pumps, and other front end–related parts are detailed in other textbook chapters. Refer to the index for more information on these components.

Vibration Damper Construction

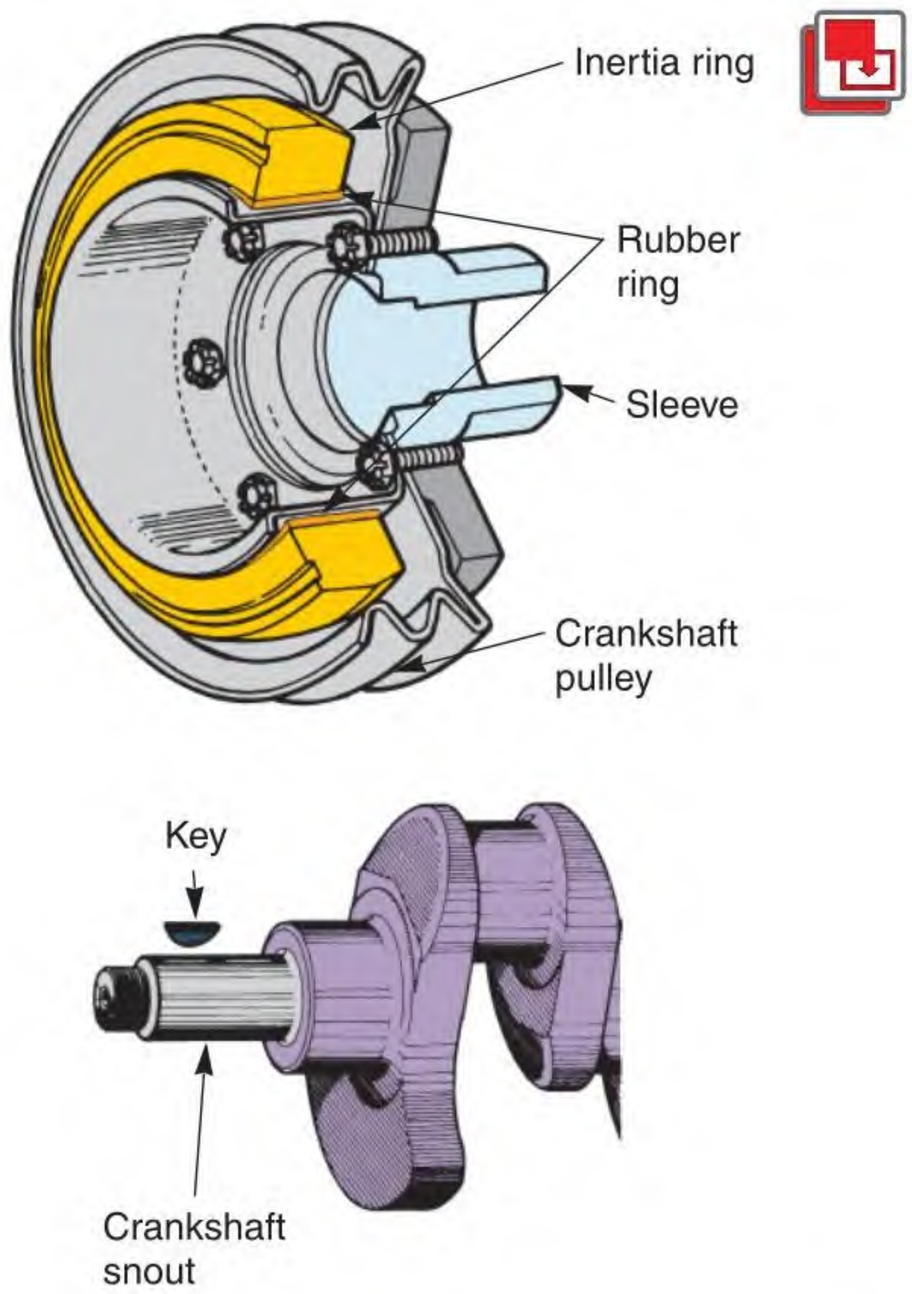
Harmonic vibration is a high-frequency movement resulting from twisting and untwisting of the crankshaft. Each piston and rod assembly can exert

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Toyota

Figure 15-1. Study how the crankshaft turns the drive chains, sprockets, and pulleys to rotate the camshaft, oil pump, and other units.



Chrysler

Figure 15-2. The vibration damper, or harmonic balancer, installs on the front of the crankshaft. A key locks the damper to the crank snout. A large bolt is commonly used to hold the damper in place. Study the construction of a vibration damper. A rubber ring separates the inertia ring and inner sleeve. This acts to deaden, or cancel, crankshaft harmonic vibration.

over a ton of downward force on its journal. This can actually flex, or bend, the crankshaft. If harmonic vibration is not controlled, the crankshaft could vibrate like a musician's tuning fork or a string-type musical instrument. Serious engine damage, usually a broken crankshaft, can result.

A ***vibration damper***, or ***harmonic balancer***, is used to control harmonic vibration. The vibration damper also cuts load variation (changes in torque applied to crank) on the engine timing belt, chain, or high-pressure fuel pump, so these parts last longer.

The vibration damper is a heavy wheel mounted on a rubber ring to control harmonic vibration. The balancer is keyed to the crankshaft snout. This makes the damper spin with the crankshaft.

The rubber ring separates the outer ***inertia ring*** and the inner sleeve. A typical vibration damper is shown in **Figure 15-2**. The inertia ring and the rubber ring set up a damping action on the crankshaft as it tries to twist and untwist. This deadens vibrating action.

A ***dual-mass harmonic balancer*** has one weight mounted on the outside of the crankshaft pulley and another on the inside. The extra rubber-mounted weight helps reduce vibration at high engine speeds.

Crankshaft Pulley

The ***crankshaft pulley*** operates belts for the alternator, water pump, air conditioning compressor, and other units. It is often part of the vibration damper. It may also simply be bolted to the front of the balancer. The pulley has either V or ribbed grooves for the belts. Refer to **Figure 15-2**.

Camshaft Drives

The ***camshaft drive*** transfers the rotational motion of the crankshaft to the camshaft(s). The camshaft drive must rotate the camshaft(s) at one-half of engine speed. It must do this smoothly and dependably. There are three basic types of camshaft drives: timing gears, a timing chain and sprockets, or a timing belt and sprockets.

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Timing Gears

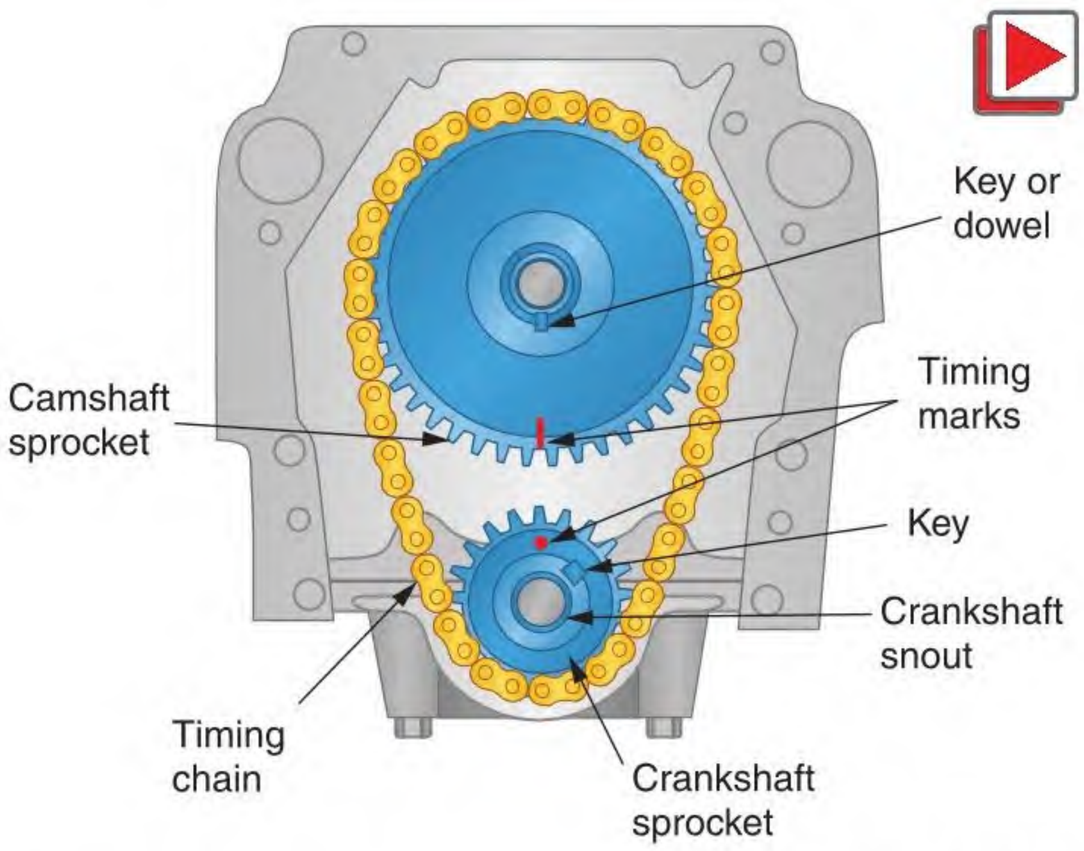
Timing gears are common in engines used for heavy-duty applications, such as taxicabs or trucks. They are very dependable and long lasting. However, they are noisier than a chain or belt drive. Gears are primarily used in cam-in-block engines where the crankshaft is close to the camshaft.

Two ***timing gears*** are used to drive the engine camshaft. A crankshaft gear is keyed to the crankshaft snout. It turns a camshaft gear on the end of the camshaft. The cam gear is twice the size of the crank gear. This results in the desired 2:1 reduction. See **Figure 15-3**.

Timing marks on the two gears show the technician how to install the gears properly. The marks may be circles, indentations, or lines on the gears. The timing marks must line up for the camshaft to be in time with the crankshaft.

Timing Chain and Sprockets

A ***timing chain*** and ***sprockets*** can also be used to turn the camshaft. See **Figure 15-4**. This is the most common type of camshaft drive arrangement on cam-in-block engines. It may also be used in OHC engines.



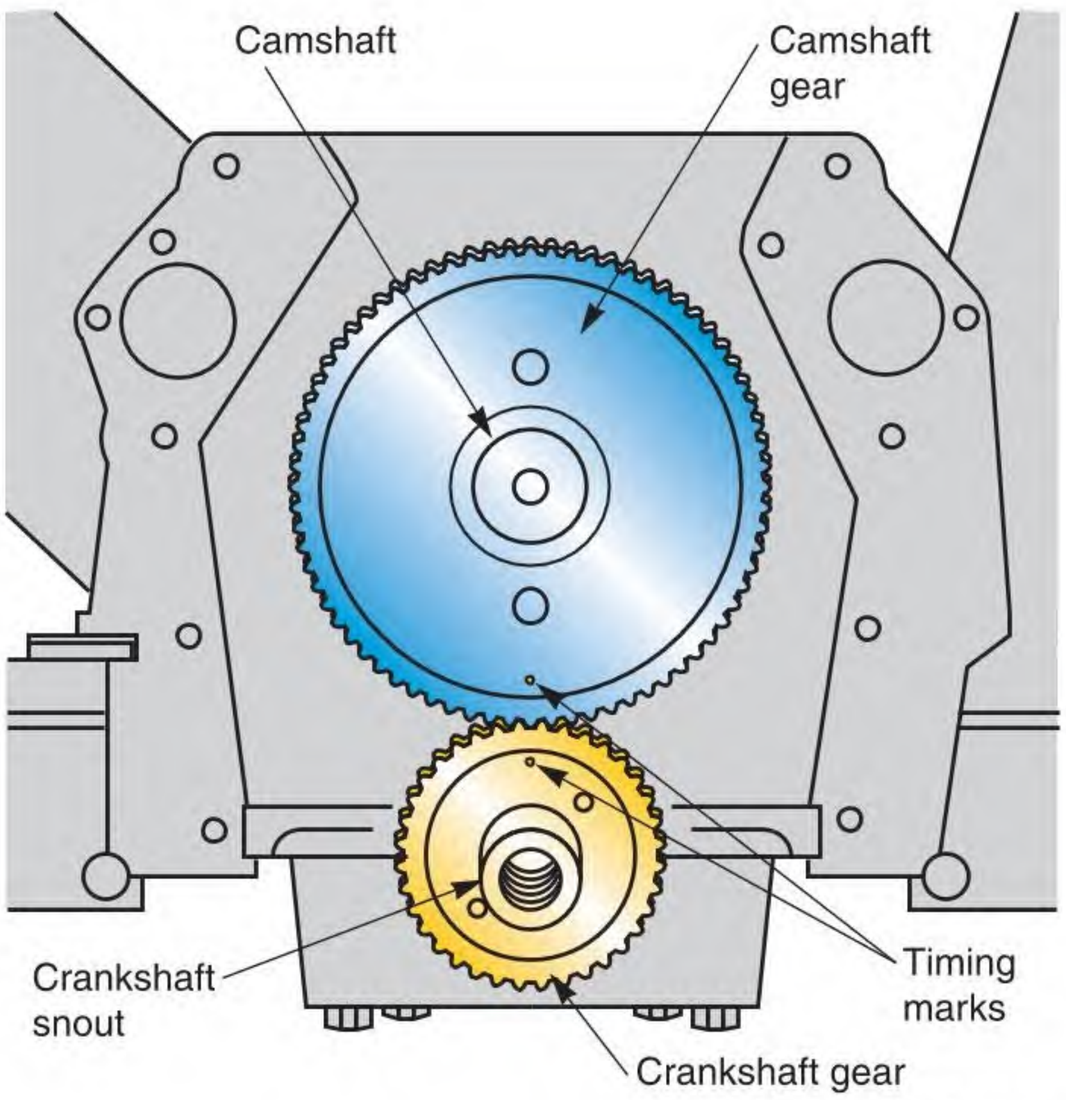
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Figure 15-4. A timing chain setup is very common. Study the part names.

A ***crankshaft sprocket*** is keyed to the crankshaft snout. A larger camshaft sprocket, with either metal or plastic teeth, bolts to the camshaft. The timing chain transfers power from the crankshaft sprocket to the camshaft sprocket. Like timing gears, the chain sprockets have timing marks. The marks must line up to properly time the camshaft with the crankshaft.

A ***chain guide*** may be needed to prevent chain slap. ***Chain slap*** occurs when the chain flaps back and forth because of excessive slack in the chain. **Figure 15-5** shows a timing chain using chain guides. The guides have a metal body with either a plastic or Teflon® face. This allows the chain to slide on the guide with minimum friction and wear.

A ***chain tensioner*** may be used to take up the slack in the chain as it and the sprockets wear. It is usually a spring-loaded plastic or fiber block. The spring pushes the block outward, keeping a constant tension on the chain. A chain-type camshaft drive for an OHC engine commonly uses guides and sometimes a tensioner. Refer to **Figure 15-6** for a front view of this setup.



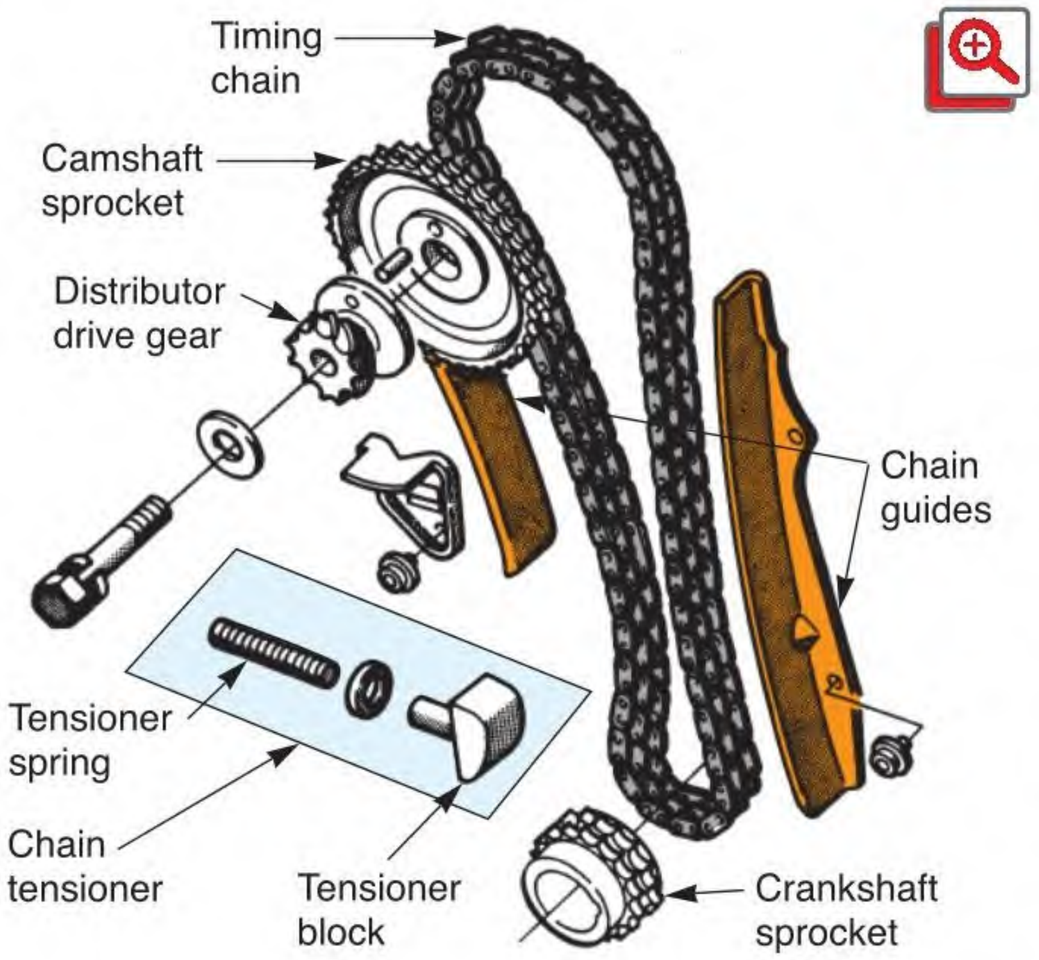
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Figure 15-3. A timing gear setup is very dependable. The crankshaft gear turns the camshaft gear at one-half of the crankshaft speed. Timing marks allow for the proper assembly of the gears.

Auxiliary Chain

An ***auxiliary chain*** may be used to drive the engine oil pump, balancer shafts, and other units on the engine. **Figures 15-6** and **15-7** show two examples. An auxiliary chain is driven by an extra

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Chrysler

Figure 15-5. An OHC timing chain assembly normally uses chain guides and sometimes a tensioner.

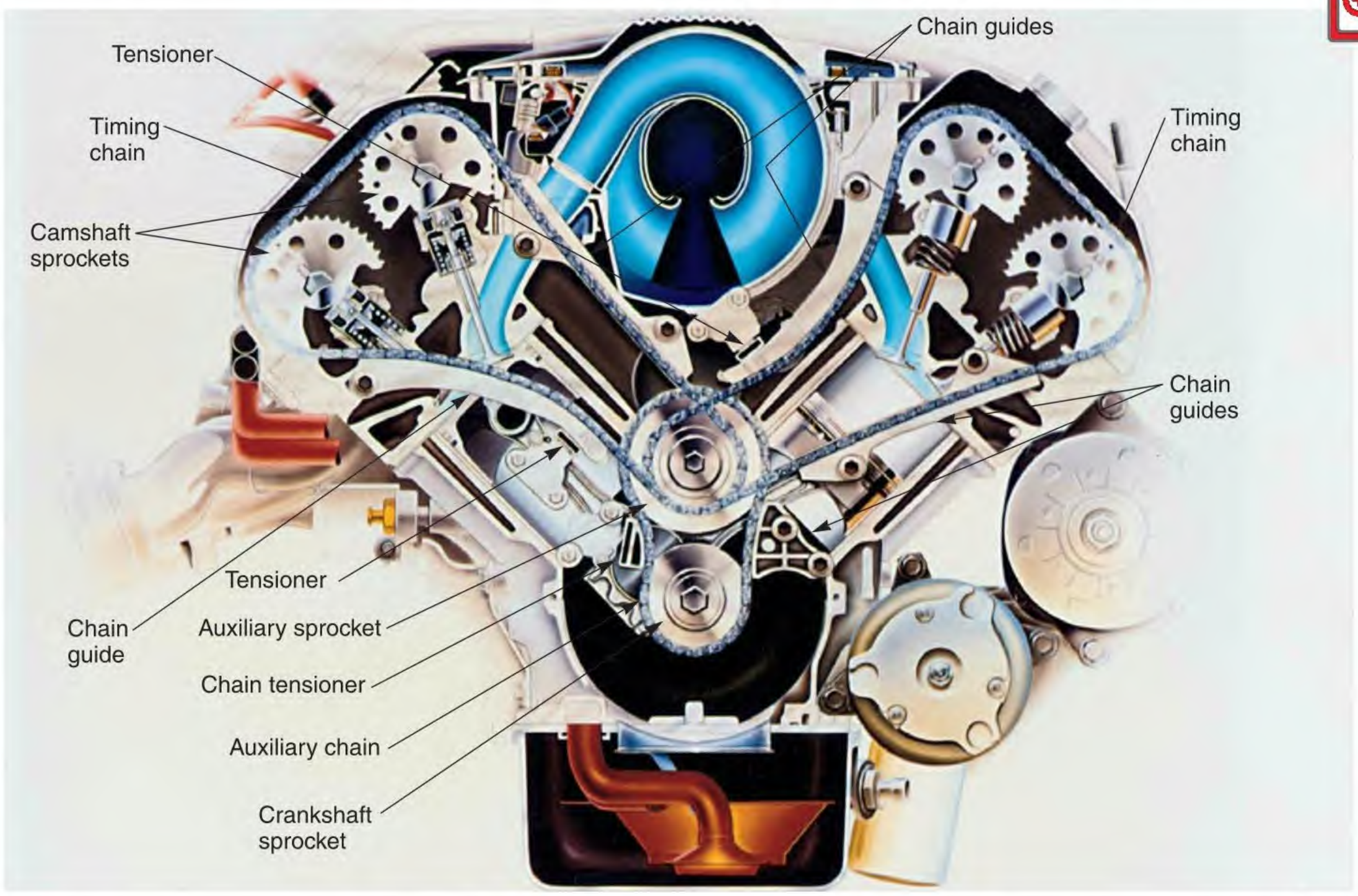
sprocket, usually placed in front of the crankshaft timing chain sprocket. Do *not* confuse an auxiliary chain with a timing chain.

Engine Front Cover Construction

An ***engine front cover***, also called a ***timing cover***, encloses the timing chain or gear mechanism and prevents oil leakage from the front of the engine. The front cover bolts to the front of the engine block. The cover may hold the front oil seal, timing pointer, crankshaft position sensor, water pump, and other parts.

A ***front oil seal*** prevents oil leakage between the crankshaft and the front cover. The seal is press-fit in the cover. See **Figure 15-8**.

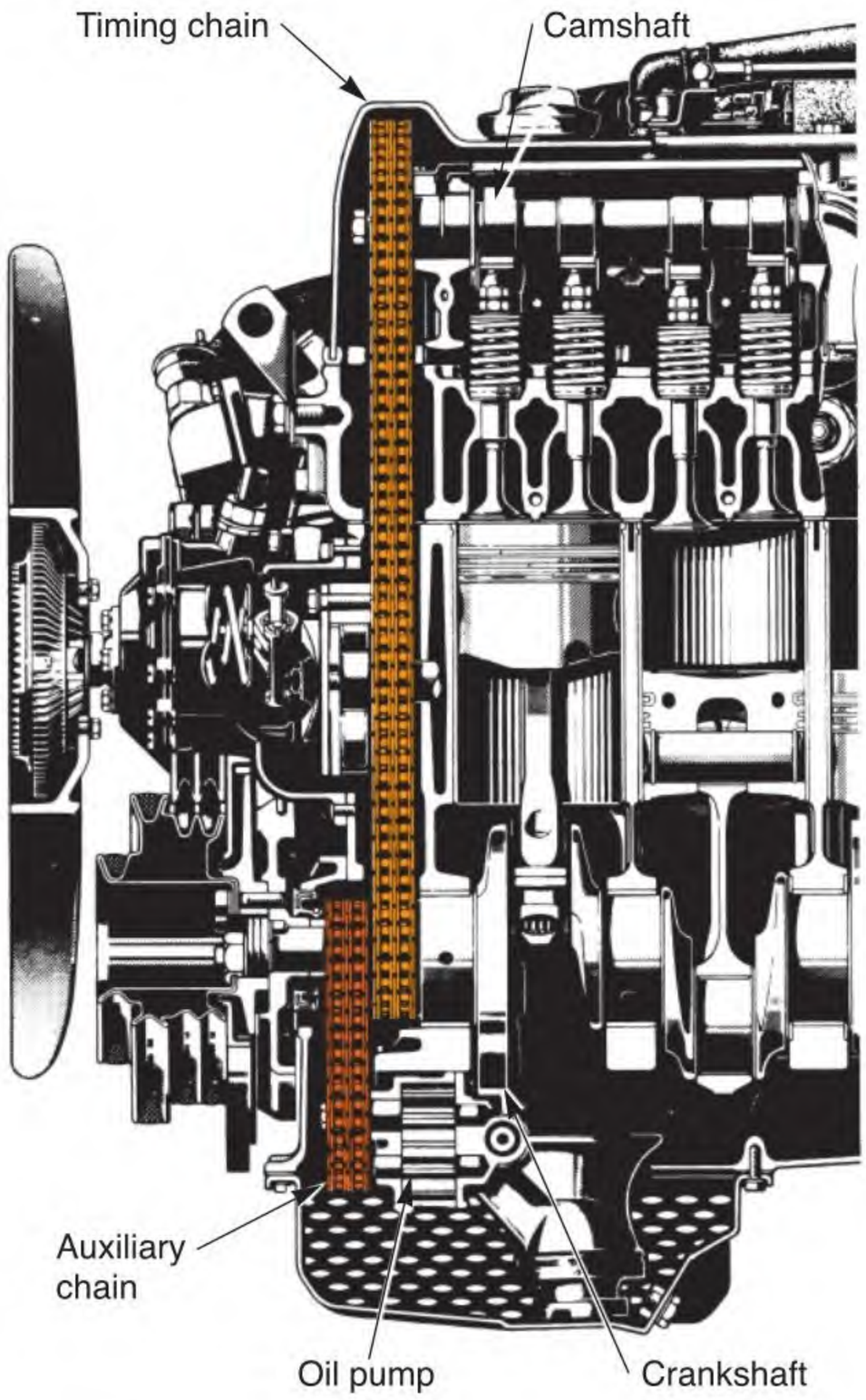
An engine front cover is commonly made of thin, stamped steel or cast aluminum. Sometimes the water pump bolts onto the front cover. Some water pump housings are cast into the front of the engine block. The core of the pump bolts onto the block housing. The oil pump may also be housed in the front cover.



Cadillac

Figure 15-6. Note the dual timing chains and the auxiliary chain in this OHC engine. Chain guides and tensioners are used on the timing chains and the auxiliary chain.

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Chrysler

Figure 15-7. A side view of a diesel engine using both a timing chain and an auxiliary drive chain.



Mazda

Figure 15-8. Note the location of the front cover on this late-model engine. In addition to enclosing the timing chain mechanism, the front cover contains the front oil seal, which prevents oil from leaking between the crankshaft and the cover itself.

Oil Slinger

An ***oil slinger*** is a washer-shaped part that fits in front of the crankshaft sprocket. When the engine is running, oil squirts out of the front main bearing and strikes the spinning slinger. Centrifugal force then throws the oil outward and onto the timing chain or gears. The oil slinger not only helps lubricate the timing mechanism, but it blocks the oil from striking the front seal, preventing leakage.

Timing Belt and Sprockets

A ***timing belt drive mechanism*** basically consists of a crankshaft sprocket, camshaft sprocket, timing belt, and belt tensioner. It is used to drive the camshaft on OHC engines.

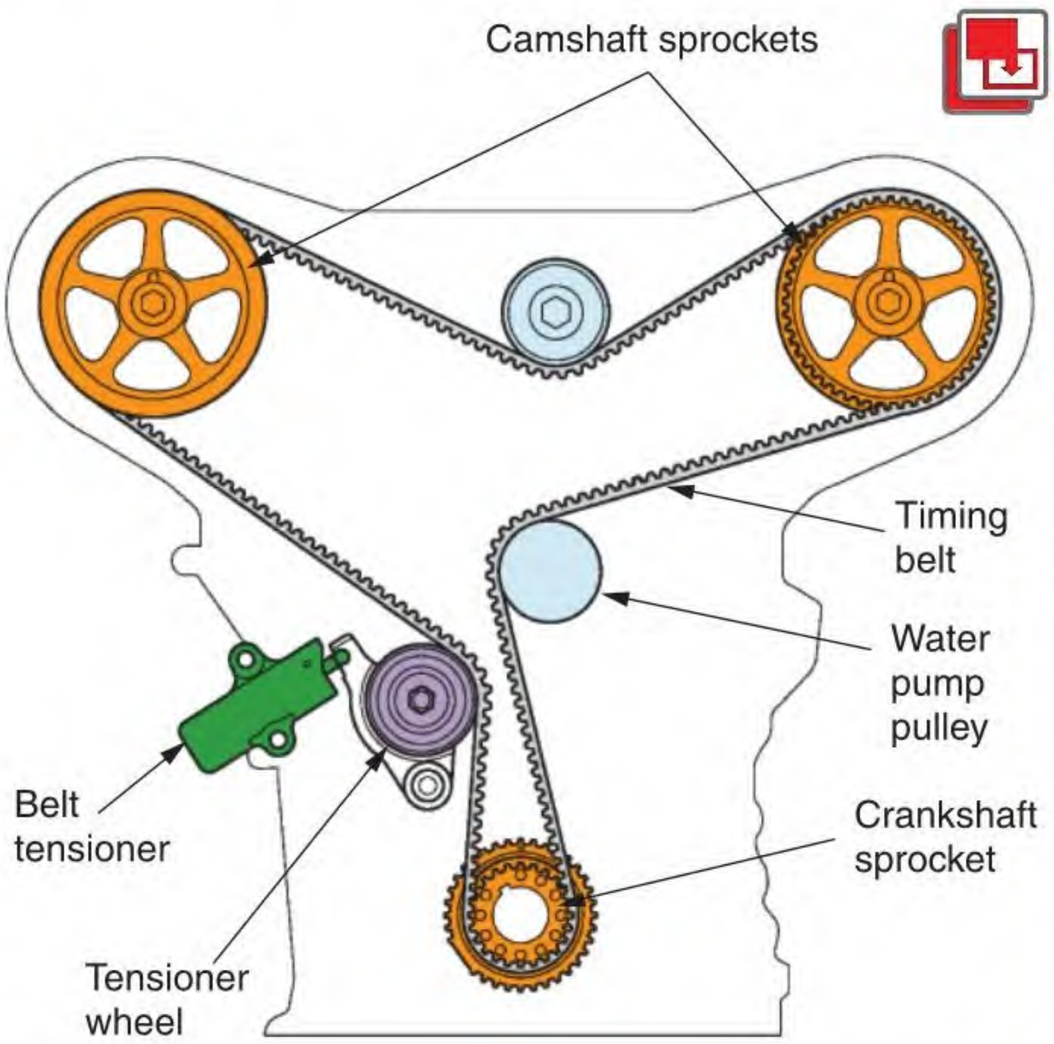
A ***timing belt*** provides a very smooth and accurate method of turning the camshaft. The timing belt and the sprockets have cogged, or square, teeth that prevent belt slippage. Some timing belts are made of fiberglass-reinforced nitrile rubber for increased strength and durability. Some are designed for a service life of over 100,000 miles (160,000 km) if not damaged by road debris or oil. Look at **Figure 15-9**.

The ***timing belt sprockets*** are usually made of cast iron or aluminum. The crank sprocket is keyed to the crankshaft snout. The camshaft sprocket normally bolts to the front of the camshaft. A dowel pin may be used to position the camshaft sprocket correctly. Belt sprockets have timing marks, just like timing gears and chain sprockets. The timing marks must be aligned with specific points on the engine. This will properly time the opening of the engine valves.

A ***belt tensioner*** is a spring-loaded wheel that keeps the timing belt firmly seated on its sprockets. The tensioner pushes inward on the back of the belt. This prevents the belt teeth from slipping on the sprocket teeth. The tensioner wheel is mounted on an antifriction bearing. This bearing is filled with grease and permanently sealed at the factory.

Some belt tensioners use both spring tension and hydraulic pressure to maintain belt tightness on its sprockets. The spring tension keeps the belt tight

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Honda

Figure 15-9. Study the parts that install on the front of this OHC engine. Cogged sprockets are used with the camshaft timing belt. A V-belt operates in the crankshaft pulley. A belt cover surrounds the timing belt and sprockets.

when the engine is shut off. The hydraulic pressure adjusts the belt tension with engine speed. At higher rpms, belt tension is increased to keep the belt from slipping or flying off.

The timing belt may also be used to drive the oil pump, diesel injection pump, or water pump.

Timing Belt Cover

A timing belt cover simply protects the belt from damage and the technician from injury. It is made from sheet metal or plastic. A gasket may seal the mating surfaces between the timing belt cover and the block. Timing belt covers are tightly sealed at the bottom to keep road debris and water off the rubber belt. If ice forms on the belt sprocket, it can cause the belt to jump off its sprockets, upsetting valve timing. This can lead to severe engine damage.

Tech Tip

A timing belt cover should not be confused with an engine front cover. A timing belt cover does not contain oil or an oil seal.

Diagnostic Case Study

Concern: Mr. Washington brought his 2009 Lexus GS350 into the shop, complaining of a knocking sound that seemed to be coming from the engine.

Cause: After asking Mr. Washington to describe the problem, Duff, the shop owner, asks specific questions about the knocking noise. He asks if the problem is the same at all engine temperatures. Mr. Washington says the knock is the same with engine cold or hot but adds that the engine seems to knock more at idle than at other speeds.

Duff starts the overhead-cam engine and notices a light rattle that seems to be coming from around the front of the engine. He passes this information along to one of the shop's ASE-certified engine repair technicians.

The technician uses a stethoscope to help pinpoint the source of the noise. He touches the tip of the stethoscope to various points on the engine to find the area emitting the loudest noise. The knock seems loudest on the sides of the timing chain cover. The technician suspects that the timing chain is hitting on the inside of the aluminum cover. He disassembles the front of engine for further inspection and discovers that the timing chain guides and the chain itself are badly worn. Marks inside the front cover serve to confirm the technician's suspicions: the worn timing chain is indeed striking the front cover.

Correction: The technician installs a new timing chain and chain guides. He also changes the oil and filter, since the oil looked very dark and dirty. When Mr. Washington returns to the shop to pick up the vehicle, the technician explains the cause of the problem and reminds him to change the oil at the recommended intervals to prevent excess engine wear.

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Summary

- The typical engine front end assembly consists of the parts that attach to the front of the engine.
- Harmonic vibration is a high-frequency movement resulting from twisting and untwisting of the crankshaft.
- A vibration damper, also called a harmonic balancer, is a heavy wheel mounted in rubber to control harmonic vibration.
- The crankshaft pulley operates belts for the alternator, water pump, and other units.
- Timing gears are two gears that operate the engine camshaft.
- A timing chain and sprockets can be used to turn the camshaft.
- A chain guide may be needed to prevent chain slap.
- A chain tensioner may be used to take up slack as the chain and sprockets wear.
- A front oil seal prevents oil leakage between the crankshaft and front cover.
- A timing belt mechanism basically consists of a crankshaft sprocket, camshaft sprocket, timing belt, and belt tensioner.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

auxiliary chain
belt tensioner
camshaft drive
chain guide
chain slap
chain tensioner
crankshaft pulley
crankshaft sprocket
dual-mass harmonic balancer
engine front cover
front oil seal
harmonic balancer
harmonic vibration
inertia ring
oil slinger
sprockets
timing belt
timing belt drive mechanism
timing belt sprockets
timing chain
timing cover
timing gears
timing marks
vibration damper

Activities

1. On an engine with the timing cover removed, locate the timing marks on the crankshaft and camshaft pulleys, gears, or sprockets. If the engine can be rotated by hand, determine whether the timing marks align properly.
2. Sketch a front-end view of an engine with a timing chain or timing belt. Show the belt or chain path and label the sprockets that the chain or belt engages.

Review Questions

Answer the following questions using the information provided in this chapter.

1. Define the term *crankshaft harmonic vibration*.
2. A(n) _____ is a heavy wheel mounted on a rubber ring to control harmonic vibration.
3. The _____ operates belts for the alternator, water pump, and other units.
4. A camshaft drive must turn the camshaft at _____ crankshaft speed.
5. Which of the following does *not* refer to timing gears?
   (A) Used on heavy-duty applications.
   (B) Dependable and long lasting.
   (C) Very quiet.
   (D) All of the above.
6. The most common camshaft drive setup for cam-in-block engines consists of a(n) _____ and a set of _____.
7. Why is a chain guide used?
8. Explain the function of a chain tensioner.
9. What does an auxiliary chain commonly drive?
10. Is an engine front cover the same as a timing belt cover?

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ASE-Type Questions

1. High-frequency movement resulting from the twisting and untwisting of the crankshaft is called:
   (A) engine knock.
   (B) after-running.
   (C) oscillating vibration.
   (D) harmonic vibration.
2. Which of the following is used to control the high-frequency movement that results from crankshaft twisting?
   (A) Vibration damper.
   (B) Crankshaft pulley.
   (C) Harmonic balancer.
   (D) Both A and C.
3. Which of the following normally operates belts for the alternator, water pump, and other units?
   (A) Auxiliary chain.
   (B) Timing sprockets.
   (C) Vibration damper.
   (D) Crankshaft pulley.
4. All of the following are basic types of camshaft drives *except:*
   (A) rod drive.
   (B) belt drive.
   (C) gear drive.
   (D) chain drive.
5. A camshaft drive must turn the camshaft at:
   (A) twice crankshaft speed.
   (B) crankshaft speed.
   (C) one-half crankshaft speed.
   (D) None of the above.
6. The two gears that operate the camshaft are the:
   (A) helical and spur gears.
   (B) crankshaft and camshaft gears.
   (C) countershaft and crankshaft gears.
   (D) camshaft sprocket and pulley gears.
7. Which of the following transfers power from the crankshaft sprocket to the camshaft sprocket?
   (A) Spur gear.
   (B) Timing idler.
   (C) Timing chain.
   (D) Timing gears.
8. Which of the following devices is used to prevent chain slap?
   (A) Chain guide.
   (B) Auxiliary chain.
   (C) Timing sprocket.
   (D) Chain link.
9. A timing belt mechanism contains each of the following *except:*
   (A) timing belt.
   (B) belt damper.
   (C) cam sprocket.
   (D) belt tensioner.
10. The washer-shaped part that fits directly in front of the crankshaft sprocket is the:
    (A) pulley.
    (B) damper.
    (C) retainer.
    (D) oil slinger.

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Chapter 16
Engine Size and Performance Measurements

After studying this chapter, you will be able to:

- Describe engine size measurements based on bore, stroke, displacement, and number of cylinders.
- Explain engine compression ratio and how it affects engine performance.
- Explain engine torque and horsepower ratings.
- Describe the different methods used to measure and rate engine performance.
- Explain volumetric efficiency, thermal efficiency, and mechanical efficiency.
- Follow safe practices when making engine performance measurements.
- Correctly answer ASE certification test questions on engine size and performance measurements.

Engine size and performance measurements are important to the technician. Shop manuals list many engine size and performance values for specific engines. You must be able to understand this information to properly communicate with others working in the auto repair industry.

Engine Size Measurement

Engine size is determined by the number of cylinders, the cylinder diameter, and the amount of piston travel per stroke. Any of these variables can be changed to alter engine size. Engine size information is used when ordering parts and when measuring wear during major engine repairs.

Bore and Stroke

Cylinder bore is the diameter of the engine cylinder. See **Figure 16-1**. It is measured across the cylinder, parallel with the top of the block. Cylinder bores vary in size, but they typically range from 3–4″ (75–100 mm).

Piston stroke is the distance the piston moves from top dead center (TDC) to bottom dead center (BDC), **Figure 16-1**. The amount of throw (offset) built into the crankshaft rod journal controls the piston stroke. The stroke also varies from about 3–4″ (75–100 mm) in automotive engines.

A shop manual normally gives bore and stroke specifications. For instance, suppose a specification for bore and stroke is given as 4.00″ × 3.00″. This means that the engine cylinder is 4″ in diameter and the piston stroke is 3″. Bore is always the first value given and stroke is the second.

Generally, a larger bore and a longer stroke make an engine more powerful. It can pull in more fuel and

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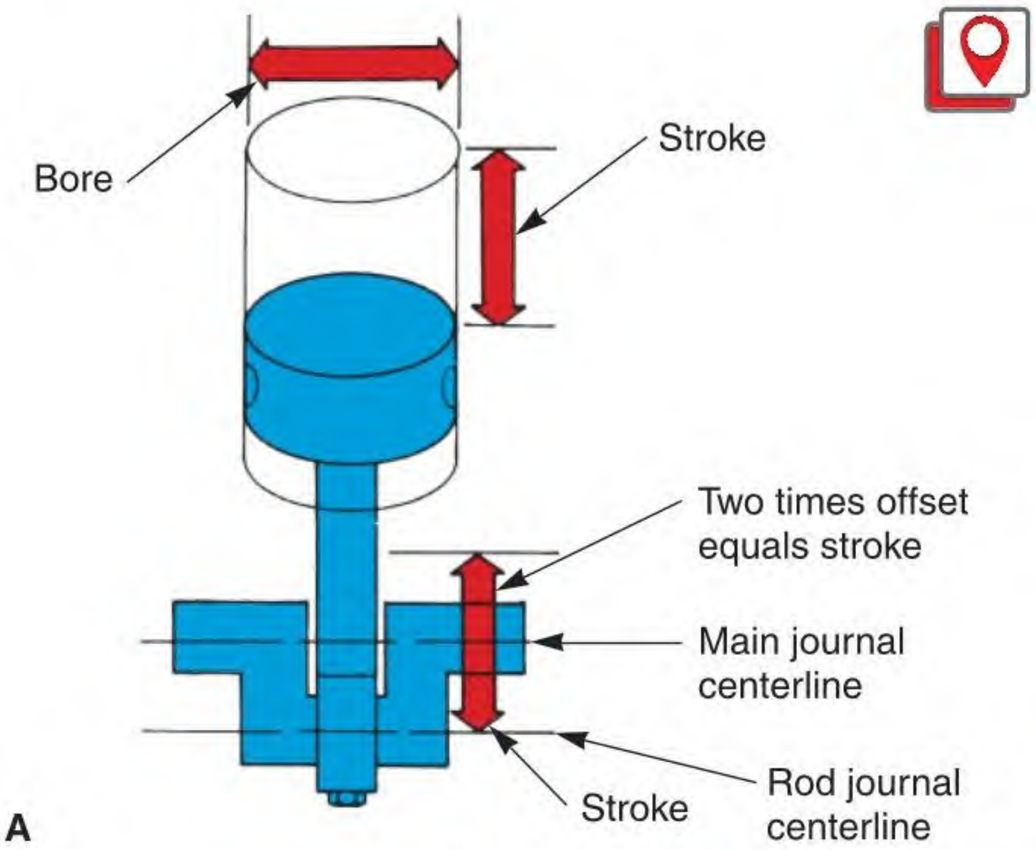


Figure 16-1. Bore and stroke measurements. A—Cylinder bore is measured across the cylinder, parallel with the deck of the engine block. Piston stroke is the distance the piston moves from BDC to TDC. Piston displacement is the amount of volume the piston moves in one upward stroke. B—Engine displacement is the volume displaced by all the pistons combined.

air (port injection) or air (direct injection) on each intake stroke. As a result, more combustion pressure is exerted on the head of the piston during the power stroke. To improve fuel economy and reduce emissions, the trend is toward smaller, more efficient engines.

Piston Displacement

Piston displacement is the volume the piston displaces (moves) as it travels from BDC to TDC. It is found by comparing cylinder diameter and piston stroke. A large cylinder diameter and large piston stroke produce a large piston displacement.

Piston displacement is calculated using a simple formula:

$$\text{piston displacement} = \frac{\text{bore squared} \times 3.14 \times \text{stroke}}{4}$$

Example: If an engine has a bore of 4″ and a stroke of 3″, what is its piston displacement?

Solution: $\text{piston displacement} = \frac{(4'')^2 \times 3.14 \times 3''}{4}$

$= 37.68$ cu. in.

Engine Displacement

Engine displacement, or ***engine size***, is the volume displaced by all the pistons in an engine (piston displacement multiplied by the number of engine cylinders). For example, if one piston displaces 25 cu. in. and the engine has four cylinders, the engine displacement would be 100 cu. in. ($25 \times 4 = 100$).

Cubic inch displacement (CID), ***cubic centimeters (cc)***, and ***liters (L)*** are units of engine displacement. For example, a V-8 engine might have a 350 CID. A V-6 could be a 3.3 L engine. A four-cylinder engine might have a displacement of 2300 cc. Since one liter equals 1000 cc, a 2 liter engine would have 2000 cc.

Engine displacement is usually matched to the weight of the vehicle. A heavy car, truck, or van needs a large engine, which produces a great deal of power. A light vehicle only needs a small, low-power engine for adequate acceleration.

Force, Work, and Power

Force is a pushing or pulling action. When a spring is compressed, an outward movement and force is produced. Force is measured in pounds or newtons.

Work is done when force causes movement. If a compressed spring moves another engine part, work has been done. If the spring does not cause movement, no work has been done. Work is measured in foot-pounds or joules. The formula for work is:

$\text{work} = \text{distance moved} \times \text{force applied}$

Example: If you use a hoist to lift a 400 lb engine 3′ in the air, how much work has been done?

Solution: $\text{work} = 3' \times 400$ lb

$= 1200$ foot pounds (ft lb)

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Power is the rate, or speed, at which work is done. It is measured in foot-pounds per second or per minute. The metric unit for power is the watt (kilowatt).

The formula for power is:

$$\text{power} = \frac{\text{distance (feet)} \times \text{force (pounds)}}{\text{time (minutes)}}$$

Example: If a hydraulic lift raises a 3000 lb car 8' in 30 seconds, how much power is needed?

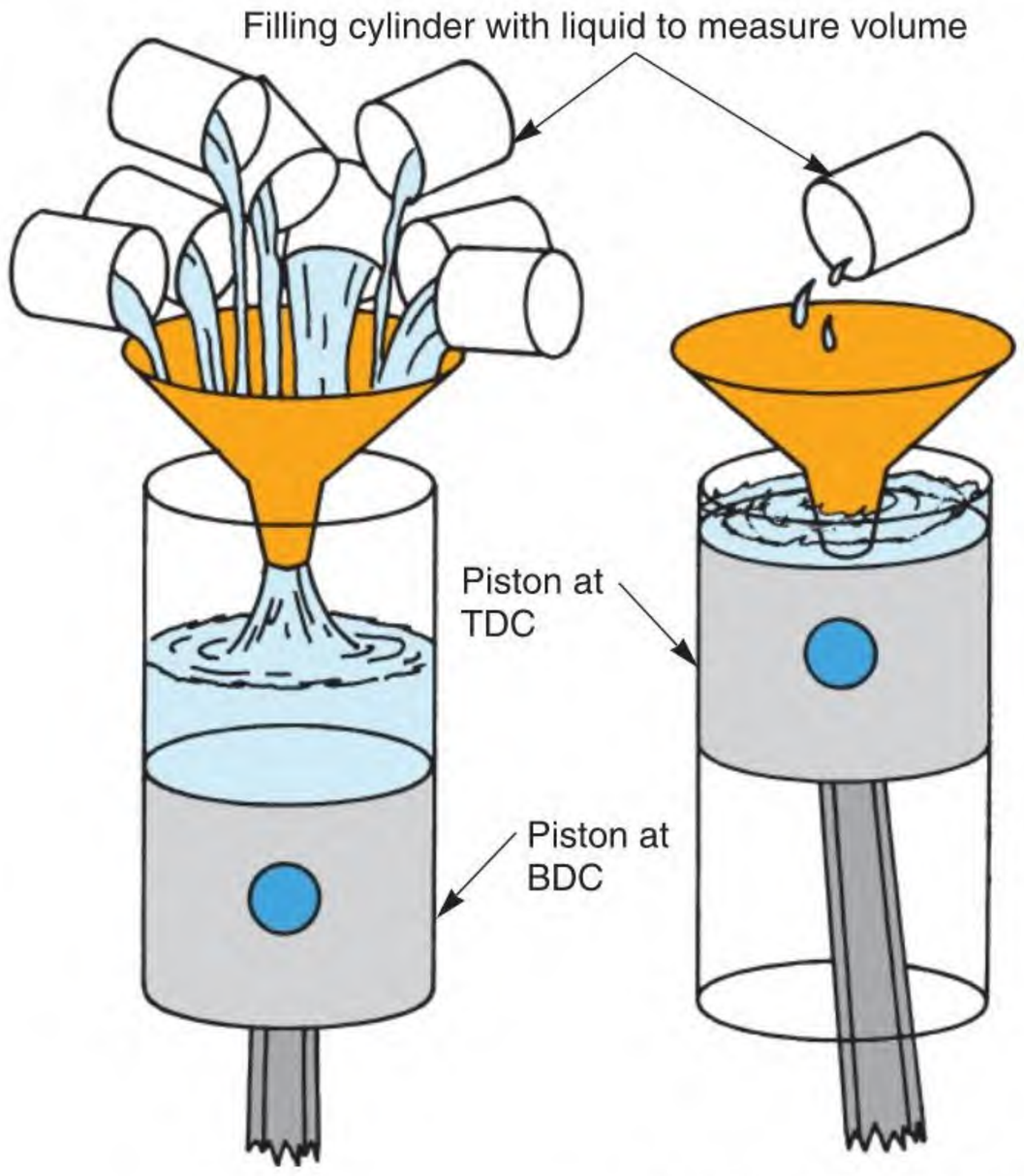
Solution:

$$\text{power} = \frac{8 \times 3000 \text{ lb}}{0.5 \text{ min.}}$$

$$= \frac{48{,}000 \text{ ft lb}}{\text{min.}}$$

Compression Ratio

Engine ***compression ratio*** compares the cylinder volume with the piston at TDC to the cylinder volume with the piston at BDC. An engine's compression ratio partially determines how much the air-fuel mixture is pressurized, or squeezed, on the compression stroke. A compression ratio is given as two numbers. For example, an engine may have a compression ratio of 9:1 (9 to 1). This means the maximum cylinder volume is nine times larger than the minimum cylinder volume. At BDC, a cylinder has maximum volume. Minimum cylinder volume occurs at TDC. Look at **Figure 16-2**.



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Figure 16-2. Compression ratio is a comparison of cylinder volumes with the piston at TDC and BDC. This engine has eight times the volume at BDC, producing an 8:1 compression ratio.

Figure 16-3A illustrates an example of a compression ratio for a gasoline engine. When the gasoline engine piston is at BDC, the cylinder volume is 40 cu. in. (0.65 L). When the piston slides to TDC, the volume is reduced to 5 cu. in. (0.08 L). Dividing 40 by 5 (0.65 by 0.08), the compression ratio for this engine would be 8:1.

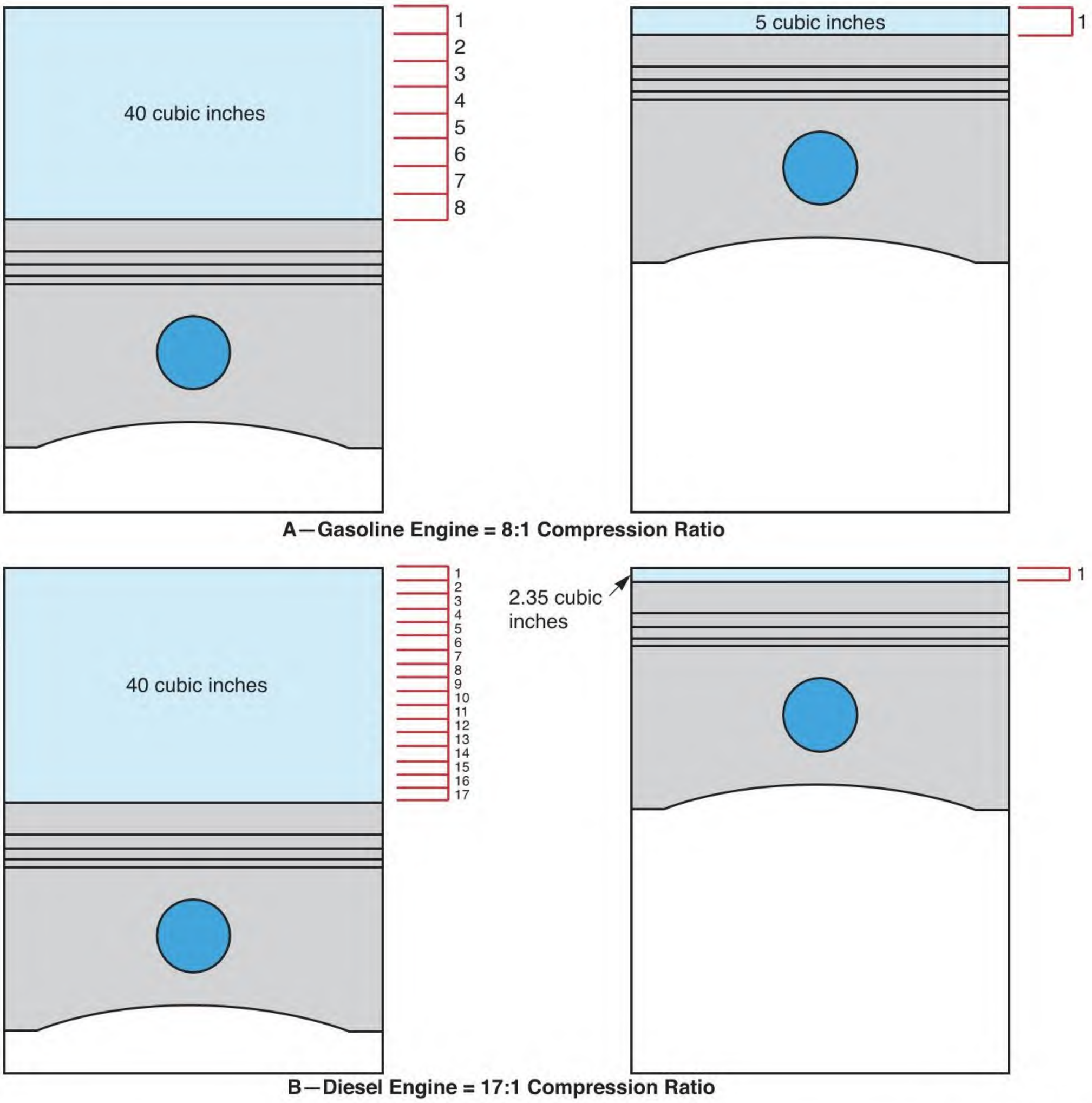
Engines manufactured in the 1960s had very high compression ratios from the factory. They were designed to run on high-octane leaded gasoline. These "muscle car engines" had stock compression ratios as high as 11 or 12:1. When lead was phased out of gasoline for environmental reasons, automakers started reducing compression ratios to improve driveability, but lost power and gas mileage.

Today's high-tech, high-efficiency engines are again being designed with relatively high compression ratios. Late-model, naturally aspirated, high-performance engines can now have compression ratios as high as 11 or 12:1.

Factory supercharged and turbocharged engines have a lower compression ratio (usually about 7 or 8:1) than naturally aspirated engines (only atmospheric pressure pushes air into the engine intake manifold). The supercharger or turbocharger forces the air charge into the engine above atmospheric pressure. The lower compression ratio allows a larger volume of air (oxygen) to be forced into the combustion chambers. In effect, the supercharger or turbocharger raises the compression ratio and pressure in the engine cylinders to provide greater fuel-charge compression, as well as more rapid and complete combustion of the fuel mixture.

Diesel engines have a very high compression ratio compared to engines designed to burn gasoline. Typical compression ratios for diesel engines range from 17:1 for automotive diesel engines to 25:1 for industrial diesels. **Figure 16-3B** illustrates an example of a compression ratio for a diesel engine. Being a compression-ignition engine, the fuel charge must be pressurized until it is hot enough to burn. Unlike a gasoline engine, no spark plug is used to produce an electric arc to start combustion. Compression pressure alone must start combustion of the fuel/air mixture.

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Figure 16-3. A diesel engine has a much higher compression ratio than a gasoline engine. A diesel must squeeze the fuel mixture very tight to cause combustion.

Compression Pressure

Compression pressure is the amount of pressure produced in the cylinder during the compression stroke. Compression pressure is normally measured in pounds per square inch (psi) or kilopascals (kPa).

A ***compression gauge*** is used to measure compression pressure. The gauge is screwed into the spark plug, injector nozzle, or glow plug hole. The ignition or injection system (whichever contains the removed part) is disabled. Then, the engine is cranked over. The gauge measures the compression pressure.

A gasoline engine has compression pressure from 130–180 psi (900–1200 kPa). A diesel engine has a much higher compression pressure of about 250–400 psi (1700–2800 kPa). A turbocharged or supercharged engine may develop only 110 to 150 psi compression pressure during a compression test.

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Service specifications will give the exact compression pressure for a new, unworn engine.

Compression pressure is an indicator of engine condition. If it is low, something is allowing air to leak out of the cylinder. The engine may have bad rings, burned valves, or a blown head gasket.

Engine Torque

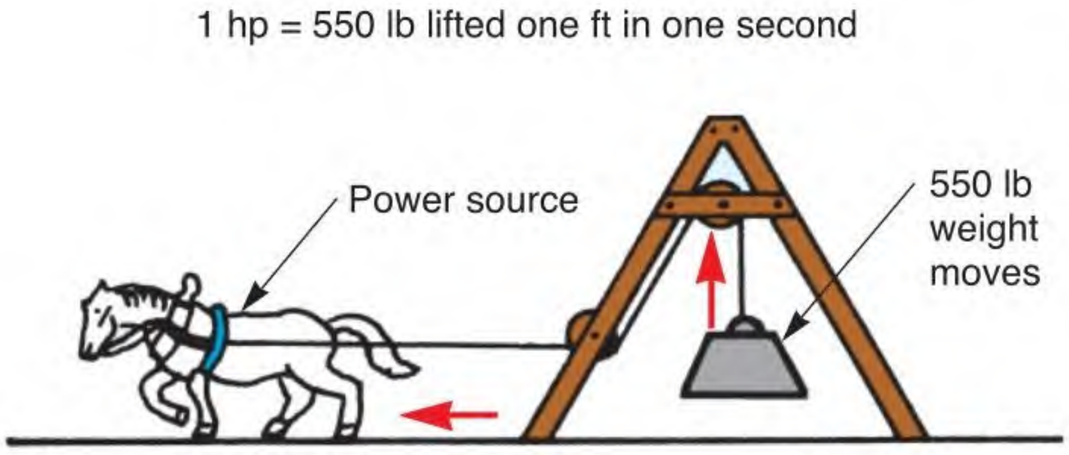
Torque is a turning, or twisting, force. When you turn a steering wheel or tighten a belt, you have applied torque.

Engine torque is a rating of the turning force at the engine crankshaft. When combustion pressure pushes the piston down, a strong rotating force is applied to the crankshaft. This turning force is sent to the transmission or transaxle, and to wheels, propelling the car.

Engine torque specifications are given in a shop manual. An example of a torque specification is 450 ft lb @ 3000 rpm. This high-performance engine would be capable of producing a maximum of 450 ft lb of torque at an operating speed of 3000 revolutions per minute. In metrics, engine torque is often stated in newton-meters (N•m).

Horsepower

Horsepower (hp) is a measure of an engine's ability to perform work (power). The term *horsepower* originated over 200 years ago when James Watt used the term to compare the work done by a steam engine to that done by horses. It was determined that one horsepower would be approximately equal to the amount of work done by a strong horse in one minute. A 300 hp engine could theoretically do the work of 300 horses, **Figure 16-4**.



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Figure 16-4. This represents one horsepower. In automotive work, one horsepower equals 33,000 lb moved one foot in one minute.

One horsepower equals 33,000 ft lb of work per minute. To find engine horsepower, use the following formula:

$$hp = \frac{\text{work (ft lb)}}{33{,}000}$$

or

$$hp = \frac{\text{distance (ft)} \times \text{weight (lb)}}{33{,}000}$$

Example: For a small engine to lift 500 lb a distance of 700′ in one minute, about how much horsepower would be needed?

Solution:

$$hp = \frac{700' \times 500 \text{ lb}}{33{,}000}$$

$$= 10.6 \text{ hp}$$

Factory Horsepower Ratings

Automobile makers rate engine horsepower at a specific engine speed. For instance, a high-performance, supercharged engine might be rated at 400 hp @ 5000 rpm. This engine power rating is normally stated in a service manual or sales literature. There are several different methods of calculating engine horsepower.

Brake horsepower (bhp) measures the usable power at the engine crankshaft. A prony brake was first used to measure brake horsepower. The engine turns the prony brake when the braking mechanism is applied, producing a force on the scale. The resulting amount of pointer deflection is then used to find brake horsepower. See **Figure 16-5**.

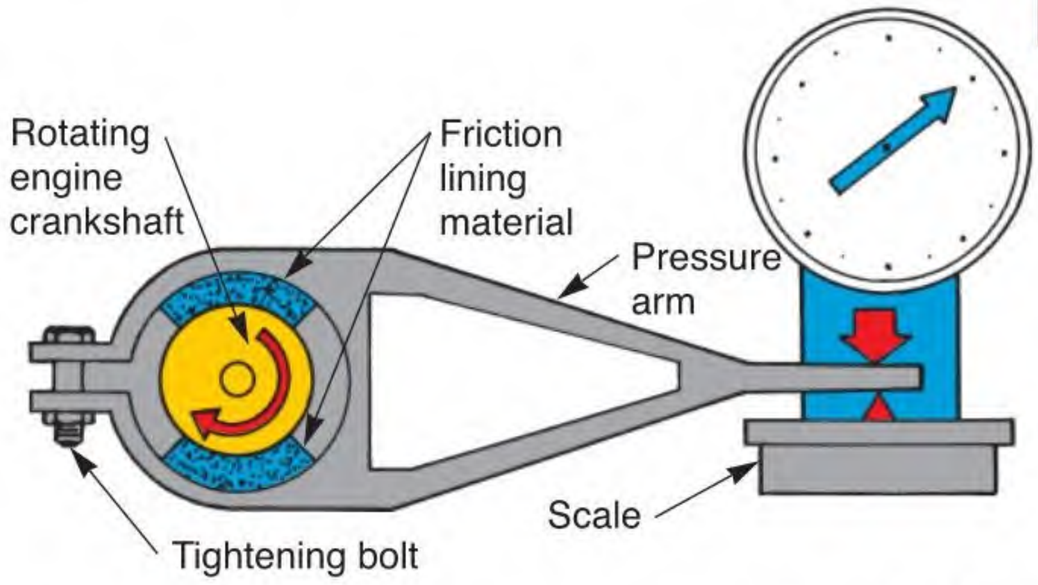
An ***engine dynamometer (dyno)*** is used to measure the brake horsepower of modern car engines. Refer to **Figure 16-6**. It functions in much the same way as a prony brake. Either an electric motor or a fluid coupling is used to place a drag on the engine crankshaft. Then, brake horsepower output can be determined.

A ***chassis dynamometer*** measures the horsepower delivered to the drive wheels. See **Figure 16-7**. It indicates the amount of horsepower available to propel the car.

Indicated horsepower (ihp) refers to the amount of power formed in the engine combustion chambers. A special pressure-sensing device is placed in the cylinder. The pressure readings are used to determine the indicated horsepower.

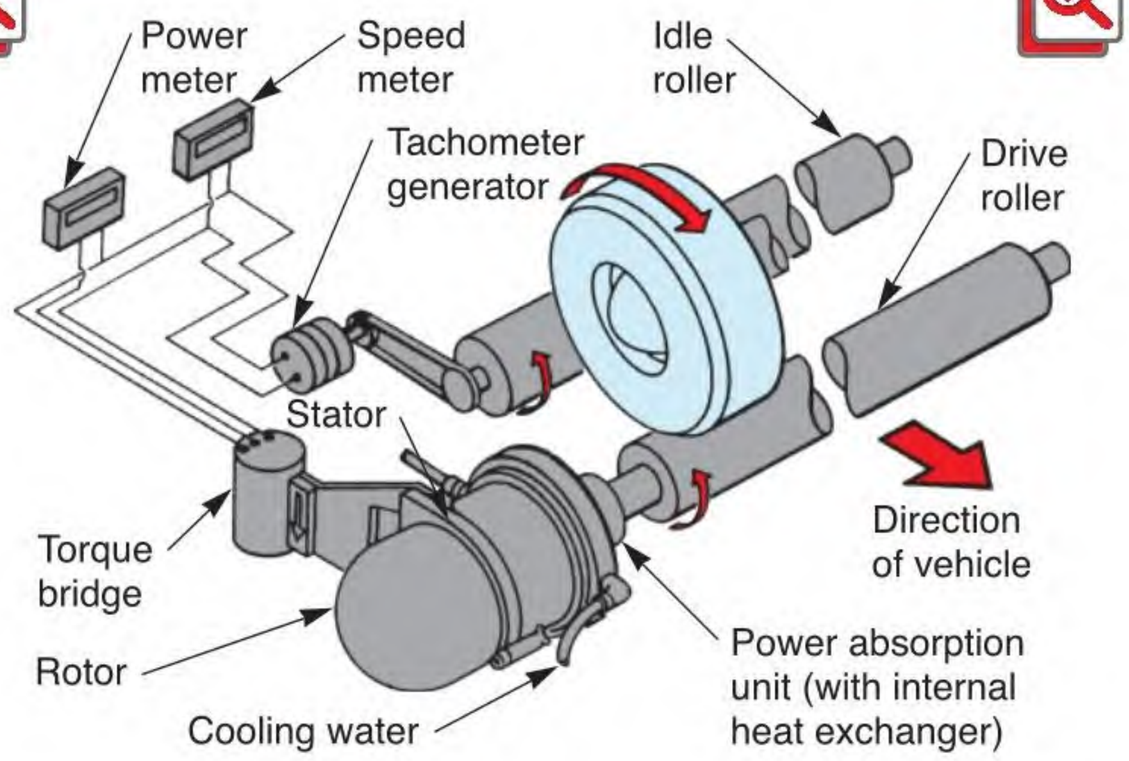
Frictional horsepower (fhp) is the power needed to overcome engine friction. It is a measure of the resistance to movement between engine parts, or

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Figure 16-5. A prony brake measures engine brake horsepower. A brake is applied to the engine crankshaft. The amount of needle deflection can be used to find horsepower.



Clayton

Figure 16-7. A chassis dynamometer measures turning power at the drive wheels. This accounts for any power consumed by the drive train.



MSD Ignition Systems

Figure 16-6. A technician is using an engine dynamometer to measure engine performance. The dynamometer loads the engine to simulate driving conditions while monitoring horsepower output, fuel efficiency, emissions, and many other engine functions.



Ford

Figure 16-8. Net horsepower is the available horsepower with the engine operating all accessories.

power lost to friction. It reduces the amount of power left to propel the car.

Net horsepower, or SAE net horsepower, is the maximum power developed when an engine is loaded by all accessories (alternator, water pump, fuel pump, air injection pump, air conditioning, and power steering pump). Net horsepower indicates the amount of power available to move the car. Look at **Figure 16-8**.

Gross horsepower (ghp) is similar to net horsepower, but it is the engine power available with only basic accessories installed (alternator, fuel pump, and water pump). Gross horsepower does not include the power lost to the power steering pump, air injection pump, air-conditioning compressor, or other extra units. Refer to **Figure 16-9**.

Taxable horsepower is simply a general rating of engine size. In some states, it is used to find the tax placed on a car. The formula for taxable horsepower (thp) is:

$$thp = \text{bore squared} \times \text{number of cylinders} \times 0.4$$

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Mazda

Figure 16-9. Gross horsepower is similar to net horsepower, but it does not include power lost to unneeded accessories.

Volumetric Efficiency

Volumetric efficiency is the ratio of air drawn into the cylinder to the maximum possible amount of air that could enter the cylinder. It is an indication of how well an engine can "breathe" on its intake stroke.

If volumetric efficiency was 100%, the cylinder would completely fill with air on the intake stroke. Engines are capable of only 80–90% volumetric efficiency. Restrictions in the ports and around the valves limit airflow.

High volumetric efficiency increases engine power because more fuel and air can be burned in the combustion chambers. The formula for volumetric efficiency is:

$$\text{volumetric efficiency} = \frac{\text{actual volume of air taken into cylinder}}{\text{volume of cylinder}}$$

Mechanical Efficiency

Mechanical efficiency compares brake horsepower and indicated horsepower. It is a measurement of mechanical friction. Indicated horsepower is the theoretical power produced by combustion. Brake horsepower is the actual power at the engine crankshaft. The difference between the two is due to friction losses.

Mechanical efficiency of 70–80% is normal. This means that 20–30% of the engine's power is lost to friction (frictional hp loss). The friction between the piston rings and cylinder walls accounts for most of this loss.

Thermal Efficiency

Thermal efficiency is found by comparing the horsepower output to the amount of fuel burned. It indicates how well an engine uses the fuel's heat energy. Thermal efficiency measures the amount of heat energy converted into crankshaft rotation.

Generally, engine thermal efficiency is 30–40%. The rest of the heat energy is absorbed by the metal parts of the engine or blown out the exhaust.

Industry Trend

Vehicle design has been greatly refined during the last few years. Sports cars like the Corvette and the Dodge Viper produce over 500 horsepower while producing far less pollution than their counterparts of past. High-performance, "race-bred parts" are found in every major system of today's sports cars.

Summary

- Engine size is determined by cylinder diameter, amount of piston travel on each stroke, and number of cylinders.
- Cylinder bore is the diameter of the engine cylinder.
- Piston stroke is the distance the piston moves from TDC to BDC.
- Piston displacement is the volume the piston displaces (moves) from BDC to TDC.
- Engine displacement, or engine size, equals piston displacement times the number of engine cylinders.
- Force is a pushing or pulling action.
- Work is done when force causes movement.
- Power is the rate, or speed, at which work is done.
- Engine compression ratio compares cylinder volumes with the piston at TDC and BDC.
- Compression pressure is the amount of pressure produced in the engine cylinder on the compression stroke.
- Torque is a turning, or twisting, force.
- Engine torque is a rating of the turning force at the engine crankshaft.

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- Horsepower (hp) is a measure of an engine's ability to perform work.
- Brake horsepower (bhp) measures the usable power at the engine crankshaft.
- An engine dynamometer (dyno) is used to measure brake horsepower.
- A chassis dynamometer measures the horsepower delivered to the drive wheels.
- Volumetric efficiency is the ratio of actual air drawn into the cylinder and the maximum possible amount of air that could enter the cylinder.
- Mechanical efficiency compares brake and indicated horsepowers. It is a measurement of mechanical friction.
- Thermal efficiency is heat efficiency found by comparing fuel burned and horsepower output.

Technical Terms



Write the definitions for the following terms on a separate sheet of paper.

brake horsepower (bhp)
chassis dynamometer
compression gauge
compression pressure
compression ratio
cubic centimeters (cc)
cubic inch displacement (CID)
cylinder bore
engine displacement
engine dynamometer (dyno)
engine size
engine torque
force
frictional horsepower (fhp)
gross horsepower (ghp)
indicated horsepower (ihp)
liters (L)
mechanical efficiency
net horsepower
piston displacement
piston stroke
power
taxable horsepower
thermal efficiency
torque
volumetric efficiency
work

Activities

1. Use a compression gauge to measure the compression of each cylinder of an engine. Check your findings against the specifications for that engine. Are all the readings "in spec," or do one or more cylinders read high or low?
2. Convert your compression readings from pounds per square inch to kilopascals, or vice versa. Multiply psi readings by 6.895 to find kPa; divide kPa readings by 6.895 to find psi.

Review Questions



Answer the following questions using the information provided in this chapter.

1. What three factors determine engine size?
2. Cylinder bore is measured across the cylinder, parallel with the top of the block. True or False?
3. Piston stroke is the distance the piston moves during a complete four-stroke cycle. True or False?
4. _____ is the volume the piston moves from BDC to TDC.
5. If an engine has a bore of 3.5″ and a stroke of 3″, what is the piston displacement?
6. Define the term *engine displacement*.
7. Explain the difference between force, work, and power.
8. When a gasoline engine's piston is at BDC, the cylinder volume is 45 cu. in. When the piston slides to TDC, the cylinder volume is 9 cu. in. What is the compression ratio for this engine?
   (A) 8:1.
   (B) 5:1.
   (C) 7:1.
   (D) 9:1.
9. Which of the following would *not* be a compression ratio for a car engine?
   (A) 2:1.
   (B) 8:1.
   (C) 17:1.
   (D) 20:1.
10. A gasoline engine may produce a compression pressure of _____ to _____ psi (_____ to _____ kPa).
11. A diesel engine can produce a compression pressure of about _____ to _____ psi (_____ to _____ kPa).

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12. What is engine torque?
13. Explain the term "horsepower."
14. The ratio of actual air drawn into an engine to the maximum possible air that could enter the engine is called _____.
15. A piston engine's thermal efficiency is approximately _____.
    (A) 80–100%
    (B) 70–80%
    (C) 40–50%
    (D) 20–30%

ASE-Type Questions

1. Engine size is determined by:
   (A) cylinder diameter.
   (B) number of cylinders.
   (C) piston travel per stroke.
   (D) All of the above.
2. The distance a piston moves from TDC to BDC is called:
   (A) piston taper.
   (B) piston stroke.
   (C) piston clearance.
   (D) piston displacement.
3. Piston displacement times the number of engine cylinders equals:
   (A) engine size.
   (B) cylinder bore.
   (C) engine torque.
   (D) compression ratio.
4. Work can be measured in:
   (A) watts.
   (B) joules.
   (C) kilograms.
   (D) kilopascals.
5. Modern gasoline engines have a compression ratio of about:
   (A) 8 or 9:1.
   (B) 11 or 12:1.
   (C) 15 or 16:1.
   (D) 20 or 21:1.
6. Compression pressure is measured in:
   (A) kilopascals.
   (B) pounds per square inch.
   (C) Both A and B.
   (D) Neither A nor B.
7. Diesel engines have compression pressure of about:
   (A) 130 to 180 psi.
   (B) 250 to 400 psi.
   (C) 425 to 500 psi.
   (D) 510 to 525 psi.
8. One horsepower equals:
   (A) 28,000 kW of work per minute.
   (B) 25,000 ft lb of work per hour.
   (C) 30,000 in lb of work per second.
   (D) 33,000 ft lb of work per minute.
9. Which of the following is used to measure brake hp of an engine?
   (A) Brake tachometer.
   (B) Compression gauge.
   (C) Engine dynamometer.
   (D) Chassis dynamometer.
10. Which abbreviation indicates the amount of power or pressure formed in engine combustion chambers?
    (A) ihp.
    (B) fhp.
    (C) ghp.
    (D) thp.

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Section 3

Fundamentals of Electricity and Electronics

Chapter 17
Electrical Principles

Chapter 18
Circuit Types and Ohm's Law

Chapter 19
Electrical and Electronic Components

Chapter 20
Electrical Tools and Test Equipment

Chapter 21
Wiring Diagrams and Wiring Repairs

Chapter 22
Basic Electrical Tests

If you look under the hood of any late-model vehicle, you will see a maze of wires connecting dozens of devices. In fact, electrical and electronic devices are found in almost every major automotive system, including the suspension, transmission, fuel, ignition, emission control, and braking systems.

Section 3 will introduce you to the basics of automotive electricity and electronics. It contains detailed explanations of electrical principles, describes various circuit types and components, discusses the tools and test equipment used when servicing these systems, outlines techniques for reading wiring diagrams and performing wiring repairs, and provides a thorough explanation of the basic electrical tests.

This section will provide you with a sound background in electricity and electronics, which is necessary to effectively troubleshoot and service today's complex vehicle systems. It will also help you pass ASE Certification Test A6, Electricity and Electronics, as well as several other ASE Certification Tests.



Chapter 17
Electrical Principles

After studying this chapter, you will be able to:

- Describe the parts of the atom.
- Explain the principles of electricity.
- Describe the principles of magnetism and magnetic fields.
- Describe the action of electric circuits.
- Compare voltage, current, and resistance.
- Compare dc and ac electricity.
- Correctly answer ASE certification test questions that require a basic understanding of electricity and electronics.

By understanding the principles of electricity, you will be much better at problem solving or troubleshooting electrical and electronic systems of a car. By knowing what electricity is and how it functions in nature, you will also have a much better grasp of the more complex electronic components covered in later chapters.

Atomic Structure

To fully grasp the concept of electricity, you must first have a basic understanding of atoms and the atomic structure of matter. ***Matter*** is anything in the universe that occupies space and has mass (weight). Matter can be a solid, a liquid, or a gas.

All matter is made up of atoms. An ***atom*** is a microscopic particle that cannot be broken into smaller pieces without losing its properties. This book, air, the sun, and even your body are made of atoms. Atoms are too small to be seen without a highly specialized electron microscope.

An ***element*** is a group of one type of atom. For example, hydrogen is the simplest element in the universe and it contains atoms of hydrogen only. There are over 100 elements in nature. They combine to form all types of matter. The periodic table of elements lists all known elements or atom types.

A ***molecule*** is a group of two or more atoms joined together. Water (H_2O) is a molecule because it contains three atoms. Each water molecule has two hydrogen atoms and one oxygen atom, hence H_2O. A ***compound*** is a substance composed of molecules containing two or more elements.

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Parts of an Atom

An atom consists of three parts:

- ***Electrons***—Electrons are negatively charged particles that circle in specific orbits around the center, or ***nucleus***, of the atom.
- ***Protons***—These positively charged particles are located in the nucleus of the atom.
- ***Neutrons***—Neutrons are particles with no positive or negative charge, but still have mass and occupy space, in the nucleus.

Figure 17-1 shows the relationship of electrons, protons, and neutrons in a simple atom.

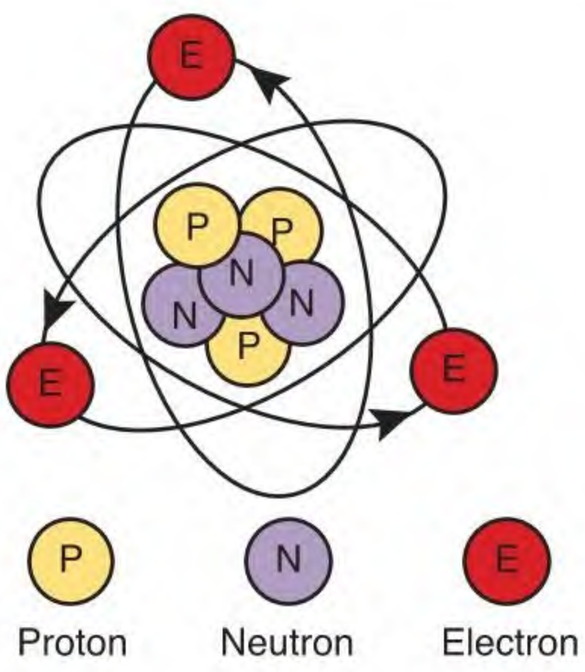
Free Electrons

Normally, an atom has a balance of forces. The number of electrons circling the center of the atom equals the number of protons in the nucleus. This makes the atom stable. However, it is possible for atoms to have extra electrons in their outer orbits. These extra electrons are known as ***free electrons***. Free electrons can be easily dislodged from one atom and made to jump to a neighboring atom, **Figure 17-2**.

Electricity

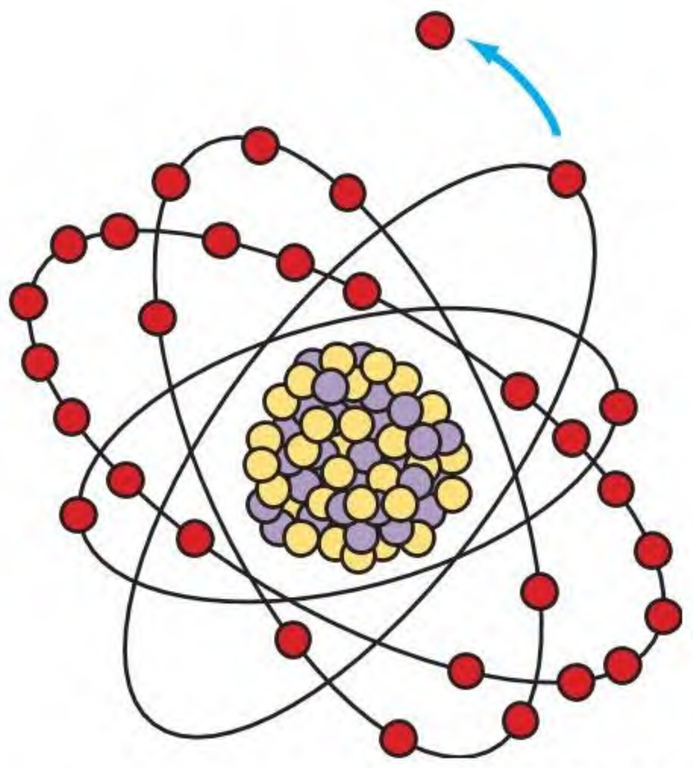
Movement of free electrons is the result of a difference in positive and negative charges between atoms. This difference causes a free electron to jump from one atom and enter the orbit of an adjacent atom. This extra electron will upset the balance of forces in the adjacent atom (adjacent atom becomes negatively charged). As a result, an electron will be forced to jump out of orbit in that atom and enter the orbit in another atom in the conductor. This will cause a chain reaction, and free electrons will continue to jump from atom to atom throughout the circuit. The resulting flow of electrons is electric current, as shown in **Figure 17-3**.

Electricity can be defined as the movement of free electrons from one atom to another. If a wire has a ***negative charge*** (excess electrons) on one end and a ***positive charge*** (excess protons) on the other end, electrical flow, or ***discharge*** will result. Electrical discharge is the flow of electrons through the atoms in a solid, gas, or liquid. The electrons will flow through the wire to balance out the atomic forces.



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Figure 17-1. The nucleus of an atom contains protons and neutrons that have no charge. Electrons orbit around the nucleus of the atom.



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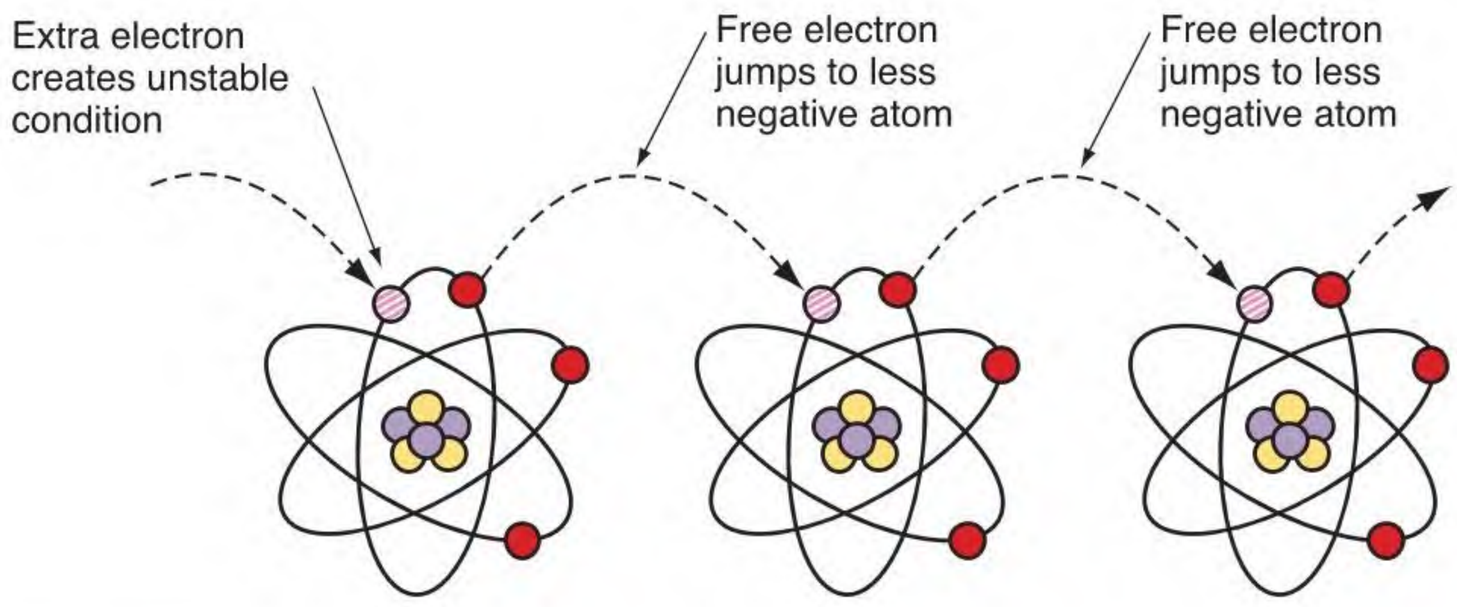
Figure 17-2. This copper atom is a good conductor of electricity because its outer electron is not tightly bonded to the atom. This electron can move from atom to atom to produce current.

Conductors and Insulators

A ***conductor*** is a substance that allows the flow of free electrons. Metal wires make good conductors because metals (gold, silver, copper, aluminum, iron, etc.) have unstable atoms that allow electrical flow from one point to another. Gold is the best conductor of all the elements.

An ***insulator*** is a substance that resists or stops the flow of electrons. The atoms in insulators are very stable and do not allow easy electron movement. For instance, the insulation on wires is designed to prevent electron flow out of the center conductor of the wire. Examples of insulators include air, glass, plastic, rubber, and porcelain.

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Figure 17-3. When a free electron jumps to an atom, that atom becomes negatively charged and unstable, forcing an electron to jump from that atom to a less negative atom. The second atom becomes unstable, and an electron jumps to the next less negative atom. This chain reaction is the basis of electricity.

Functions of Electricity

Electricity has three basic functions—to produce light, heat, and motion. For example, electricity can be sent through a lightbulb. The filament in the bulb heats up and glows white hot, producing light.

When free electrons flow through a conductor with high resistance, such as a filament in an incandescent lightbulb, an electrical friction results. Just as rubbing your hands together produces heat, the electrons rubbing against the atoms in the filament produce heat. This is why incandescent lightbulbs grow warm when they are lit.

Electricity is also used to produce movement of parts, as well as magnetism. The magnetism is used inside electric motors, relays, solenoids, and other electric devices to cause motion and to do work.

Mechanical vs. Electrical

In newer automobiles, electrical devices have replaced many mechanical devices. Electrical devices can do the job of mechanical devices more quickly and efficiently.

With electronics, the car can be designed for higher fuel economy and higher performance, but with fewer toxic emissions. The vehicle can be made to be lighter, ride more smoothly, stop more quickly, and provide more comfort and convenience for its driver and passengers. As you will learn, modern vehicles have an advanced computer system that will detect and identify hundreds of problems so they can be repaired quickly and easily.

Electrical vs. Electronic

An ***electrical device*** is a conventional component that uses electricity to do work, such as an electric motor, a mechanical switch, relay, solenoid, lightbulb, etc. While these devices are still used today, the term refers to devices that were used prior to the invention of the transistor, computer, and electronics industry.

An ***electronic device*** is a more modern solid state component that does not use moving parts for operation. Examples include diodes, transistors, sensors, and computers. Electronic devices normally operate off of low voltage (one volt or less) and alter current flow during operation.

Tech Tip

This book will use the term "electrical" or "electronic" as it best describes the situation. There is some overlap and confusion as to when an electrical component or system should be classified as electronic because most automotive devices operate on low voltage (around 12 volts dc, or direct current).

When a component uses less than one or two volts for operation, it is *electronic*. The voltage in a home wall outlet, an appliance, or a hybrid electric drive system is much higher (120 volts or more ac, or alternating current) and would always be classified as *electrical*.

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Magnetism

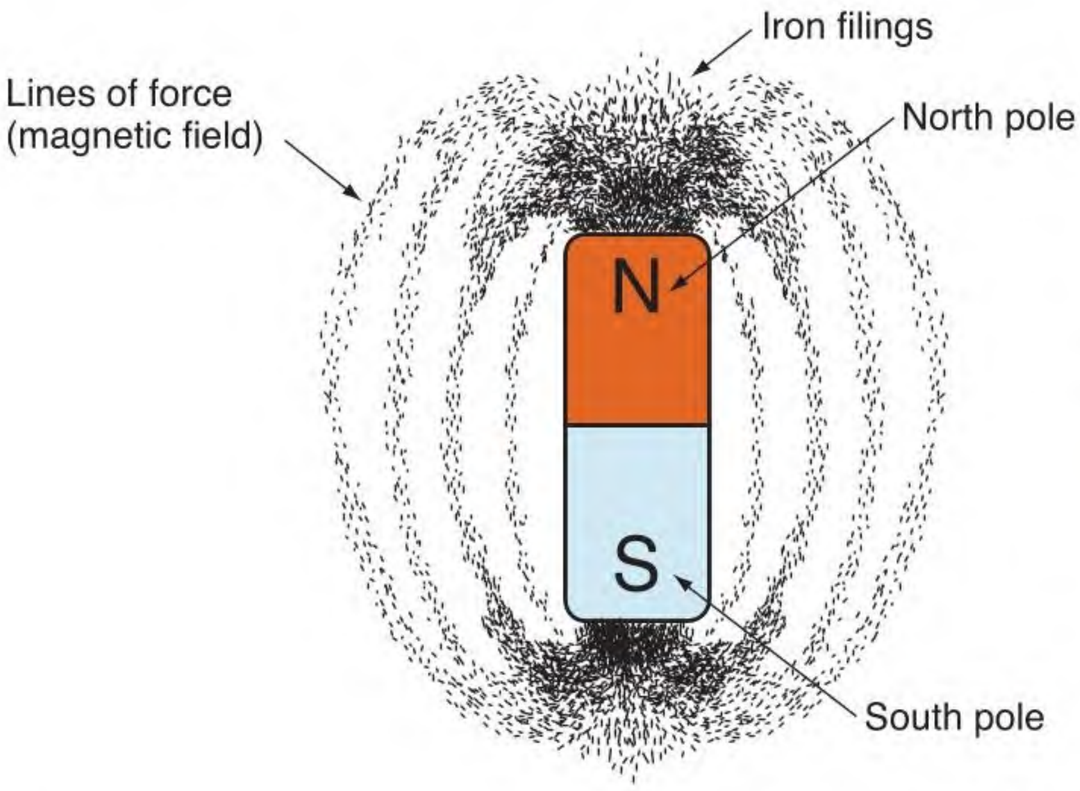
Magnetism plays an important role in the production and use of electrical energy. For the purpose of this text, magnetism is an atomic force that can attract or repel ferrous (iron-containing) substances through space, air, or solid matter.

You are probably familiar with a permanent magnet. As shown in **Figure 17-4**, it has north (positive) and south (negative) poles. An invisible ***magnetic field***, or ***flux***, exists between the poles of a magnet. The magnetic field is caused by the movement of electrons and can be used to act on ferrous (iron) substances. Even though the magnet is not in direct contact with the ferrous object, its magnetic field can affect the object.

When a piece of iron is magnetized, the molecules in the iron are aligned to produce north and south poles. This makes a magnetic field develop around the magnet. **Figure 17-5** illustrates how a permanent magnet acts on a piece of metal. Note how the magnetic field surrounds the magnet and the metal nail. If iron filings are placed on the tip of the nail, they cling to the nail because of the magnetic field.

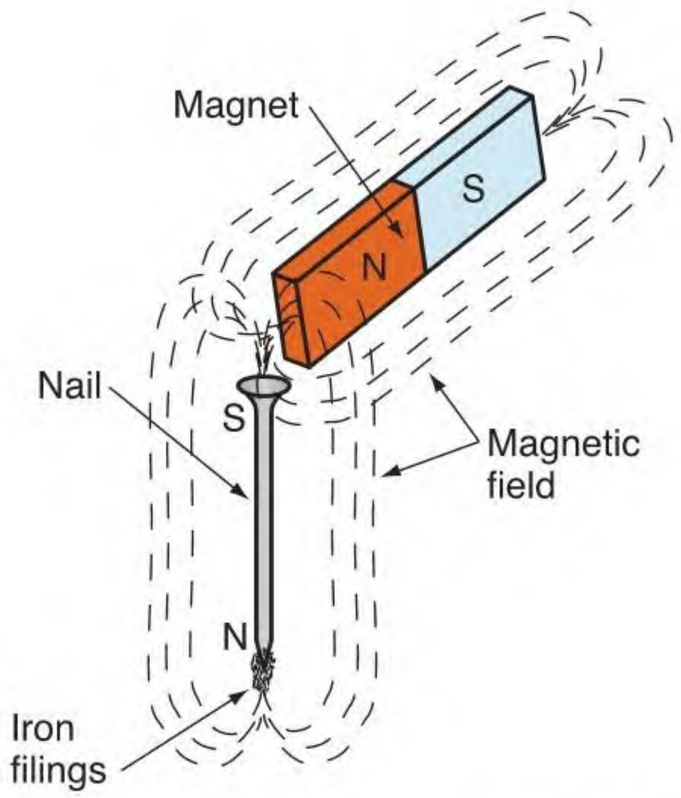
Tech Tip

A magnetic field acts on ferrous substances only. It has no effect on nonferrous substances such as plastic and glass.



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Figure 17-4. A permanent magnet has north and south poles. The north pole has a positive charge, and the south pole has a negative charge. If you sprinkle iron particles around a magnet, you can see action of the magnetic field.



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Figure 17-5. A magnet acting on a nail shows the effect of a magnetic field. Note how the field surrounds both the magnet and the nail. The magnetic field magnetizes the nail temporarily to hold the iron particles.

Like and Unlike Charges

The interaction of magnetic substances follows two basic rules:

- Like charges repel each other.
- Unlike charges attract each other.

For example, try to touch the south poles (like charges) of two magnets together. The two magnets repel each other. If you push them together on a tabletop, they actually slide apart. On the other hand, if you place a north pole and a south pole (unlike charges) near each other, they will attract. Magnetic force pulls them together with considerable force. See **Figure 17-6**.

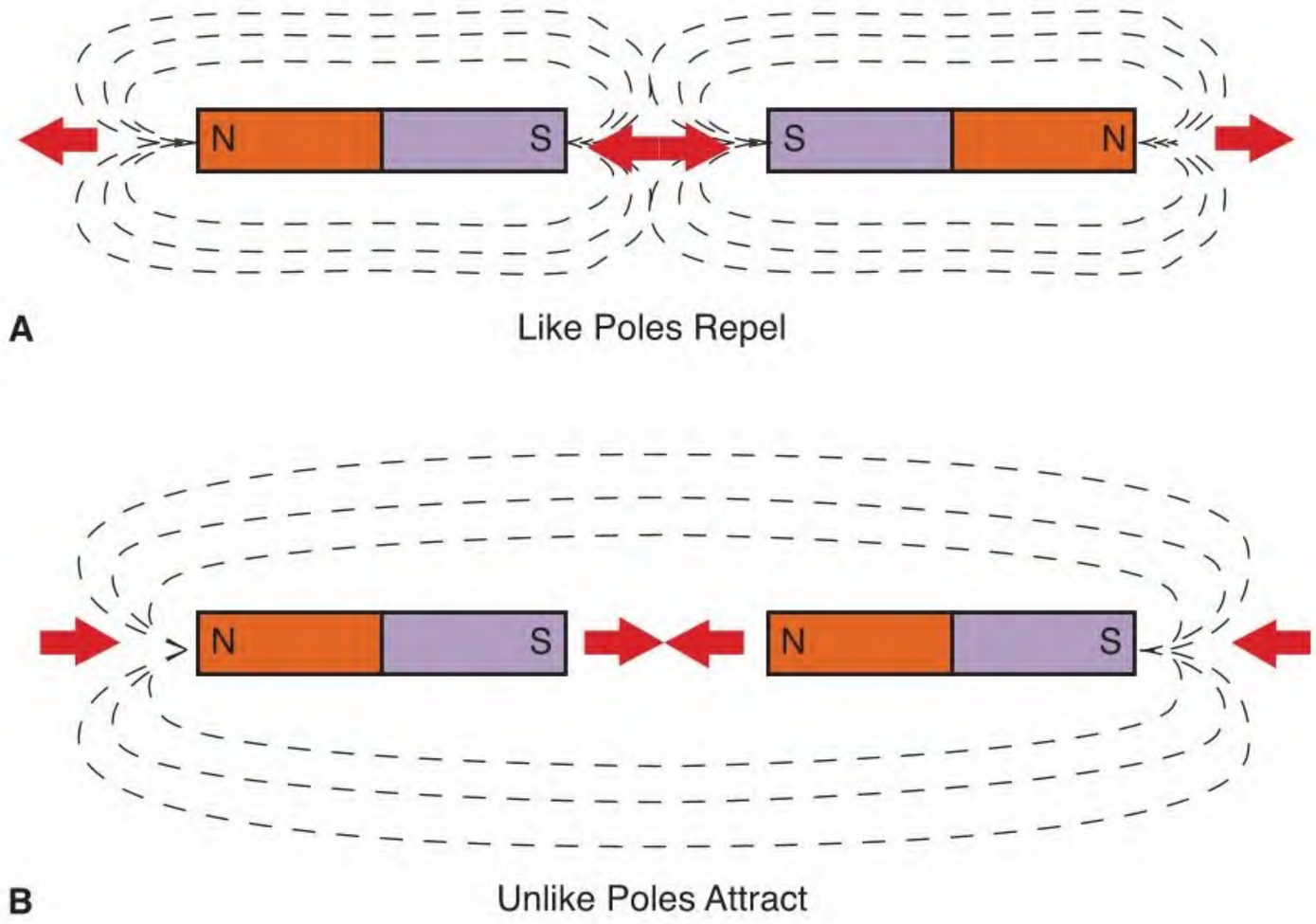
As you will learn later, this pushing and pulling force can be used in numerous electric devices, including motors, relays, and solenoids.

Electromagnetism

Electromagnetism is a branch of physics that deals with the interaction of electricity and magnetism. Electricity can be used to produce magnetism, and magnetic fields can be used to produce electricity. As shown in **Figure 17-7**, when electricity flows through a wire, a magnetic field sets up around the wire. The magnetic field is weak, but it can be detected with electronic test equipment.

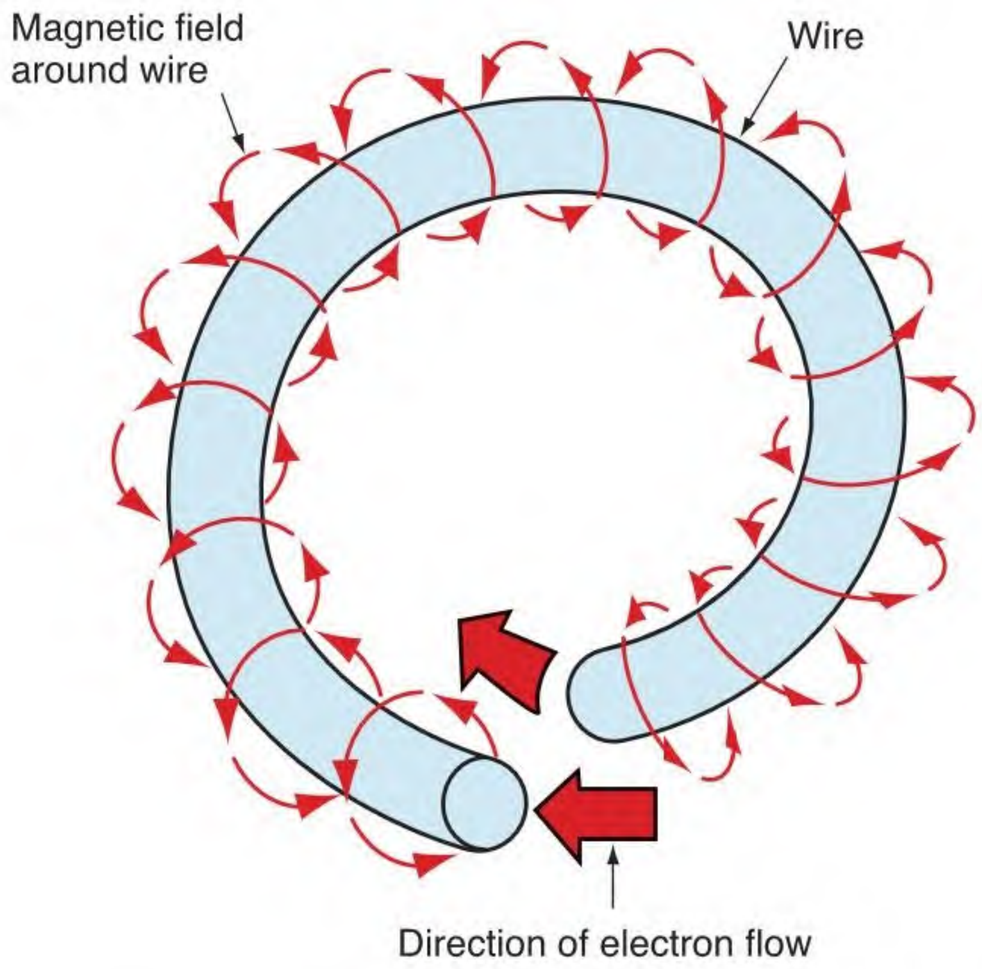
You can demonstrate the presence of the magnetic field by placing a piece of cardboard around the

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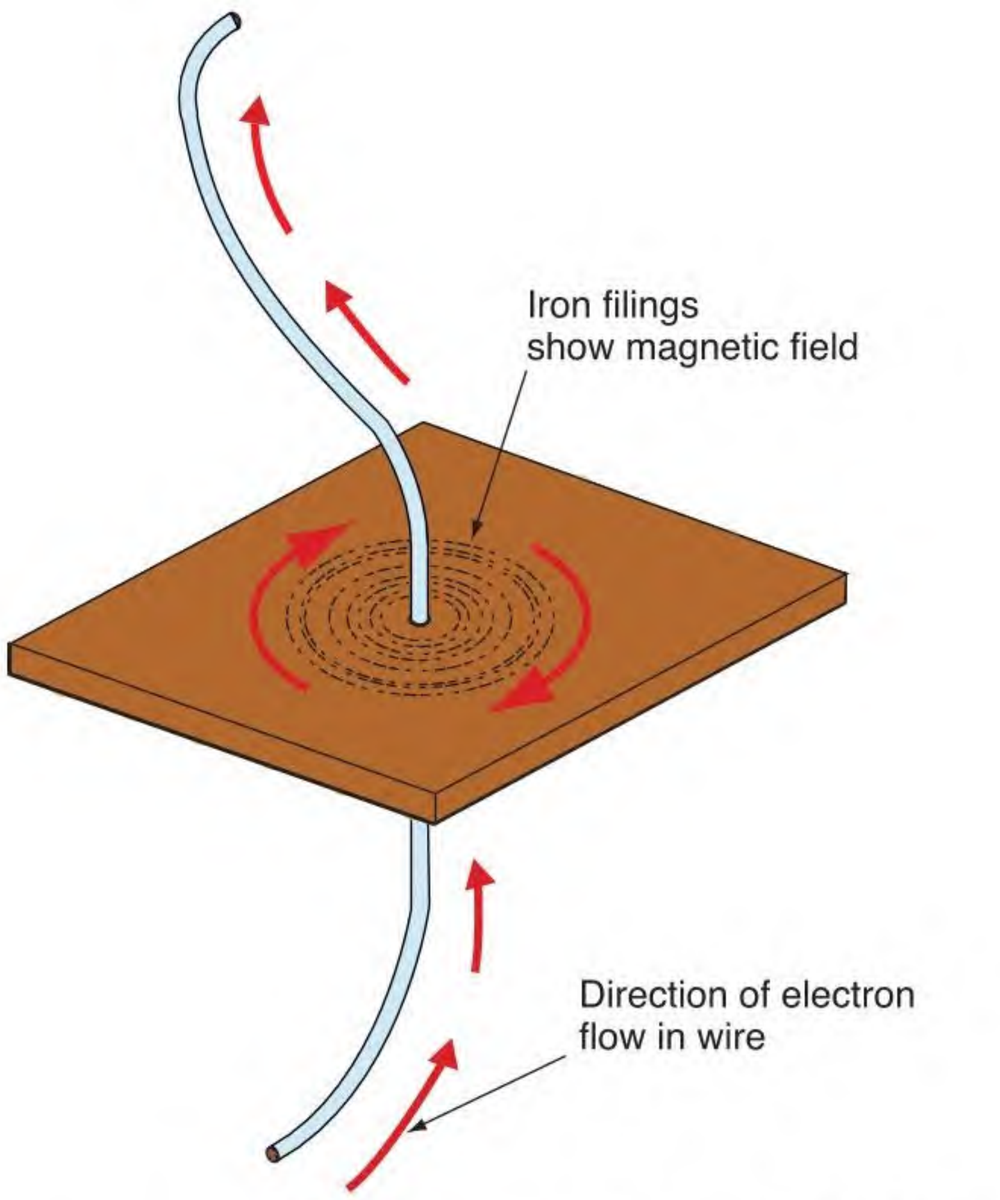
Figure 17-6. Two bar magnets demonstrate action of like and unlike charges. A—If two like charges are brought together, they repel each other. B—If two unlike charges are brought together, they attract each other.



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Figure 17-7. Electricity flowing through a wire sets up a weak magnetic field around the wire.

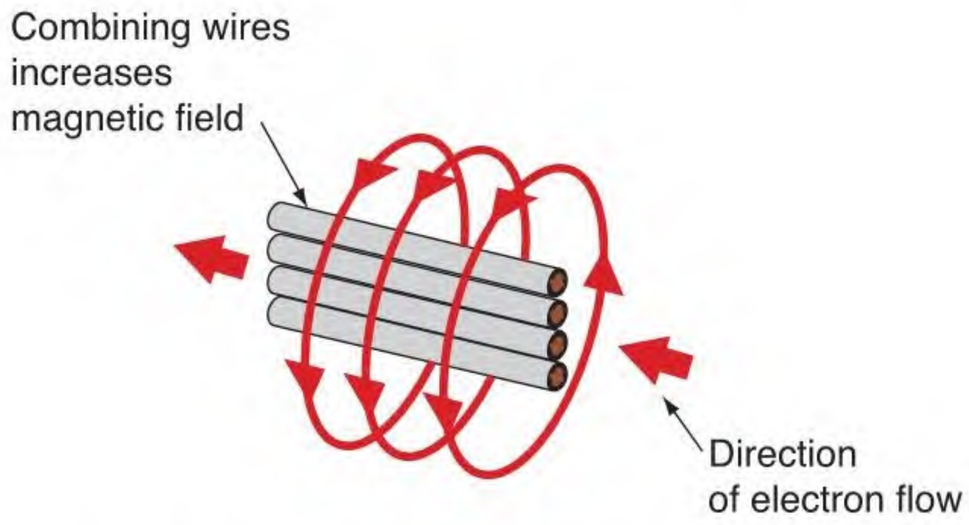
wire and then sprinkling iron powder on the cardboard. See **Figure 17-8**. The magnetic field sets up at right angles to the wire. When several electricity-carrying wires are placed next to each other, the magnetic field strengthens, as shown in **Figure 17-9**. Inserting



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Figure 17-8. If you pass a current-carrying wire through a piece of cardboard and sprinkle iron filings on the cardboard, the iron filings align to show the magnetic field produced by the flow of electricity.

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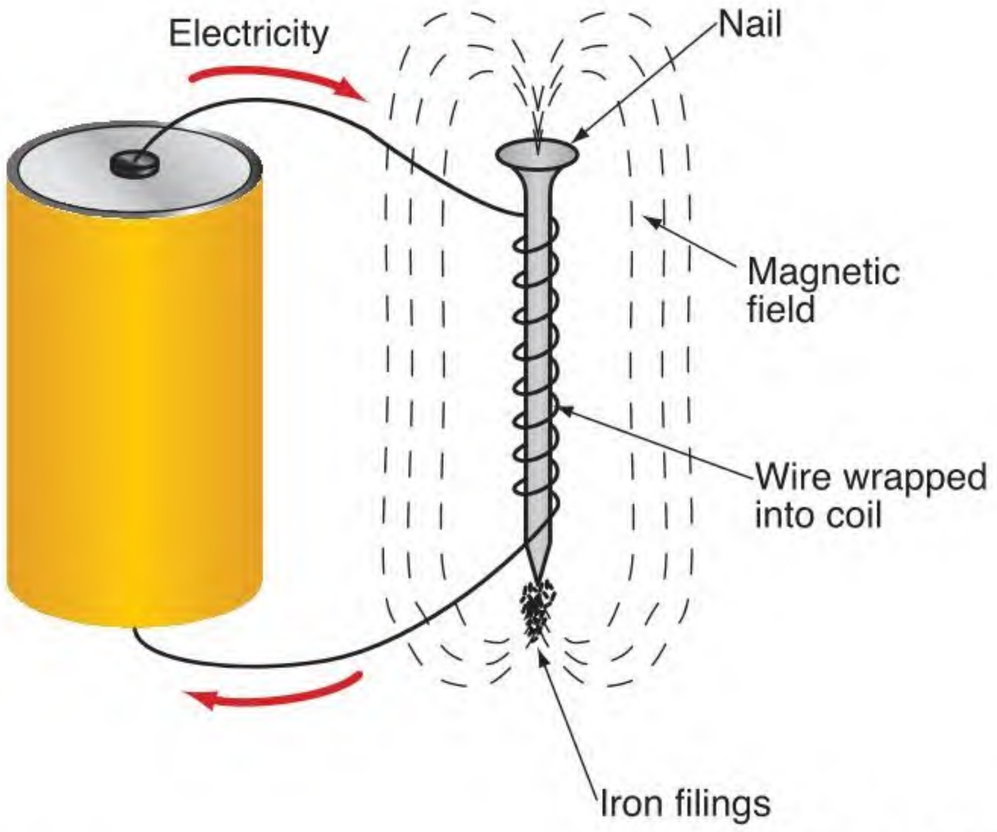
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Figure 17-9. Placing several electricity-carrying wires close together strengthens the magnetic field around them.

an iron core through the coils of wire strengthens the magnetic field further, creating an ***electromagnet*** (electrically energized magnet), **Figure 17-10**. This principle is used in numerous electric components.

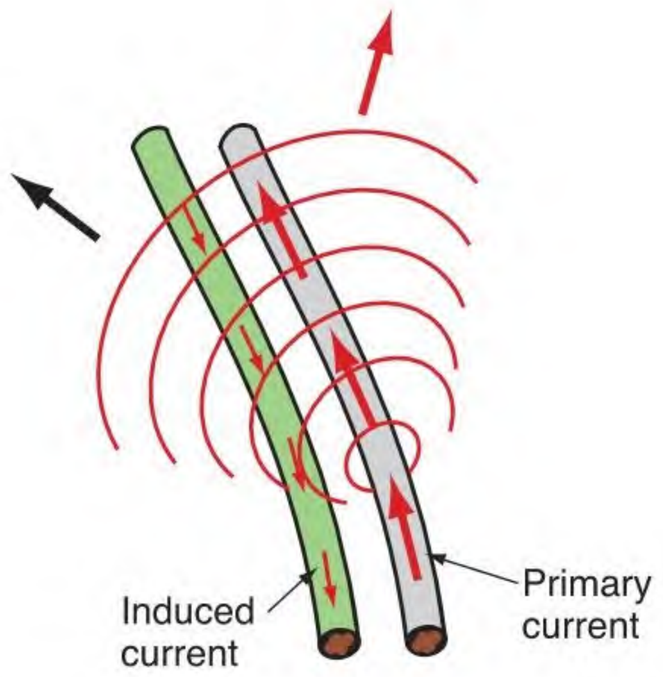
Induction

Induction is the process of creating electricity in a wire by passing the wire through a magnetic field. Electricity can also be induced in a wire if the wire is near an expanding and collapsing magnetic field. The magnetic field acts on the free electronics in the wire to produce electricity. The principle of electrical induction is used in alternators, inductive meters, and other electrical-electronic components. Refer to **Figure 17-11**.



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Figure 17-10. An electromagnet can be made by wrapping wire around iron core. Electricity through the wire produces a powerful magnetic field.



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Figure 17-11. Electricity can be induced in a wire by moving the wire through a magnetic field. Electricity can also be induced in a wire that is in close proximity to an expanding and a collapsing magnetic field.

Electric Circuits

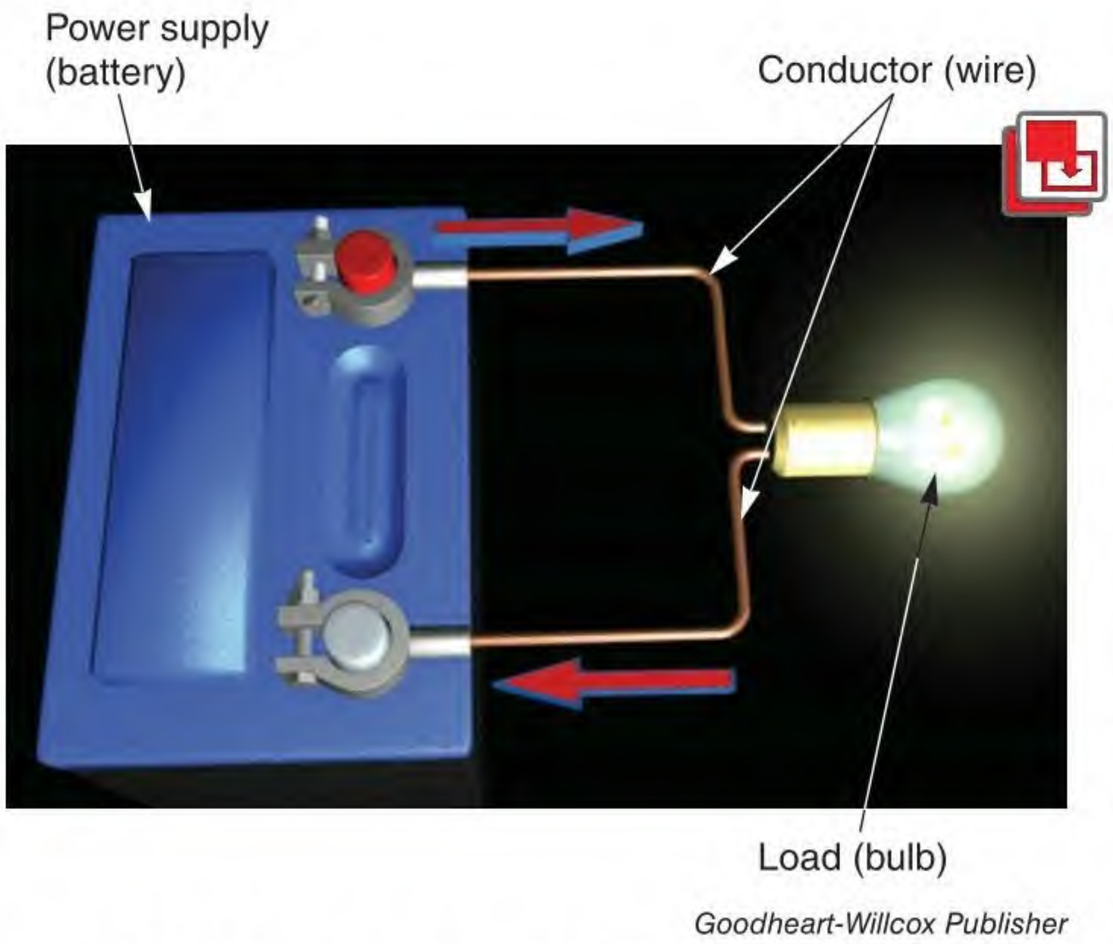
Now that you understand something about electrical principles, you are ready to review a basic electric circuit. An ***electric circuit*** consists of the basic components needed to utilize electrical energy. These components include:

- Power supply—A power supply is a source of electrical energy, such as a battery or an engine-driven generator.
- Load—A device that uses the electrical energy, such as a lightbulb or an electric motor, is a load.
- Conductor—A conductor is a substance (element or alloy) that can carry electrical current through a circuit (wires, metal frame of vehicle, engine block, etc.).

Figure 17-12 shows a simple electric circuit. The battery (power supply) or engine-driven generator (alternator) applies electrical voltage (volts) into the wire (conductor). Electric current (amps) flows through the wire and lightbulb filament (load). The filament heats up and emits light. Electric current continues through the wire and electrons return to the battery through the return conductor, or frame ground. This simple circuit can be expanded to make much more complex electric circuits, but all circuits operate on this basic principle.

A hydraulic circuit can be used to demonstrate the action in an electric circuit. See **Figure 17-13**. The hydraulic pump is comparable to the battery. It produces the pressure for circuit operation. The hydraulic

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Figure 17-12. A simple electric circuit requires these basic parts. The power source feeds electrons into the circuit. Conductors carry electrons to and from the load. The load uses the electrical energy to do work.

hoses represent the conductors or wires in the circuit. They allow flow between the power source and the load device. The hydraulic ram is comparable to an electric load (a lightbulb in this example).

The control valve is comparable to an electric switch or a variable resistor. Both the control valve and the switch or variable resistor control flow through the circuit. If the valve (switch) is closed, the flow stops and the circuit will not function.

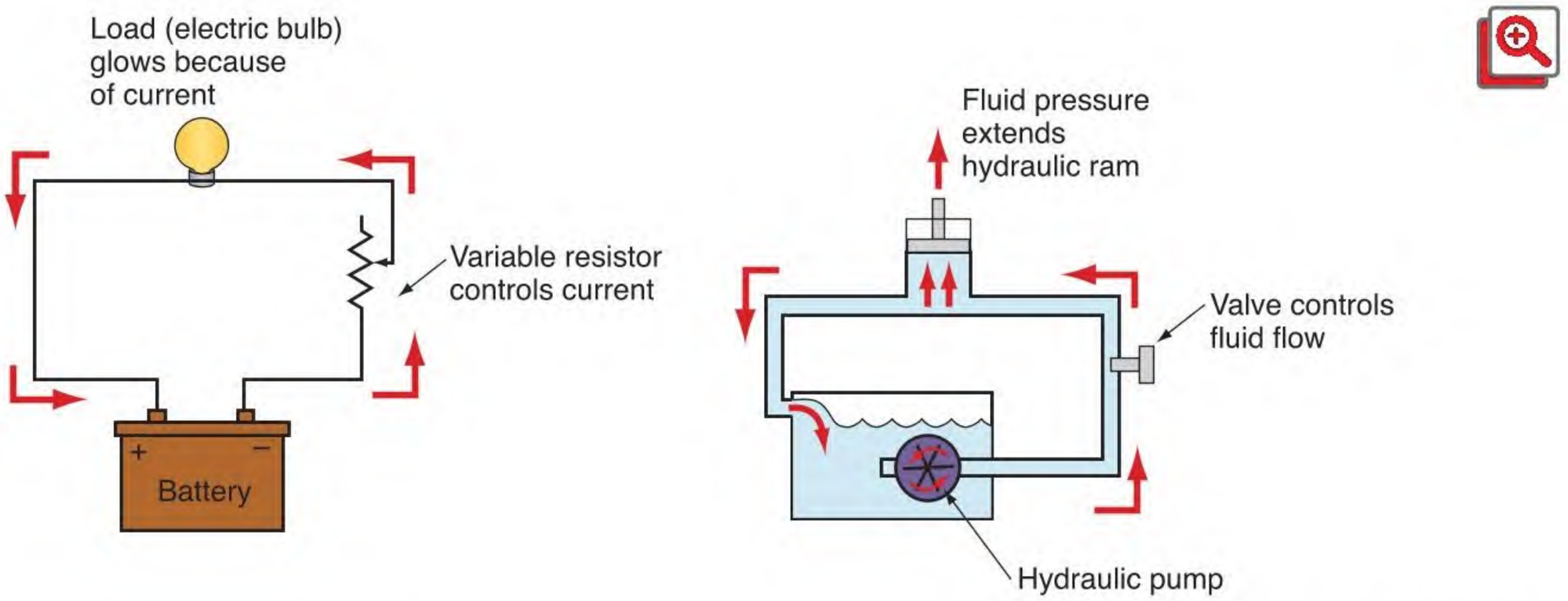
All electric circuits have three fundamental properties: voltage (electrical pressure), current (rate of electron flow), and resistance (opposition to current). These three properties are interrelated; the value of each property depends on the value of the other two, as described in the following paragraphs. A house garden hose demonstrates the principles of voltage (water pressure), current (water flow), and resistance (water valve restriction). See **Figure 17-14**.

Voltage

Voltage is the electrical force, or pressure, that pushes free electrons and causes current. It is also known as ***electromotive force (EMF)*** or ***potential difference***, and refers to how voltage has the power or force to cause electron movement through a conductor.

Voltage is measured in ***volts*** and is represented in formulas and diagrams by the letters *V* or *E*. Increasing voltage increases current because more free electrons flow through the circuit. Reducing voltage reduces current.

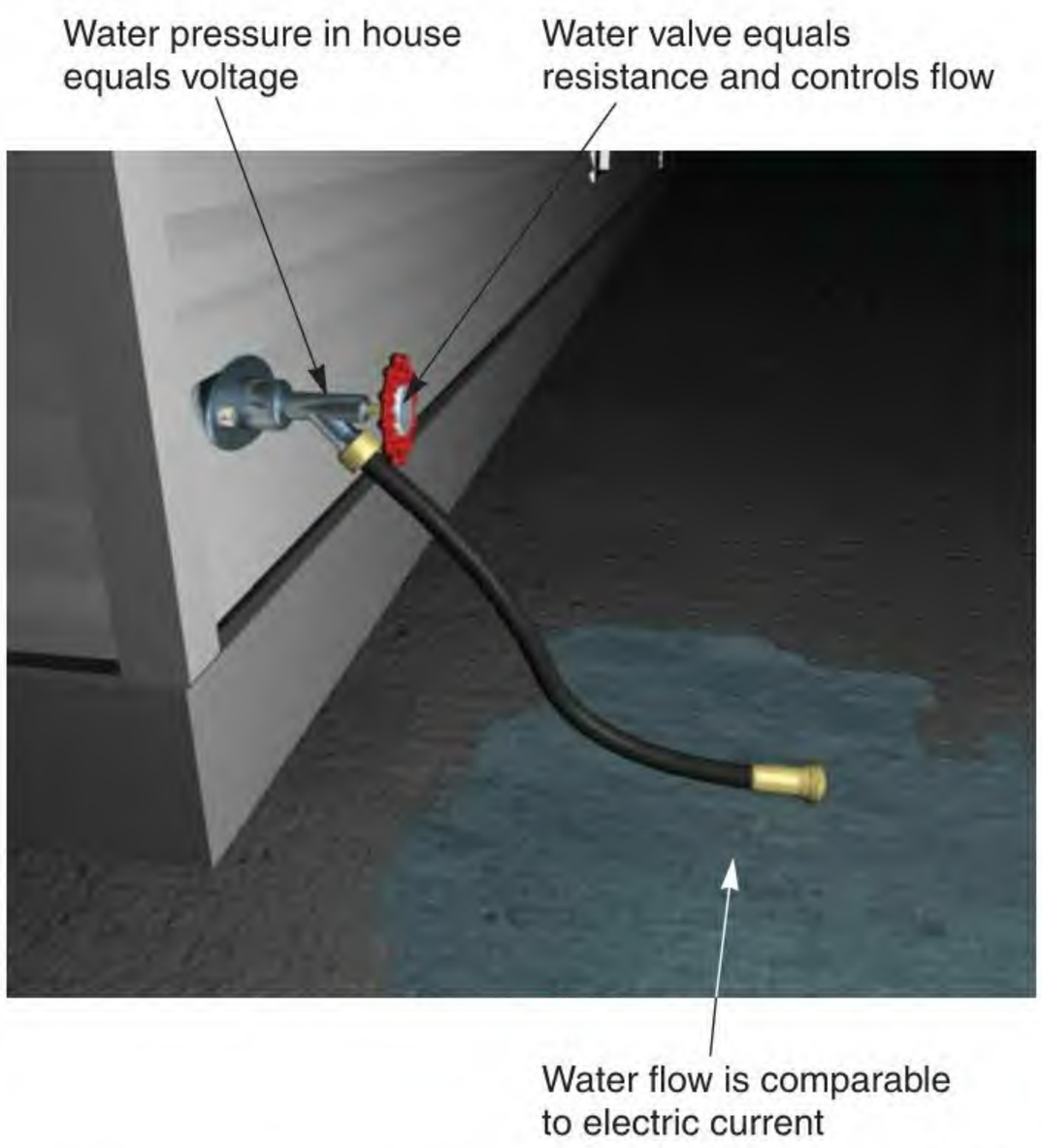
For example, in a simple circuit containing a lightbulb, higher voltage forces more free electrons through the bulb filament and the bulb glows more brightly. If lower voltage is applied, the bulb does not glow as brightly. This applies to other circuits and loads as well.



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Figure 17-13. Hydraulic circuit compared to electric circuit. The hydraulic pump is comparable to a power source. The flow control valve is similar to an electric switch or variable resistor. In both circuits, the load (hydraulic ram, electric fan) is the purpose for the circuit.

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Figure 17-14. The valve on a garden hose demonstrates resistance in a circuit. The water pressure represents voltage and produces current, or flow. The valve provides resistance and controls flow. When the valve is fully open, resistance is low, so water (current) flow increases, and vice versa.

Current

Current, or amperage, is the rate of electron flow in a circuit. The term *current* is also commonly used to simply mean the flow of electrons in a circuit. Current is measured in electrical units called ***amperes*** (commonly shortened to amps) and is the result of voltage in a complete circuit. Current is represented in formulas and diagrams by the letter *I*.

Current is high if resistance is low or if voltage is high. Current is reduced by high resistance or low voltage.

For current to exist in a circuit, there must be a power source, a complete conducting path, and a load. If the path is not complete, there will be no current.

Resistance

Resistance is the opposition to free electron flow. It is used to limit or control current. Measured in ***ohms*** (Ω), resistance is designed into all electric circuits. The load (a lightbulb, for example) has an internal resistance that uses the energy of the current. Resistance is represented in formulas and diagrams by the letter *R*.

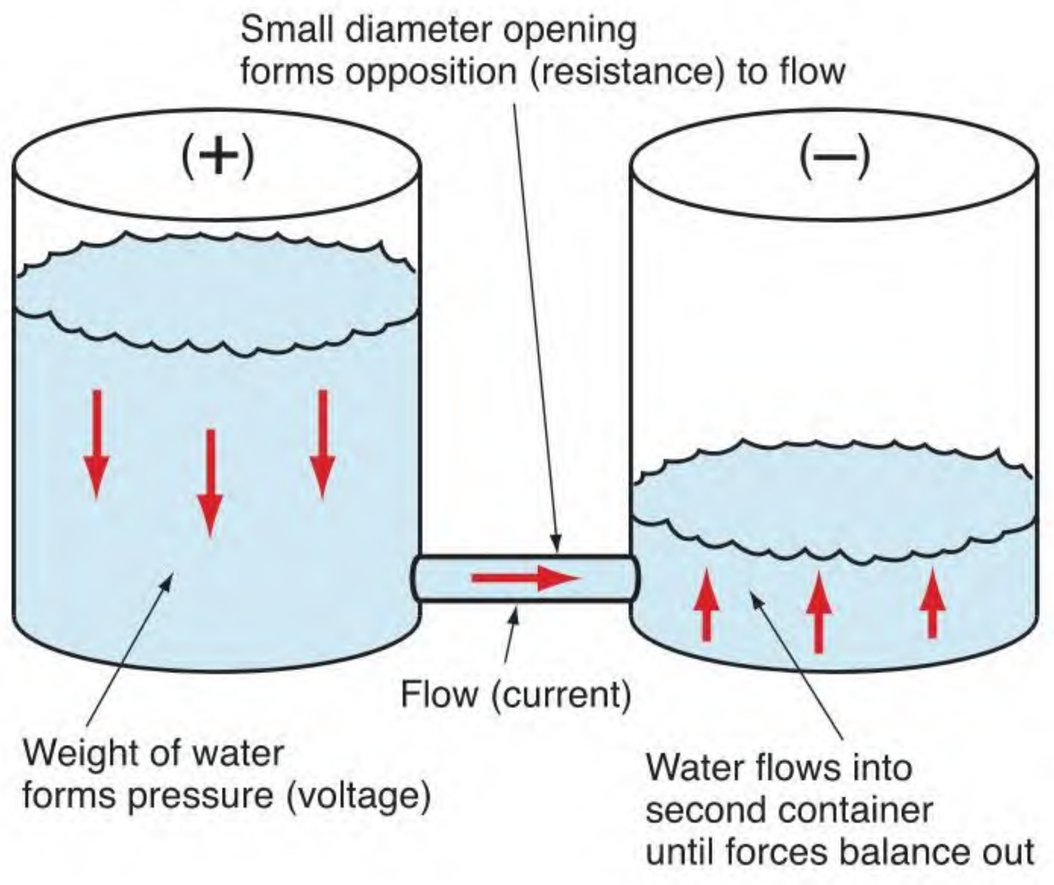
As illustrated in **Figure 17-14**, resistance is comparable to the water valve on a garden hose. If the valve is opened fully, resistance is low and flow is high. If you partially shut the water valve, resistance becomes higher and flow drops off. If you completely close the water valve, resistance is maximum (infinite), and flow stops completely.

Tech Tip

A short circuit results when there is not enough resistance to current flow. Excess electron flow and the resulting heat in a shorted circuit will instantly burn wires and components.

Relationship of Voltage, Current, and Resistance

The water circuit shown in **Figure 17-15** demonstrates the relationships between voltage, current, and resistance. Imagine two containers connected with a piece of tubing. Fill one container with water and



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Figure 17-15. Two containers connected by tubing demonstrate electrical action. If the left container is filled with water, water pressure, or potential difference, results. This forces the water to flow through the tube, producing current. The tube acts as resistance to limit the flow. The current stops when the water level (potential difference) is equal in the two containers.

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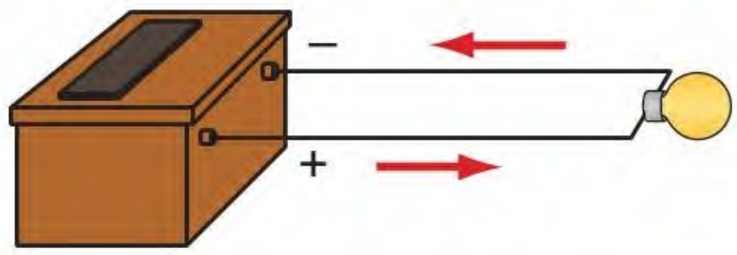
leave the other container empty. Water flows through the tube to equalize the amount of water in the two containers. This is similar to the electrical action of charges in atoms trying to balance out in a circuit.

The difference between the weights of the water in the two containers represents voltage, or the pressure trying to balance out the forces. The flow through the tube represents current. The diameter of the tubing represents the resistance that controls the amount of flow. An electric circuit can be thought of in the same way.

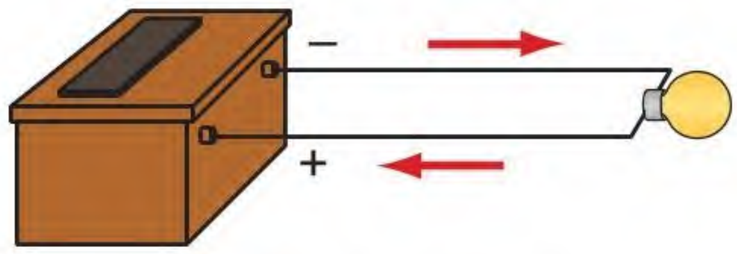
Conventional and Electron Theories

Current through a circuit can be explained by two different theories. The ***conventional current theory*** says that electrons flow through a circuit from positive (+) to negative (–). Electrons leave the positive terminal of the battery, flow through the circuit, and then reenter the battery through the negative terminal.

According to the ***electron flow theory***, electrons leave the negative (–) terminal of the battery, flow through the circuit, and then reenter the positive (+) terminal. The electron flow theory is just the opposite of the conventional current theory. Actually, the electron flow theory is the most accurate. Electrons are naturally attracted to the positive terminal. However, it is more convenient to use the conventional current theory in automotive work. Therefore, conventional current theory is used in all chapters that describe current, except for Chapter 19, which discusses semiconductor components. These components are best described using electron flow theory. See **Figure 17-16**.



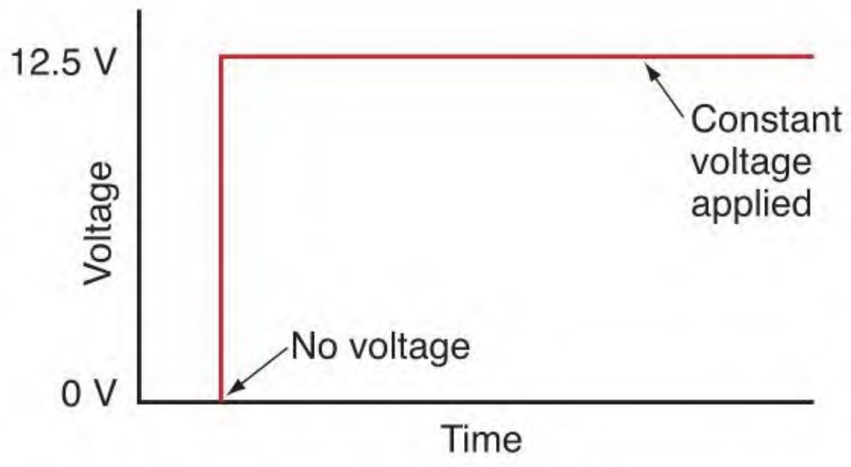
Conventional Current Theory
(Positive to Negative)



Electron Flow Theory
(Negative to Positive)

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Figure 17-16. In conventional current theory, electrons flow from positive to negative. In electron flow theory, electrons flow from negative to positive.



DC Current

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Figure 17-17. Direct current moves in one direction only. This graph shows how dc voltage and direction remain the same over time.

Direct and Alternating Current

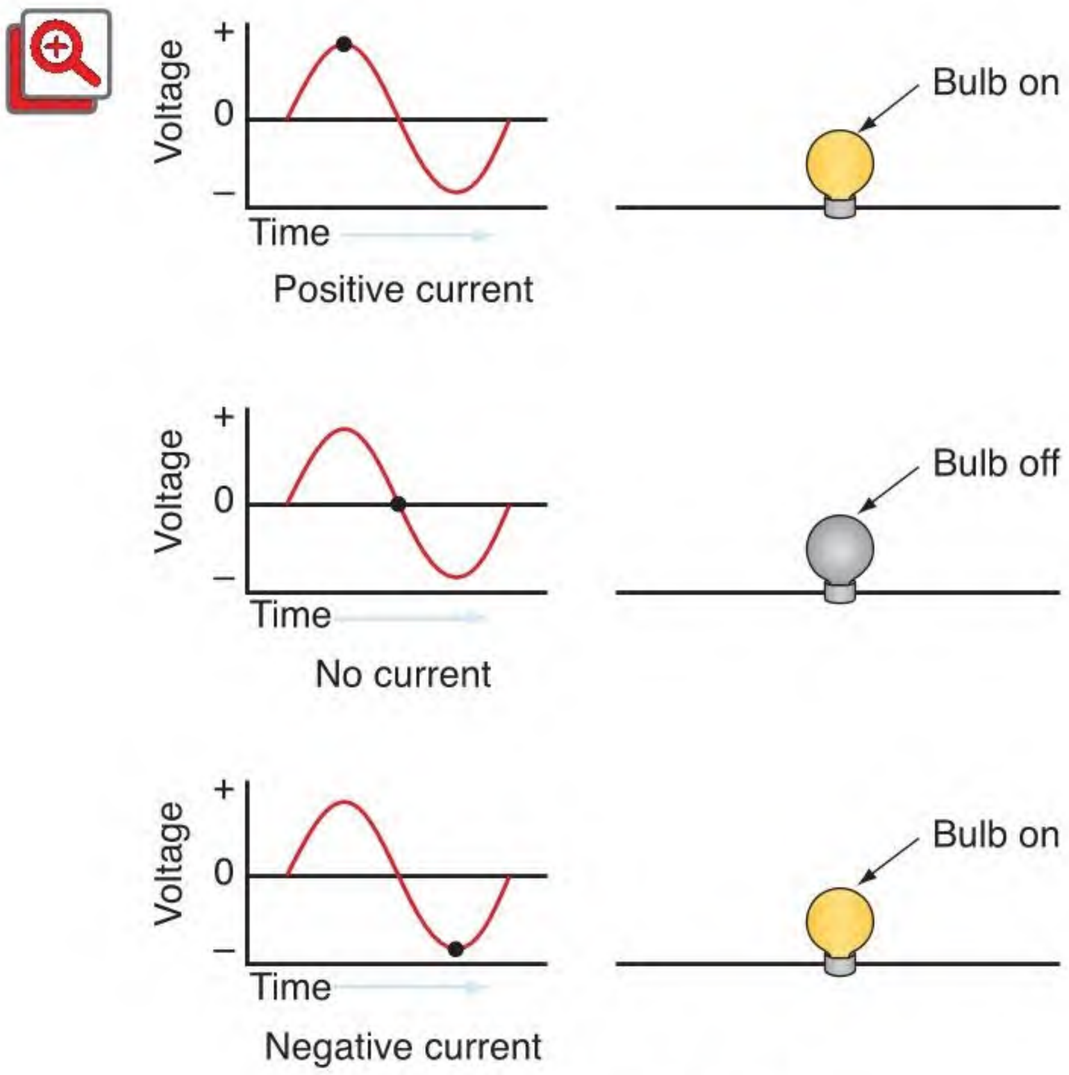
Direct current (dc) is electron flow in one direction only. Most automotive circuits operate on direct current. Current flows through a circuit from positive to negative. See **Figure 17-17**.

Alternating current (ac) is electron flow in alternating directions. This means that electrons flow in one direction, reverse, and then flow in the opposite direction. The polarity (positive or negative state) of ac cycles back and forth in the circuit. Most automotive circuits do not use ac. However, as you will learn in later chapters, a charging system alternator produces an internal ac that is rectified (changed back into dc) before leaving the alternator. Some computer system sensors also produce an ac output.

The curves in **Figure 17-18** illustrate how voltage in an ac circuit changes over time. The voltage begins at zero, and then increases to the first peak. The voltage then decreases, returning to zero and continuing to decrease to the negative peak. The voltage then increases back to zero, and the process repeats. Together, one complete positive curve and one complete negative curve form one ***cycle***.

The curve that represents alternating current in a basic circuit is a ***sine wave***. Note that the amplitude (height) and frequency of the wave are constant. ***Frequency*** is the number of cycles per second, or ***Hertz (Hz)***.

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Alternating Current

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Figure 17-18. Alternating current reverses direction so quickly that the effect is not visible to the human eye.

In your home wiring, 120 volts ac cycles at 60 Hz. This is so fast that it cannot be seen with the human eye. A lightbulb appears to be glowing constantly when it is actually turning on and off at 60 Hz, or 60 times per second. Some home appliances (furnace, air conditioner, air compressor) require 240 volts ac. A hybrid electric drive train operates on up to approximately 600 volts ac.



Green Tech

Energy Efficiency

Automotive shops use large amounts of energy in various ways. One of the ways automotive shops can be more environmentally friendly is to conserve energy. Using appliances that have the Energy Star label is one way to help be more energy efficient. Another way to conserve energy is to install lights that are either set on timers or that use motion-activated sensors. This way, lights are only on when needed. Using programmable thermostats and clean air filters in your ventilation systems will help conserve energy.

Summary

- An atom is made up of electrons, protons, and neutrons. The negatively charged electrons circle around the nucleus of the atom.
- The atoms of some elements have a few electrons that are only loosely held to the atom. These electrons can be made to move from atom to atom, producing electricity.
- A conductor is an element that allows electron flow.
- An insulator does not have free electrons. The electrons are locked in their orbits, and this resists electron flow.
- A permanent magnet has an invisible magnetic field around it. This field acts on ferrous objects.
- Unlike charges attract each other, and like charges repel each other. This principle is used to produce current, motion, and other functions.
- An electromagnet can be made by wrapping wire around an iron core. Electricity in the wire produces a magnetic field.
- Electricity can be induced in a wire by passing the wire through a magnetic field.
- A simple electric circuit consists of a power supply (battery), conductor (wires), and load (power-using device).
- Voltage is the pressure that moves free electrons through a conductor.
- Current is the rate of electron flow.
- Resistance is the opposition to current and is used to limit current.
- Direct current moves in one direction only. Automobile electrical systems primarily operate on direct current.
- Alternating current moves one way and then the other. In automobiles, ac is found inside the alternator and in the wiring to some sensors.

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Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

alternating current (ac)
amperes
atom
compound
conductor
conventional current theory
current
cycle
direct current (dc)
discharge
electric circuit
electrical device
electricity
electromagnet
electromagnetism
electromotive force (EMF)
electrons
electron flow theory
electronic device
element
flux
free electrons
frequency
Hertz (Hz)
induction
insulator
magnetic field
magnetism
matter
molecule
negative charge
neutrons
nucleus
ohms
positive charge
potential difference
protons
resistance
sine wave
voltage
volts

Activities

1. Using sketches and principles you have learned about basic electricity, prepare a presentation showing how electricity can be created through magnetism.
2. Create an electromagnet using fine wire, an iron nail, and a 9-volt battery. After creating the magnet, use it to pick up small objects, such as paper clips.
3. Research Ohm's law on the Internet. In a classroom presentation, explain the relationship between voltage, current, and resistance.

Review Questions

Answer the following questions using the information provided in this chapter.

1. The three basic parts of an atom are _____, _____, and _____.
2. What is a free electron?
3. What causes an electron to jump from atom to atom, in relation to electricity?
4. A substance that allows the flow of free electrons is a(n) _____.
5. A(n) _____ is a substance that inhibits or stops the flow of free electrons.
6. When free electrons flow through a conductor with high resistance, _____ is produced.
7. What is magnetism?
8. When a piece of iron is magnetized, the molecules in the iron _____ to produce north and south poles.
9. An invisible _____ exists between the poles of a magnet.
10. What happens if you place two like charges near each other?
11. _____ is the branch of physics that deals with the interaction of electricity and magnetism.
12. How can you create a simple electromagnet?
13. What is induction?
14. List the parts of a basic electric circuit and describe their functions.
15. What is voltage?
16. The rate of electron flow in a circuit is called current, or _____, and it is measured in _____.
17. What is the function of resistance in an electric circuit?
18. What happens to current if voltage increases and resistance remains constant?
19. What happens to the voltage if current increases and the resistance remains constant?
20. According to conventional current theory, in which direction do electrons flow?
21. What is the difference between direct current and alternating current?

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ASE-Type Questions

1. Technician A says electrons and protons form the nucleus of an atom. Technician B says electrons have a negative charge. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Technician A says electricity is the movement of free atoms from one place to another. Technician B says electricity is the movement of free elements from one place to another. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. Technician A says silver is a good electrical conductor. Technician B says iron is a good electrical conductor. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. An atomic force that can attract or repel ferrous substances is known as:
   (A) magnetism.
   (B) electricity.
   (C) current.
   (D) voltage.
5. Technician A says an insulator is a substance that resists the flow of electricity. Technician B says the atoms in an insulator are very stable and resist electron movement. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Technician A says a load is a basic component of an electric circuit. Technician B says a power supply is a basic component of an electric circuit. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. The electrical pressure that causes current is known as:
   (A) voltage.
   (B) amps.
   (C) resistance.
   (D) magnetism.
8. Technician A says that as voltage increases and resistance remains constant, current increases. Technician B says that as voltage decreases and resistance remains constant, the number of free electrons flowing through a circuit decreases. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Technician A says the electron flow theory states that electrons flow through a circuit from positive to negative. Technician B says the conventional current theory states that electrons flow through a circuit from negative to positive. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. Technician A says dc circuits are not normally used in automotive circuits. Technician B says certain automotive computer sensors use ac. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Chapter 18
Circuit Types and Ohm's Law

After studying this chapter, you will be able to:

- Compare the operating characteristics of series, parallel, and series-parallel circuits.
- Explain the operation of a frame-ground circuit.
- Recall the three Ohm's law formulas that express the relationships among voltage, current, and resistance.
- Explain how changes in voltage and resistance affect current.
- Use Ohm's law and circuit-type formulas to calculate unknown circuit values.
- Use the formula for calculating electric power or wattage.
- Interpret electrical prefixes.

This chapter details the arrangement and action of basic electric circuits. Even very complex circuits consist of many basic circuits wired together. The first part of this chapter explains the basic circuit types and how they function. The last part of the chapter discusses Ohm's law, which governs the relationships between current, voltage, and resistance in electric circuits.

Circuit Types

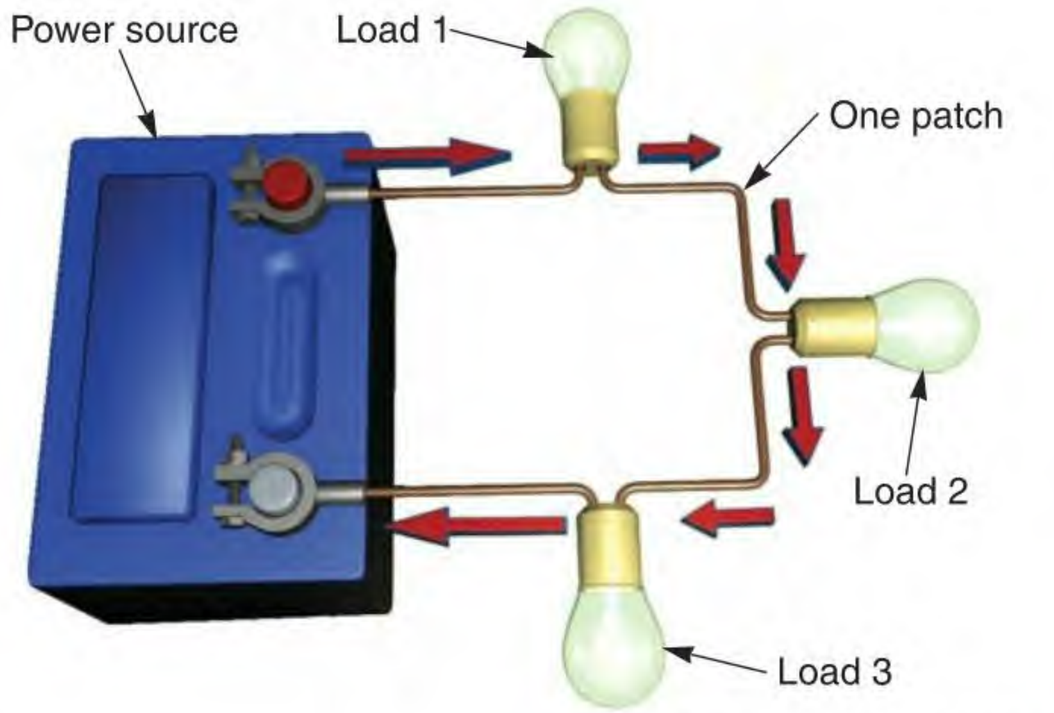
A ***circuit*** is a closed electrical path for current. The three main types of circuits are series, parallel, and series-parallel circuits. In automotive systems, a combination of these circuit types is used to produce complex networks. However, if you understand the basic circuit types, you can troubleshoot any circuit by breaking it down into its basic circuit components.

Series Circuit

A ***series circuit*** has only one path for current. One or more electric loads are wired into this single path. See **Figure 18-1**.

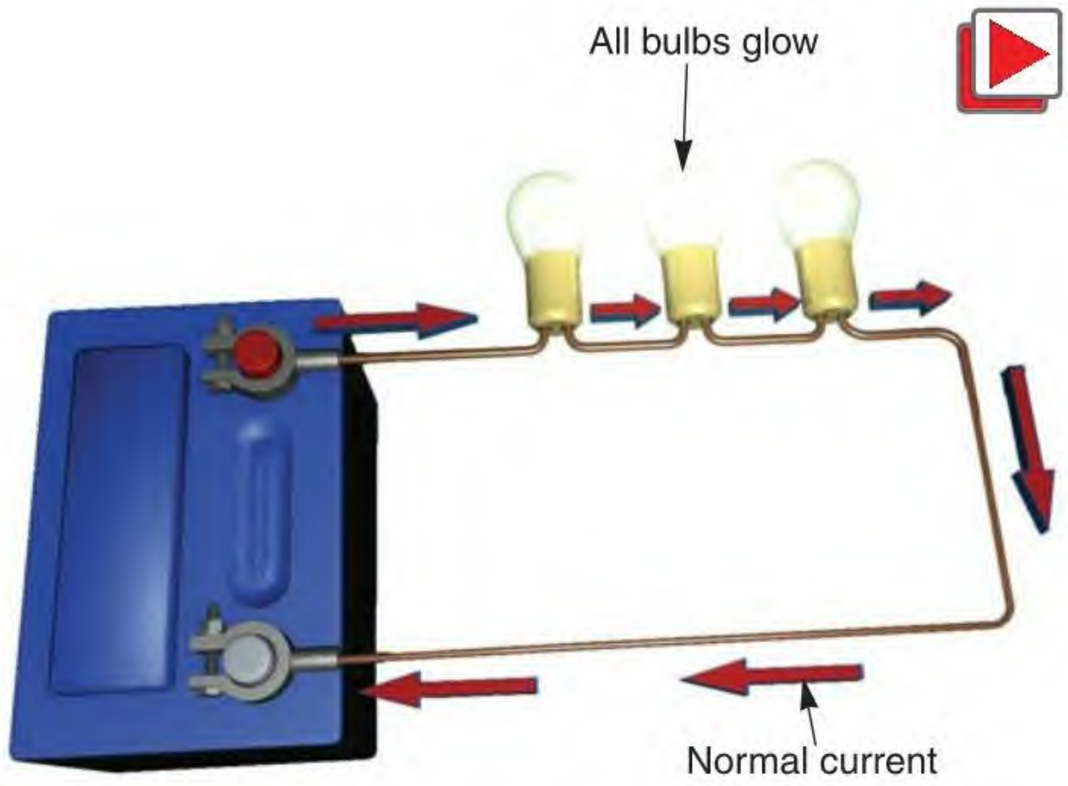
Figure 18-2 shows the basic action of a series circuit. If a switch is connected in series with three lightbulbs, it controls all three bulbs. When the switch is closed (connected), the circuit is complete and the bulbs glow. If the switch is open (disconnected), none of the bulbs glow. If one of the bulbs burns out in a string of lights wired in series, all of the other lights go out. The broken filament in the burned-out bulb acts as an open switch to stop current flow. See **Figure 18-3**.

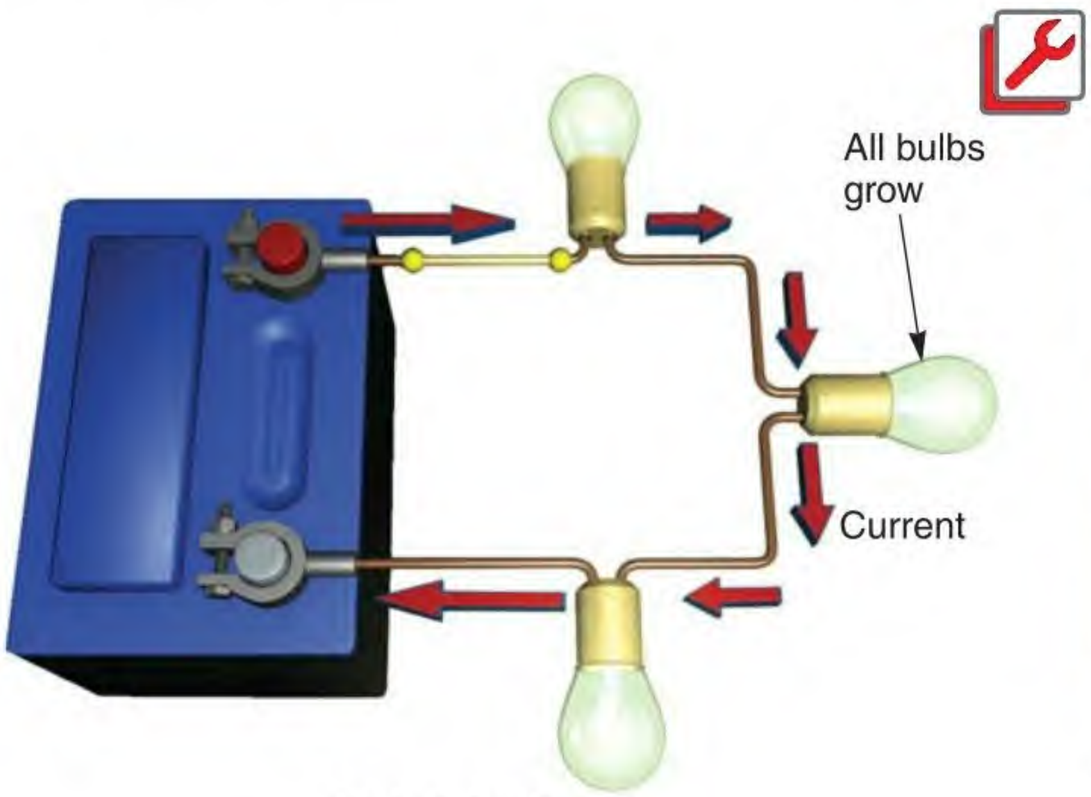
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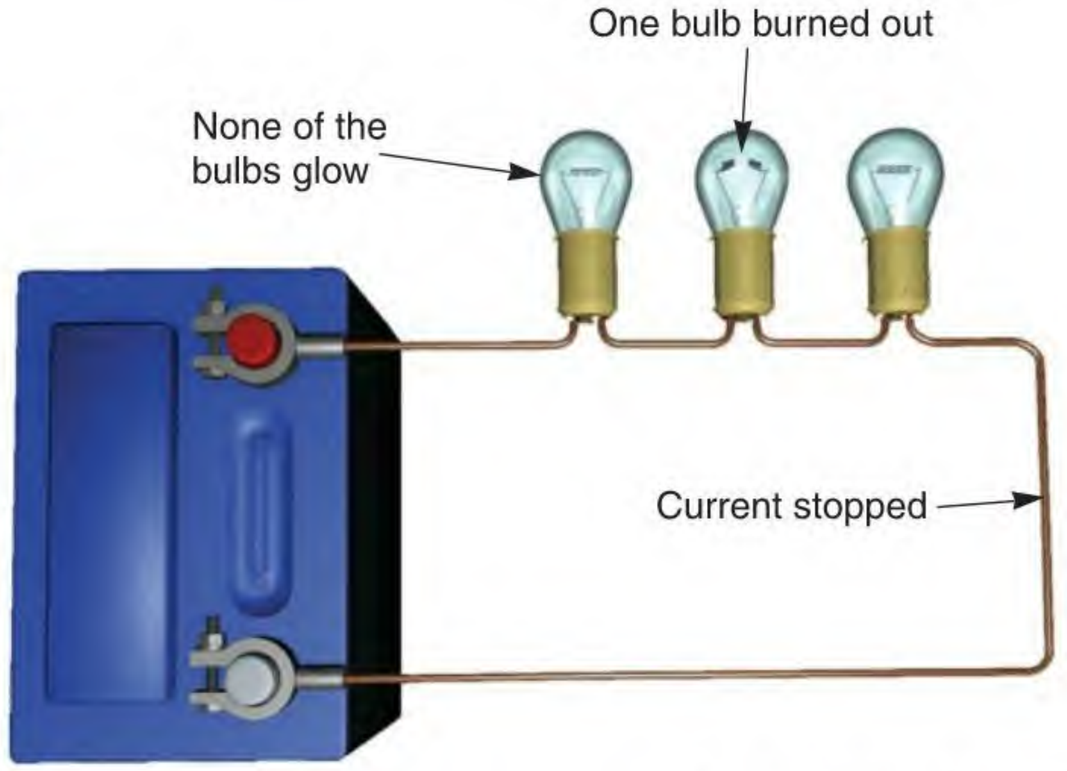


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Figure 18-1. Series circuits have one or more loads connected in a single electrical path.

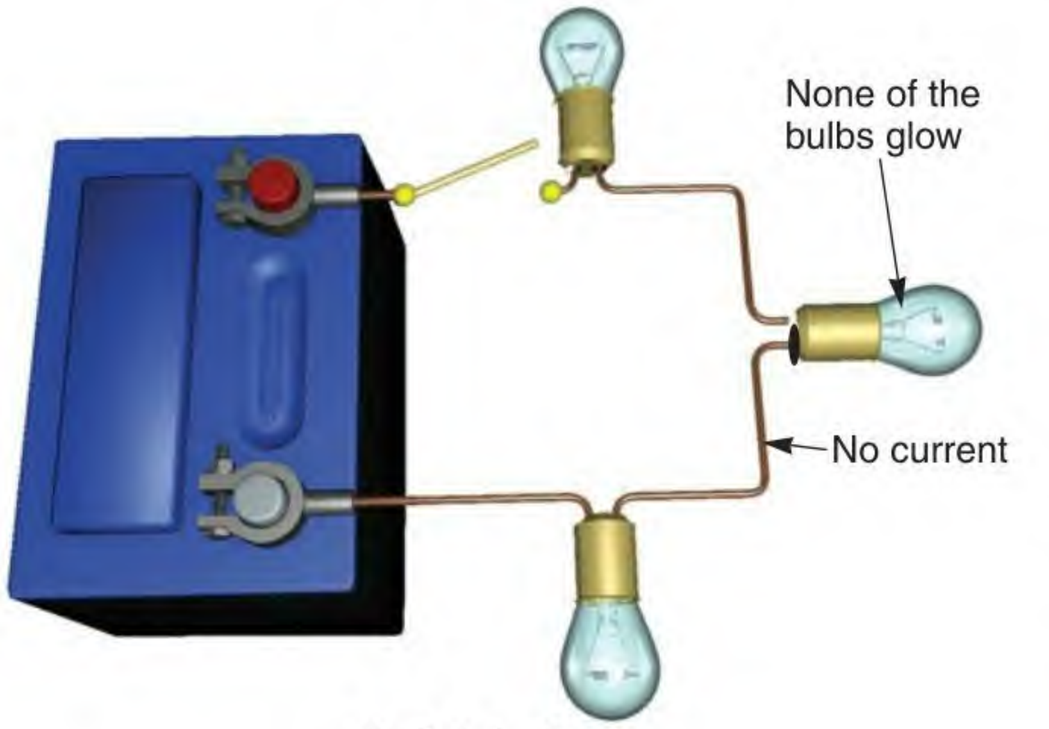






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Figure 18-3. If one bulb burns out in a string of lights wired in series, all of the bulbs go out.



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Figure 18-2. In this circuit, a switch is wired in series with three lightbulbs. When the switch is closed, all three bulbs glow. When the switch is open, it blocks current to all the bulbs.

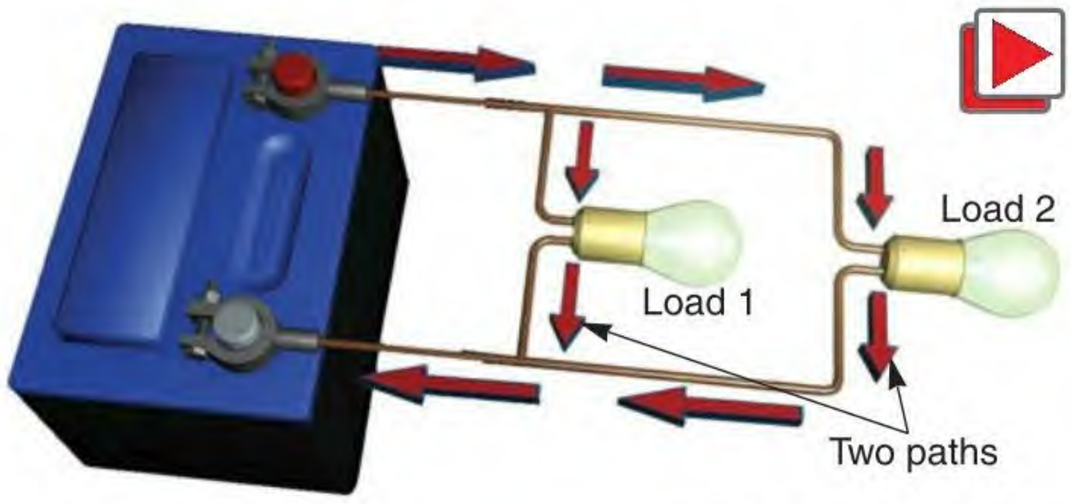
Parallel Circuit

A ***parallel circuit*** has more than one path for current, as shown in **Figure 18-4**. Two or more loads are placed on separate paths in the circuit. **Figure 18-5** shows the basic operation of a parallel circuit. Because the bulbs are wired in parallel, they can function independently. In a string of lights wired in parallel, one burned-out light does not affect the operation of the other bulbs in the parallel circuit. See **Figure 18-6**.

Series-Parallel Circuit

A ***series-parallel circuit*** is a combination of a series circuit and a parallel circuit. Some of the components are wired in series, and others are wired in parallel. See **Figure 18-7**.

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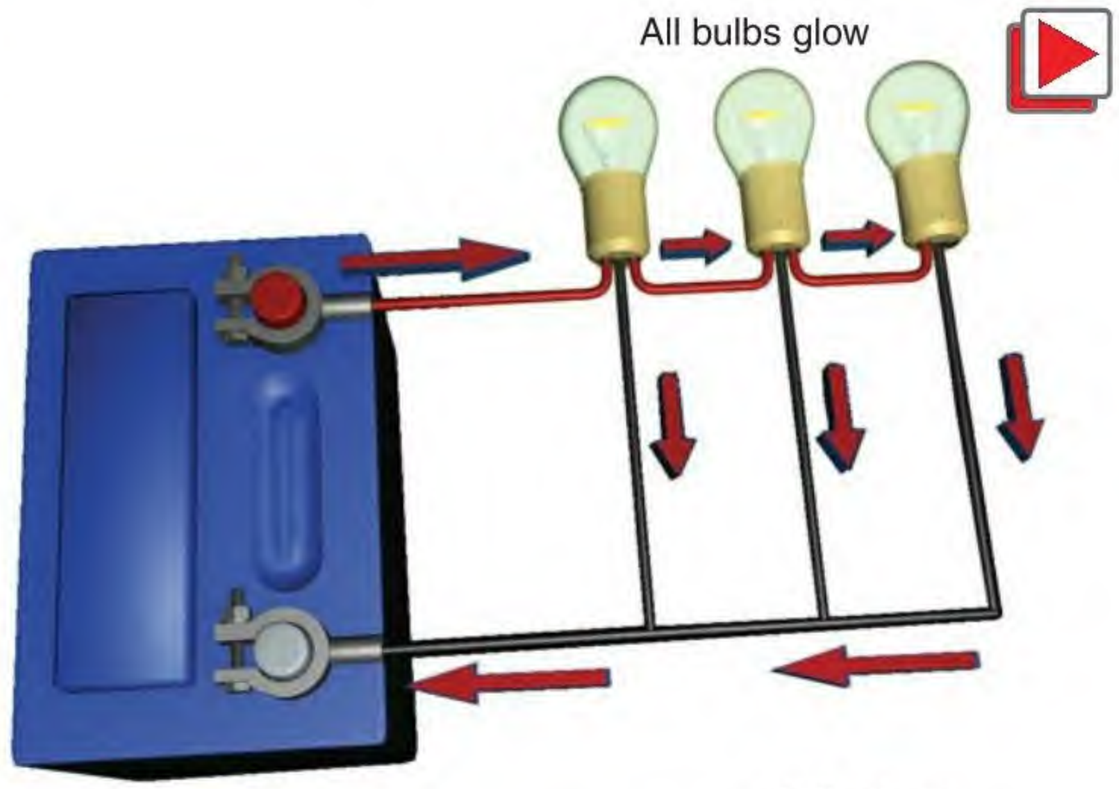
Figure 18-4. A parallel circuit has more than one path for current. In this example, two bulbs are wired in parallel. Each parallel branch operates independent of the others.

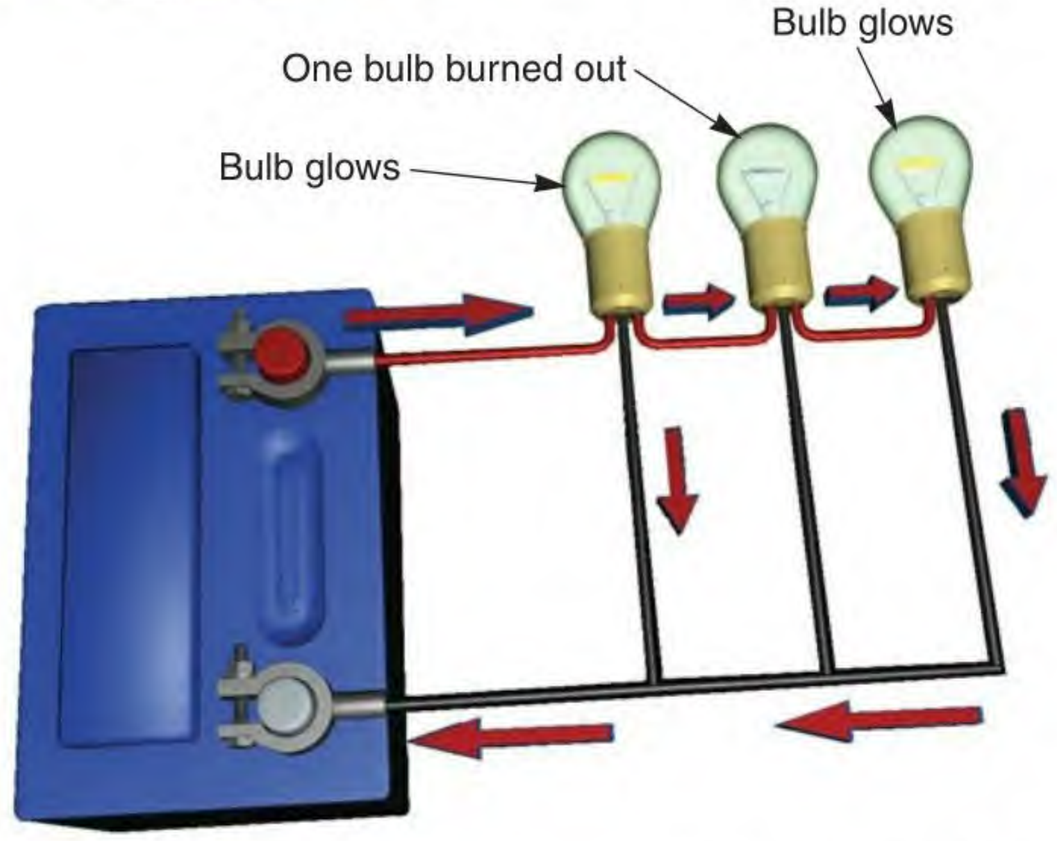
Frame-Ground Circuit

A ***frame-ground circuit***, also called a ***one-wire circuit***, uses the metal structure of the vehicle to return electricity to the power source. This eliminates the need to run yards of wire from the electric components back to the power source. Ground wires can be attached directly to the metal vehicle frame or body structure, which serves as a return path to the power source. The negative battery cable is also attached to the vehicle's frame or body. This allows the metal structure of the vehicle to serve as a large conductor, **Figure 18-8**.

Tech Tip

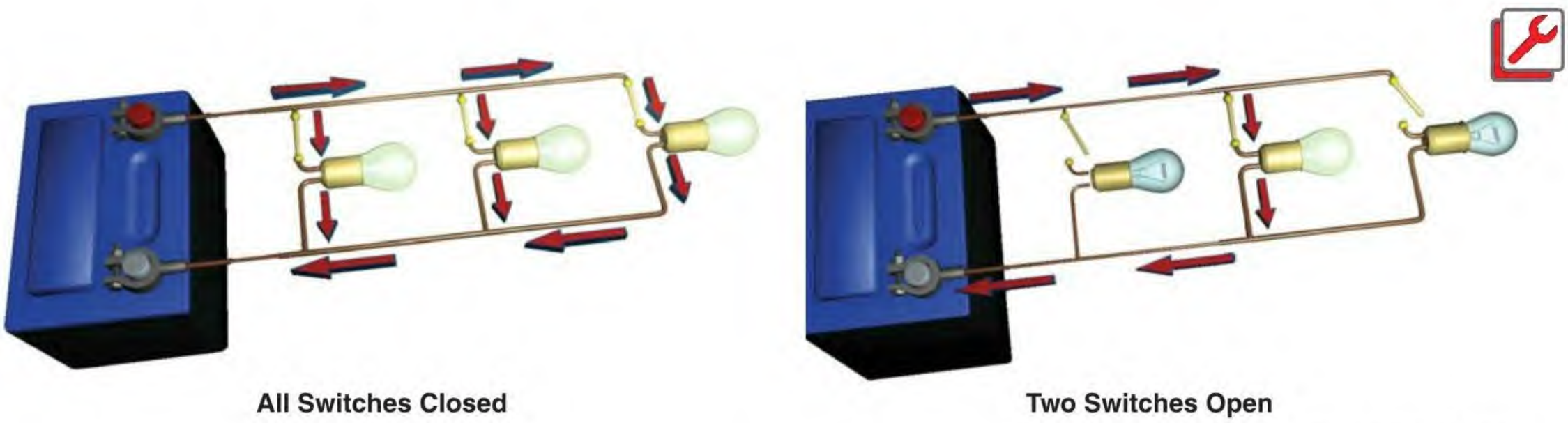
The following description of a frame-ground circuit is based on conventional current theory, which states that electrons flow from the positive terminal of a power source to the negative terminal.





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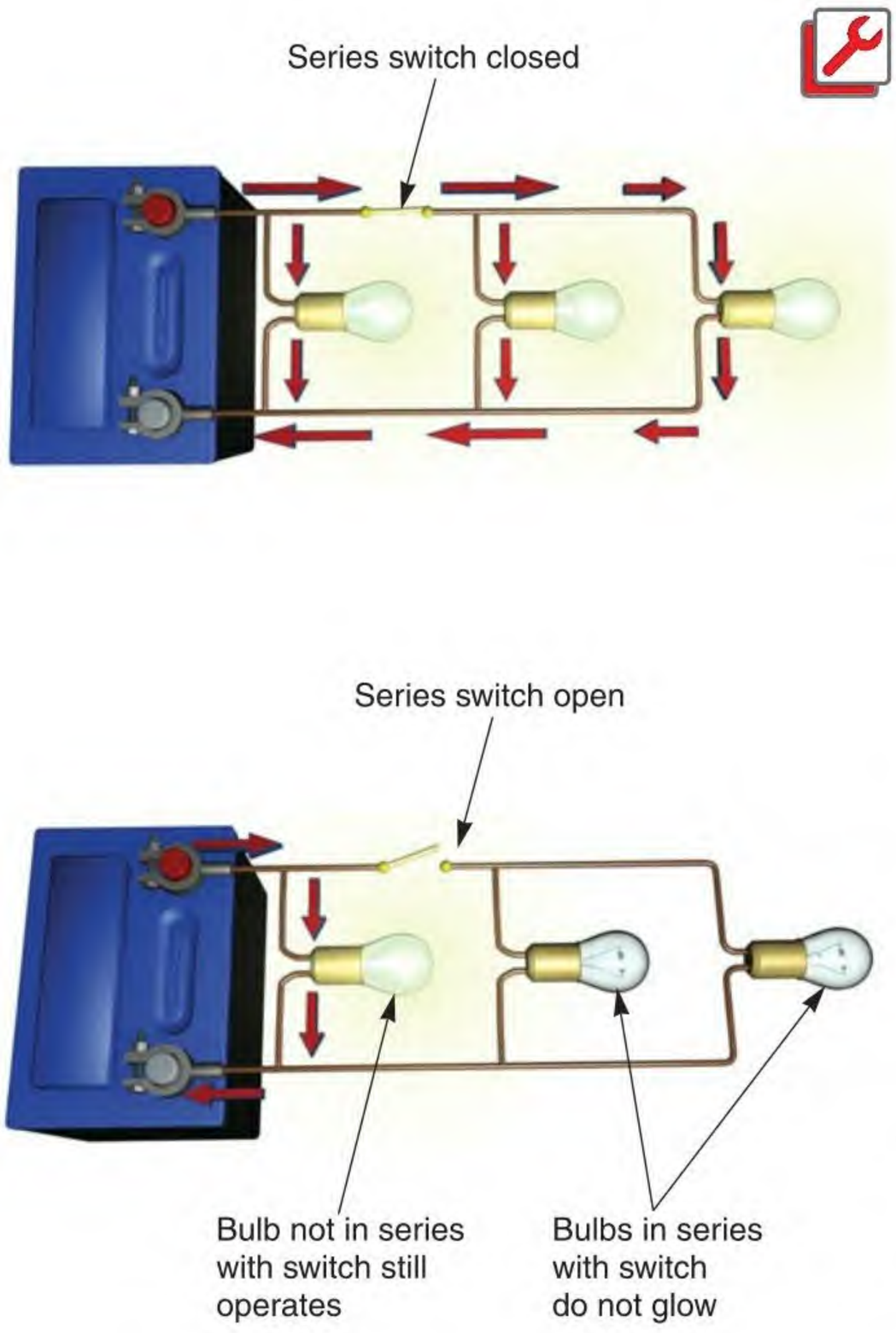
Figure 18-6. A string of lights wired in parallel can function even though some of the bulbs burn out.



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Figure 18-5. In these circuits, three sets of switches and bulbs are wired in parallel. When all switches are closed, all the bulbs glow. With two switches open, the lights in those branches of the circuit do not glow. However, the third bulb glows because it is wired in parallel with the other bulbs and its switch is closed.

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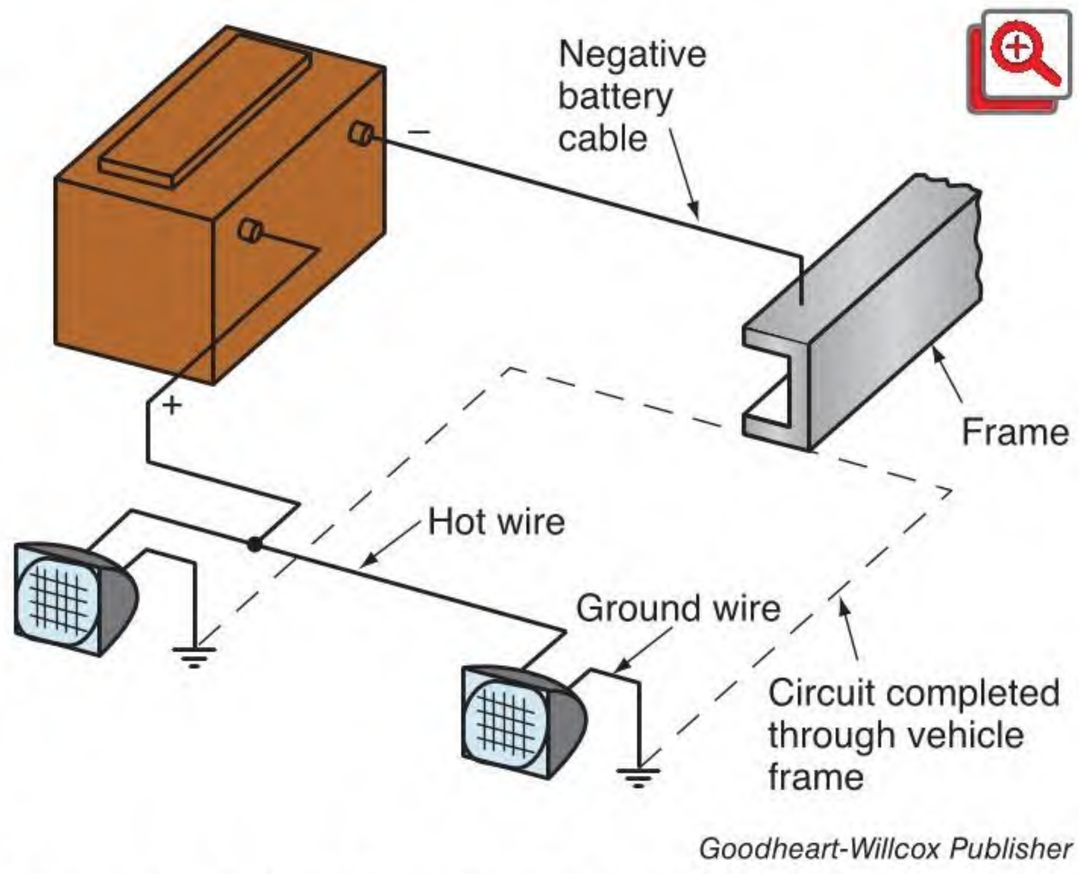
Figure 18-7. A series-parallel circuit is a combination series circuit and parallel circuit. In this example, three bulbs are wired in parallel. A switch is wired in series with two of the bulbs. When the switch is closed, all of the bulbs receive current. When the switch is open, current is blocked to two of the bulbs.

Electrons flow from the positive terminal of the battery to the load, through the frame, and back into the negative terminal of the battery to complete the circuit.

The wire that carries current to the load is the ***hot wire***. It is the section of the circuit between the positive terminal of the battery and the load. The ***ground*** is the part of the circuit between the load and the negative terminal of the battery. See **Figure 18-9**.

Ohm's Law

Ohm's law is a set of formulas that expresses the relationships between voltage, current, and resistance in an electric circuit. You must understand Ohm's law and electrical measurements to fully grasp electrical troubleshooting methods.



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Figure 18-8. Note how auto manufacturers use the frame or unibody structure of a vehicle to complete an electric circuit. The battery is connected to the frame of the vehicle. The ground side of the electric component is also connected to the frame. This allows the current to flow through the metal parts of the vehicle and back to the battery.

Ohm's law can be stated as three different formulas. See **Figure 18-10**. As these formulas show, voltage, current, and resistance interact to affect the operation of a circuit. If you know any two of the three electrical values in a circuit, you can calculate the third value using one of these formulas. In the formulas, *E* stands for voltage, *I* stands for current, and *R* stands for resistance.

- $E = I \times R$

  Voltage equals current multiplied by resistance

  volts = amps × ohms
- $I = E \div R$

  Current equals voltage divided by resistance

  amps = volts ÷ ohms
- $R = E \div I$

  Resistance equals voltage divided by current

  ohms = volts ÷ amps

As shown in **Figure 18-11**, 1 volt is needed to push 1 amp of current through 1 ohm of resistance. Remember that voltage pushes current through a resistance. If any one value changes, it affects the others.

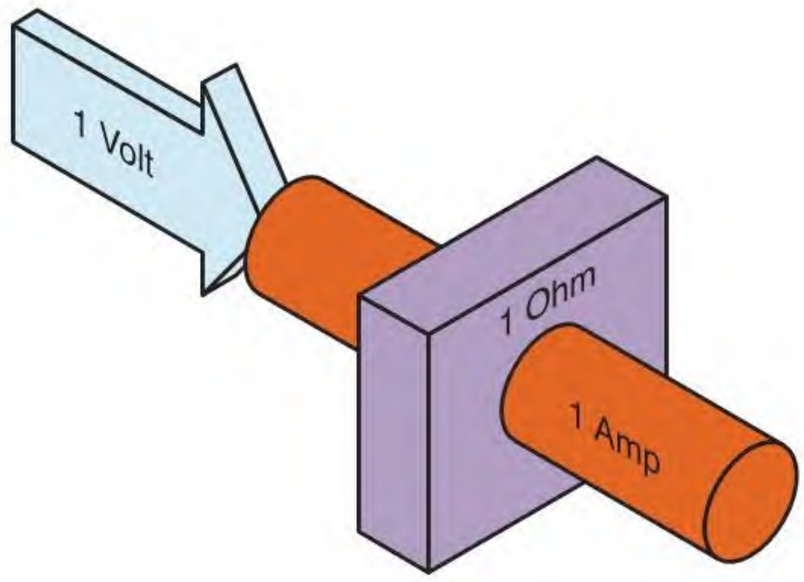
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Figure 18-9. Hot and ground wires in typical automotive circuits. A—The hot wire carries current to the horn. B—The large ground wire is bolted to the body structure to serve as a ground conductor going back to the battery.



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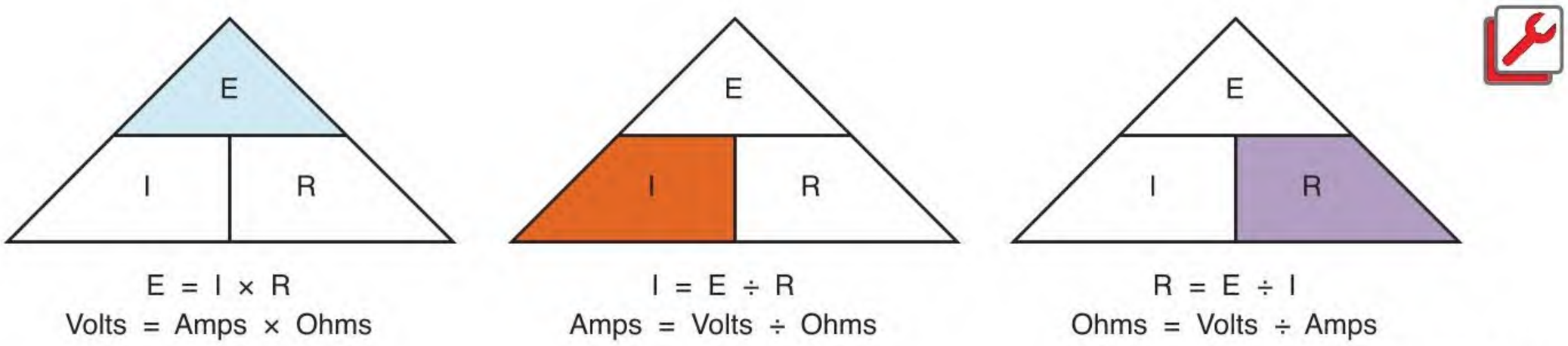
Figure 18-11. It takes 1 volt to push 1 amp through 1 ohm of resistance. This relationship allows you to use math to calculate the unknown value when you know the other two values.

Change in Resistance

A change in resistance alters the amount of current in a circuit. If resistance is low, current will be high. If resistance is high, current will be low.

For example, if a circuit has 12 volts (12 V) and a resistance of 3 ohms (3 Ω), you can use Ohm's law to calculate a current of 4 amps (4 A). However, if resistance increases to 12 ohms because of a bad connection, current drops to only 1 amp. See **Figure 18-12**.

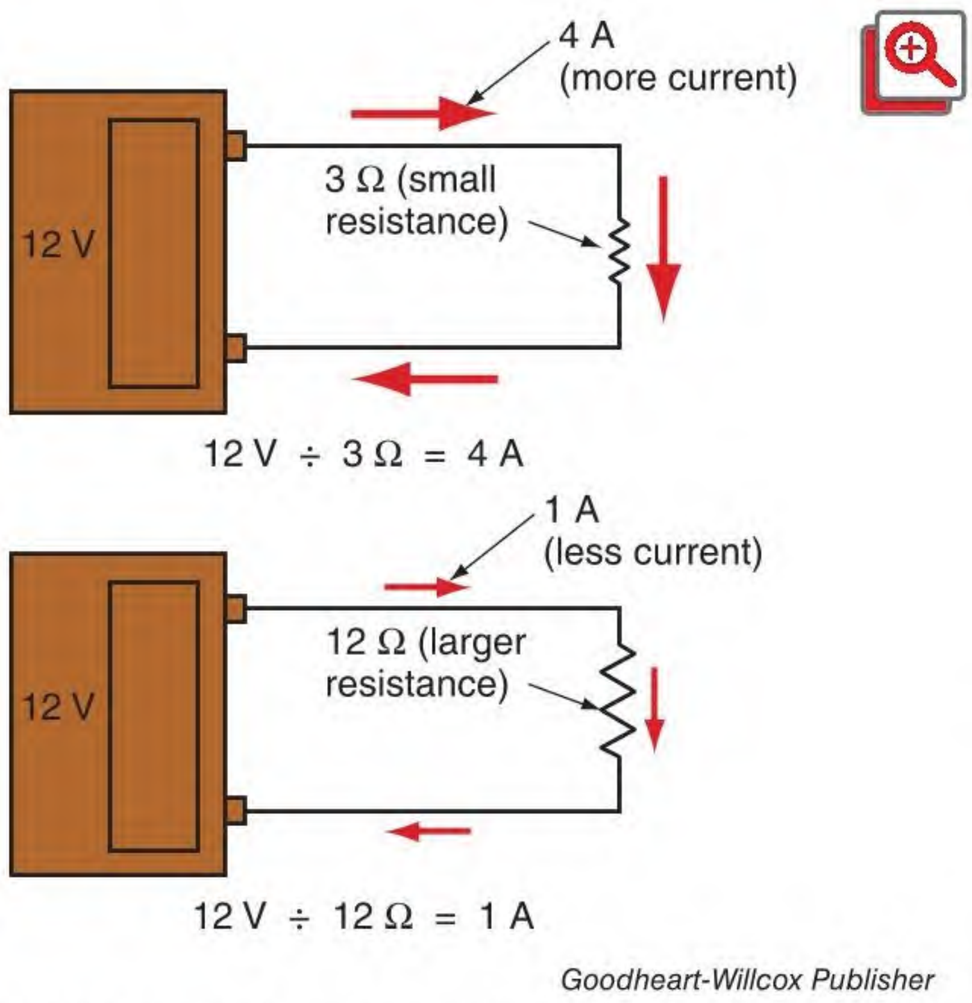
Most automotive electrical problems are caused by a change in circuit resistance. A poor electrical connection (increased resistance), for example, reduces current in the circuit. This might cause a lightbulb to burn dimly or upset a signal from a computer system sensor.



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Figure 18-10. These triangular diagrams may help you remember the formulas of Ohm's law. The horizontal bar in the center of the triangle stands for division. The vertical bar stands for multiplication. *I* (current) and *R* (resistance) are on opposite sides of the vertical bar, so they must be multiplied to find *E* (voltage). *E* is over *R*, so *E* is divided by *R* to find *I*. *E* is also over *I*, so *E* is divided by *I* to find *R*.

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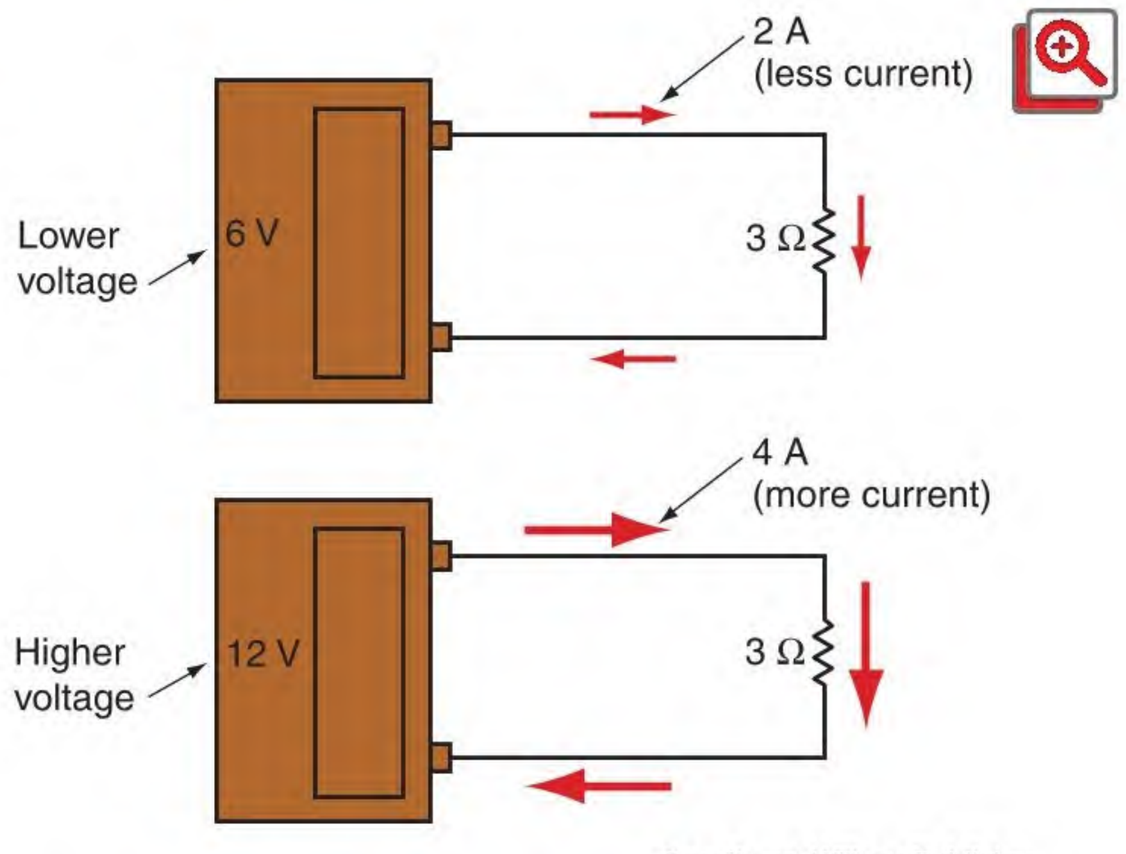


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Figure 18-12. If voltage remains constant, a circuit with high resistance has less current than a circuit with low resistance because more free electrons can flow through the smaller resistance.

Change in Voltage

A change in voltage also affects the amount of current in a circuit. A rise in voltage increases current, and a drop in voltage decreases current. Again, you can use Ohm's law to demonstrate this principle. See **Figure 18-13**.

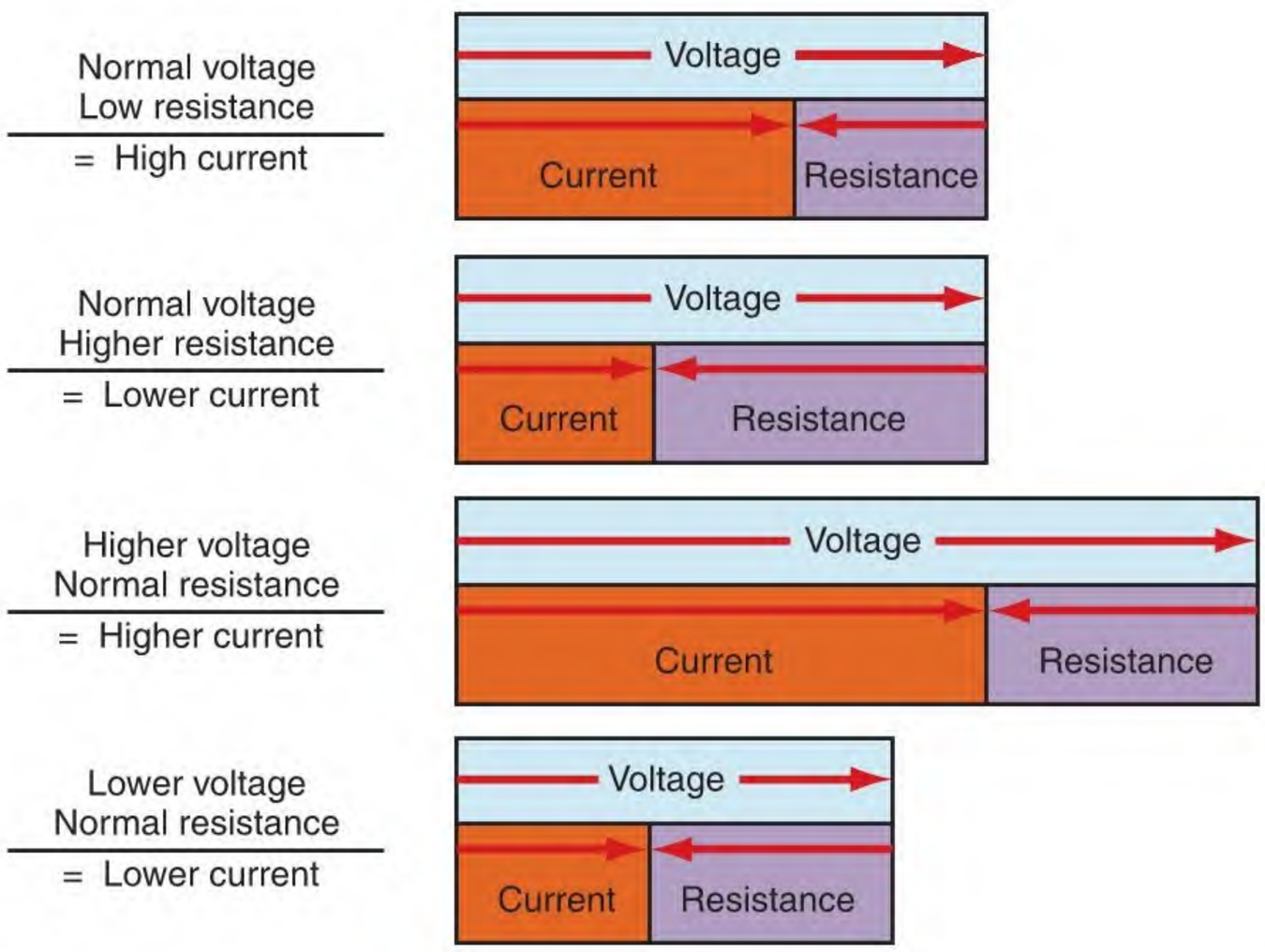


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Figure 18-13. In these circuits, different voltages are connected to the same resistance. Note that higher voltage produces higher current.

Change in Current

Any change in a circuit's current is a result of increased or decreased voltage or resistance. Current in a circuit depends on these two factors. Without sufficient current in a circuit, the load will not function properly. An electric motor might run too slowly or a bulb might burn dimly. With too much current in a circuit, components or wires may overheat or burn. **Figure 18-14** summarizes the effect of voltage and resistance on current.



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Figure 18-14. Summary of the effect of voltage and resistance on current.

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Circuit Calculations

Ohm's law applies to the total current, voltage, and resistance in electric circuits. To find these total values, however, you will need to apply formulas specific to the circuit types.

Series Circuit Calculations

Three general rules apply to a series circuit:

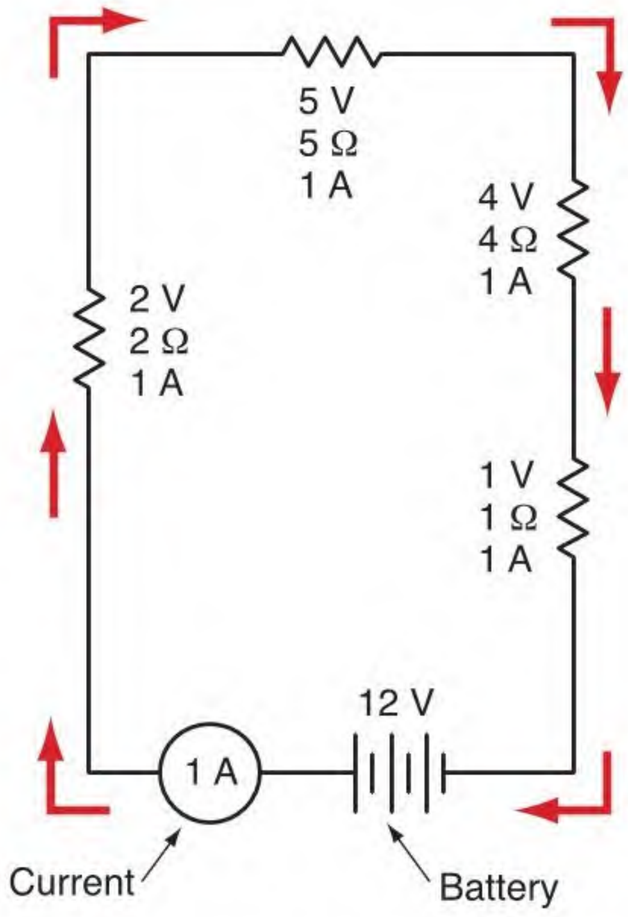
- Current is the same everywhere in a series circuit. No matter where you connect an ammeter in a series circuit, the reading will be the same.
- Total resistance (R_t) is the sum of all of the resistances in the circuit. The formula for total resistance in a series circuit is:

  $R_t = R_1 + R_2 + R_3 + \ldots + R_n$

  (In this formula, *n* equals the total number of resistances in the circuit.)
- The voltage drop across each resistance equals the voltage applied. The voltage used by all resistance elements equals the total voltage, or supply voltage (E_t).

To get the total resistance for the circuit, you add the two resistances. You can then use the total resistance with Ohm's law to find current. See **Figure 18-15**.

You can add the resistances to find that R_t equals 12 Ω. Divide volts by ohms to find the value of the current. In this case, the current equals 1 A (12 V ÷ 12 Ω). See **Figure 18-16**.



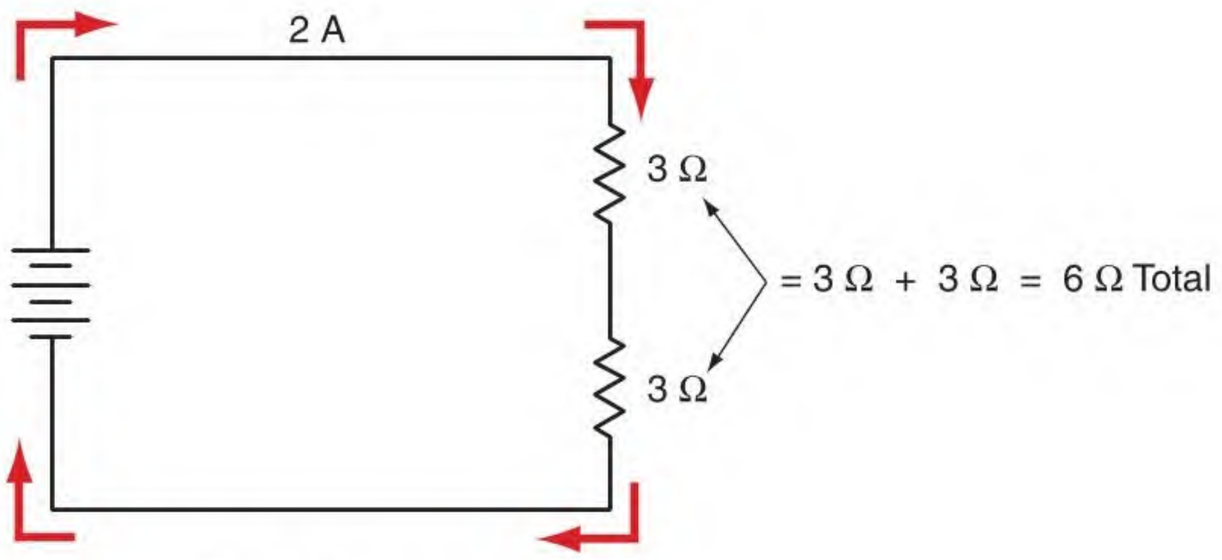
$E_t = 2\,V + 5\,V + 4\,V + 1\,V = 12\,V$

$R_t = 2\,\Omega + 5\,\Omega + 4\,\Omega + 1\,\Omega = 12\,\Omega$

$I_t = \frac{12\,V}{12\,\Omega} = 1\,A$

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Figure 18-16. Use Ohm's law to check resistance and current in this series circuit. Add all resistance values to get R_t. Then divide voltage by resistance to get current.



$I = \frac{E}{R} = \frac{12}{6} = 2\,A$

$R = \frac{E}{I} = \frac{12}{2} = 6\,\Omega$

$E = R \times I = 6 \times 2 = 12\,V$

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Figure 18-15. In a series circuit, add the individual resistance values to get total resistance. You can then use the total resistance to find the amount of current.

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Parallel Circuit Calculations

Parallel circuits also have three basic rules:

- Total current (I_t) is the sum of all branch currents. In a circuit with three branches carrying 2 amps each, the total circuit current is 6 amps.
- Total circuit resistance is less than the resistance in any one branch. If each of two branches has a resistance of 4 Ω, the total resistance for the circuit is 2 Ω.
- The total voltage equals the supply voltage, and the voltage is the same throughout the circuit. If branches are parallel, they receive the same supply voltage.

Figure 18-17 illustrates how resistance controls current in a parallel circuit. Note that the current is lowest in the branch with the highest resistance and that current is highest in the branch with the lowest resistance. This figure also demonstrates the basic rule that current follows the path of least resistance.

Several methods can be used to calculate resistance in a parallel circuit, depending on the number of branches and the values of the resistances. The ***reciprocal method*** works on all parallel circuits. In general, the ***reciprocal*** of a number equals 1 divided by that number. In the reciprocal method of calculating resistance, the reciprocal of the total resistance equals the sum of the reciprocals of all of the branch resistances:

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots + \frac{1}{R_n}$$

In this formula, *n* equals the total number of resistance elements in the circuit. **Figure 18-18** shows how to use the reciprocal method to calculate total resistance in a parallel circuit that has four branches with different resistance values. After you have calculated the total resistance, you can use the voltage and resistance values to find total current.

Series-Parallel Circuit Calculations

In a series-parallel circuit, you can find the total resistance of the circuit by calculating the resistance of each parallel section and then adding the series resistances to these values to obtain a single ***equivalent resistance***. **Figure 18-19** shows how to calculate an equivalent resistance. First, use the reciprocal method to find the total resistance of the parallel portion of the circuit. This reduces the circuit to the equivalent of a series circuit. Then add the total resistance of the parallel portion to the total series resistance to find the equivalent resistance.

When working with more complex series-parallel circuits, start by working with the parallel sections of the circuit to arrive at *R* for each section. Then add any series resistance to these values to find the total resistance. See **Figure 18-20**.

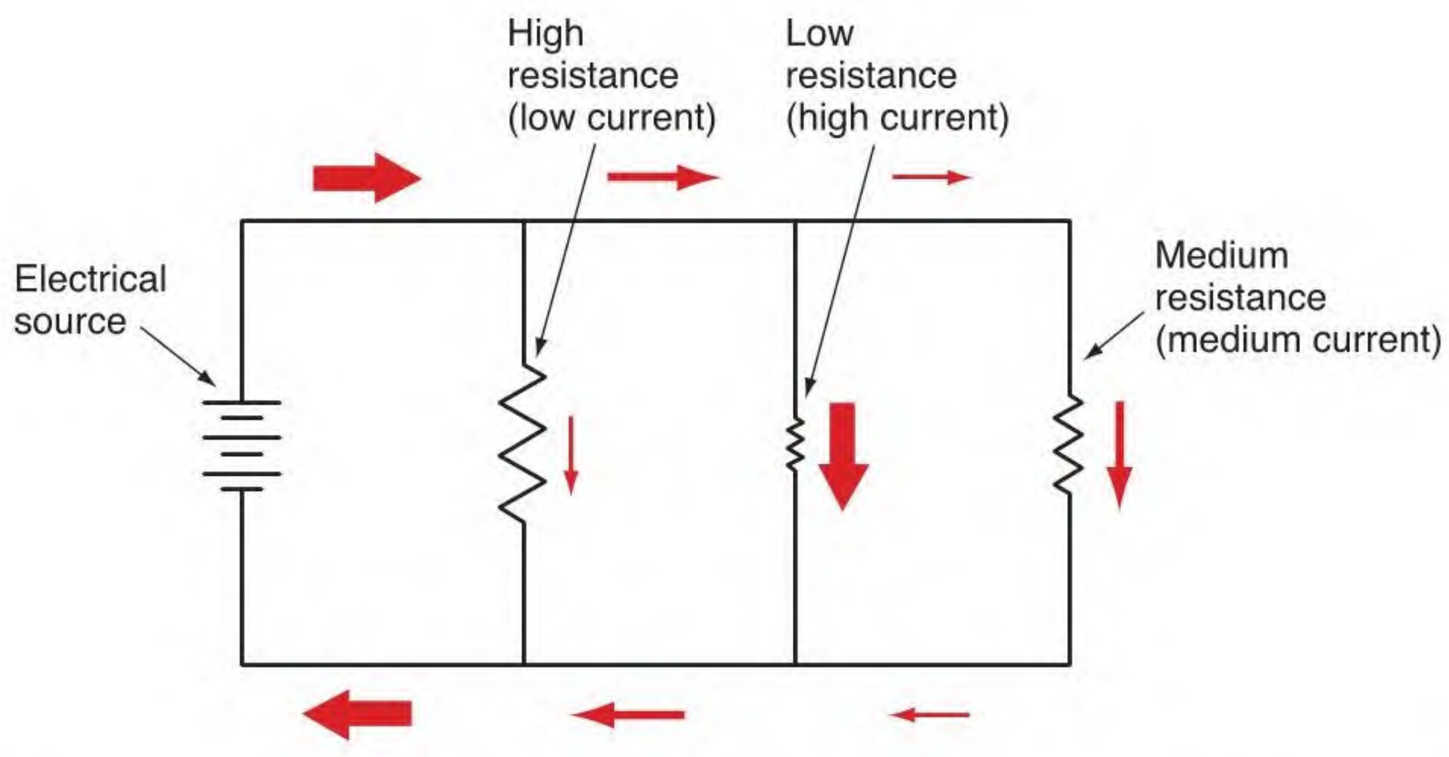
Electric Power Calculations

Electric power is the work done by an electric current. Its unit of measurement is the ***watt***. You can calculate electric power if you know the current and either the voltage or the resistance for the circuit. The formulas for power (*P*) are:

$$P \text{ (in watts)} = E \times I$$

or

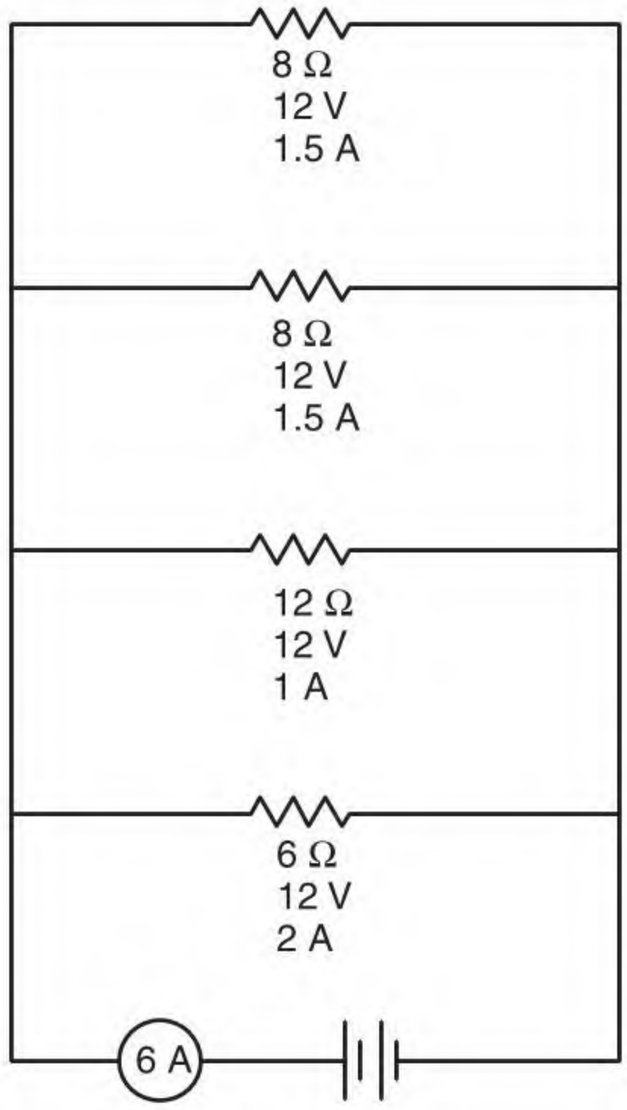
$$P = I^2 \times R$$



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Figure 18-17. Parallel circuit operation is more complex than series circuit operation. In this circuit, the parallel branches have different resistance values. There is less current in branches with high resistance than those with low resistance. Low resistance allows a greater amount of current.

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Total Voltage = Supply Voltage = 12 V

Calculate Total Resistance

$$\frac{1}{R_t} = \frac{1}{8\ \Omega} + \frac{1}{8\ \Omega} + \frac{1}{12\ \Omega} + \frac{1}{6\ \Omega}$$

Convert to decimals and use a calculator:

$$\frac{1}{R_t} = 0.1250\ \Omega + 0.1250\ \Omega + 0.0833\ \Omega + 0.1667\ \Omega$$

$$\frac{1}{R_t} = 0.5000\ \Omega$$

$$\text{The reciprocal of } 0.5000 = \frac{1}{0.5000}$$

$$R_t = \frac{1}{0.5000} = 2\ \Omega$$

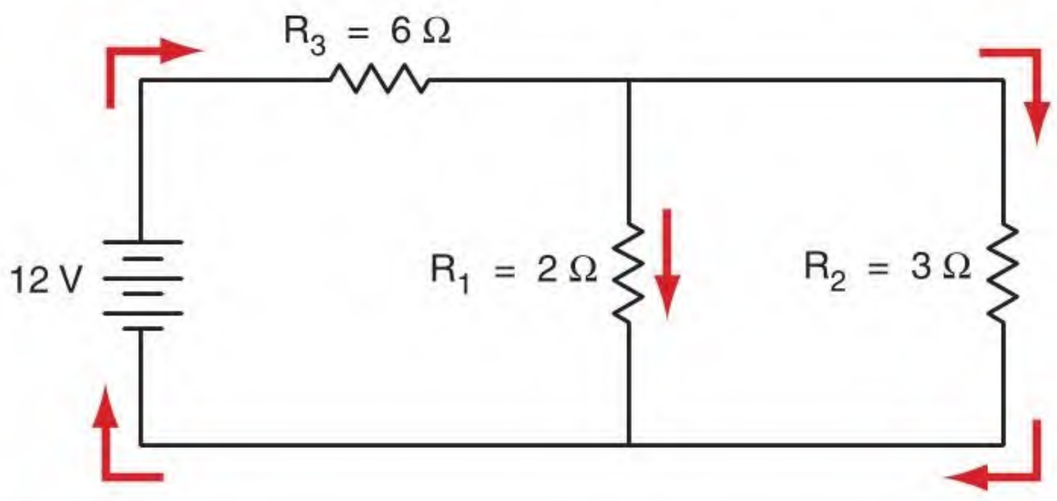
Calculate Total Current

$$I_t = 1.5\ A + 1.5\ A + 1\ A + 2\ A$$

$$I_t = 6\ A$$

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Figure 18-18. The reciprocal method can be used to calculate the total resistance in this parallel circuit. Notice that the total resistance is lower than the resistance in any one branch. Once total resistance is known, you can calculate total current.



Calculate Equivalent Resistance

Resistance in parallel part of circuit:

$$\frac{1}{R} = \frac{1}{2\ \Omega} + \frac{1}{3\ \Omega}$$

$$\frac{1}{R} = 0.50\ \Omega + 0.33\ \Omega$$

$$\frac{1}{R} = 0.83\ \Omega$$

$$R = \frac{1}{0.83\ \Omega}$$

$$R = 1.20\ \Omega$$

Resistance in series part of circuit:

$$R = 6\ \Omega$$

Equivalent Resistance (R_t)

$$R_t = R \text{ in parallel} + R \text{ in series}$$

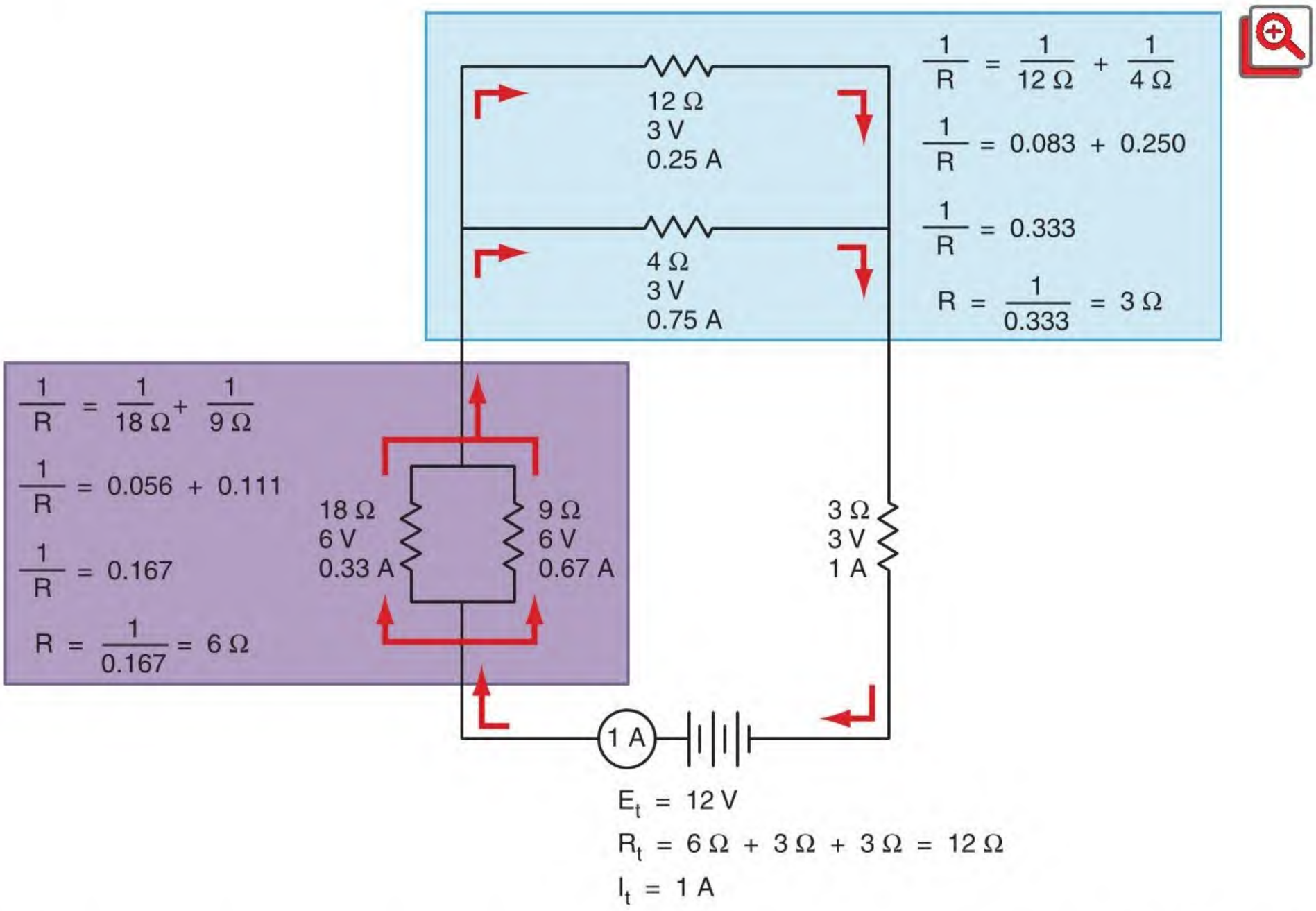
$$R_t = 1.20\ \Omega + 6\ \Omega$$

$$R_t = 7.2\ \Omega$$

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Figure 18-19. To calculate equivalent resistance in a series-parallel circuit, break the circuit into its individual series and parallel sections. Calculate the resistance in each parallel section. Then add the total resistance in the parallel sections to the resistances in the series sections to find the equivalent resistance.

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Figure 18-20. Even in complex series-parallel circuits, you can find the equivalent resistance by working with each parallel and series part separately.

Power ratings are sometimes used in automotive electronics. Lightbulbs, especially headlight bulbs, are sometimes rated in watts. Hybrid motor-generators and HV batteries can be rated in kilowatts (kW, or 1000s of watts). Vehicle batteries may also have a watt rating to indicate their power potential.

Prefixes for Electrical Units

Depending on the type of circuit, electrical values may be very large or very small. To avoid the need to read and write large numbers, prefixes are used with these values to indicate a multiplier, or exponent, of the value. Refer to **Figure 18-21**.

In automotive circuits, currents are sometimes very small. For these values, milliamperes (mA) are used to show current draw: 1 mA equals 0.001 (1×10^{-3}) A.

Some resistance values, such as those for spark plug wires, can be very large. In these cases, resistance may be given in kilohms (kΩ): 1 kΩ equals 1000 (1×10^{3}) Ω.

Note the symbols associated with each prefix in **Figure 18-21**. These symbols are used with base units such as volts, amperes, and ohms to indicate the prefixes for electrical values. Examples include:

- 5 MΩ (megohms) = 5,000,000 Ω.
- 10 kΩ (kilohms) = 10,000 Ω.
- 32 mA (milliamperes) = 0.032 A.
- 12 µF (microfarads) = 0.000012 farad.

Electronic specifications may be given in prefix form, so you should memorize the meaning of each prefix, especially *mega-*, *kilo-*, *milli-*, and *micro-*. These are the most commonly used prefixes in automotive electronics.

Workplace Skills

Electrical devices have been around since the days of Thomas Alva Edison and his greatest invention, the lightbulb. Edison worked very long hours, up to 20-hour days, in his test laboratory trying to perfect his electrical inventions. Appropriately, Edison's most famous saying was and still is, "Genius is one percent inspiration and 99 percent perspiration!"

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Prefix	Symbol	Multiplier	Exponent Form	Example
tera-	T	1,000,000,000,000	10^{12}	1.5 TV = 1.5 × 10^{12} = 1,500,000,000,000 V
giga-	G	1,000,000,000	10^{9}	32 GV = 32 × 10^{9} = 32,000,000,000 V
mega-	M	1,000,000	10^{6}	4.6 MΩ = 4.6 × 10^{6} = 4,600,000 Ω
kilo-	k	1,000	10^{3}	2.8 kΩ = 2.8 × 10^{3} = 2,800 Ω
deka-	da	10	10^{1}	6 daV = 6 × 10^{1} = 60 V
deci-	d	0.1	10^{-1}	8 dA = 8 × 10^{-1} = 0.8 A
centi-	c	0.01	10^{-2}	7.2 cA = 7.2 × 10^{-2} = 0.072 A
milli-	m	0.001	10^{-3}	3.6 mA = 3.6 × 10^{-3} = 0.0036 A
micro-	μ	0.000 001	10^{-6}	19 μV = 19 × 10^{-6} = 0.000 019 V
nano-	n	0.000 000 001	10^{-9}	5 nV = 5 × 10^{-9} = 0.000 000 005 V
pico-	p	0.000 000 000 001	10^{-12}	43 pΩ = 43 × 10^{-12} = 0.000 000 000 043 Ω

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Figure 18-21. These prefixes are commonly used on wiring diagrams. Notice that the symbol M means something entirely different from the symbol *m*.

Summary

- The three basic types of circuits are series, parallel, and series-parallel circuits.
- A series circuit has one or more loads connected in the same path.
- A parallel circuit has two or more separate paths for current, and each path can operate independently of the others.
- A series-parallel circuit has both series and parallel sections in one circuit.
- Many automotive circuits are frame-ground or one-wire circuits. The vehicle's metal structure is used to carry current back to the source. This reduces the amount of wire needed to complete the circuits.
- Ohm's law consists of a set of formulas that express the relationships between voltage, current, and resistance in a circuit. If you know any two of the three values, you can use Ohm's law to calculate the unknown value.
- If circuit resistance increases, current decreases. If resistance decreases, current increases. If voltage increases, current increases also.
- Current is the same everywhere in a series circuit. Total resistance is the sum of all series resistances. The voltage drop across each series resistance equals the applied voltage source.
- In a parallel circuit, total circuit current is the sum of all branch currents. Total circuit resistance in a parallel circuit is less than any one branch resistance. The voltage applied to each branch is the same.
- To find the equivalent resistance in a series-parallel circuit, evaluate the parallel section to find its total resistance, and then use the formula for series resistance.
- Prefixes are commonly used to express very large or very small electrical values.

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Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

circuit
electric power
equivalent resistance
frame-ground circuit
ground
hot wire
Ohm's law
one-wire circuit
parallel circuit
reciprocal
reciprocal method
series circuit
series-parallel circuit
watt

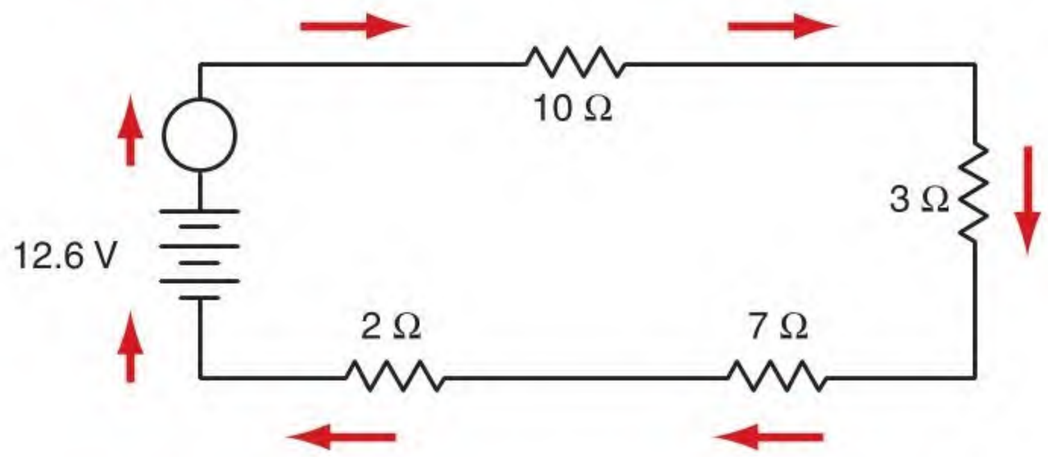
Activities

1. Look up your own car's wiring diagrams using an online service information program. Note the symbols and types of diagrams included in the literature.
2. Using service information for any make of hybrid vehicle, look up the wiring diagrams for the vehicle's electric drive train. Study its circuits and how sensors, the battery pack, power control module, and motor-generator are wired together.

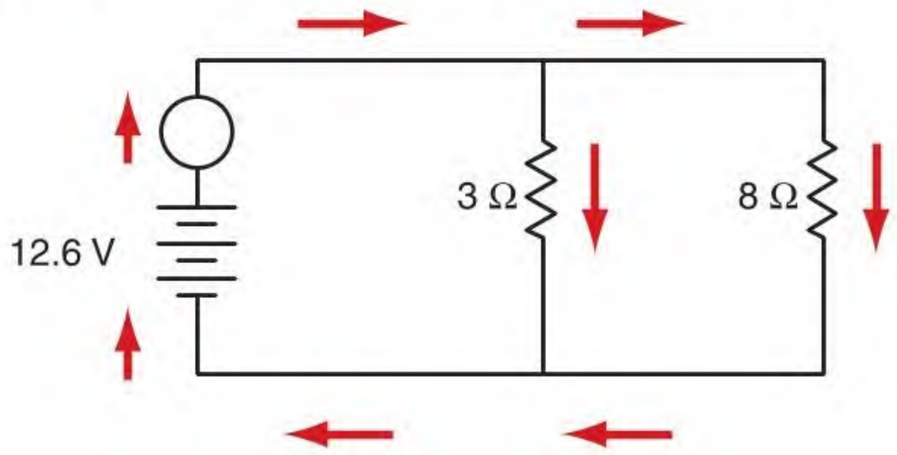
Review Questions

Answer the following questions using the information provided in this chapter.

1. In what way is a parallel circuit different from a series circuit?
2. What is a series-parallel circuit?
3. In a frame-ground circuit, the vehicle's _____ serves as a large conductor to carry current.
4. Why are many automotive circuits frame-ground circuits?
5. Write the formulas that express the relationships between voltage, current, and resistance in a circuit.
6. If resistance increases in a circuit, what will happen to current?
7. If a circuit has a current of 3 A and a resistance of 5 Ω, how much voltage is applied to the circuit?
8. If a circuit has a current of 25.4 amps with 12.6 volts applied, what is the circuit resistance?
9. In which type of circuit can you find total resistance by adding all of the individual resistances?
10. In which type of circuit is the total current equal to the sum of all the branch currents?
11. Calculate the total resistance and current for the following circuit.



12. Find total resistance and current for this circuit.



13. Describe how to find the equivalent resistance in a series-parallel circuit.
14. If you know the total current and resistance in a circuit, how can you find electric power in watts?
15. How many ohms are in 14.4 kΩ?
16. How many microamps are in 0.000034 A?

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ASE-Type Questions

1. Technician A says a series circuit has only one path for current. Technician B says a series circuit can have only one load. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Which of the following is *not* a common type of electric circuit?
   (A) Parallel circuit.
   (B) Series-parallel circuit.
   (C) Frame-ground circuit.
   (D) Series-ground circuit.
3. Technician A says the term *hot wire* refers to the section of the circuit after the load or electric device. Technician B says the ground wire refers to the section of the circuit after the load or electric device. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. Technician A says the ***frame-ground circuit***, also called a ***one-wire circuit***, uses the metal structure of the vehicle to return electricity to the power source. Technician B says the ground includes the portion of the circuit between the load and the negative terminal of the battery. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. A 12-volt circuit has a resistance of 2 ohms. How much current is in the circuit?
   (A) 4 amps.
   (B) 6 amps.
   (C) 1 amp.
   (D) 3 amps.
6. Technician A says a change in circuit resistance will change the amount of current in the circuit. Technician B says a change in circuit voltage will change the amount of current in the circuit. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. Technician A says current is the same everywhere in a series circuit. Technician B says current is the same in each branch of a parallel circuit. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. One milliamp is equal to:
   (A) 0.001 amp.
   (B) 100 amps.
   (C) 1000 amps.
   (D) 10,000 amps.
9. 10,000 ohms can also be written as:
   (A) 10 kilohms.
   (B) 1 megohm.
   (C) 1 kilohm.
   (D) 10 megohms.
10. A 12-volt automotive circuit has a current of 3 amps. Technician A says the electric power in this circuit is 36 watts. Technician B says the electric power in this circuit is 4 watts. Who is right?
    (A) A only.
    (C) B only.
    (B) Both A and B.
    (D) Neither A nor B.

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Just as a few simple digits (0-9) can be combined and arranged in different ways to create an infinite range of numbers, so too can a handful of basic electronics components be combined to perform a wide range of different functions. Understanding what these basic components do will help you understand how they work together in a complete circuit.

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Chapter 19
Electric and Electronic Components

After studying this chapter, you will be able to:

- Identify electric and electronic components.
- Explain the function and operation of electric and electronic components.
- Interpret electric and electronic component ratings and values.
- Recognize the symbols and letter designations for electric and electronic components.
- Recall the properties of semiconductor materials.
- Recall the common types of transistors.
- Give examples of photonic devices.

This chapter will introduce the most common types of electric components and electronic components. You will learn about electric components such as resistors, coils, solenoids, relays, and fuses. You will also learn about diodes, transistors, light emitting diodes, and other electronic, or "solid state," components. The information in this chapter is very important if you are to become a successful technician in today's automotive industry.

Electric Components

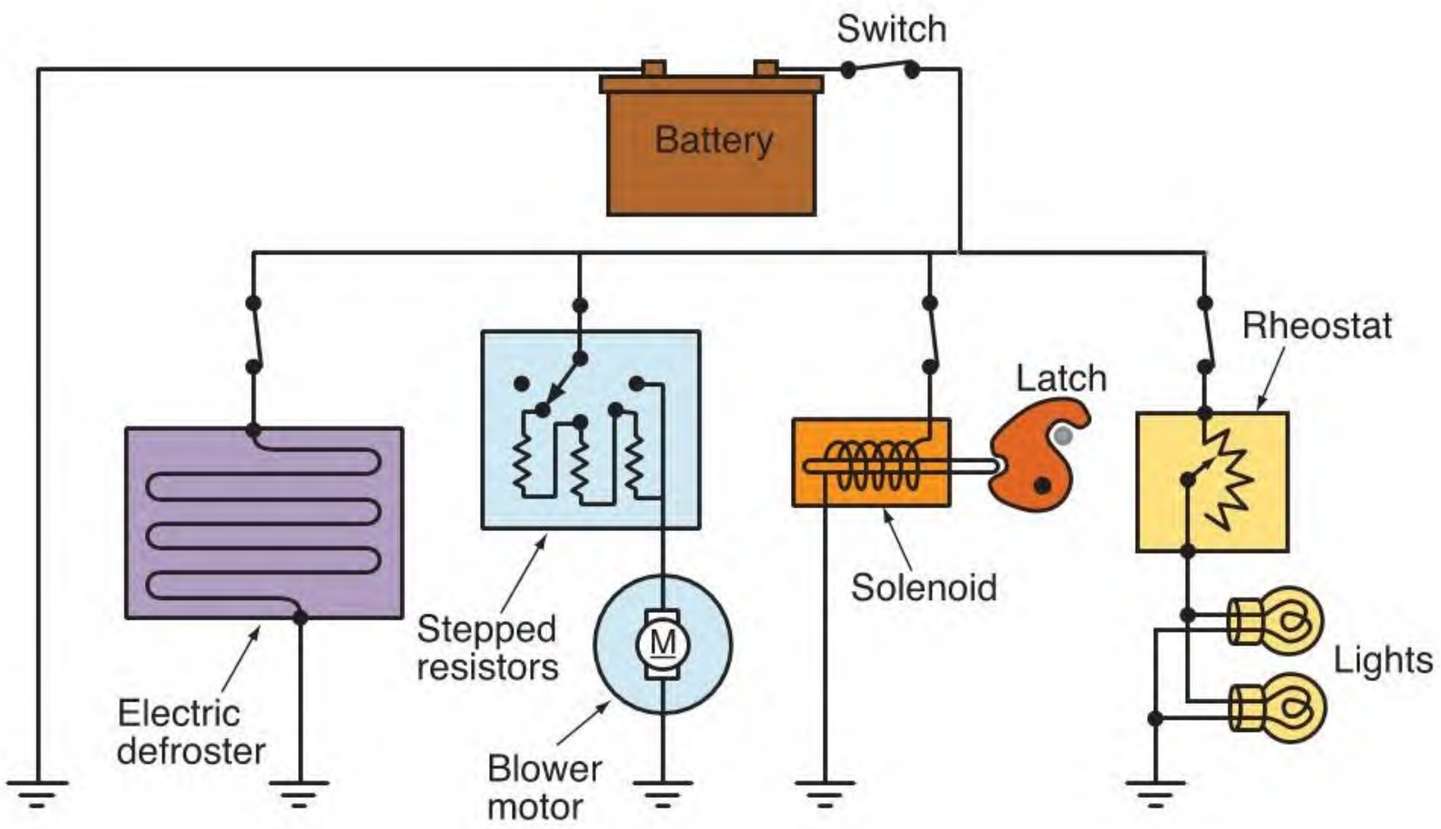
Today's vehicles use an array of electric components, as illustrated in **Figure 19-1**. This section reviews the basic construction and operation of important electric components that can be found on late-model passenger vehicles.

Resistors

If a circuit had no resistance, it would burn up from excess current and heat. A lightbulb, for example, uses a small resistance element inside a sealed glass housing to generate heat and light. A ***resistor*** limits and controls current flow in a circuit. Resistor devices come in various shapes and sizes, depending on their function. Refer to **Figure 19-2.**

A fixed resistor has a set ohms value that does not change. A variable resistor has a range of internal resistance that can be adjusted. When you turn or slide a control knob, a contact moves along a resistor element. As the contact moves, a different amount, or length, of resistor is connected inside the device, changing the resistance value. Look at **Figure 19-3**. There are two basic types of variable resistors, rheostats and potentiometers.

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Ford

Figure 19-1. Conventional electric components are still used to do many tasks in a vehicle's electrical system. You will learn about these components in this and other chapters.

	General Resistor Symbol
1000 Ω	Resistance Value
10 W	Watt (Power) Rating
5%	Tolerance

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Figure 19-2. In addition to the resistance value, resistors have a watt rating and a tolerance. The watt rating indicates how much load or power the resistor can handle. The tolerance indicates how much the resistance value of the resistor can vary from its nominal value.

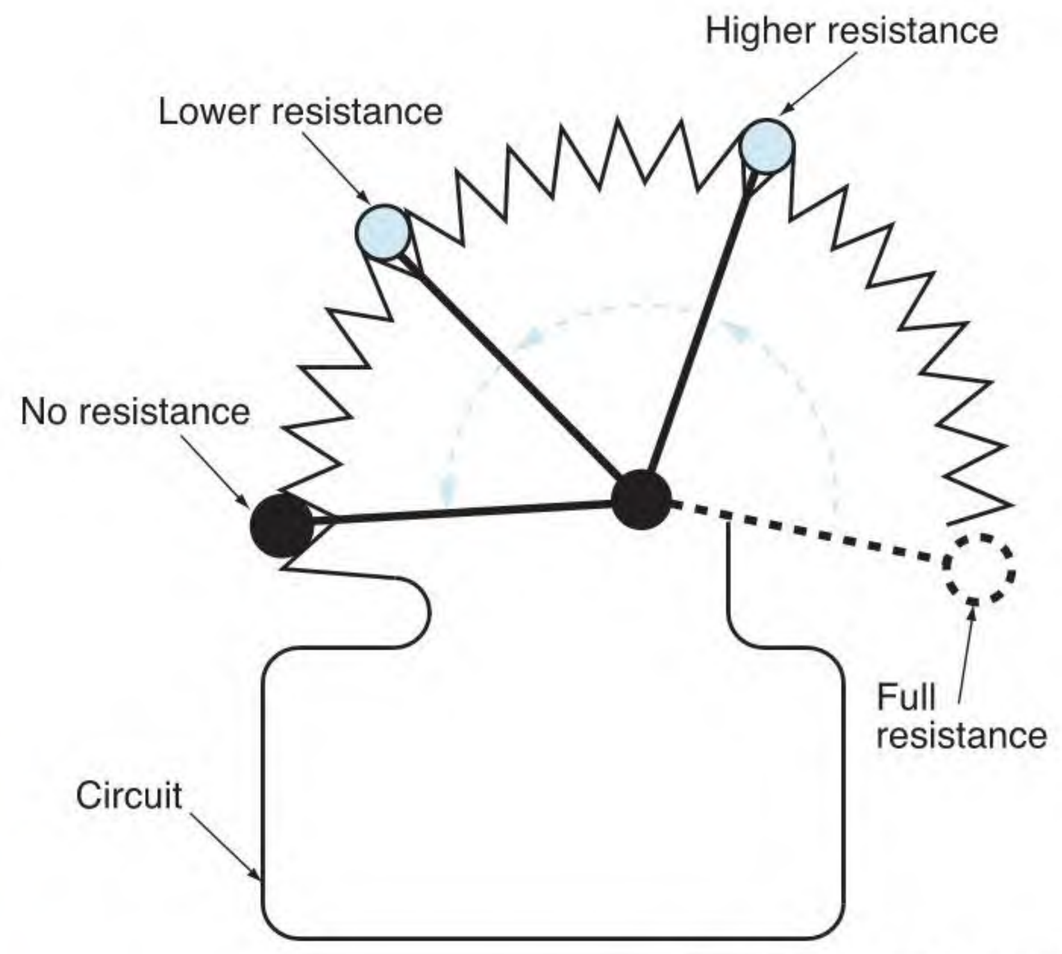
Variable Resistor	
Symbol	Letter Designation
	R V

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Figure 19-3. Variable resistors can produce a range of resistance values.

A rheostat is a variable resistor with two electrical terminals (connections). One terminal is wired to one end of the resistance unit. The other terminal is connected to a sliding contact. Turning the control knob moves the contact and alters the resistance value. See **Figure 19-4**.

A potentiometer is a variable resistor that has three electrical connections. It has one connection

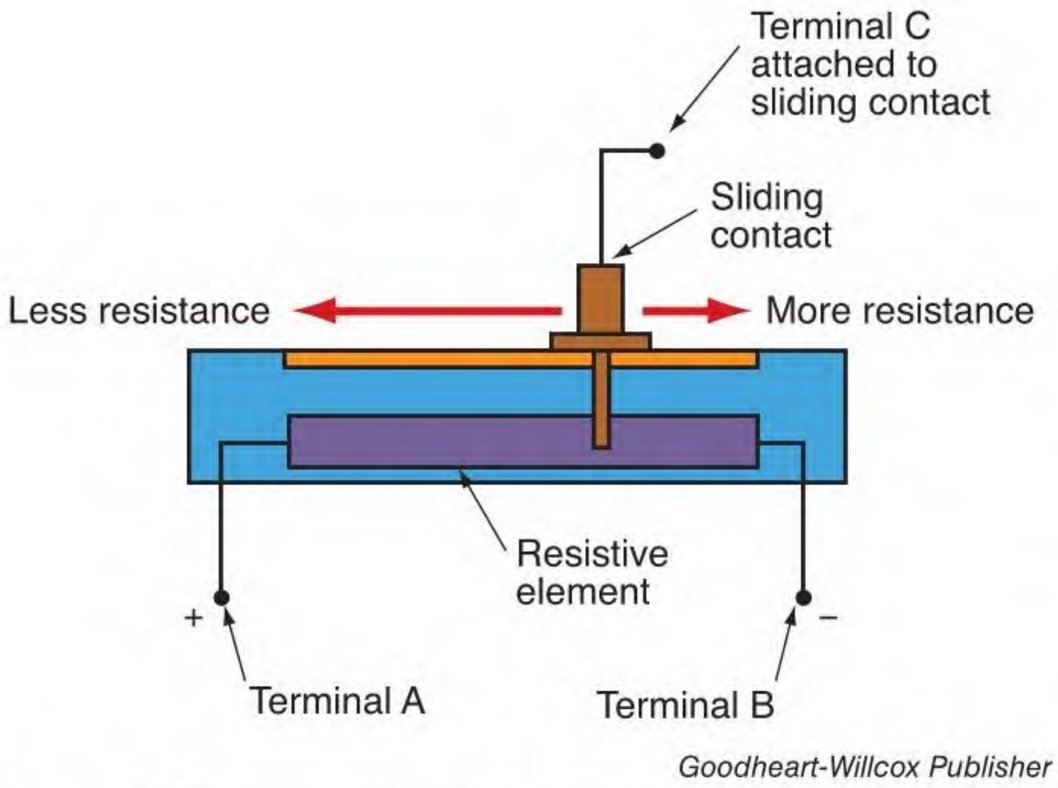


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Figure 19-4. This rheostat can provide a range from full resistance to no resistance at all.

at each end of the resistance unit and one for the sliding contact. This allows for more complex use of the variable resistance. For example, it can be used to produce a variable voltage drop or voltage signal. As the sliding contact is moved along the resistance unit, the internal resistance and resulting voltage drop change. This type of variable resistor might be used as a sensor for a computer system. See **Figure 19-5**.

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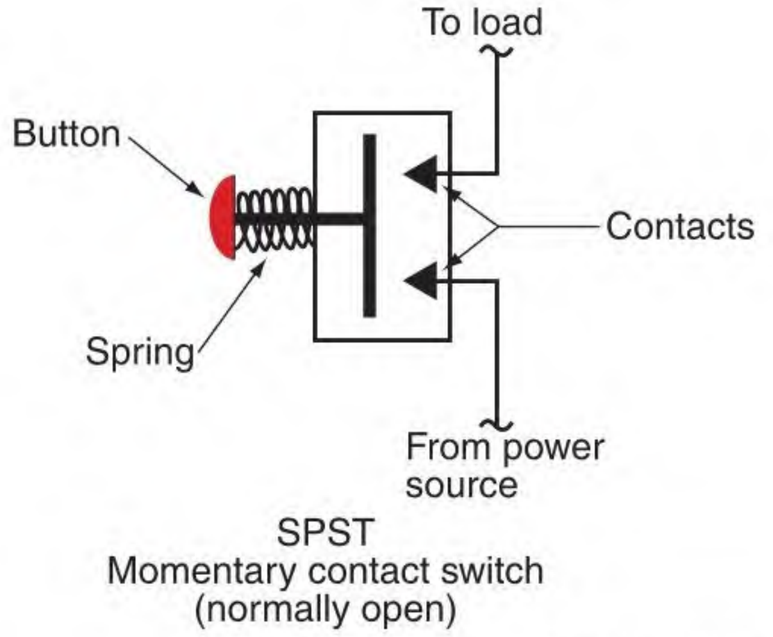
Figure 19-5. A potentiometer has three terminals. Terminal A is the positive terminal, terminal B is the negative terminal, and terminal C is connected to a contact that slides along a resistive element. As the sliding contact gets closer to terminal B, resistance between terminals B and C increases and voltage decreases. As the sliding contact moves closer to terminal A, resistance decreases and voltage increases.

Switches

A ***switch*** is used to connect or disconnect the power supply in a circuit. For a list of common types of switches and their corresponding symbols,

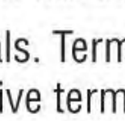
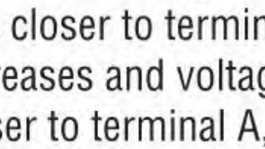
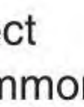
Figure 19-6. Switches are discussed in the following sections of this chapter.

A push-button switch has a spring-loaded button that, when pressed, makes or breaks an electrical connection across two contacts. A push-pull switch is a special type of push-button switch that stays in each position until it is moved. In some vehicles, a push-pull switch is used to turn the headlights on and off. When the driver pulls the switch out, the headlights come on and remain on until the driver pushes the switch back to the off position. See **Figure 19-7**.



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Figure 19-7. This push-button switch is normally open, which means the circuit is disconnected unless the button is pressed.

Switch	Symbol	Description
Single-Pole, Single-Throw Switch (Toggle Switch)		Has one swinging arm that can make contact with one stationary contact (pole). It is either open or closed and has two external terminals. This type of switch might be used for fog lights or other dash-mounted controls.
Single-Pole, Double-Throw Switch		Has one movable contact arm but two different stationary contacts. The arm can make an electrical connection with either of the stationary contacts.
Double-Pole, Double-Throw Switch		Has two moving arms, each having two stationary contacts.
Normally Closed Switch		Completes its internal connection when at rest (not activated). Activating the switch opens the internal contacts to stop current flow.
Normally Open Switch		Open or disconnected when at rest (not activated). A push-button switch is an example of a normally open switch.

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Figure 19-6. Common types of switches and their symbols are shown.

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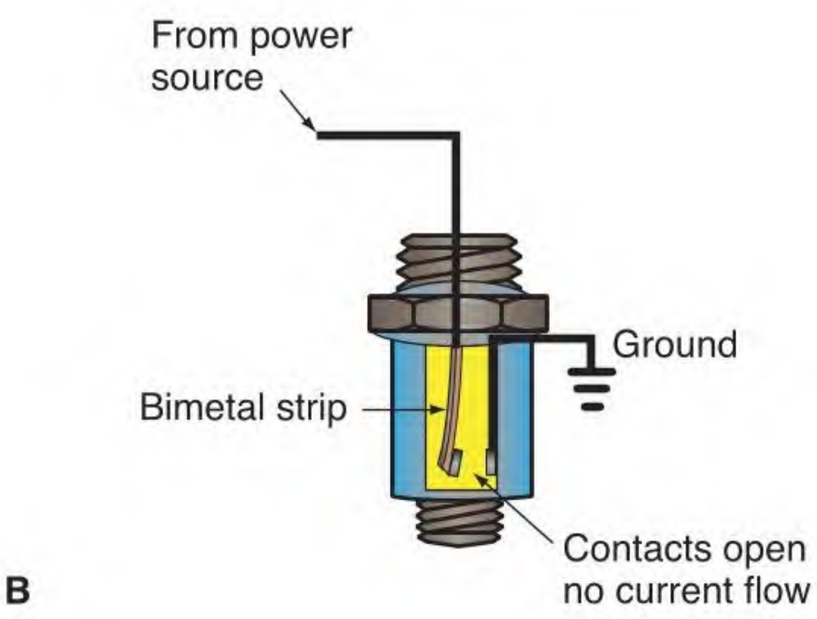
A thermal switch is a temperature-sensitive switch. It opens and closes with changes in temperature. This type of switch uses a bimetal strip (two different metals bonded together) so it warps and bends when heated. See **Figure 19-8**.

When the switch is cold, the bimetal strip is curved away from the internal switch contacts, so the circuit is open. When switch temperature increases, the two metals in the bimetal strip expand at different rates. This causes the strip to straighten, closing the switch contacts. One application for a thermal switch is to sense engine overheating and operate a dash warning light or even shut down power to the ignition system to prevent engine damage.

A pressure switch reacts to changes in internal pressure. Most pressure switches have an internal diaphragm attached to an electrical contact. When pressure drops below about 10 psi, the diaphragm is at rest and the contacts are open. When pressure becomes high enough, the diaphragm flexes to close the contacts, completing the circuit. A common application for a pressure switch is the engine oil light circuit. When the diaphragm closes the contacts, the oil pressure light on the dash is activated. See **Figure 19-9**.

A mercury switch uses liquid mercury to open and close its switch contacts. Mercury is a good conductor. It serves as a position switch that reacts to the location of a part. For example, a mercury switch can be used to activate the underhood light or the trunk light in a vehicle. When the switch is in one position, the mercury does not touch the contacts, so the switch is open. When the switch is tilted the other way (hood or trunk open), the mercury flows down over the contacts to close the switch. Refer to **Figure 19-10**.

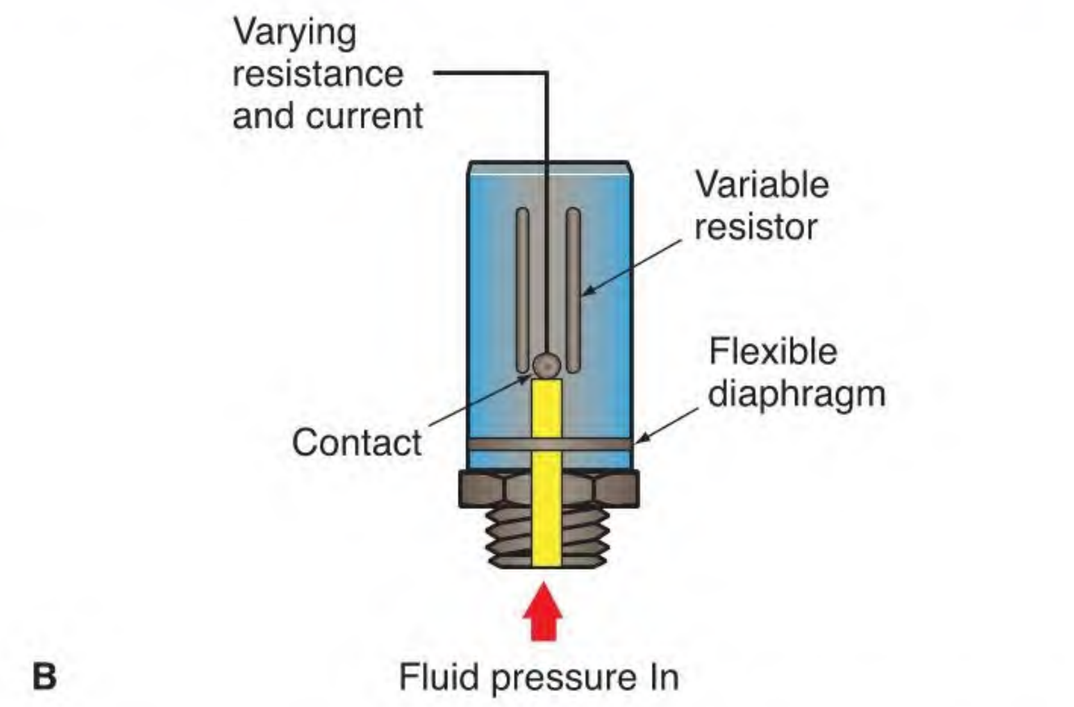




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Figure 19-8. A thermal switch uses a bimetal strip to react to heat. The two metals have different coefficients of expansion—they expand at different rates as the switch heats up. The difference in expansion rates causes the bimetal strip to change shape, closing the contacts.

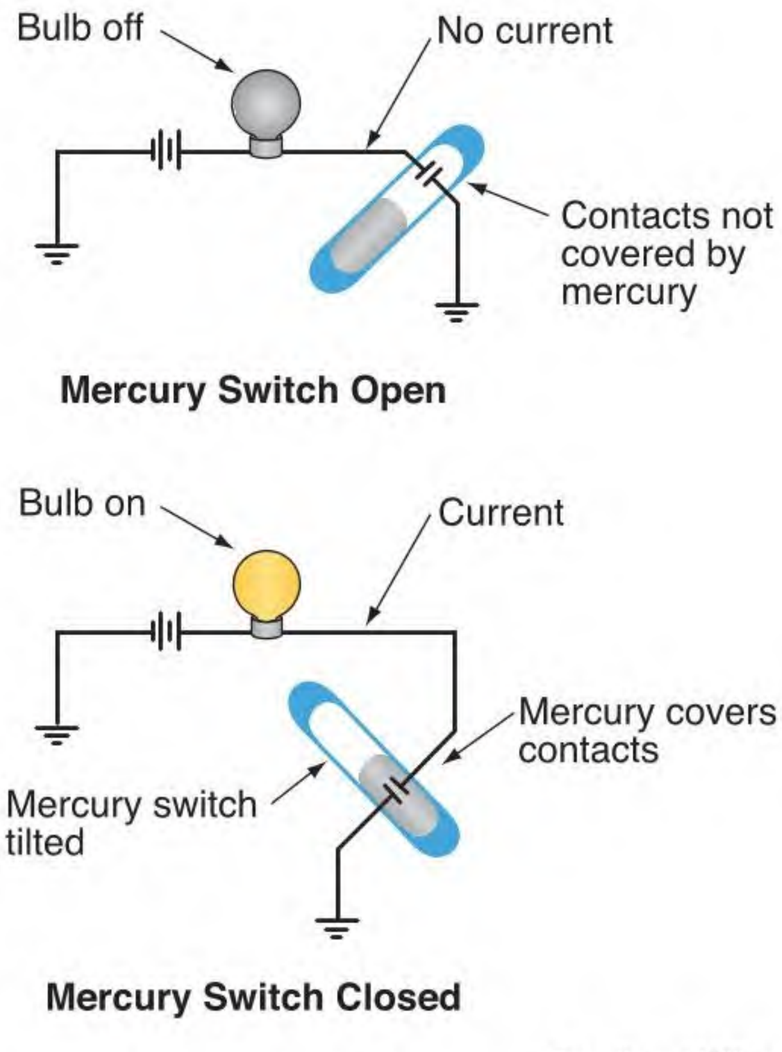




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Figure 19-9. This is one type of pressure switch that uses a variable resistor and contacts. It is used to operate the low oil pressure light and oil pressure gauge. Low pressure allows the diaphragm to close the contacts in the switch and activate the dash light. When oil pressure is normal, the variable resistor allows enough current flow to keep the oil gauge needle near the middle of its face, but since the contacts are open, the oil warning light stays off.

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Figure 19-10. In a mercury switch, the liquid mercury acts as a conductor. The circuit closes when the mercury flows over the contacts.

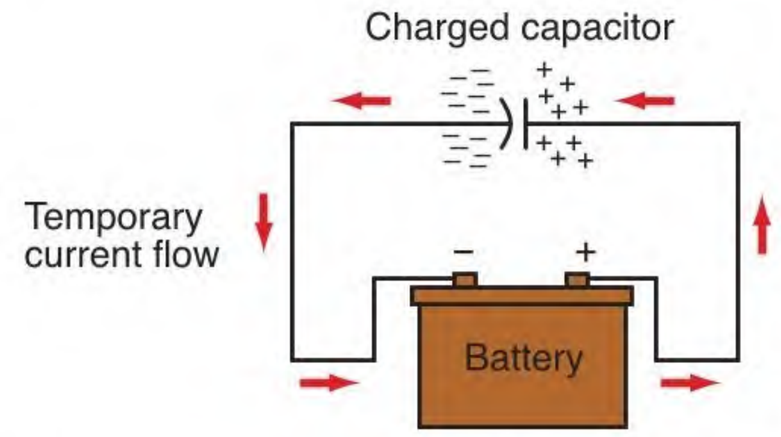
Dozens of other types of switches are found in modern vehicles. Examples include the ignition switch, dimmer switch, turn signal switch, stoplight switch, wiper switch, vacuum switch, and inertia switch. These specialized types of switches will be explained in later chapters where they apply.

Capacitors

A ***capacitor*** is a storage device for electrons, or electrical energy. A capacitor is made by wrapping two conductor strips around an insulating strip, or dielectric. The insulating strip allows the two conductors to be placed close together but keeps them from touching.

When direct current is applied to a circuit that contains a capacitor, electrons build up on the conductor strip attached to the negative terminal of the battery. As electrons build up, the capacitor becomes charged. Look at **Figure 19-11**. A positive charge collects on the other conductor strip.

When the charge in the capacitor equals the dc voltage from the battery, electrons can no longer flow through the capacitor. Therefore, small capacitors can be used to stop dc voltage. Larger capacitors can be used to even out voltage fluctuations. They supply extra voltage when the dc voltage dips, and they absorb voltage if the dc voltage spikes.



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Figure 19-11. A capacitor is an "electrical shock absorber" in ac circuits and will store an electrical charge in dc circuits. Direct current charges the capacitor. When fully charged, the capacitor blocks direct current.

Alternating current can pass through a capacitor. The alternating current charges a capacitor while current is in one direction. Then the capacitor discharges back into the circuit when the current changes direction.

In vehicles, capacitors can be used as a noise suppressor to prevent static in the radio or sound system. They are connected into the wiring to absorb or counteract voltage spikes that cause radio noise. In late-model vehicles, microscopic capacitors are found in computer circuits, sound systems, navigation systems, and printed circuits.

The size, or electrical storage ability, of a capacitor is rated in ***farads (F)***. A 1 farad capacitor connected to a 1 volt source stores 6.28×10^{18} electrons. Most capacitors cannot store this much electricity, however. Only "super-capacitors" used in hybrid drive trains or stereo systems can store more than this much energy. Most small capacitors are generally rated in microfarads (μF) or picofarads (pF). A microfarad equals a millionth of a farad. A picofarad equals a trillionth of a farad. Capacitors also have a voltage rating to prevent electrical arcing and component failure. Any voltage applied must not exceed the capacitor voltage rating.

Fuses

A ***fuse*** is used to protect a circuit from damage caused by excess current. It is connected in series with the circuit, right after the source, so that all current goes through the fuse. See **Figure 19-12**.

When current is normal, there is current through the fuse element. If something goes wrong in the circuit to increase current too much, the element overheats and melts. This breaks the circuit and protects the wires from overheating damage.

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Fuse	
Symbol	Letter Designation
	F

B

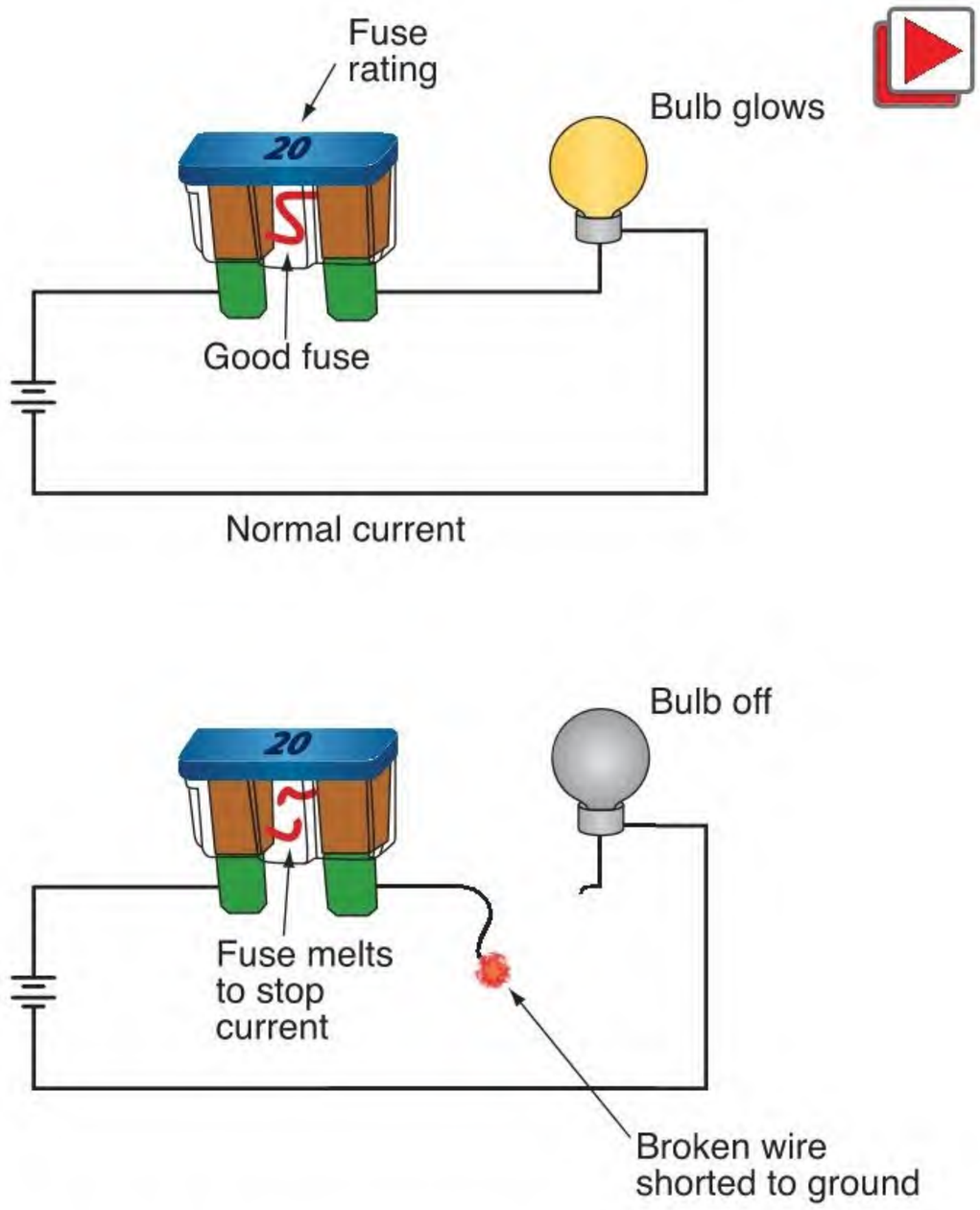
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Figure 19-12. Study fuses. A—Fuses help prevent a circuit from damage due to too much current. When current becomes too high, the fuse element blows, causing a break in the circuit and stopping current. B—Study the symbol and letter designation for fuses.

Without a fuse, an electrical fire could result from overheated wires glowing red-hot, causing their insulation to ignite. A ***short circuit*** results when a hot wire touches any ground. This may cause a tremendous amount of current through the circuit. The excess current can burn up wires in a fraction of a second. A fuse protects circuits from excess current and resulting damage. Fuse action is illustrated in **Figure 19-13**.

Fuse Ratings

A fuse rating is the amount of current a fuse can handle before its element melts. For example, "20 A" printed on the fuse means that the fuse is rated to protect a circuit designed for 20 amps. When you replace a fuse, always install a fuse with the same fuse rating. In automotive applications, the voltage value is understood to be 12 V.



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Figure 19-13. Any problem that increases current too much will make the fuse blow. Here, a wire has broken and shorted to ground. The resulting high current burns the fuse element in half to stop current and protect the circuit.

Caution

Never install a fuse with a higher fuse rating than specified. Even though this might keep the fuse from blowing, it can cause wires and electrical connections to overheat. You must correct the circuit problem and install a fuse with the same rating as the original.

Fuse Panels

A fuse panel, or fuse box, is a plastic housing with metal terminals that holds the vehicle's fuses and other related electric components, such as relays. Most fuse panels mount under the dash of the vehicle, in the engine compartment near the firewall, under the rear seat, or in the trunk of mid- or rear-engine vehicles. See **Figure 19-14**.

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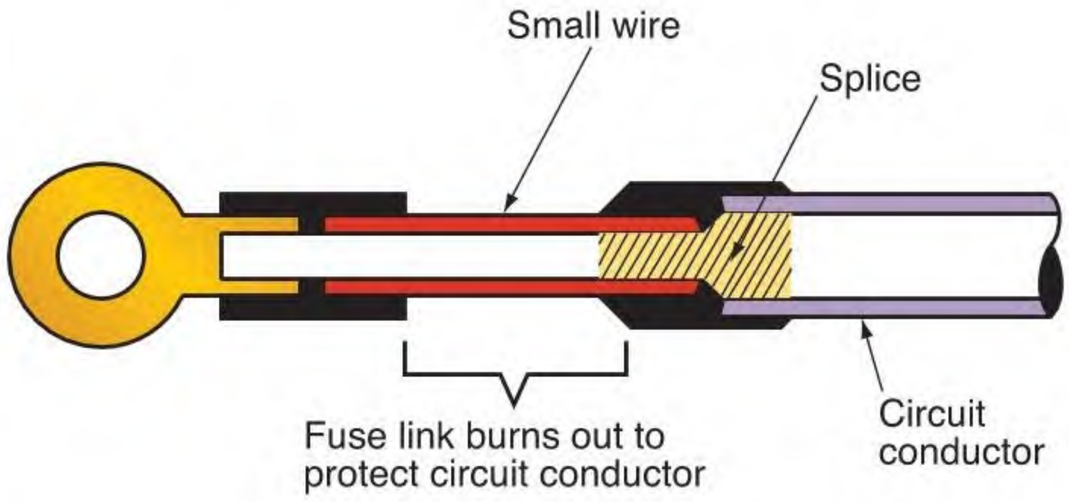
Figure 19-14. This fuse panel is located in the vehicle's engine compartment. You may have to remove the cover to gain access to the fuses.

Fuse panels usually have a guide showing fuse circuits and fuse ratings. In some vehicles, the fuse guide is printed on the back of the fuel panel cover. In others, the name of the circuit is abbreviated next to the fuse on the fuse panel. This shows which circuit is protected by each fuse. The fuse rating may also be printed next to the fuse socket in case a fuse is removed.

Fuse Links

A fuse link, or fusible link, is a section of smaller-gauge wire connected in series with the larger-gauge circuit wiring. It is designed to serve as a very large fuse.

Fuse links are normally located in the engine compartment, where power feeds from the 12-volt battery or starter solenoid. The fuse link is usually wired between the 12-volt battery and the fuse panel. Fuse links provide circuit protection before the fuse box in the passenger compartment. If a wire is shorted to ground before it reaches the fuse panel, the fuse link overheats and burns in half. This protects the rest of the wiring from major damage. See **Figure 19-15**.



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Figure 19-15. A fuse link, or fusible link, is sometimes wired into main circuits to protect them from major shorts to the 12-volt battery. This cutaway view shows the section of smaller-gauge wire that serves as a fuse. The smaller wire burns if the current exceeds circuit design limits.

Tech Tip

When replacing a fuse link, use the recommended wire size. Do not use the same wire size used in the rest of the circuit or you will no longer have circuit protection. Procedures for replacing a fuse link are explained in a later chapter.

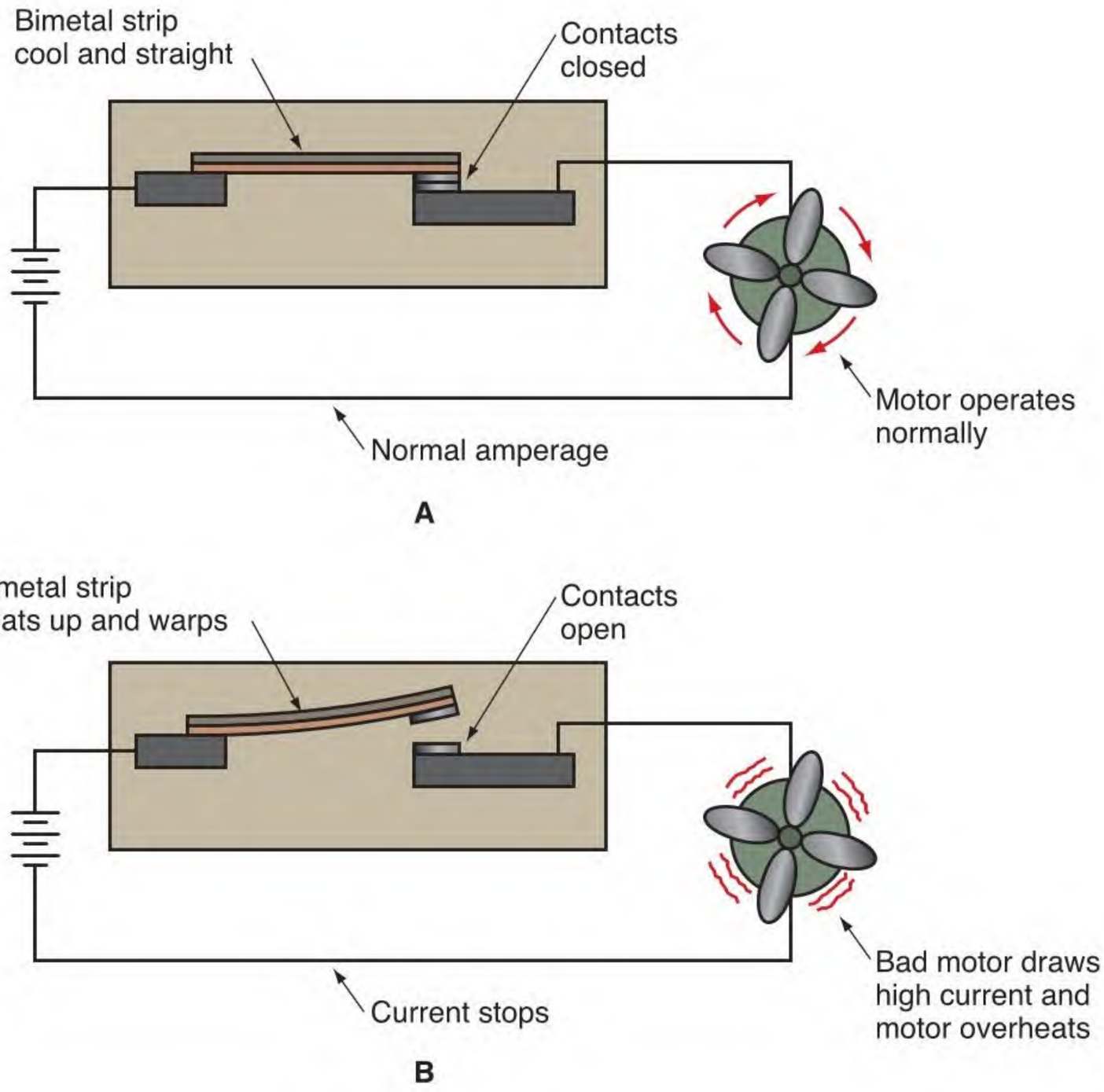
Circuit Breakers

A ***circuit breaker*** performs the same function as a fuse or fuse link: it protects a circuit from damage from excess current. However, a circuit breaker is not ruined when it is activated, or "tripped." Circuit breakers can sense a high-current condition and disconnect the circuit temporarily. They automatically reconnect the circuit after it cools down. If the high-current condition still exists, they trip again, and the cycle repeats. This action is ideal for the headlight circuit, which must not turn off permanently.

In a self-resetting circuit breaker, a bimetal strip acts as a movable contact. Under normal current, the bimetal strip remains cool and straight, and the contact remains closed. When a problem exists in the circuit, high current through the strip causes overheating. As the circuit breaker heats up, the high-expansion metal in the bimetal strip expands more than the low-expansion metal, making the strip warp, or bend. This opens the contacts in the circuit breaker. See **Figure 19-16**.

With no current, the circuit wiring and the bimetal strip cool to a temperature that is safe for circuit operation. The bimetal strip regains its original shape, closing the contacts and restarting current flow.

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Figure 19-16. Circuit breaker action is shown here. A—This circuit is functioning normally. The motor is in good condition and is drawing the specified current. B—This motor has bad bearings. It is overheating and drawing too much amperage. As a result, the bimetal strip overheats, bends, and opens circuit. After cooling, breaker allows the circuit to operate until it again overheats and draws too much current.

Warning

The circuit breaker's amp rating specifies the highest current that the breaker can tolerate without tripping. Never install a circuit breaker with a higher amp rating. This could cause wire or component overheating, and possibly an electrical fire. Always install a circuit breaker with the manufacturer's recommended amp rating.

Coils

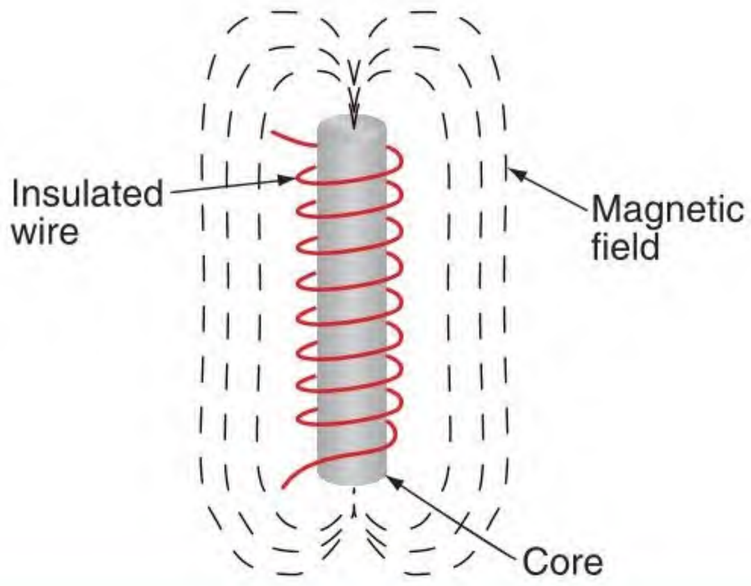
A ***coil***, also called a choke or inductor, consists of insulated wire loops placed close together to create an electromagnetic field. Coils are usually wrapped around an iron core to strengthen the electromagnetic properties.

Coils are used in electrical circuits to resist the fluctuation of current and voltage. Unlike capacitors, coils provide little opposition to direct current. In automotive applications, coils are commonly used in electric devices to provide a magnetic field. They are used in transformers, solenoids, motors, relays, sensors, and other components. See **Figure 19-17**.

Transformers

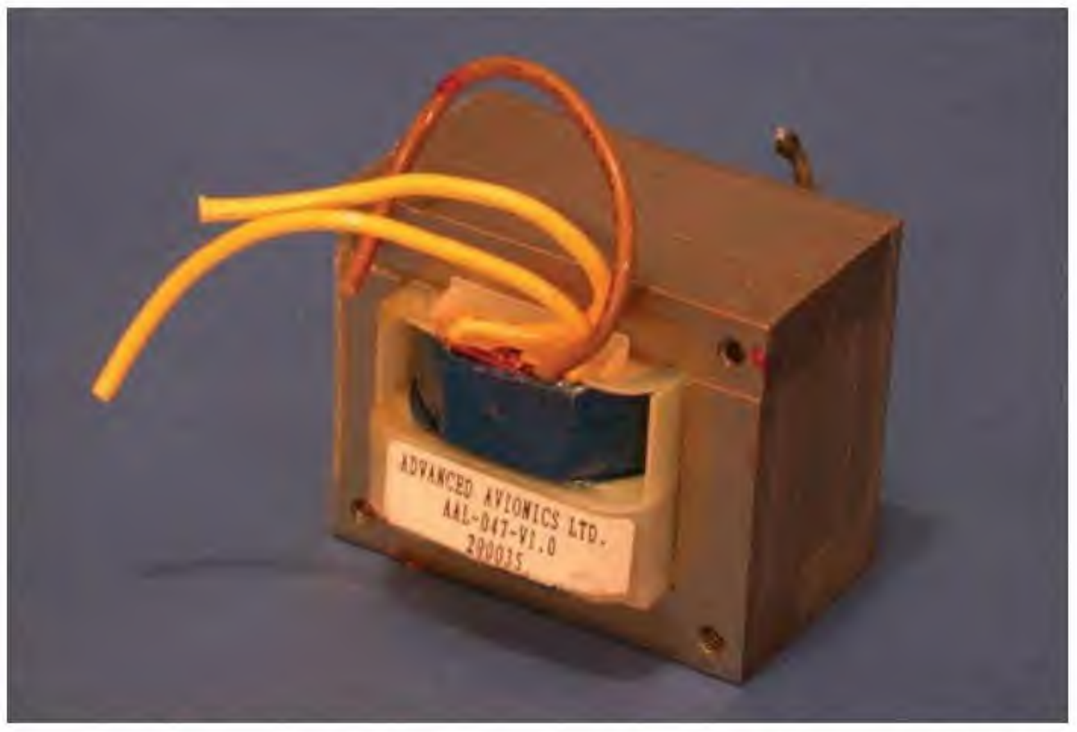
A ***transformer*** uses two sets of coils to transform voltage and current to higher or lower levels. For example, an ignition system coil is used to transform battery voltage into high voltage for firing the spark plugs. Other types of transformers are used to isolate different parts of a circuit, reduce voltage, or match the impedance of circuit sections. ***Impedance*** is resistance to alternating current at a given frequency. Refer to **Figure 19-18**.

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Figure 19-17. A coil consists of insulated wire formed in loops and usually wrapped around a core. It is used in many kinds of electric devices.



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Figure 19-18. A transformer contains two coils in one housing. It can be used to isolate two circuits, increase voltage, or decrease voltage.

Transformers are made by wrapping an insulated wire around a core, usually an iron core. Another set of windings is wrapped around a second core. If current through one set of windings fluctuates (increases or decreases in strength), voltage is induced in the other set of windings. If the current and electromagnetic field around the windings stays the same, voltage is not induced in the other windings. See **Figure 19-19**.

The ***turns ratio*** represents the relationship between the number of windings, or wraps, of wire in each transformer coil. If both coils have the same number of windings, the turns ratio is one to one (1:1). The induced voltage in the second coil is the same as the voltage in the first coil. This equal input and output produces an isolation transformer, which isolates one circuit from another.

A step-up transformer is one in which the second coil has more windings than the first coil. The additional windings in the second coil generate a proportionally higher voltage. For example, in a transformer that has a turns ratio of 1:2, application of 12 volts to the first coil produces an output of 24 volts in the second coil. The most common step-up transformers on an automobile are ignition coils, which fire the spark plugs in the engine's ignition system.

In a step-down transformer, the second coil has fewer windings than the first coil. This reduces the output voltage compared to the input voltage. For example, in a transformer that has a turns ratio of 2:1, 12 volts in the first coil produces an output of only 6 volts in the second coil. Step-down transformers are found in computers to lower voltage for integrated circuits. See **Figure 19-20**.

The voltage and current in a transformer are inversely proportional. When a transformer increases voltage, current decreases. If a transformer reduces voltage, current increases. Current can be sacrificed to gain voltage, or voltage can be sacrificed to gain current.

Relays

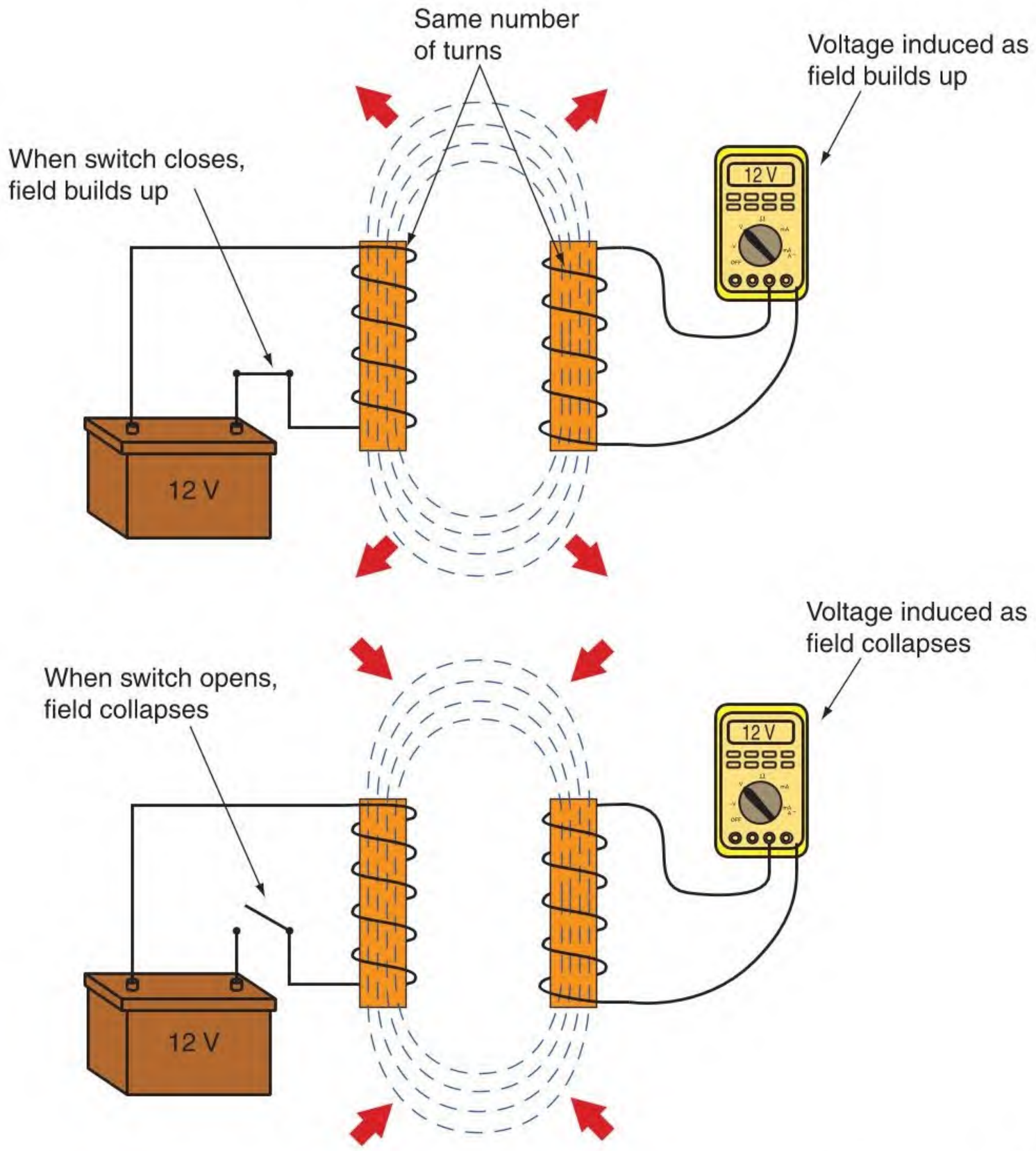
A ***relay*** is a device that uses a small input current to control a larger current in a circuit. A small coil opens and closes a set of contact points. Without relays, huge switches would be needed to carry the high current load of some electric circuits. Look at **Figure 19-21**.

A vehicle's horn is an example of an application that uses a relay. When you press the horn button on the steering wheel, a small control current flows to the horn relay. This closes the contacts in the relay and a larger current flows to and energizes the horn. Using a relay allows the wires running up the steering column to the horn button to be much smaller than they would otherwise have to be. Relays are normally located in the fuse box, **Figure 19-22**.

Solenoids

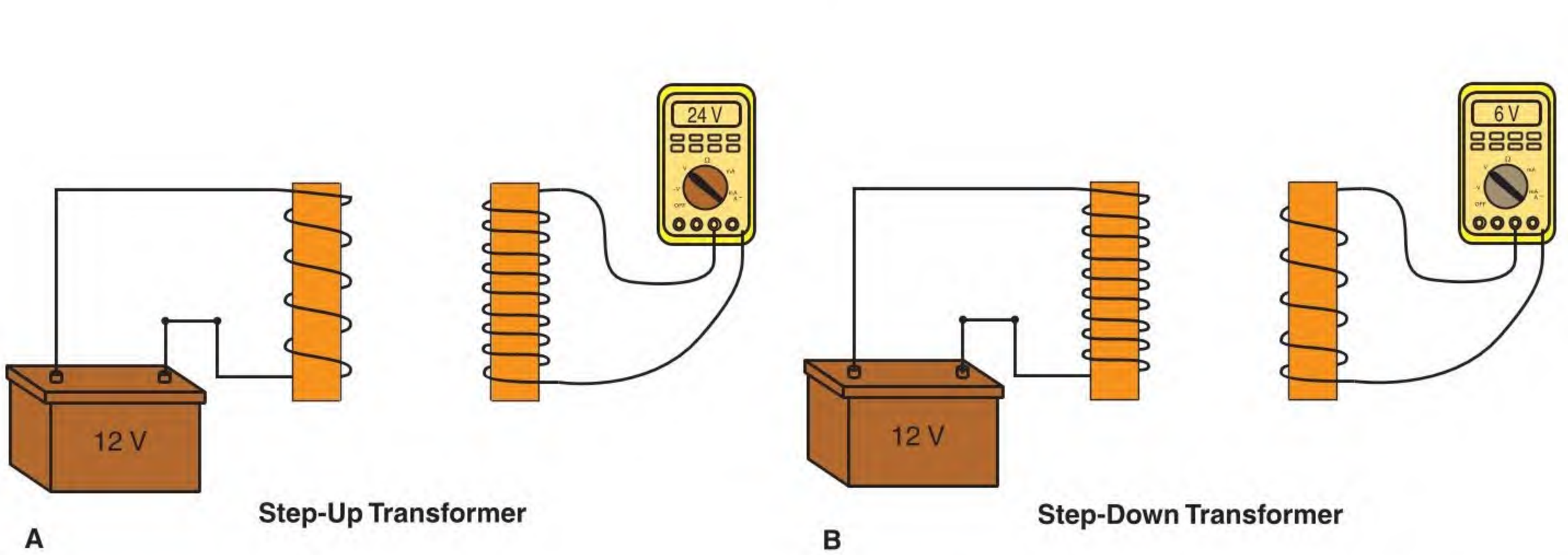
A ***solenoid*** is an electromagnet that moves a metal core, or plunger. The core movement can be used to close very large electrical contacts or move parts into engagement. See **Figure 19-23**.

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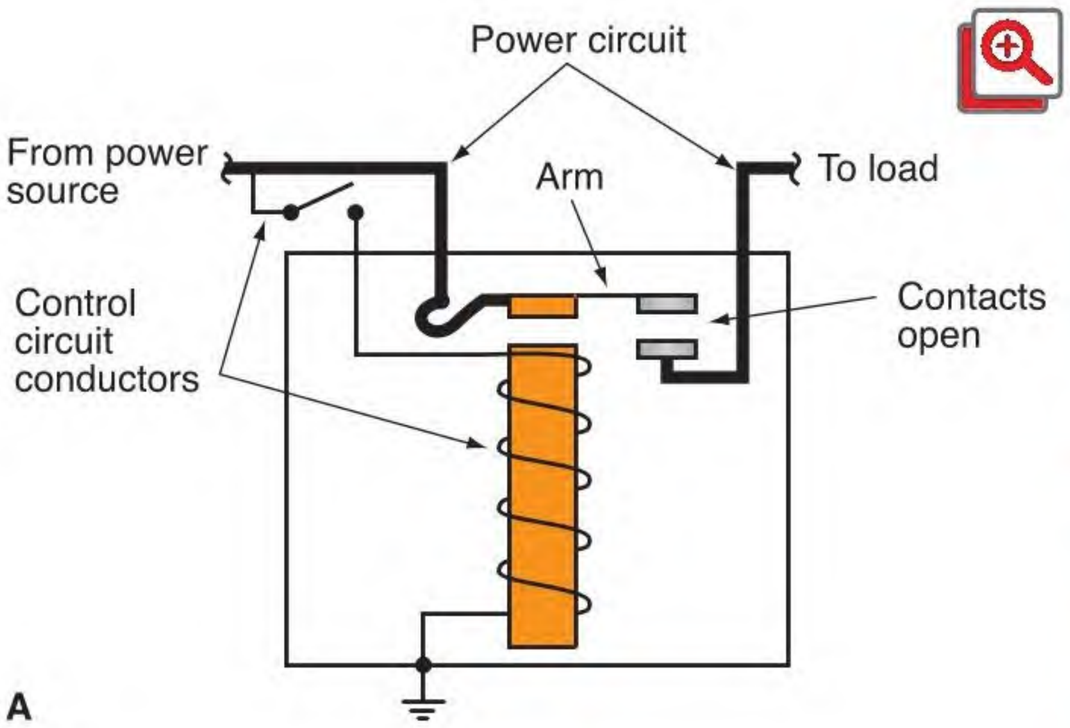
Figure 19-19. The field around one coil can induce voltage in another coil when the field builds or collapses. If the number of windings are different, the transformer can be used to increase or decrease voltage.



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Figure 19-20. Transformers can be used to increase or decrease voltage. A—A step-up transformer has more windings in the second coil to produce higher voltage. B—A step-down transformer has fewer windings in the second coil to produce lower voltage.

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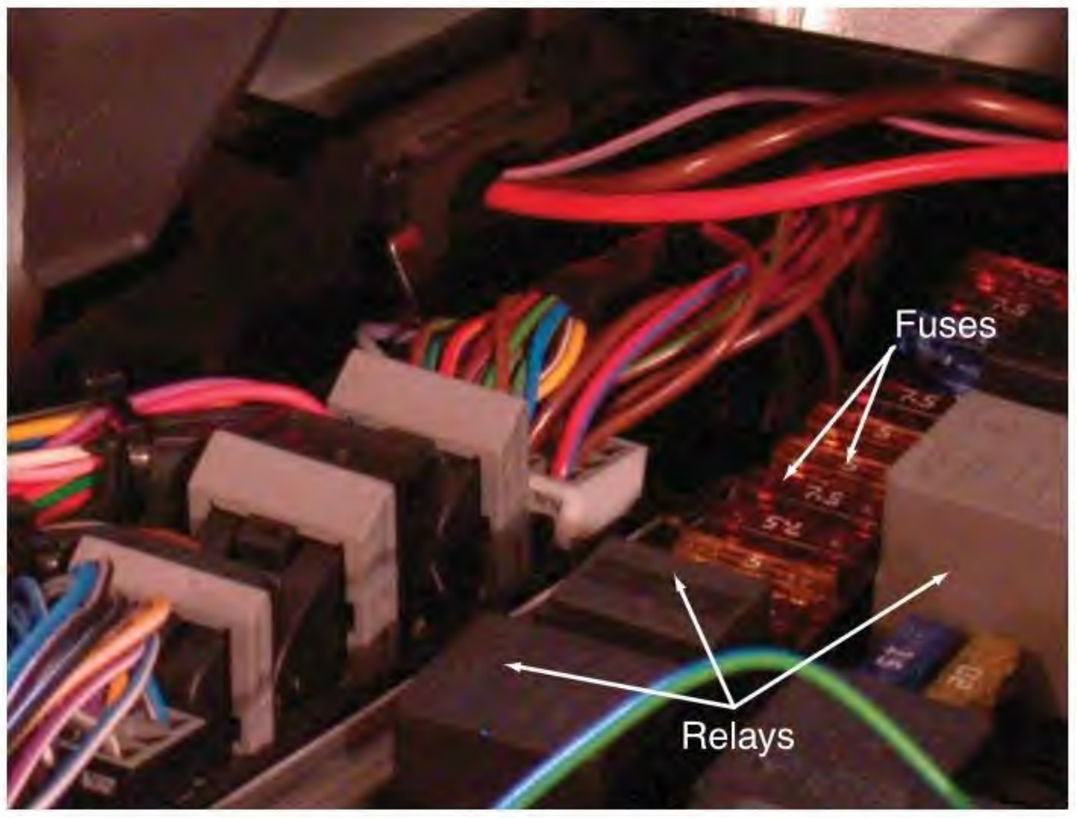
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Figure 19-21. Study the action of this relay. A—When the control circuit is open, the contact points in the relay are open and the load circuit is off. B—When the control circuit is activated, a magnetic field builds around the coil. The magnetic field attracts the point arm, pulling the contact points closed. This turns on the main circuit, allowing a high amount of current to the load.

Solenoids use electric current to produce motion. This motion might be used to operate a trunk latch. When there is current through the solenoid windings, the magnetic field pulls the core into the windings. Then, when current is broken, spring action pushes the core back out. Refer to **Figure 19-24**.

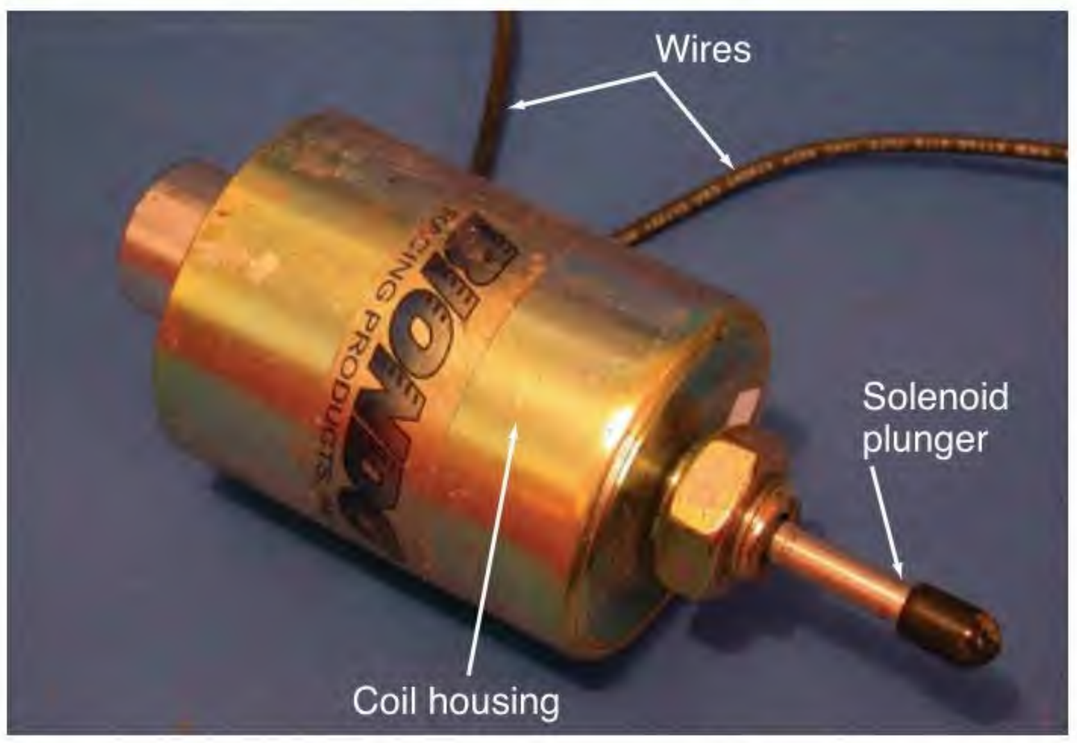
In an automobile, a starter solenoid is used to complete the battery-to-starting motor circuit. It serves as a huge relay to connect this high-amperage circuit. Some starter solenoids also move the starter gear into engagement with the flywheel ring gear on the back of the engine.

Smaller solenoids can be used to control engine throttle position and engine speed. Solenoids are also used to open and close gasoline injectors in an electronic fuel injection system.



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Figure 19-22. These are relays found under the hood of one make and model vehicle. You would have to refer to cover guide or manual to find out which circuit each relay controls.



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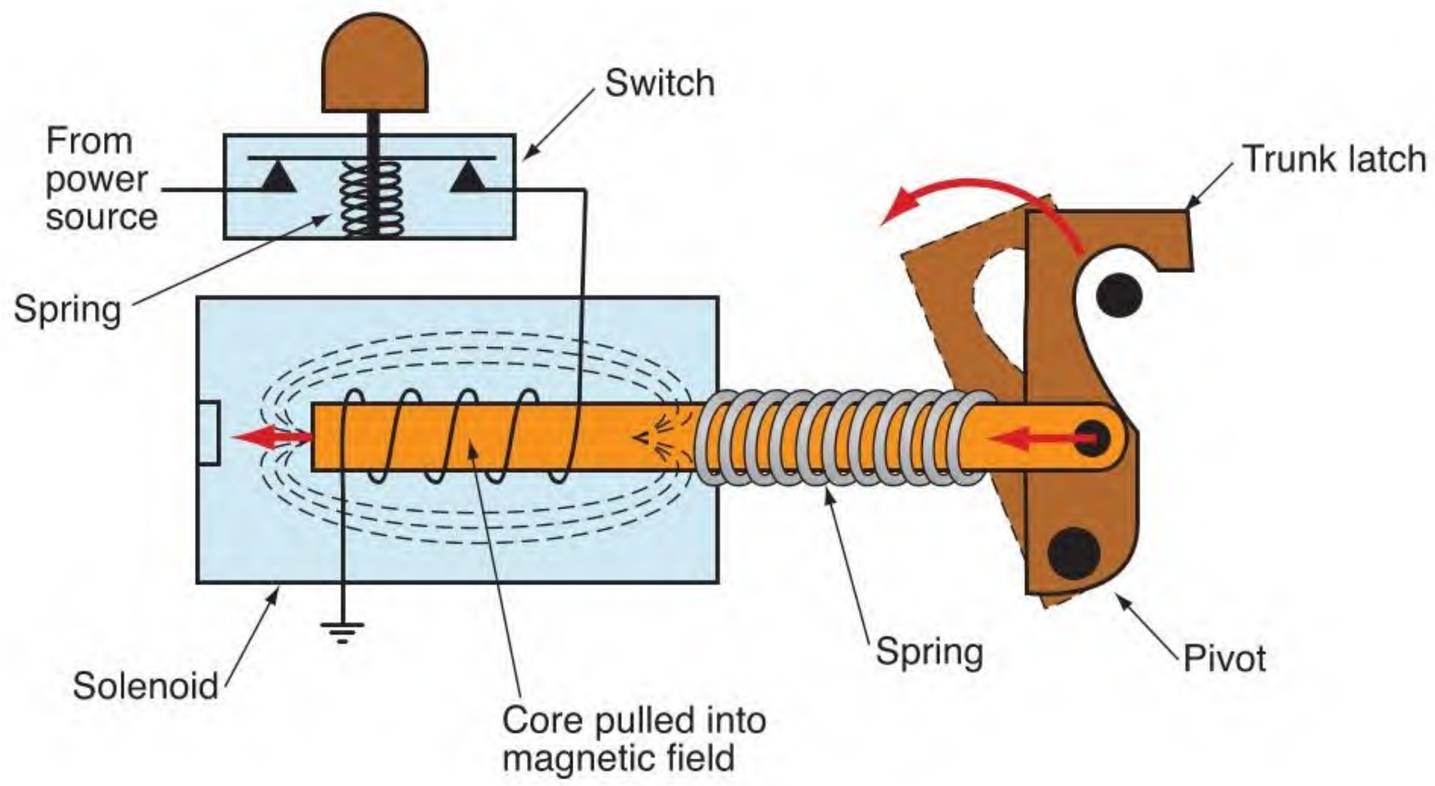
Figure 19-23. An electric shifter solenoid with its symbols is shown here.

Electric Motors

Electric motors use magnetic fields to produce a powerful rotating action, **Figure 19-25**. A set of windings is wound around a central core. This core is mounted on a shaft so it can rotate. The core and shaft are called an ***armature***. The shaft is mounted in bearings to allow the armature to rotate. Either stationary permanent magnets or stationary windings (electromagnets) are placed around the armature.

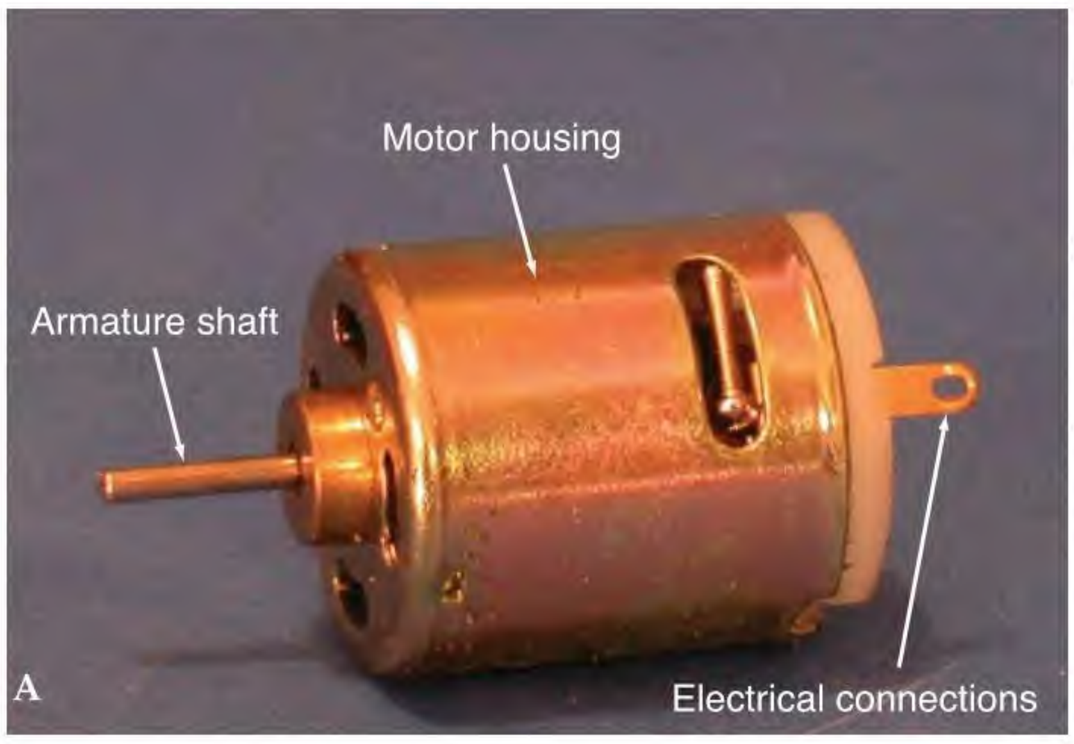
The ends of the armature coil are connected to two semicircular ***commutators***. The commutators are

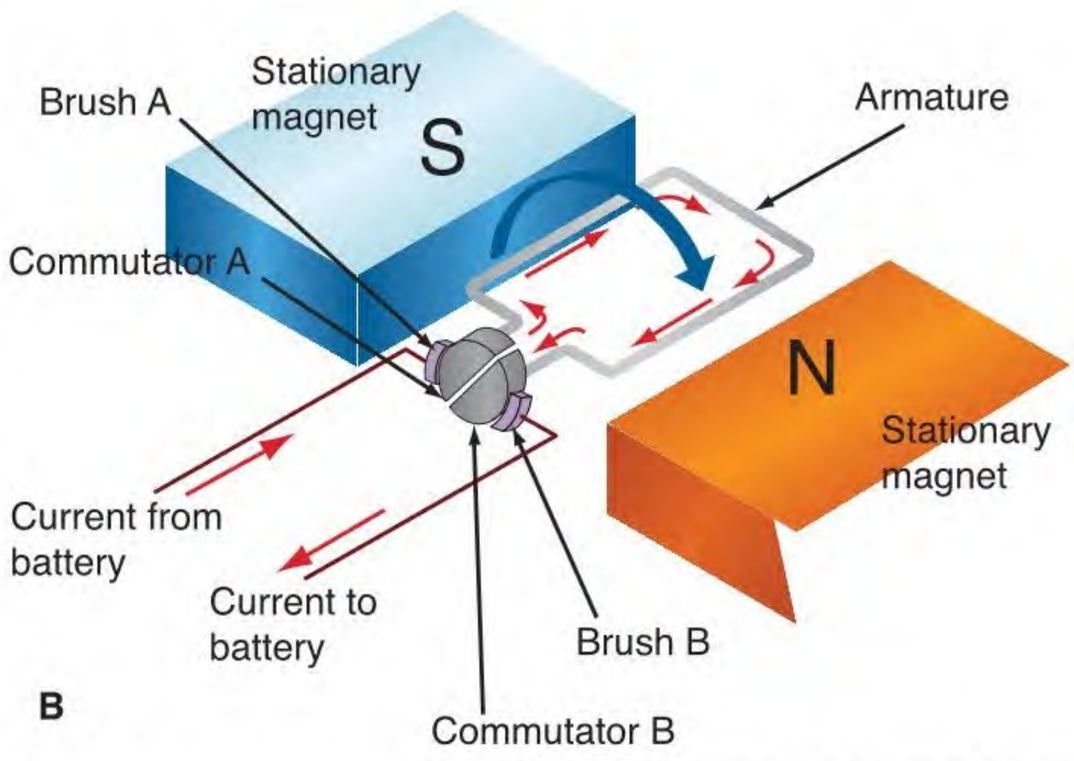
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Ford

Figure 19-24. A solenoid can be used to operate a trunk latch. The magnetic field around the coil pulls the core into the coil, swinging the trunk latch back on its pivot to release the trunk. The spring forces the latch back into its original position when the magnetic field collapses.





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Figure 19-25. An electric motor uses magnetic fields to spin an armature.

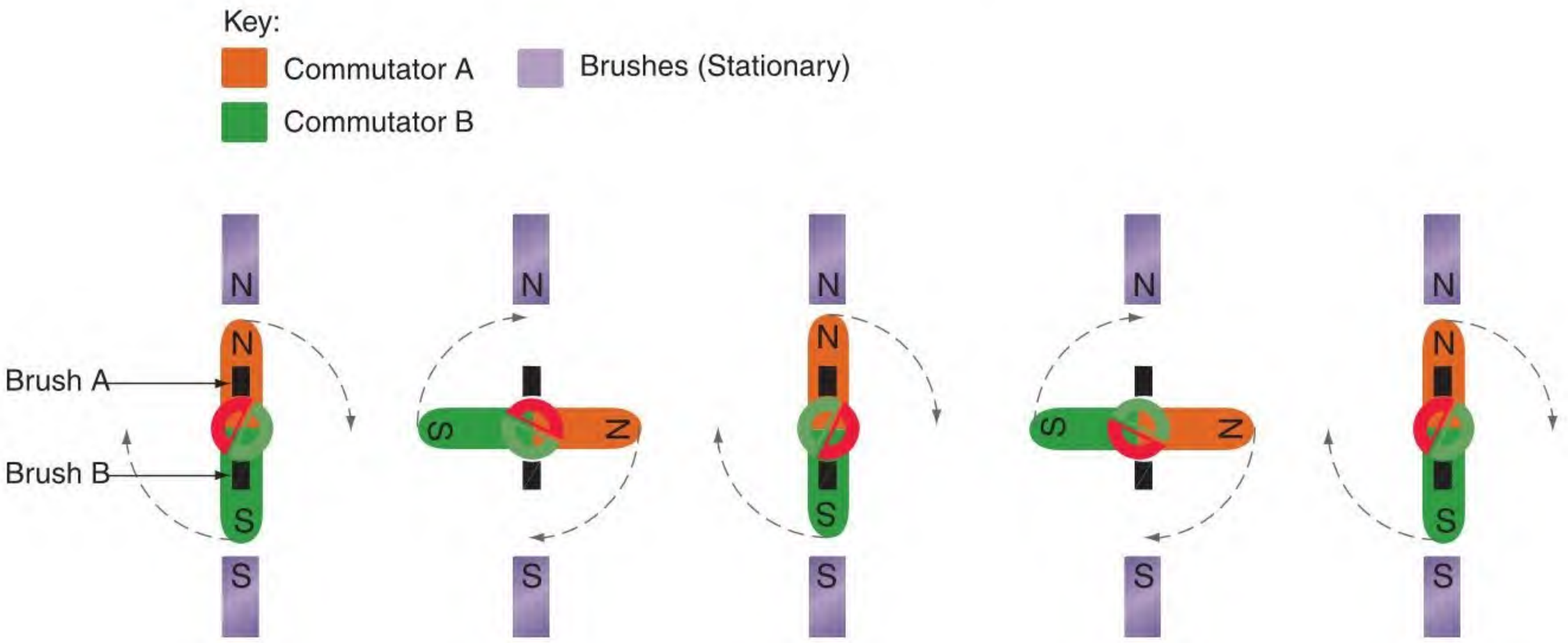
attached to the armature, so they rotate with it, but they are also in contact with two stationary ***brushes*** that are connected to a power source.

Current flows from the negative terminal of the power source, through brush A and commutator A, through the armature, through commutator B and brush B, and back to the positive terminal of the power source. This sets up an electromagnetic field in the armature.

As shown in **Figure 19-26**, the armature's north pole is near the north pole of the stationary magnet, and its south pole is near the south pole stationary magnet. Since like charges repel, the armature swings a quarter turn. At this point, the north pole of the armature is near enough to be attracted to the south pole of the stationary magnet, so the armature swings another quarter turn.

Since the commutators rotate with the armature, the current now flows from the negative terminal through brush A to commutator B, which reverses the flow through the armature. Because the flow is reversed, north poles are together again, so the armature rotates a third quarter turn. Attraction between the opposite poles causes the fourth quarter turn, completing one full rotation. The process then begins again.

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Figure 19-26. Electric motors use magnetic fields to keep the armature spinning, based on the principles that like poles repel each other and opposite poles attract.

Electronic Components

Electronic components, or solid state components, are composed of semiconductor material, which allows the device to control electricity. They are typically smaller and lighter than most electric components, and they do not consume as much energy. This is the fundamental advantage of electronic components.

Semiconductors

As you may recall, a conductor passes free electrons, and an insulator blocks the flow of free electrons. A ***semiconductor*** is a crystal material that can act as either a conductor or an insulator, depending on conditions.

Semiconductors are made from silicon, germanium, or other substances that conduct a limited amount of electricity in a manner that can be controlled. For example, silicon is a nonmetallic element contained in many types of sand. To make a semiconductor, silicon is melted and cooked at about 2600°F (1428°C). Then the silicon is doped, or combined chemically, with substances such as phosphorus and boron. This causes the silicon to grow into useful crystals (substances with symmetrical atomic structures).

The two basic types of semiconductors are P-type and N-type. A ***P-type semiconductor*** is doped so that it has excess protons. This creates holes, or spaces in the atoms for free electrons. As a result, a P-type semiconductor is a relatively positive substance that attracts electrons. Remember that *P* stands for positive.

An ***N-type semiconductor*** is doped so that it has excess electrons. Substances are added to the silicon to provide free electrons that can move through the N-type semiconductor material. Remember that the *N* stands for negative.

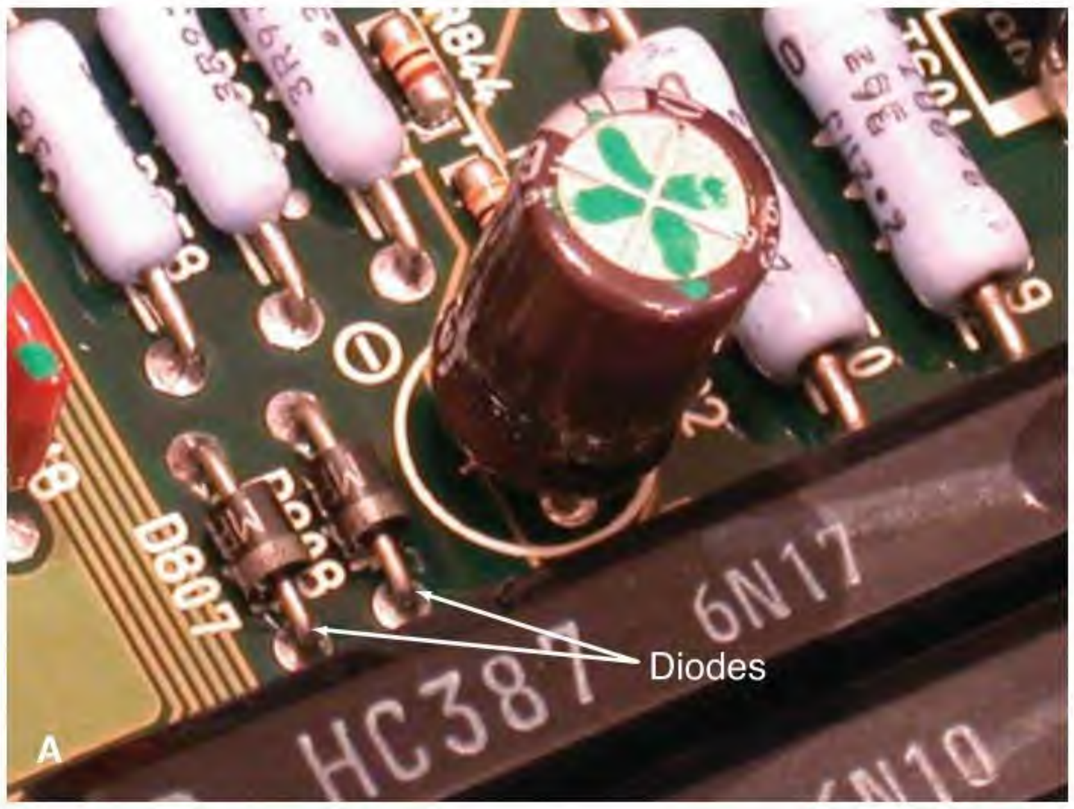
In its pure state, silicon is a good insulator. Its semiconductor properties—N-type or P-type—are determined by the number of holes or free electrons that result from the doping process. Neither type is very useful by itself. By using the two types together, however, numerous useful devices can be manufactured.

Diodes

A ***diode*** is made by joining a piece of N-type semiconductor with a piece of P-type semiconductor. A wire lead is attached to each end of the diode. The result is a device that blocks direct current in one direction and passes direct current in the other direction. A diode, therefore, acts as an electric check valve, **Figures 19-27** and **19-28**.

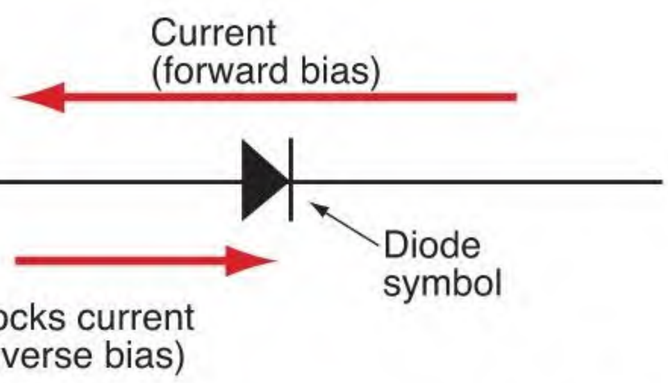
When a diode is connected so that it acts as a conductor, it is said to have a ***forward bias***. The battery charge pushes the electrons and holes closer to the ***PN junction*** (the common edge of the P-type and

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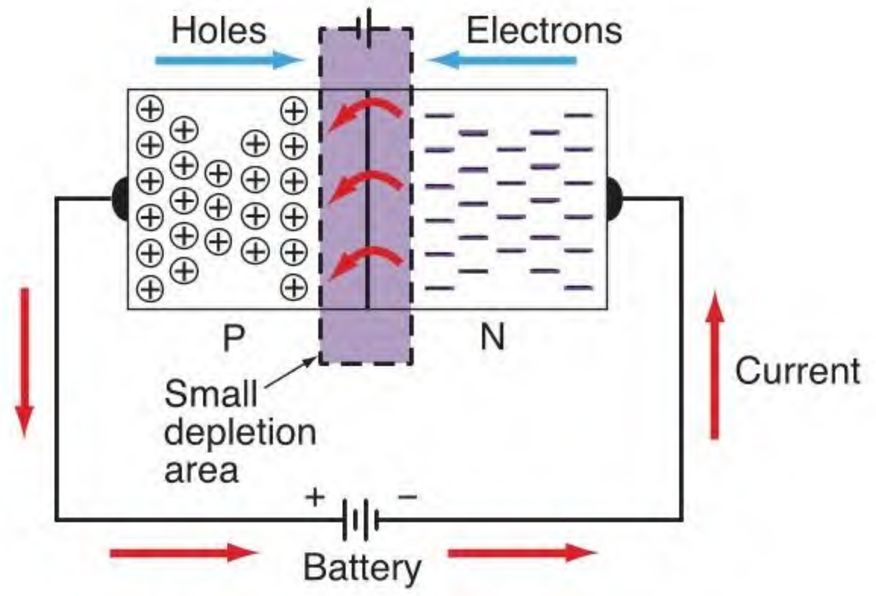
Figure 19-27. The simplest semiconductor device is a diode. A—Two small diodes on a circuit board. Note that they are labeled with a D for diode. Also notice the silver strip on each diode. Diodes usually have a strip on one end so you know how they should be installed in a circuit. B—These are the parts of a diode.

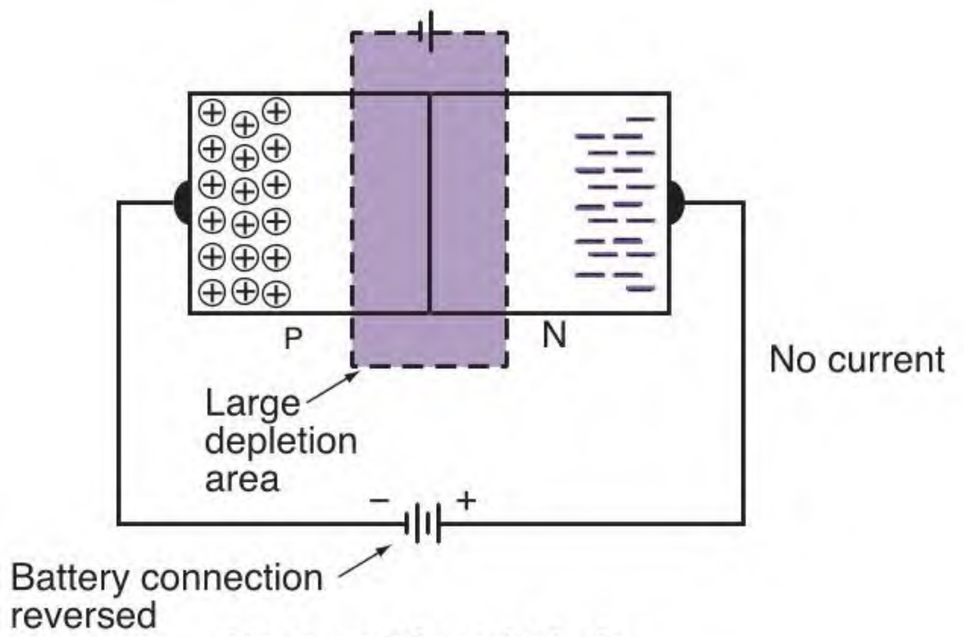


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Figure 19-28. The arrow in the diode symbol points in the direction of current.

N-type semiconductors). This reduces the size of the depletion area (area surrounding the PN junction that is void of holes and electrons) around the PN junction so that electrons can flow across the junction. A voltage drop of about 0.7 volts is needed to produce a forward bias current across a diode. See **Figure 19-29A**.





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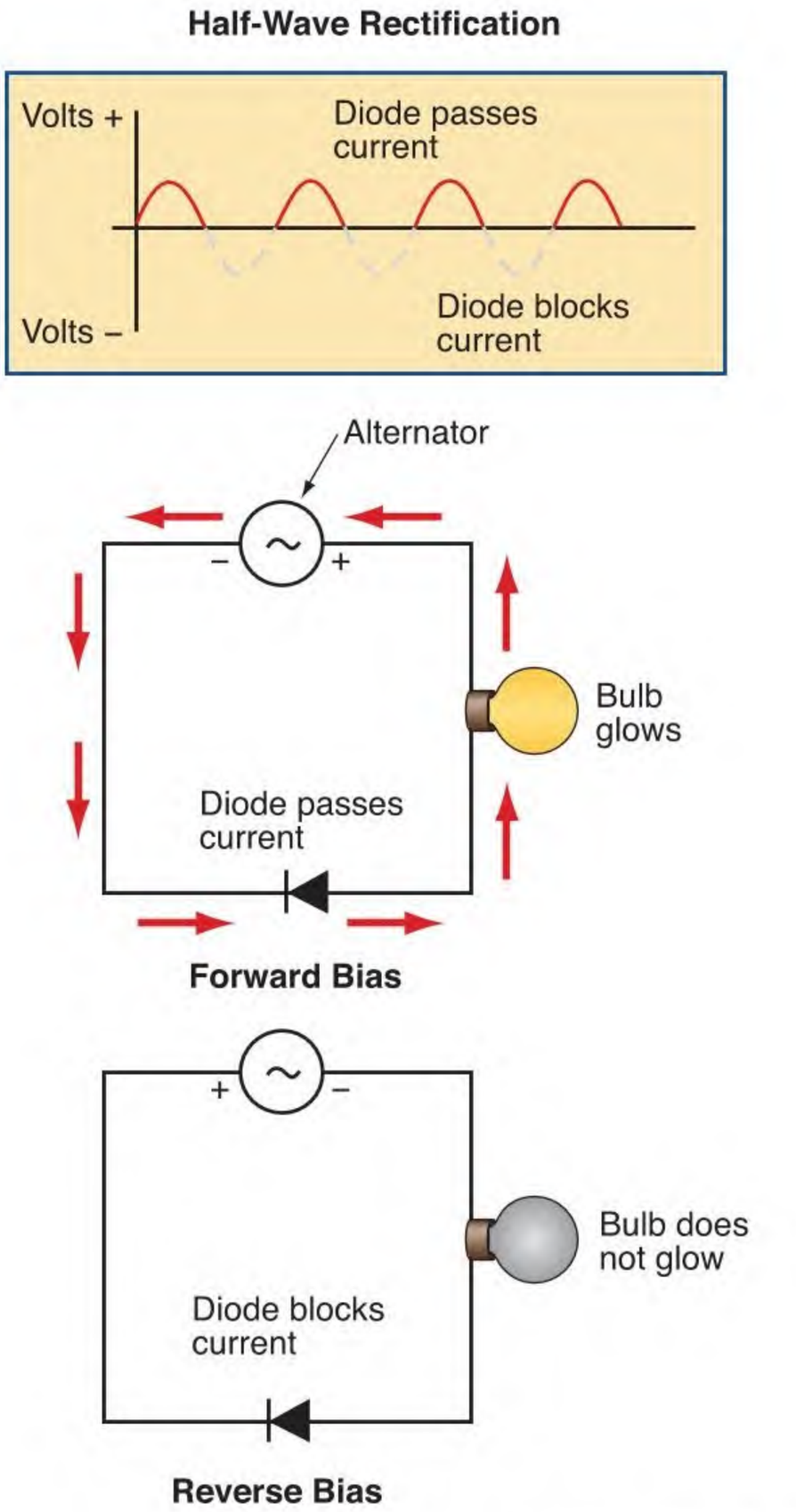
Figure 19-29. Diode operation is shown. A—A forward-biased diode has a small depletion area around its PN junction. Electrons flow easily across the depletion area. B—A reverse-biased diode has a large depletion area. The junction acts as an open switch to block current.

When a diode is wired so that it acts as an insulator, it has a ***reverse bias***. The battery connections are reversed, so the electric charge pulls electrons and holes away from the PN junction. This makes the depletion area larger, blocking current through the diode, as shown in **Figure 19-29B**.

Reverse bias voltage is a rating of the maximum voltage a diode can block without being damaged. If this voltage is exceeded, the diode is ruined. Automotive diodes are rated to operate on less than 15 volts.

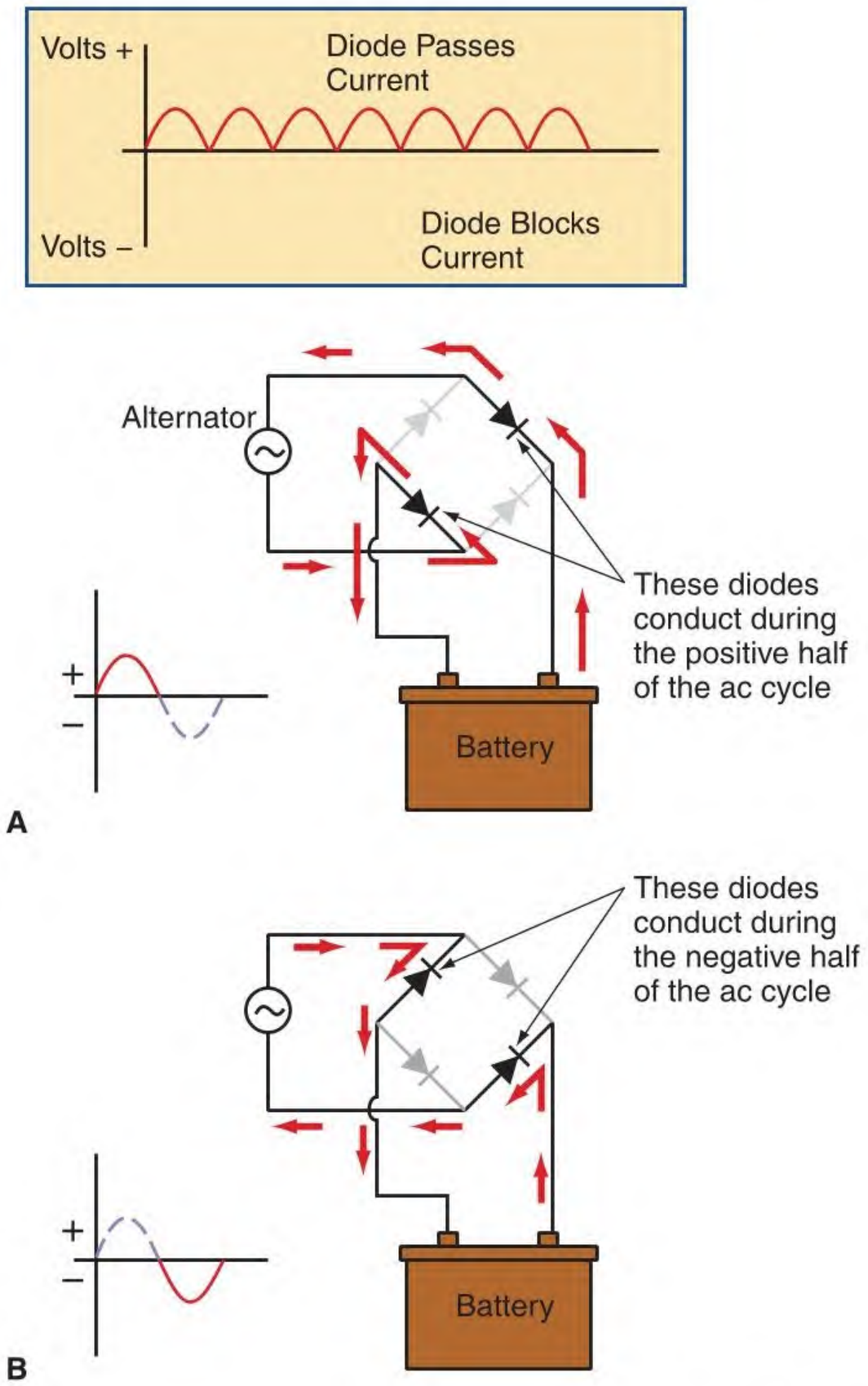
Diodes are commonly used to convert alternating current to direct current. This process is called ***rectification***. If a diode is placed in a circuit with alternating current, the diode allows current in one direction only. Refer to **Figure 19-30**.

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Figure 19-30. When ac is fed into a diode, diode conducts current in one direction only, producing half-wave rectification. The bulb glows only when the diode has forward bias.



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Figure 19-31. Several diodes wires as shown produce full-wave rectification. Both halves of the ac sine wave produce direct current.

A single diode in series with an ac source produces ***half-wave rectification***. In this configuration, only half of each ac ***wave*** is allowed through. ***Full-wave rectification*** allows both halves of each ac wave through. Both halves flow in the same direction. **Figure 19-31** shows how diodes can be used to produce full-wave rectification.

Diodes are commonly used inside a vehicle's charging system alternator. The initial output of an alternator is ac. The ac must be rectified into dc for use in the automobile's electric and electronic systems.

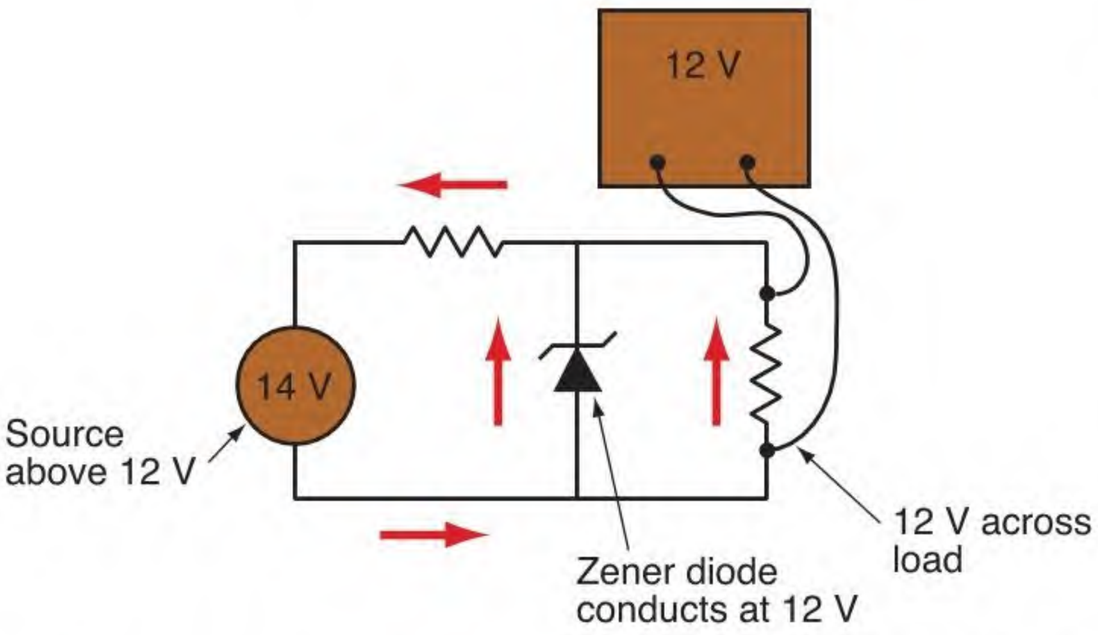
Zener Diodes

A ***zener diode*** is a special type of diode that serves as a voltage regulator. It conducts current normally when it is forward biased. It also blocks current when it is reverse biased. However, when a specific reverse-bias voltage is reached, the zener diode begins to conduct current. See **Figure 19-32**.

Transistors

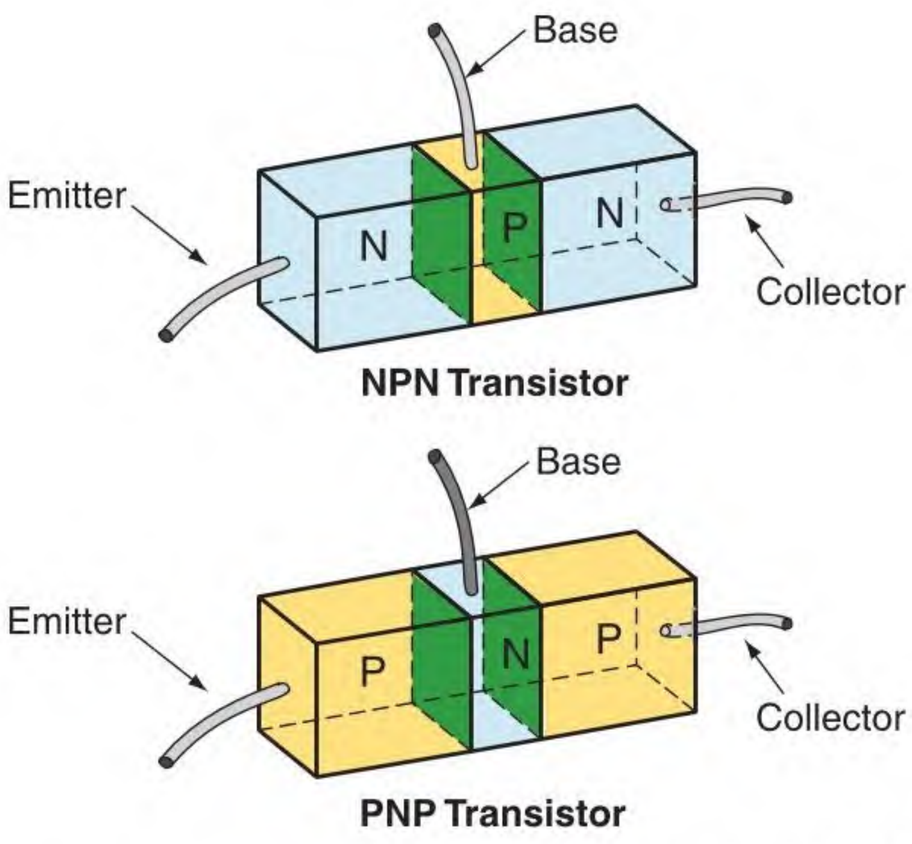
A ***transistor*** is a semiconductor device that regulates current or voltage in a circuit. It can act as a switch for electronic signals or serve as a current amplifier. *Trans-* stands for "transfer" and *-sistor* stands

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Figure 19-32. A zener diode is commonly used as a voltage regulating device. When in reverse bias, it begins to conduct when a specific threshold voltage is reached. This limits the voltage drop across the zener diode.



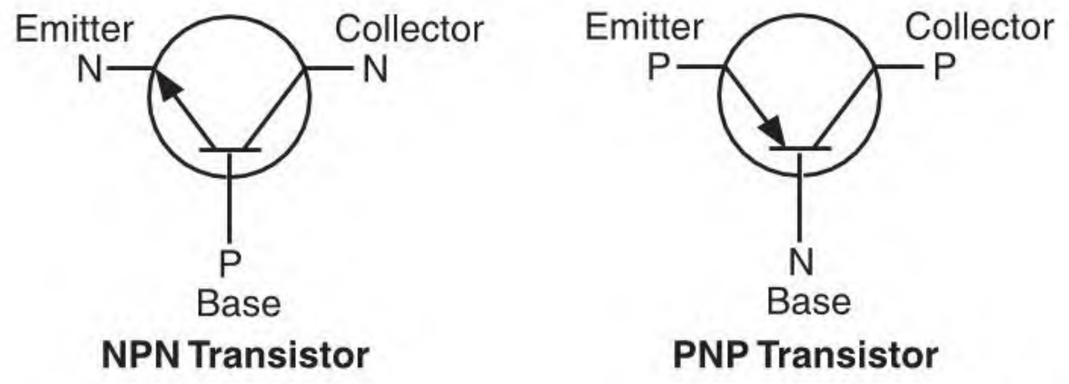
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Figure 19-33. The arrangement of semiconductor materials and leads in PNP and NPN transistors.

for "resistance." A transistor transfers, or changes, from a resistor to a conductor with electric stimulation.

A ***bipolar junction transistor (BJT)*** is made by joining three semiconductor materials. An ***NPN transistor*** has two N-type semiconductors and one P-type semiconductor bonded together. A ***PNP transistor*** has two P-type semiconductors and one N-type semiconductor. Small wire leads are attached to each type material. See **Figures 19-33** and **19-34**.

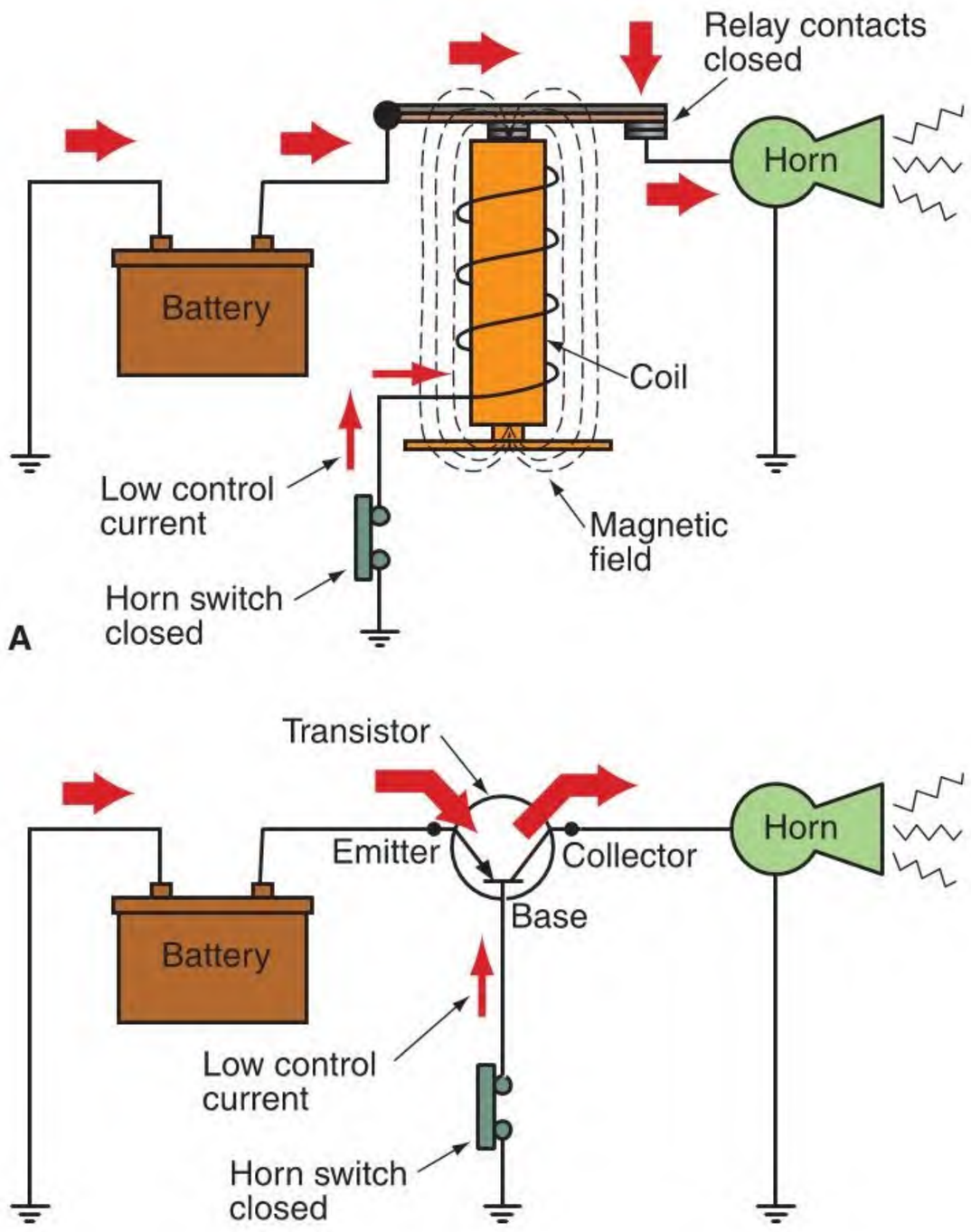
The base of a bipolar junction transistor is the "trigger" lead. A low current through the base turns the transistor on. When the transistor is on, a high circuit current passes through the emitter and collector leads. A transistor can



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Figure 19-34. The arrow in the transistor symbol always points to an N-type material.

act as an electronic switch, much like an electric relay. The action of a transistor compared to a relay to operate a horn circuit is illustrated in **Figure 19-35**.



Echlin

Figure 19-35. A relay does the same thing a transistor does. Current from the dash switch can be used to send higher current to another circuit for operation. A—In an electric relay, when a low control current passes through the relay windings, the resulting electromagnetic field closes the contact points, allowing a higher current to the horn. B—In a transistor, a low control current to the base makes the transistor act as a conductor, allowing a higher current to pass through the emitter-collector to operate the horn.

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As you can see, a transistor and a relay can perform the same function. They both can use a low control current to operate a much higher circuit current. However, a transistor is much smaller than a relay, and it does not have moving parts to wear out.

Signal transistors are small transistors used to amplify low power signals or switch low currents on and off. These transistors are located in complex electronic circuits, such as those found in radios and computers. Smaller signal transistors often feed current to the base circuits of power transistors.

Power transistors are used to control high current levels. For example, power transistors are used to operate the speakers in radios. They are the output devices that regulate the fluctuating current that makes the speaker diaphragms vibrate and produce sound. Power transistors are normally mounted on a heat sink. A heat sink is used to transfer heat away from a transistor. This helps keep the transistor from overheating, which would damage the semiconductor, **Figure 19-36**.



Figure 19-36. Transistors are used to ground circuits with medium current draw so they are energized. A—A power transistor is usually mounted on a heat sink. B—Silicone grease and a washer are used to help heat flow away from the transistor.

Piezoelectric Crystal

A ***piezoelectric crystal*** is a device that produces a low current output when physical pressure is applied. A diaphragm can be linked to the piezo crystal to make a microphone. Sound waves make the diaphragm flex back and forth, which places various amounts of pressure on the piezoelectric crystal. As a result, the crystal produces small voltage fluctuations. The strength of the voltage signal can be used as an indication of pressure from sound waves, like a microphone. Refer to **Figure 19-37**.

Photonic Devices

A ***photonic device*** is any device that can emit or detect light. A ***photon*** is a particle of electromagnetic light energy. Photonics is a fast-growing field of electronics, and photonic semiconductors are now being found in automotive electronics.

Light Emitting Diodes

A ***light emitting diode (LED)*** is a photonic semiconductor that emits light when it is electrically energized. Since an LED converts electricity directly into light, it is much more efficient than most other light sources. See **Figure 19-38**.

A light emitting diode is a PN junction with semiconductors made of gallium (a chemical element) that have been doped with special substances, such as phosphorus. When the LED is connected to a power source, light is emitted. The chemical makeup of the doping material determines the color of the LED light, **Figure 19-39**.

A light emitting diode chip is housed in a plastic bulb. Wire leads extend out the bottom of the housing.

LEDs can be used as indicator lights in the dash panel and interior dome lights. They are now used for exterior applications such as taillights, marker lights, and headlights.

Fiber Optics

Fiber optics is a field of electronics in which light is used to carry data through small strands of plastic or glass fiber. Each fiber is about the size of a human hair. Hundreds of fibers can be bundled into a

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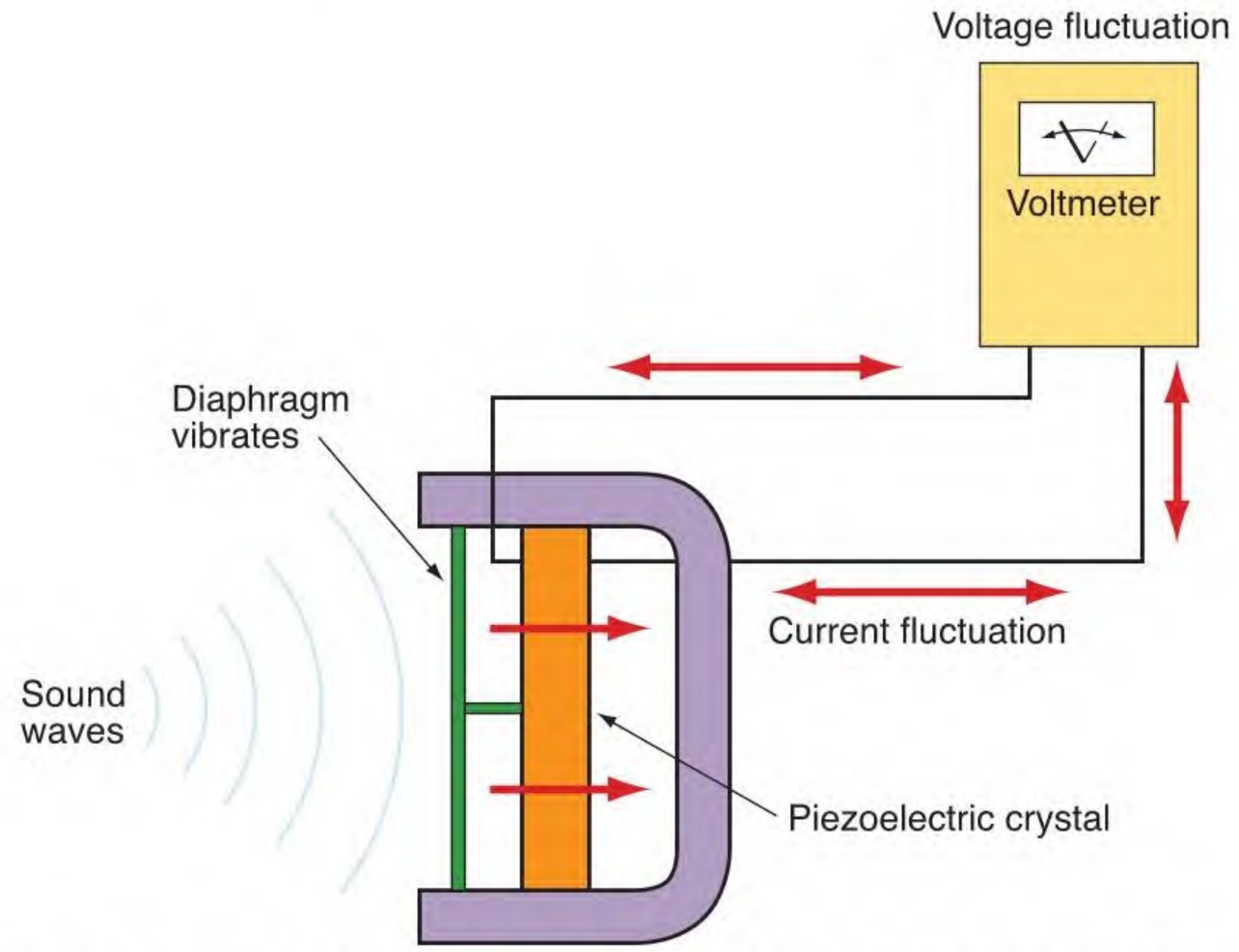


Figure 19-37. A piezoelectric crystal converts physical pressure into electrical output. This is ideal for making a microphone.



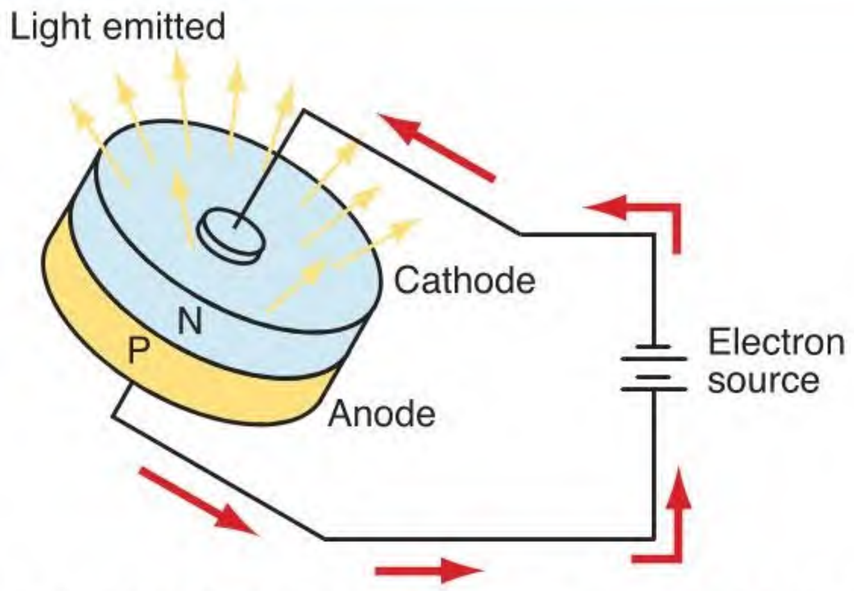


Figure 19-38. LEDs will put out a large amount of light while drawing little current. A—A small LED can emit a tremendous amount of light for its size. B—When current passes through the semiconductors, light is emitted.

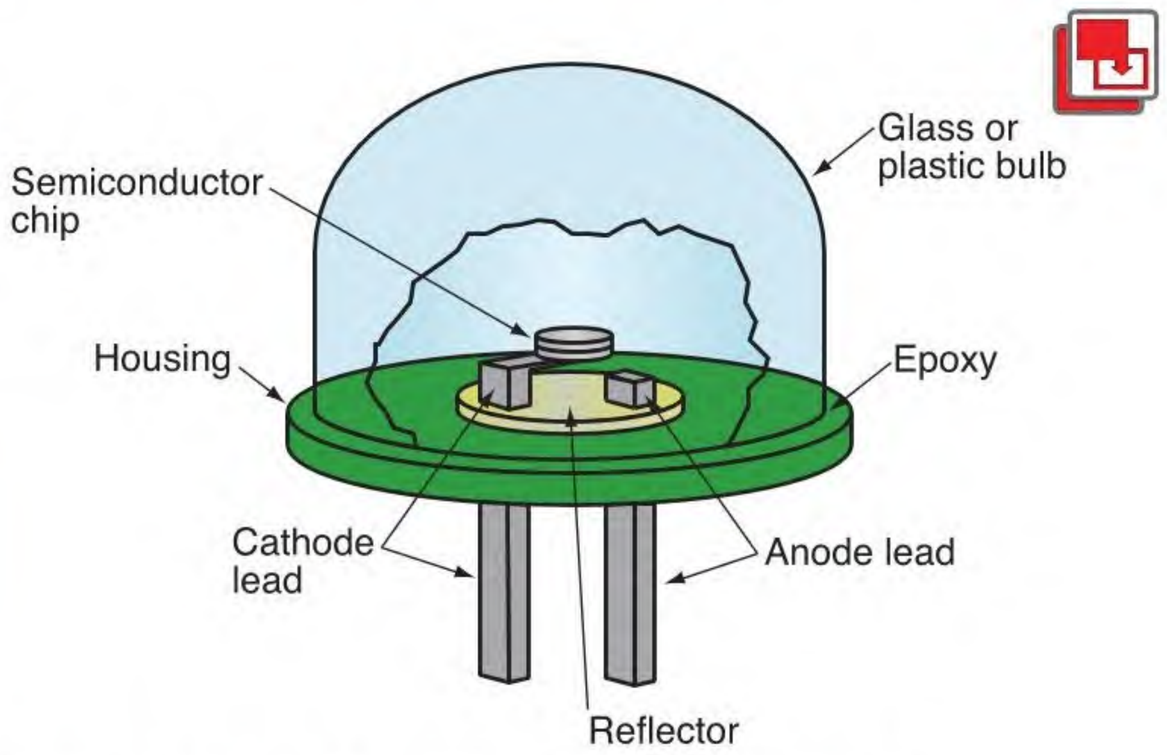


Figure 19-39. Study the parts of a light emitting diode.

single cable to transfer huge amounts of data. Look at **Figure 19-40**.

Fiber-optic cables carry light generated by LEDs or laser diodes, which are similar to LEDs but more powerful. The data stream to be carried is fed into the circuit as voltage, which modulates (changes) the light waves. The outer part of each fiber is coated with a substance that makes the light bounce off the inner wall of the fiber and shoot out the other end.

A light detector can be used to sense the light signal. The signal can then be amplified into a higher current signal to operate other devices. One strand of fiber-optic material can be used to send the same amount of electrical data as a large bundle of conventional metal wires.

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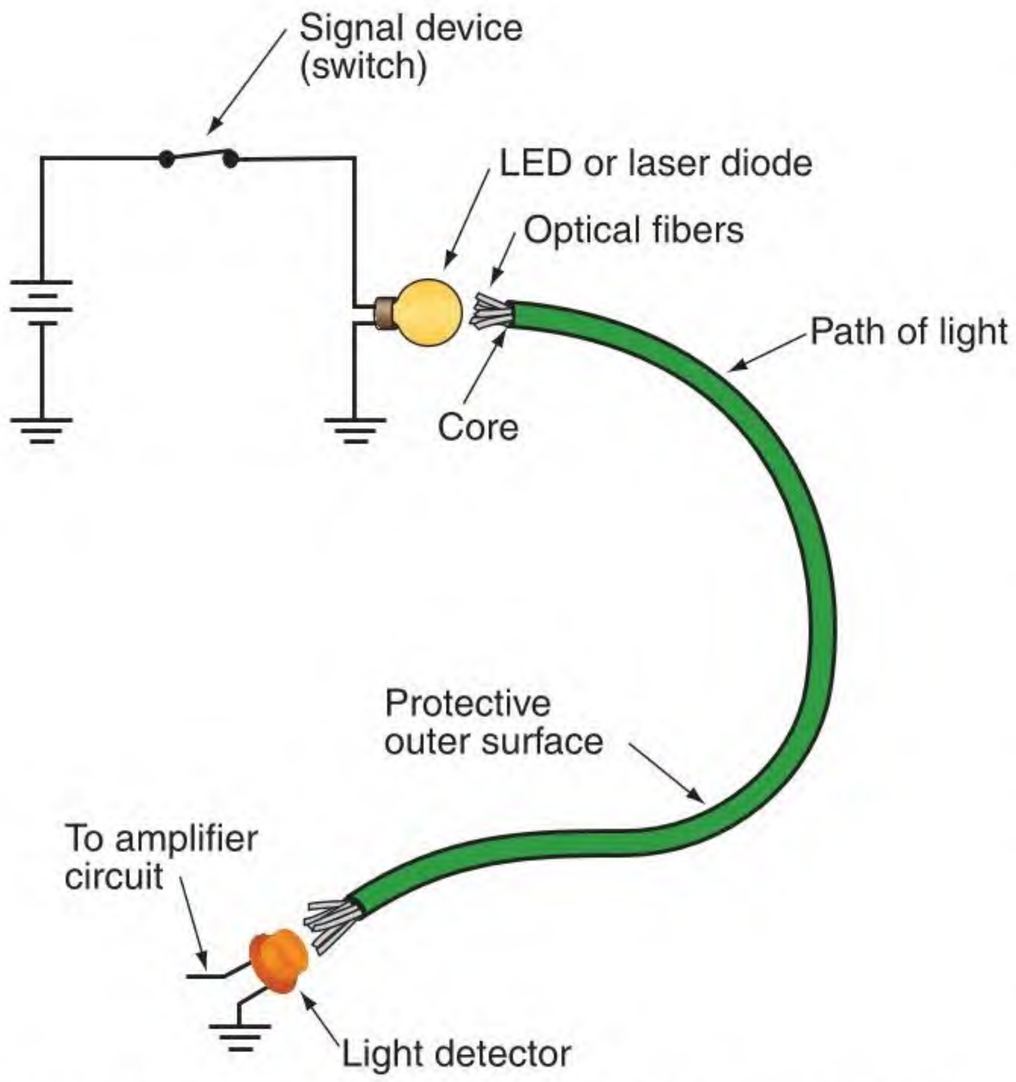


Figure 19-40. A fiber-optic cable consists of hundreds of optical fibers that carry information modulated onto light waves produced by a laser diode or LED.

Photonic systems are more reliable and efficient than all-electronic systems. They are also faster and take less space. Laser and fiber development are progressing rapidly, enabling error-free transmission of signals over distances greater than 100 miles without reamplification.

Photovoltaic Cells

A ***photovoltaic cell***, or solar cell, is a photonic device that converts light directly into current. A basic photovoltaic cell, **Figure 19-41**, consists of a glass outer layer that contains a transparent negative terminal, an antireflective layer to increase the cell's efficiency, a layer of N-type semiconductor material, a layer of P-type semiconductor material, and a metal base.

More layers, containing other types of semiconductors, are often used to help increase efficiency. The photovoltaic cell converts the photons to electrons, which form a current that can be used to power external devices. The cell's electromagnetic field also provides a voltage output of about 0.5 V.

If we connect several photovoltaic cells in series, we can increase voltage output. Four silicon photovoltaic cells in series would generate approximately 2 V. If we connect the cells in parallel, the voltage stays the same, but the current output increases. This makes it possible to use the output for higher load devices, such as a small fan to cool the inside of a vehicle when it is sitting in the hot sun. See **Figure 19-42**.

Photoresistors

A ***photoresistor*** is a semiconductor that acts as a resistor in the dark but changes to a conductor when exposed to light. If a battery is connected to the photoresistor with the light source off, no current is allowed through the device because the photoresistor has high resistance. When the light source is turned on, resistance becomes much lower, and the photoresistor changes to a conductor to allow current.

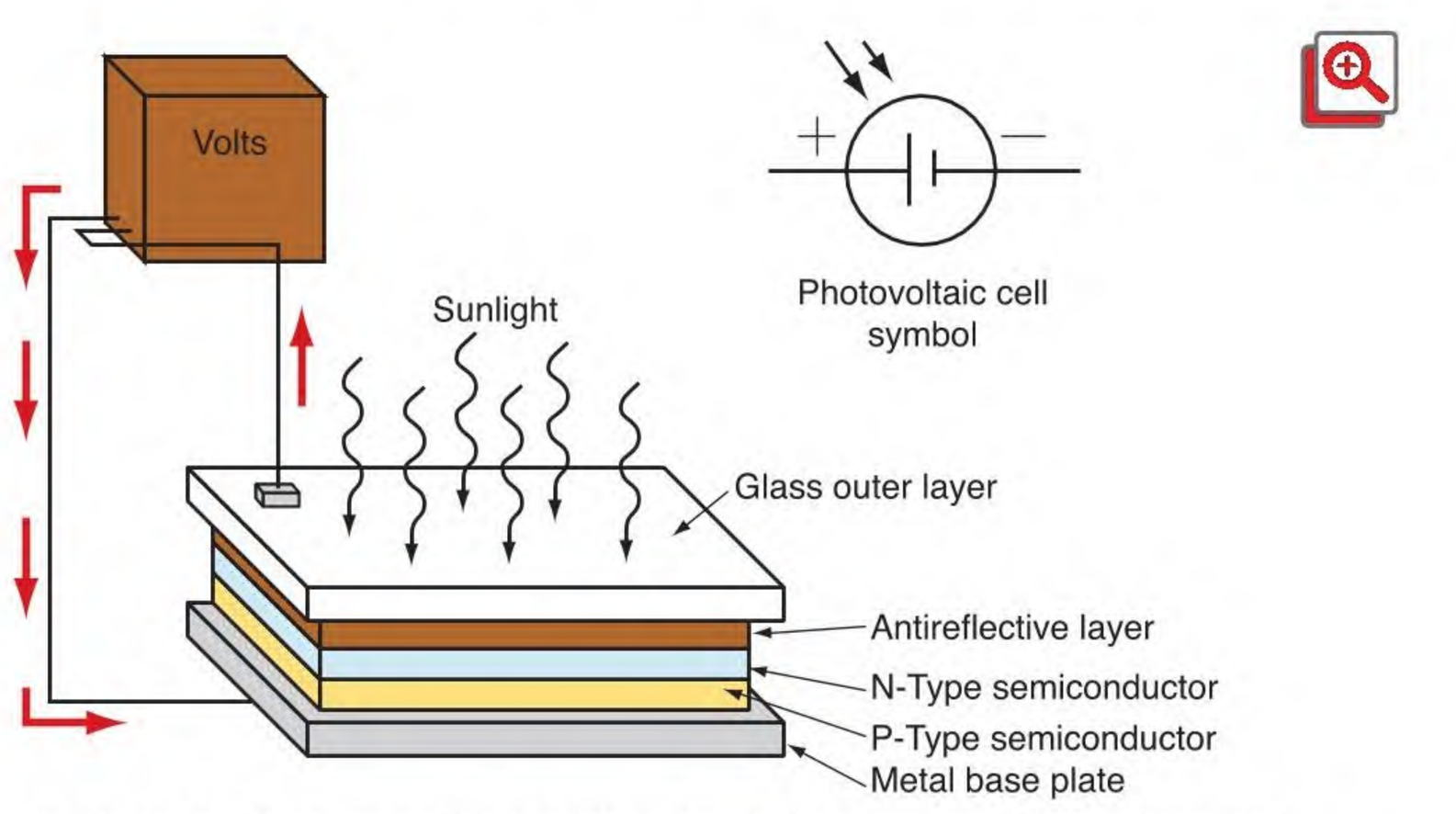


Figure 19-41. A solar cell converts light into electricity. The semiconductor surfaces trap light energy and feed electrons to the output leads.

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Figure 19-42. Ambient light is making this photovoltaic cell develop a low voltage. Sunlight would make it develop a higher voltage.

Photodiodes

All PN junctions are sensitive to light. A ***photodiode*** is a PN junction device that can function in one of two ways, depending on how it is connected in a circuit. It can produce a low voltage when excited by light. It can also be used to control current by allowing current flow when excited by light.

Phototransistors

A ***phototransistor*** performs a function similar to that of a photodiode. When light strikes the phototransistor, the emitter-collector junction conducts current. When light is blocked, the emitter-collector junction changes to an insulator and blocks current. A phototransistor might be used as a sensor in a control circuit in an automatic headlight dimming system to turn the headlights on and off by reacting to light conditions.

Liquid Crystal Displays

A ***liquid crystal display (LCD)*** is a device that has a fluid crystal material sandwiched between two sealed glass plates. This device can polarize light (make all the light waves vibrate in a single plane) to display numbers, letters, or other images. Both glass plates have a polarizing film on them, but one is turned at 90° to the other. See **Figure 19-43**.

When the liquid crystals are aligned with the top plate, they reflect light. However, when a charge is applied, their orientation changes, and they block the light. The areas of blocked light can be arranged by applying the charge to areas of a specific shape to form the images we see.

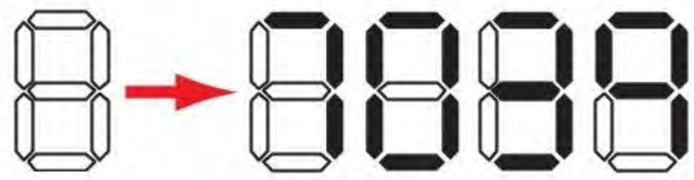


Figure 19-43. In a basic LCD numeral display, seven charge areas are arranged as shown here. By applying a charge to different combinations of the charge areas, the LCD can display the numerals 0 through 9.

Liquid crystal displays have thousands of practical uses. LCDs are used in the instrument cluster of late-model vehicles to show speed, tachometer graphics, odometer displays, and other information.



Customer Relations

Always "go the extra mile" to improve customer satisfaction. For example, you might want to place faulty parts in a plastic bag to show your customers. This will help demonstrate the shop's integrity and show each customer that you want them to understand your repair work.

Summary

- A resistor limits current flow in a circuit. A fixed resistor has only one resistance value. A variable resistor can be changed to have various resistance values. A tapped resistor can be connected differently to change its internal resistance.
- A switch connects and disconnects power to and from a circuit. Many different kinds of switches have been developed to meet different needs.
- A capacitor is a storage device for electricity. It is commonly used to smooth current in a circuit.
- Fuses are used to protect circuits from high current. Without a fuse, a short could cause enough current to burn up wires and components.
- Circuit breakers are another form of circuit protection device. They also stop current if current draw becomes too high. However, circuit breakers are not ruined after one use.

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- A coil is an insulated wire wrapped in loops, usually around an iron-containing core.
- A transformer uses two coils located close together. A transformer can isolate circuits, increase voltage, or decrease voltage.
- A relay uses a small input current to control a larger circuit current.
- A solenoid is an electromagnet used to move an iron plunger or core. It can be used to complete a very high-amperage circuit, something like a relay. It can also be used to engage parts—to move the engine throttle linkage, for example.
- An electric motor uses magnetic forces to spin an armature. The spinning action can be used to do work.
- Electrical and electronic symbols are used on wiring diagrams instead of isometric drawings of the individual parts. This saves time in creating the diagrams and makes the diagrams clear and easy to read.
- Electronic devices are composed of semiconductor material, which allows the device to control electricity. Examples include diodes, transistors, solar cells, and integrated circuits.
- A semiconductor is a substance that can change from an insulator to a conductor with external stimulation. A P-type semiconductor has more holes, which gives it a relatively positive charge; N-type material has more electrons.
- A diode passes current in one direction only.
- Transistors switch or amplify current in a circuit.
- Photonic semiconductors are devices that emit or detect light. They are used extensively in electronics to provide information and to produce direct current.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

armature
bipolar junction transistor (BJT)
brush
capacitor
circuit breaker
coil
commutator
diode
electric motor
electronic components
farads (F)
fiber optics
forward bias
full-wave rectification
fuse
half-wave rectification
impedance
light emitting diode (LED)
liquid crystal display (LCD)
NPN transistor
N-type semiconductor
photodiode
photon
photonic device
photoresistor
phototransistor
photovoltaic cell
piezoelectric crystal
PN junction
PNP transistor
P-type semiconductor
rectification
relay
resistor
reverse bias
reverse bias voltage
semiconductor
short circuit
solenoid
switch
transformer
transistor
turns ratio
wave
zener diode

Activities

1. Using what you've learned in this chapter, sketch a schematic for a circuit that includes a resistor, a switch, a capacitor, and a fuse.
2. Use the Internet to research any of the topics covered in this chapter. Look up articles, pictures, and animations of these components.

Review Questions

Answer the following questions using the information provided in this chapter.

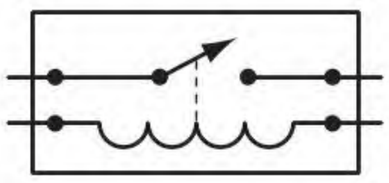
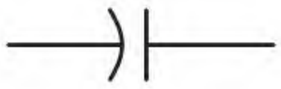
1. A(n) _____ is an electric component that limits current in a circuit.
2. Explain the difference between a normally open and a normally closed switch.
3. How does a typical thermal switch operate?
4. Explain the operation and application of a mercury switch.
5. What component can be used to block direct current while allowing alternating current to pass?

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6. How does a fuse protect a circuit?
7. What could happen if you install a new fuse that has a higher fuse rating than the old fuse?
8. A(n) _____ is a section of small wire connected to a larger wire to protect a circuit.
9. A(n) _____ does the same thing as a fuse but it is not ruined when activated by high current.
10. Which type of transformer decreases voltage but increases current?
11. What is the basic purpose of a relay?
12. What is a solenoid?
13. A(n) _____ component is typically smaller, lighter, and more energy efficient than its electric equivalent.

Matching

For questions 14 through 21, match the electrical symbols in the left-hand column by placing the letter of the description in the right-hand column beside the number of the matching symbol.

14. 
15. 
16. 
17. 
18. 
19. 
20. 
21. 

A. Capacitor
B. Fuse link
C. Fixed coil
D. Lightbulb
E. Transformer
F. Fuse
G. Variable capacitor
H. Relay
I. Variable resistor
J. Solenoid

22. What material, used extensively in electronics, can act as either an insulator or a conductor?
23. Explain the difference between P-type and N-type semiconductors.
24. How does a diode function?
25. For what purpose are zener diodes commonly used?
26. What semiconductor device is used to switch or amplify current in a circuit?
27. What type of transistor is controlled by voltage?
28. What semiconductor device emits light when it is electrically energized?
29. Explain how fiber-optic material can be used to transmit information.
30. What is a photovoltaic cell?

ASE-Type Questions

1. Technician A says the small base circuit of a transistor controls current flow. Technician B says the small emitter circuit controls current flow. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Technician A says a rheostat has at least three electrical connections. Technician B says a potentiometer has at least three electrical connections. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. A particular type of resistor has a tolerance of 3%. Technician A says this indicates that the resistor's current value can be 3% above or below its stated specification. Technician B says this indicates the resistor's resistance value can be 3% above or below its stated specification. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. Technician A says that a diode only allows current flow in one direction? Technician B says a diode simply regulates current flow in both directions.
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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5. Technician A says a push-button switch has a spring-loaded button that, when pressed, makes or breaks an electrical connection. Technician B says pressure switch is a special type of push-button switch that stays in one position until you move it. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Technician A says a mercury switch can be used to activate the underhood light in a vehicle. Technician B says a pressure switch can be used in the engine oil light circuit. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. Technician A says a capacitor blocks dc current and is commonly used as a noise suppressor for automotive radios. Technician B says a capacitor has the ability to store electrical energy. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. Technician A says a 20-amp automotive fuse will handle 25 amps of current without blowing. Technician B says that a replacement fuse must have the same amp rating as the original. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Technician A says a circuit breaker is designed to protect a circuit from high current. Technician B says a circuit breaker's rating is given in amps. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. Technician A says coils are usually wrapped around an iron core. Technician B says coils block direct current flow. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
11. Technician A says a transformer can be used to isolate a circuit. Technician B says a transformer can be used to change the voltage in a circuit. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
12. Technician A says the voltage and current in a transformer are inversely proportional. Technician B says impedance is resistance to alternating current at a given frequency. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
13. An electrical device that uses a small input current to control a larger current is known as a(n):
    (A) transformer.
    (B) relay.
    (C) inductor.
    (D) solenoid.
14. Technician A says a semiconductor can act like an insulator. Technician B says a semiconductor can be used as a conductor. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
15. When a diode is forward biased, it acts like a(n):
    (A) conductor.
    (B) insulator.
    (C) resistor.
    (D) transistor.
16. Technician A says a diode is commonly used to convert alternating current into direct current. Technician B says one diode in series with an ac source produces full-wave rectification. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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17. Technician A says a transistor is a device used to amplify current in a circuit. Technician B says a transistor is a device used to rectify current in a circuit. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
18. All of the following are common types of transistors *except:*
    (A) power transistor.
    (B) field-effect transistor.
    (C) zener transistor.
    (D) high-frequency transistor.
19. Technician A says a thyristor is a controllable diode. Technician B says a thyristor can be used to control different amounts of current. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
20. All of the following are photonic devices *except:*
    (A) light emitting diodes.
    (B) field-effect transistors.
    (C) solar cells.
    (D) photoresistors.

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Chapter 20
Electrical Tools and Test Equipment

After studying this chapter, you will be able to:

- Identify tools that are commonly used during electrical repairs.
- Summarize the use of test equipment for various vehicle systems.
- Summarize the use of multisystem test equipment such as scan tools and engine analyzers.
- Select the proper tool or tester for the job.

As discussed, today's vehicles are virtually impossible to fix without the right tools and equipment. This is especially true with electrical and electronic repairs. Modern vehicles, with their on-board computers, sensors, actuators, and complex wiring, require the skill of a well-trained and well-equipped technician.

Electrical Repair Tools

Electrical repair tools include the soldering tools and wire stripping tools used by the automotive electronic technician. Study the benefits, methods, and dangers of using these essential tools.

Soldering Tools

Solder is an alloy that has a relatively low melting point compared to other metals. ***Soldering*** is the process of using heat and molten solder to join wires, terminals, and other components. Soldering is the best method of making permanent electrical connections. Soldered connections have low resistance. They also resist corrosion and vibration failure.

Soldering tools are used to heat components (wires or terminals) and melt the solder onto the connection to form a permanent electrical circuit path. A ***soldering gun*** has a transformer that sends high current through a high-resistance tip to quickly generate heat for soldering. A soldering gun has a high power rating and is trigger-operated. It is ideal for automotive electrical repairs because the tip heats up in only a few seconds.

A ***soldering iron*** must be plugged into a wall outlet and allowed to heat up for several minutes before use. This makes it slightly less convenient than a soldering gun, with its trigger and fast heat-up. However, the tip on a soldering iron is generally smaller and more suited to delicate work on circuit boards.

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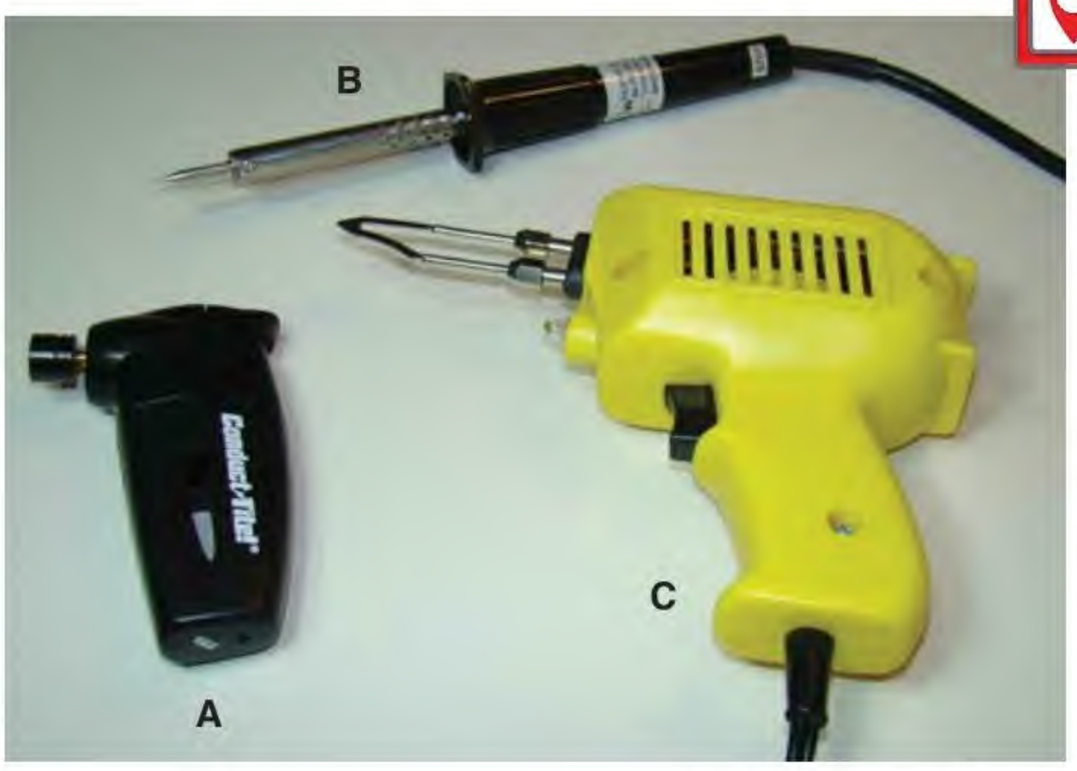
A ***soldering torch*** burns butane gas to instantly generate heat for soldering wires and electric components together. The soldering torch is gaining popularity because it does not have to be plugged into a wall outlet, and it generates heat even more quickly than a soldering gun. Refer to **Figure 20-1**.

Warning

Never solder near flammable materials. The heat of a soldering gun can cause fabric, carpet, some cleaning solvents, gasoline, and other combustible materials to catch fire.

Various soldering aids have been developed for use in soldering. For example, a ***flux brush*** can be used to apply a paste-type flux to a joint. ***Flux*** chemically cleans the metal surfaces so the molten solder flows out and bonds with the base metals properly. If a metal surface is very dirty or corroded, it should be cleaned with a wire brush before the flux is applied.

Soldering picks can be used to scrape corrosion from components before solder is applied. They can also be used to help hold or pin down small components while soldering.



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Figure 20-1. A soldering torch, iron, or gun will heat wires and metal connectors enough to melt solder onto the components. When the solder cools and hardens, it forms a metal conductor between two components. A—A miniature soldering torch uses butane gas to heat and melt solder to join components not located in confined places. B—A soldering iron can reach tight places more easily than a soldering gun or torch. C—The metal tip of an electric soldering gun heats up quickly to melt solder and join electric components and wires.

A ***heat sink*** is a spring-loaded, clamp-on aluminum device that helps prevent overheating of electronic components while soldering. For example, a heat sink might be clamped onto the wires going to a transistor before the leads to a circuit are soldered. The heat sink absorbs heat away from the transistor, preventing damage to the sensitive semiconductor materials due to overheating.

A ***desoldering bulb*** is a tool for removing molten solder during electrical repairs. The technician uses a soldering gun, iron, or torch to melt the solder for component removal or disconnection. Then the technician squeezes the bulb, places it near the molten solder, and releases the bulb to suck the solder away from the joint. This frees the wire, lead, or component for removal.

Other soldering aids include a ***soldering sponge***, which is soaked in water and used to clean the tip of the soldering gun or iron. ***Holding devices*** free the technician's hands to use the soldering gun and solder.

Wire Stripping Tools

To make an electrical repair, insulation must often be stripped from the wires to expose the metal conductor. The wires can then be soldered together or joined with crimp-on type electrical connectors. ***Wire stripping pliers*** are designed for quickly peeling the plastic insulation off metal wires. See **Figure 20-2**.

Crimp Connecting Tools

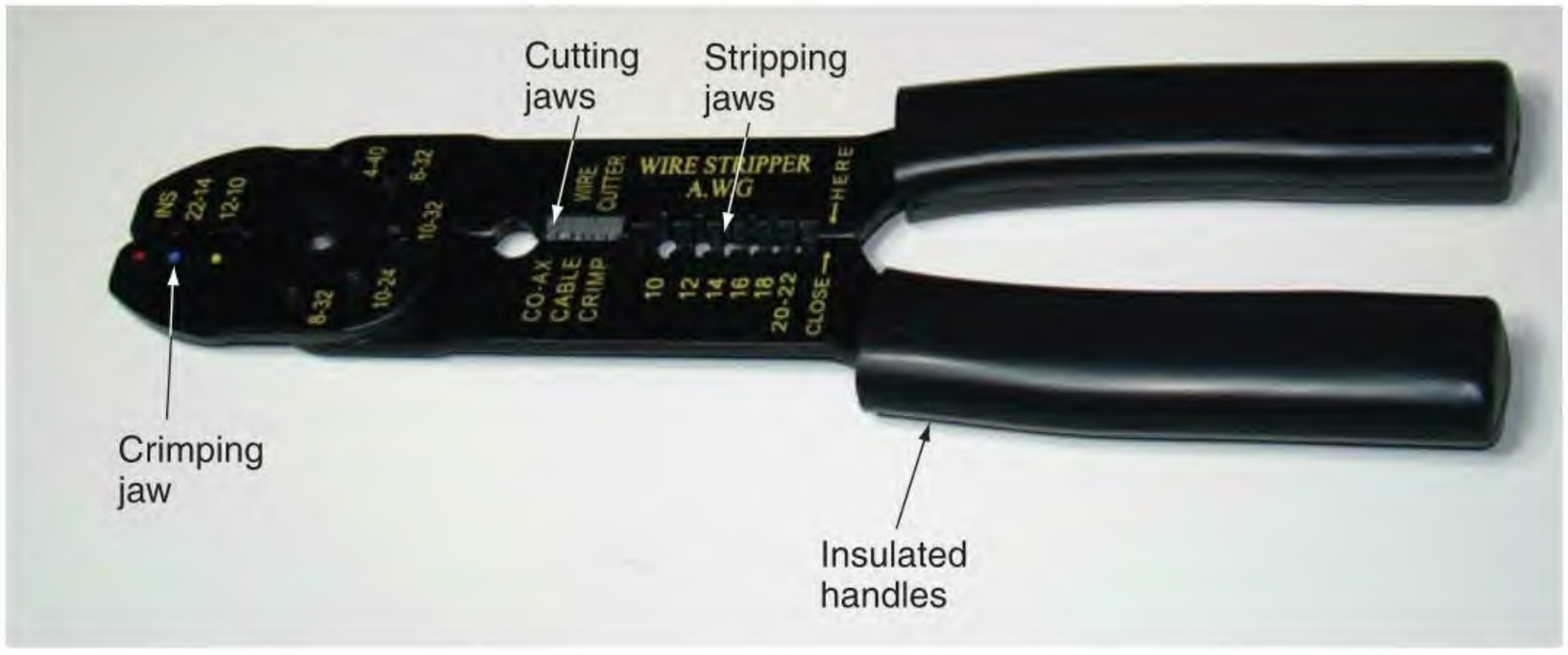
Crimp connectors provide an easy way of joining wires or installing a terminal on a wire. Before using crimping tools, you must first strip the wire. Make sure the right amount of conductor is exposed. If the conductor is too short or too long, the crimp connector will not work properly. After stripping the insulation from the wire, twist the conductor to hold the wire strands together so they will feed into the crimp connector easily.

Use ***crimping pliers*** to crush the metal part of the connector around the wire conductor. Use the correct size of jaws with the crimping tools. The jaws should be positioned over the metal part of the terminal. Electrical pliers may be used to crimp the tabs of crimp connectors around wires.

Electrical Test Equipment

Most automotive repair shops today have equipment that can diagnose problems in many different vehicle systems. Scan tools, engine analyzers, and exhaust gas analyzers are among the most common.

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Figure 20-2. Wire stripping pliers have jaws for peeling off plastic or rubber insulation from wires. They include conventional pliers, as well as cutting holes of different diameters for stripping and cutting.

Scan Tools

A ***scan tool***, or scanner, checks the operation of vehicle sensors, actuators, wiring, and computers. Scan tools connect to a diagnostic link, or underdash test terminal, on the vehicle. They measure computer system operating voltages and interpret on-board trouble codes, providing the technician with information about the condition and possible issues with all of the vehicle's circuits. Refer to **Figure 20-3**.

When connected to the diagnostic link and after data exchange with the on-board computers, this type of scan tool will display all the vehicle's stored trouble codes. Each trouble code represents a specific circuit problem or condition. By checking the assemblies, wires, and components related to the trouble code, the technician can find and correct vehicle problems much more easily.

A more advanced scan tool is shown in **Figure 20-4**. It can retrieve and help analyze diagnostic trouble codes and collect computer system information. It can also monitor the operation of hundreds of sensors in real time and display the results as a graph, chart, or gauge reading.

Test Lights

Test lights are frequently used to check a circuit for power or ***continuity*** (complete circuit path). They



Snap-on Tool Corp.

Figure 20-3. This basic scan tool, or code reader, reads trouble codes from the vehicle's computer to help pinpoint the locations of any problems. Plug the scanner into the vehicle's diagnostic link under the left side of the instrument panel, or dash.



Snap-on Tool Corp.

Figure 20-4. This advanced scan tool will complete more troubleshooting functions than a code reader. Besides reading trouble codes, it will perform live tests and monitor circuit electrical values. It will also act as an oscilloscope to trace voltage over time.

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Figure 20-5. A circuit-powered test light uses circuit voltage to illuminate a small lightbulb. The test light must be grounded and then touched on terminal of connector. If test light glows, you know that you have power flowing through the circuit to that test point. Use only a high-impedance (resistance) test light tool to ensure current draw through the tool will not damage delicate computer circuits.

provide the quickest method of checking for voltage or a complete circuit. See **Figure 20-5**.

A circuit-powered test light is energized by the circuit voltage. The alligator clip is connected to any ground on the vehicle. Then the pointed probe is touched to a circuit conductor. If the circuit has power, the test light glows. If the tester does not glow, something is preventing current flow in the circuit.

Caution

Some electronic circuits and components can be ruined by the current draw of a test light. Always use high-impedance or high-resistance test lights or a meter. Refer to the appropriate service information if you are not sure about a testing procedure.

A self-powered test light, or continuity tester, contains a small battery and is used to check a circuit for continuity or low resistance. The source of circuit voltage must be disconnected. The self-powered test light's alligator clip is grounded and the probe is



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Figure 20-6. Noid lights are test lights used to check the operation of electronic fuel injectors. Noid lights plug into the wiring harness going to the fuel injectors. If the computer is working and all wiring harness leads are good, the noid lights will glow or flicker to show an injector opening pulse (voltage signal).

touched to the circuit. If the test light glows, the circuit is complete back to ground. This type of test light is not used as much as the circuit-powered test light.

Noid lights are used to check for power in the wiring harness going to electronic fuel injectors. A noid light is plugged into the harness connector going to an injector. If the computer is sending power to the injector, each noid light will glow, indicating there is sufficient power flowing to open the injector. Refer to **Figure 20-6**.

Multimeters

A ***multimeter***, also called a volt-ohm meter or VOM, is used to measure exact electrical values in vehicle circuits. It combines a voltmeter, ohmmeter, and ammeter into one case. A multimeter is an essential tool of the auto electronic technician

An ***analog multimeter*** uses a needle or pointer to show electrical readings. In addition to measuring constant values, it can detect changes in voltage, current, or resistance. The needle moves left or right to show temporary or rapid changes in electrical values. An analog meter can still be handy because it will show intermittent voltage and current fluctuations more clearly than a digital meter.

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A ***digital multimeter*** uses a liquid crystal display to show a digital readout, **Figure 20-7**. It does not have a swinging pointer to show changing electrical values. Digital multimeters are therefore better suited for measuring constant values. The digital multimeter has replaced the analog type in many applications because of its convenience.

A ***digital-analog meter*** is a digital meter that has both an alphanumeric display and a bar graph to show fluctuating electrical values. This is the most commonly used type of multimeter in the auto repair shop. The alphanumeric display shows voltage, resistance, current, and other values as a decimal number in the display window. The bar graph is a small line or series of dots that shows rapid changes in electrical values. For example, if you wiggle a loose electrical connection, the bar graph moves right and left to show a rapid change in conduction, but the digital number display is too difficult to read with rapid readout changes in electrical values.



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Figure 20-7. A—A digital multimeter uses an alphanumeric display to give readings. A digital meter is for taking readings that do not fluctuate. It also draws less current than older analog instruments and may prevent component damage. B—A digital-analog meter combines the best properties of digital and analog meters. It can show both steady and fluctuating readings, and draws less current than most analog meters.

Tech Tip

A high-impedance (resistance) digital-analog multimeter is recommended for testing most computer circuits. It draws very little current and will not damage delicate computer circuits. A conventional analog meter draws more current and might burn up integrated circuits and other small electronic components.

A multimeter that uses a conventional pickup must touch metal components in a circuit to take a reading. For example, to measure current with a conventional pickup, you must disconnect the wires and attach them to the leads of the multimeter. Then the meter shows current draw through the circuit.

A multimeter with an ***inductive pickup*** does not have to touch the metal components in a circuit. It measures the magnetic field around a current-carrying wire. For example, an inductive pickup might be used to measure current output from an alternator. The inductive pickup is placed around the wire insulation to make an amperage reading. See **Figure 20-8**.

Inductive Wire Tracers

An ***inductive wire tracer*** can be used to find internal breaks in wires and disconnected wires or



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Figure 20-8. An inductive pickup clamps around the outside of the insulation to measure the strength of magnetic field around wire. The meter converts magnetic field strength into a current value in amps. Inductive meters are accurate to within approximately plus or minus one amp. A conventional ammeter hardwired in series with the circuit are accurate to within plus or minus one milliamp (0.001 amp).

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terminals. A pulse generator is connected to the circuit. This produces a pulsing, low-voltage alternating current in the wiring. Then the inductive probe is moved along the wire. The tracer makes an audible beeping sound if the wire has continuity and is carrying the pulsing signal. When the tracer moves past a break in a wire or a poor connection, the signal stops or changes in tone. This shows you the location of the wiring problem.

Tech Tip

You might want to isolate the computer and other delicate electronic components before using an inductive wire tracer. This will ensure that they are not damaged during the testing.

Oscilloscopes

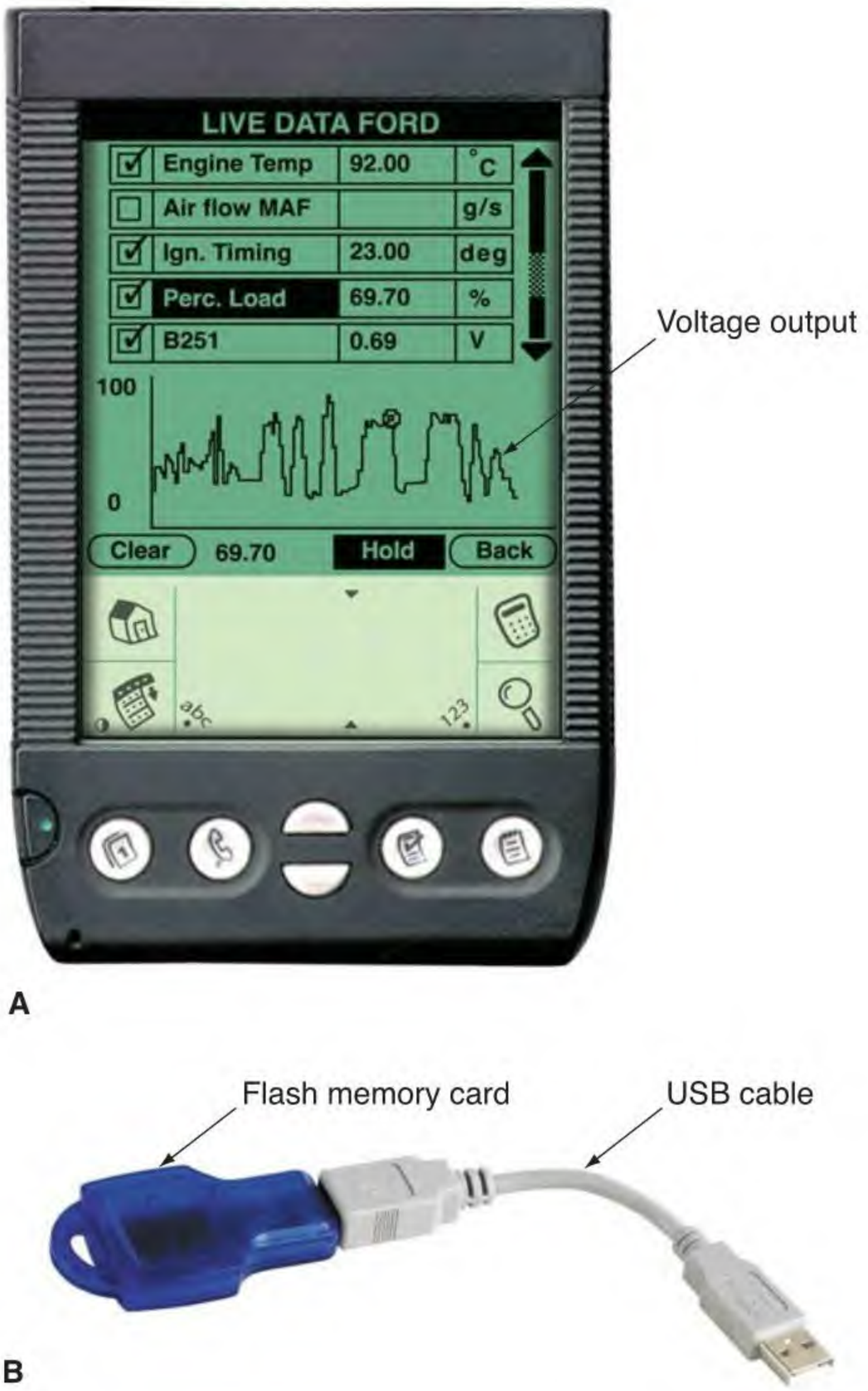
An ***oscilloscope***, or scope, is a diagnostic tool that displays a line pattern, or trace, representing circuit voltages in relation to time. By comparing the test scope pattern to a known good pattern, the technician can determine whether something is wrong in the vehicle's circuit. Oscilloscopes are sometimes needed to check ignition systems, engine speed sensors, and other operating voltages over time.

A handheld scope usually consists of an oscilloscope and a multimeter combined in one housing. It is used for advanced troubleshooting of electrical/electronic problems. The handheld scope can be used to perform voltage, current, and resistance measurements over short intervals of time. It can display instantaneous voltage variations coming from sensors, actuators, or vehicle control units. Adapters are available that allow an oscilloscope to measure other variables, such as pressure, temperatures, high current, or weak magnetic waves. See **Figure 20-9**.

Load Testers

A ***load tester*** is used to test the condition of 12-volt batteries, as well as conventional charging and starting systems. Load testers are commonly used to draw current out of the battery while measuring voltage. If the voltage stays within specifications with the specified current draw, the battery is good. If not, a battery problem may exist. To check the operation of the charging system, the load tester measures current to the battery with the engine running. A load can be placed on the system to measure maximum alternator output. A load tester can also be used to check the condition of the starting system. Starter current draw can be measured and compared to specifications. See **Figure 20-10**.

Modern load testers have an inductive current pickup. The amp (current) lead is clamped around the outside of the battery cable.



OTC/SPX Corp.

Figure 20-9. A scope is handy when trying to find problems that are difficult to locate. The scope will measure voltage or current over time very accurately. A—This handheld scope displays live data, such as engine temperature, ignition timing, duty cycle, sensor output voltage, and sensor/actuator waveforms showing voltage output over time. B—Some oscilloscopes can be connected to a flash memory card so data can be downloaded into the shop's computer for further evaluation with diagnostic software.

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Figure 20-10. A load tester is the best way to check the condition of a vehicle's battery, charging system, or starting system. Today's load testers have inductive pickups that clamp around the battery cable to measure high current draw from the starter or battery. A large carbon pile resistor in the load tester absorbs the high heat of the high current draw.

Charging System Analyzers

A ***charging system analyzer*** quickly measures charging system voltage to determine alternator operation. It has indicator lights that inform you of the alternator output. Some handheld charging system testers are connected across the battery and place a high current load on the system to check current output from the alternator.

System-Specific Test Equipment

Test equipment that is specific to one system on a particular make and model vehicle is available. For example, an alarm tester is designed to help diagnose a specific vehicle alarm system.

A ***keyless entry tester*** checks the condition of the key chain sending unit and the signal sensor of a vehicle's keyless entry system. If the doors do not unlock when the sending unit on the key chain is pressed, the technician can use this tester to help troubleshoot the system.

A ***park assist tester*** helps troubleshoot the output from a laser at the rear of the vehicle in a park assist system. It can be held next to the sensor to detect a laser output and determine if the unit is working properly.

A ***tire pressure monitor calibration tool*** can be used to calibrate and test the tire pressure sensors. Basically, you must set the tire pressure to specifications. Then, you must follow factory instructions to ready the vehicle for tire pressure monitor calibration (turn the key on and off several times, press brake pedal, or turn a light switch on and off several times). This will activate Bluetooth or another wireless system so the calibration tool can communicate with the vehicle. Finally, you can aim the tool at each tire as directed by the tool to calibrate the sensors and test their operation.

Diesel Test Equipment

Diesel engines do not have electric ignition systems. However, they do use glow plugs to aid cold starting. Special tools are needed to do electrical tests on a diesel engine.

A ***glow plug analyzer*** can be used to test diesel glow plugs and the operating condition of a diesel engine. It measures the internal resistance of or current flow to each glow plug. Some analyzers can also measure glow plug temperature. These glow plug testers can detect a dead cylinder because the temperature and resistance of a glow plug in a nonfiring cylinder are different from the temperature and resistance in the other cylinders. A dead cylinder in a diesel engine will show up as a cool cylinder and cool glow plug. See **Figure 20-11**.



Hybrid Tip

Most hybrid vehicles operate on high voltage levels that can damage low-voltage test meters. Only a meter with high-voltage insulation can be used to take electrical measurements on high-voltage hybrid components such as the battery pack, orange high-voltage cables, and the motor-generator. See **Figure 20-12**.

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Figure 20-11. A glow plug analyzer checks electric heating elements that warm engine combustion chambers to aid in starting a cold diesel engine.



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Figure 20-12. This high-voltage meter can safely measure dc and ac voltage up to 1000 volts with 0.1% accuracy. Never use conventional low-voltage instruments on high-power, hybrid circuits. Low-voltage instruments are delicate and would instantly burn out if connected to a voltage higher than its insulating rating.

Summary

- Soldering tools are needed to make wiring repairs. Soldering is the best method of joining wires and terminals.
- Wire stripper pliers are used to pull insulation from wires.
- A noid light provides a quick way of checking a circuit for power or continuity.
- A multimeter is used to measure voltage, current, and resistance. An analog multimeter uses a conventional needle to show readings. A digital multimeter uses vacuum fluorescent or liquid crystal displays to give readouts.
- Most manufacturers warn against using a test light to test some electronic circuits. They can draw too much current and damage delicate electronic components.
- An inductive wire tracer uses a signal generator to produce a weak ac signal in the vehicle's wiring. The probe can then be used to find internal breaks or disconnected wires.
- An oscilloscope is a diagnostic tool that displays a line pattern, or trace, representing circuit voltages in relation to time.
- Test equipment for charging and starting systems includes a battery tester, load tester, and charging system analyzer.
- System-specific test equipment includes alarm testers, keyless entry testers, and park assist testers.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

analog multimeter
charging system analyzer
continuity
crimp connector
crimping pliers
desoldering bulb
digital-analog meter
digital multimeter
flux
flux brush
glow plug analyzer
heat sink
holding device
inductive pickup
inductive wire tracer
keyless entry tester

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load tester
multimeter
noid light
oscilloscope
park assist tester
scan tool
solder
soldering
soldering gun
soldering iron
soldering pick
soldering sponge
soldering torch
test light
tire pressure sensor recalibration tool
wire stripping pliers

Activities

1. Use the Internet to research solder with different type of cores, such as rosin-core solder and acid-core solder. Write a summary explaining why one is used more often than the other.
2. Visit an automotive repair shop. Examine the scan tools used by their technicians. Write a short report on your findings.

Review Questions

Answer the following questions using the information provided in this chapter.

1. Why is soldering the method of choice for making electrical repairs?
2. Describe the advantages of using a solder gun, iron, and torch.
3. What types of tests are conducted using a scan tool?
4. What is an oscilloscope?
5. How is a circuit-powered test light used?
6. When might you use an digital-analog multimeter instead of a digital only multimeter?
7. Why can older analog multimeters damage computers?
8. What is a load tester?
9. Name three examples of test equipment that may be specific to a particular vehicle make and model.
10. What special equipment might be needed to work on diesel engines?

ASE-Type Questions

1. Technician A says soldered connections have high resistance. Technician B says solder has a relatively low melting point compared to other metals. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Technician A says that a soldering gun is generally better suited to delicate work on circuit boards than a soldering iron. Technician B says using a soldering torch heats up faster than a soldering iron. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. Technician A says an inductive wire tracer generates pulses of ac in the wiring being tested. Technician B says an inductive wire tracer checks for continuity in the wiring. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. Technician A says that the best way to splice a broken wire is to use a crimp connector. Technician B recommends soldering. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. Technician A says an oscilloscope can be used to check ignition system operating voltages. Technician B says an oscilloscope can be used to check output signals from computer system sensors. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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6. Technician A says a load tester can be used to check the condition of a vehicle's battery. Technician B says a load tester can be used to check the condition of a vehicle's starting system. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. Which of the following tools measures voltage over time?
   (A) Luminosity meter.
   (B) Pyrometer.
   (C) Oscilloscope.
   (D) Load tester.
8. Technician A says a scan tool can be used to check computer system actuator operations. Technician B says a scan tool can be used to check the operation of computer system sensors. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Technician A says that before using a tire pressure monitor calibration tool, tire pressure should be set to specifications. Technician B says the tire pressure monitor calibration tool must be plugged into the vehicle's computer. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. A diesel engine has a possible dead cylinder. Technician A is going to use a magnetic timing meter to check this problem. Technician B is going to use a glow plug harness tester to check for a possible dead cylinder. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Chapter 21
Wiring Diagrams and Wiring Repairs

After studying this chapter, you will be able to:

- Compare wire types and sizes.
- Explain the effects of wire size on resistance.
- Identify wire protection devices.
- Apply proper techniques to cut and strip wires.
- Perform proper procedures to join components or wires by soldering.
- Identify wire terminals and connectors.
- Perform proper procedures for making connections using various types of connectors and terminals.
- Perform proper procedures for servicing factory connectors without damaging them.
- Perform proper procedures for repairing wiring and fuse links.
- Use component location charts and illustrations while troubleshooting problems.
- Interpret wiring diagrams.
- Use a grid to locate specific components on wiring diagrams.
- Select and use the appropriate wiring diagrams to troubleshoot an electrical problem.

A late-model vehicle may have well over a quarter mile of wires linking its electric/electronic components. Hundreds of connectors are used to join these wires into workable circuits. The wires, connectors, and wiring harnesses must carry current under adverse operating conditions such as summer heat and winter cold. They must be able to withstand vibration, moisture, and road salt. A problem with even one wire or connector can adversely affect the operation or performance of the engine, drive train, and other major systems. It is therefore essential that you fully understand automotive wiring and know how to repair it correctly.

Automotive Wiring

Automotive wiring includes many types of conductors, from very small wires and printed circuit conductors to large battery cables. You must be familiar with different types of wiring and understand their characteristics. This knowledge will enable you to work successfully on the electrical wiring of any make or model vehicle.

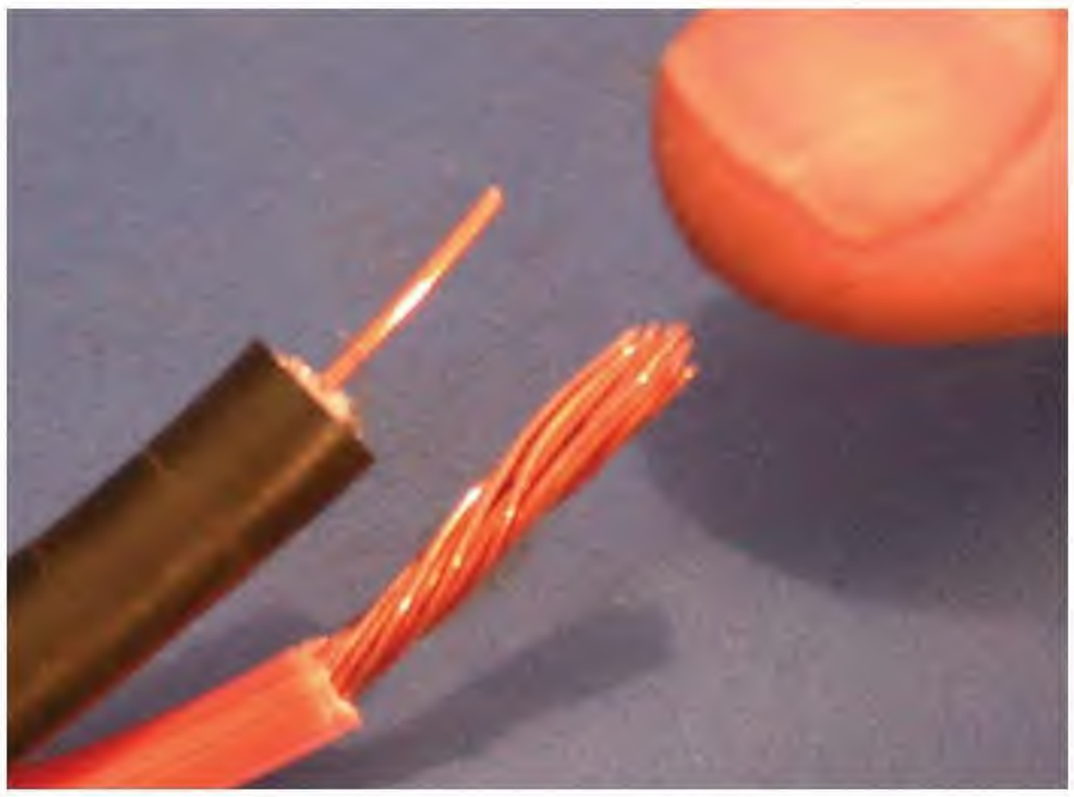
Types of Wire

The ***wire*** used in automotive circuits consists of a central metal conductor surrounded by plastic insulation. The type of metal used to make the conductor in a wire, as well as the type of insulation bundling, and shielding, varies depending on the application.

Solid and Stranded Wire

An electric wire consists of either a solid metal (usually copper or similar metal alloy) conductor or a stranded wire conductor inside a plastic outer covering. Both types are shown in **Figure 21-1**.

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Figure 21-1. Solid wire can be found inside components and shielded cable, such as an antenna cable, where there is little or no movement. Stranded wire is used in most auto wiring because it can withstand movement and vibration without breaking.

A ***solid wire*** has a single conductor inside the plastic insulation. This type of wire is sometimes used inside components such as relays or sensors. Solid wire is a good conductor, but it is not very flexible. The metal conductor may break with severe or prolonged vibration.

Stranded wire has numerous individual metal strands twisted together inside the insulation. Stranded wire is normally used throughout a motor vehicle because it is flexible and can withstand vibration without breaking.

Parallel Wire

Parallel wire has two or more individually insulated conductors or wires molded into one flat or round body of multicolor insulation. For example, wires for a computer circuit are often made as one set of parallel wires connecting components. Speaker wires are also usually parallel wires. Parallel wiring lays flat, stays organized for easy pinpoint testing, and can carry multiple signals or circuit currents efficiently.

Primary and Secondary Wire

Primary wire is small wire that carries low voltage (13–15 volts dc) to the components, circuits, and ECUs in a vehicle. Primary wire is used in insulated wiring harnesses throughout most of the vehicle. Another name for primary wire is body wiring.

Secondary wire is used to carry high voltage (but little current) in the engine's ignition system. Since it carries very little current, but high voltage, the conductor is relatively small and the insulation is very thick. This keeps high voltage from arcing through the insulation to ground. See **Figure 21-2**.

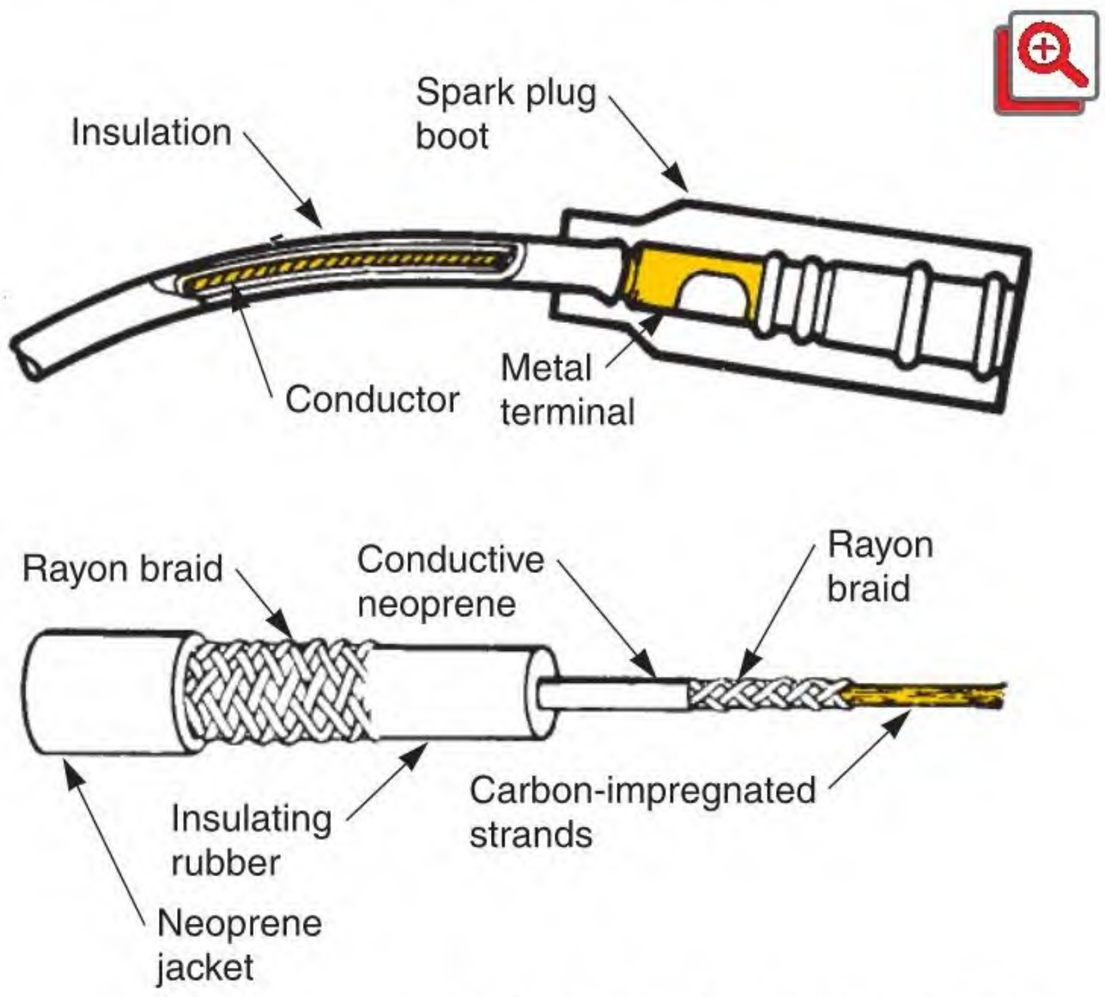
Secondary resistance wire, or ***carbon-core wire***, has internal resistance designed into the metal conductor. It is designed to help prevent radio interference or static from the high-voltage pulses going to the spark plugs.

Secondary nonresistance wire has a stranded metal conductor with no extra carbon resistance. This type of wire is used only in high-performance applications, such as off-road racing, because it causes static in nearby radios. Secondary wire is discussed fully in a later chapter.

Cables

The term ***cable*** refers to a wire with a large-diameter conductor. Examples include battery cables, starter cable, hybrid high-voltage cables, and coax cable. The outside diameter of a cable is generally much larger than that of a wire, and cables can contain one or more conductors.

Cables that carry battery current to the starting motor and return current to the battery from ground are commonly called ***battery cables***. The positive battery cable connects the positive terminal of the battery to the vehicle's electrical system. It usually connects to



Champion Spark Plugs/Federal Mogul Corp.

Figure 21-2. Secondary wire has a small conductor but very thick insulation. The insulation prevents the high voltage from leaking to ground.

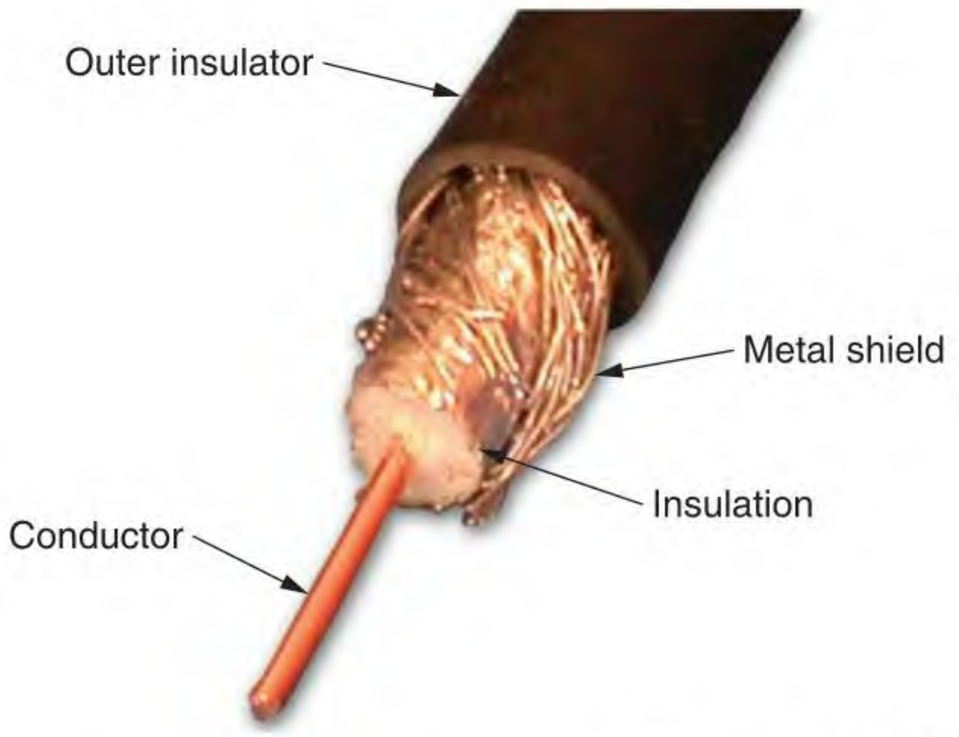
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the starting motor solenoid. Smaller wires connect the solenoid terminal to the fuse box and other devices. The negative battery cable connects from the battery negative to ground. This cable usually bolts to the side of the engine block to provide a good ground connection for the starting motor. The negative cable does not have to be insulated. See **Figure 21-3**.

Coaxial cable, also called coax or shielded wire, has a center conductor surrounded by a braided metal shield. Insulation separates the conductor and the braided metal shield. This keeps magnetic pulses, such as magnetic waves from cell phone towers, from inducing unwanted voltage pulses into the center conductor. Induced current or voltage can upset computer system operation or cause static in radios.

Coaxial cable is commonly used as antenna wire for AM-FM radios. The antenna lead must be protected from unwanted magnetic fields from the engine's ignition system and other electromagnetic power sources. This prevents electromagnetic induction in the center wire conductor and keeps static energy from entering the cable and upsetting the reception of the stereo. See **Figure 21-4**.

Twisted pair wire consists of multiple insulated conductors wrapped around each other in a spiral pattern. This design helps prevent unwanted magnetic fields from being induced into the wire. For instance, twisted pair may be used to connect the computer and various sensors, especially those near the ignition system and those that generate a weak electrical signal. This helps keep high-voltage pulses from upsetting the small voltage signals going to the computer. ***Shielded twisted pair wire*** may also have a sheath of metal around the conductors to block radio interference.



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Figure 21-4. Coaxial cables block any magnetic fields that might induce current into the wire. With low voltage and current levels in many circuits, this is important to ensure proper operation.

Hybrid power cables carry electric current to and from a hybrid vehicle's motor-generator, power control unit, and HV battery. They feed tremendous amounts of regenerative braking energy into the HV battery to store kinetic energy electrically. Upon acceleration, the hybrid power cables feed this current back into the motor-generator to help accelerate and propel the vehicle.

Tech Tip

Refer to the text index for more information about hybrids and required safety precautions for working on high-voltage power lines.

Hybrid power cables are normally orange for easy identification and safety. Hybrid cables are even larger than 12-volt battery cables, up to No. 00 (double ought) or No. 000 (triple ought). Refer to **Figure 21-5**.

Warning

Never come into contact with the metal conductors of hybrid drive cables. Many hybrid power trains operate on up to 600 volts. Always wear thick insulated rubber gloves and use nonconductive plastic tools and high-voltage test equipment when working on an electric drive system to protect from electric shock and equipment damage.



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Figure 21-3. Battery cables are very large and have a small gage number.

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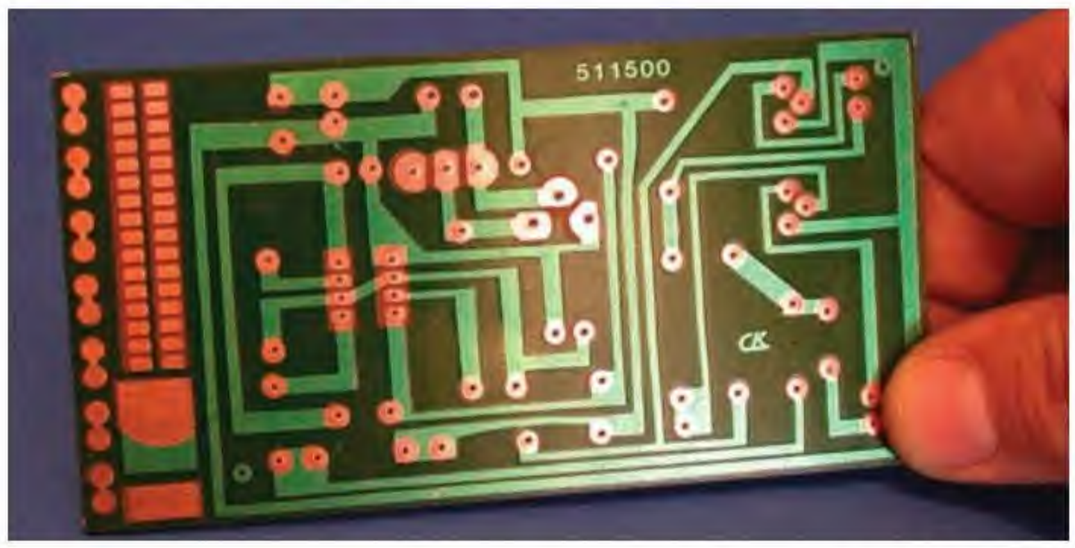


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Figure 21-5. These power cables carry high voltage to and from the motor-generator in a hybrid vehicle.

Printed Circuits

Printed circuits consist of copper foil bonded onto a plastic or fiber base to form a compact conductor. See **Figure 21-6**. Printed circuits are used on the back of the instrument panel cluster and in many electronic circuits. On instrument panel printed circuits, components snap or fasten to conductor strips and do not need to be soldered. This is illustrated in **Figure 21-7**.



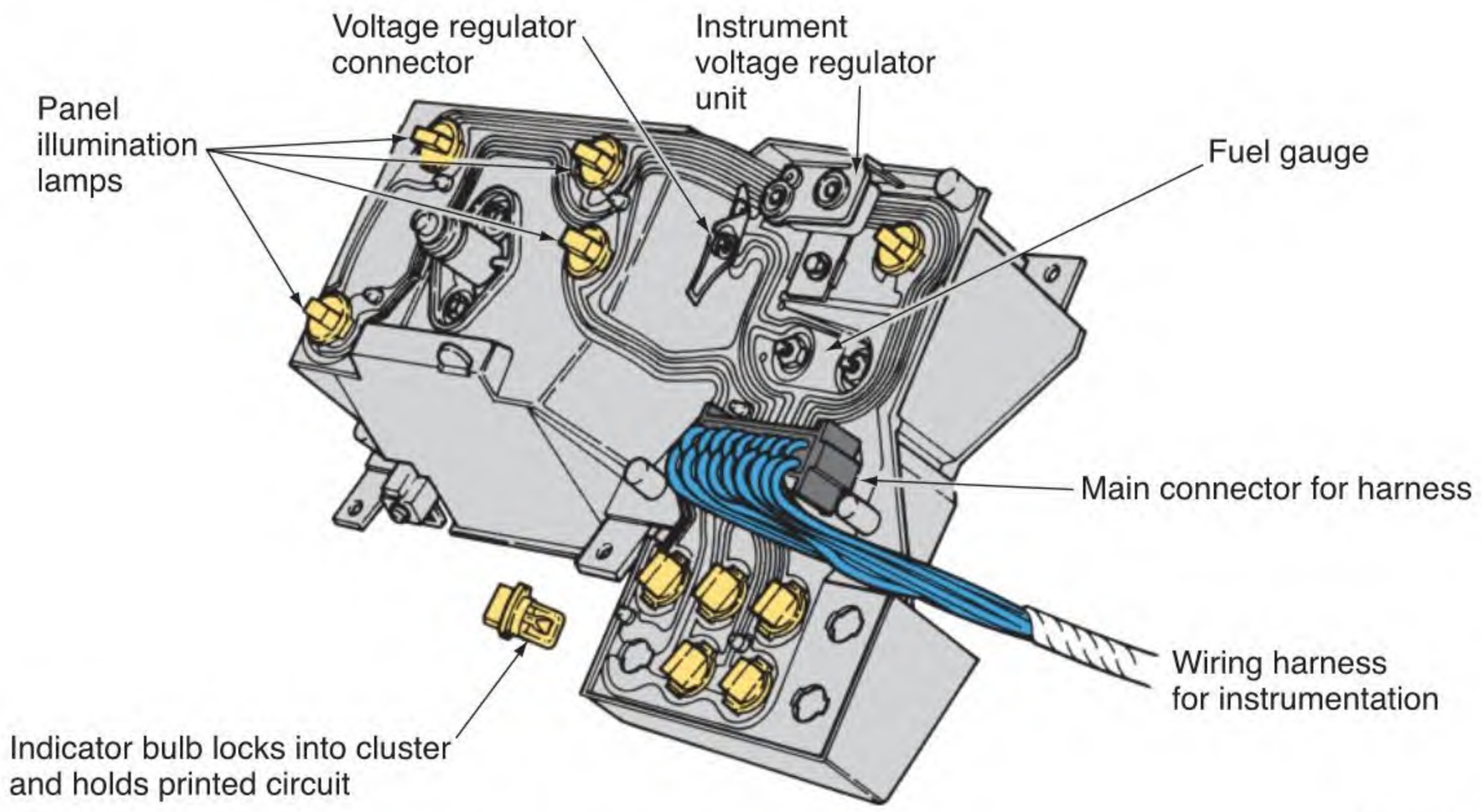
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Figure 21-6. Printed circuit wiring is made by depositing thin metal strips onto a plastic or fiber base material. The metal strips replace wires in the printed circuit.

Wire Size

Wire size, or ***wire gage***, is determined by the diameter or cross-sectional area of the wire's metal conductor. It does not include the thickness or diameter of the insulation. Wire size limits how much current, or amperage, a wire can carry without overheating. If a small wire carries too much current, it can burn up almost instantly, melting the metal conductor and its insulation. To avoid this, wire size must be matched to the circuit amperage draw at peak load conditions. See **Figure 21-8**.

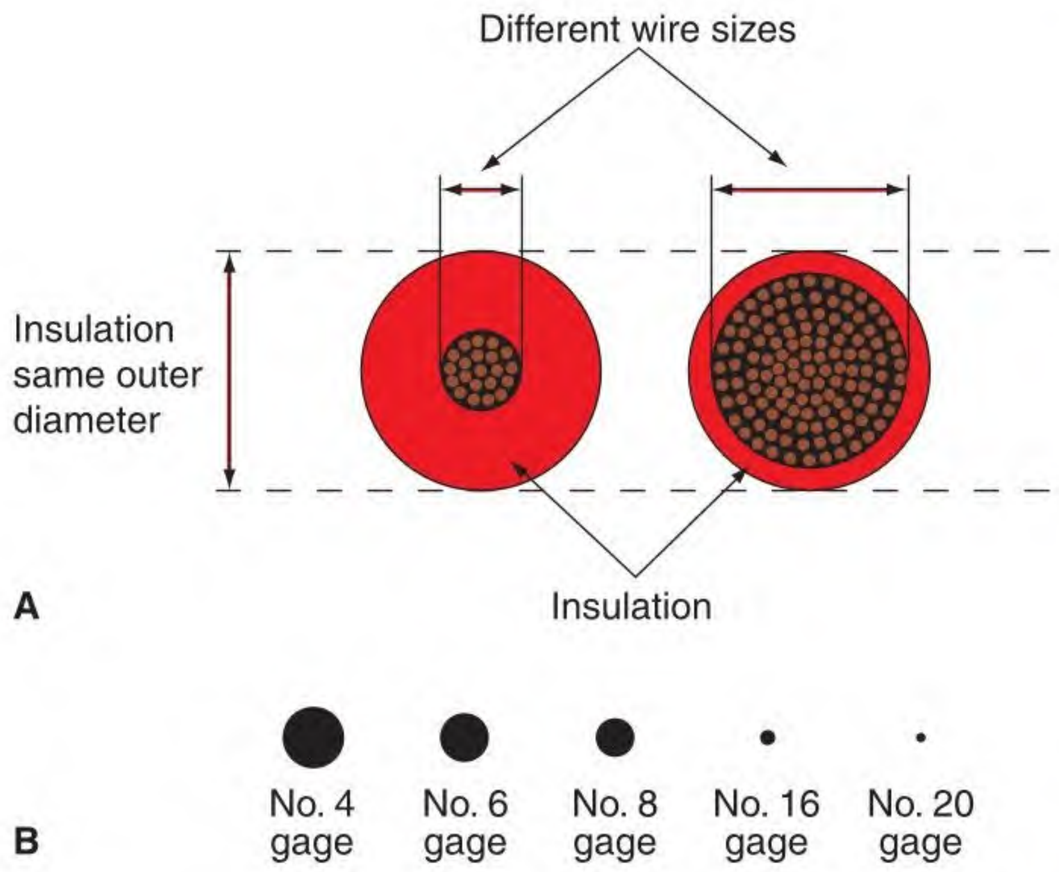
In automotive technology, wire size is rated by the ***American Wire Gage (AWG) system***. Gage numbers



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Figure 21-7. This rear view of an instrument cluster shows one application of printed circuit wiring. The components are not soldered to this type of printed circuit. Nuts or snap fittings lock components to the printed circuit.

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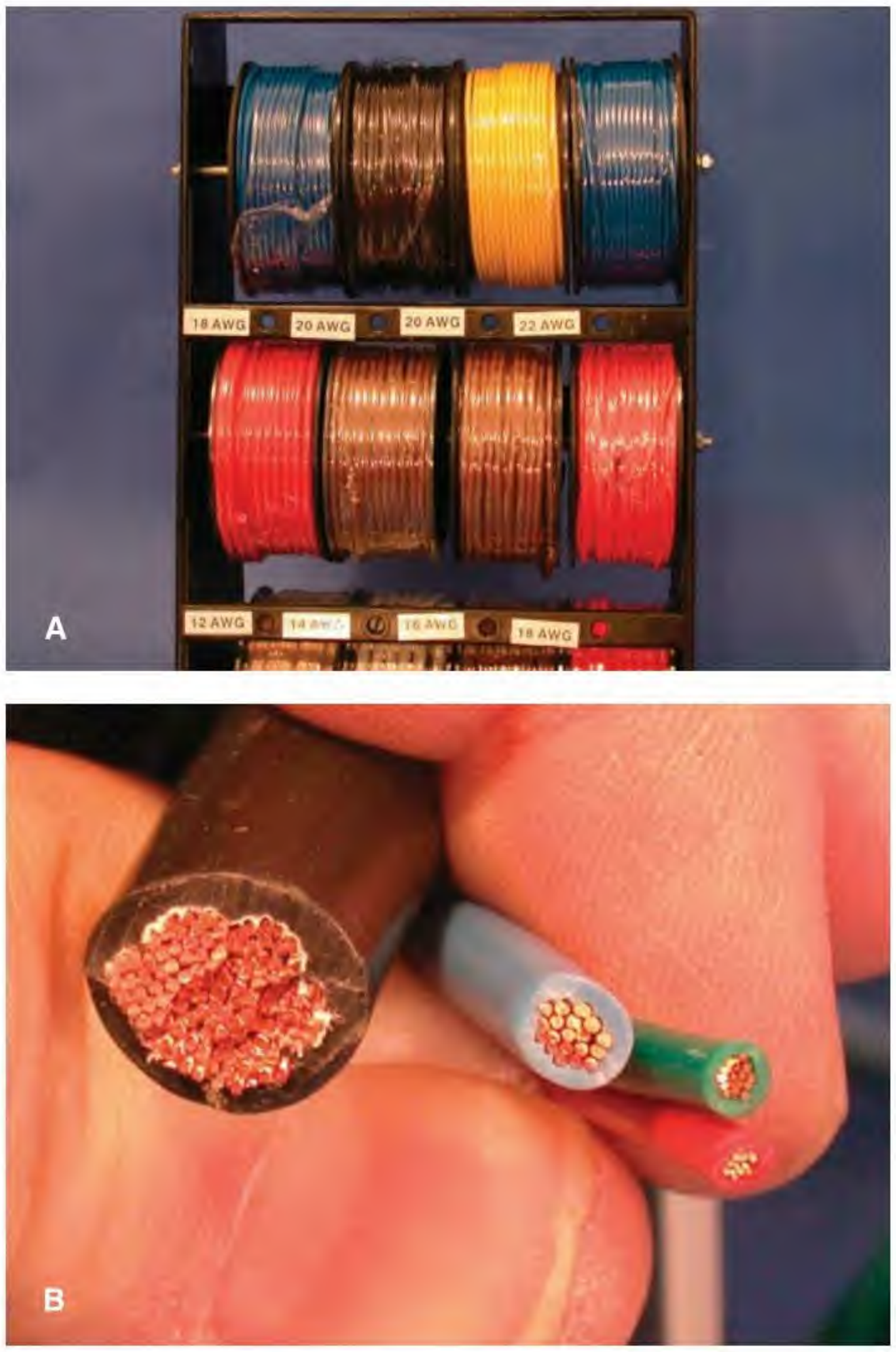
Figure 21-8. Always use the same wire size when replacing damaged wires. A—Wire size is determined by the diameter of the conductor. It does not include insulation thickness. B—In the AWG system, larger gage numbers indicate smaller wire diameters. In this illustration, actual wire sizes are shown (without insulation) for comparison.

are used to indicate conductor diameters. See **Figure 21-9**. A smaller number or wire gage denotes a larger conductor diameter, and vice versa. This system was designed for solid wires. However, stranded wire is also rated this way, with some variations depending on the wire manufacturer and weaving of the conductor strands.

Wire gages in an automobile generally range from gage 0 to gage 30. Wire gage 0 is a very large battery cable for carrying extremely high current without overheating. Wire gage 30 has a tiny conductor for electronic applications with low current draw. **Figure 21-10** is a chart of AWG wire sizes. Wire diameters are generally measured in mils or circular mils. A ***mil*** equals 0.001″, and a ***circular mil*** equals the area of a circle that has a 0.001″ diameter.

The resistance in a wire depends on several factors, including the ambient temperature, thickness of the wire, type of metal used, and type of wire (solid or stranded). Resistance is measured in ohms per 1000 feet. The Resistance column in **Figure 21-10** shows resistance for stranded copper wire at a temperature of 77° F.

Smaller diameter wire has more resistance than a larger diameter wire of the same material and design. This is why smaller wire overheats and burns if used to replace larger wire. The electrons moving through



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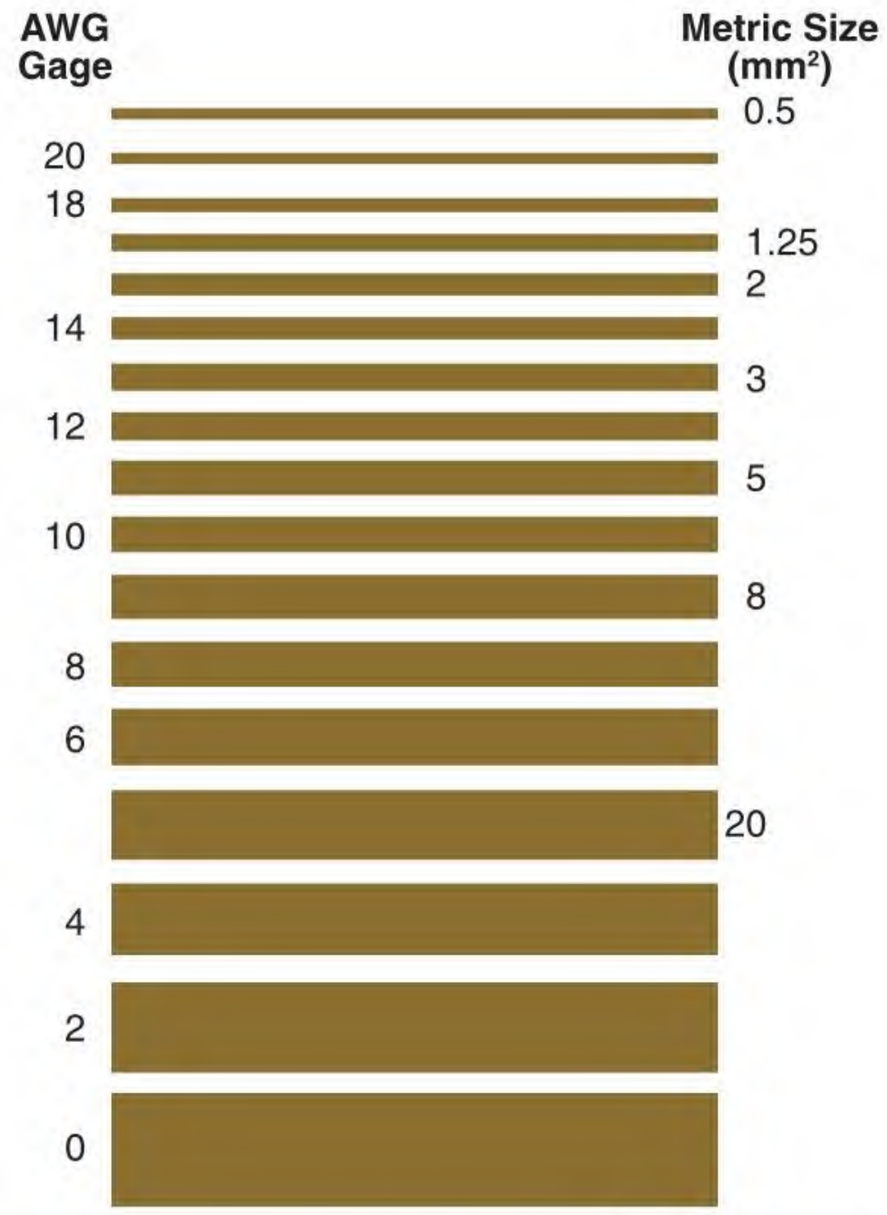
Figure 21-9. This wire dispenser has been purchased to speed stereo speaker repairs. A—The dispenser has several sizes and types of wire on rolls for easy removal. B—Wire sizes can vary from large battery cable (left) to small wires (right). C—A wire gauge measures wire sizes accurately.

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AWG Size (Gage)	Wire Diameter (Mils)	Cross-Sectional Area (Circular Mils)	Resistance (Ohms per 1000 ft.)
20 Smallest	36.9	1022	10.3632 Largest
18	46.5	1624	6.5227
16	58.7	2583	4.0843
14	74.1	4107	2.5756
12	93.3	6530	1.6215
10	117.7	10,383	1.0180
8	148.4	16,510	0.6401
6	187.1	26,251	0.4023
4	236.0	41,741	0.2533
2	297.6	66,371	0.1594
0 Largest	375.2	105,535	0.1003 Smallest

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Figure 21-10. This chart shows sizes, diameters, and resistances for stranded wire. Solid wire is similar, but has slightly less resistance.



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Figure 21-11. Actual wire sizes in the AWG and metric systems. Notice that AWG wire diameter increases as the gage number decreases, whereas metric wire diameter increases as the size number increases.

the smaller wire create so much electrical friction that the atoms vibrate violently, separating the molecular bond between the atoms in the metal conductor.

Caution

The automobile manufacturer mathematically sizes every wire to match its circuit load during the vehicle's design stage of production. Never change wire size from the OEM (original equipment manufacturer) gage when doing repairs. This could void the vehicle warranty and lead to circuit failure problems.

Figure 21-11 compares AWG gages and metric wire sizes. A ***metric wire size*** is given as the cross-sectional area of the wire in square millimeters (mm^2). Therefore, unlike AWG gage numbers, metric wire sizes increase as the diameter of the wire increases.

Battery cables, ground cables, starting motor cables, and hybrid power cables are much larger than the rest of a vehicle's wiring. Depending on the vehicle, engine displacement and type, and battery size, conventional battery cables typically range from 4 gage to the thicker 0 gage. Starting motor, starter solenoid, and other high-power circuits might use 7 to 4 gage wire.

Wire Current-Carrying Rules

Several rules apply to wires and their ability to carry current. These include:

- Wire resistance increases as conductor diameter decreases.
- Resistance depends on the material used in the conductor. For example, silver has less resistance than copper; copper has less resistance than aluminum.
- Resistance increases as the length of the wire increases.
- In most conductors, resistance increases as temperature increases.

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Tech Tip

Excess current heats a conductor and can melt or burn its insulation. To prevent this problem, always replace a wire with a new one of the same gage, conductor material, and length.

Wire Protection Devices

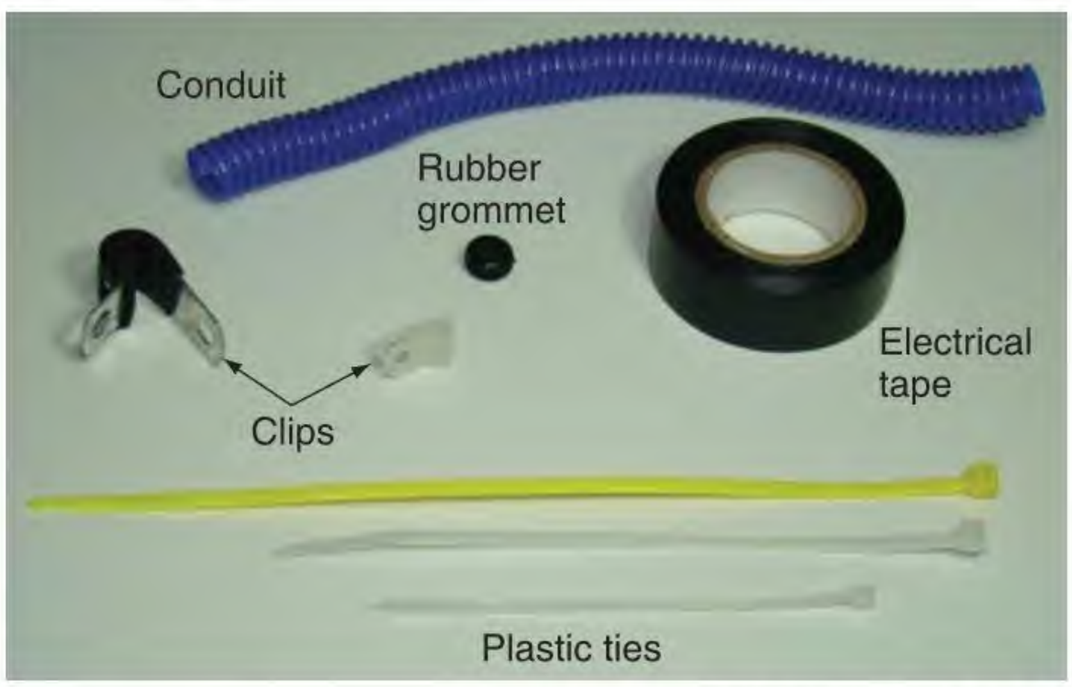
Wires are protected from damage by various kinds of ***wire protection devices***. These devices include electrical tape, plastic tubing, retainers, clips, boots, and straps. Examples are shown in **Figure 21-12**.

When you work with wire, always replace all wire protection devices. Remember that the manufacturer would not have installed these devices if they were not needed. Failing to reinstall even one retaining clip could lead to wiring failures.

Wiring Harnesses

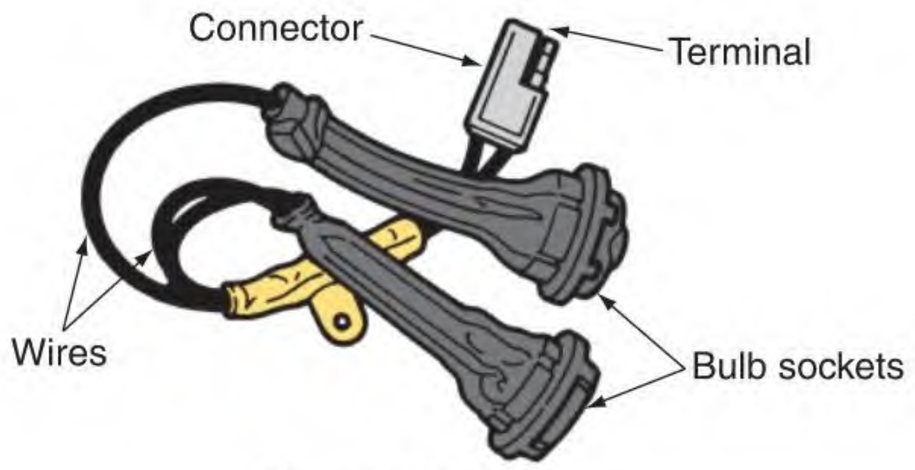
A ***wiring harness*** is a set of several wires wrapped together with tape or enclosed together in a plastic sheath for protection. Wires and connectors branch out from the harness to connect to various components. A wiring harness organizes and protects the wiring and also makes for a neater appearance than dozens of individual wires running separately.

Wiring harnesses are usually named after their location in the vehicle. For example, the harness that feeds to the sensors and other devices on an engine is called an engine wiring harness. See **Figure 21-13**.

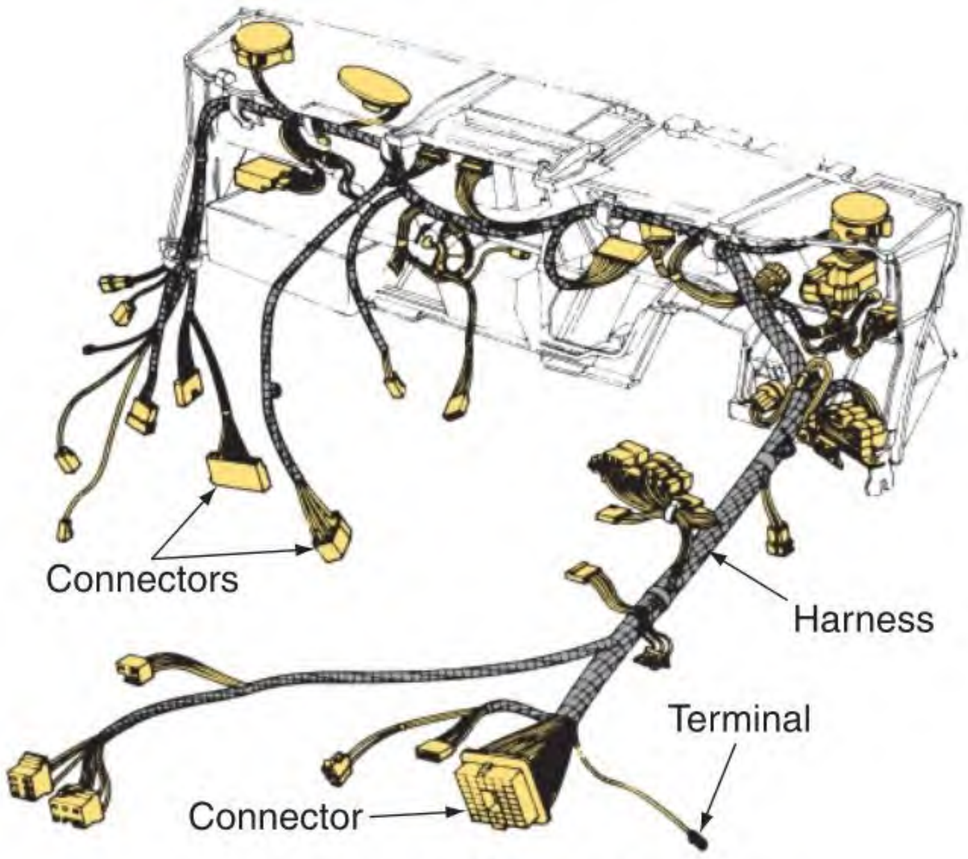


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Figure 21-12. Wire protection devices are needed to protect wires from damage caused by vehicle movement, vibration, heat, cold, and other potential dangers.



Simple Harness



Complex Harness

A



B

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Figure 21-13. Always look closely and study the wire connector to see how it is released and pulled apart without damage to the plastic lock mechanism. If you damage the locking clip on an electrical connector, the connector can come loose and disconnect the circuit. A—Wiring harnesses can be simple or complex. Connectors allow the wires to connect to other wires and components. B—This wiring harness had to be disconnected before the engine was removed from the vehicle.

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Tech Tip

If many wires are damaged—by fire, for instance—it is usually best to install a new wiring harness. The harness can be purchased from the vehicle manufacturer or an auto salvage yard. This saves time and results in a better repair.

Cutting and Stripping Wire

Wire can be cut using diagonal cutting pliers, electricians' pliers, or most wire stripping pliers. Whichever tool you use, be sure to cut completely through the wire on the first try. If you cut partway through stranded wire and then cut again, the strands may be damaged or cut unevenly. See **Figure 21-14**.

When splicing an old wire to a new wire, cut off a small piece of the old wire and strip off its insulation. A new cut exposes uncorroded or undamaged new wire that has been protected inside its insulation.

It is best to use wire strippers to strip (remove the insulation from) wires. Select a stripping hole size that matches the specific wire size. Clamp the wire insulation in the stripping jaws. Then pull the wire through the jaws. This cuts and strips the insulation without damaging the metal conductor. See **Figure 21-15**.

Soldering

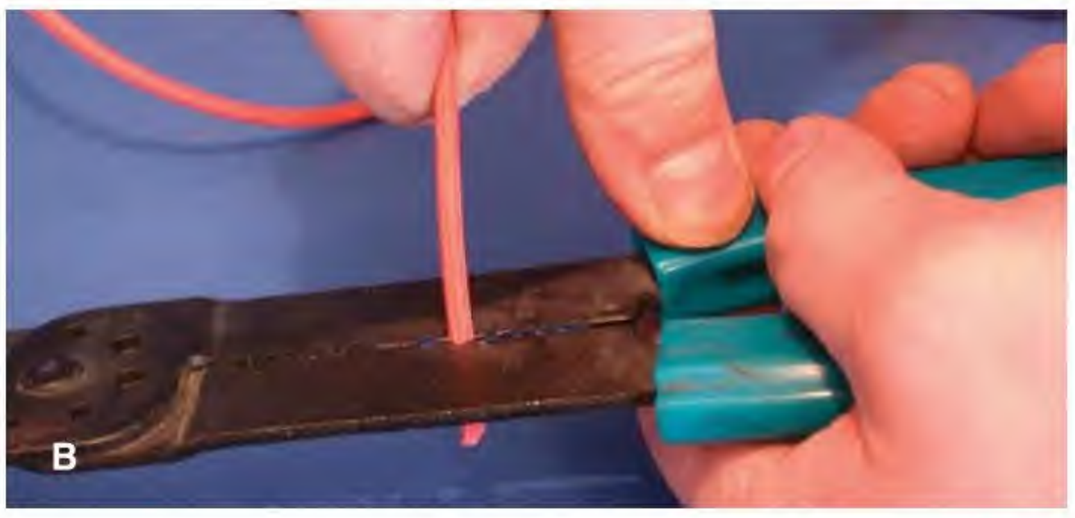
Soldering involves using heat and solder to join electric components or wires. Soldering is an essential skill that you must master before attempting even basic electrical repairs. Solder comes in roll form for easy application to an electrical connection.



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Figure 21-14. When cutting wire, cut all the way through on the first try. This will ensure that strands are cut evenly and are not damaged.







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Figure 21-15. Always use stripping pliers to peel off insulation. A—Insert the wire into the correct size stripping jaw. Jaw size must match wire size. B—Use your thumb and fingers to pull the wire through the stripping jaws. C—After stripping, make sure none of the strands have been broken or damaged.

Solder

Solder is an alloy (mixture of metals) that has a relatively low melting point. Several different types of solder are available. Traditionally, most solder has been made of a mixture of lead (Pb) and tin (Sn). One common type contains 60% lead and 40% tin. However, lead can be toxic if absorbed into the skin or if soldering fumes are inhaled over a prolonged period of time. The trend in the industry is to use solder that does not contain lead. To increase safety, silver (Ag), tin-silver (SnAg), and tin-copper (SnCu) solder are now commonly used instead of lead solder.

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Rosin-core solder contains a flux (lead-free cleaning agent) inside the solder designed for doing electrical repairs. Modern rosin-core fluxes are water-soluble. ***Acid-core solder*** has an internal acid flux and should *not* be used for electrical repairs. The acid can cause corrosion and electrical problems. Acid-core solder is sometimes used to repair metal engine radiators. See **Figure 21-16**.

Tinning

Tinning is a process of heating, cleaning, and preparing the surface of the soldering gun tip and the electric components to accept molten solder. It consists of placing a thin coat of solder on the soldering gun tip or the parts to be soldered. This makes the solder joint easier to create and results in a better electrical connection. After tinning, heat transfers more easily from the soldering gun tip into the parts to be soldered.

Before tinning, inspect the tip of the soldering gun or iron. If the tip is pitted, use a file to form a clean, smooth surface. Badly pitted tips should be replaced.

To tin the soldering tip, first heat the tip. If needed, wipe debris from the tip using a water-soaked sponge. Then melt some solder onto the tip. Make sure the solder adheres all the way around the tip. See **Figure 21-17**.

Soldering Technique

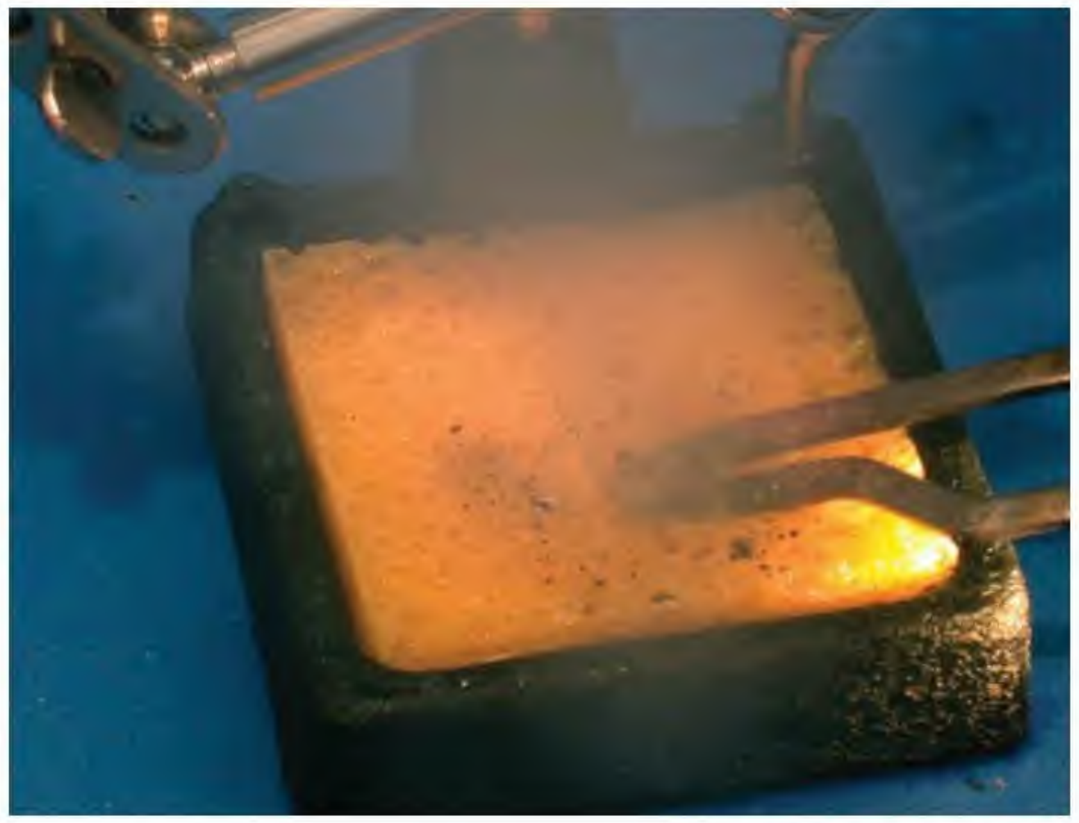
Follow these basic procedures for soldering:

1. Preheat the electric components with the soldering tip or torch until the solder melts when touched and held onto the hot surfaces.



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Figure 21-16. Solder with water-soluble flux is used to solder electrical and electronic connections.



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Figure 21-17. To clean the soldering tip, dip the hot tip into a water-soaked sponge. The water instantly boils to remove oxidation and debris from the soldering tip.

Warning

Do not overheat the components or flux! If you apply enough heat to burn the flux, you will contaminate the joint and must clean it again. If you try to solder through burned flux, the solder will not stick to the wires or components. If the wire insulation melts, it will also contaminate the joint and the solder will not stick or bond properly.

2. After sufficient preheating, keep the soldering gun tip in contact with the connection. Touch the solder onto the wires or component leads. Allow the preheated parts to partially melt the solder. See **Figure 21-18**. Then apply a little heat to both the wire leads and solder. This will make the solder flow out onto the metal surfaces of the conductors.
3. If the solder does not bond, reclean the metal parts. Recut and strip the wires. Brush on fresh paste-type flux and try again.
4. After a smooth puddle of molten solder forms, remove the heat and solder. Do not wiggle or move the joint for a few seconds after heat removal. This could weaken or break the electrical solder connection. Inspect the joint after allowing it to cool for a few seconds.

Stranded wires can be soldered together without connectors or leads. The procedure for soldering stranded wires is illustrated in **Figure 21-19**.

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Figure 21-18. Touch the solder to the wire and terminal, but not to the soldering gun tip. This will ensure that the parts are hot enough that solder bonds to them properly for a good electrical connection. A common mistake is touching solder to gun tip and letting hot solder flow down over cool metal components. This results in a weak, high-resistance electrical connection.

Tech Tip

When soldering, always preheat the components. Never touch solder onto the soldering gun tip and allow solder to drip onto the joint. The components will not be hot enough, and the solder will not bond to the components securely. This will result in a poor electrical connection or one that comes apart easily.

Covering Exposed Conductors

Electrical tape is commonly used to cover and protect the soldered conductors. Use moderate pressure while wrapping the tape around the joint. Wrap the tape to achieve a neat, smooth, tight layer of tape.

Liquid electrical tape is a liquid coating that can be brushed over conductors to insulate them from moisture. When the liquid electrical tape dries, it creates a plastic or rubber-like substance that protects the conductor. See **Figure 21-20**. Liquid electrical tape is an excellent choice when a joint must be protected from moisture. It will keep the joint dry, while electrical tape may not.

Heat shrink tubing is another alternative to electrical tape. This hollow plastic tubing shrinks when heat is applied. The heat shrink tubing slides over the joint. Then it is heated with a heat gun. The high temperatures make the plastic tubing shrink down tightly around the wires to produce an insulating barrier over the conductor.

Connectors

Various types of connectors are used on today's vehicles. ***Connectors*** are wire-splicing devices with metal ***terminals***, or connection points, for joining the ends of two or more wires. Many connectors have locking clips that hold the connectors together, ensuring a good electrical connection. **Figure 21-21** shows the most common types of single-wire connectors and terminals.

Crimp Connectors

Crimp connectors can be used to make many electrical repairs. They provide a quick and easy way of joining wires or installing a terminal on a wire by crimping, or crushing, a metal lug around the wire conductor.

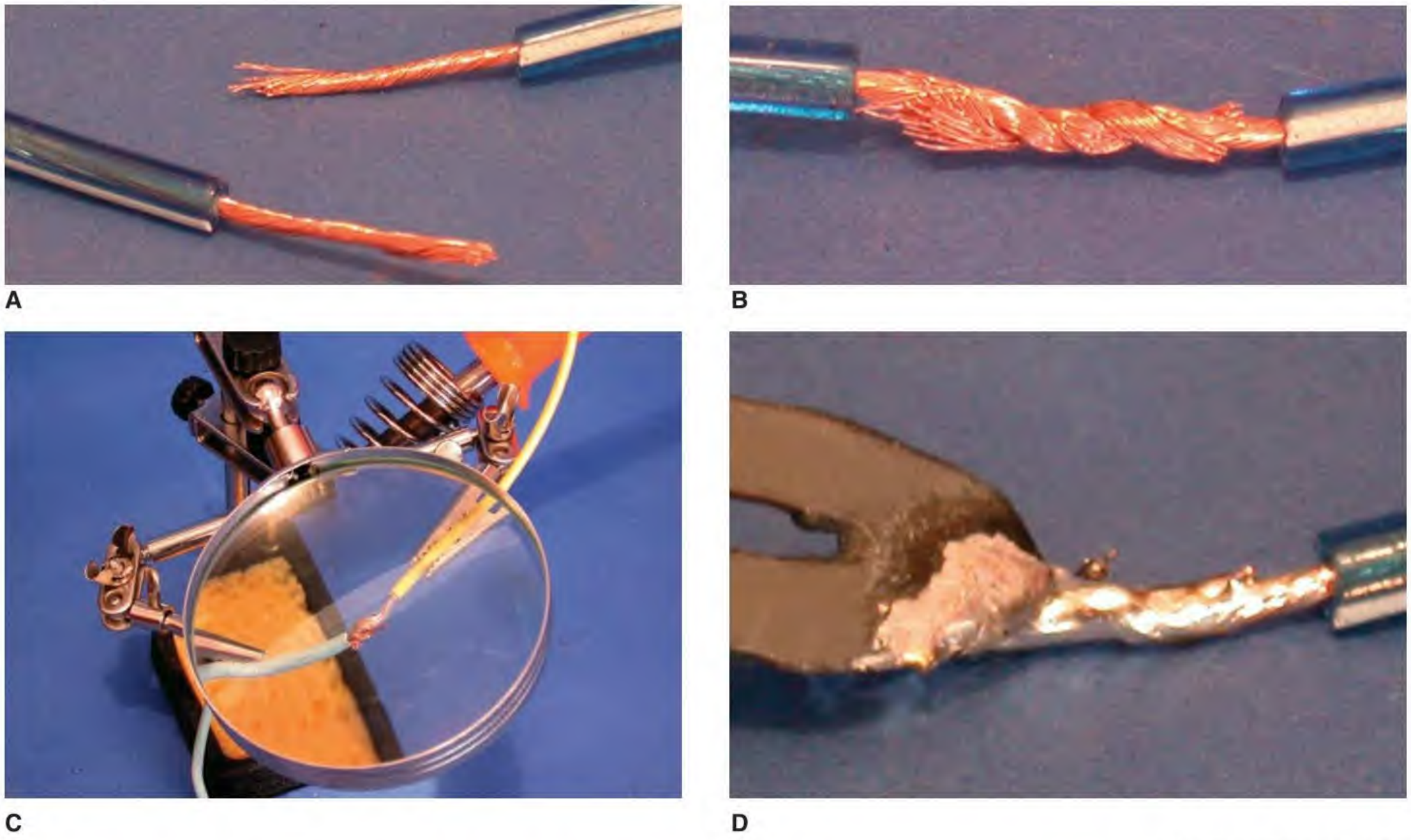
To use a crimp connector, first strip the wire. Make sure the right amount of conductor is exposed. If the conductor is too short or too long, the crimp connector will not work properly. After stripping the insulation from the wire, twist the conductor to hold the wire strands together so that they will feed into the crimp connector easily. See **Figure 21-22**.

Use crimping pliers to crush the metal part of the connector around the wire conductor. Crimping jaws of various sizes are normally provided, so make sure you use the right ones. **Figure 21-23** shows the crimping procedure for creating a butt splice, in which the two wires butt against each other inside a splice connector.

Tech Tip

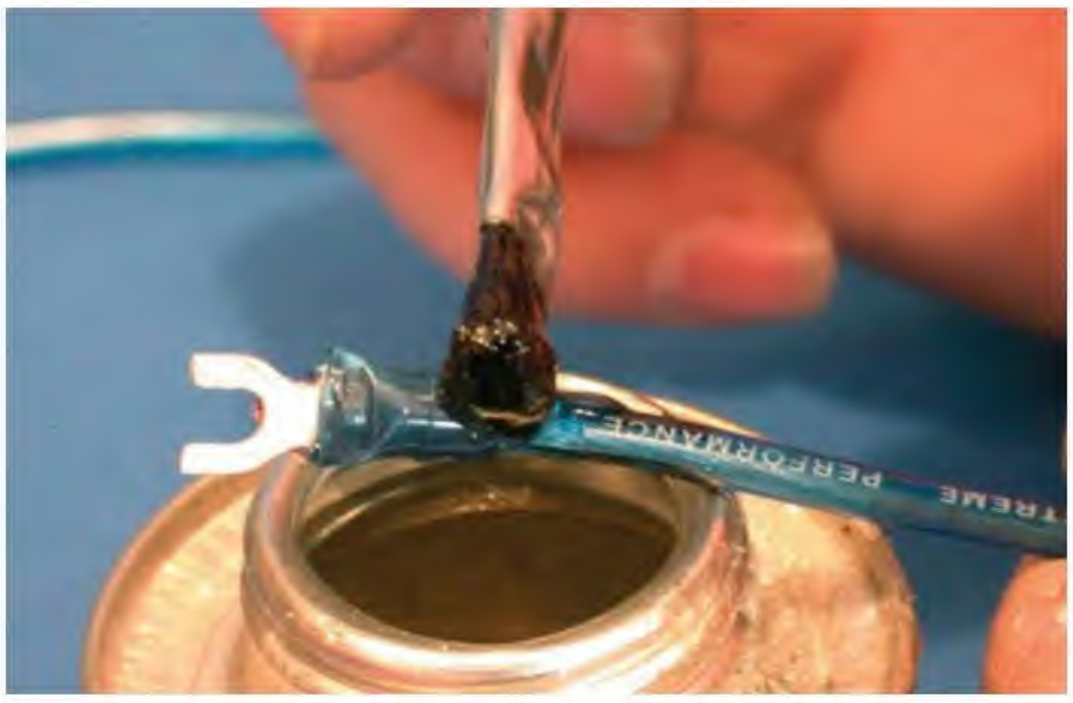
A common mistake is to place the jaws of the crimping pliers over the plastic part of the connector rather than over the metal lug inside the connector. This will compress only part of the metal lug, and a weak connection will result. Make sure the jaws are positioned correctly over the metal lug before crimping an electrical connector. Refer to **Figure 21-24**.

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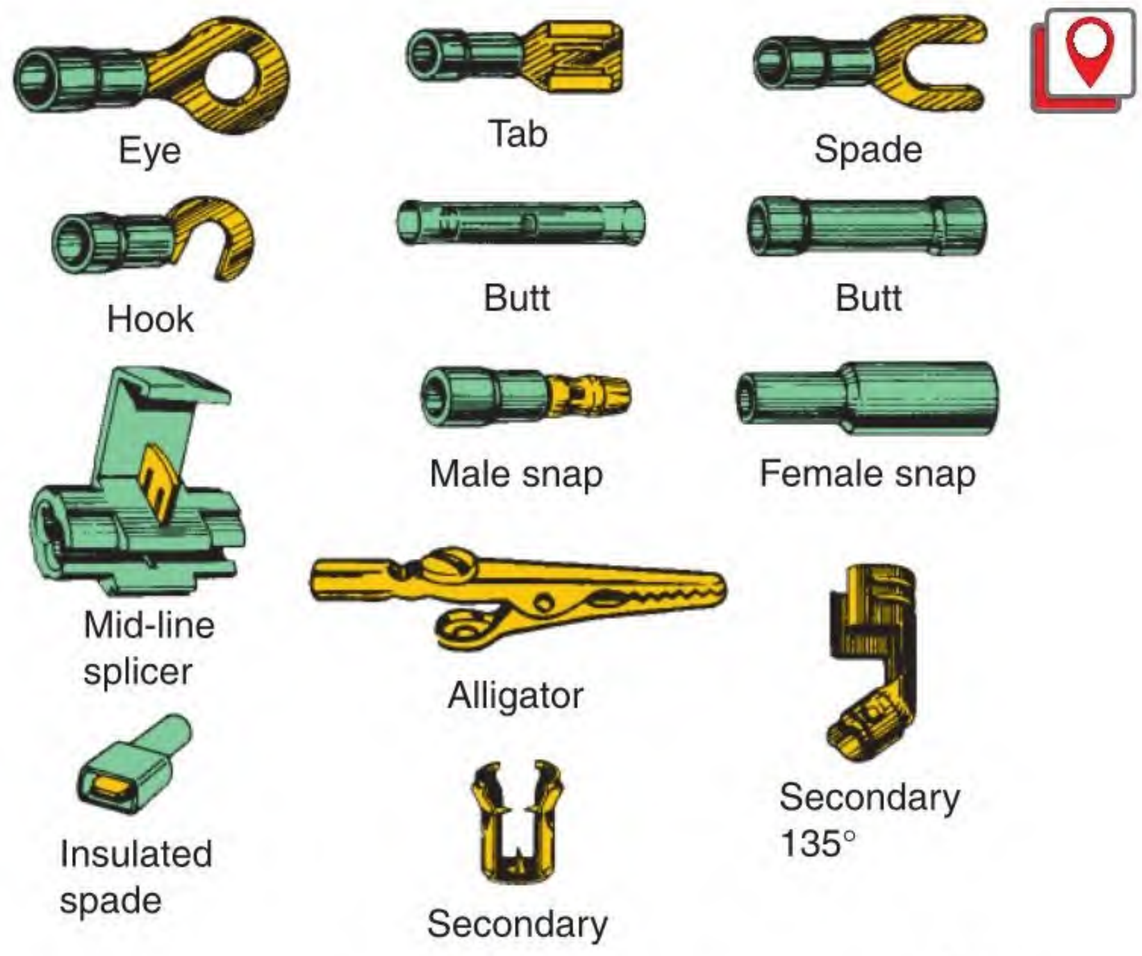
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Figure 21-19. Joining wires using a solder joint. A—Strip about one inch of insulation from both wires. B—Wrap or twist the wire ends together. C—Use a soldering stand to hold the wires together while soldering. The magnifying glass allows you to view the solder more closely as it flows into the wire strands. D—Solder the twisted ends by the heating wires, not the solder, so that heat conducts into the wire strands and liquefies the solder. After it cools, cover the soldered splice with shrink wrap or electrical tape.



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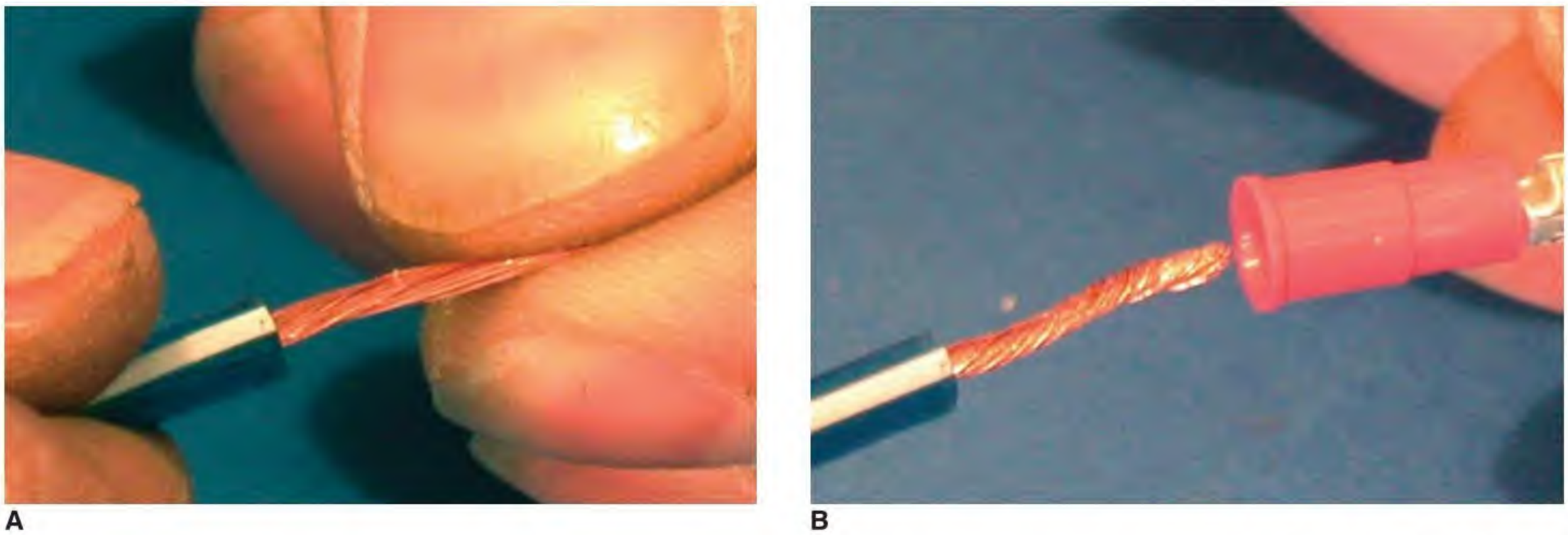
Figure 21-20. Liquid electrical tape is sometimes used in place of conventional electrical tape. It is ideal when the conductor must be sealed to keep out moisture.



Belden

Figure 21-21. These are most common types of single-wire connectors and terminals.

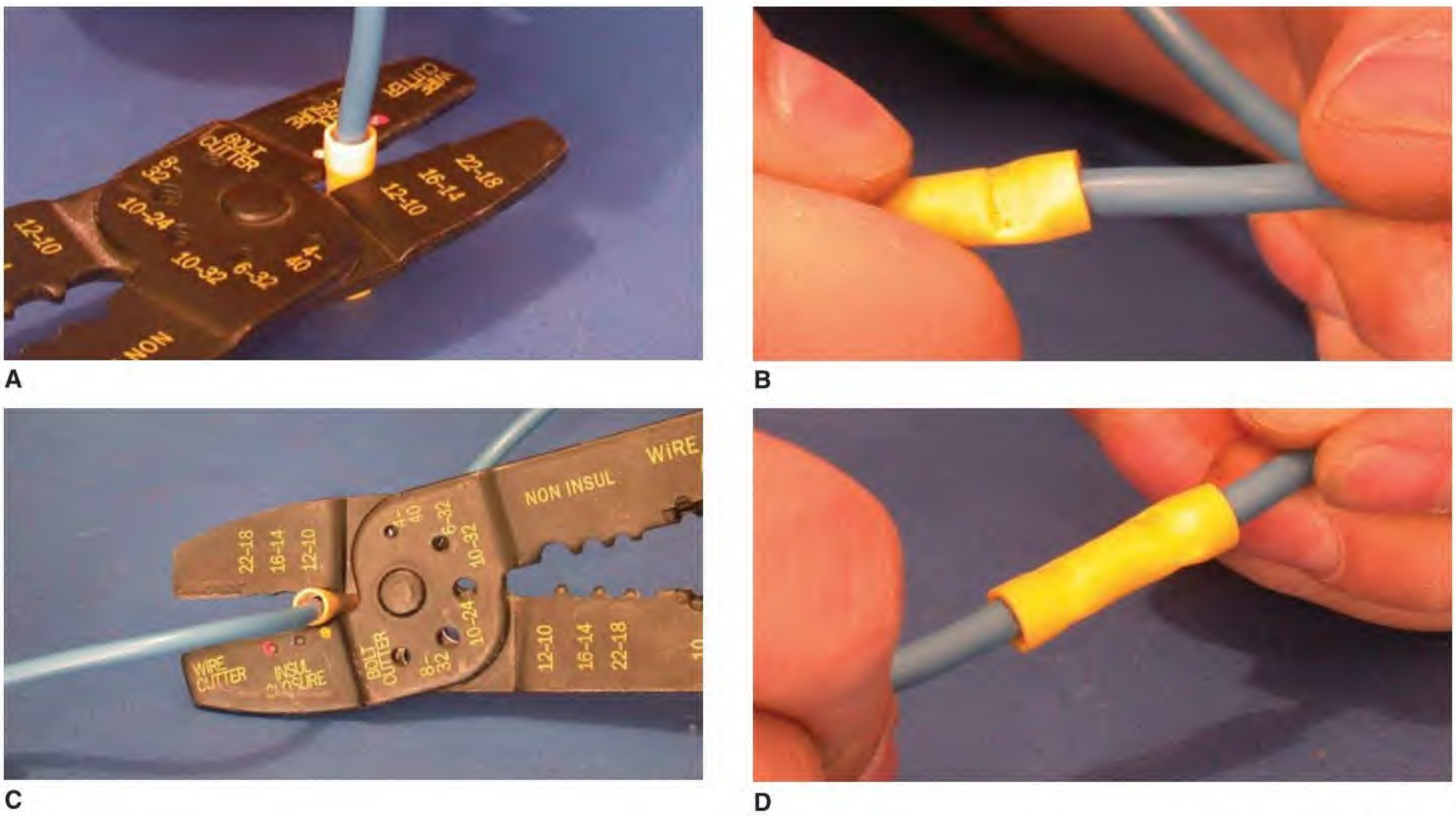
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A B

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Figure 21-22. Always wrap stranded wire ends tight before reconnection to the circuit. A—Before inserting stranded wire into a terminal, twist the strands together. B—The twisted strands will feed through the terminal easily. Twisting the strands helps avoid stray or broken strands at the connector.



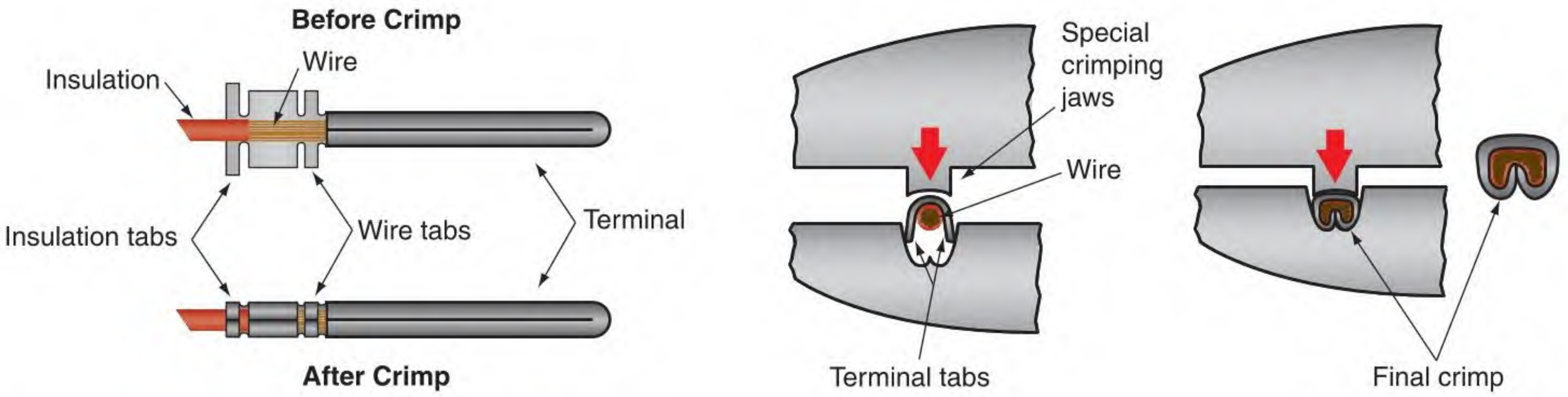
A B

C D

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Figure 21-23. Steps for butt-splicing wires with a crimp connector. A—Crimp the splice connector down over the first wire. B—Tug on the connector and wire to make sure it is secure. C—Crimp the other wire down into same connector. D—Tug on the wires to make sure they will not pull out of the connector.

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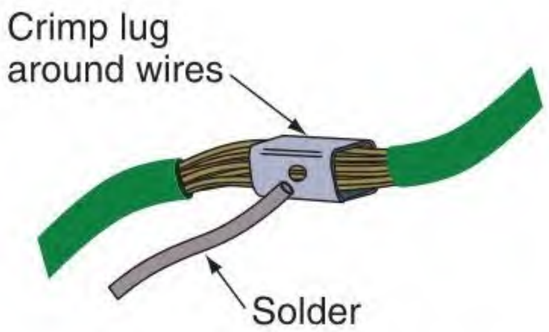
Figure 21-24. Forming a crimp connection using electrical pliers.

Caution

If a wire pulls out of a crimp connector, it may cause a short circuit. Make sure the connector is secure. Solder a connector to the wire when possible. To solder a connector to two wires, first crimp the connector around the wires. Then solder the wires and metal lug together. This makes for an excellent repair. Refer to **Figure 21-25** and **Figure 21-26**.

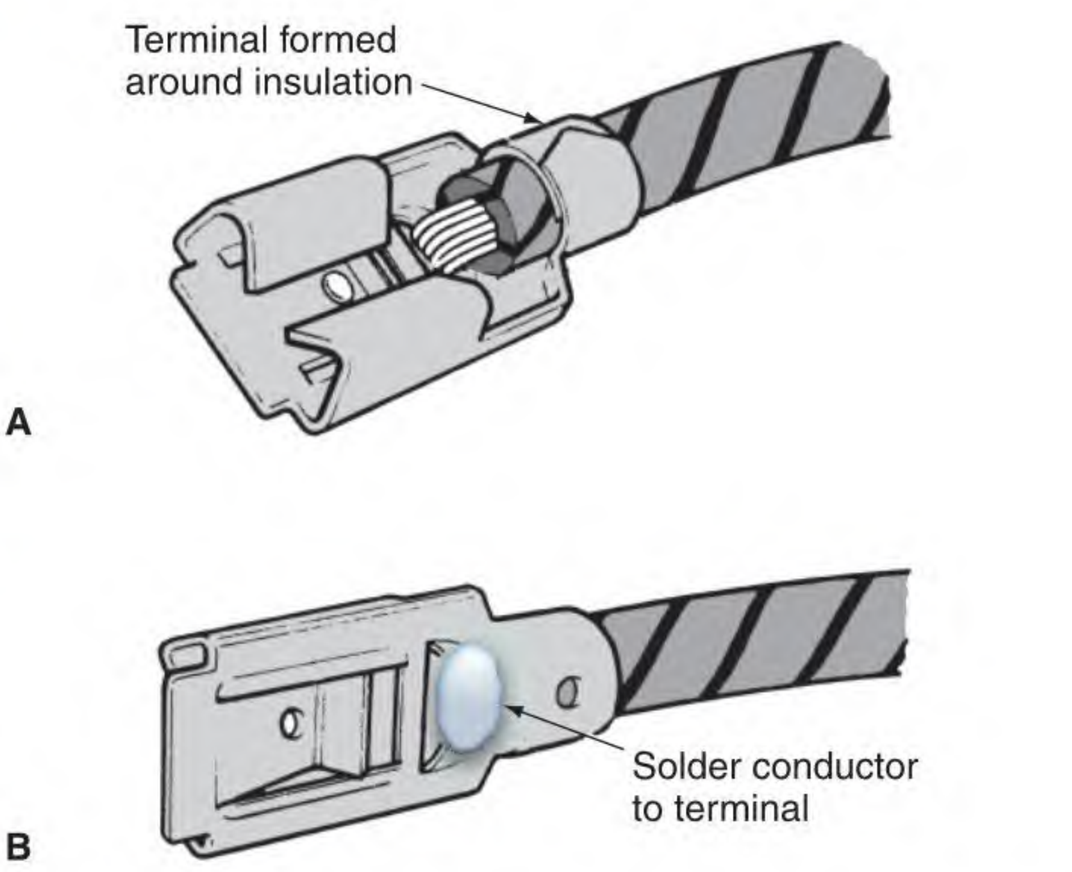
Self-Stripping Connectors

A ***self-stripping connector*** cuts through a wire's insulation and locks onto the conductor. This type of connector is useful when you must connect to an existing wire in a harness. Self-stripping connectors are often used to splice in a wire for an electric accessory, such as trailer lights, or to bypass a bad connection or wire. See **Figure 21-27**.



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Figure 21-25. One of the best ways to join two wires is to crimp a metal lug over both wire ends. Then solder the wires and lug together into a single junction. Tape over the exposed conductor after checking the joint.



Lister Diesels

Figure 21-26. In this type of connection, the terminal is crimped down around the wire insulation. Then the wire conductor is soldered to the terminal.

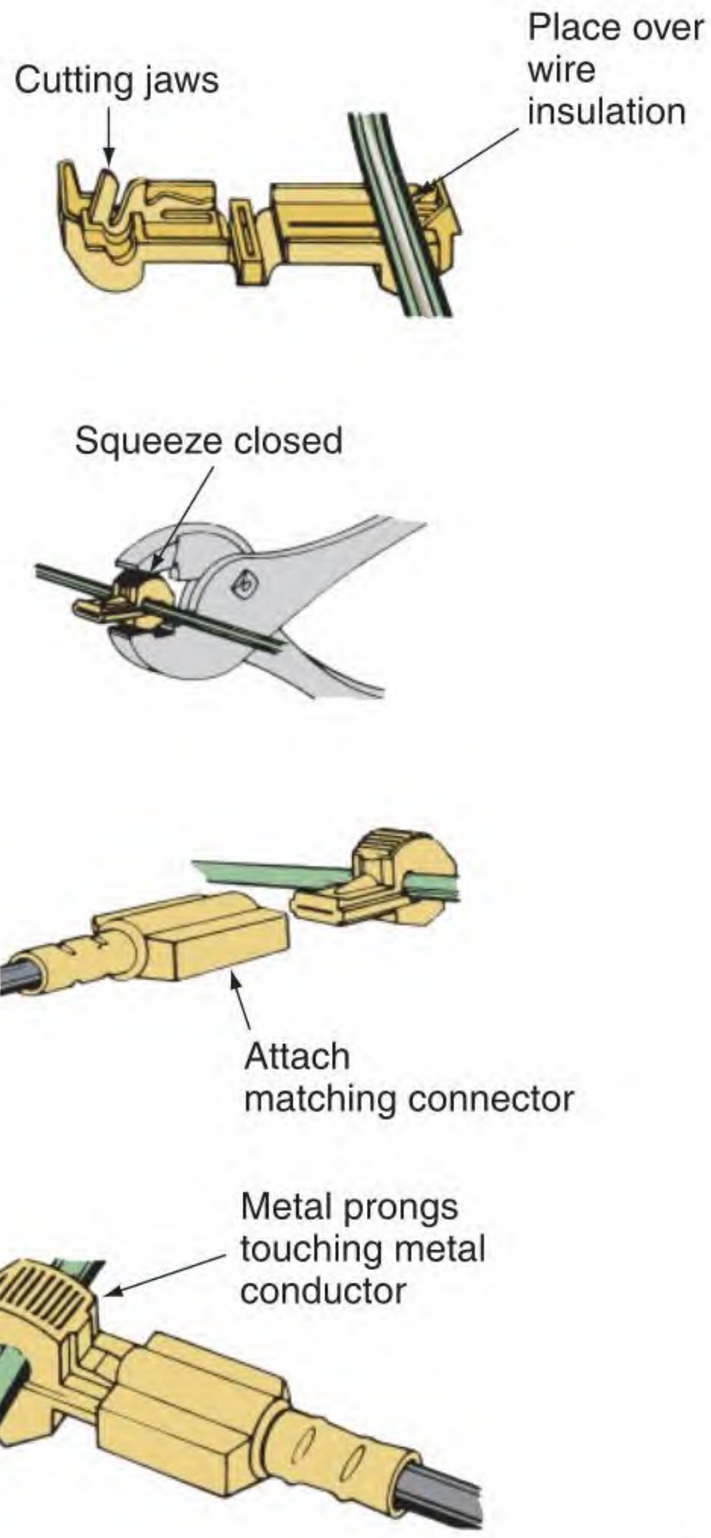
Factory Connectors

Various types of connectors are installed on vehicles at the factory. ***Harness connectors*** are multi-terminal connectors that join several wires and have a special locking feature. In most cases, the connector consists of a two-part plastic housing that snaps together to prevent the conductor terminals from working free.

Disconnecting Factory Connectors

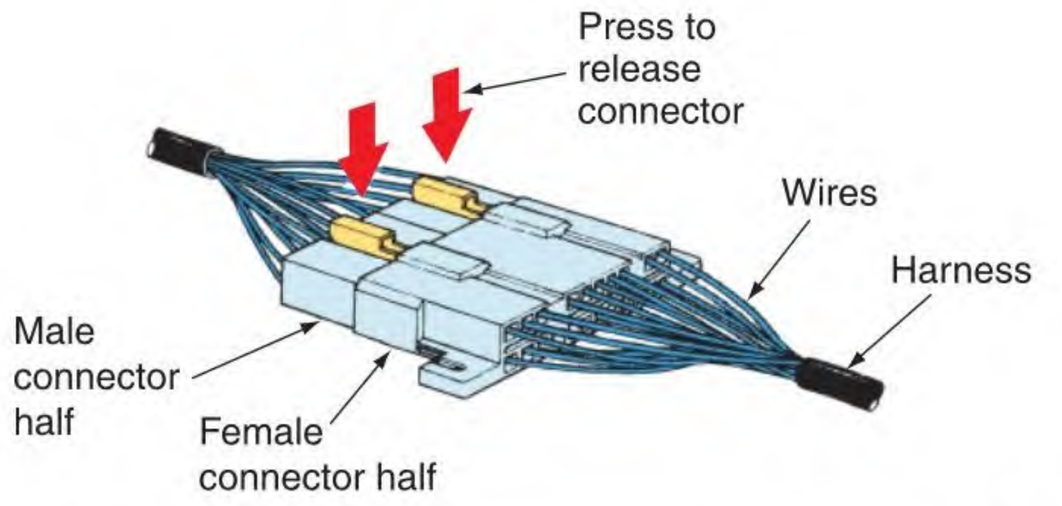
Most electrical connectors require special methods or tools for disconnection. Many have a plastic latch that holds the two halves of the connector together. You may have to squeeze or pry up on the latch to free the connector. **Figure 21-28** shows an example.

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G-P Parts

Figure 21-27. This self-stripping connector makes it easy to splice into an existing wire. It snaps over the wire and cuts through the insulation to make contact with the conductor.



Toyota

Figure 21-28. Factory harness connectors house several wires and terminals. Most have a locking feature. You must release the tabs before pulling the connector apart.

Tech Tip

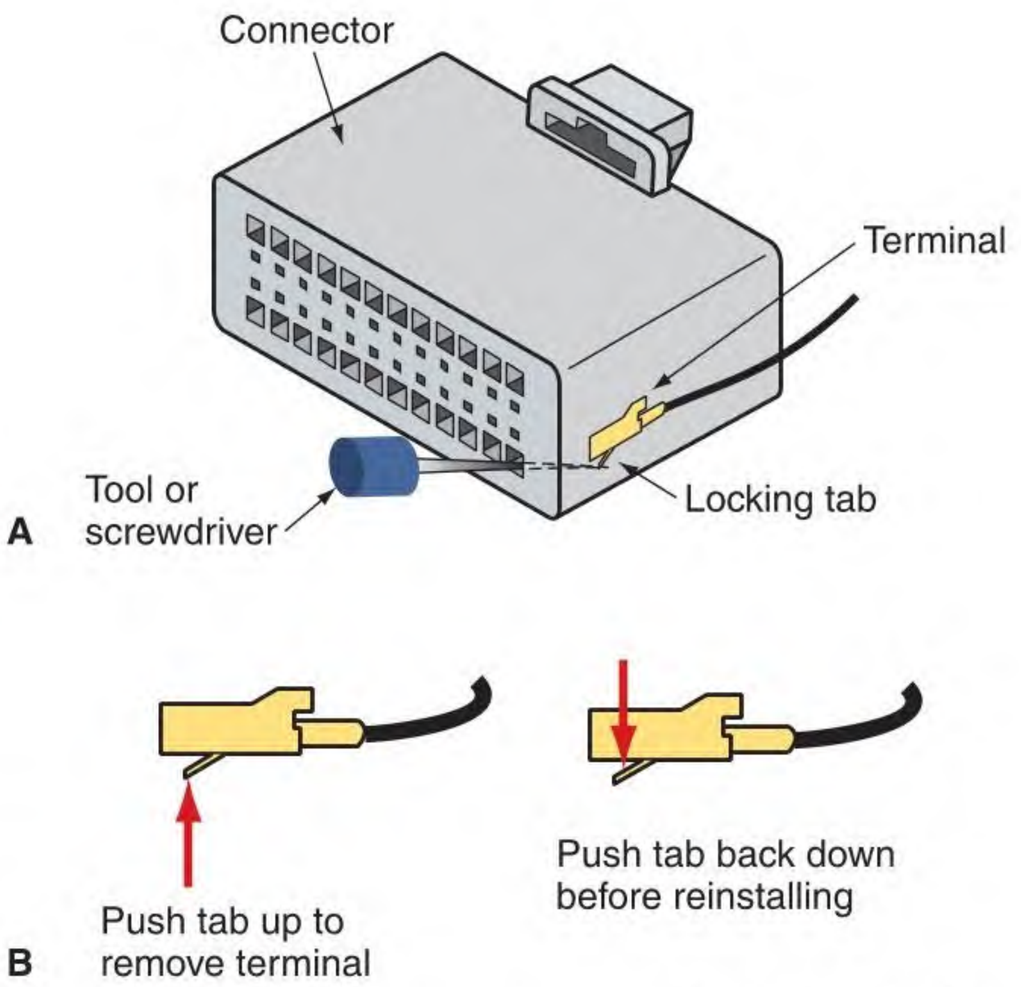
Connector damage can result if you force a connector apart. Always obtain the right tool and use the proper methods when disconnecting harness connectors. If in doubt about how to release a connector, refer to the service manual.

Terminal Replacement

Sometimes it is necessary to replace a terminal inside a factory connector. The terminal usually has a small metal tab or lever that locks inside the plastic connector. A small screwdriver or special tool can be used to free the terminal. Then the wire and terminal can be pulled out of the plastic connector.

When reinstalling a terminal in a factory connector, make sure the small metal tab is bent outward properly. It must stick out far enough to lock tightly inside the connector. Use a small screwdriver or pick to bend the tab out if needed. See **Figure 21-29**.

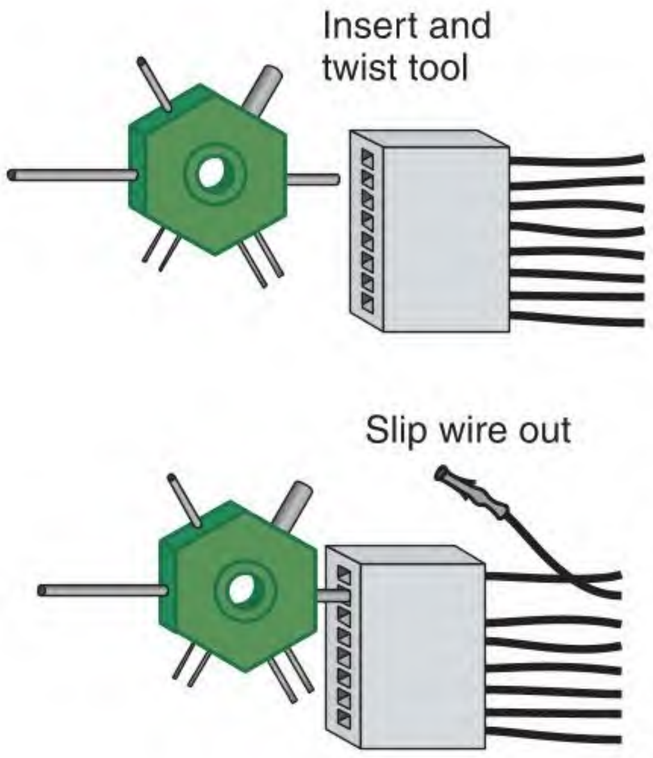
Special connector tools are available to release terminals from several types of automotive connectors. You must slide the correct side of the tool inside the connector to release the locking device on the terminal. Refer to **Figure 21-30**.



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Figure 21-29. Sometimes the terminals inside factory connectors become damaged. A special tool or small screwdriver is needed to free the terminal from the connector.

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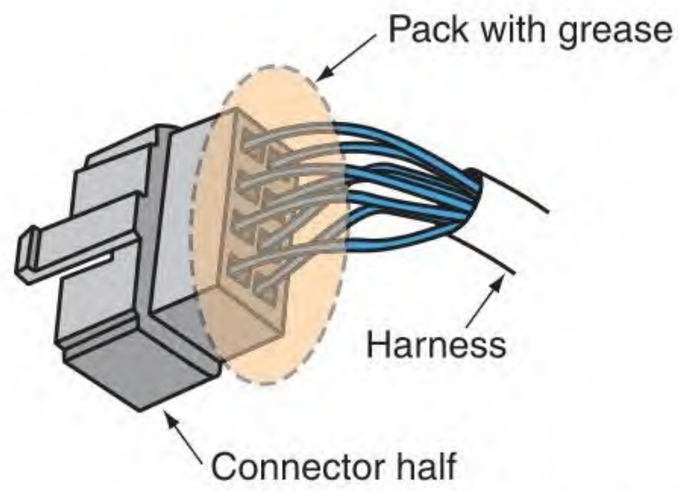
Lisle Corp.

Figure 21-30. Some makes of cars require special tools to quickly and safely disconnect their plastic wiring harness connectors. A—This special tool is designed to release various types of terminals from their connectors. B—The tool has different ends to fit and release connectors from various manufacturers.

Protecting Electrical Connections

Most manufacturers recommend that you apply ***dielectric grease*** to the terminals before refastening connectors. This special grease blocks moisture and helps prevent corrosion without affecting electrical conduction. If corrosion or moisture is a problem, you can also pack the outer opening of the connector with dielectric grease. This not only keeps moisture away from the terminals but also prevents an increase in circuit resistance. See **Figure 21-31**.

Some electrical connectors are equipped with a soft rubber boot that you must pull off before you can service the connection. Be sure to reinstall the boot completely to keep moisture and water from entering and contacting the conductors, possibly affecting circuit operation. If a wire is fed through a metal body panel, make sure a rubber grommet is properly installed, as shown in **Figure 21-32**. If the grommet pops out of the metal body panel, the wire insulation may be cut and abraded, causing a "dead short" to ground. A "dead short" is due to any current carrying conductor that is accidentally connected to earth or frame ground. With no resistance in the short circuit, all current will flow into ground, usually overheating and burning wires.

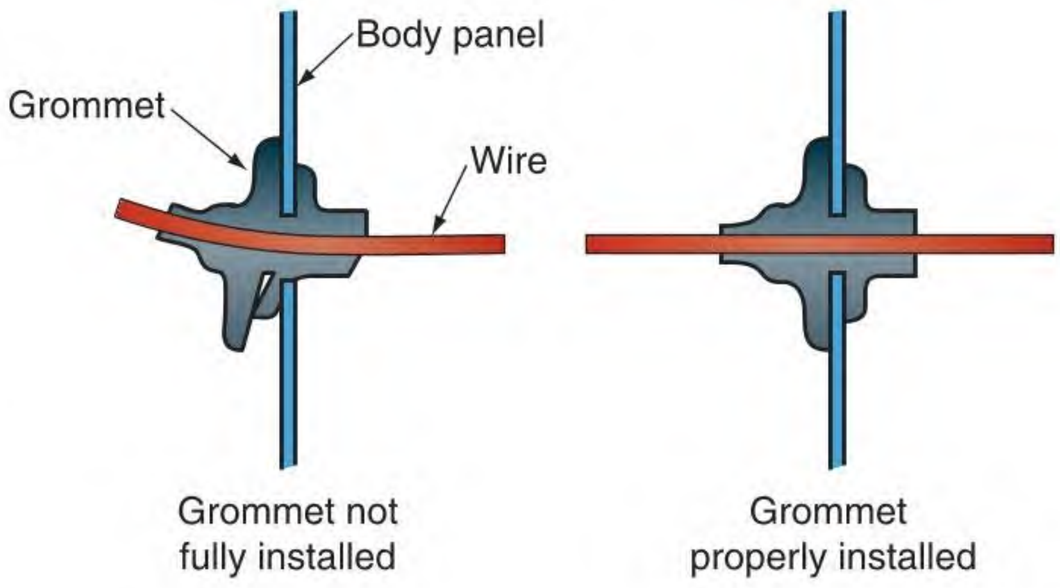


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Figure 21-31. Special grease can be applied to terminals and the outside of a connector to prevent corrosion and a bad electrical connection.

Wiring Repairs

Wiring repairs include many tasks that return a circuit to its normal operating condition. This might involve replacing a burned wire or connector, soldering a wire to a terminal, or crimping a terminal over a wire.



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Figure 21-32. Make sure grommets are fully installed to keep wires from abrading and shorting to ground.

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Bypassing a Connector

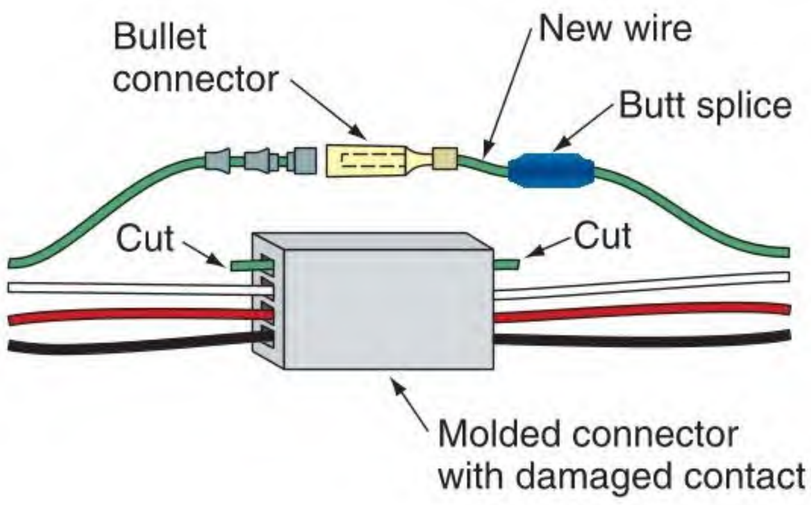
You may need to bypass (route the electron flow around) a connector if the connector is burned or its metal terminals are damaged and a new one is not available. A connector bypass or replacement might also be required if the wiring harness is very complex or difficult to remove and replace. Refer to **Figure 21-33**.

To bypass a connector, use a new piece of wire to make an electrical path around the terminals in the connector. Cut off the affected wires leading into both sides of the connector. Then butt-splice a new piece of wire to join the cut ends. A ***butt splice*** is a splice in which the wires are placed end-to-end, without overlap. Crimp connectors will work, but you should solder the wires together, if possible.

Bypassing a connector can save time, especially if the connector contains several terminals. If all of the other wires and terminals are good, they can remain joined using the existing connector. Only the bad electrical connection is bypassed.

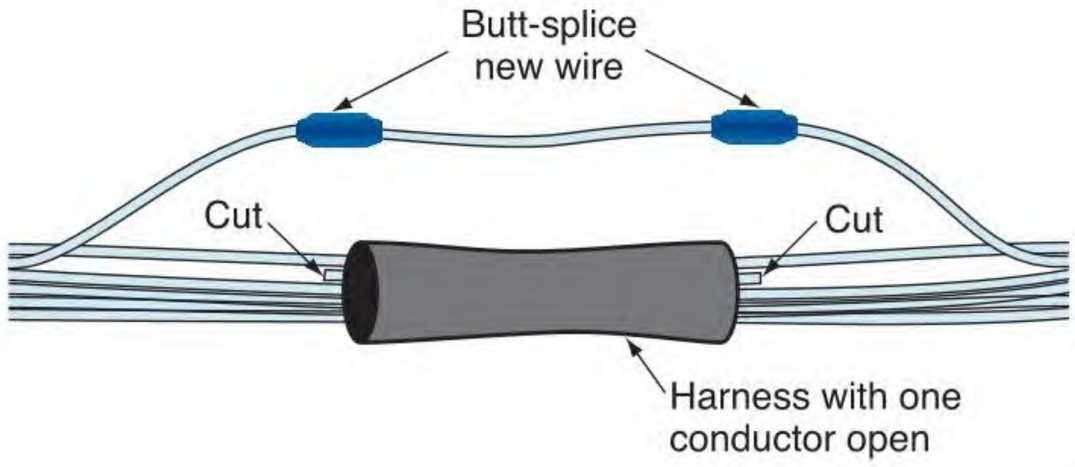
Bypassing a Wire

If tests find one wire to be broken or shorted inside a wiring harness, the easiest solution might be to bypass the wire by running a new wire in place of the bad one on the outside of the wiring harness. To bypass a wire, use a new piece of wire to make an electrical connection around the bad section of a wiring harness. The rest of the harness can remain intact. This method is useful if the wire runs through a complex or hidden harness, such as one that runs under the dash or through the firewall. See **Figure 21-34**.



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Figure 21-33. When a connector is burned or damaged, it is sometimes easier to bypass the bad connection with a new wire. Butt splice the new wire as shown.

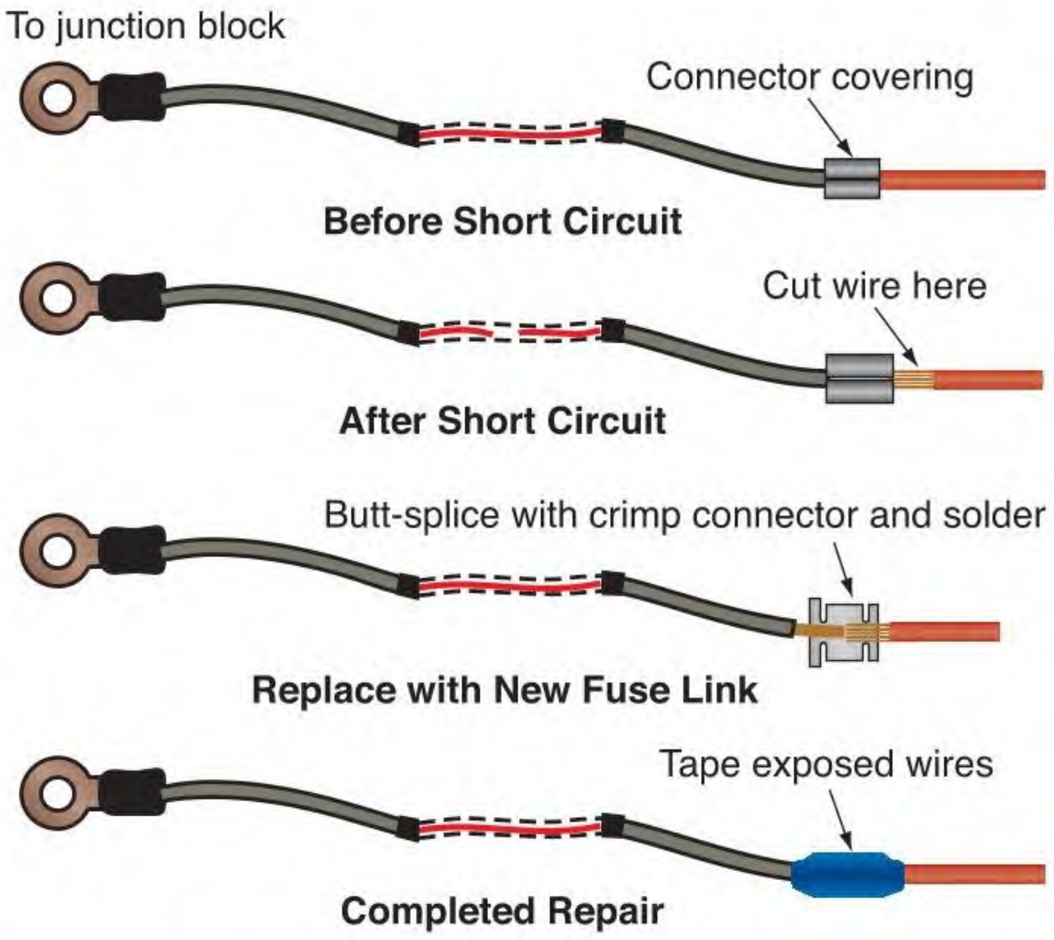


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Figure 21-34. If a wire is broken or shorted inside a complex wiring harness, you can fix the problem by bypassing the bad wire. Cut the bad wire on each end of the harness where it is easily accessible. Then run new wire to connect the cut ends.

Fuse Link Service

A ***fuse link*** protects the wiring before it gets to the fuse box. The fuse link burns in half to protect the circuit if any unfused wire (cables between the battery and fuse boxes) is shorted and draws excess current. This may shut down the power to several major circuits, such as the starting and lighting circuits. See **Figure 21-35**.



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Figure 21-35. To replace a fuse link, cut off the old link and solder on a new link or the correct gage wire.

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Tech Tip

Before replacing a fuse link, it is important to correct the short circuit problem. Correcting the short will keep the new fuse link from burning. Disconnect the 12-volt battery positive and use an ohmmeter to find the short to ground. The shorted circuit will show little or no resistance (ohms) on your ohmmeter.

Service Procedure

This is the procedure to replace a fuse link:

1. Disconnect the negative battery cable.
2. Remove or cut off the burned fuse link.
3. Strip the ends of the main circuit feed wire.
4. Obtain a factory fuse link or the correct gage replacement wire. Either should be a smaller gage than the main circuit wiring.
5. Use an all-metal connector to butt-splice the link to the main circuit wire.
6. Solder the wires and connectors together.
7. Tape, coat, or shrink wrap the soldered connections.
8. Reconnect the 12-volt battery and check circuit operation.

Tech Tip

Refer to the service manual for additional information about the fuse links for specific vehicle makes and models. The manual will provide any special procedures and specifications needed to replace the fuse link wire.

Adding Electric Accessories

Many computer circuits have wiring that is sensitive to any change in voltage, current, and resistance. Taping or splicing into them could upset circuit operation. Therefore, when adding electric accessories or optional devices to a vehicle, avoid splicing into the factory wiring if possible. It is best to wire any additional electric circuit as an independent fused circuit going directly to the 12-volt battery and a new ground. This would apply to trailer or camper wiring, fog lights, alarms, and other new devices.

Twisted Cable Service

Many sensors operate on very low current and voltage levels, and their signals can be affected by any induced voltage. Therefore, some computer system wiring harnesses use shielded twisted cable. This cable is designed to prevent voltage from being induced into the wire and upsetting the operation of the computer. Follow service manual recommendations when replacing this type of cable to prevent computer system problems. Wires should be tightly twisted in the same direction before soldering.

Wiring Diagrams

Wiring diagrams, also called ***wiring schematics***, are drawings that show how the wires connect to each component in an electric or electronic circuit. Symbols represent components, and lines represent wires. Wiring diagrams serve as electrical "road maps." Wiring diagrams show how wires connect to each other and to components.

Electrical/Electronic Symbols

The electrical symbols you have studied in this chapter are only a few of the many electrical and electronic symbols used on wiring diagrams to show circuit components and wiring connections. Symbols are used to save space and to simplify reading. **Figure 21-36** shows some of the symbols that are commonly used in automotive wiring diagrams. To become a competent technician, you must be able to understand these symbols.

Symbols are used in the diagram to replace the isometric drawing of the 12-volt battery, fuse, switch, motor, and lightbulb. The wiring diagram clearly shows the relationship of the electric components in the circuit. An example of how an electric circuit compares to a wiring diagram is shown in **Figure 21-37**.

Tech Tip

The symbols and diagrams used in factory service manuals vary. Refer to a symbol chart in each manual to find the symbol used for each electric or electronic component.

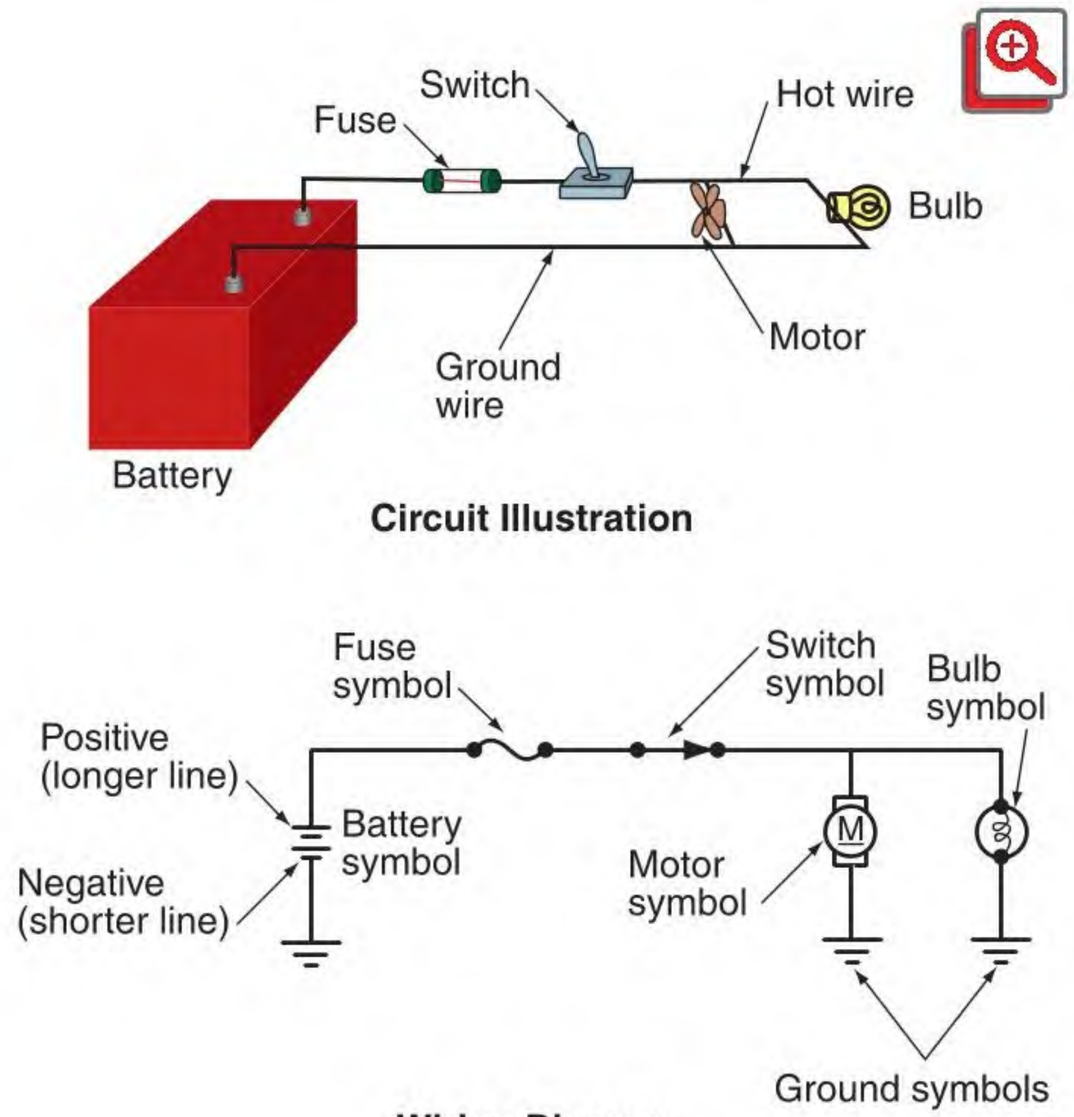
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Legends of Symbols Used on Wiring Diagrams			
+	Positive		Connector
−	Negative		Male connector
	Ground		Female connector
	Fuse		Denotes wire continues elsewhere
	Gang fuses with bus bar		Denotes wires goes to one of two circuits
	Circuit breaker		Splice
	Capacitor	J2 2	Splice identification
Ω	Ohms		Thermal element
	Resistor	TIMER	Timer
	Variable resistor		Multiple connector
	Series resistor		Optional Wiring with Wiring without
	Coil		"Y" windings
	Step up coil	88:88	Digital readout
	Open contact		Single filament lamp
	Closed contact		Dual filament lamp
	Closed switch		L.E.D.—light emitting diode
	Open switch	T	Thermistor
	Closed ganged switch		Gauge
	Open ganged switch		Sensor
	Two pole single throw switch		Fuel injector
	Pressure switch	#36	Denotes wire goes through bulkhead disconnect
	Solenoid switch	#19 STRG COLUMN	Denotes wire goes through steering column connector
	Mercury switch	INST PANEL #14	Denotes wire goes through instrument panel connector
	Diode or rectifier	ENG #7	Denotes wire goes through grommet to engine compartment
	Bi-directional zener diode		Denotes wire goes through grommet
	Motor		Heated grid elements
	Armature and brushes		

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Figure 21-36. Study these electrical and electronic symbols.

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Figure 21-37. Compare the circuit illustration with the wiring diagram that describes it. Both represent the same components and electrical connections.

Wiring Harnesses Names

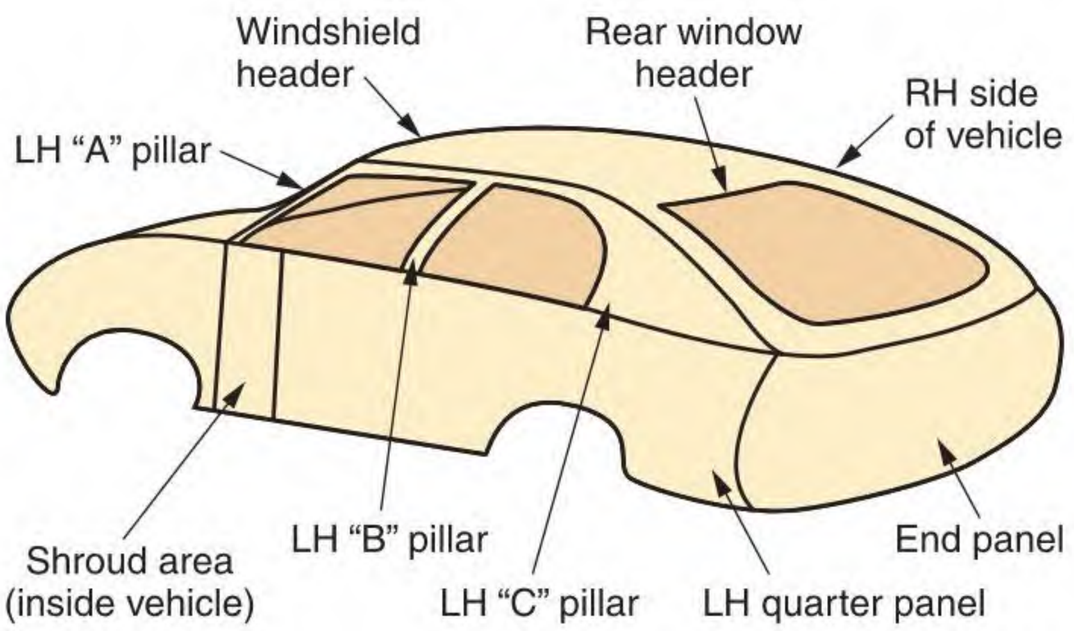
Most wiring harnesses are named after their location on a vehicle. They can also be referenced by location. Therefore, when using wiring diagrams, you may need to know the body part names to determine wire locations. Refer to **Figure 21-38**.

The left side of a vehicle is normally the driver's side. The left side may be abbreviated "LH" on a wiring diagram. The right side of the vehicle, abbreviated "RH," is on the passenger side. If you forget which side is which, imagine yourself sitting in the vehicle and looking forward. The vehicle's right and left are now your right and left.

Wire Code Identification System

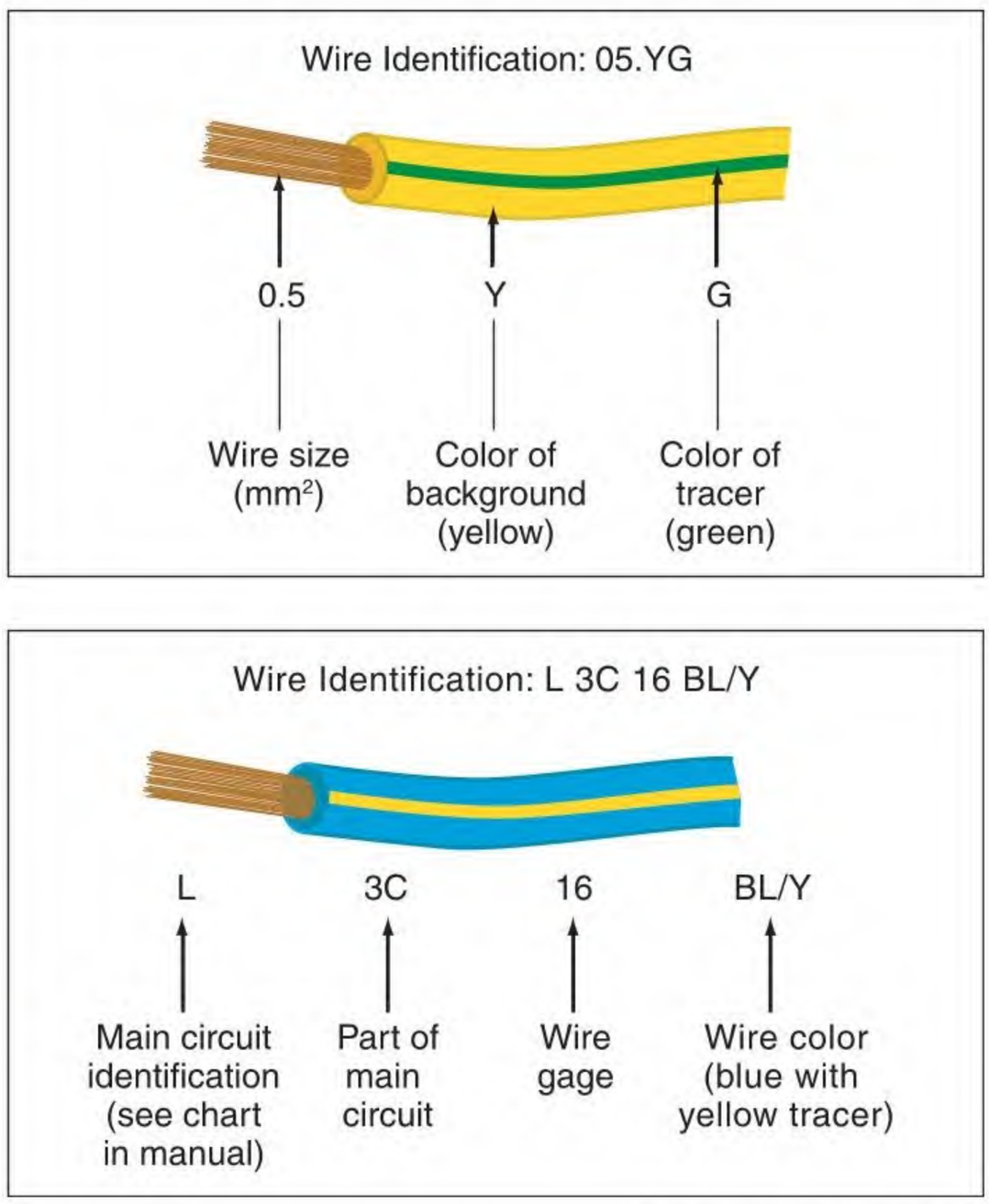
The ***wire code identification system*** is an alpha-numeric (numbers and letters) method of identification that explains the color, location, and gage size of wires on a wiring diagram. Wire code identification systems vary with the manufacturer. Refer to the service information for specifics. See **Figure 21-39**.

A ***wire color code*** (red, blue, green with black stripe, etc.) on a specific wire allows you to trace or follow one wire to different locations in the vehicle. Even if a wire travels through the vehicle's firewall and is hidden, you can still find the other end of the wire by locating the identical color code markings. The wires can be a solid color or have stripes, bands, or hash marks. This makes it easy to tell one wire from another. Refer to **Figure 21-40**.



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Figure 21-38. Most wiring harnesses and components are called out by their location in the body structure of a vehicle.



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Figure 21-39. Two types of wire codes that are commonly found in service information.

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Wiring Color Code Chart			
Color Code	**Color**	**Standard Tracer Color**	**Color**
BK	Black	WT	White
BR	Brown	WT	White
DB	Dark blue	Y	Yellow
DG	Dark green	Y	Yellow
GY	Gray	BK	Black
LB	Light blue	BK	Black
LG	Light green	BK	Black
O	Orange	BK	Black
PK	Pink	DG	Dark green
R	Red	WT	White
TN	Tan	WT	White
VT	Violet	BK	Black
Y	Yellow	DG	Dark green

Main Circuit Identification Codes	
A	Battery circuit to ammeter
B	Backup light circuit
C1	Air conditioning circuit
C2	Heater circuit
D	Instrument panel illumination circuits
E	Emergency, stoplights, and turn signal circuits
F	Power seat circuits
G	Gauges and warning light circuits
H	Horn circuit
J	Ignition system circuits

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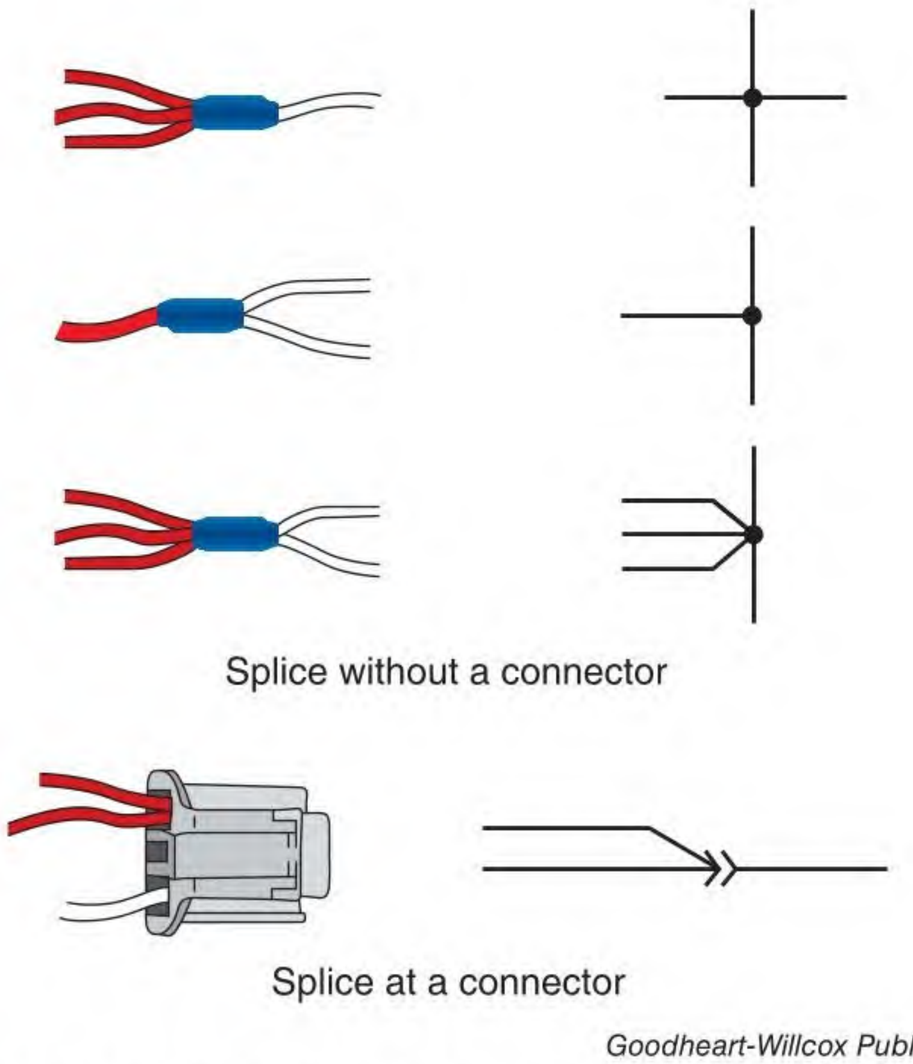
Figure 21-40. Since codes vary, always refer to the charts that explain abbreviations and codes. These charts give color codes and circuit identification codes.

Wiring Splices

Wiring splices are places where two or more wires are connected. They are normally shown on a wiring diagram as a dot where the wires connect. They can also be shown as lines (wires) that run together, but most wiring diagrams use the dot to avoid confusion. Refer to **Figure 21-41**. Splice code charts can be used with a wiring diagram to give added information about the circuit. An example is given in **Figure 21-42**. A capital "S" indicates a splice in this diagram.

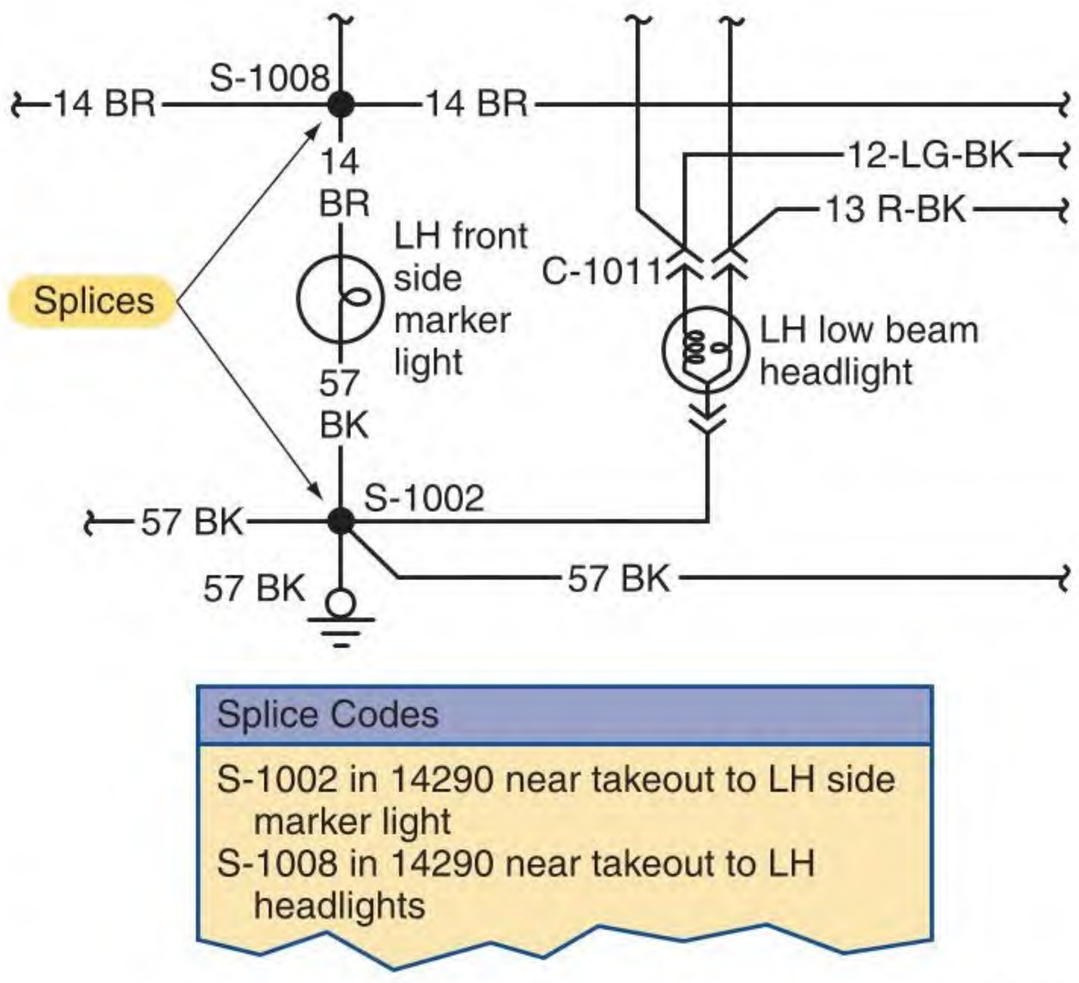
Electrical Grounds

Electrical grounds show where circuits connect or fasten to the metal frame or chassis of a vehicle.



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Figure 21-41. Wire splices are usually shown by placing a dot over the wires. However, note the possible variation when a wire is spliced at a connector.

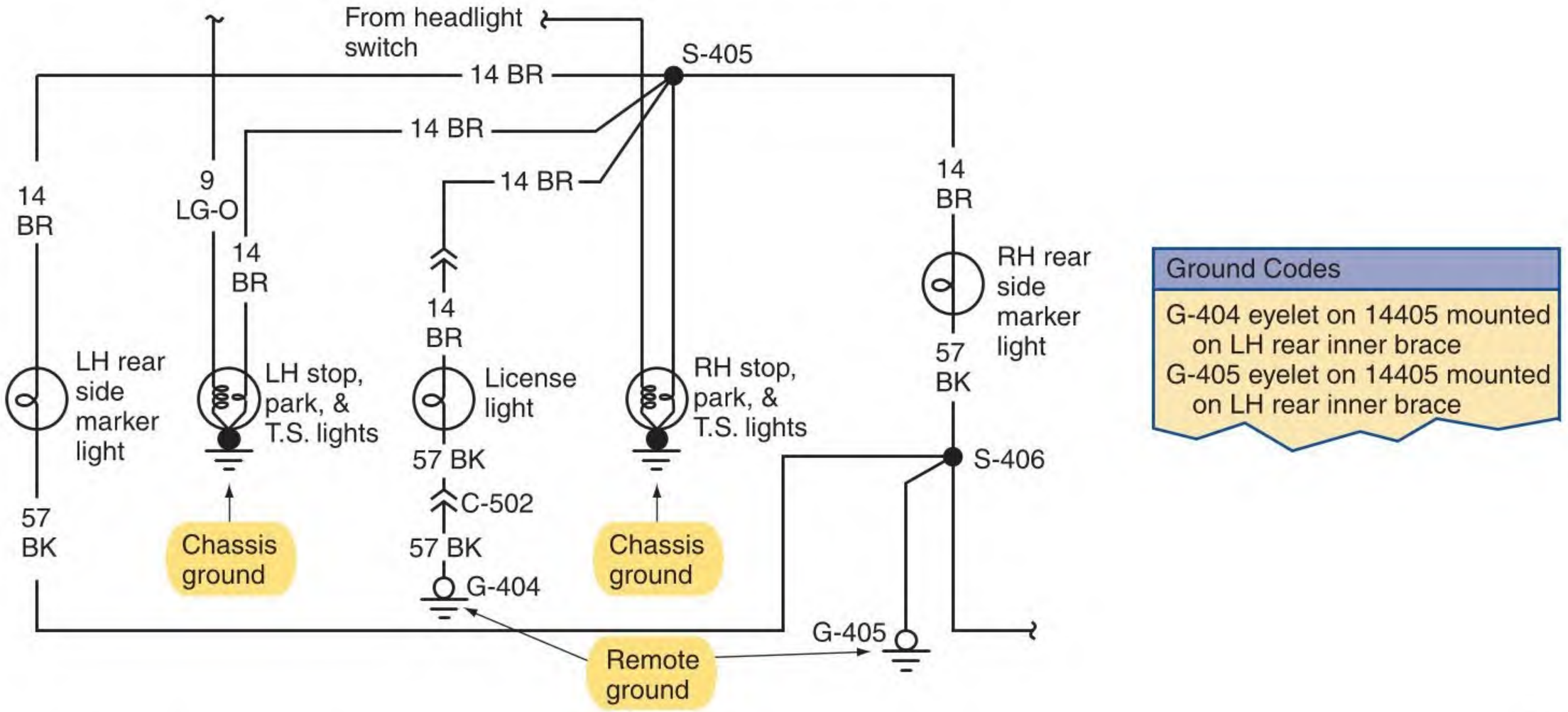


Ford

Figure 21-42. Many wiring diagrams have additional charts that give more information. In this diagram, S-1002 and S-1008 are splices, and the accompanying chart gives their exact location.

A ***remote ground*** has an extra wire running from the circuit to ground. A ***chassis ground*** uses the metal part of a component to attach to ground. Refer to **Figure 21-43**.

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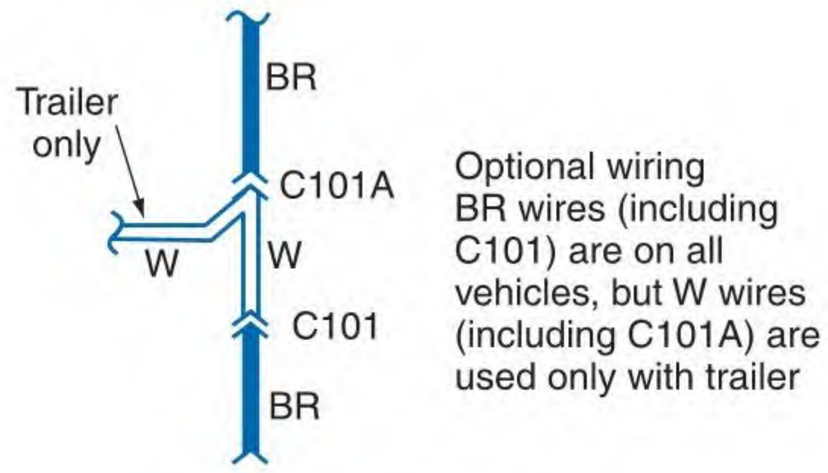
Figure 21-43. Grounds are sometimes numbered and prefaced with a capital "G" on wiring diagrams.

Note the difference in the symbols for each type of ground. Also notice the chart that supplements the wiring diagram. A capital "G" indicates a ground on some schematics.

Alternate Circuits and Optional Wiring

An alternate circuit is a possible circuit variation given on a wiring diagram. For example, a wiring diagram may show the electrical connections for a vehicle with an automatic transmission and for a vehicle with a manual transmission. This allows one diagram to serve as two diagrams.

Optional wiring is wiring provided in a circuit that may not be in use. In **Figure 21-44**, wiring is provided for trailer lights, even though the trailer package harness may not be installed on the vehicle.

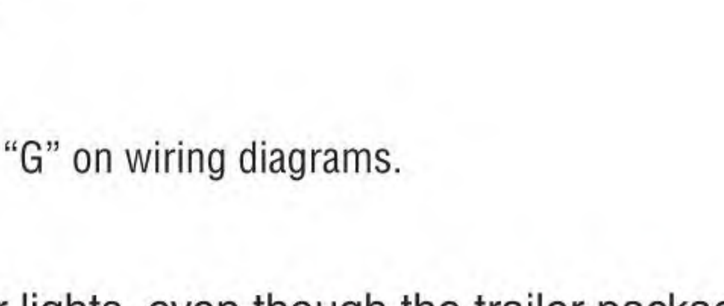


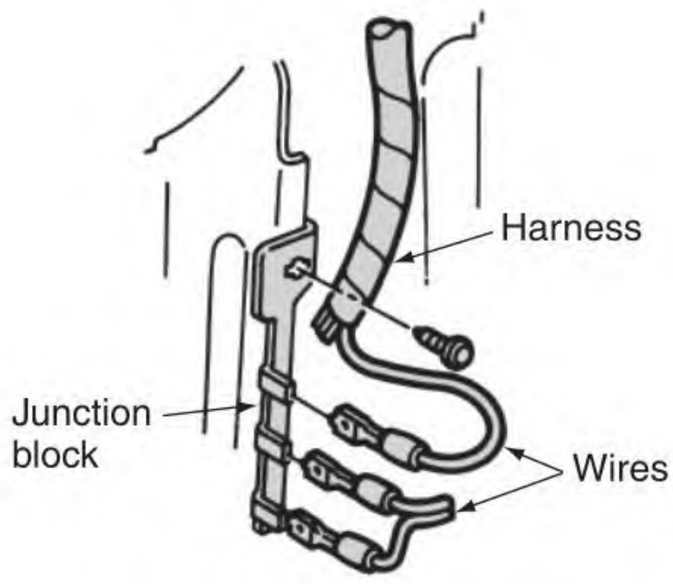
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Figure 21-44. Optional wiring may or may not be used. This example shows optional wiring for trailer towing.

Junction Blocks

A ***junction block*** is a component that allows several wires to be connected to a common conductor. The junction block serves as a splice, but the wires can easily be removed from the junction. See **Figure 21-45**.





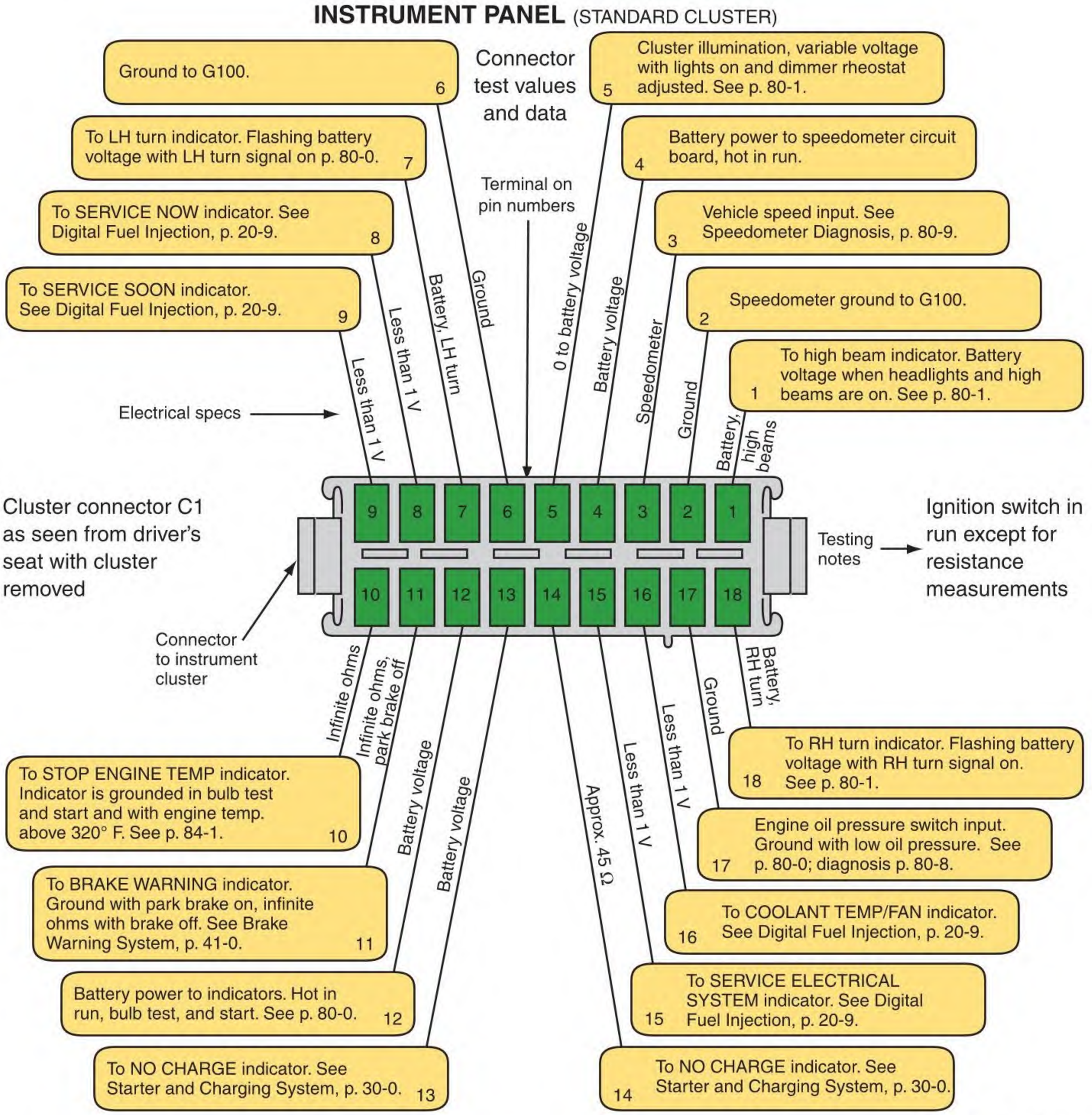
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Figure 21-45. A junction block and its symbol.

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Connector Electrical Values

The electrical values of a connector are the voltage, current, and resistance specifications at a connector for a known good circuit. An end view of the connector is usually illustrated. The electrical value that should be present at each terminal in the connector is also given. This allows you to use a multimeter to check the circuit for problems quickly and efficiently. If your measurements include any values that are higher or lower than these given values, a circuit problem exists. An example of a service manual page showing connector electrical values for one make of vehicle is shown in **Figure 21-46**.



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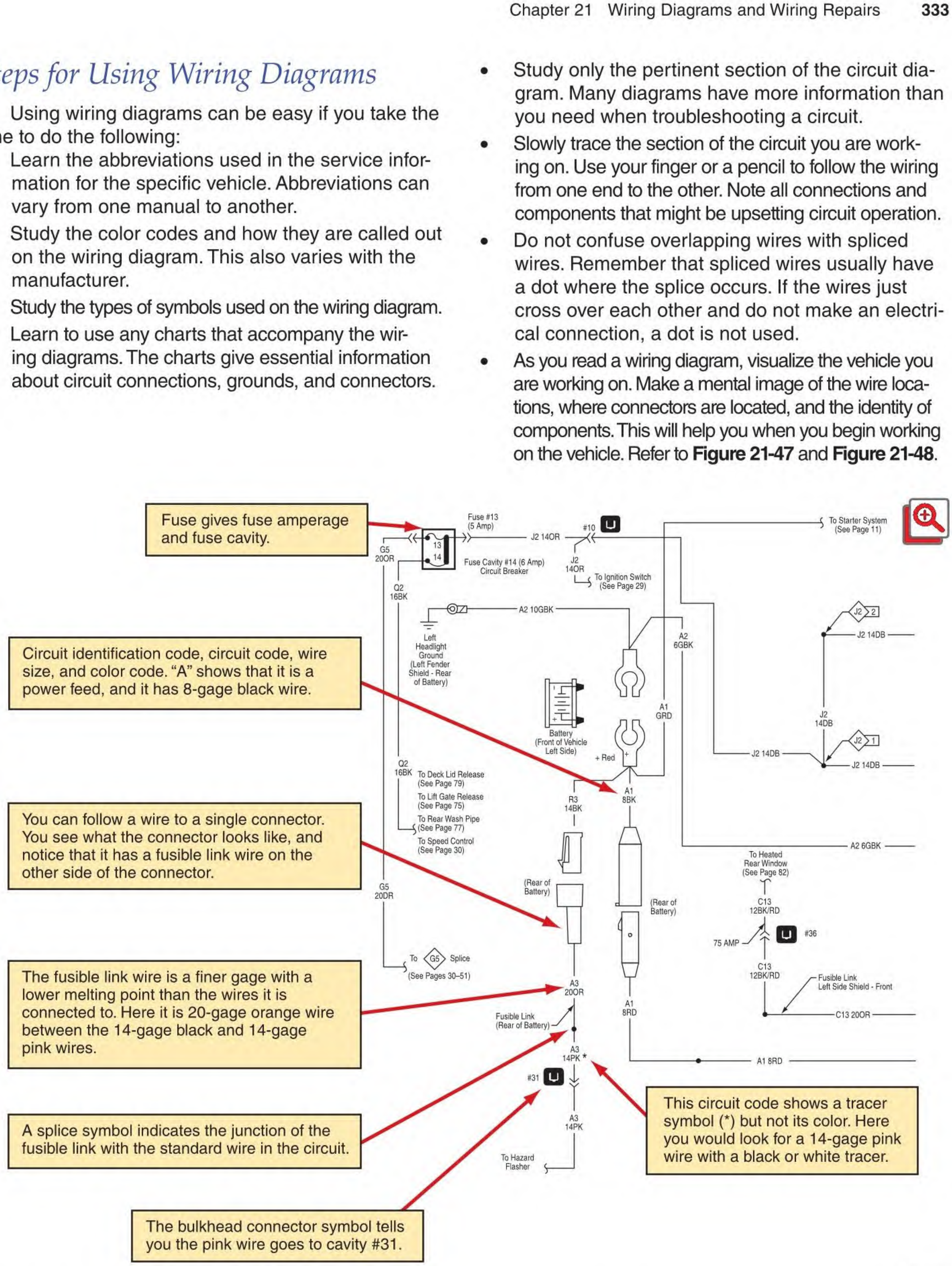
Figure 21-46. This connector illustration shows terminal numbers, actual test values, and the destination of terminal wires. It is useful when you are trying to find faults in a specific section of wiring.

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Steps for Using Wiring Diagrams

Using wiring diagrams can be easy if you take the time to do the following:

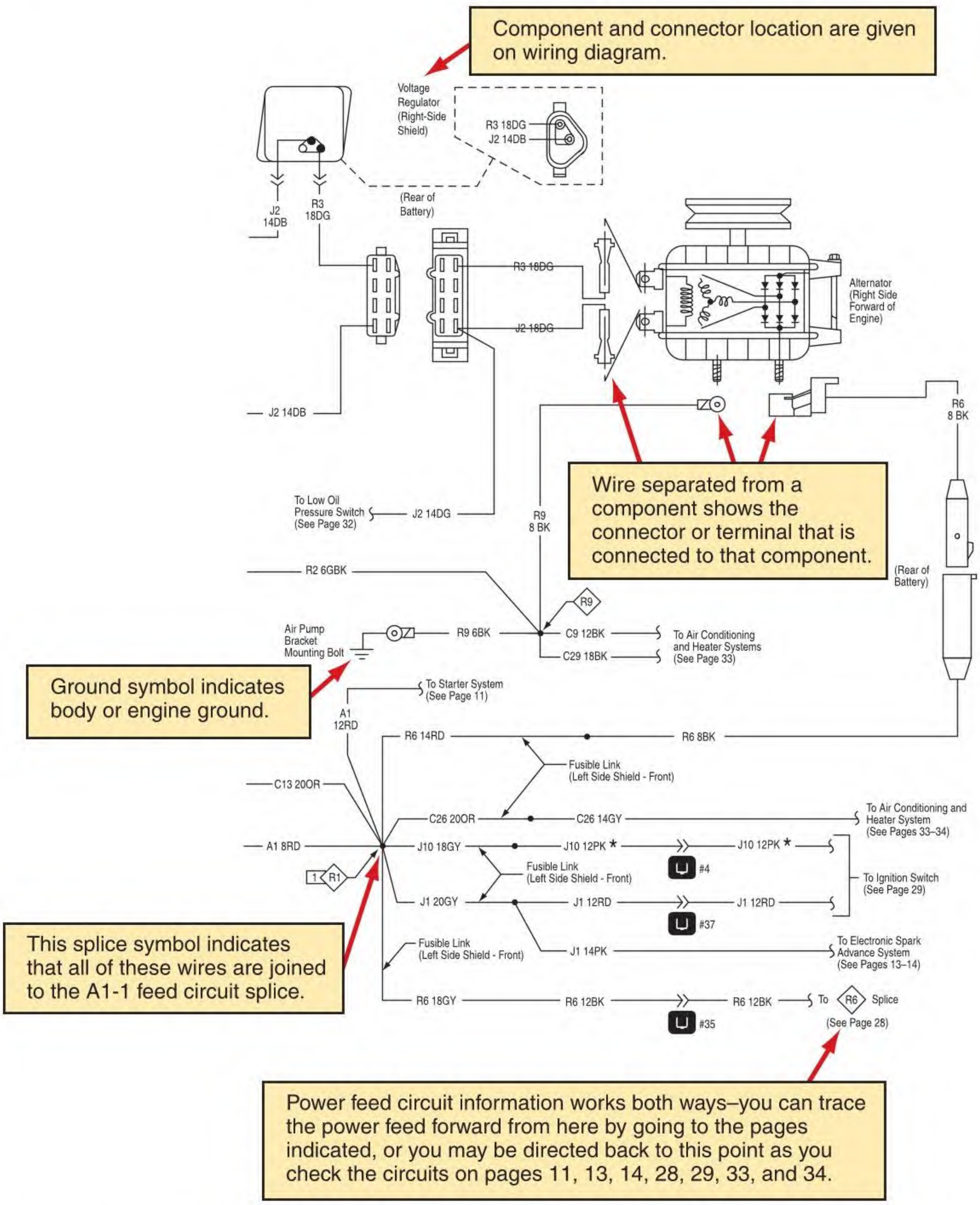
- Learn the abbreviations used in the service information for the specific vehicle. Abbreviations can vary from one manual to another.
- Study the color codes and how they are called out on the wiring diagram. This also varies with the manufacturer.
- Study the types of symbols used on the wiring diagram.
- Learn to use any charts that accompany the wiring diagrams. The charts give essential information about circuit connections, grounds, and connectors.
- Study only the pertinent section of the circuit diagram. Many diagrams have more information than you need when troubleshooting a circuit.
- Slowly trace the section of the circuit you are working on. Use your finger or a pencil to follow the wiring from one end to the other. Note all connections and components that might be upsetting circuit operation.
- Do not confuse overlapping wires with spliced wires. Remember that spliced wires usually have a dot where the splice occurs. If the wires just cross over each other and do not make an electrical connection, a dot is not used.
- As you read a wiring diagram, visualize the vehicle you are working on. Make a mental image of the wire locations, where connectors are located, and the identity of components. This will help you when you begin working on the vehicle. Refer to **Figure 21-47** and **Figure 21-48**.



Chrysler

Figure 21-47. Study the meaning of the diagram symbols and abbreviations on this wiring diagram.

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Chrysler

Figure 21-48. Study the meaning of the symbols and other information this wiring diagram contains.

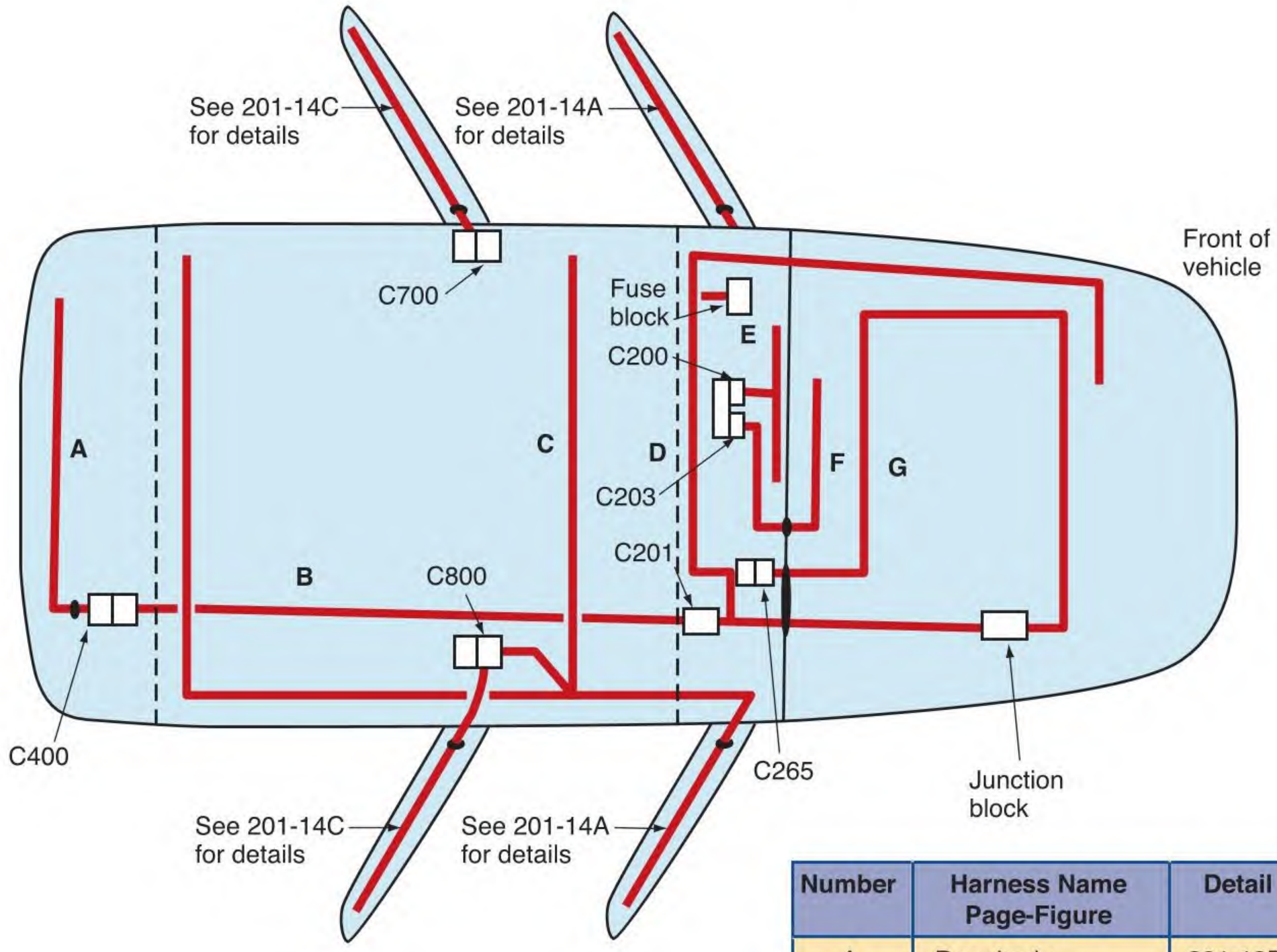
Types of Wiring Diagrams

Wiring diagrams may take many different forms, depending on the specific information they contain. For example, a wiring diagram that shows harness routing looks quite different from one that shows a block diagram of a circuit.

Harness Routing Diagram

A ***harness routing diagram*** shows how major wiring is arranged and where it is located in the vehicle. This type of diagram shows how the main harnesses feed through the body of the vehicle. Notice that a code system is used to identify the sections of the harnesses in **Figure 21-49**.

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Number	Harness Name Page-Figure	Detail View
A	Rear body	201-12B
B	Front body	201-12A
C	Cross body	Left–201-15A Right–201-12D
D	Dash	201-8B
E	Instrument panel	201-16A
F	Air conditioning	201-8A
G	Engine	201-2A

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Figure 21-49. This illustration shows main harness routing. It shows the locations of main connectors for making electrical tests. This might be helpful when you are trying to find shorts in harness wires.

Connector Diagram

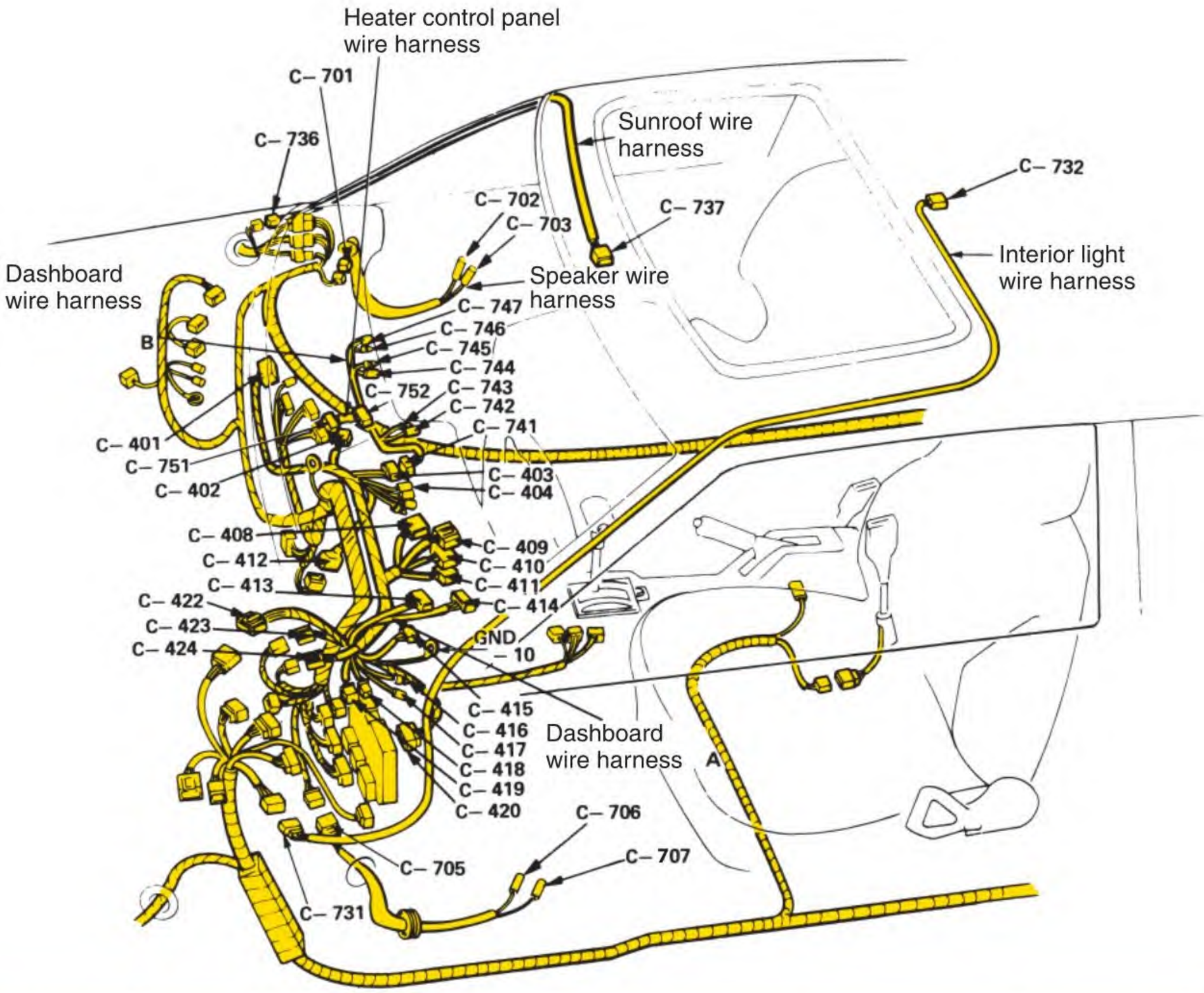
Connector diagrams show the location of connectors and identify each terminal in a connector. These diagrams are very important when you are trying to diagnose electrical problems. Connector diagrams show which connector terminals should be tested when troubleshooting. Connectors are indicated by a capital "C." **Figure 21-50** shows the location of connector C401. The chart tells you the number of pins or terminals in the C401 connector and its destination (to the clock). An example of another type of connector diagram is shown in **Figure 21-51**.

Power Distribution Diagram

A ***power distribution diagram*** shows how 12-volt battery current feeds to the main components or sections of the vehicle's electrical system. You might use this type of diagram if major systems are dead. An example of a power distribution diagram is shown in **Figure 21-52**.

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In this diagram, note how the 12-volt battery cable is connected to the starter solenoid. Fuse links protect the circuitry before the fuse panel. Large wires feed off the solenoid terminal to the light switch, fuse panel, alternator, and other components. If fuse link B were to blow, power would not be fed to the light switch and fuse panel. However, power would still go to the alternator and to wire "5red."

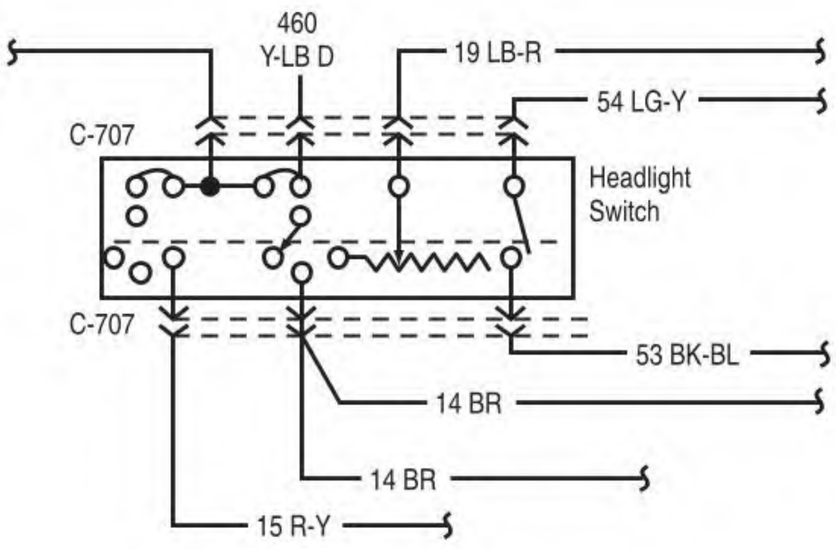


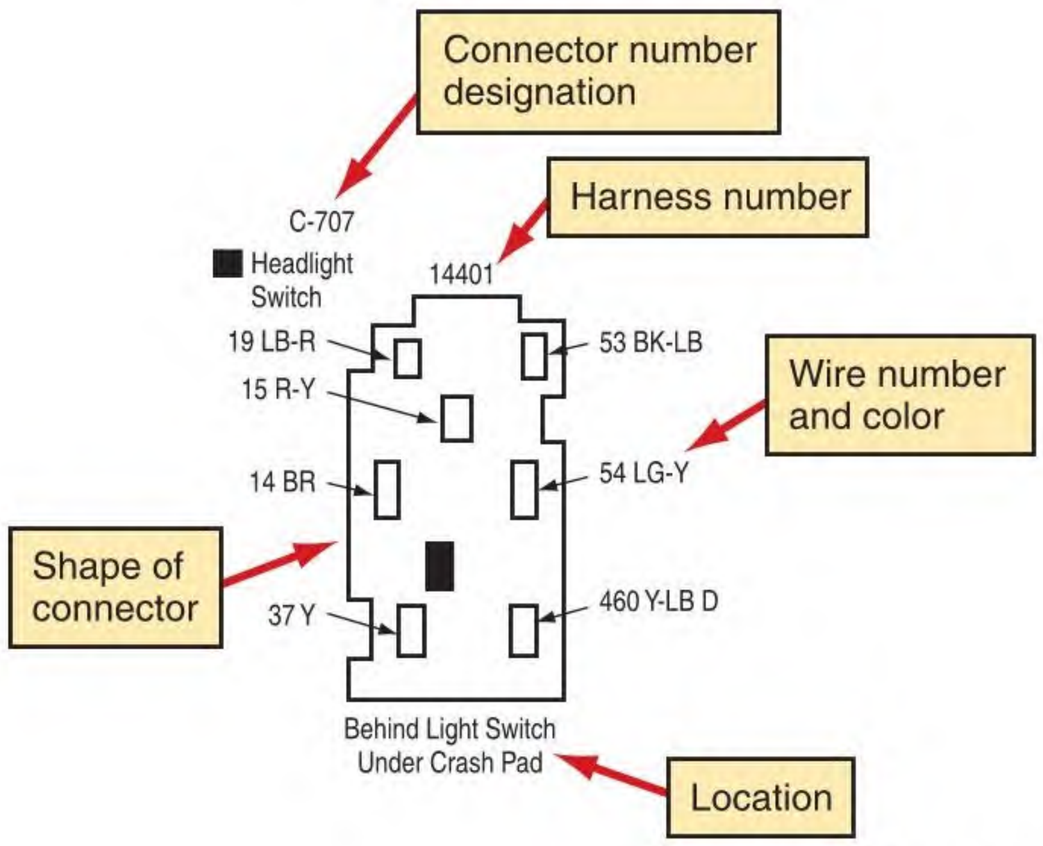
Connector, Terminal Number	Number of Pins	Location	Destination	Remarks
C401	6	Center dashboard	To clock	
C402	9	Behind right gauge panel	To hazard/rear defroster switch	
C403	3	Center dashboard	To dashboard wire harness B(C741)	
C404		Center dashboard	To auxiliary input jack	
C408	5	Behind gauges	To speed sensor	
C409	14	Behind gauges	To safety indicator	
C410	10	Behind gauges	To A/T indicator	
C411	12	Behind gauges	To combination meter	
C412	4	Center dashboard	To heater wire harness (C216)	
C413	9	Behind right gauge panel	To headlight/sunroof switch	
C414	10	Behind warning light	To warning light	

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Figure 21-50. This illustration provides a diagram and chart to identify connector and ground numbers, locations, and destinations.

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Figure 21-51. Another type of connector diagram.

Location Grid

As discussed earlier, the locations of components in electric and electronic circuits may be given in illustrations, charts, or wiring diagrams. If you are not sure where to find a potentially faulty relay, for example, you can refer to the service information.

A ***location grid*** is used to locate components or connections quickly on a large wiring diagram. It is an alphanumeric system marked off around the outside of a wiring diagram. Some sources have location charts that list components as alphanumeric (letter-number) codes, as illustrated in **Figure 21-53**. To use the grid, find the intersection of the number and letter given. For example, the service information might refer to 3C as the location of a coil pack. Align the intersection of 3 on one grid line with the C on the other grid line. This produces a small area on the large wiring diagram to help you find the coil pack.

What components are located in the area 3C in the wiring diagram in **Figure 21-54**?

Main Wiring Diagram

A ***main wiring diagram*** is a large diagram that contains symbols for all major wiring and electric/electronic components on a vehicle. The main wiring diagram may vary, depending on the manufacturer. Different symbols may be used, and the diagram may or may not have a location grid. The method of indicating color codes and wire sizes may also vary. Always refer to the service information, **Figure 21-55**.

System Wiring Diagram

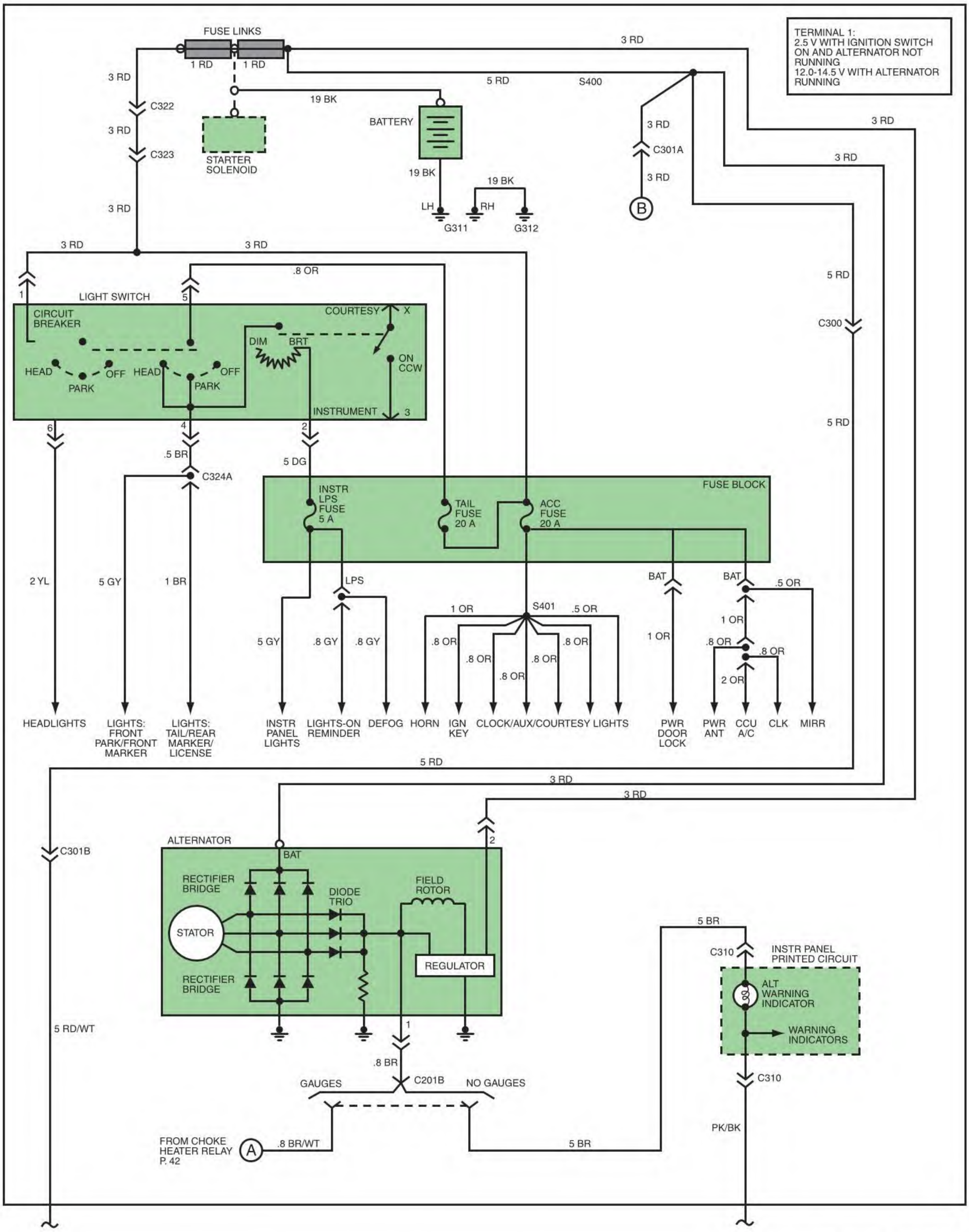
A ***system wiring diagram*** contains only the components and wires for a particular circuit. It contains a section of the main wiring diagram. For example, the service information might include an ignition system wiring diagram, fuel injection system wiring diagram, and computer control system wiring diagram.

A system wiring diagram is useful when you have narrowed down a possible problem to a specific circuit. You can then analyze the circuit to locate the problem. Refer to **Figure 21-56**.

Block Diagram

A ***block diagram*** uses boxes and symbols to illustrate components. It uses lines to represent wires and hoses. A block diagram simplifies a system or circuit so you can easily understand how an area of the system operates and how major components interact. By studying a block diagram, you can make a mental image of how the circuit functions. Then you can think about the symptoms to help arrive at a possible solution for any circuit trouble. See **Figure 21-57**.

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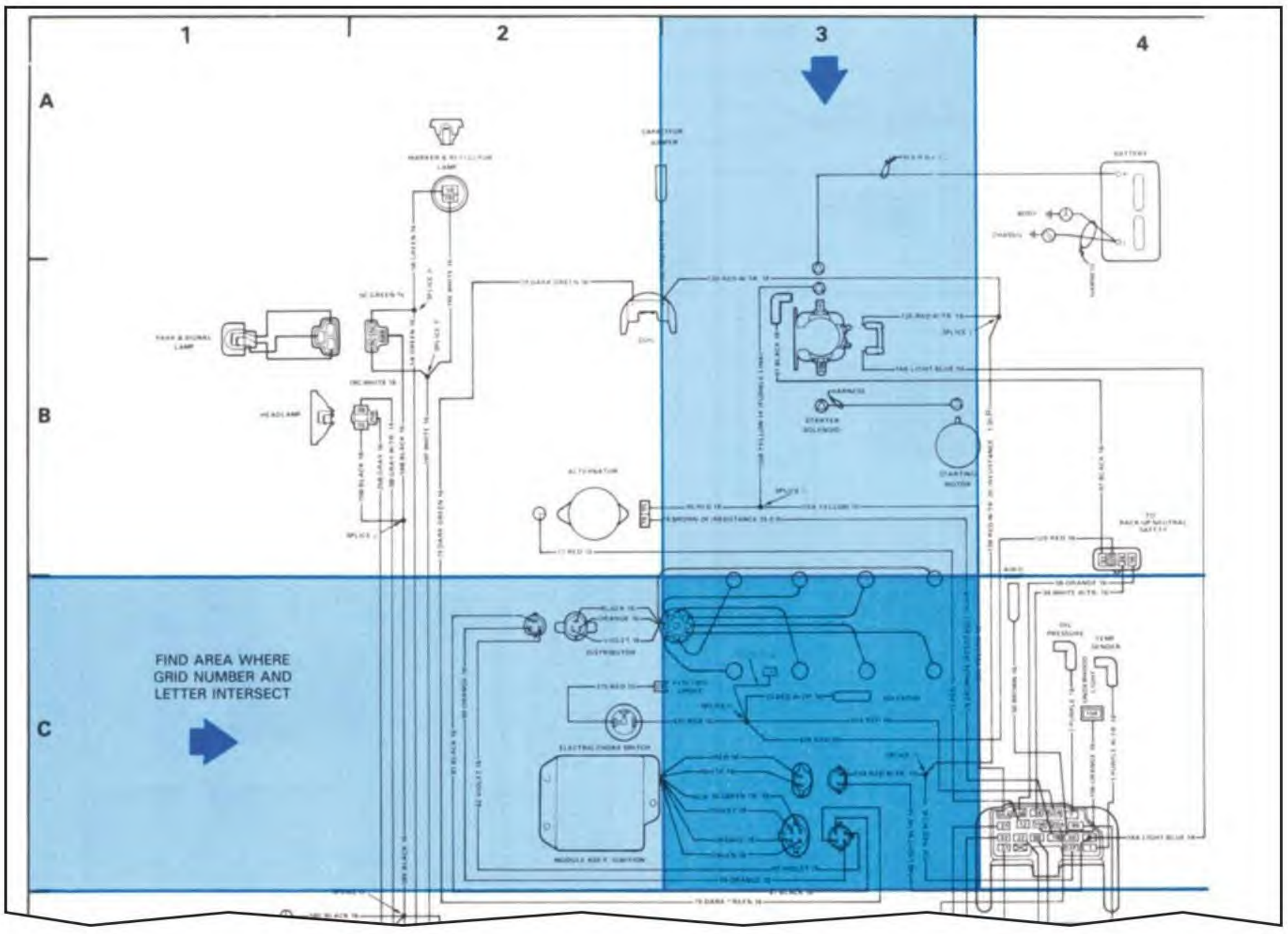
Figure 21-52. A power distribution diagram is helpful when you are working on main wires that feed to the light switch, fuse block, alternator, or other components. Can you find the generator warning light?

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Component	Location	Page
Fuse Panel	Under lower RH side of instr. panel	6-2
C131	At heater blower case	11-4
C132	Center instr. panel support brace	11-6
C134	Under RH instr. panel near fuse panel	15-3
C135	Under RH instr. panel near fuse panel	15-4
C148	Inside front light harness	26-1
C160	LH rear quarter extension wall	18-3
C161	LH rear quarter extension wall	18-3
C162	LH rear quarter extension wall	18-5
S1587	Instr. panel harness near steering column	8-8
S2109	Lights harness at end panel	7-2

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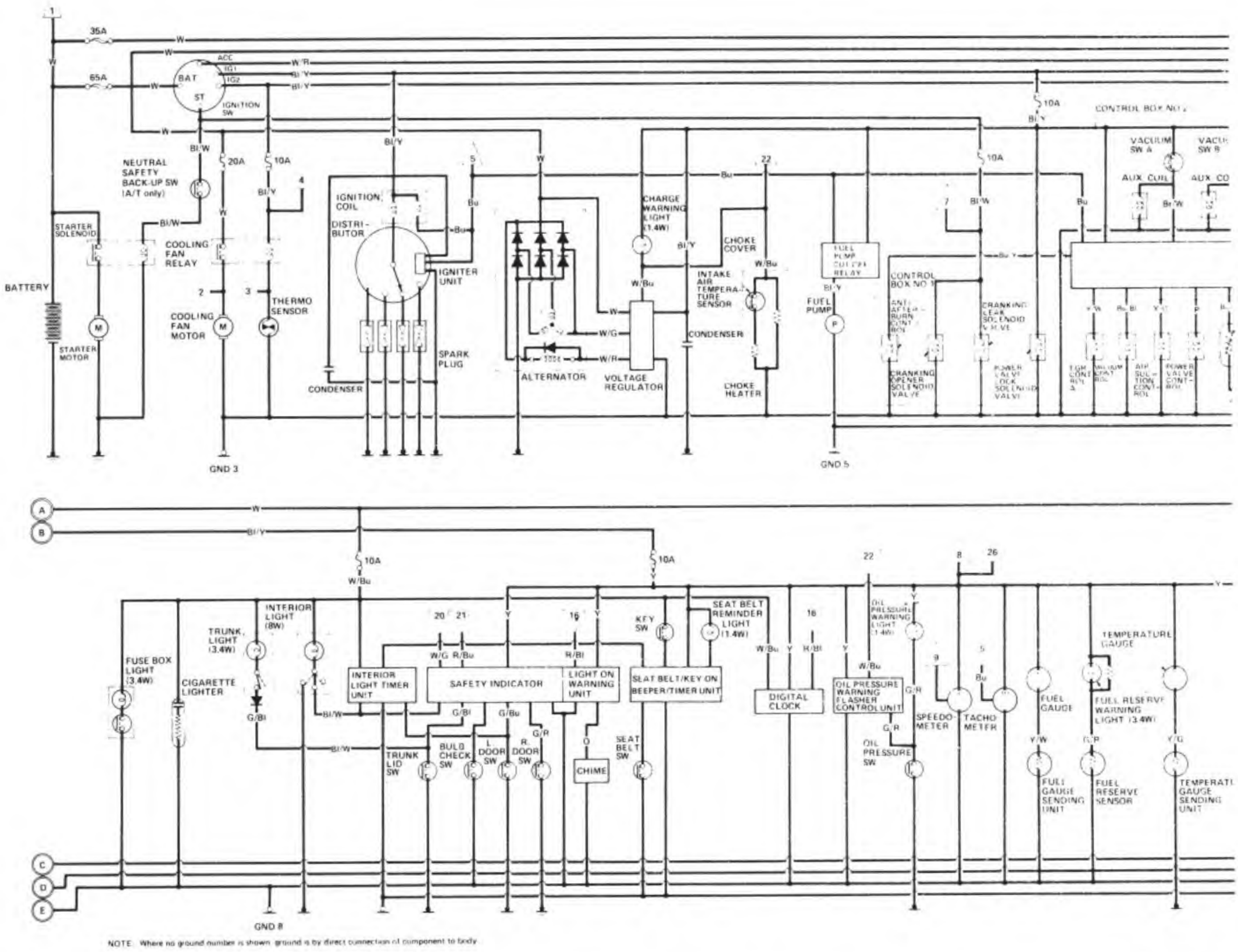
Figure 21-53. This excerpt from a component location table gives a written explanation of location and also the page number of the service manual where you can find further information about each component.



Ford

Figure 21-54. A location grid helps you locate items on a large wiring diagram. To find grid area 3C, for example, you would find 3 at the top or bottom of the diagram and C on the left or right side. Grid area 3C is where the two intersect.

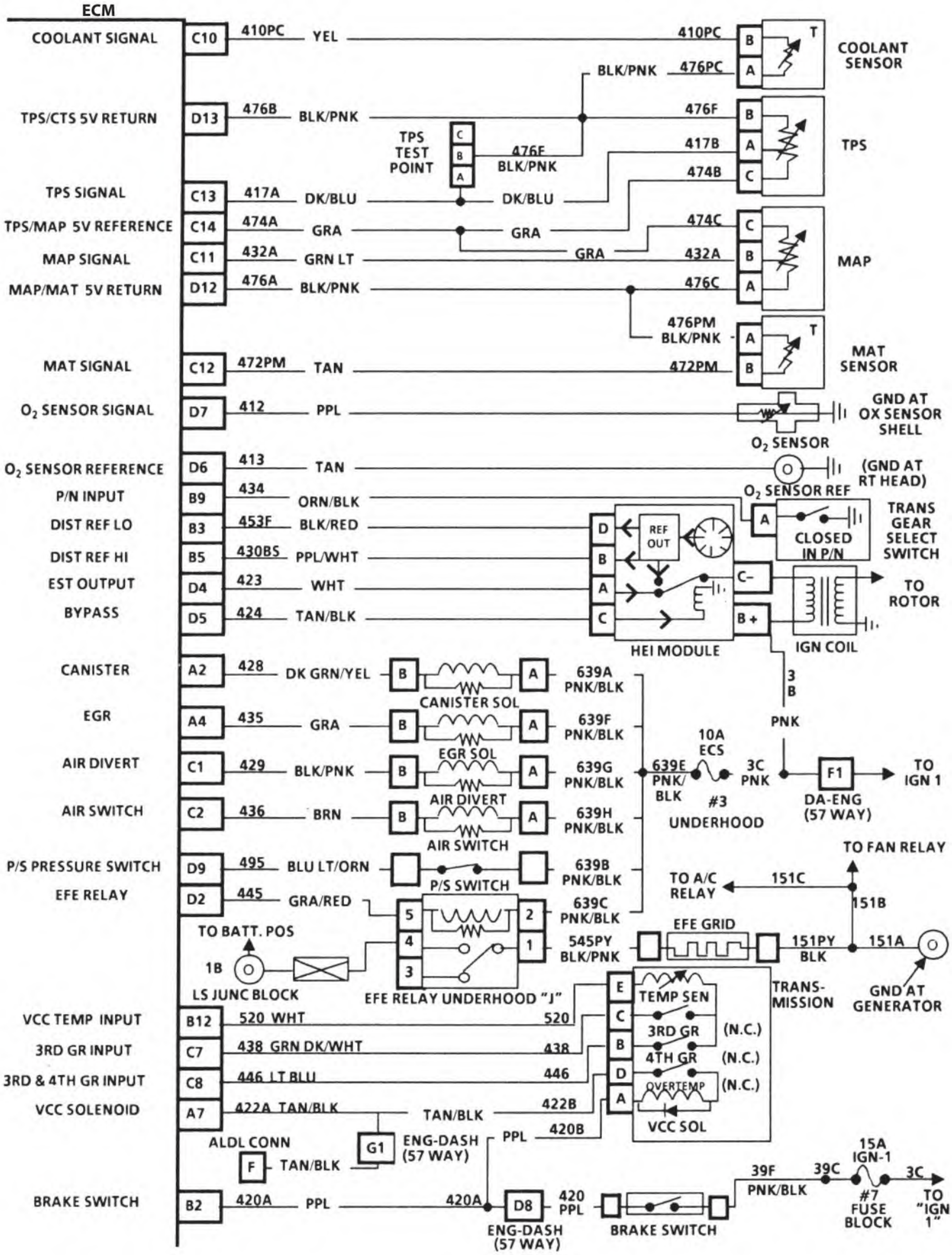
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Figure 21-55. In this main wiring diagram, the battery is on the left, and wires feed out to the right to other components.

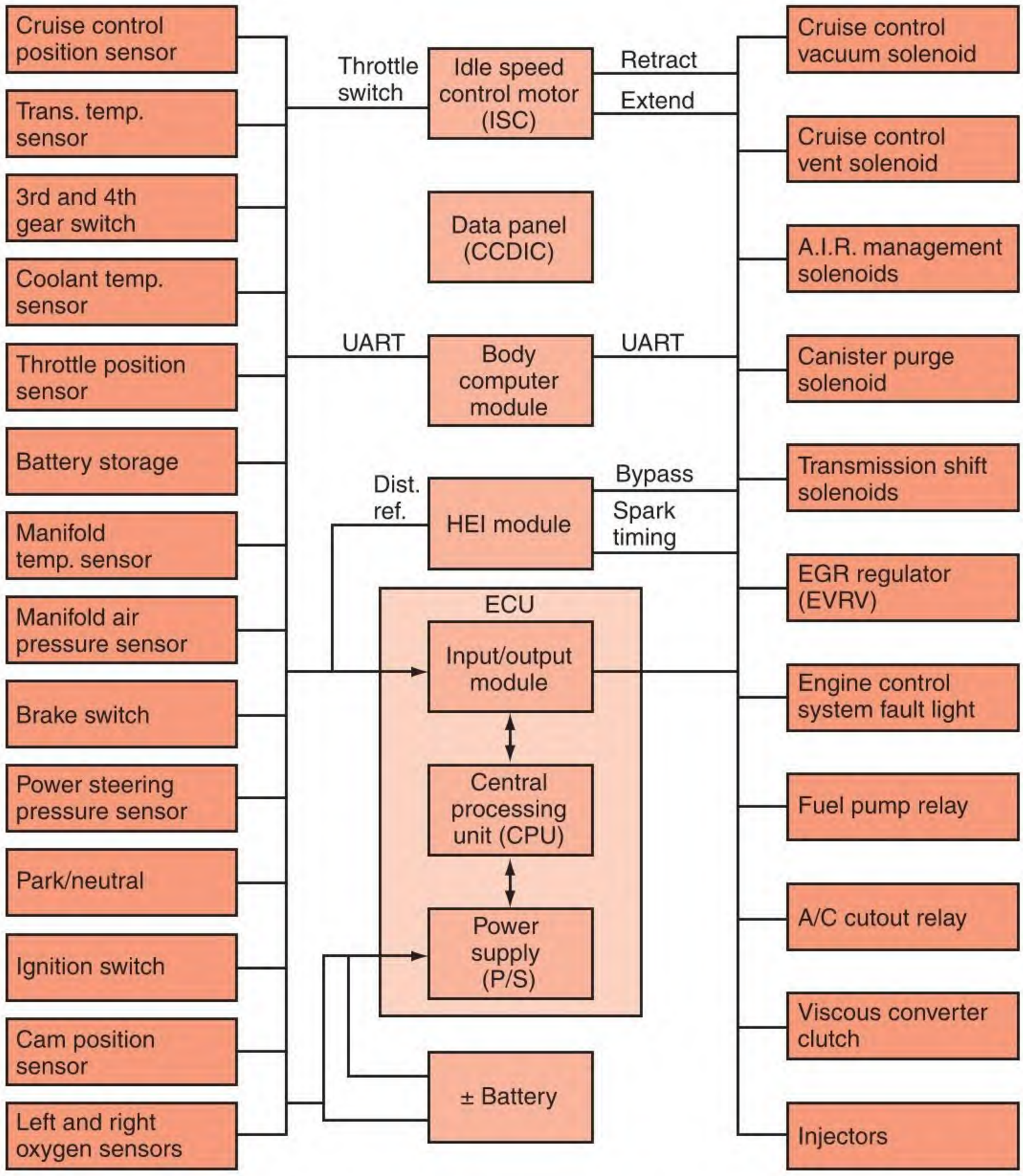
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Figure 21-56. This diagram only shows wiring for a specific electronic control module.

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Figure 21-57. This block diagram is for a vehicle's computer system. Note the different input and output devices.



Workplace Skills

A comeback is a vehicle that is returned to the shop by a dissatisfied customer. To satisfy the unhappy customer, the shop may need to repair the vehicle again, free of charge. An excessive number of comebacks will damage a shop's reputation and reduce its profits. A shop may take disciplinary action against technicians who create comebacks through careless work. Therefore, it is important to perform all repairs carefully.

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Summary

- Most automotive circuits use stranded wire because it withstands vibration and movement better than solid wire.
- Wire size is commonly given as a gage number. A smaller gage number represents a larger diameter conductor, and vice versa.
- Wire resistance depends on the diameter of the conductor, wire length, the type of conductor, and temperature.
- Wire color codes allow you to trace wire from one location to the next, even when some of the wire is hidden from view.
- A wiring harness is a set of several wires enclosed in tape or a plastic protection device. Connectors branch out from the harness and link to electric components or other harness connectors.
- Use wire stripping pliers to remove insulation from wires. Avoid using cutters to strip wires.
- Soldering is the best way to join one wire to another or to join a wire to a terminal.
- Electrical tape is commonly used to cover a metal joint after soldering. Liquid electrical tape is useful when the joint must be protected from moisture. Heat shrink tubing also covers and protects a soldered joint.
- Crimp connectors provide a quick and easy method of joining wires or terminals to wires. Crimping pliers are used to form the metal part of the connector around the wire conductor. When possible, you should solder crimp connectors to ensure a permanent electrical connection.
- Factory connectors usually have a locking feature that keeps the connectors from pulling apart with vibration. Use the correct procedure to release a connector without damage.
- When replacing a fuse link, use the correct replacement wire gage size. Always solder the new link in place to prevent unwanted resistance.
- Wiring diagrams show how wires connect to electric/electronic components.
- Wire splices are usually shown with a dot where the two wires connect.
- A remote ground has an extra wire running to ground. A chassis ground uses the metal part of the component to serve as the ground.
- An alternate circuit is a possible circuit variation. An optional circuit is one that is shown on the diagram but may not be in use.
- Connector diagrams show connector locations and detail the terminals inside the connector.
- A power distribution diagram shows how battery current is fed to major components.
- A location grid can help you find the location of components or connections quickly on a large wiring diagram.
- A main wiring diagram shows all electric components and wires. A system diagram only shows part of the main diagram. A block diagram uses blocks and symbols to represent components and is used for visualizing system operation.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

acid-core solder
American Wire Gage (AWG) system
battery cables
block diagram
butt splice
cable
carbon-core wire
chassis ground
circular mil
coaxial cable
connector diagram
connector
dielectric grease
electrical ground
fuse link
harness connector
harness routing diagram
heat shrink tubing
hybrid power cables
junction block
liquid electrical tape
location grid
main wiring diagram
metric wire size
mil
optional wiring
parallel wire
power distribution diagram
primary wire
printed circuit
remote ground
rosin-core solder
secondary nonresistance wire
secondary resistance wire
secondary wire
self-stripping connector
shielded twisted pair wire
solder
soldering
solid wire
stranded wire
system wiring diagram

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terminals
tinning
twisted pair wire
wire
wire code identification system
wire color code
wire gage
wire protection device
wiring harness
wiring schematic
wiring splice

Activities

1. Search for an engine wiring diagram in a service manual or on the Internet. Study the diagram and then write a paragraph explaining what components are illustrated in the diagram.
2. Use the Internet to search for a wiring diagram for an electric door wiring harness. Make a list of the components included in the schematic, and compare the symbols used to those shown in **Figure 21-36**.

Review Questions



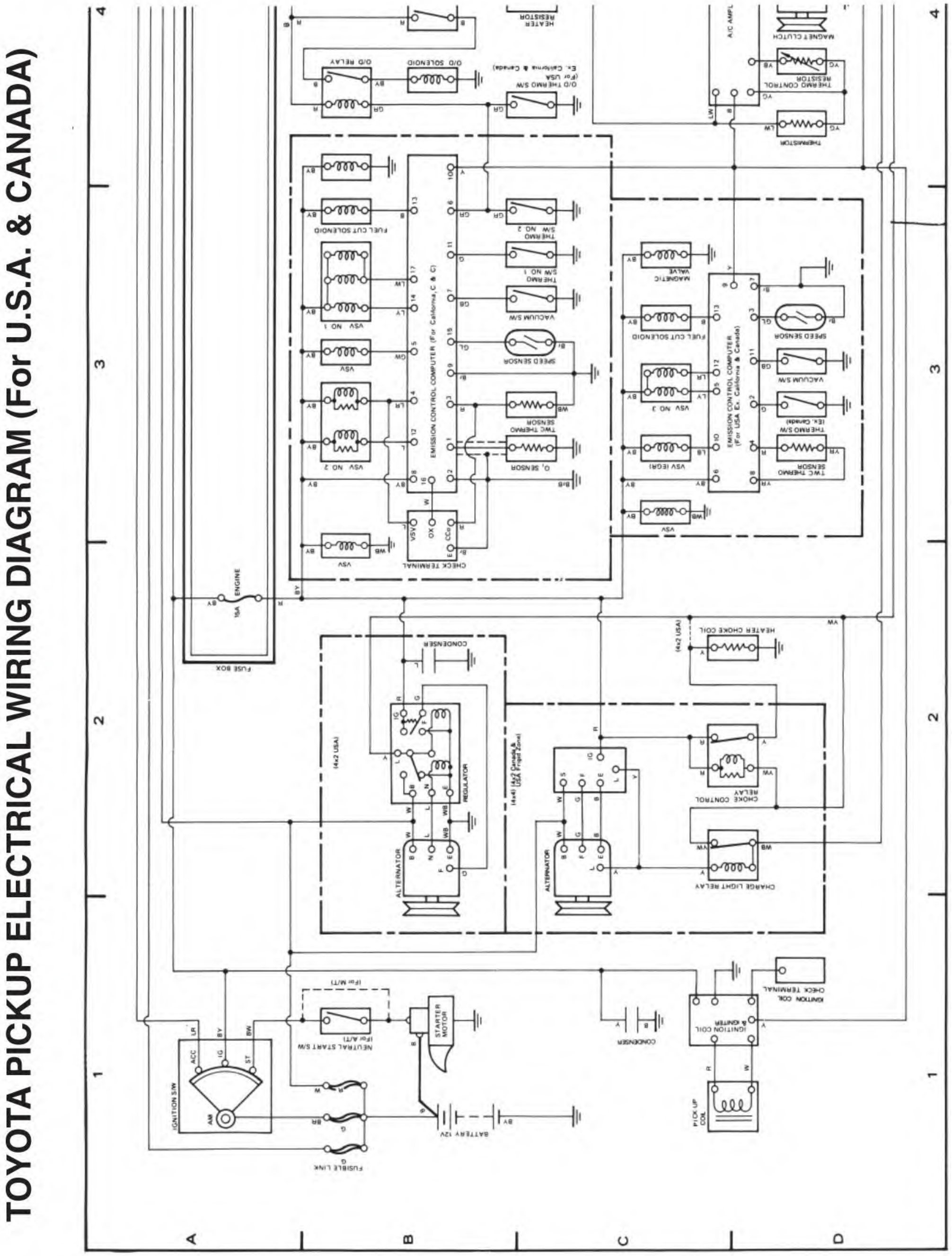
Answer the following questions using the information provided in this chapter.

1. Why is most automotive wire stranded?
2. Why is copper wire considered a better choice than aluminum for a wire conductor?
3. What type of wiring has copper foil conductor strips mounted on a plastic or fiber base?
4. Is a 10 gage wire smaller or larger than a 12 gage wire?
5. What is the difference between metric wire sizes and AWG wires sizes?
6. Why are wires color coded?
7. Name four characteristics that affect the resistance in a wire.
8. What is the purpose of a wiring harness?
9. Why is it important to cut all the way through a wire on the first try?
10. Name at least five types of wire protection devices.
11. In your own words, describe the proper way to solder a wire onto a terminal.
12. When is liquid electrical tape a better choice than conventional electrical tape for covering exposed conductors?
13. Explain the procedure for installing a crimp connector.
14. What must you do to disconnect a factory harness connector without damaging the connector?
15. Briefly explain how to bypass a wire.
16. A wiring diagram shows a dot where two lines on the diagram intersect. What does this mean?
17. Explain the two types of grounds.
18. What wiring component allows several wires to make a common connection?
19. How would you use a connector diagram that gives electrical values?
20. What type of wiring diagram would you use to find out why major electric circuits fail to have voltage?

    Use **Figure 21-58** to answer questions 21 through 23.

21. What components are located in grid area 1B?
22. What color wires connect to the ignition system pickup coil?
23. What is the grid location for the choke control relay?

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Toyota

Figure 21-58. Use this diagram to answer questions 21–23.

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ASE-Type Questions

1. Technician A says stranded wire is normally used to connect an automobile's electronic components. Technician B says solid wire is generally more flexible than stranded wire. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Technician A says automotive wiring is usually between 4 and 12 gage. Technician B says automotive wire size must be matched to the circuit load. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. Technician A says wire resistance increases as conductor diameter decreases. Technician B says wire resistance increases as conductor length increases. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. Technician A says wire resistance depends on the type of material used for the conductor. Technician B says wire resistance depends on the temperature of the conductor. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. A wire has come loose from an automotive component. Technician A says the tip of the soldering gun should be tinned before the wire is soldered. Technician B says the wire and the component lead should be preheated before melting solder onto the joint. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. All of the following are wire protection devices *except:*
   (A) heat shrink tubing.
   (B) flux.
   (C) liquid electrical tape.
   (D) wiring harness.
7. A crimp connector must be replaced. Technician A twists the wire strands before inserting the wire into the connector. Technician B fastens the new connector to the wire by squeezing the connector's plastic cover. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. One of an automobile's fuse links is burned. Technician A says the circuit problem should be identified and corrected before the link is replaced. Technician B says the battery cable should be disconnected before the link is replaced. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. A vehicle's fuel injection control unit is difficult to locate. Technician A checks a wiring diagram in the service information to help locate this component. Technician B checks a component location table in the service information to locate the vehicle's fuel injection control unit. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. Technician A says the term "left side of the vehicle" is sometimes abbreviated in an automotive wiring diagram as LH. Technician B says the term "left side of the vehicle" refers to the passenger side of the vehicle. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
11. Technician A says wire code identification systems provide information about the appearance, location, and size of wire in a given circuit. Technician B says wire code identification systems vary from manufacturer to manufacturer. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Chapter 22
Basic Electrical Tests

After studying this chapter, you will be able to:

- Use a systematic approach to find and correct electrical problems.
- Explain causes of basic circuit problems given their symptoms.
- Use testing devices to check component operation.
- Use a multimeter to measure circuit voltage, voltage drop, resistance, and amperage.
- Test basic electric and electronic components.

Basic circuit testing procedures are essential to today's automotive technicians. Knowing how to analyze circuit problems and use basic test instruments are fundamental skills. This chapter introduces basic circuit problems, explains their causes, and summarizes the tests needed to find and correct malfunctions.

Basic Circuit Problems

Almost all electrical and electronic problems are caused by something in the circuit that increases or decreases current, resistance, or voltage. For example, a broken wire could stop or decrease current, or a charging system problem could increase output voltage and current.

Unfortunately, when a basic circuit problem occurs in a complex circuit, such as a computer control system, it may not seem so simple. For example, a poor electrical connection in a feed wire to a sensor can cause a false signal to return to the computer. The computer, reacting to this signal, might then alter the operation of the fuel injection system, emission control system, or ignition system. A technician might think that any of these systems or the computer itself is at fault. Several systems may appear to have a problem. In reality, all of the problem symptoms are caused by a poor electrical connection in one wire.

As you can see, it is important to keep an open mind when diagnosing electrical problems. If analyzed properly, problems can usually be found and corrected easily.

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Electrical Diagnosis and Repair

Electrical diagnosis involves using a logical sequence of steps to find the source of an electrical problem. Before you begin troubleshooting, verify the symptoms and problem to be sure that the customer has described the trouble accurately. Frequently, the vehicle owner or service writer may not completely describe what is wrong with the vehicle. Verifying the problem may give you added information when determining what to do next. See **Figure 22-1**.

Systematic Approach

The systematic approach to troubleshooting involves using the theory of system operation and logical thought processes to find the source of the problem quickly. A well-planned procedure must be followed to find the source of a malfunction. **Figure 22-2** shows a mnemonic (memory-jogging phrase) that may help you remember the steps in using a systematic approach to troubleshooting.

Tech Tip

With the on-board computers, sensors, actuators, and complex circuits used in late-model vehicles, a systematic approach to problem diagnosis is essential. Never use trial and error when trying to find and correct electrical problems.



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Figure 22-1. Verify the problem before you begin the troubleshooting process.

Veronica	***Verify*** the symptoms and problem.
Never	***Narrow*** down the problem sources.
Touches	***Test*** to find the cause.
Much	***Make*** the repair.
Voltage	***Verify*** the repair.

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Figure 22-2. Use this mnemonic to remember the steps in the troubleshooting process.

Verify the Symptoms

Check the vehicle carefully to find out which components are not working. Note any unusual noise, blown fuses, trouble codes, or other conditions. Try to determine which parts might be capable of causing these symptoms. Also, think of the parts that cannot be causing the symptoms. Ask yourself the following questions:

- What could be causing the specific symptoms? Picture the parts in the circuit and how they function. Mentally trace through the circuit or use a wiring diagram to find out what wires, connections, and components are in the circuit to find potential trouble sources.
- How many components are affected? If several components are not functioning normally, you know that something close to the power source is probably at fault. If only one or two sections of the circuit are faulty, you know to begin your tests at these sections of the circuit.
- Is the problem always present, or does it only occur some of the time? If the trouble only occurs some of the time, the conditions causing the problem must be simulated. For example, a loose electrical connection might open and close with vibration or movement. By wiggling wires in the circuit, you can simulate the driving conditions and try to make the problem occur.
- Is the problem affected by heat or cold? If the problem only occurs on a hot day or with the engine warmed to full operating temperature, heat may be activating the problem. Many electronic

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circuits are greatly affected by heat. In fact, too much heat can ruin an electronic component. This might tell you which component is at fault.

- Is the problem affected by moisture? If you discover that the trouble only occurs on a wet day, you again have more information to use when analyzing the source of a problem. Moisture cannot enter a sealed electronic circuit, but it can enter and affect wire connections and components exposed to the environment. This type of thinking might help you in the troubleshooting process.

Narrow down the Cause

After verifying the symptoms, narrow down the cause to one system or circuit, if possible. Use the symptoms to visualize what is happening inside the circuit. Use your knowledge of the specific system and basic rules of electricity to determine what might be wrong.

If you are not familiar with the circuit, use a diagram to trace the circuit with the malfunction. For example, if the right headlight is not working, but the left one is, you could narrow down the problem to the circuit feeding current to the right headlight. You have, through logical thought, narrowed down the source of the electrical problem to one section of the circuit. If both headlights fail to function, then anything in the complete headlight circuit could be the cause. Further tests, probably at the power source to the circuit, would be needed to narrow down the cause.

Perform the Proper Tests

The next step is to perform the tests needed to check the specific section of the electrical system. If one headlight does not work, you might check the bulb first. If the bulb is good, you might test for power to the bulb socket. Again, you must think of how the circuit operates to select the next most logical test.

Use proper testing methods to verify your assumption about what might be wrong in the circuit. If tests prove that your first assumption is not causing the trouble, proceed to the second most logical place to test. When you are testing circuits, remember the following:

- If only one component does not work, start your tests at that component. Chances are the problem is in the inoperative component or in the section of the circuit leading to the component.
- If more than one component does not work, start your tests at the power source for the circuit. A blown fuse or loose power feed wire could be preventing current in the whole circuit.

If you have difficulty finding a problem, refer to the troubleshooting charts and circuit diagrams found in the service information. These diagrams are specific to the vehicle's make and model and will give you ideas for finding the source of the problem. Always think about the symptoms and problems while working. Visualize current through the circuit, as well as each connection and each component. A new testing method or another potential problem source may occur to you at any time.

Make and Verify the Repair

Following the steps described in this section should help you determine exactly what the problem is. After you have found the source of the problem, make the repair. This might involve replacing a bad component, soldering a broken wire, or repairing a faulty connector.

Finally, verify the repair by making sure the circuit is operating normally. If needed, test-drive the vehicle to make sure road shock and vibration do not affect the repair. Then you can be confident that the problem will not recur after the owner drives away.

Types of Circuit Problems



The four basic types of circuit problems are open circuit, high resistance, intermittent trouble, and short circuit. This section of the chapter defines these problems, lists their causes, and explains how each can cause different symptoms depending on the circuit configuration.

Open Circuit

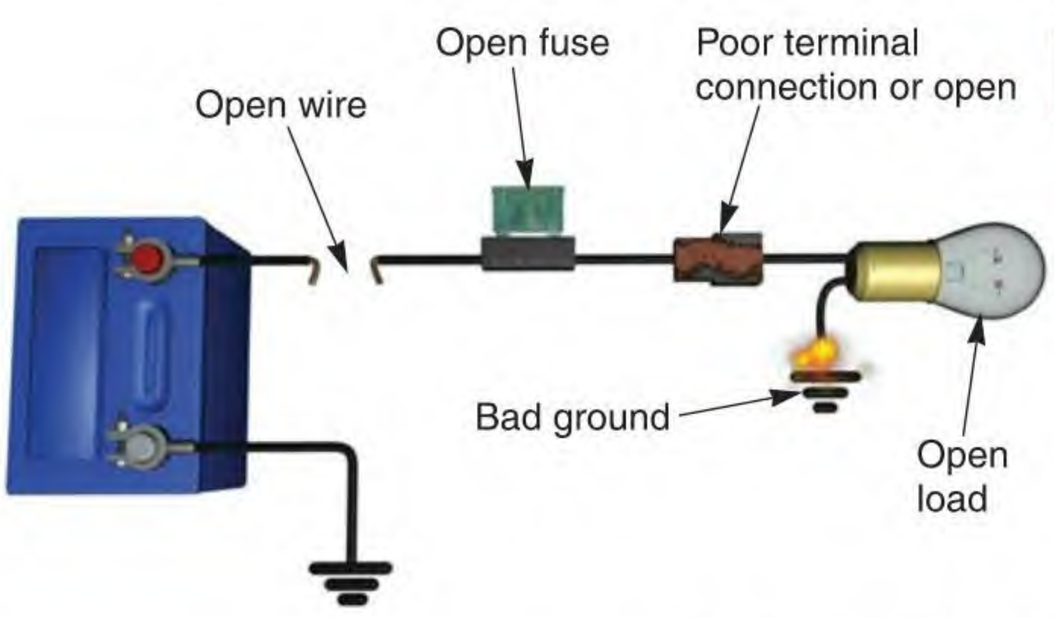
An ***open circuit*** is a complete break or disconnection in the circuit. An open circuit, or "open," stops current through a section of the circuit. See **Figure 22-3**.

An open circuit can be caused by a:

- Broken wire conductor.
- Blown fuse.
- Burned switch contacts.
- Loose connection.
- Burned or corroded connector terminals.
- Failed electric component.

When current is not reaching a component, find out which of these potential problems is present in the circuit. As shown in **Figure 22-4**, the open can occur before the load, after the load, or in the load. If the

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Figure 22-3. These are some of the sources of opens or breaks in a circuit. In a series circuit, everything after break is "dead."

open occurs in series with a component, the component will not function. However, if the open occurs in a parallel branch, the branches that do not contain the open circuit will still function. Refer to **Figure 22-5**.

High Circuit Resistance

High circuit resistance reduces current, but it does not stop all current like an open circuit. A high resistance might make a bulb glow dimly or a motor turn too slowly. See **Figure 22-6**. High circuit resistance is usually caused by a poor electrical connection. A corroded or burned connector terminal is the most common cause. Faulty components can also have high internal resistance. See **Figure 22-7**.

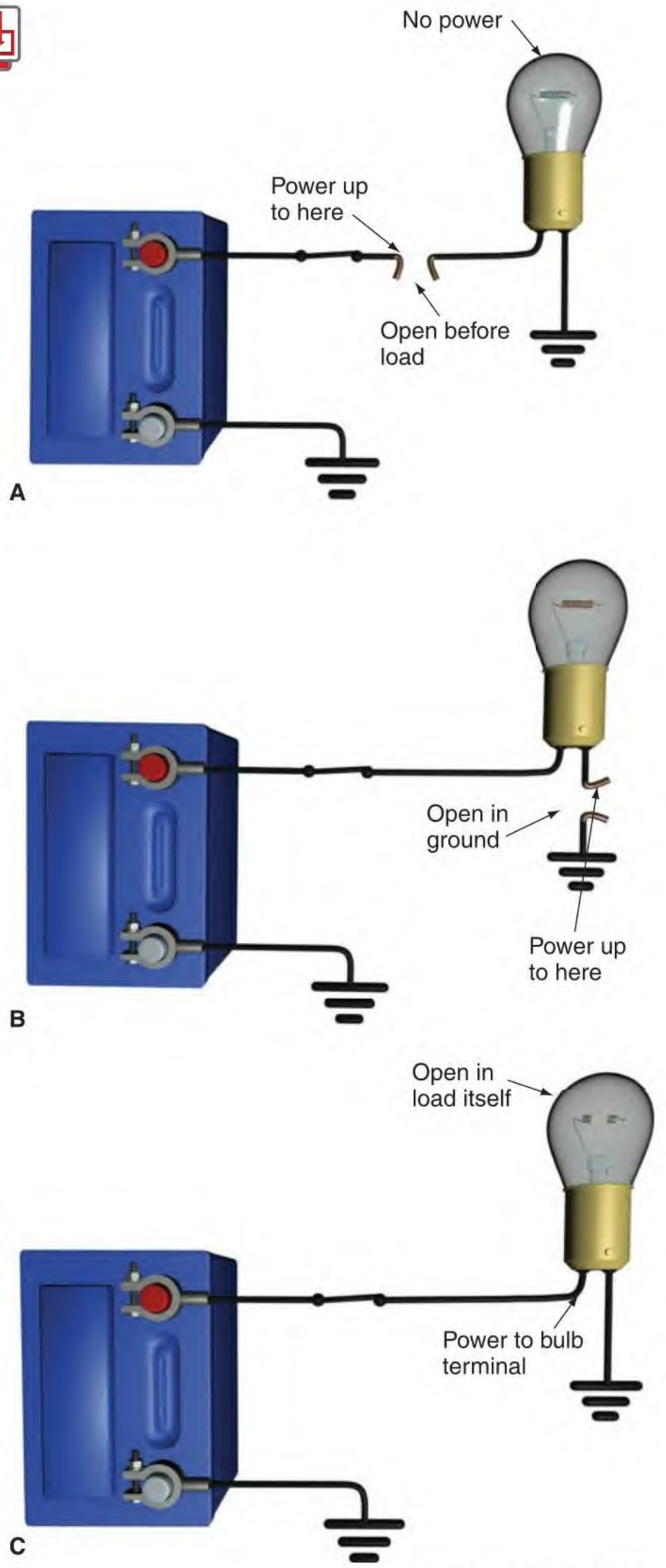
Short Circuit

A ***short circuit*** is caused by a conductor accidentally touching ground or another conductor. Shorts are caused by wire insulation damage. There are several classifications of shorts, and each causes different symptoms.

A ***hot wire short to ground*** produces low circuit resistance and extremely high current. This usually blows the fuse or circuit breaker. The fuse or circuit breaker protects the circuit from excess current damage caused by the hot wire short. See **Figure 22-8A**.

A short in an unprotected section of a circuit can cause an electrical fire when excess current overheats a conductor and melts its insulation. The melted insulation then allows other conductors to come into contact. As a result, several wires can begin to burn. This can happen in a matter of seconds.

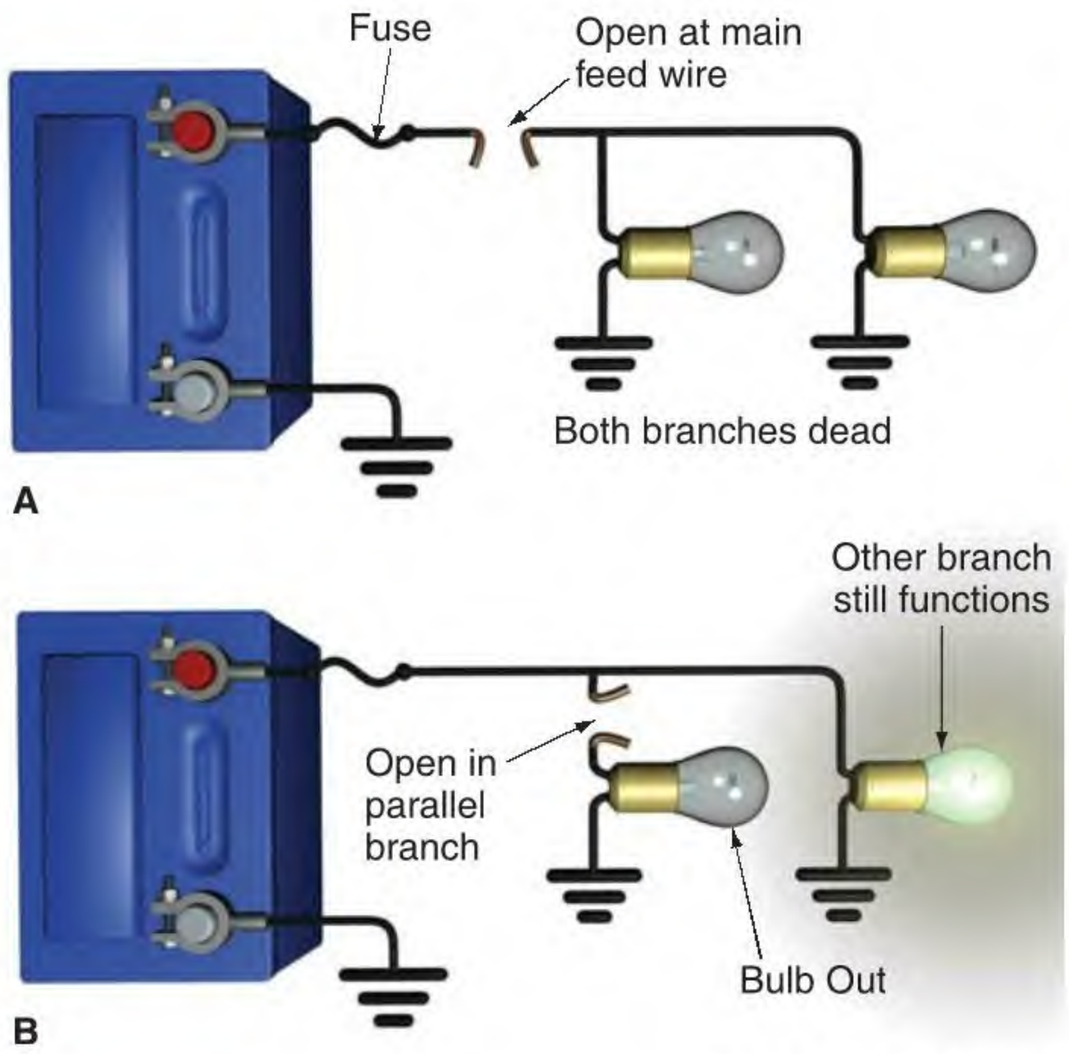
A ***grounded circuit*** is caused by a ground wire shorted to ground. This usually has no noticeable



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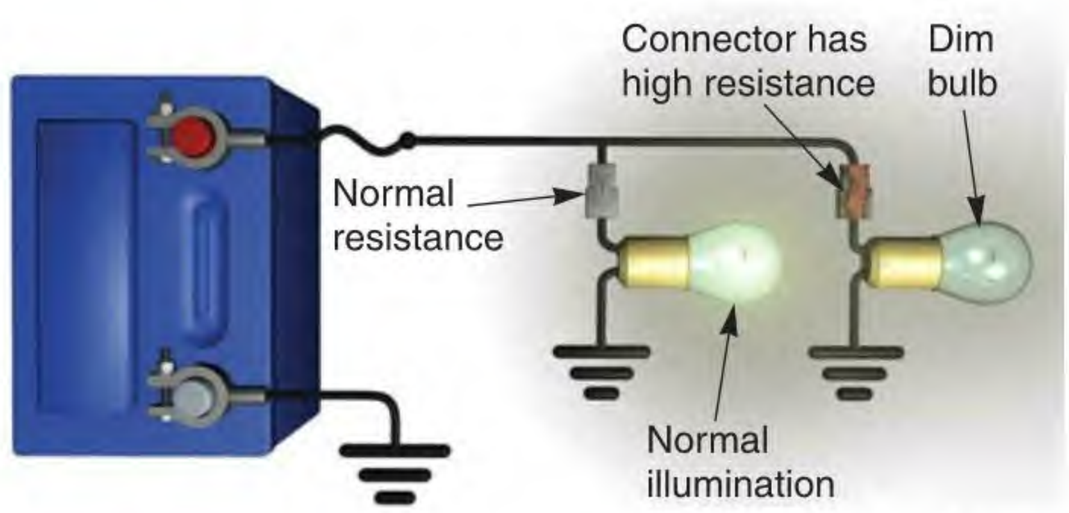
Figure 22-4. See the action of a basic light circuit. A—If the open occurs before the load, voltage cannot travel to the bulb socket. B—If the open occurs after the load, the socket does not have a return ground circuit path. C—An open in the bulb itself is a common example of an open inside the load.

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Figure 22-5. Opens in a parallel circuit may cause different symptoms, depending on where in the circuit they occur. A—An open in the main wire feeding the parallel branches disrupts power to both branches. B—If the open is on one of the parallel branches, the other branches still function normally.



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Figure 22-6. A high circuit resistance is similar to an open, but some current can still exist in the circuit. In this example, high resistance in the top connector reduces current through that branch. Therefore, the bulb in that branch burns dimly.

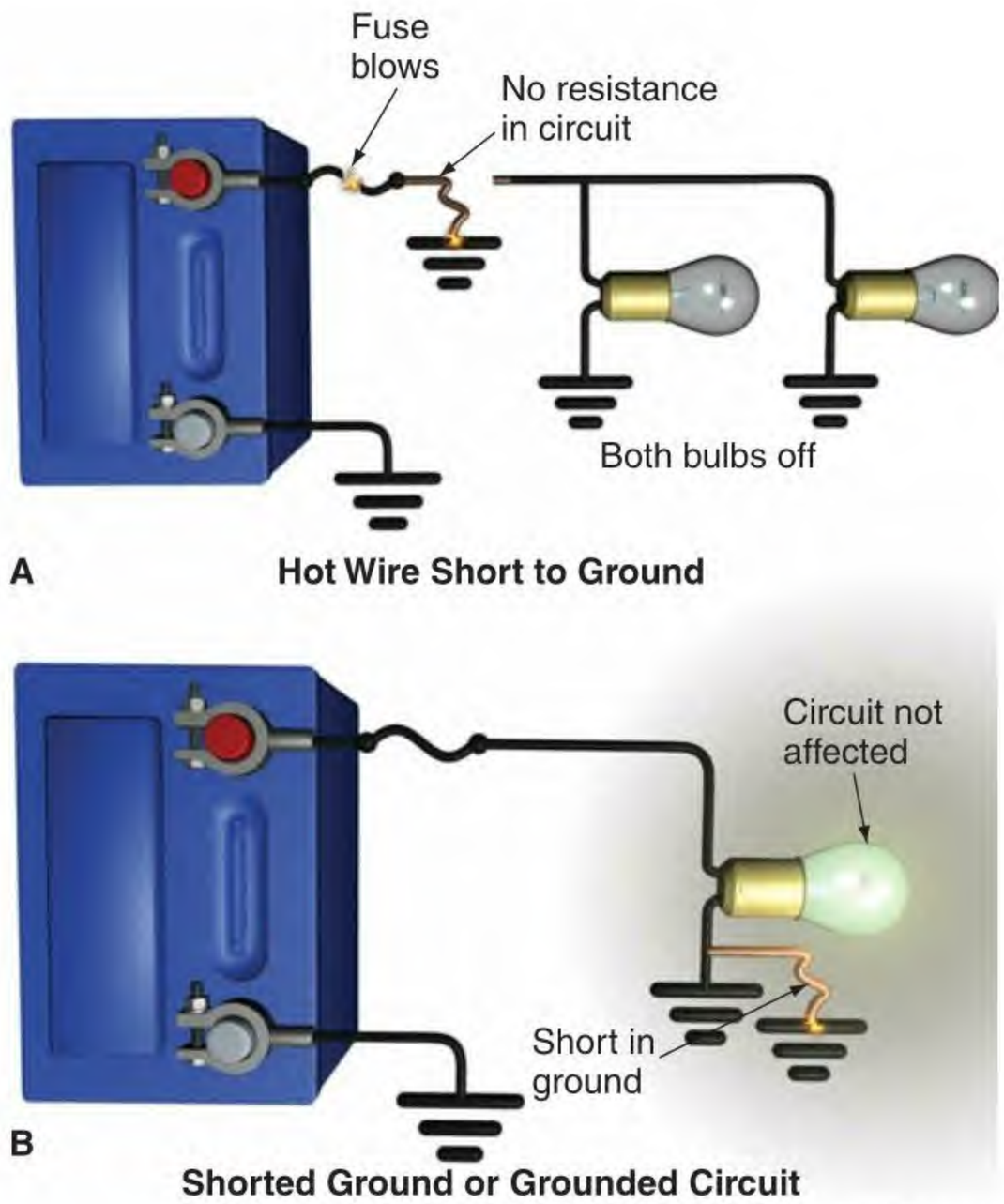
effect. The short just provides another path to ground. See **Figure 22-8B**.

Figure 22-9 shows how a short in different locations in a circuit can cause different symptoms. As shown in **Figure 22-9A**, a short after a load does not blow the fuse. There is still a resistance unit (bulb) between the power source and short to limit current. However, since the short is between two loads, it



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Figure 22-7. Some sensors, such as this oxygen sensor, produce an output of less than one volt. Any resistance in the circuit leading to the sensor could produce false signals for the computer and upset engine or other system operation.



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Figure 22-8. These are examples of short circuits. A—When a hot wire is shorted to ground, it causes very high current that blows the fuse. Both bulbs fail to function because of the open fuse. B—When a ground wire is shorted to ground, it does not affect the circuit. The short just provides a second path for ground.

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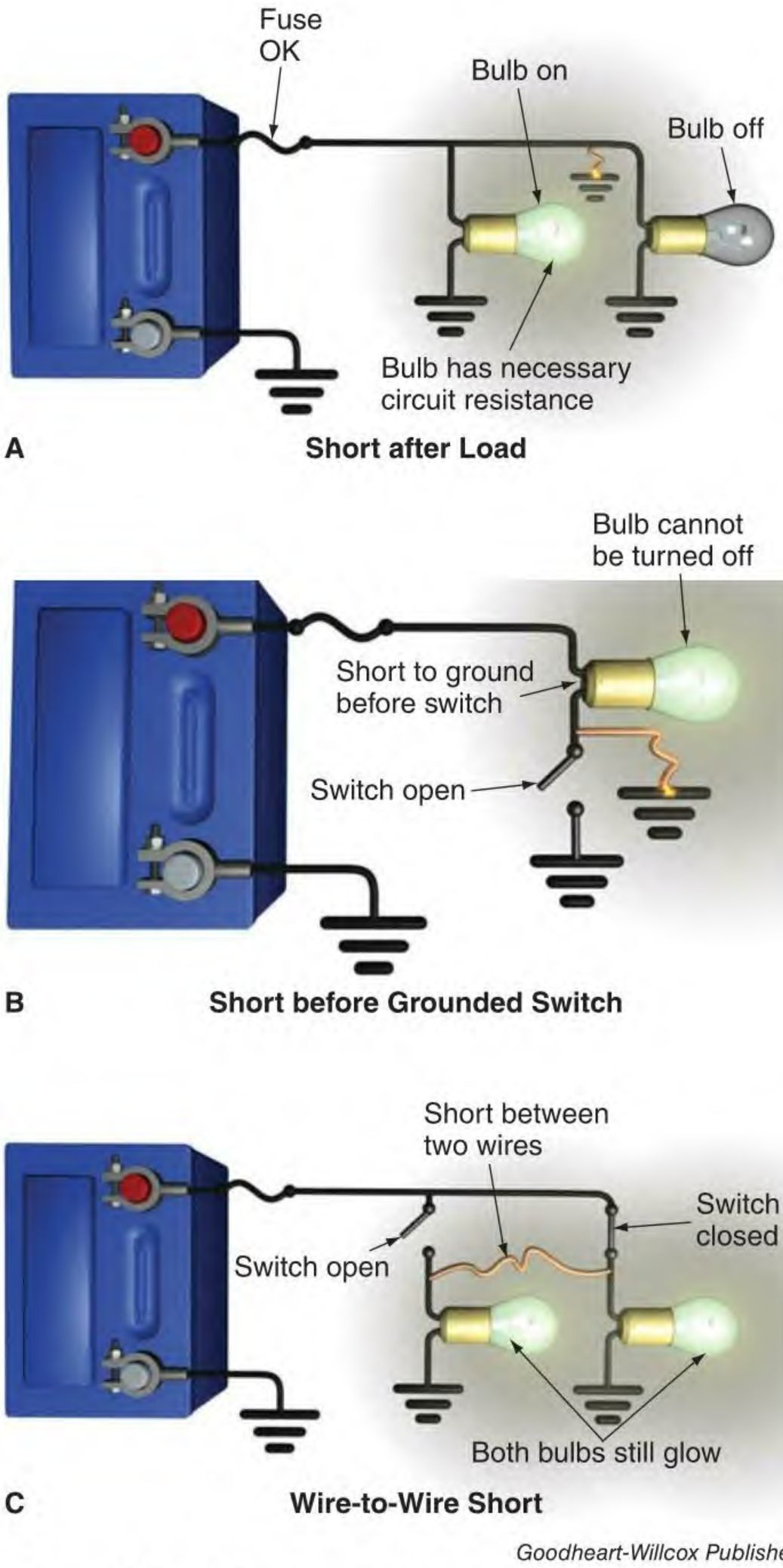


Figure 22-9. The location of the short in a circuit affects the symptoms that appear. A—A short after a load cuts power to the second load. However, the first load still works. Current increases slightly because of less resistance in the circuit. However, current may not increase enough to blow the fuse because of the resistance of the first load. B—Short before a grounded switch. The load stays on all the time, even with the switch open. Current bypasses the switch to ground. C—In this wire-to-wire short, the short feeds current across two branches. Even with one switch off, current leaks over to the other branch. Only when both switches are off will the bulbs turn off.

shunts current away from the second load. The second load (bulb) will not function. The current seeks the path of least resistance through the short to ground.

Figure 22-9B shows how a short before a switch can prevent a circuit from being shut off. A short before the grounded switch allows current in the circuit, even with the switch off.

Figure 22-9C shows an example of a wire-to-wire short. The conductors in two wires are touching because of damaged insulation. In this case, the short could make both loads (bulbs) function even when the switch to one of the loads is turned off.

Intermittent Problems

An ***intermittent problem*** is one that occurs only under certain conditions. The problem may be present one time but may not show up later. This makes testing difficult because the symptoms may not occur when you are troubleshooting.

Many intermittent problems are caused by poor electrical connections. For example, two terminals in a connector may be loose. Most of the time, the two terminals make contact and the circuit functions normally. However, when the vehicle hits a bump, the jolt may separate the loose terminals, causing the circuit to malfunction temporarily. An intermittent failure can result.

Using Testing Devices

This section of the chapter summarizes the use of electrical testing devices, including jumper wires, test lights, and multimeters. To be an effective technician, you must know how to use this equipment.

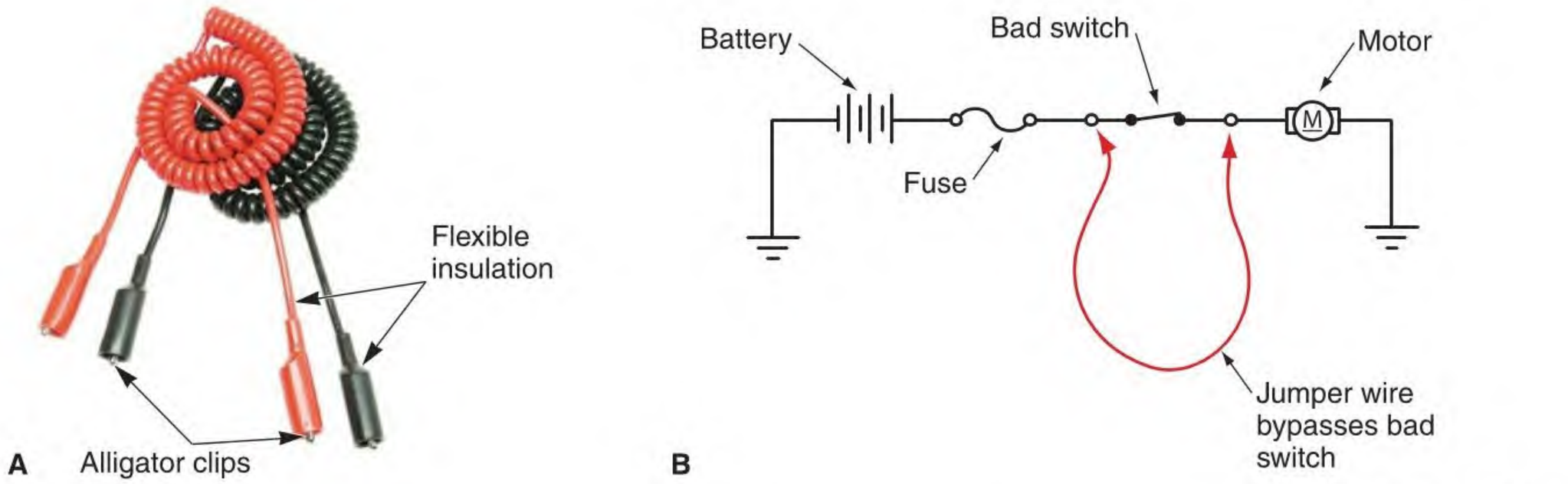
Tech Tip

When you are looking for shorts or opens, wiggle or move the wires while you are testing. This might move the conductor enough to produce the problem. It might also correct a problem temporarily so you can detect the trouble. Always look for wire damage. Check for cut or smashed wire insulation and loose connections. Any of these can cause a malfunction.

Using Jumper Wires

A ***jumper wire*** is a piece of wire with alligator clips on both ends, as shown in **Figure 22-10A**. It is commonly used to bypass components or to apply voltage

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Figure 22-10. Jumper wires allow you to bypass a section of the circuit for testing. Be careful not to connect the battery voltage to any ground. A—Jumper wires can be used to bypass a component or connect power to a circuit for testing. B—A jumper wire provides an easy way to bypass a component or connect power directly to a component or section of circuit. In this example, if bypassing the switch makes the motor run, the switch is bad.

to a component or section of a circuit. **Figure 22-10B** shows a good example of how a jumper wire can be used to check a switch. You might use the jumper wires to bypass the switch if symptoms point to an open switch; for example, if turning the switch on does not feed current to the load (motor). If attaching the jumper around the switch turns the motor on, the switch is bad.

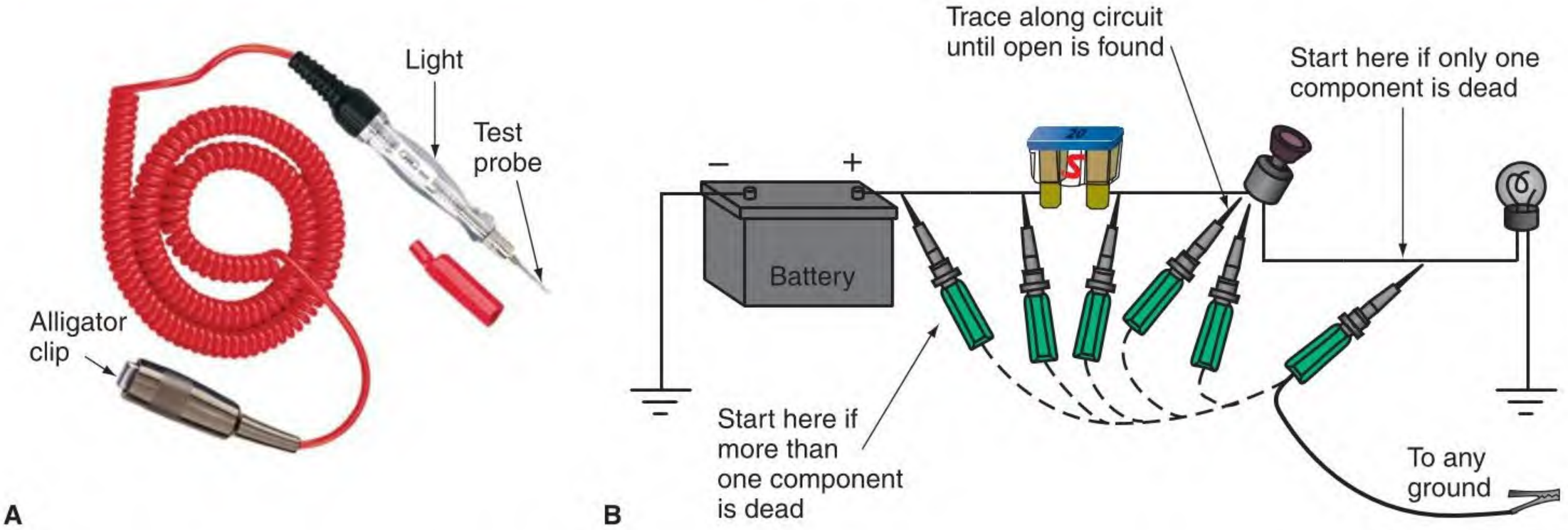
Warning

Never use a jumper wire to bypass a high-resistance component, a fuse, or a circuit breaker. This could allow excess current and cause an electrical fire.

A jumper can also be used to connect voltage directly to the load. If the load begins to work, something is wrong in the circuit leading to the load. If jumping directly to the load does not make it work, the load itself or the ground may be at fault.

Using a Test Light

A ***test light*** provides a quick and easy way of checking a circuit for power or continuity. See **Figure 22-11A**. Most test lights have a sharp probe for touching conductors and an alligator clip for grounding. As previously discussed, test lights can be either circuit-powered or self-powered. Circuit-powered test lights are more commonly used in auto repair.



Snap-on Tool Corp.

Figure 22-11. A test light is a quick way to check for battery voltage in a wire or component. A—A test light provides a way to check for power or voltage in a circuit. B—With the circuit-powered type, the alligator clip is grounded. Then the test probe is touched to the circuit at different locations to find breaks in the circuit.

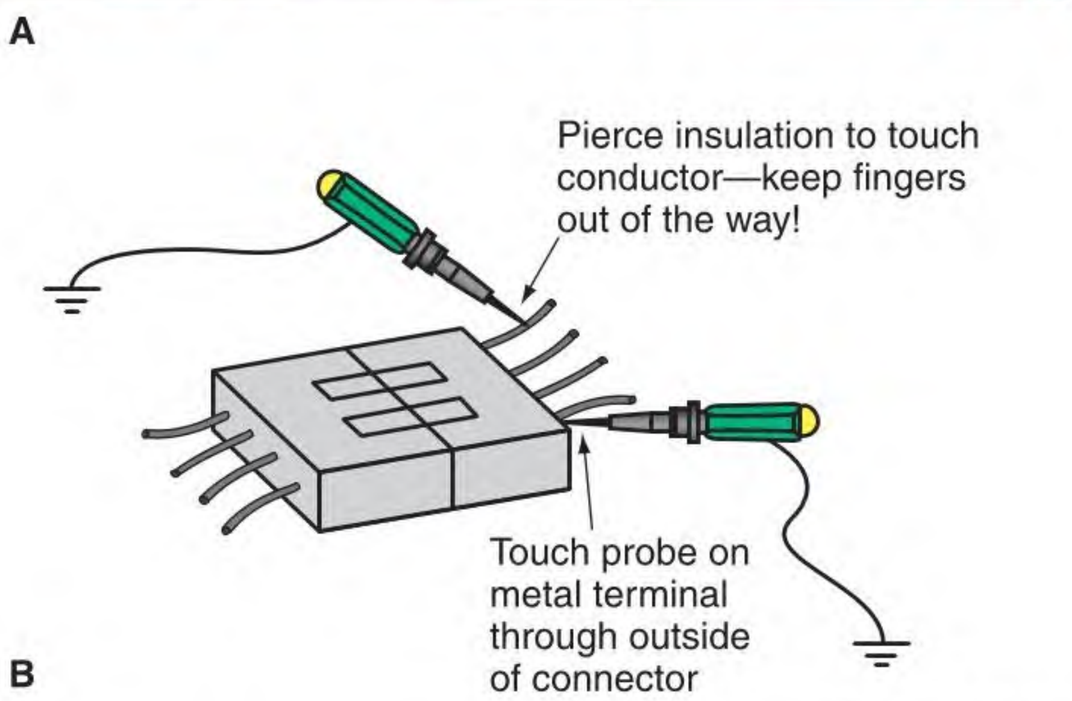
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A circuit-powered test light uses the circuit voltage to illuminate the tester bulb. **Figure 22-11B** shows how to use a circuit-powered test light to check for power. The alligator clip is connected to any good ground. Then the test probe is touched on different points in the circuit. If the test light glows, the circuit is good up to that point. See **Figure 22-12A**. As soon as the test light fails to glow, you have found the problem area.

Sharp test light probes can be used to puncture wire insulation to check for power in the conductor. See **Figure 22-12B**. This is useful when you cannot access a connector for your tests. The test light can also be inserted into the back of a connector so that the probe touches one of the metal terminals in the connector. The connector can also be unplugged to check for voltage.



A



B

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Figure 22-12. If the test light glows dimly, you have a high resistance or poor electrical connection in the circuit. A—A test light is being used to check for power to the power window switch. B—The test light has a sharp, pointed tip. It can be touched on a terminal or pushed through wire insulation to touch the conductor.

Tech Tip

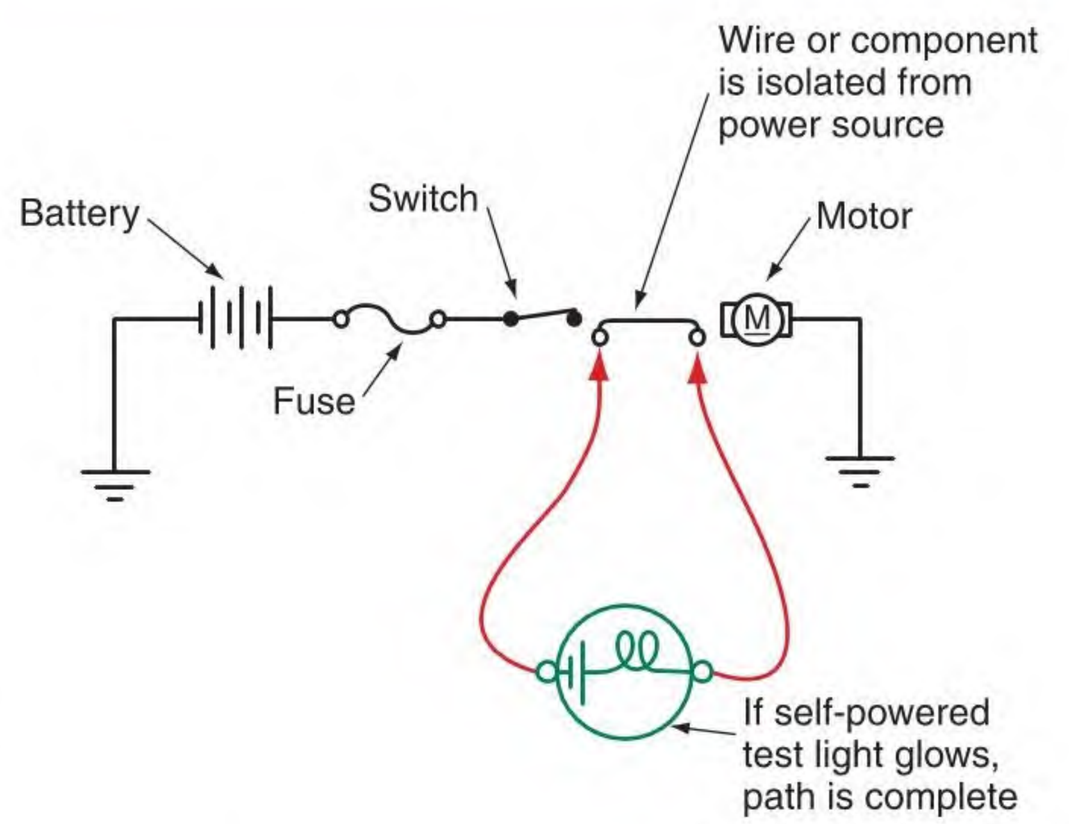
Avoid using a test light probe to puncture the insulation on wires in a computer or sensor circuit. Moisture can enter through the hole in the insulation. If the wire is to a sensor with a weak or low voltage signal, this can upset the small signal going to the computer, and a computer system malfunction may result.

A self-powered test light, or continuity tester, has an internal battery. It uses its own power source to check for a complete electrical path, so the circuit's power source must be disconnected for testing. **Figure 22-13** shows how a self-powered test light can be used to check for continuity.

Figure 22-14 shows how a test light can be used to help find shorts. The test light is substituted for the fuse in the affected circuit. As long as the circuit is complete, the test light glows. Wiggle the wires or disconnect components or wires until the test light goes out. When the test light does not glow, you have found the source of the short.

Warning

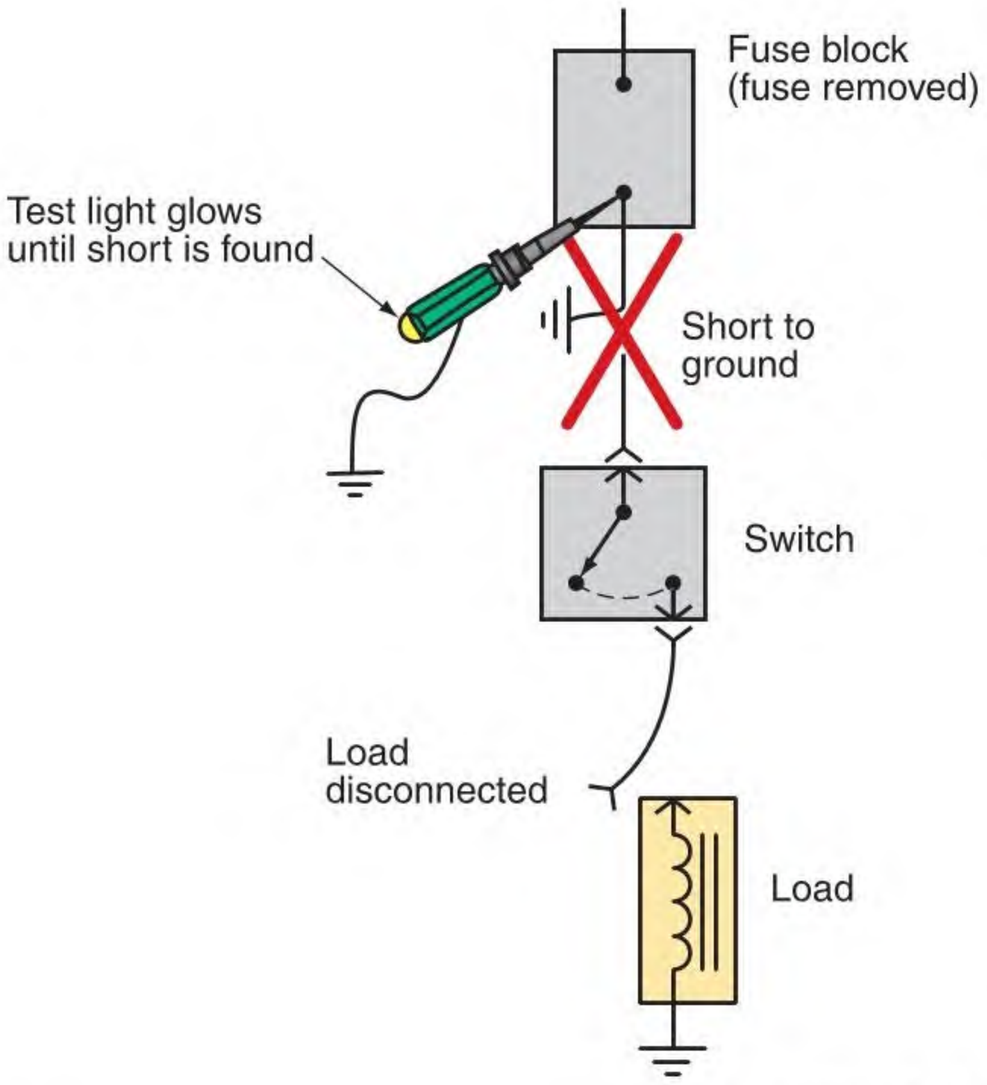
Test light probes are very sharp. It is easy to jab the probe through your skin when trying to penetrate the wire insulation. Do not place your fingers behind the probe when testing.



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Figure 22-13. To use a self-powered test light, you must first disconnect the circuit power source.

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Figure 22-14. Using a test light to help find a short circuit. Remember to disconnect the circuit before testing if you are using a self-powered test light.

Using an Inductive Wire Tracer

An inductive wire tracer uses a signal generator and an inductive pickup to find shorts. See **Figure 22-15A**. The signal generator is connected to the vehicle battery as shown in **Figure 22-15B** or to the battery and to the affected circuit. This produces a weak, fluctuating voltage in the wiring. The pickup, or detector, can then be moved along the outside of the wiring as shown in **Figure 22-15C**. It senses the fluctuating magnetic field around the outside of the wire. If you move the sensor over a short in the wire, the audible tone changes or the tracer makes a beeping sound, depending on the particular tracer.

Using a Multimeter

A multimeter is a voltmeter, ammeter, and ohmmeter combined in one housing. Also called a VOM (volt-ohm-milliammeter), it is an essential tool for automotive technicians. It can make accurate measurements of circuit values, which you can compare to known good values. If the measured values are high or low, you know a problem exists in the circuit.

Meter Connections

As you may recall, a ***voltmeter*** measures electrical pressure, or voltage (V). A voltmeter is connected in parallel with the circuit being tested. The circuit's power source must operate the voltmeter. See **Figure 22-16A**.

Caution

Many hybrid drive systems operate on high voltage. Use *only* test instruments rated for high voltage when testing high-voltage hybrid drive trains. High-voltage test equipment has thicker internal insulation to prevent internal electric arcs that would damage a low-voltage test instrument.

An ***ohmmeter*** measures the resistance to current in ohms (Ω). Power must be disconnected from the component or portion of the circuit being tested. Then the ohmmeter can be connected to each end of a wire



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Figure 22-15. This is an inductive circuit tracer. A—A circuit tracer consists of a signal generator and an inductive pickup. B—The signal generator must be connected to the battery to generate an ac signal in the vehicle wiring. C—Move the tracer along the wires. The tone changes or the unit beeps when you move the tracer over a break or bad connection in the wiring.

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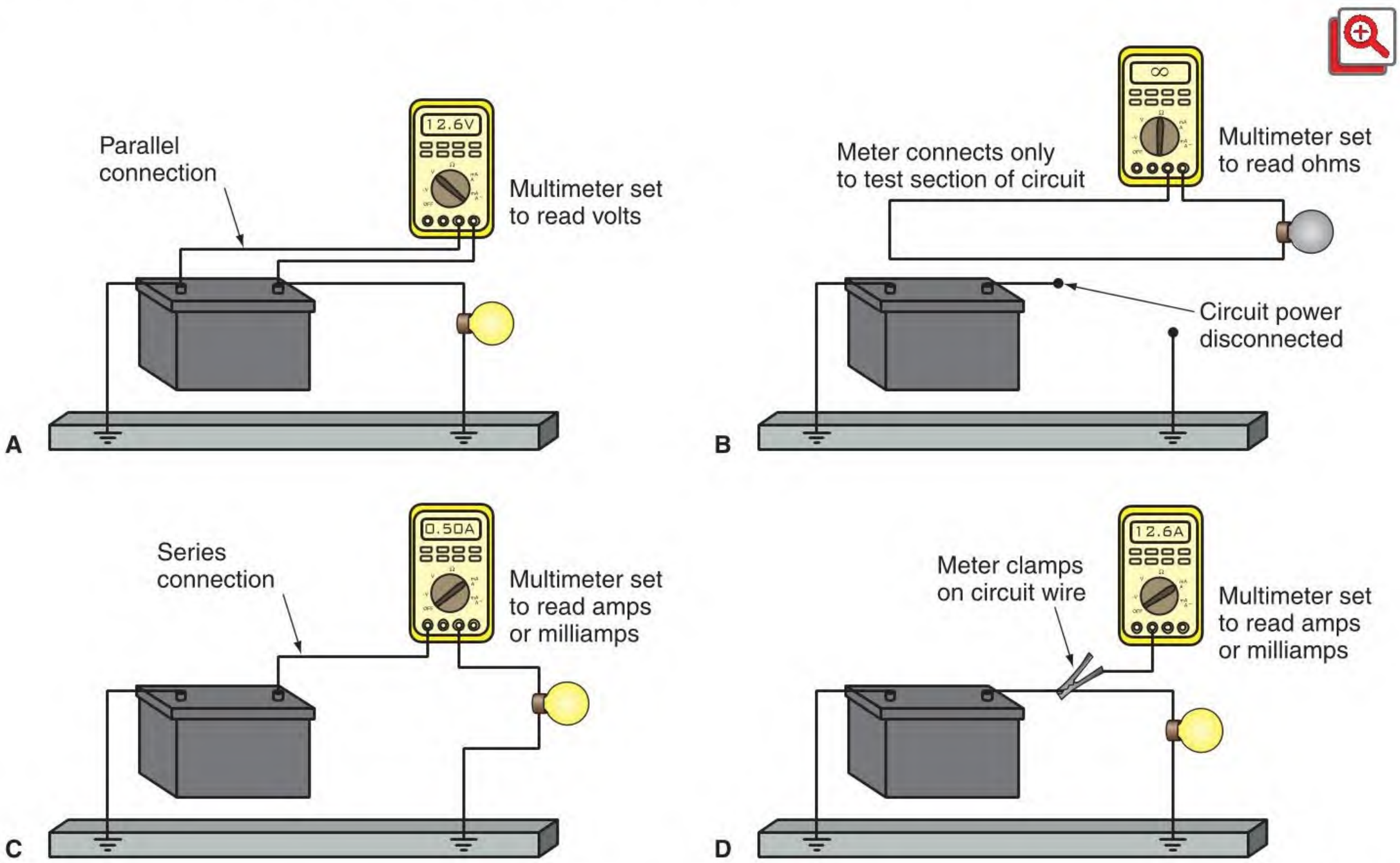
or component to check its internal resistance. This is shown in **Figure 22-16B**.

An ***ammeter*** measures current in amps (A). A conventional ammeter must be connected in series with the circuit being tested. All circuit current must pass through the ammeter. See **Figure 22-16C**. However, inductive ammeters have a clip-on pickup that fits over the wire insulation, as shown in **Figure 22-16D**. The pickup senses and measures the magnetic field around the wire, which is proportional to the current in the wire. The ammeter calculates and displays the reading in amps. An inductive pickup is a handy meter attachment for analyzing charging systems and hybrid power system operation. Most meters connected in series will not read more than a few amps without an inductive pickup.

Meter Controls

Most digital and digital-analog multimeters have a large function knob that can be rotated to select the type of electrical reading to be taken. The function knob can select a reading in volts dc or ac, amps dc or ac, and ohms. It may also have other settings, such as rpm and diode testing. See **Figure 22-17**. Meter control buttons are usually provided to allow you to select other function variables: zero meter, minimum/maximum readings during the test, range, hold, duty cycle (percent on and off), and sound alert. Most multimeters also have different test lead sockets or holes, as shown in **Figure 22-17**. Each socket is for a different type or range of measurement.

Most digital meters are ***auto ranging***—they automatically change to the correct scale. All you have to do is set the meter knob for volts, amps, or ohms, and the meter adjusts itself automatically to the correct range. For example, a digital meter might display a "k" next to the number readout when you are measuring a high resistance, as shown in **Figure 22-18**. This means the meter is displaying the value in kilohms. A reading of 9.27 kΩ equals 9270 ohms. An "M" next to the readout means the value is displayed in megohms. If no prefix is shown, the reading is in ohms.



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Figure 22-16. These are the methods normally used to connect a voltmeter, ammeter, and ohmmeter to a circuit. A—A voltmeter is normally connected in parallel with the circuit. B—Power must be disconnected from the component being tested so the ohmmeter can use its battery power to measure resistance. C—A conventional ammeter is wired in series with the circuit to measure current. D—An inductive ammeter clamps onto the outside of the wire and reads the magnetic field around the wire.

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Figure 22-17. Study the basic parts of this digital-analog multimeter.



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Figure 22-18. Auto ranging meters automatically adjust to the correct value range. This value is being displayed in kilohms (kΩ).

Tech Tip

To read a meter correctly, you must understand the electrical multipliers shown on the meter display. The prefixes used on digital multimeters are standard for electrical units.

Figure 22-19 shows a few voltmeter readings. This meter has function settings for dc volts and ac volts. The volts setting is used for most measurements in a



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Figure 22-19. Sample voltage settings and readings. A—The meter can be set to read volts dc (straight line) or volts ac (curved line). B—The meter displays ac or dc in the display window, depending on which type of voltage is being read. This is an ac voltage reading. C—This is the dc voltage reading. D—This is the dc voltage reading in millivolts.

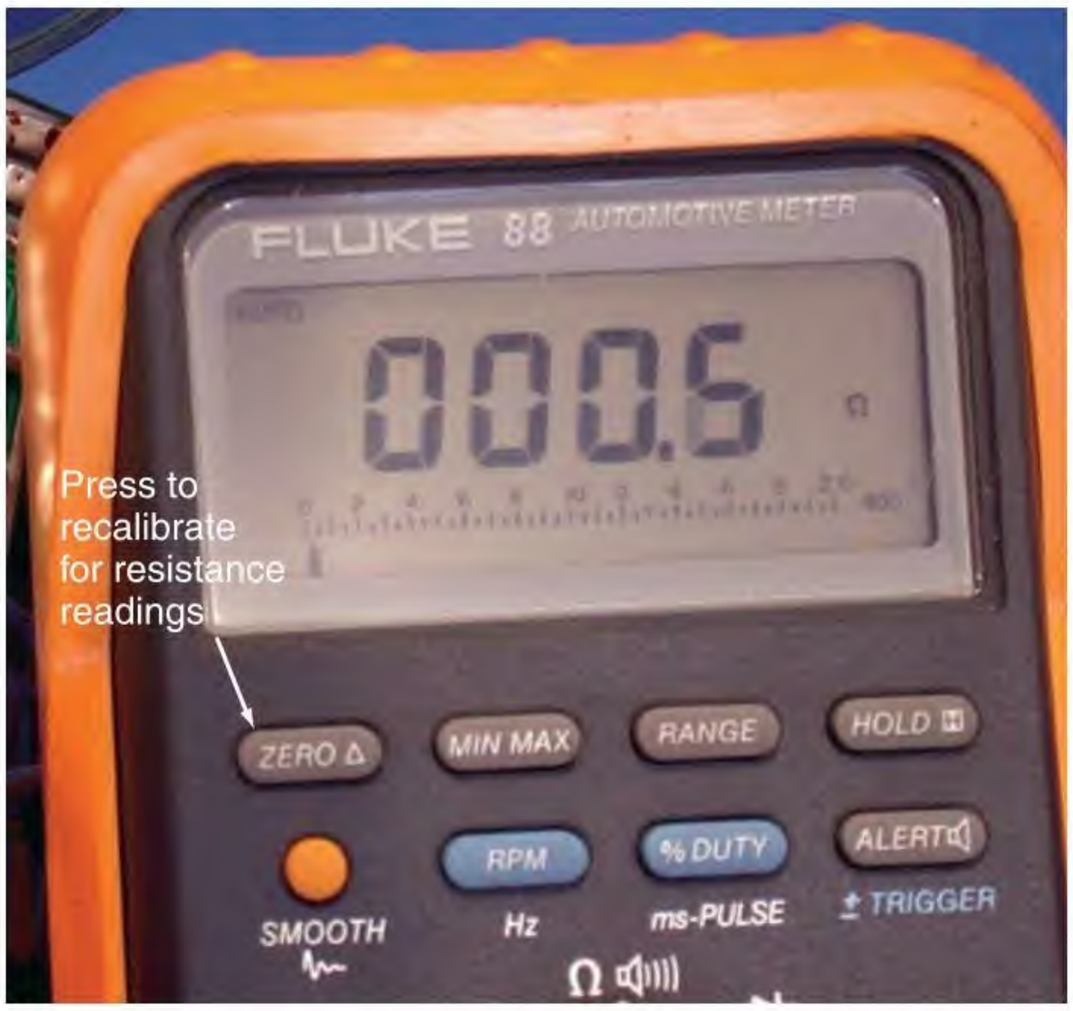
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vehicle's electrical systems. The volts might be used to check the signals from speed or position sensors that generate a small ac signal indicating engine or driveline speed.

Figure 22-20 shows some ohmmeter readings from a digital multimeter. Note the multiplier shown on the far right of the display screen. Some ohmmeters must be calibrated to zero before you can make accurate resistance measurements. The calibrate function compensates for battery condition and provides accurate measurements. To calibrate the ohmmeter, touch the two meter leads together. The meter should display a reading of zero ohms. If it does not, press the Zero button to recalibrate the meter to zero. See **Figure 22-21**.

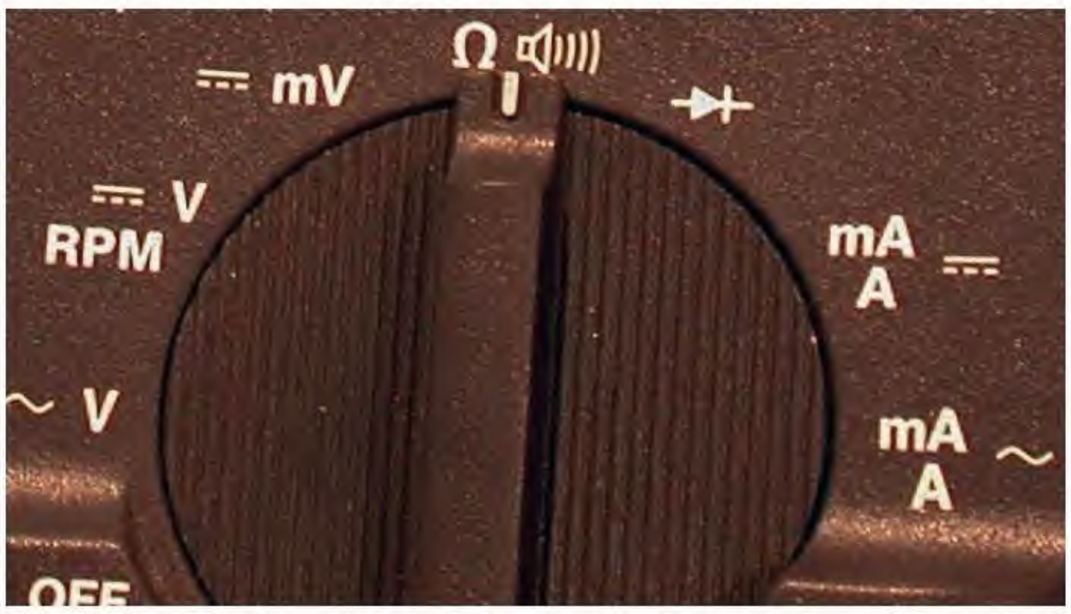
Figure 22-22 shows a multimeter set to make current (amp) readings. To avoid blowing a fuse in the ammeter, make sure the possible amp reading is below the rating of the ammeter. Meter damage can occur if you accidentally send too much current through a meter. Use an inductive pickup for higher amp readings.

The bar graph on a digital-analog multimeter serves as an analog display that can show rapid changes in readings. The bar graph functions much



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Figure 22-21. Press the Zero button while touching the two leads together to recalibrate the meter to zero before taking resistance readings.



A



B



C



D

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Figure 22-20. Sample ohmmeter settings and readings. A—The function knob must be set to ohms. B—This reading is displayed in ohms. C— Note the capital M next to this reading. The reading is displayed in megohms. D—What unit of measurement is used in this reading?

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like the needle on an analog meter. If a circuit or component has an intermittent open or bad connection, the bar graph display moves back and forth to display this rapid change in the reading. The digital display changes as well, but it may not be able to keep up with the reading changes. See **Figure 22-23**.

Some older meters are not auto ranging and must be switched to the correct range. For example, the meter might have a kilohms setting, which means each reading must be multiplied by 100 to find the value in ohms. If the reading is in megohms, you must multiply the reading by 100,000. Various voltage and current settings are also provided on some meters that are not auto ranging.

Voltage Measurements

Voltage measurements are also useful in determining the condition of a circuit or components. By checking the voltage, you can gather more information about the electrical problem. For example, by measuring battery voltage, you can check the charge or condition of a vehicle's battery. A fully charged 12-volt battery should have 12.6 volts. If your voltmeter reads only 11 volts, the battery either needs to be recharged, or it has an internal problem, such as low electrolyte, deteriorated plates, or shorts in cells.

As another example, imagine your engine cranks very slowly and will not start. You might measure the voltage across your positive and negative battery terminals to measure the battery's state of charge. A fully charged 12-volt battery will have 12.6 volts. As it is drained of



A



B



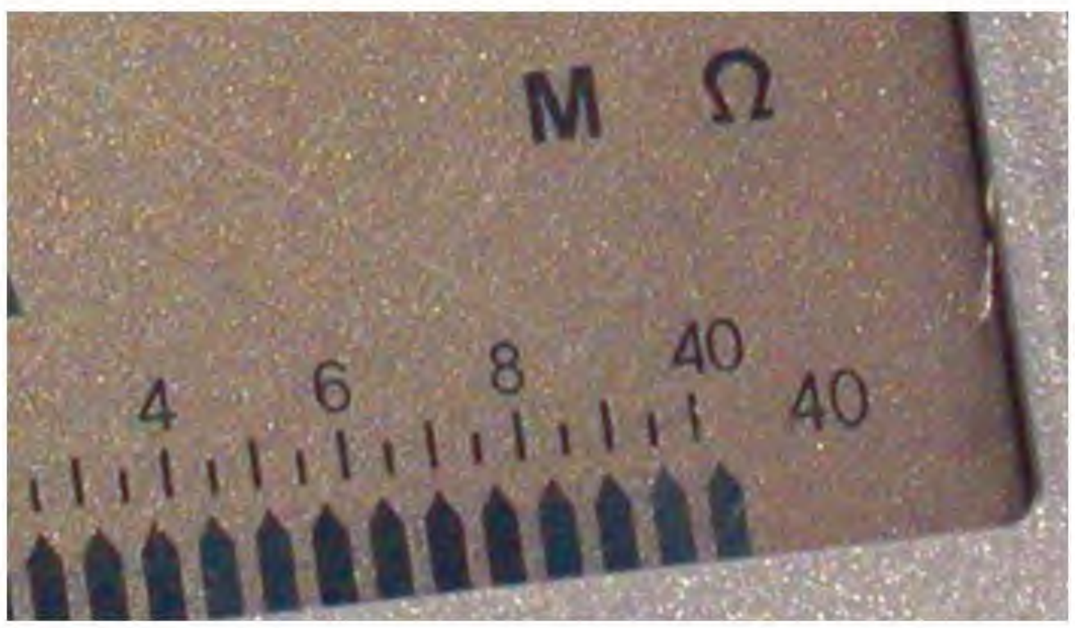
C

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Figure 22-22. Making ammeter readings on a digital multimeter. A—Turn the function knob to A for amps. B—Plug the test leads into the correct sockets for ammeter use. C—Notice the prefix in the units display. What does this ammeter read?



A



B

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Figure 22-23. The bar graph on a digital-analog multimeter allows you to see fluctuating values easily. A—The analog bar graph shows almost zero resistance. B—The bar has moved all the way to the right to show a maximum resistance reading. This can happen very rapidly and in quick succession, showing rapid fluctuations clearly.

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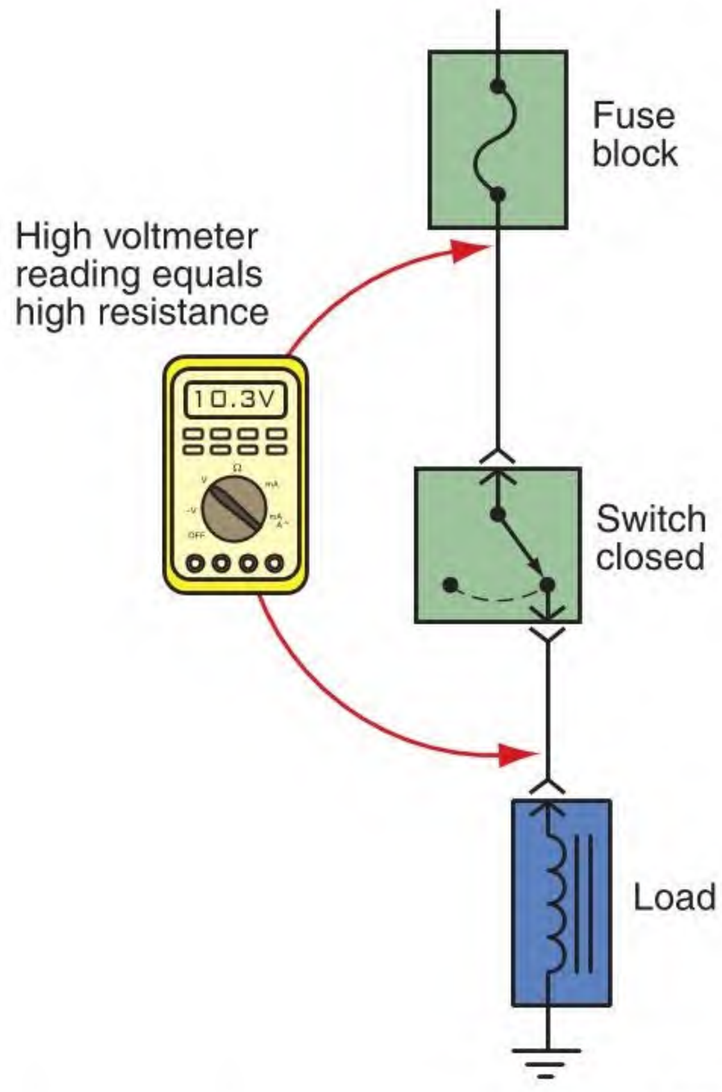
electrical energy, this voltage goes down to 11.5 volts, 10 volts, until the battery is "dead" at zero volts.

Voltage Drop Measurements

A ***voltage drop measurement*** determines the internal resistance of a wire or component. Instead of disconnecting the power source and using an ohmmeter, you can check voltage drops to find resistance for each circuit section without disconnecting the circuit. This is a much faster way of checking a circuit for high resistance.

For example, suppose you suspect a switch of having a poor internal connection and high resistance. To measure the voltage drop, connect the voltmeter across the input and output leads of the switch, as shown in **Figure 22-24**. If the voltage drop across the closed switch is too high (more than about one volt for most switches), then the switch has a poor internal connection. A good switch, when closed, has little or no voltage drop.

Figure 22-25 further illustrates the principle of voltage drop measurements. If the load resistances are equal, the voltage drop is equal across these components. As you may recall from Chapter 3, the sum of all voltage drops equals the supply voltage in a series circuit. **Figure 22-26** shows how voltage drops vary with resistance.



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Figure 22-24. Voltage drop measurements check resistance without requiring you to disconnect components. If the closed switch has a high voltage drop, the circuit has a high resistance problem.

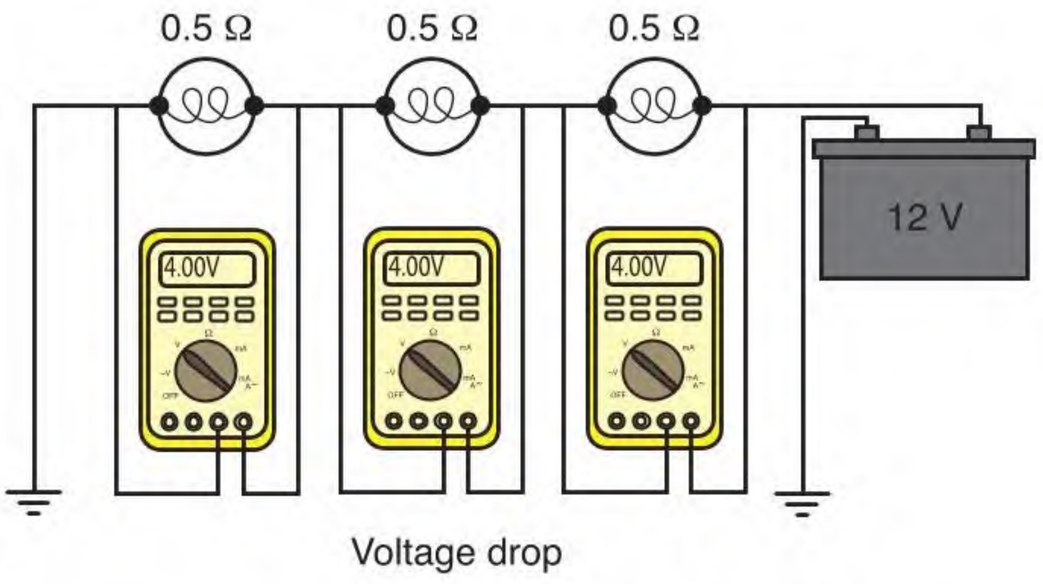
Resistance Measurements

Resistance measurements are commonly taken when the circuit or component is disconnected or when very accurate resistance readings are needed. **Figure 22-27** illustrates some examples of resistance measurements.

Infinite resistance, shown with an ∞ (infinity) symbol, means the circuit path is not complete. Something is preventing current through the tested circuit or component. There is no continuity with an infinite resistance reading. ***Zero resistance***, or no resistance, means a perfect electrical path exists between the two test points. This shows that there is continuity and a resistance of 0 in the tested circuit or component.

Amperage Measurements

Amperage measurements are needed to check the condition of various components. **Figure 22-28** illustrates how an ammeter reading might be used to check the condition of a motor. The measured values can be compared to known good readings. A high current draw might point to a problem producing a drag on the motor, such as bad armature bearings or a short in a winding. A low current measurement might point to a problem that is preventing normal current, such as burned motor brushes, poor terminal connections, or a bad ground.

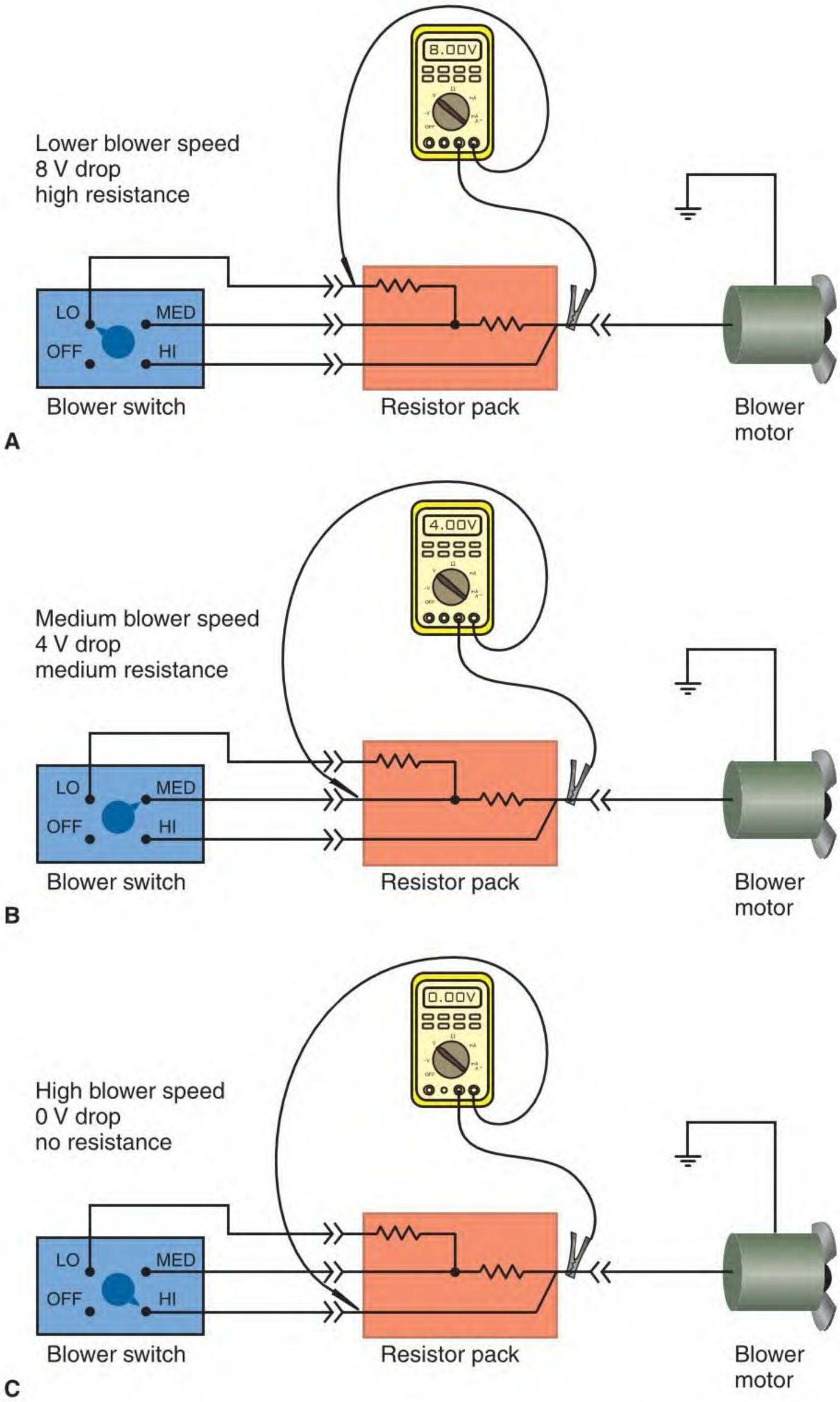


Total resistance = 0.5 Ω + 0.5 Ω + 0.5 Ω = 1.5 Ω
Total voltage = 4 V + 4 V + 4 V = 12 V

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Figure 22-25. A component's resistance determines its voltage drop, so components that have equal resistance have equal voltage drops. Total circuit voltage drop equal voltage applied.

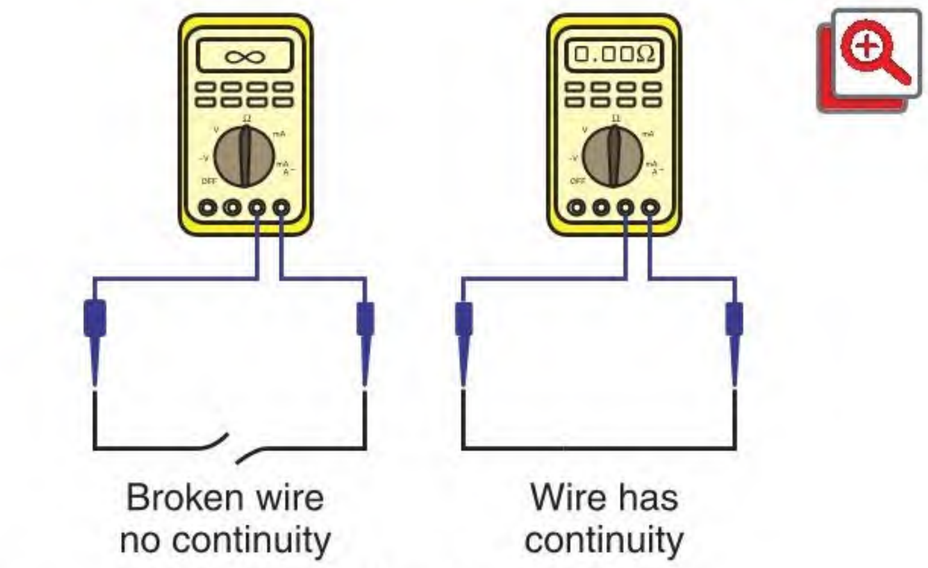
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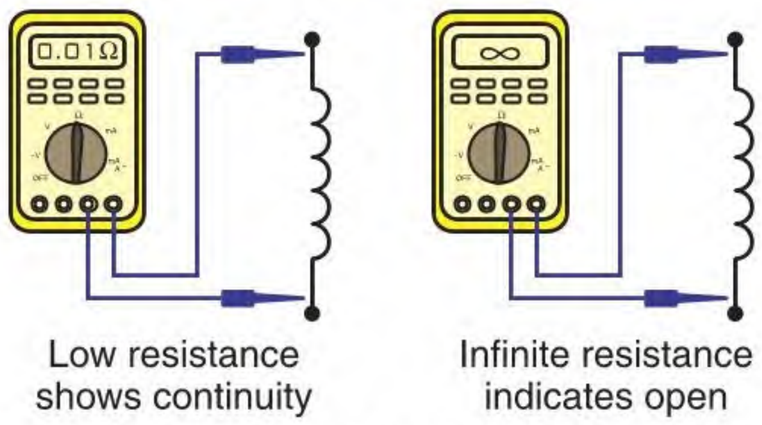
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Figure 22-26. Example of how voltage drops can be used to check internal resistances without disconnecting components from a circuit. A—The branch of the resistor pack for the lowest blower speed shows a high voltage drop and a high resistance. B—The branch of the resistor pack for medium blower speed has a medium voltage drop and a medium resistance. C—The branch of the resistor pack for high blower speed must have low resistance to pass high current. The voltage drop is also low.

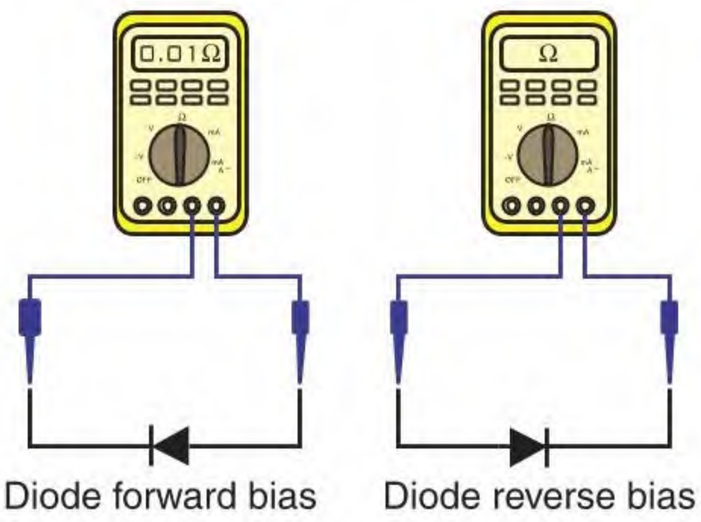
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A Checking Wire Continuity



B Checking Coil



C Checking Diode

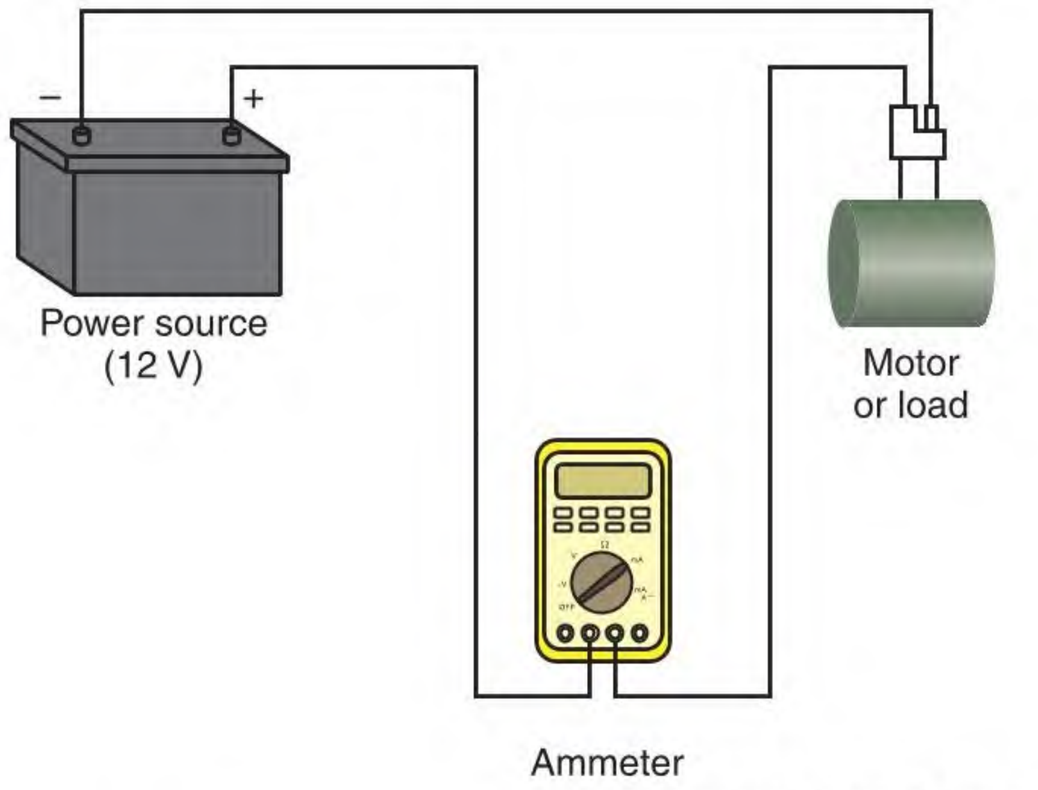
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Figure 22-27. These are some examples of resistance measurements. A—A wire conductor should have low resistance. B—A coil is basically a conductor wound in a spiral. It should have very low resistance. C—The ohmmeter should show a high resistance when connected in one direction across a diode. It should show low resistance in the other direction. This shows that the diode is functioning as a one-way electric check valve.

Rules for Using Multimeters

As you work with multimeters to diagnose electric or electronic circuit problems, keep these rules in mind:

- Make sure the test leads are connected properly. An incorrect connection may damage electronic components or the meter itself.
- Set the meter to read a high enough value. If you have the meter set on 0 to 10 amps, for example, and you try to measure 100 amps, you might burn up the meter or blow its fuse.
- Use a digital or digital-analog meter to check computer circuits.
- Place the meter in a secure location. Multimeters are expensive, and they can be ruined if they are dropped. Also keep them away from moving or hot engine parts.
- Keep the test leads away from hot or moving parts to ensure that they do not get caught in engine fans, burned on hot exhaust manifolds, or suffer other physical damage.
- Use the specifications in the service manual to determine whether a circuit or component is faulty. Component and circuit resistance, voltage, and current values vary from model to model.
- If needed, zero or calibrate the ohmmeter before use to ensure accuracy.
- To help find intermittent problems, wiggle wires and carefully use a heat gun or freeze spray on electronic components. This can help change the reading to indicate the problem.



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Figure 22-28. Using an ammeter to check a circuit. If current is too high, a low resistance or high voltage is indicated. If current is low, a high resistance or low supply voltage is indicated.

Caution

A heat gun produces enough heat to damage sensitive electronic components. Use the heat gun sparingly and avoid generating very high temperatures around these components.

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Basic Component Tests

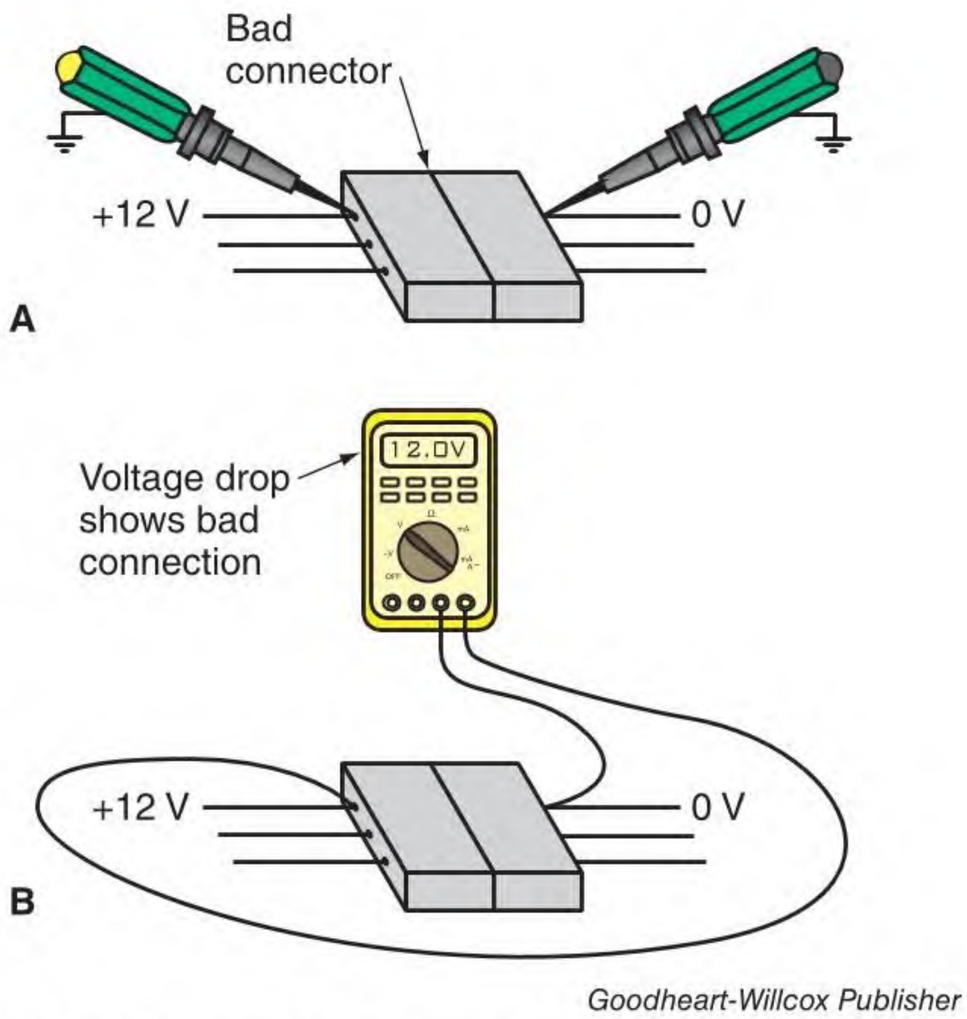
This section of the chapter briefly explains how to test basic electric and electronic components. Understanding these test procedures will help you later when you study other, more specific tests.

Testing Connectors

A good connector has little or no resistance across its terminals. A bad connector has resistance that decreases current through the connector. This reduced current can upset or stop the operation of the circuit that contains the connector.

A test light can be used to check for power on both sides of a connector. See **Figure 22-29**. This test might be used when a circuit is completely dead, indicating that power is not reaching a component or section of a circuit. First, check for power going into the connector. See **Figure 22-30A**. Then check for power on the other side of the connector. Make sure you check the same wire or terminal. Unless you are testing a weather-pack connector, you can touch the test probe on the terminals through the outside of the connector. If the test light does not glow on both sides of the connector, you have found a high resistance or poor electrical connection.

A voltage drop test can also be used to check a connector. See **Figure 22-30B**. A good connector has little voltage drop. A high voltage drop indicates poor terminal contact.



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Figure 22-30. Testing a connector. A—Using a test light, you can quickly check for power on both sides of a connector. If the test light glows on one side only, a bad terminal connection is indicated. B—Use a voltmeter to check the voltage drop across a connector. A high drop shows a high resistance problem.

Testing Resistors

Various types of resistors are used in various automobile circuits. After a period of use, resistors can break down and change resistance. This can upset the operation of the circuit. An ohmmeter can be used to test actual resistance. See **Figure 22-31**. A voltmeter can also be used to check the resistor's voltage drop. If the resistor is not within specifications, it should be replaced.

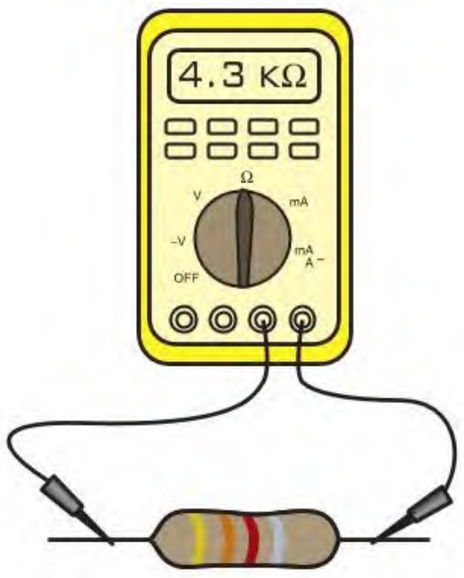


OTC/SPX Corp.

Figure 22-29. A good set of test leads makes it possible to probe all types of electrical connectors without damaging them. To prevent damage, never insert a large test probe into a small connector terminal.

Testing Variable Resistors

A good variable resistor should exhibit a gradual change in resistance as you turn its shaft or move its



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Figure 22-31. The resistance of all resistors in a vehicle must be within specifications. After a period of service, resistor values can change enough to upset circuit operation.

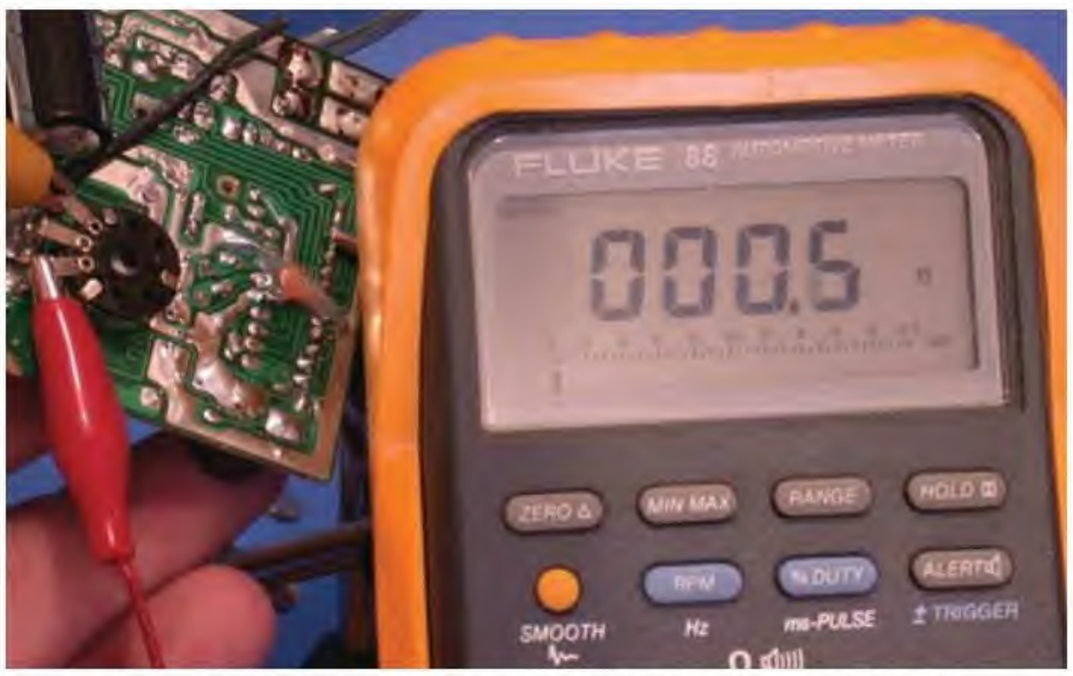
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slide. A bad variable resistor might be open (infinite resistance) or shorted (zero resistance). It may also be stuck at a specific resistance value, or its resistance may not vary properly with shaft or slide movement.

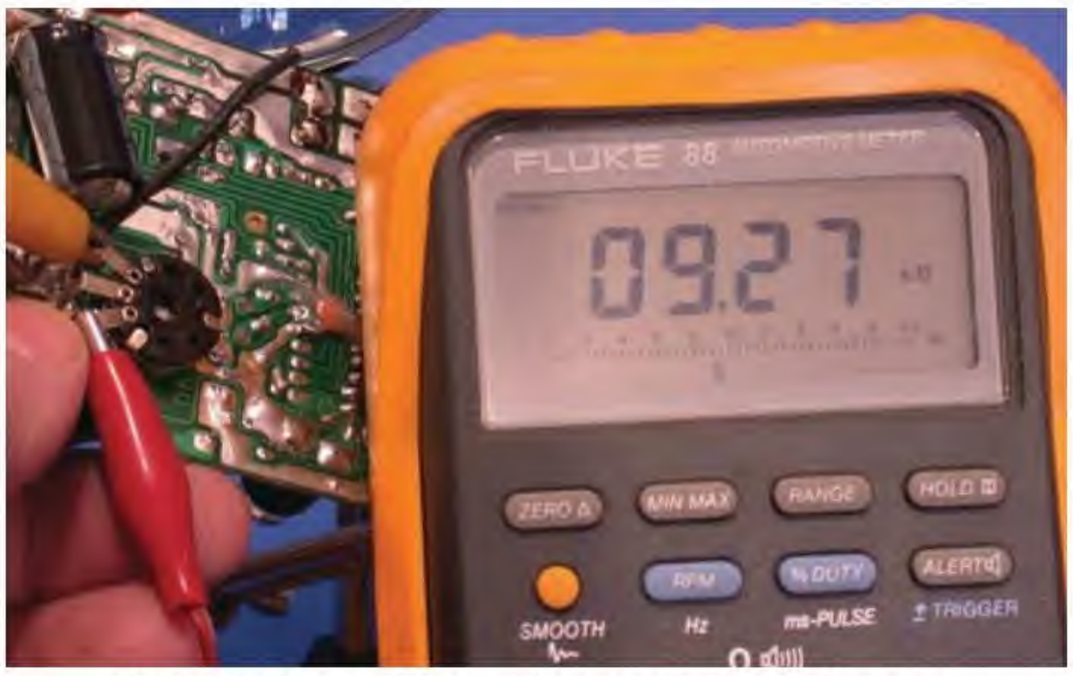
In most conditions, an ohmmeter is the most accurate way of checking a variable resistor. The service manual usually gives resistance specifications for different variable resistor positions. If test values differ from specifications, the variable resistor is bad. See **Figure 22-32**. You can also check a variable resistor by testing voltage drops, but specifications are not given this way.

Testing Switches

A good switch blocks current in one position and passes current freely in the other position. A bad switch may not turn on and off, or it may have high resistance when on. A switch can be tested using a test light, voltmeter, or ohmmeter.



Variable Resistor at a Low-Resistance Position



Variable Resistor at a High-Resistance Position

Union Electronics

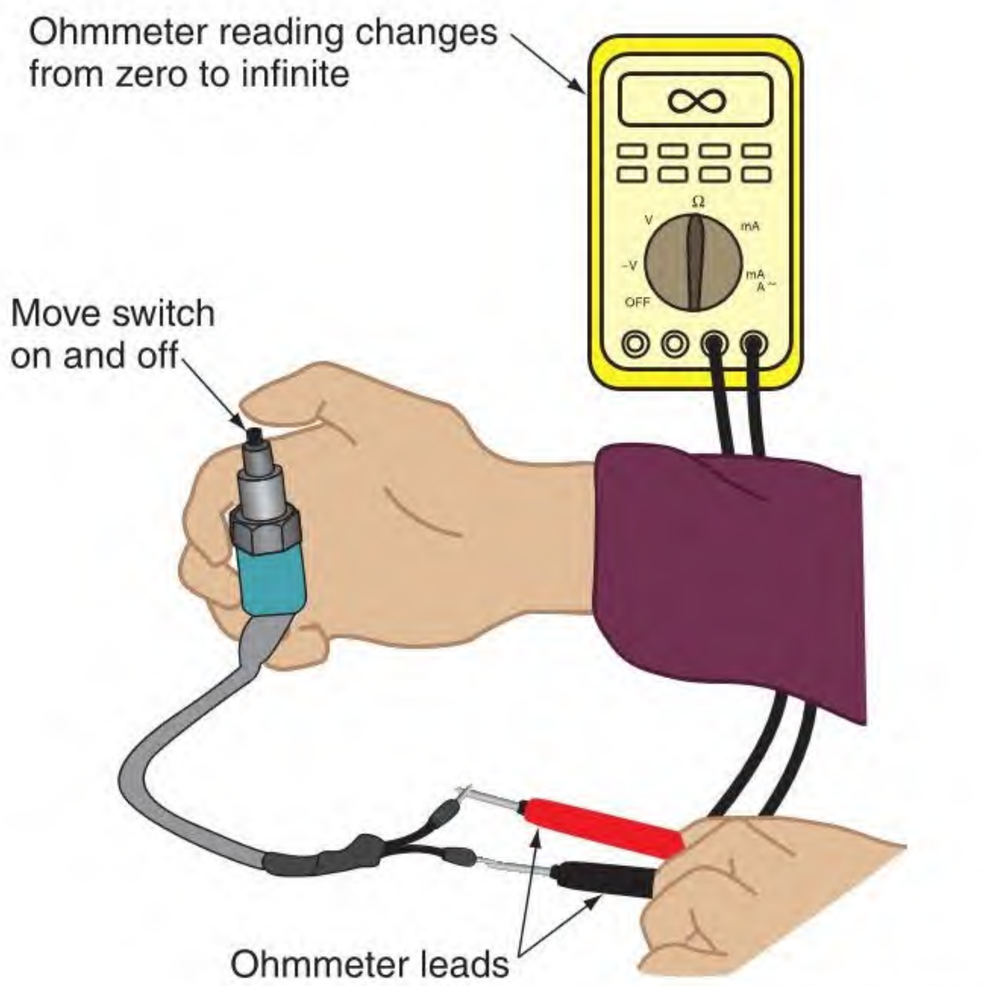
Figure 22-32. A variable resistor, or potentiometer, should have a specific resistance reading at each position. Compare your readings with those given in the service manual.

If the switch is still installed, a test light can be used to check for power in the two positions. A voltmeter can also be connected across the switch. It should show full voltage drop when the switch is off and little or no voltage drop when the switch is on. An ohmmeter can be used if the switch is removed or isolated from the circuit. The switch should have zero resistance when on and infinite resistance when off. See **Figure 22-33**.

Testing a Transducer Switch

The internal resistance of a ***transducer switch*** changes with a change in a condition. Examples include temperature switches, position switches, and pressure switches. When a transducer switch fails, it usually stays in the same position (on or off) even though conditions change.

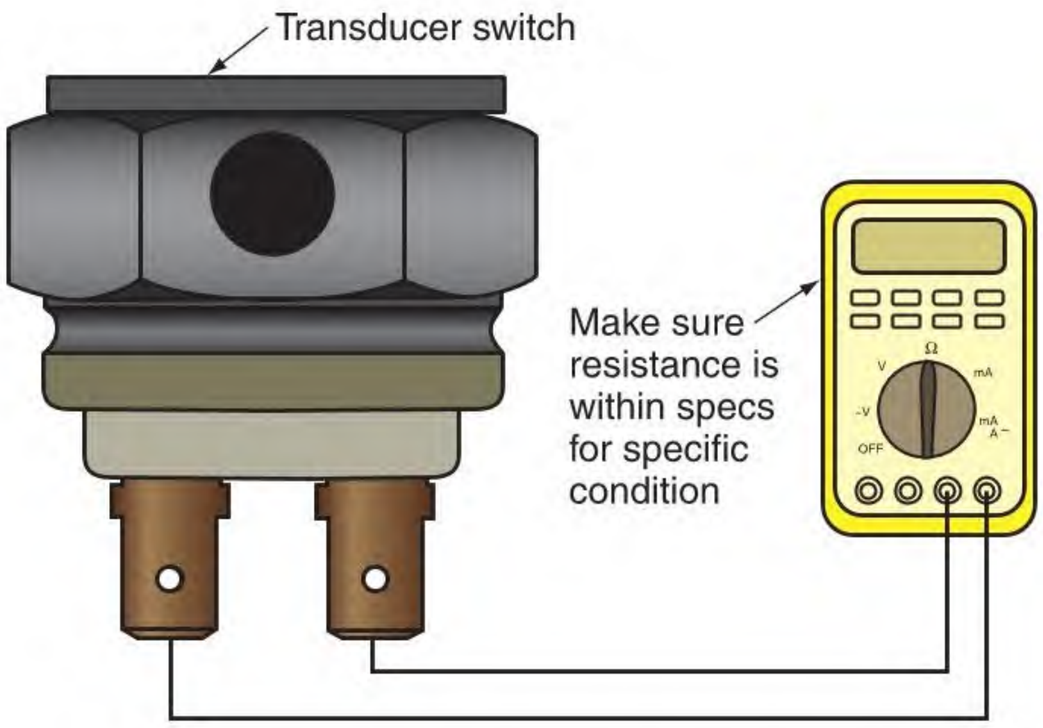
An ohmmeter is normally used to check a temperature switch because the leads to the switch can be disconnected easily. See **Figure 22-34**. Measure the unit's internal resistance when cold and hot (two conditions). You may have to remove the unit so you can control its temperature using a hot plate or a heat gun. You can also use a thermometer to measure the temperature of the switch while it is installed in the engine. If the resistance values are not within specifications for specific temperatures, the temperature switch has failed.



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Figure 22-33. A bad switch may be shorted closed or burned open. Resistance should be zero when the switch is closed and infinite when the switch is open.

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Figure 22-34. A transducer switch may be open or shorted closed, or its resistance may be higher than normal. It is normally easy to remove the wires and measure the transducer's resistance. You can also use a jumper wire to bypass the transducer switch to see if the circuit begins to function.

A quick way of checking a temperature switch and its circuit is to bypass it. Use a jumper to connect the two leads that go to the temperature switch. This should make the temperature light glow or temperature gauge read fully hot or cold, depending on gauge design.

Caution

Never bypass a sensor switch unless you are sure the switch is designed to have almost zero resistance when closed. If a normally operating sensor is designed to have some resistance, even when closed, you could short out the circuit and cause circuit damage when testing.

Testing Relays

Relay problems usually result from worn, burned, or sticking contact points that prevent normal circuit operation. The small coil windings in a relay can also break, preventing the points from closing.

Many circuits are controlled by relays. Always look for relays in wiring diagrams and check them if power is not reaching a circuit on the output side of a relay.

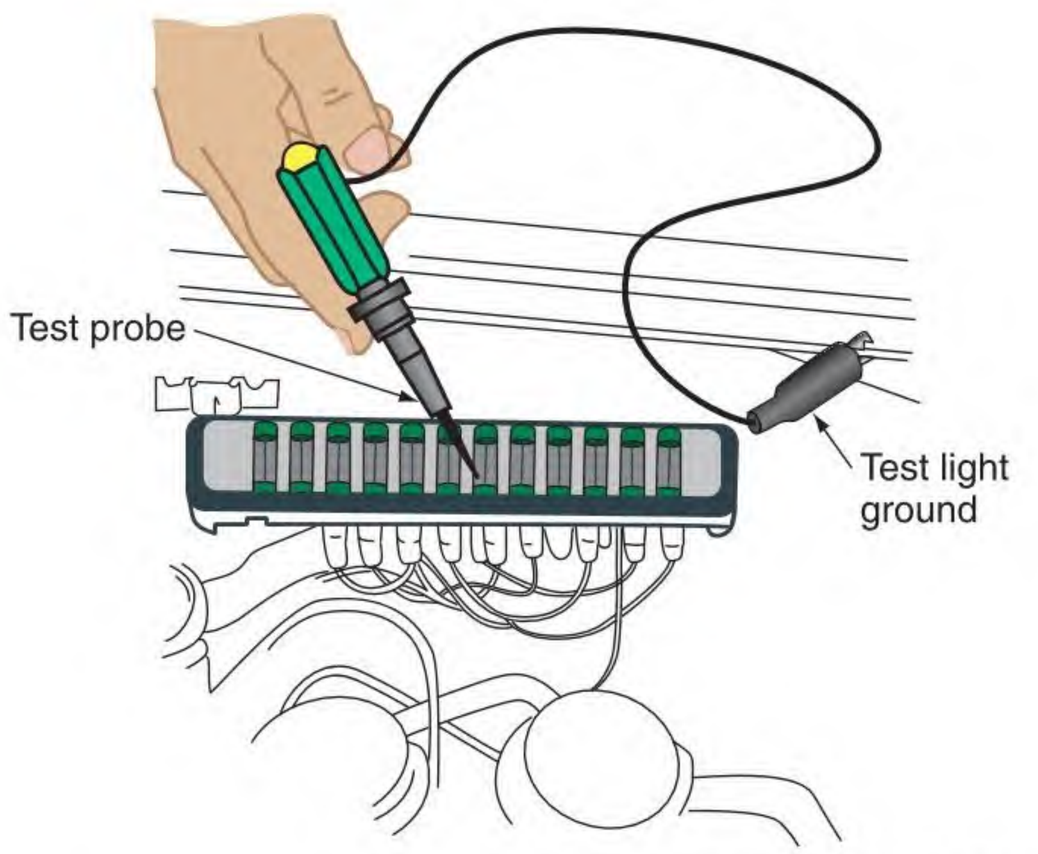
Relays can be located almost anywhere on a vehicle—in the engine compartment, under the dash, on a fuse box, or under the rear seat cushion. The service manual will give relay locations for the vehicle being repaired.

To test a relay, first make sure a voltage signal is being fed to the relay windings. You can check this with a test light or voltmeter. If power is reaching the relay, check that the relay points are closing. Check for voltage leaving the closed relay points. If not, replace the relay.

Testing Fuses

A fuse can be checked quickly using a test light. See **Figure 22-35**. The test light should glow when connected to either side of the fuse. If the light glows only on the feed side, the fuse is blown. If you find that the fuse is blown, you should check for a short that may have caused the fuse to blow. However, sometimes fuses fail after prolonged service, even if there is no short in the circuit.

A voltmeter can also be used to check a fuse, but it is not as handy as a test light. If the meter is digital and makes an audible signal when the voltage changes, you can check the fuse without too much trouble. Again, voltage should be present on both sides of the fuse.



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Figure 22-35. Using a test light is the easiest way to check for a blown fuse. A blown fuse will light the tester on the feed side, but it will not light the tester on the output side.

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Testing Capacitors

Capacitors are commonly used to absorb fluctuating voltage or current in a vehicle's electrical system. They can be used to prevent interference in the radio caused by unsmooth dc current or switches opening and closing. Capacitors were also used in older contact point ignition systems to prevent contact point burning.

Warning

A capacitor can store an electric charge. You should always ground the capacitor lead before testing the capacitor. A capacitor cannot hurt you, but it can startle you enough to make you jump and be injured. You also do not want a capacitor to discharge into and damage your ohmmeter.

To test a capacitor, you can use either an ohmmeter or a capacitor tester. To use a capacitor tester, follow the manufacturer's directions. To use an ohmmeter, disconnect and ground the capacitor's lead. Connect the ohmmeter leads across the capacitor as shown in **Figure 22-36**. At first, the ohmmeter should show low resistance as the capacitor takes a charge from the ohmmeter batteries. As the capacitor approaches its full charge, the ohmmeter reading should increase to infinite resistance. This shows that it is blocking dc current but storing voltage.

Testing Diodes

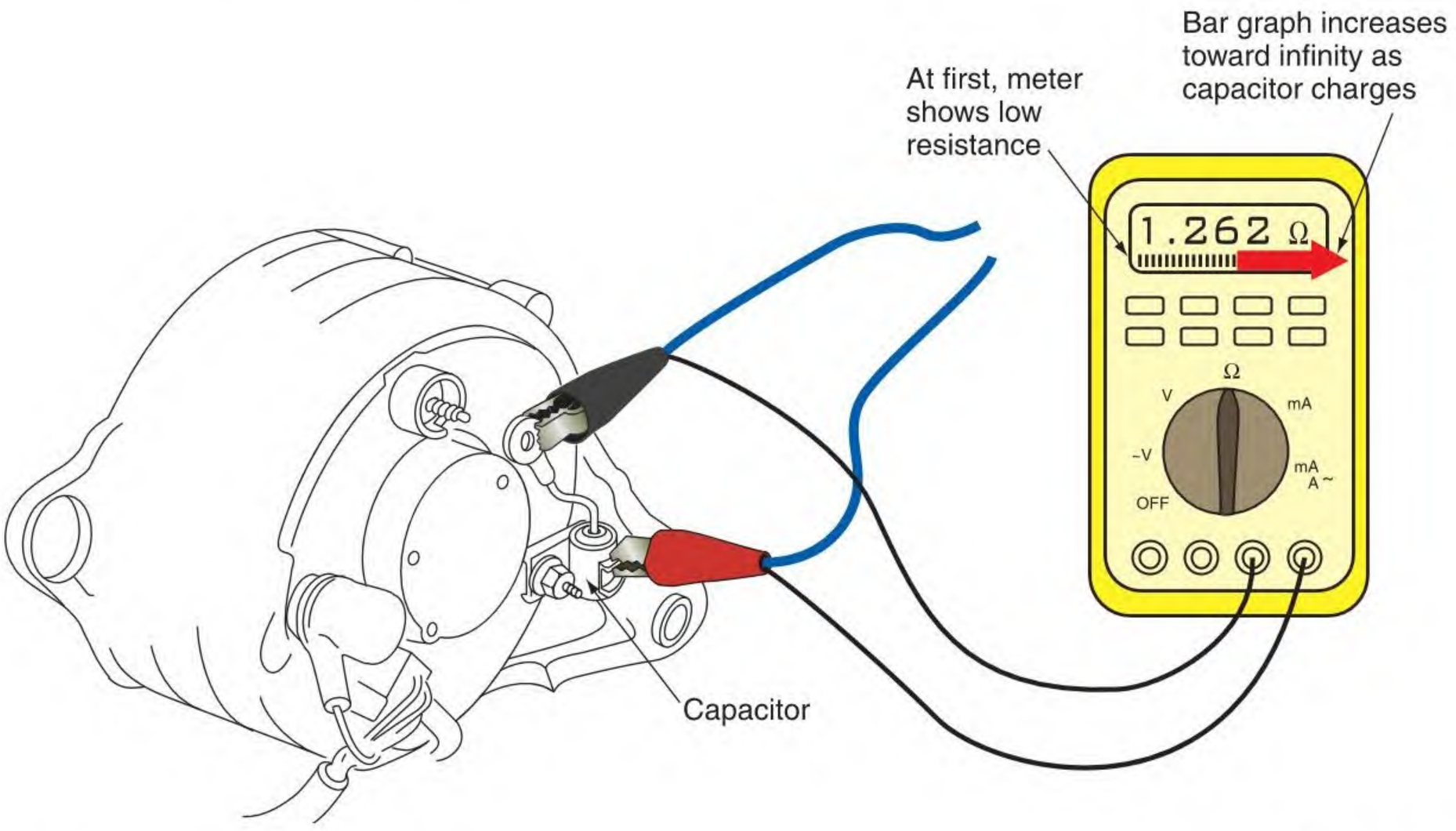
An ohmmeter is normally used to check diodes. A bad diode may have an internal open (PN junction burned and separated), or it may be shorted (PN junction burned and fused). The diode should have infinite resistance in one direction and low resistance in the other. If it does not, the diode should be replaced.

Testing other Components

Methods for testing other electric and electronic components are discussed in later chapters. **Figure 22-37** shows how an ohmmeter and voltmeter can be used to test various components. If you use common sense, your knowledge of component operation, and recommended testing practices, you should have little trouble finding problems.

Electrical Service Chemicals

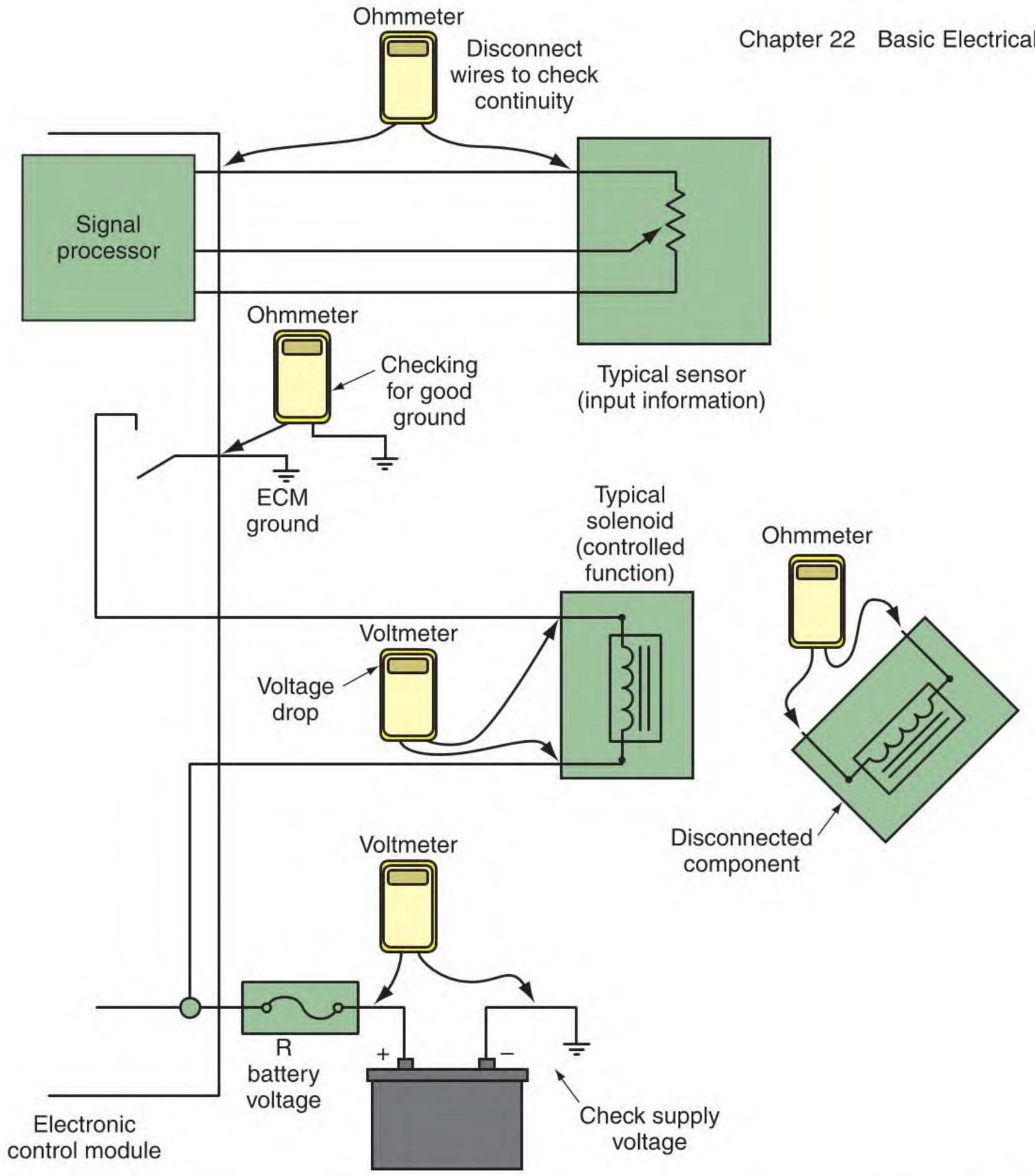
Several chemicals can be helpful when you are doing electrical tests and repairs. ***Electrical solvent*** can be used to clean oil and grease from components



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Figure 22-36. Before using an ohmmeter to check a capacitor, be sure to ground the capacitor lead to discharge any electricity stored in the capacitor.

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Figure 22-37. You must use common sense and the basic rules given in this chapter when making electrical measurements. By thinking about the circuit and specific components, you should be able to use logical steps to find circuit problems.

before soldering. It can also be used to remove soldering flux from a component. ***Contact cleaner*** is a chemical for cleaning deposits from contacts, switches, and other components.

Freeze spray can be used to find intermittent problems in electronic components. Electronic components are very sensitive to temperature. When you spray the freeze solution on a component, the component's temperature lowers instantly. This may cause a change in the component's output, helping you find some internal problems.



Green Tech

Fluorescent Shop Lights

To keep your shop energy efficient, one step you can take is to replace any high-power lights with fluorescent lights. There are varying levels of efficiency in fluorescent lights as well. The T system designates the tube diameter for fluorescent lamps. Older fluorescent lights may be T12 lights. To be more efficient, these should be replaced with T8 lights. The lights with smaller diameters will give off more light and use less power.

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Summary

- Most circuit problems are caused by something very simple, such as a broken wire or loose terminal connection. However, when this basic trouble is in a complex circuit, it can be very difficult to locate and repair. Correct techniques must be used to find electrical problems in a modern vehicle.
- Use a systematic approach to diagnose electrical trouble. First verify a problem and analyze the symptoms. Then narrow down the possible causes of the problem. Perform the proper tests to find the exact trouble. After making the repair, recheck to be sure the problem has been corrected before releasing the vehicle to the customer.
- If only one component does not work, start your tests at that component. If several components in the same circuit are not working, start your tests at the power source to the circuit.
- Common circuit problems include an open circuit, high circuit resistance, short circuit, and intermittent circuit problems.
- Jumper wires, test lights, inductive circuit tracers, and multimeters are important testing devices and can be used to find most types of circuit trouble.
- A voltmeter must be connected in parallel with the circuit. A conventional ammeter must be connected in series with the circuit. An inductive ammeter has a lead that clips over the outside of the wire. An ohmmeter must not be connected to a source of power. It uses internal batteries to measure circuit or component resistance.
- Voltage drop measurements provide an easy way of checking for high resistance. You do not have to disconnect the power source and isolate the component, as with an ohmmeter. A high voltage drop indicates a high resistance. A low voltage drop indicates a low resistance.
- Learning how to perform basic tests on connectors, resistors, switches, fuses, and other basic components will help you understand how to test more complex components.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

ammeter
auto ranging
contact cleaner
electrical diagnosis
electrical solvent
freeze spray
grounded circuit
hot wire short to ground
infinite resistance
intermittent problem
jumper wire
ohmmeter
open circuit
short circuit
test light
transducer switch
voltage drop measurement
voltmeter
zero resistance

Activities

1. While wearing rubber gloves and eye protection, measure the voltage of two old car batteries. Write down the voltage reading for each. Charge both batteries for 15 minutes, then recheck the voltage. Do both batteries charge up at the same rate? Recharge both batteries for two hours and repeat your voltage measurements. Write a short paragraph on your findings.
2. While wearing safety gear, measure the resistance of a temperature sensor at room temperature. Record your resistance reading. Using a heat gun, heat the sensor to 100°F, and record the sensor resistance reading. Does the sensor seem to be working? Write a paragraph on your findings.

Review Questions

Answer the following questions using the information provided in this chapter.

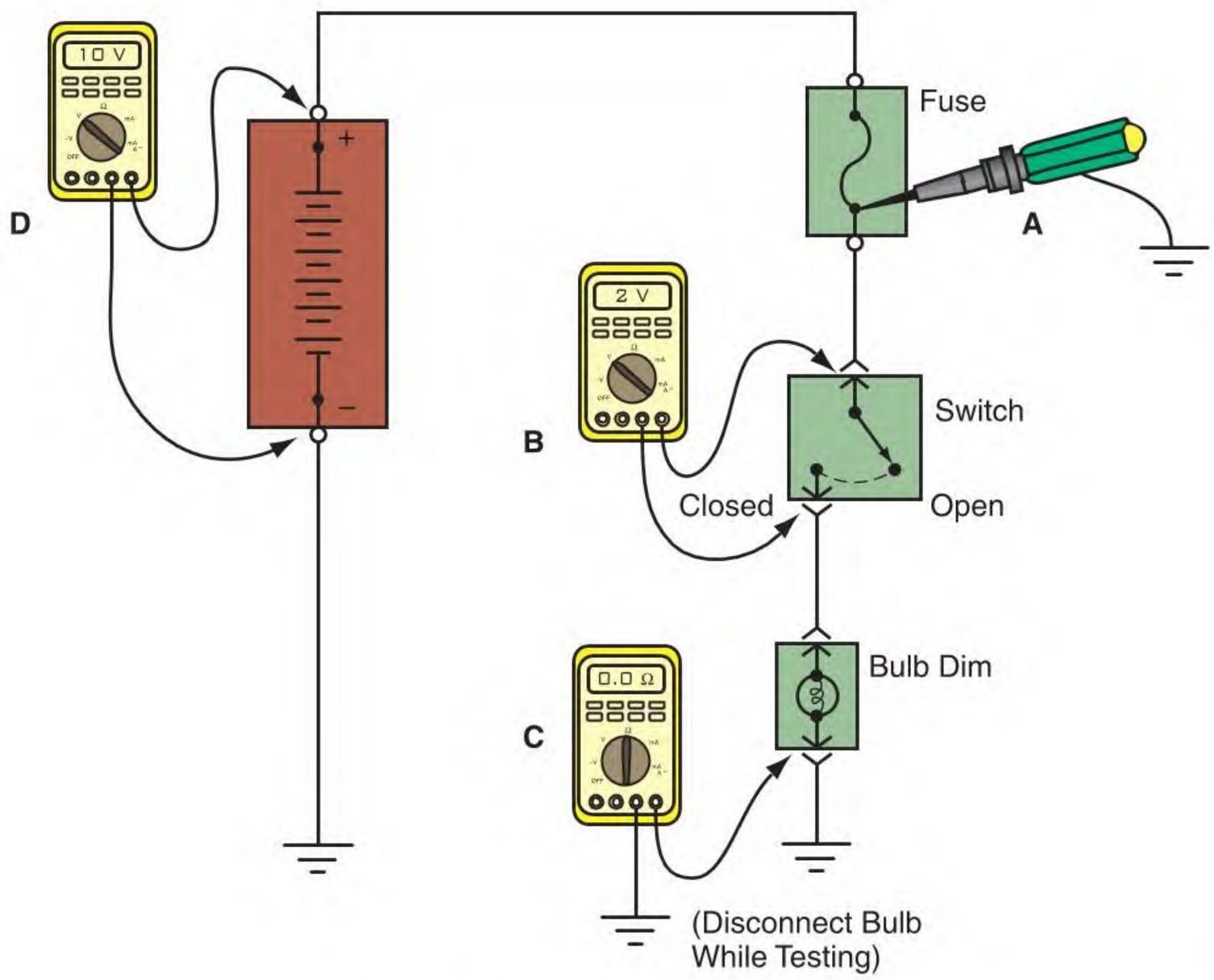
1. What are five questions you might ask yourself when trying to find a problem?
2. If only one component does not work, where should you start your tests?
3. If more than one component does not work, where should you start your tests?

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4. What effect does an open circuit have on current?
5. What six conditions may cause an open circuit?
6. What might make a bulb glow dimly or a motor run slowly?
7. Explain how a short might cause an electrical fire.
8. What is an intermittent problem?
9. How would you use a jumper wire to check a switch?
10. Which testing device usually provides the quickest and easiest way to check a circuit for continuity?
11. Which testing device uses a signal generator and inductive pickup to find shorts and opens in wires?
12. Explain how to connect a conventional ammeter and an inductive ammeter to test a circuit.
13. An ohmmeter shows a reading of 2.500 kΩ. What is the meter reading in ohms?
14. Explain how you can use voltage drop measurements to determine whether a switch is functioning correctly.
15. List eight rules for using multimeters.
16. Which type of multimeter should be used to check for voltage in a computer circuit?
17. Explain how to use a test light to check a connector.
18. What three testing devices might be used to test a switch?
19. What is the most accurate way to check a variable resistor?

Use the circuit drawing in **Figure 22-38** to answer questions 20 through 24. The battery produces 12.6 volts (6 cells at 2.1 volts each). The bulb burns very dimly with the switch on.

20. Would test A be needed with these symptoms or conditions?
21. What does test B tell you?
22. Test C would verify:
    (A) That electricity is not leaking through the bulb socket.
    (B) That the ground does not have low resistance.
    (C) That the ground does not have high resistance.
    (D) All of the above.
    (E) None of the above.
23. What would you learn from test D?
24. How would you repair the circuit problem?



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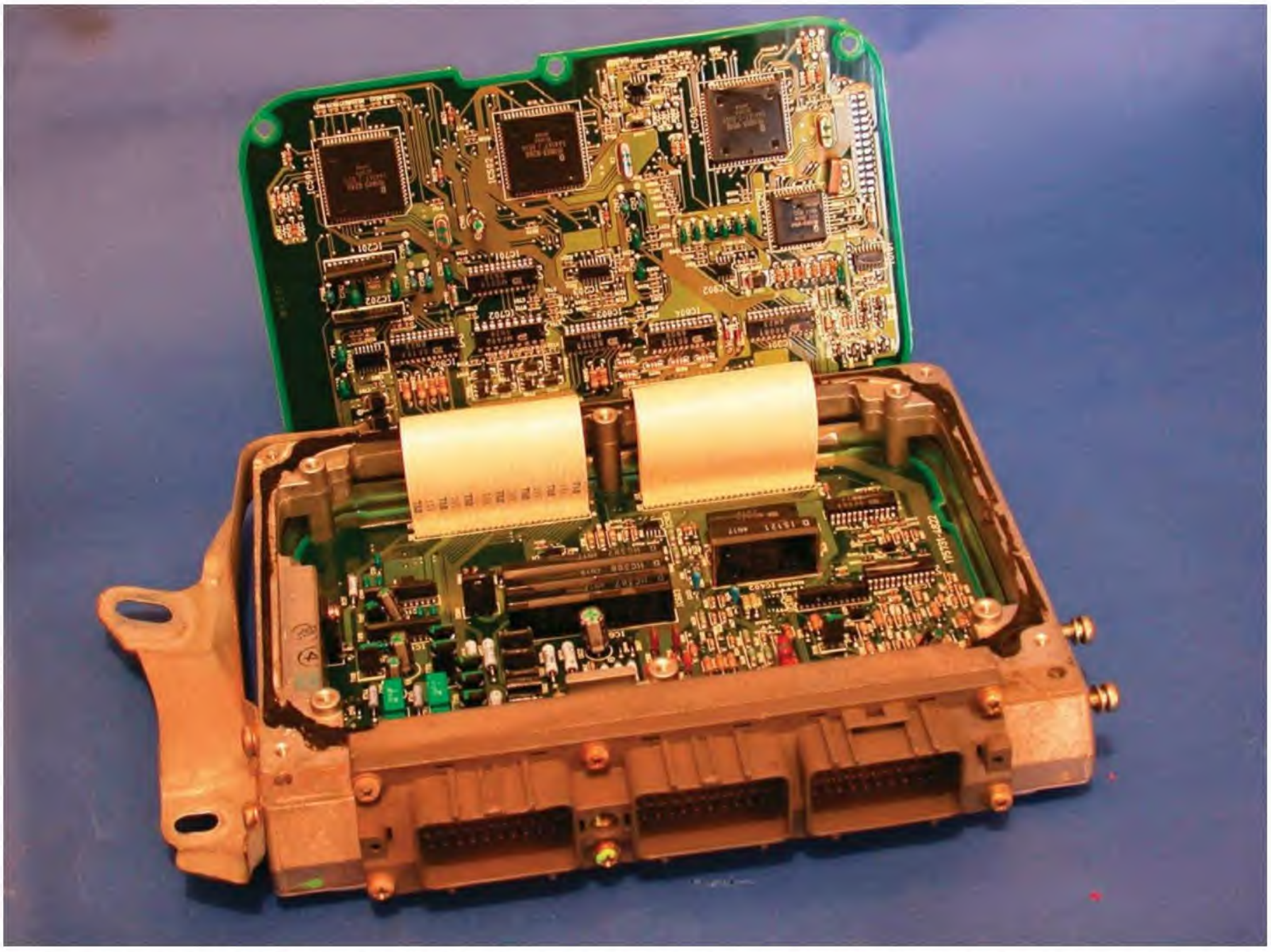
Figure 22-38. Use this circuit illustration to answer review questions 20 through 24.

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ASE-Type Questions

1. Technician A says a basic circuit problem can be caused by something in the circuit that increases voltage. Technician B says a basic circuit problem can be caused by something in the circuit that decreases resistance. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. An automobile is brought into the shop with an engine electrical problem. Technician A says the first step to electrical diagnosis is to verify the symptoms and the problem. Technician B says electrical diagnosis involves using a logical sequence of steps to find the source of the problem. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. More than one component in a particular automotive electric circuit is not working. Technician A starts testing the circuit at the power source. Technician B starts testing the circuit at its load. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. There is an open in an automobile's headlight circuit. Technician A says this problem can be caused by a blown fuse. Technician B says the problem may be caused by burned switch contacts. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. Technician A says an open will always stop current in a circuit. Technician B says high circuit resistance will normally reduce current in a circuit. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Technician A says a short circuit can be caused by a conductor touching ground. Technician B says a short circuit can be caused by a conductor touching another conductor. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. Technician A says intermittent problems occur only under certain conditions. Technician B says intermittent problems are often caused by poor electrical connections. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. Test light use is being discussed. Technician A says that self-powered test lights are the most common type of test light used in automotive repair. Technician B says that you should avoid using a test light probe to puncture wire insulation whenever possible. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. The current in an automotive taillight circuit needs to be checked. Technician A connects a conventional ammeter in parallel with the circuit being tested. Technician B connects a conventional voltmeter in series with the circuit being tested. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. A particular diode has a reading of infinite ohms in both directions. Technician A says this indicates the diode is in good condition. Technician B says this indicates that the diode has an internal short. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Automotive computers contain complex integrated circuit chips and conventional electronic components that are attached to printed circuit boards.

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Section 4

Computer Control Technology

Chapter 23
Computer System Fundamentals

Chapter 24
On-Board Diagnostics and Scan Tools

Chapter 25
Computer System Service

Today's vehicles are as much electronic as they are mechanical. Computers control and monitor every major system in a modern car or light truck. It is virtually impossible to work on almost any vehicle without a basic knowledge of computers.

Section 4 details the theory and operation of computer systems, explains how to use a scan tool to find problems in computerized systems, and describes the use of pinpoint tests to verify the basic electrical/electronic faults identified by the scan tool.

This important section will prepare you for almost every other chapter in this textbook. Study it carefully! This section will also help you pass several ASE Certification Tests that require an understanding of computers, sensors, actuators, scan tools, and related topics, including Test A6, Electrical/Electronic Systems and Test A8, Engine Performance.





Chapter 23
Computer System Fundamentals

After studying this chapter, you will be able to:

- Compare computer systems to the human body's nervous system.
- Describe the input, processing, and output sections of a basic computer system.
- Summarize computer system signal classifications.
- Sketch a block diagram for a computer system.
- Explain input sensor and output device classifications and operation.
- Summarize where computers, sensors, and actuators are typically located.
- Explain how a computer uses sensor inputs to determine correct outputs.
- Correctly answer ASE certification test questions that require a knowledge of automotive computer system fundamentals.

An automotive ***computer*** is a complex set of electronic circuits. An automotive computer will produce programmed electrical control currents for actuators after receiving specific input signals from sensors. Computers now monitor and control all major systems of a modern vehicle.

It is almost impossible to work on almost any automotive system without having a sound knowledge of vehicle computers. In the past, automotive systems (ignition, cooling, emissions, and fuel, for example) worked independent of each other. Today, on-board computer networks work together at lightning-fast speeds to react to almost any condition, making the passenger vehicle a much safer, efficient, and powerful means of transportation.

Tech Tip

Complex sensors (oxygen sensors, MAP sensors, throttle sensors, yaw sensors, etc.) will also be studied in later textbook chapters. Refer to the index for more information on any specific type of sensor, actuator, or circuit.

Cybernetics

The term ***cybernetics*** is often used to refer to the study of how electrical-mechanical devices can duplicate the action of the human body. Comparing the human body to a computer system is an easy way to explain this subject. Just as your brain communicates with and controls parts of your body, an automotive computer system can communicate with and control parts of a vehicle. See **Figure 23-1**.

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Computer system input		Human nervous system
Knock sensor input	⟷	Hearing input
Oxygen sensor input	⟷	Smell input
Light dimming photo cell input	⟷	Sight input
Pressure sensor input	⟷	Touch input
Low oil level sensor input	⟷	Taste input
Solenoid, relay, or servo motor output	⟷	Muscle movement output
Dash graphic display output	⟷	Talk, write, draw output
Memory and processor IC circuits in computer	⟷	Brain's memory and thought

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Figure 23-1. Cybernetics compares the human body to a computer system. Study this chart comparing the human nervous system and an automotive computer system.

The Nervous System (Computer Input)

The human nervous system uses chemical-electrical signals to control the body. If you touch a sharp needle, nerve cells in your finger "fire" and send a signal through a strand of nerve cells in your hand, up your arm, and into your brain. The strand of nerve cells forms a "wire" that connects your finger and brain. The nerve cells in the tip of your finger are comparable to a sensor, or input device, in a computer system.

The Brain (Computer Processing)

The brain uses billions of cells interconnected by linking cells called neurons. Each neuron chemically-electrically connects tens of thousands of neighboring cells. When the brain "thinks," minute electrical impulses travel from neuron to neuron. One simple thought might involve electrical impulses between hundreds of thousands of cells in a specific pattern. This is not unlike the electrical action inside the circuits of a computer.

The brain is comparable to a super powerful computer. It can process the inputs from the nervous system and determine what actions should be taken.

For example, imagine you accidentally poke a sharp needle into your finger. The result is chemical-electrical signals for pain and a reaction signal to pull the needle away from your finger. First, your brain would almost instantly tell you, "my finger is being injured." Your brain would then take corrective action to protect your finger.

The brain makes decisions much like computers produce logical outputs. The cells in the brain can be either chemically-electrically charged (on) or not be charged (off). By connecting all the brain cells in complex logic/memory circuits, the brain can decide what to do in almost any situation.

The Reflex Action (Computer Output)

The needle prick signal from the nerve endings in your hand activates specific brain cells to fire and produce a chemical/electrical reaction (pain). A reflex output (voltage) is then produced by your brain (computer) and sent back down the nerves (wires) in your arms. This chemical-electrical output signal stimulates the muscles in your arm and hand to pull back, protecting your finger from the sharp object. The reflex action of your muscles is similar to the action of an actuator, or output device, in a car's computer system.

Computer Circuit Advantages

There are several reasons that computers are being used in modern vehicles. Computers provide several advantages.

- Computer systems can compensate for mechanical wear. Also, they do not have as many mechanical parts to wear and go out of calibration.
- Computers "think" very quickly and can alter outputs in milliseconds (thousandths of a second). This lets a computer alter outputs almost instantly as inputs and operating conditions change.
- Computers reduce fuel consumption and lower emissions by precisely metering fuel into the engine. The computer sensor circuit "sniffs" the exhaust gases to find out if too much or too little fuel is entering the engine.
- Computers also increase engine power by accurately controlling ignition timing, fuel injection, emission control system operation, etc.
- Computers reduce vehicle weight because they are much lighter than mechanical control mechanisms.

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- Most computers have on-board diagnostics that can detect and record system problems. The on-board computer can produce and store an output code that tells the technician where a fault might be located.
- Computers can increase driver convenience by better control of the passenger compartment environment and dash displays.
- Computers can improve passenger safety by controlling the anti-lock brakes, air bags, suspension, and other systems.
- Computers can compensate for component wear and failure to keep the car driveable.

Digital Electronics

Digital electronics is a field of study dealing with the ways a computer uses on-off signals to produce "artificial intelligence." A computer analyzes input signals from sensors. It has memory in which fixed and semi-fixed data is stored, using small integrated circuits (ICs). The computer can make logical choices on how to control specific outputs by comparing the input signals from sensors to known signals.

Binary Numbering System

The ***binary numbering system*** uses only two numbers, zero and one, and is the key to how computers operate. The numbers zero (0) and one (1) can be arranged in different sequences to represent other numbers, letters, words, a computer input, a computer output, or a condition.

To use the binary system, a computer turns switches (transistors, for example) either *on* or *off*. *Off* would represent a zero (0) and *on* would represent one (1) in the binary system, **Figure 23-2**.

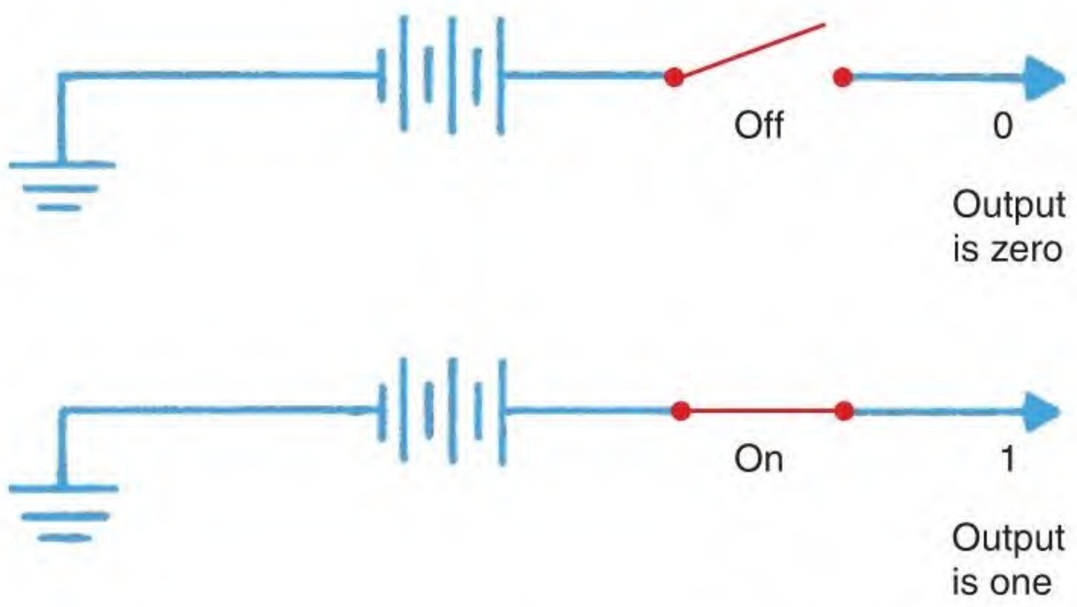
Note that a 0011 in binary would equal a three (3) in the base 10 decimal system. A 0110 in binary would equal a six (6) in the base 10 system. Study the conversion chart in **Figure 23-3**.

In binary language, a zero or a one is called a bit. A pattern of four bits is a nibble. A pattern of eight bits is called a byte, (pronounced "bite"). One or more bytes are referred to as a word. You are more likely to hear this terminology when you work with home or personal computers.

Gating Circuits

A ***gate*** is an electronic circuit that produces a specific output voltage for given input voltages. Just as a diode will pass current when forward biased (output lead would have voltage representing one) and stop current when reverse biased (output would be zero or no voltage), gates have programmed (previously known) outputs. Shown in **Figure 23-4**, the most common computer gates are:

- NOT gate—Also called an inverter gate, a NOT gate will reverse its input. If the input has voltage applied (1), the output terminals will not have voltage (0) or vice versa. A NOT gate can be used to make other gates.
- AND gate—An AND gate requires voltage (1) at both inputs to produce a voltage (1) at the output. If pins A and B are both one (1), the output will be 1. If only pin A or pin B is one, the output will be 0.



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Figure 23-2. Since electronic components can be either on or off, the binary numbering system is ideal for digital logic and computer circuits. The binary system has only two numbers, zero and one, which represent off and on conditions.

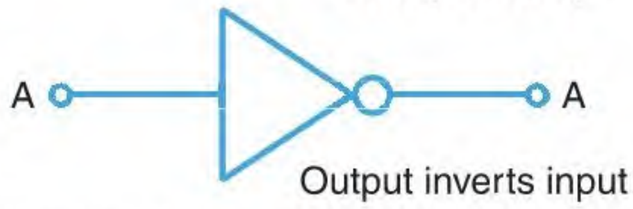
Decimal number	Binary number code 8 4 2 1	Binary to decimal conversion
0	0 0 0 0	= 0 + 0 + 0 + 0 = 0
1	0 0 0 1	= 0 + 0 + 0 + 1 = 1
2	0 0 1 0	= 0 + 0 + 2 + 0 = 2
3	0 0 1 1	= 0 + 0 + 2 + 1 = 3
4	0 1 0 0	= 0 + 4 + 0 + 0 = 4
5	0 1 0 1	= 0 + 4 + 0 + 1 = 5
6	0 1 1 0	= 0 + 4 + 2 + 0 = 6
7	0 1 1 1	= 0 + 4 + 2 + 1 = 7
8	1 0 0 0	= 8 + 0 + 0 + 0 = 8

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Figure 23-3. Binary numbers can be converted into decimal (base ten) numbers. Note how the right-hand binary number equals one and the left-hand number equals eight.

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Not (inverter)



A	A
1	0
0	1

A—Inverter simply reverses its input.

AND



A	B	A • B
0	0	0
0	1	0
1	0	0
1	1	1

B—AND gate requires both inputs to be on for an output.

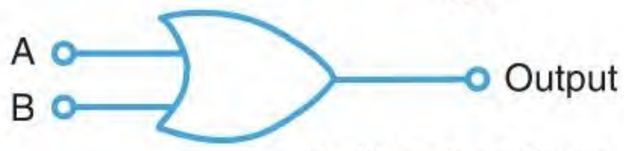
NAND



A	B	A • B
0	0	1
0	1	1
1	0	1
1	1	0

C—NAND gate is an inverted AND gate; there is no output when both inputs are on.

OR



A	B	A + B
0	0	0
0	1	1
1	0	1
1	1	1

D—OR gate only needs input voltage on either terminal to get an output voltage.

NOR



A	B	A + B
0	0	1
0	1	0
1	0	0
1	1	0

E—NOR gate is an inverted OR gate; no input voltage will produce an output voltage.

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Figure 23-4. Study the basic types of computer gates. Truth tables on the right show what the output of each gate will be with different inputs.

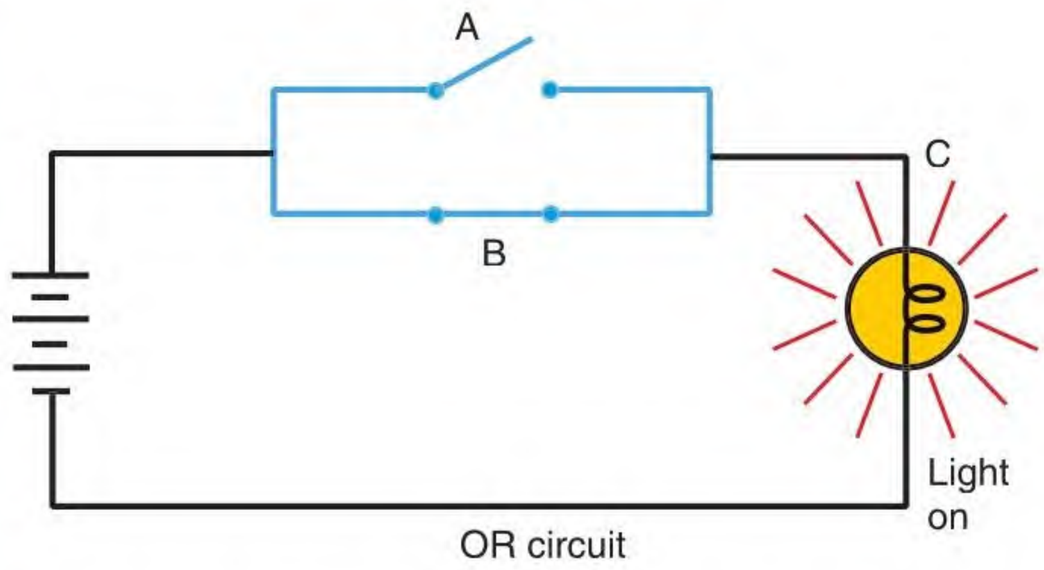
- A NAND gate—An inverted AND gate is a NAND gate. Its output will be opposite that of an AND gate. Note the small circle or dot on the output lead of the gate. The small circle represents an inverter.
- OR gate—An OR gate will produce an output (one or on) if either input is energized (1). A or B input voltage (1) will result in voltage (1) at the output lead.

OR gate



A	B	A or B
0	0	0
0	1	1
1	0	1
1	1	1

A or B on = C on



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Figure 23-5. Compare the OR gate and the switch setup in this simple circuit. Either A or B will turn on the light and produce a one, or on, output.

- NOR gate—An inverted OR gate is a NOR gate. Note the small circle that represents an inverter. The output is inverted to produce an output opposite that of an OR gate.

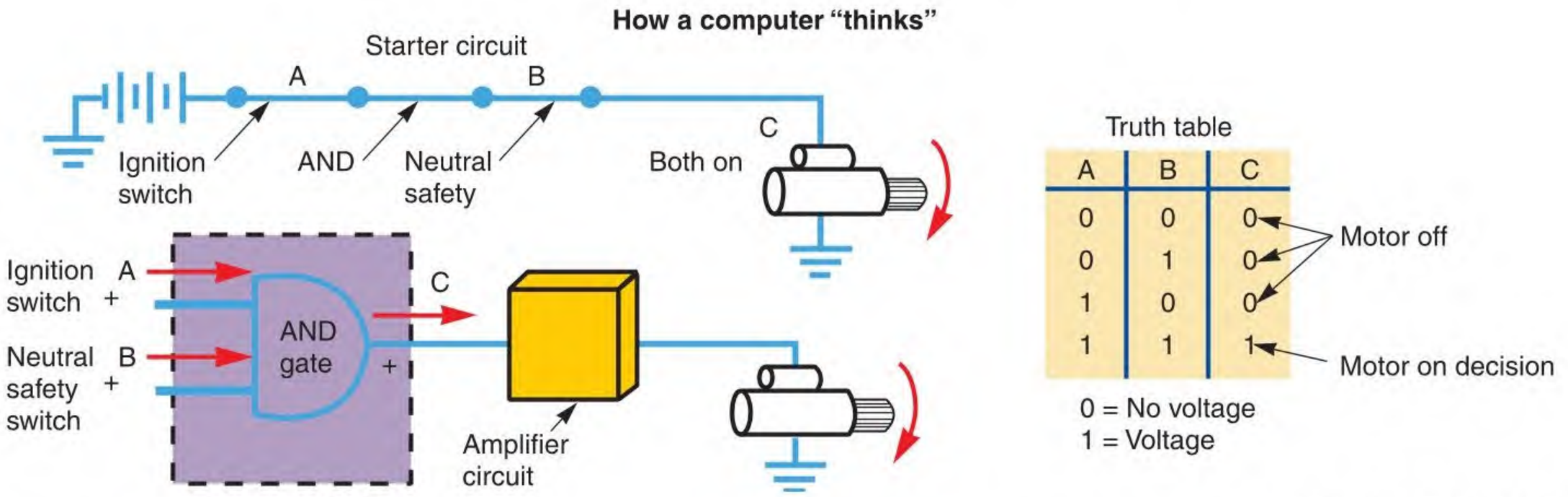
Truth Tables

A truth table is a chart that shows what the output of a gate will be with different inputs. Look at the truth table for an OR gate shown in **Figure 23-5**. Note that if two switches are wired in parallel, either switch A or switch B (OR gate) will turn the light *on* (output 1). The output will be *on* (1) with A or B or both energized. Only when neither input is *on* will the output be *off* (0). A truth table graphically shows how a gate functions.

Gates are often called *logic devices* because they make logical decisions (outputs) based on specific inputs (facts). If an AND gate was compared with two switches wired in series, both switches (A and B) must be *on* to activate the starter motor, **Figure 23-6**. Compare these circuits to the action of the gates and the truth tables.

Logic gates can be connected together to form super-complex circuits. Millions of gates can be interconnected to produce thousands of preprogrammed outputs (decisions) from numerous inputs (facts). This is how a computer works, or thinks. Its circuitry and software are designed to make the correct output signals based on various input signals. In this way, a

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Figure 23-6. Compare this starting circuit with the computer gate circuit and truth table. It shows how a computer gate can make a decision. Two input conditions (A and B) must be satisfied in both circuits to produce an output to the starting motor. The same principle, only with thousands of gates and dozens of inputs and outputs, is used inside an automotive computer.

computer knows what to do to keep the vehicle operating efficiently with many different variables.

Integrated Circuits

An ***integrated circuit (IC)*** is an electronic circuit that has been reduced in size and etched on the surface of a tiny semiconductor chip, **Figure 23-7**. Metal conductors on the top of the chip connect these various electronic components to form the circuit. Wire leads allow for input and output connections to and from the IC chip. Technicians often have to reprogram the integrated circuits in a vehicle's computers to rectify problems.

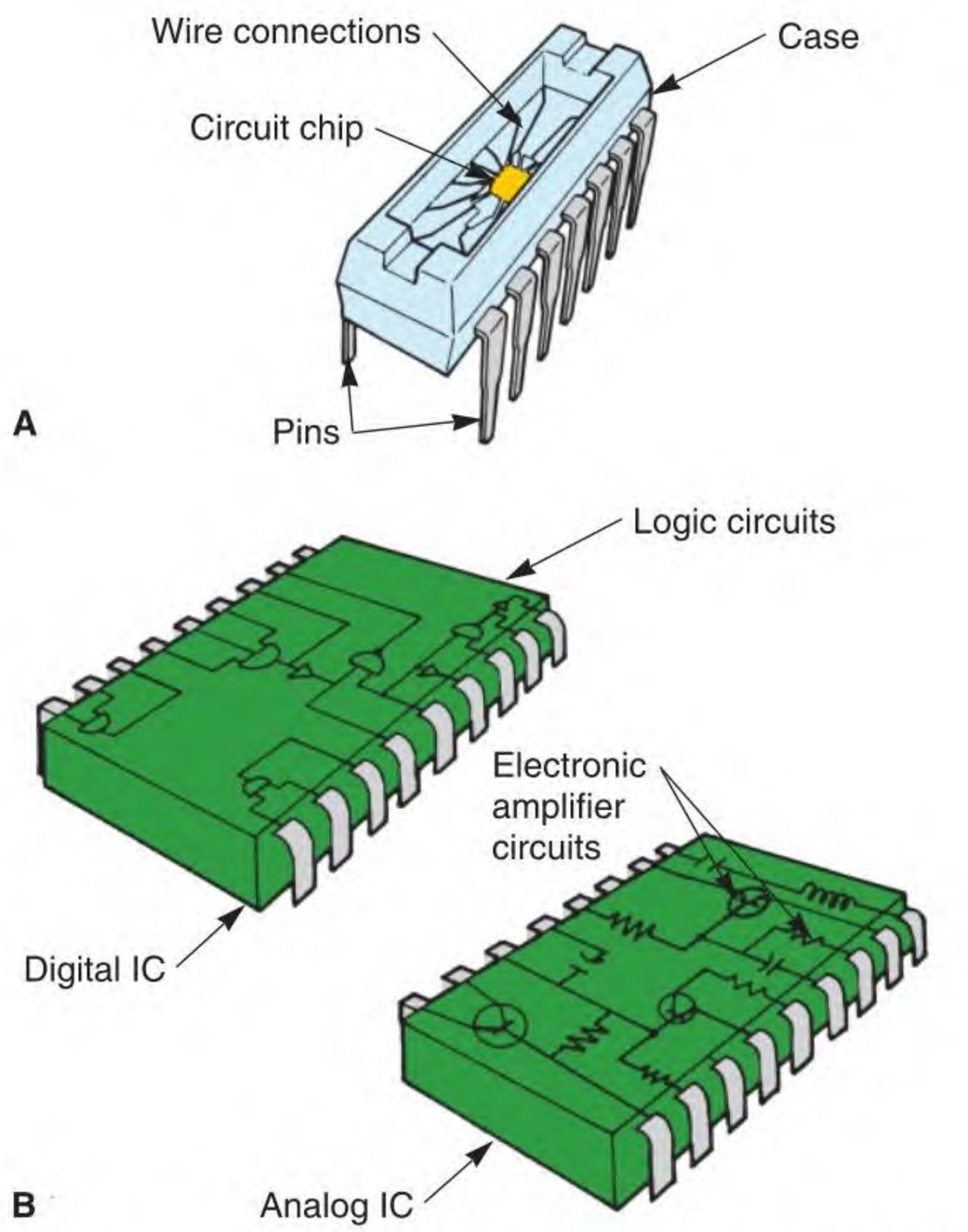
Computer Signals

A ***computer signal*** is a voltage variation over short periods of time. It is a specific arrangement of pulses or waves used to carry electronic data, or information. You must be familiar with computer signals to understand the operation and service computer systems.

Computer signals can be digital (square or on/off scope waveform) or analog (smooth, gradual change in current and voltage), as in **Figure 23-8**.

Digital signals are on-off signals, like those produced by a rapidly flipping switch. Voltage output goes from maximum to minimum. A digital signal basically produces a square wave. See **Figure 23-9**.

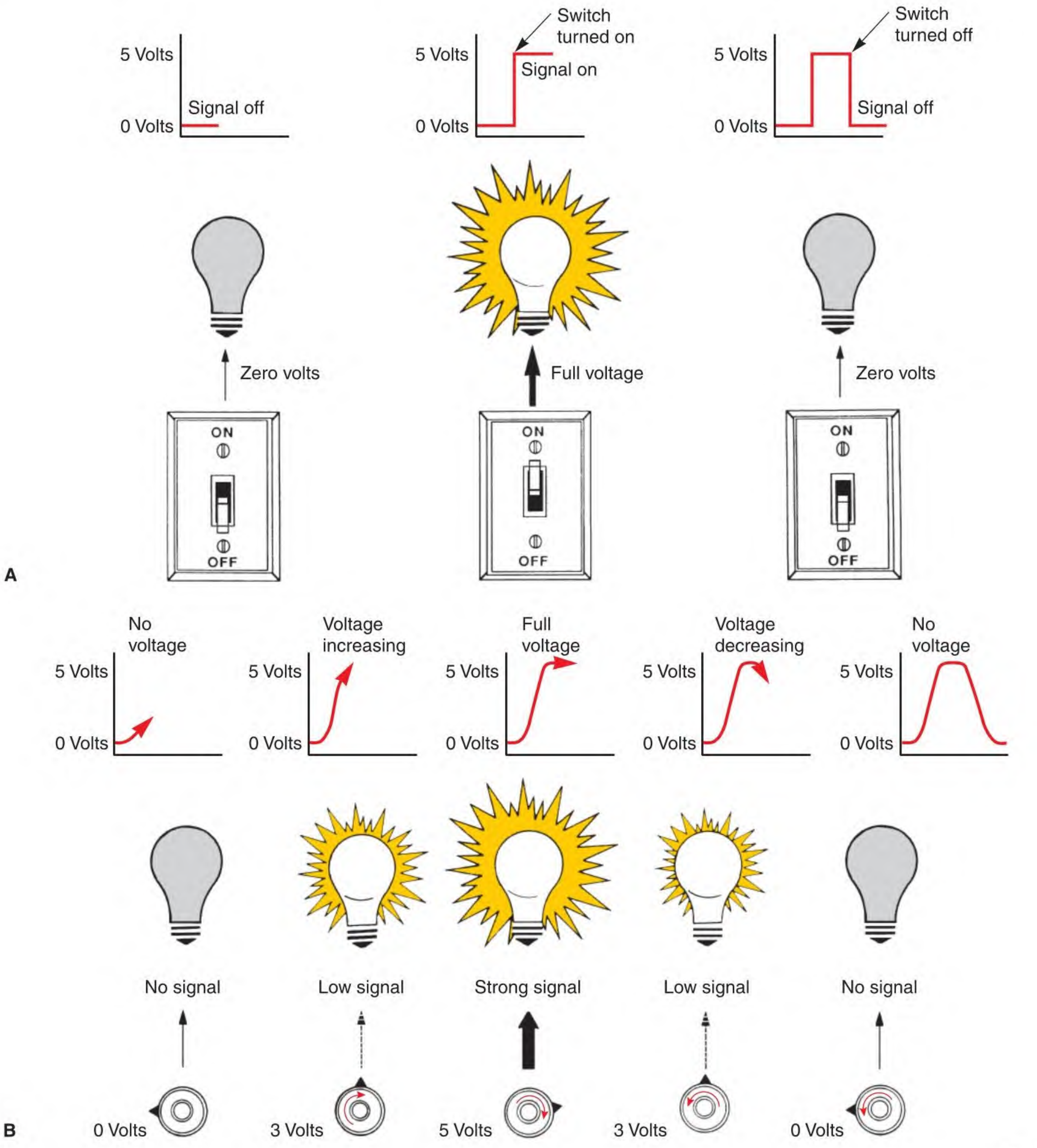
An example of a sensor providing a digital signal is a Hall effect-type crankshaft position sensor, which shows engine RPM using a 12 V signal. Compare crankshaft and camshaft signals in **Figure 23-10**.



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Figure 23-7. An integrated circuit has been photographically reduced in size, etched on a silicon chip, and placed inside a protective case. A—Note how a tiny chip is installed inside this plastic case. Tiny wires connect the chip to each metal pin. The pins then plug in or are soldered to other parts of the circuit. B—These are two broad classifications of integrated circuits. Digital circuits use gates to produce logic circuits for computers. An analog IC is a small amplifier circuit for increasing output strength or altering output.

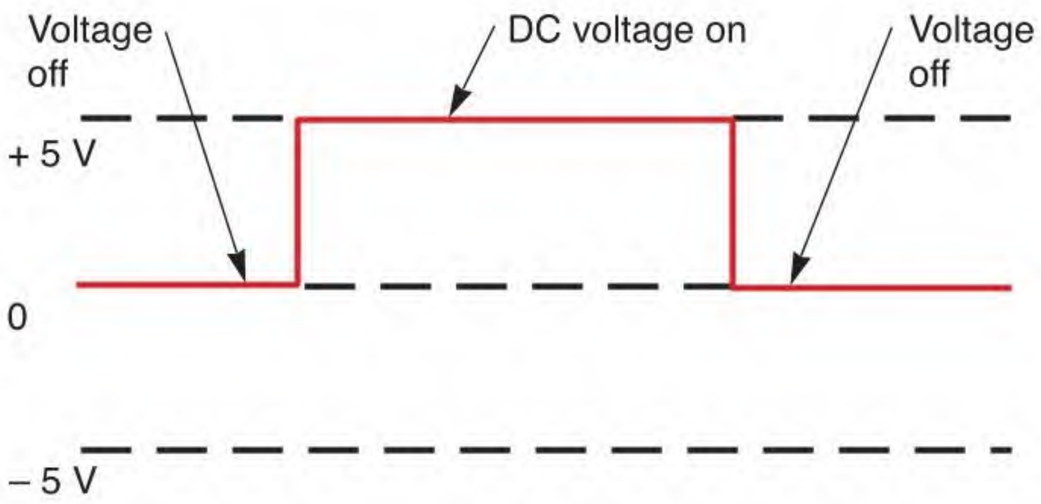
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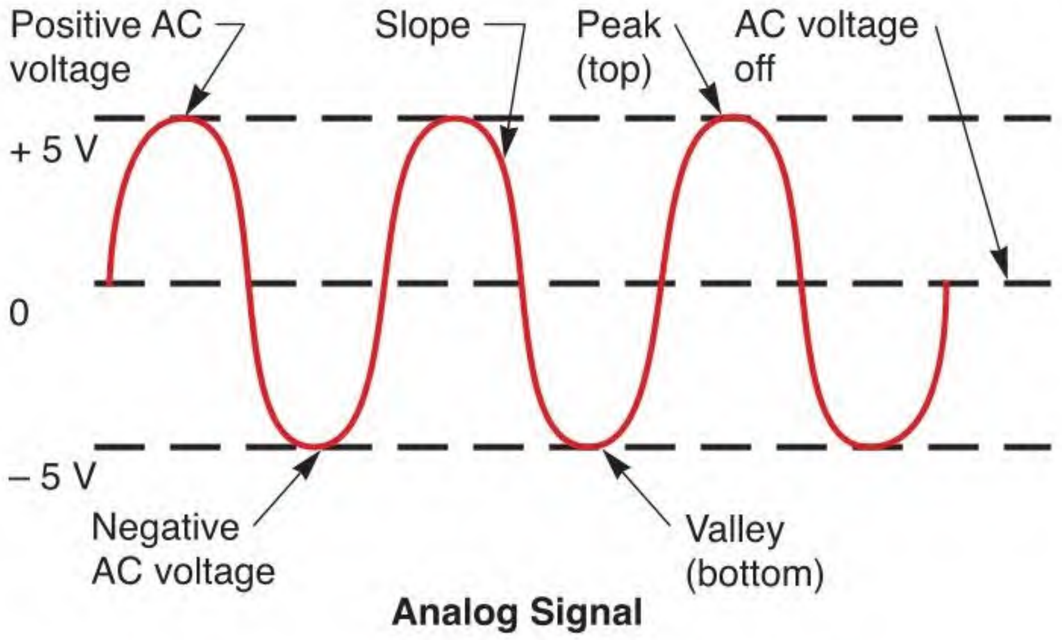
Ford

Figure 23-8. Compare digital and analog signals. A—A digital signal is similar to the output from a light switch, which would produce a square wave. B—An analog signal would be similar to the output from a light dimming switch. Circuit voltage would progressively go up or down as the variable resistor is rotated.

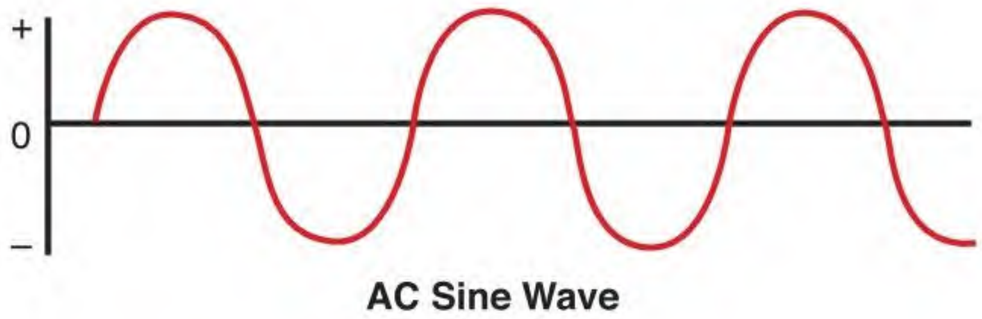
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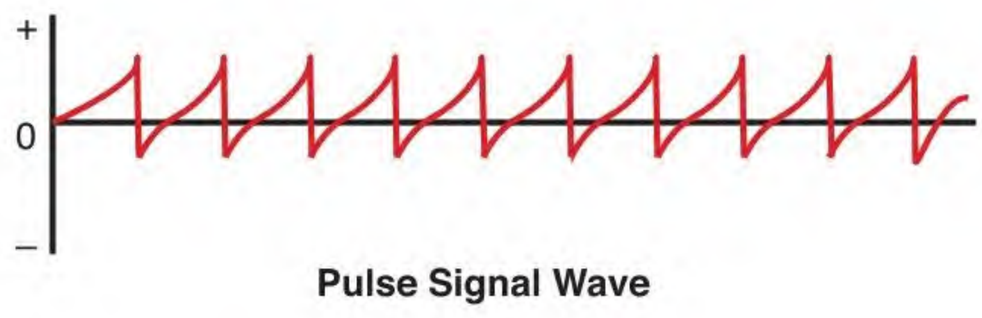
Digital Signal



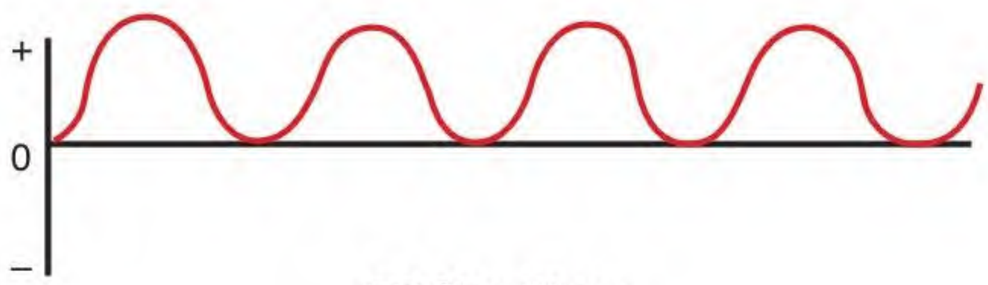
Analog Signal



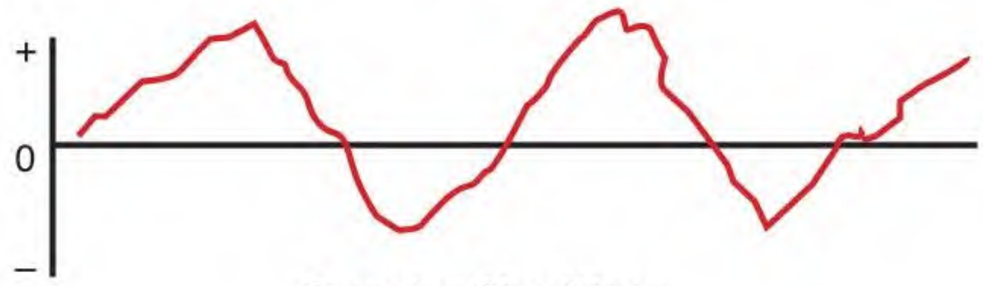
AC Sine Wave



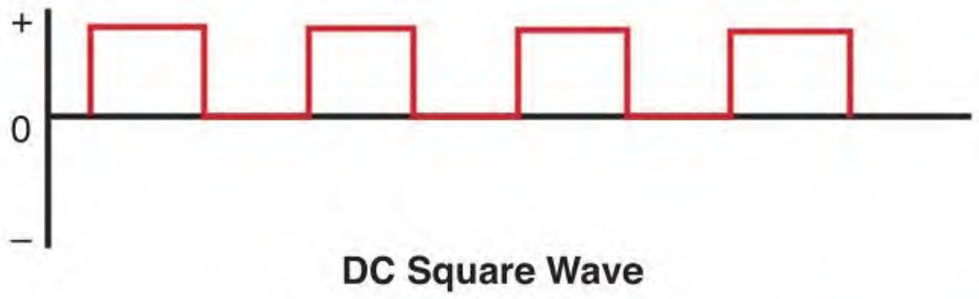
Pulse Signal Wave



DC Sine Wave



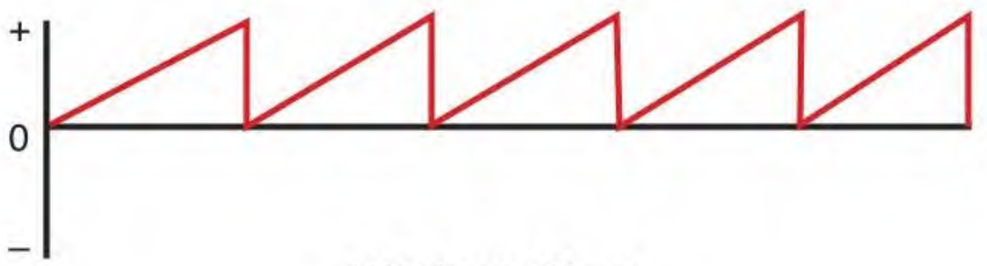
Complex Sine Wave



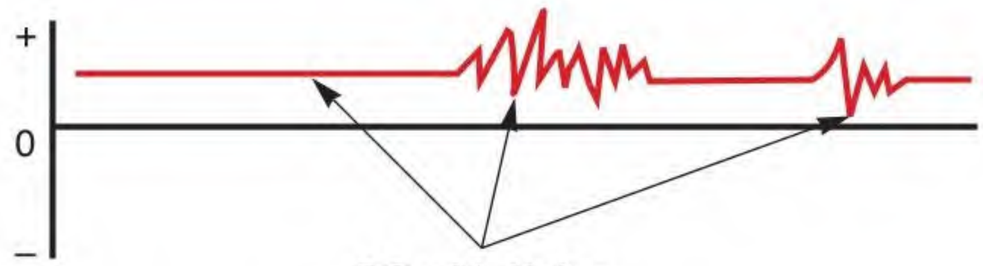
DC Square Wave



Voice Waves



DC Ramp Wave



DC with Noise

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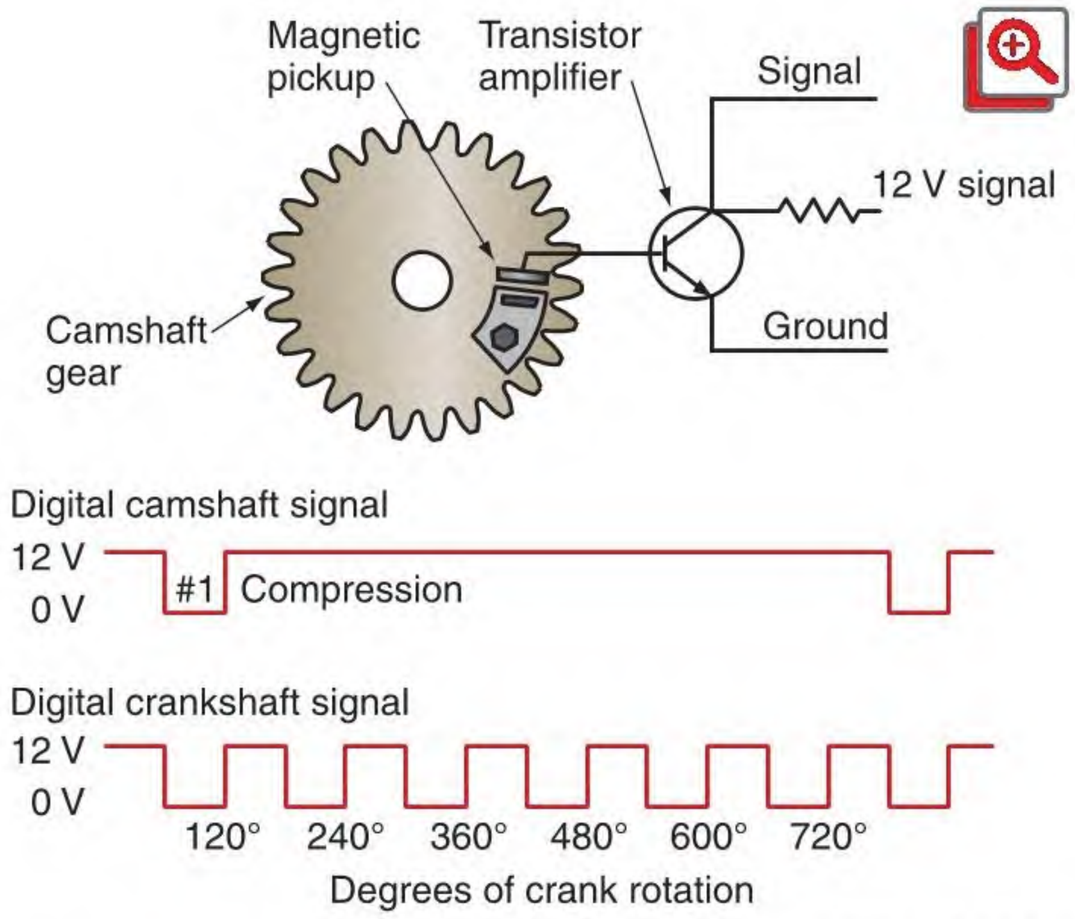
Figure 23-9. These are the basic signals found in computer system circuits. Voltage is shown vertically and time is shown horizontally. An oscilloscope can be used to measure computer signals.

An ***analog signal*** gradually changes in strength. For example, a sensor's internal resistance (and resulting voltage signal) may smoothly increase or decrease with changes in temperature, pressure, or part position. The change in resistance will cause a change in the resulting voltage signal. An analog signal will produce a curved wave or an irregular wave. Refer to **Figure 23-9**.

Computer signals can be measured with an oscilloscope or a scan tool with a scope function. If a scope is connected to a sensor that generates a signal voltage, a trace of the signal, or ***waveform***, can be viewed on the scope. A speed sensor waveform is illustrated in **Figure 23-11**.

There are many types of electrical waveforms within the analog-digital categories. A few of the most common waveforms include:

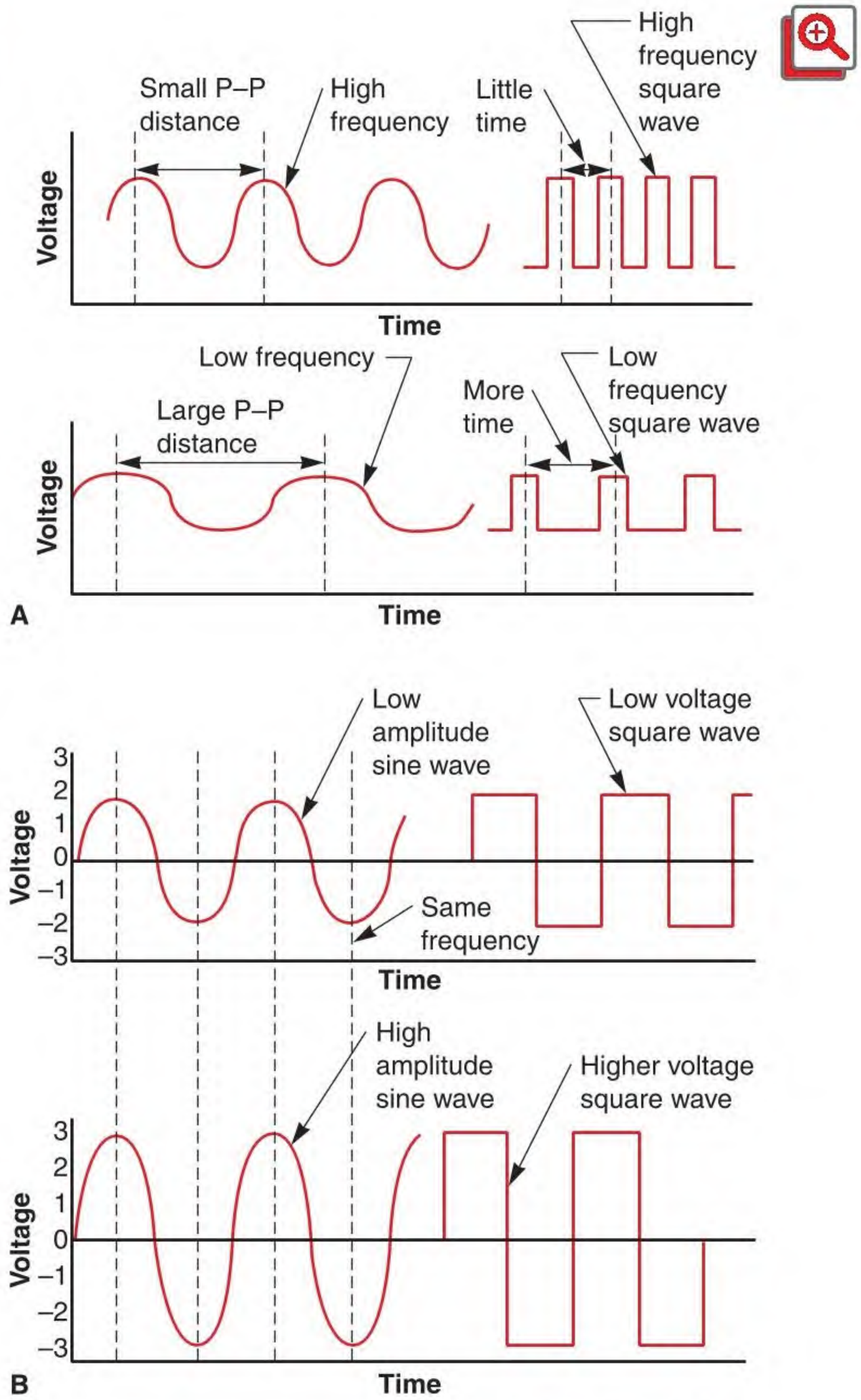
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Figure 23-10. Note how the speed sensors are operated by a crankshaft and camshaft trigger wheel. This lets the computer compare and adjust ignition timing and cam timing for maximum engine efficiency.

- AC sine wave—This wave is a curving signal that smoothly fluctuates above and below zero volts. The electricity in your home or inside an alternator would produce an alternating current (ac) sine wave at 120 V.
- DC sine wave—This type of wave is a curving, fluctuating signal that stays at or above zero volts. Most magnetic speed sensors produce a low-voltage sine wave on a test scope.
- DC square wave—This digital, on-off signal stays at or above zero volts. The computer converts dc sine waves from sensors into dc square waves for logic chips inside the computer.
- DC ramp wave—A wave that moves steadily up from zero and then switches off almost instantly is a dc ramp wave.
- Pulse wave—A pulse wave is a signal that rises progressively from zero and then almost instantly returns to zero.
- Complex sine wave—This signal voltage moves up and down erratically but gradually.
- Voice wave—A voice wave is an irregular wave that corresponds to the frequency of the human voice's airwaves. A microphone produces a weak analog wave proportional to the airwaves hitting the microphone.



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Figure 23-11. Scope patterns give you much more information about circuit operation than conventional voltmeter readings. A—Compare the differences in waveform frequencies. B—Note how the waveform amplitude, or voltage level, is denoted.

- DC noise wave—A dc noise wave is a straight line (dc) with some voltage fluctuations (noise). Noise is usually unwanted voltage spikes in a circuit and is caused by induced voltage from an outside source.

Computer Signal Terminology

There are several terms used to describe computer signals. Signal frequency, or ***pulse width***,

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generally refers to how fast a voltage signal changes over time. The signal frequency from a sensor might be measured in milliseconds, or thousandths of a second.

A high-frequency signal would be very short (narrow), or have a short pulse width. A low-frequency signal would be longer (wider), or would have a long pulse width.

Signal amplitude refers to how much voltage is present in the wave. A high-amplitude signal would have more voltage than a low-amplitude signal. Most automotive computer systems use a signal amplitude of about 3–5 V.

Duty cycle is the percentage of *on* time compared to total cycle time. Along with pulse width, it can be used to measure a signal or pulse as a percentage. For example, if a solenoid is sent a 50% duty cycle, it will be turned on half the time and off half the time.

Computer System Operation

There are three stages of computer system operation:

- ***Input***—Vehicle sensors convert a condition into an electrical signal that can be used by the computer.
- ***Processing*** and ***storage***—The computer compares sensor inputs to data and operating parameters in its memory to determine what action should be taken to control the vehicle's control circuits. The computer can remember programming, as well as store trouble codes in its memory chips.
- ***Output***—The computer produces electrical outputs that are used to control solenoids, servo motors, relays, and other actuators. These actuators perform physical actions to alter component operation for maximum vehicle efficiency.

Computer System Block Diagram

A ***computer system block diagram*** is a simple service manual drawing that shows how the sensors, the actuators, and the computers interact. It uses basic squares or rectangles to represent components and lines to represent wires. A computer block diagram is handy when trying to find out what types of sensors are used and what conditions are controlled by a specific computer system. A block diagram for one computer control system is shown in **Figure 23-12**.

Sensors

Most ***vehicle sensors***, or transducers, change a physical condition into an electrical signal. ***Transduce*** means to change from one form to another. Just as our eyes, ears, nose, fingers, etc., can sense conditions, vehicle sensors can detect the operating conditions of a car or truck. The computers use the voltage signals from sensors to control the actuators.

Sensors can be found almost anywhere on a vehicle. Many are mounted on the engine. Others can be located on or in the transmission or transaxle, in the exhaust system, on the wheel hubs, on and in the fuel tank, on the suspension, or even in the trunk (impact sensor). If in doubt, refer to the service manual for the specific vehicle to find sensor types and locations, **Figure 23-13**.

Sensor Classifications

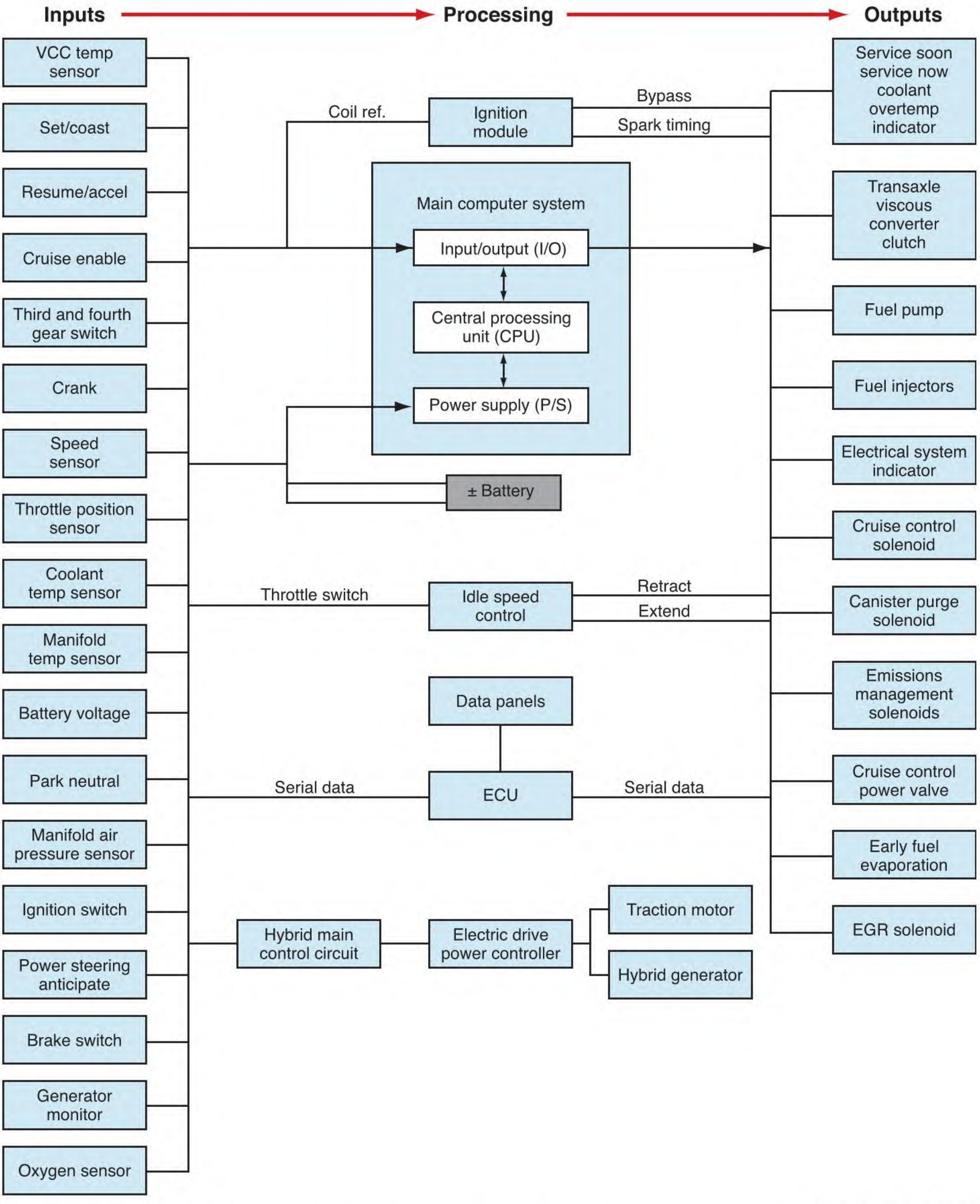
An automobile uses several types of sensors to provide electrical data to its many computers. There are dozens of specific names for vehicle sensors. However, they can all be classified into two general categories: active sensors and passive sensors.

An ***active sensor*** produces its own voltage signal internally. This very weak signal is fed back to the computer for analysis. ***Shielded wire***, which has a flexible metal tube around the conductor to block induced voltage and interference, is often used with active sensors.

A ***passive sensor*** is a variable resistance sensor. Voltage is fed to the sensor from the computer. The passive sensor's resistance varies with changes in a condition (temperature, pressure, motion, etc.). The computer can detect the resulting change in voltage caused by the change in resistance. Within these two categories are several sensor types:

- Variable resistor sensor—This type of sensor changes its internal resistance with a change in a condition; its ohms value may change with temperature, pressure, etc. It is an analog sensor. Examples of variable resistance sensors are throttle position and temperature sensors. A ***potentiometer*** is a variation of a variable resistor sensor. It has three external connections instead of two. One lead connects to each end of the resistor, and the remaining lead connects to a wiping arm that slides over the fixed resistor. This arrangement more precisely controls the current throughout than a two-connection variable resistor sensor.

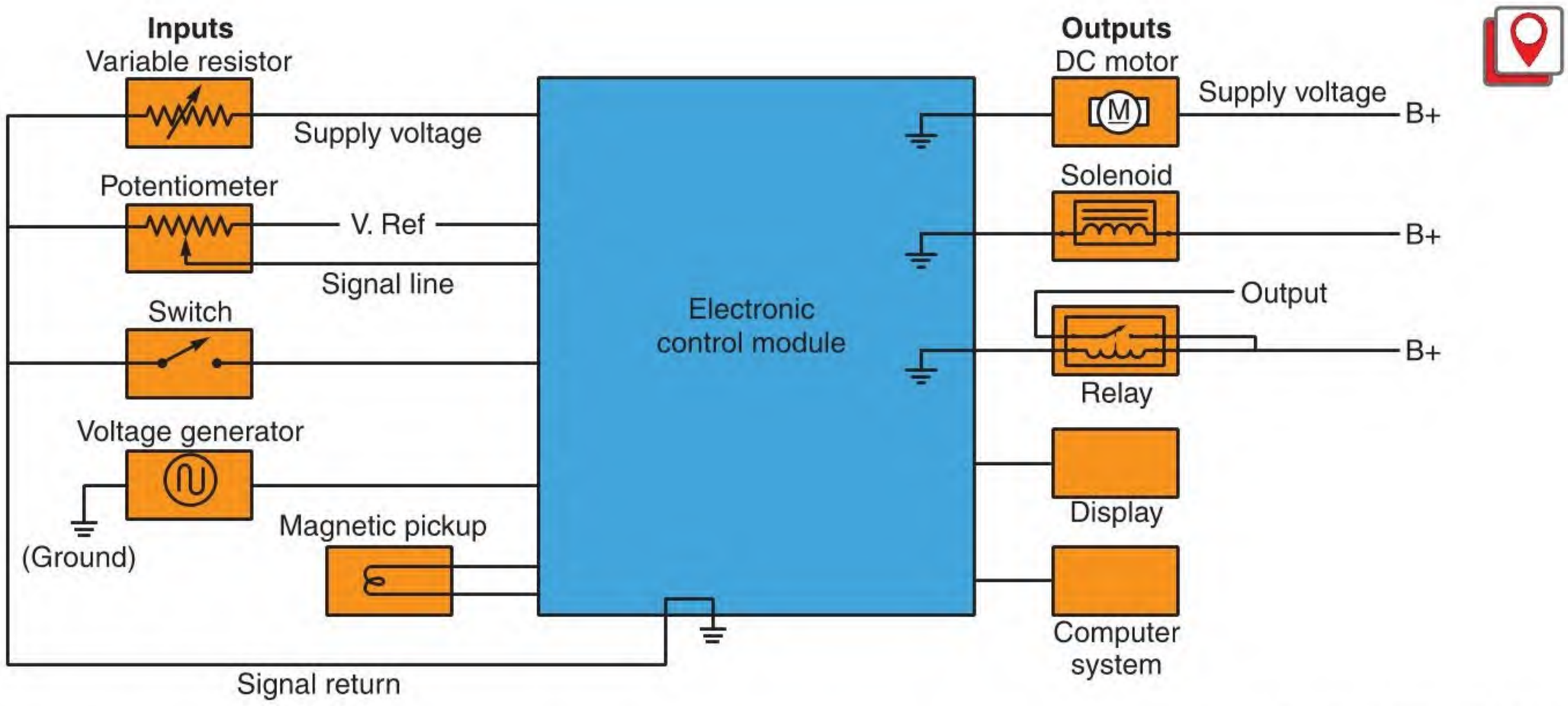
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Figure 23-12. Study the block diagram for this computer system. Note the different modules and the various input and output devices.

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Figure 23-13. These are the basic classifications of input sensors and actuators. Each sensor feeds a different type of signal to the computer.

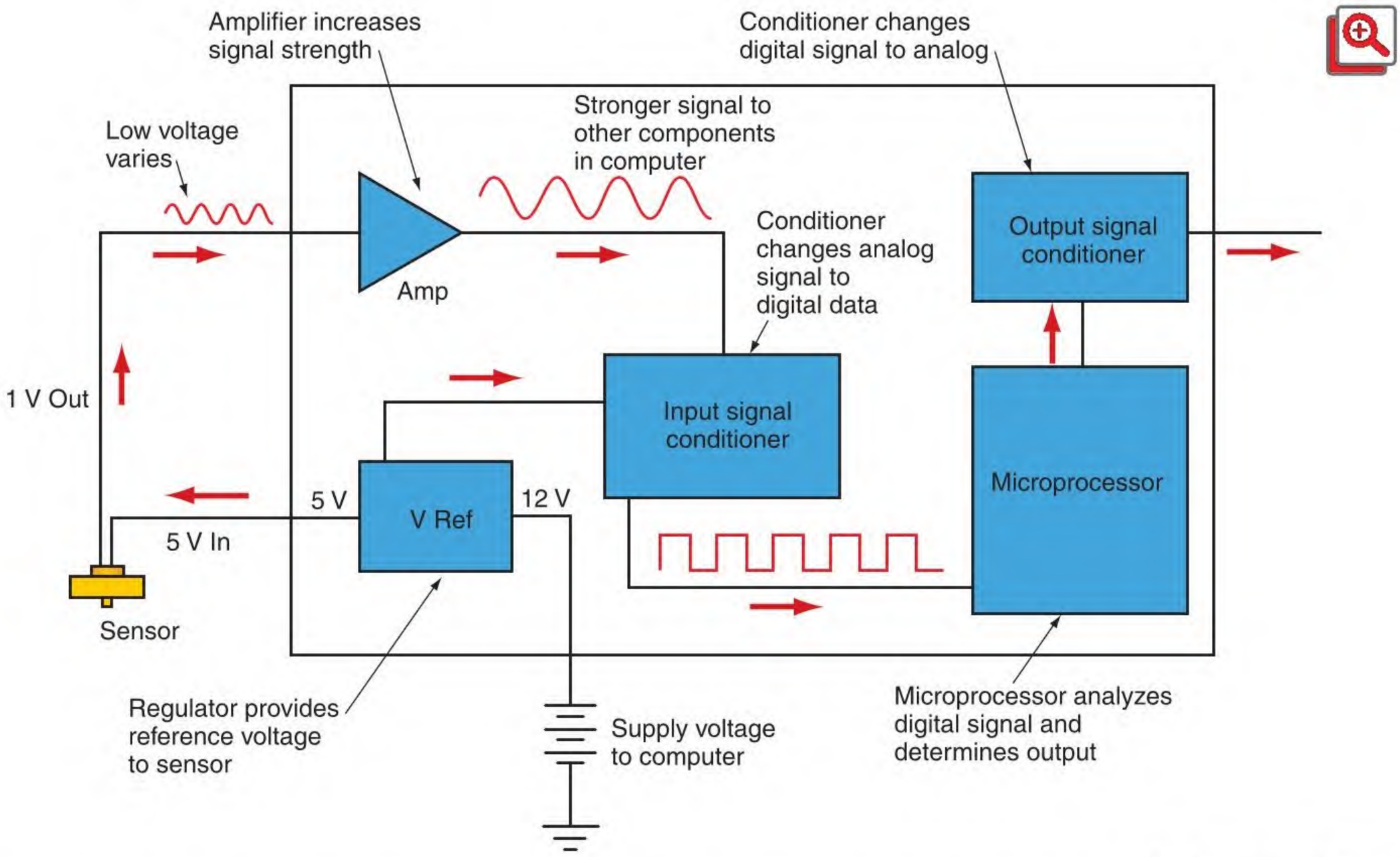
- Switching sensor—This type of sensor opens or closes the sensor circuit to provide an electrical signal for the computer. Transmission pressure switches are examples of this type of sensor. A switching sensor can detect almost any condition and produces a digital signal (either *on* or *off*).
- Magnetic sensor—A magnetic sensor uses part movement and induced current to produce a signal for the computer. This type of sensor is commonly used to monitor speed (vehicle speed sensor) or part rotation. It usually produces an analog signal. Magnetic sensors are also referred to as permanent magnet (PM) generators.
- Hall-effect sensor—This type of sensor uses a special semiconductor chip to sense part movement and speed. It produces a digital signal. These sensors are used as crankshaft and camshaft position sensors, as well as pickup devices in some electronic ignition distributors.
- Optical sensor—This type of sensor uses light-emitting diodes and photo diodes to produce a digital signal. Optical sensors may be used to sense part rotation and speed. These sensors are used in some distributors and as speed sensors mounted outside the speedometer.
- Knock sensor—This type of sensor generates voltage from a physical shock or motion on a crystal. It is sometimes used to listen to a condition, such as engine pinging upon rapid acceleration.
- Solar sensor—This sensor converts sunlight directly into an electrical signal. It is made of a semiconductor material that converts photons (light energy) into direct current.
- Direction sensor—This type of sensor detects the polarity of a moving magnet. This is a variation of a magnetic sensor. Unlike a magnetic sensor, it can signal which direction a part is rotating. It can produce signals for North, South, East, and West and is used in some navigation systems.

Reference Voltage

Reference voltage, sometimes abbreviated Vref, is the base voltage used to carry a computer signal. The computer sends a reference voltage to a passive sensor so a signal can be fed back for processing. A reference voltage is needed so a change in sensor resistance can be read by the computer as a change in current and voltage, **Figure 23-14**.

The reference voltage is typically around 5 volts. The computer steps down battery voltage so that a smooth, constant supply of dc voltage is fed to the passive sensors. The sensor alters the reference voltage by changing its internal resistance. This change in reference voltage is interpreted by the computer as a change in condition or state.

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Figure 23-14. A reference voltage of about 5 volts dc is sent out to the sensor. By varying the amount of voltage/current returning to the computer, the sensor gives data about an operating condition. Small amplifiers and conditioners treat this signal so it can be used by a microprocessor.

Sensor Types

The most common sensors used in late-model vehicles include the following:

- Intake air temperature (IAT) sensor—This sensor measures the temperature of intake air as it enters the intake manifold. The IAT is also called a manifold air temperature (MAT) or an inlet air temperature sensor.
- Engine coolant temperature (ECT) sensor—This sensor measures the temperature of engine coolant. In most cases, it is simply referred to as a coolant temperature sensor.
- Oxygen (O_2) sensors—These sensors measure the amount of oxygen in the engine's exhaust gases before and after the catalytic converter. Most newer sensors contain heaters and are referred to as heated oxygen sensors (HO_2S).
- Manifold absolute pressure (MAP) sensor—This sensor measures intake manifold vacuum in relation to a reference pressure (usually a vacuum).
- Barometric pressure (BARO) sensor—This type of sensor measures the outside air pressure around the engine. It is combined with the MAP sensor on most newer vehicles.
- Throttle position sensor (TPS)—This sensor measures the opening angle of the throttle valves to detect how much power is requested by the driver.
- Fuel pressure sensor (FPS)—A modern fuel pressure sensor threads into the fuel rail to monitor the amount of gasoline pressure available at the inlet of the fuel injectors. Some measure fuel pressure over time and can detect a leaking or clogged injector automatically.
- Engine speed sensor (ESS)—This sensor measures engine speed. It is often located next to a trigger wheel on the engine crankshaft snout. In older vehicles, it is located inside the distributor.
- Crankshaft position sensor—This type of sensor measures crankshaft position, rotation, and speed.

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- Camshaft sensor (CS)—This sensor measures camshaft position, rotation, and speed so the computer knows the stroke of the engine (intake, compression, power, or exhaust).
- Mass airflow (MAF) sensor—This sensor sometimes measures the amount of intake air flowing into the engine. It is often referred to as an airflow sensor or an airflow meter.
- Knock sensor (KS)—A knock sensor is usually a piezoelectric sensor that detects engine pinging, preignition, or detonation so the ECM can retard ignition timing or reduce turbocharger boost pressure.
- Transaxle/transmission sensor—This sensor checks transaxle or transmission gear selection, oil pressures, part speeds, loads, and other functions. A neutral safety switch is a part of a safety circuit to keep the engine from starting when the transaxle/transmission is not in *Park* or *Neutral*.
- Brake switch—This type of sensor detects brake pedal application.
- Wheel speed sensors—These sensors measure wheel rotational speed for anti-lock brake, traction control, and hybrid drive systems.
- Oil level sensor—This sensor measures the amount of oil in the engine oil pan.
- EGR sensor—This type of sensor measures the position of the exhaust gas recirculation valve pintle.
- Impact sensors—These sensors detect a collision to shut off the fuel pump and engine. A similar type of impact sensor is used to deploy the air bag system.
- Vehicle speed sensor—This type of sensor measures the vehicle's road speed so the ECM can adjust fuel, ignition, transmission, suspension, and other system operations. It is located in the transmission/transaxle housing or as part of the electric drive train.
- Fuel tank pressure sensor (FTPS)—This sensor measures the pressure or vacuum inside the closed evaporative monitoring system. It is similar in construction and operation to a MAP sensor. If someone leaves the gas cap off the vehicle, the system will detect a pressure leakage to inform the driver with a trouble code.
- Battery temperature sensor—This type of sensor monitors battery temperature so the computer can adjust vehicle operation to affect charging system output as needed.
- Computer-mounted sensors—These sensors are tiny sensors wired inside a vehicle's computer. Yaw sensors, direction sensors, interior temperature sensors, and others can be located inside the computer itself.
- Hybrid drive circuit sensors—These sensors monitor HV battery temperature, generator output, HV battery charge, power control module output, motor-generator torque/speed, and other conditions.

Circuit Sensing

Circuit sensing involves using the computer itself instead of dedicated sensors to monitor component and circuit operation. The computer monitors current flow through various components and circuits. For example, some circuit sensing systems can monitor fuel injector operation (injector coil winding current), ignition coil action (current through ignition coil windings), and computer operation (current through computer circuits). The windings and the wires in the circuits serve as the sensors.

Tech Tip

For more information on computer system sensors and other components, refer to the index. More details of specific kinds of vehicle sensors are given in later chapters where this information is relevant.

Computers

The term *computer* is a general term that refers to any electronic circuit configuration that can use multiple inputs to find preprogrammed outputs.

Automobile manufacturers use many names for their computers, including:

- Central processing unit (CPU).
- Electronic control unit (ECU).
- Electronic control module (ECM).
- Engine control module (ECM).
- Electronic control assembly (ECA).

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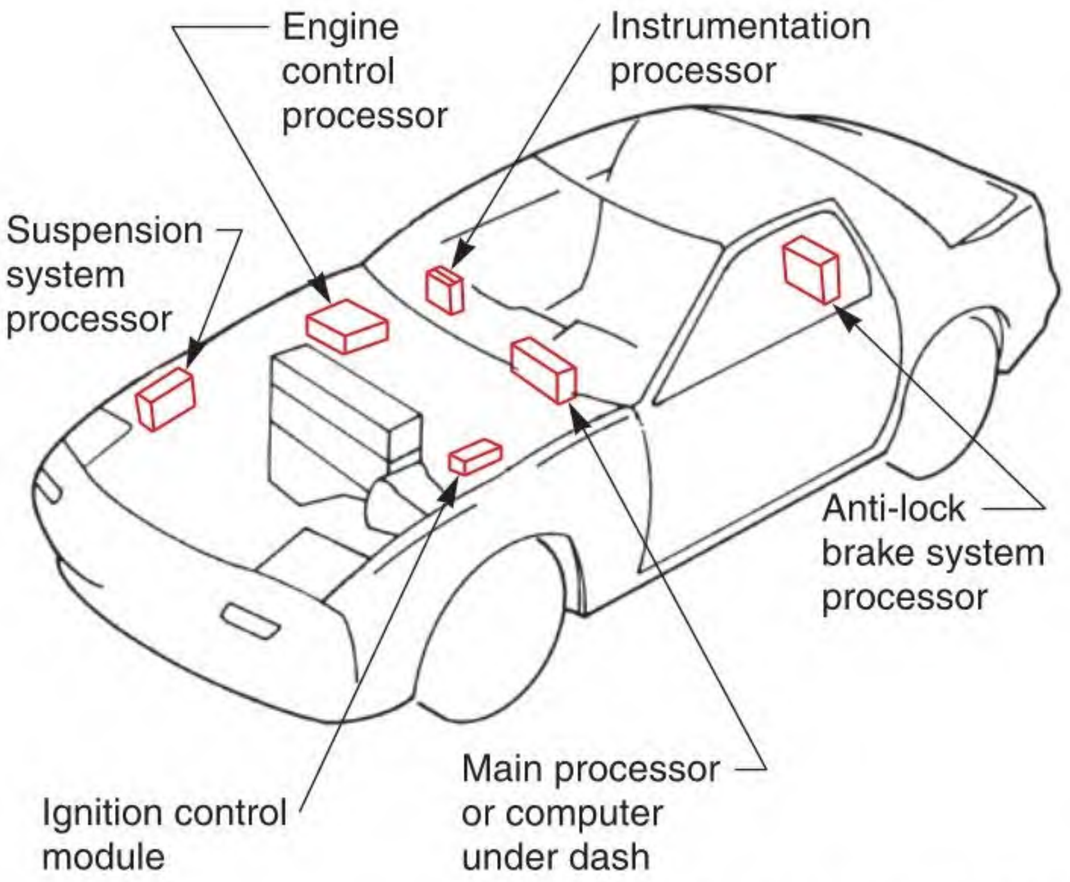
- Powertrain control module (PCM).
- Vehicle control module (VCM).
- Microprocessor.
- Logic module.

Keep these names in mind when reading service manuals. To prevent confusion, this textbook will use the term *control module* when referring to automotive computers in general.

Computer Locations

Automotive computers may be located under the dash on the passenger side of the vehicle. This protects the delicate circuits and components in the computer from engine heat, vibration, and moisture. However, computers, like the high-temperate electric drive train controller, can also be located in the engine compartment, in the trunk, or under the seats. See **Figure 23-15**.

When located in the engine compartment, the computer is closer to most sensors and actuators. Less wiring and fewer connectors are needed to tie the system together. Computers used to operate the anti-lock brakes and other systems are often found anywhere in the vehicle. Engine and powertrain control modules are located under the dash, in the engine compartment, or in another central location. Computers used with specific systems, such as the ignition or air conditioning systems, are close to, in, or under the system components.



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Figure 23-15. One or more computers can be used on the same car. Note the potential locations.

Computer Types

Several types of computers can be used in a car. The number and types of computers will vary with the manufacturer. The most common types are:

- Vehicle control module—This large, powerful computer processes data from sensors and other, less powerful control units. It coordinates engine, transmission, traction control, and anti-lock brake functions, and instrumentation, for example.
- Powertrain control module—This module is a powerful computer used to monitor and control the engine, transmission, and other systems.
- Engine control module—This computer uses sensor inputs to control engine idle speed, fuel injection, ignition timing, emission control devices, and other operating parameters.
- Anti-lock brake module—This small computer uses wheel speed sensor inputs and other inputs to control anti-lock brake application.
- Instrumentation module—This small computer uses sensor inputs to operate a digital dash display.
- Ignition module—This small computer uses sensor inputs to control ignition timing, spark plug firing, or ignition coil pack operation.
- Suspension system module—This small computer uses vehicle speed, suspension, and steering sensor inputs to control ride stiffness or shock absorber action.
- Climate control module—This small computer used to control the operation of the heating, ventilation, and air conditioning systems.
- Air bag module—This small computer controls the vehicle's air bag system. This electronic circuit also stores power to deploy the air bags in the event that battery power is severed and lost in a collision.
- HV power control module—This module consists of a set of electrical and electronic circuits that alter current and route it between the battery pack and motor-generator in a hybrid vehicle.
- Hybrid control module—This module controls the power control module and motor-generator to keep the battery pack operating at the optimum temperature and state of charge.
- Body module—This computer provides memory and other functions for the radio, driver's information center, electronic compass, trip computer, navigation, exterior and interior lights, etc.

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Again, the number and types of computers used will vary with the year, make, and model of vehicle. The trend is to use a body ECM and an engine control module ECM to process most of the input data and control most outputs for the vehicle. In conjunction with these computers, smaller computer modules are used for the brake system, suspension system, ignition, hybrid drive, and other circuits. Refer to the service manual to find out what types of computers are used on a specific vehicle and what each computer is called.

Tech Tip

A computer used to be nicknamed a "black box." This is because its mysterious electronic circuitry was enclosed in a box-shaped housing, sometimes made of black plastic or metal. Modern computers are still a mysterious marvel of electronic circuit complexity.

Computer Operation

This section will summarize the operation of a computer. Even though you will probably never repair a computer, it will be helpful to you as a technician to understand how a computer uses sensor inputs and produces actuator outputs using complex electronic circuits.



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Figure 23-16. This photo shows the inside of a computer. Note that it uses integrated circuits attached to a printed circuit board.

Figure 23-16 shows the inside of an automotive computer. It is composed of printed circuit boards, integrated circuits, capacitors, resistors, power transistors, and many other basic electronic components.

Parts of a Computer

Even though you may never see the inside of an ECM when you repair cars, this information will help you understand what is happening when you troubleshoot and reprogram automotive computers. All computers can be divided into sections that have specific functions.

The computer housing is a metal or plastic enclosure that protects electronic components from unwanted induced currents, moisture, and physical damage.

A circuit board is a plastic or fiberboard insulator with flat metal conductors printed on its surface to connect and hold components. A computer harness connector is a multi-pin terminal that attaches to the vehicle's wiring harness.

The computer's clock is an integrated circuit that uses a constant pulse rate to coordinate when or how quickly signals are sent throughout the complex circuits.

The microprocessor is usually the largest integrated circuit in a computer. The microprocessor analyzes data from sensors and compares it to known good operating values in memory. Memory chips store digital data. The microprocessor chip can then produce decisions or calculations for the proper output for actuators (fuel injector pulse width, ignition timing, throttle valve position, and other functions).

A ***voltage regulator*** converts battery and generator voltage into lower, cleaner dc voltage that can be safely used by the ECM circuits, dash displays, and sensors.

A computer amplifier simply strengthens various signals inside the computer. An amplifier might increase the voltage signal from the oxygen sensor, which is less than one volt. Then, the signal is strong enough to be used by circuits in the computer.

Conditioners, also called converters or interfaces, alter signals for use by other chips and circuits in the computer. An input conditioner alters the input from some sensors. It filters incoming data (voltage and current changes). For example, many sensor signals are analog. The conditioner can convert an analog signal into a comparable digital, square wave signal that the computer can understand. An output conditioner is needed to change digital signals back into analog signals for use by power transistors energizing actuators or other computers.

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Both input and output conditioners protect the computer from shorted or grounded circuits. If a sensor, output device, or related circuit is shorted or grounded, the conditioner will not accept the signal and will open the circuit to protect the ECM circuitry from damage.

A ***buffer*** is a device that can serve as a temporary storage area for data. It can also protect internal computer chips from improper data. For example, if data is fed into the computer too quickly, the buffer can hold the data and then feed it into the other devices at a controlled rate. In many cases, the buffer is built into the input conditioners.

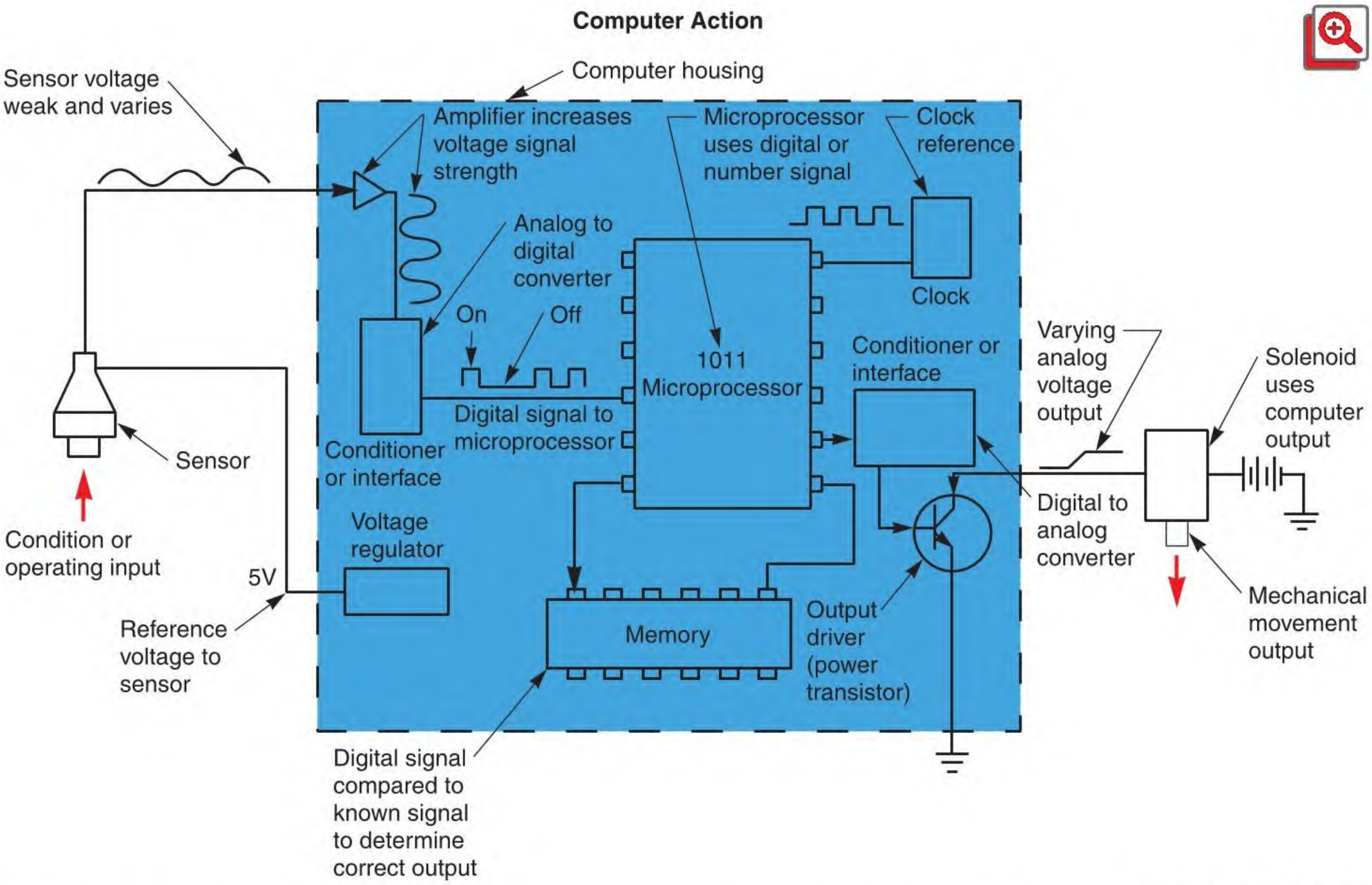
Computer memory stores data for the microprocessor. Trouble codes and vehicle-operating data are stored in memory.

Output drivers are power transistors that step up current by providing a ground path to operate actuators (fuel injectors, solenoids, servo motors, and other high-current devices).

Computer Microprocessor Operation

The term *microprocessor* means small (micro) computer (processor). A microprocessor is an integrated circuit capable of analyzing data and calculating appropriate outputs. It is the brain of a computer. See **Figure 23-17**.

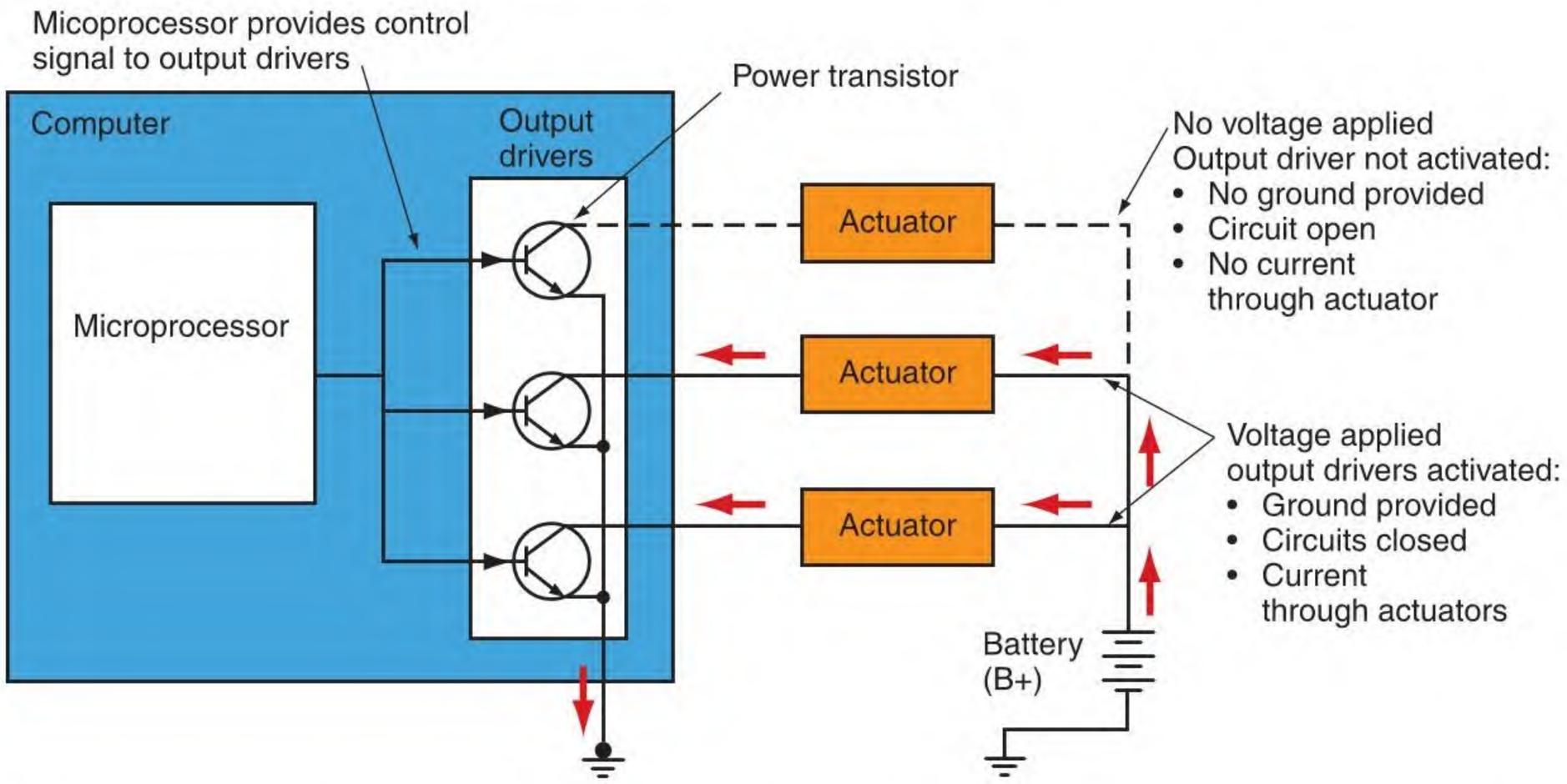
A microprocessor uses the binary number system to make decisions, comparisons, or calculations. Digital pulses from the conditioners are fed into the microprocessor. Since these inputs are off (0) or on (1) voltages, they can be used by the logic gates in the processor. A microprocessor also uses data stored in the computer's memory. It compares input signals to memory data to decide what the outputs should be for maximum efficiency. Refer to **Figure 23-18**.



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Figure 23-17. Trace the flow of data through this simplified computer system. Can you explain the purpose of each component?

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Figure 23-18. A computer will normally activate each output by grounding its circuit. Power is present at the output devices at all times, but there is not a complete circuit path. When a computer's output drivers, or power transistors, are turned on, they will conduct current through ground to energize the output devices.

Tech Tip

The computers used on late-model vehicles have more computing power and memory than their predecessors. For example, computers used in late-model vehicles have 16- to 64-bit processors and large read only memory chips. The computers found in older vehicles contain 8-bit processors and smaller memory chips and are not powerful enough to monitor and control present-day vehicle systems.

Computer Memory Operation

Computer memory uses gates that are capable of storing data as voltage charges. The integrated circuits inside the memory chips will hold the data (*on* or *off* charges) until it is needed by the microprocessor. There are several basic types of computer memories:

- ***Random access memory (RAM)***—Random access memory is a memory chip used by the computer to store information or data temporarily. This data is erased if battery power to the computer is removed.
- ***Read only memory (ROM)***—Read only memory stores permanent data that cannot be removed from memory. This memory chip contains calibration tables and look-up tables for the general make and model car.
- ***Programmable read only memory (PROM)***—Programmable read only memory contains permanent data that is more specific than the data stored in ROM. The microprocessor can read from the PROM, but it cannot write to the PROM. A laptop computer with factory software is required to reset PROM chips. The PROM contains specific information about the vehicle's engine (number of cylinders, valve sizes, compression ratio, fuel system type), transaxle (shift points, gear ratios, etc.), weight, tire size, optional accessories, and any unique features. There are three types of PROM used in late-model vehicles:
- ***Erasable programmable read only memory (EPROM)***—Erasable programmable read only memory can be changed. However, in most cases, the changes can only be made by the manufacturer using special equipment. This type of memory is also responsible for storing semipermanent data, such as odometer or mileage readings for an electronic dash display.
- ***Electrically erasable programmable read only memory (EEPROM)***—Electrically erasable programmable read only memory can be altered by the technician in the field. This allows the manufacturer to easily change operating parameters if a performance or driveability problem is discovered.

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- ***Flash erasable programmable read only memory (FEPROM)***—Flash erasable programmable read only memory is similar to EEPROMs in all respects. FEPROM is simply another name for an EEPROM.

Another type of memory found in some computers is known as ***keep alive memory (KAM)***. KAM allows the computer to have an adaptive strategy. An ***adaptive strategy*** is needed as parts wear and components deteriorate. The information stored in KAM allows the computer to maintain normal vehicle performance with abnormal inputs from sensors. It gives the computer the ability to also ignore false inputs to maintain good driveability.

The ECMs used on late-model vehicles use modified flash PROMs (high-speed programmable read only memory) that is permanently fixed to the circuit board but can be erased and reprogrammed quickly with a laptop.

On older vehicles, the PROM chip is removable. During computer replacement, the chip can be removed from the old computer and reused in the new computer. Data is retained in the PROM even when the chip is removed from the computer.

Output Drivers

Output drivers, sometimes referred to as quad drivers or power transistors, control current flow through the actuators. When energized by the computer, the drivers ground the actuator circuits. The actuators can then produce movement, such as turning the electric cooling fans.

Actuators

Mentioned earlier, ***actuators*** are the hands and arms of a computer system. They allow computers to do work and alter the operation of other components and systems.

Actuator Locations

Actuators can be found almost anywhere on a vehicle. They can be located on the engine, in the doors or dash, under the hood, and in the trunk. Check an appropriate service manual for exact actuator locations.

Actuator Classifications

A computer system uses several types of output devices, or actuators, to control part operation. All actuators can be grouped into the following categories:

- Solenoid
- Relay
- Servo motor
- Display devices
- Control module

A ***solenoid*** has tiny wire windings that form an electromagnet that moves a metal core or plunger when energized. The core movement can then act on other components, such as a fuel injector valve, throttle valve, or door locks.

A ***relay*** is another actuator that reacts to a small control signal from the computer to control a much higher current flow to large components or systems, such as the starting motor, air conditioning, or headlights.

A ***servo motor*** is a very small dc motor actuator that can produce a rapid spinning motor when energized by a relay or main computer. A common use for a servo motor is to control engine idle speed by opening or closing a small air passage into the engine intake manifold.

Electronic ***display devices*** include vacuum-fluorescent, liquid-crystal, and plasma displays to provide output information in the dash instrument cluster(s).

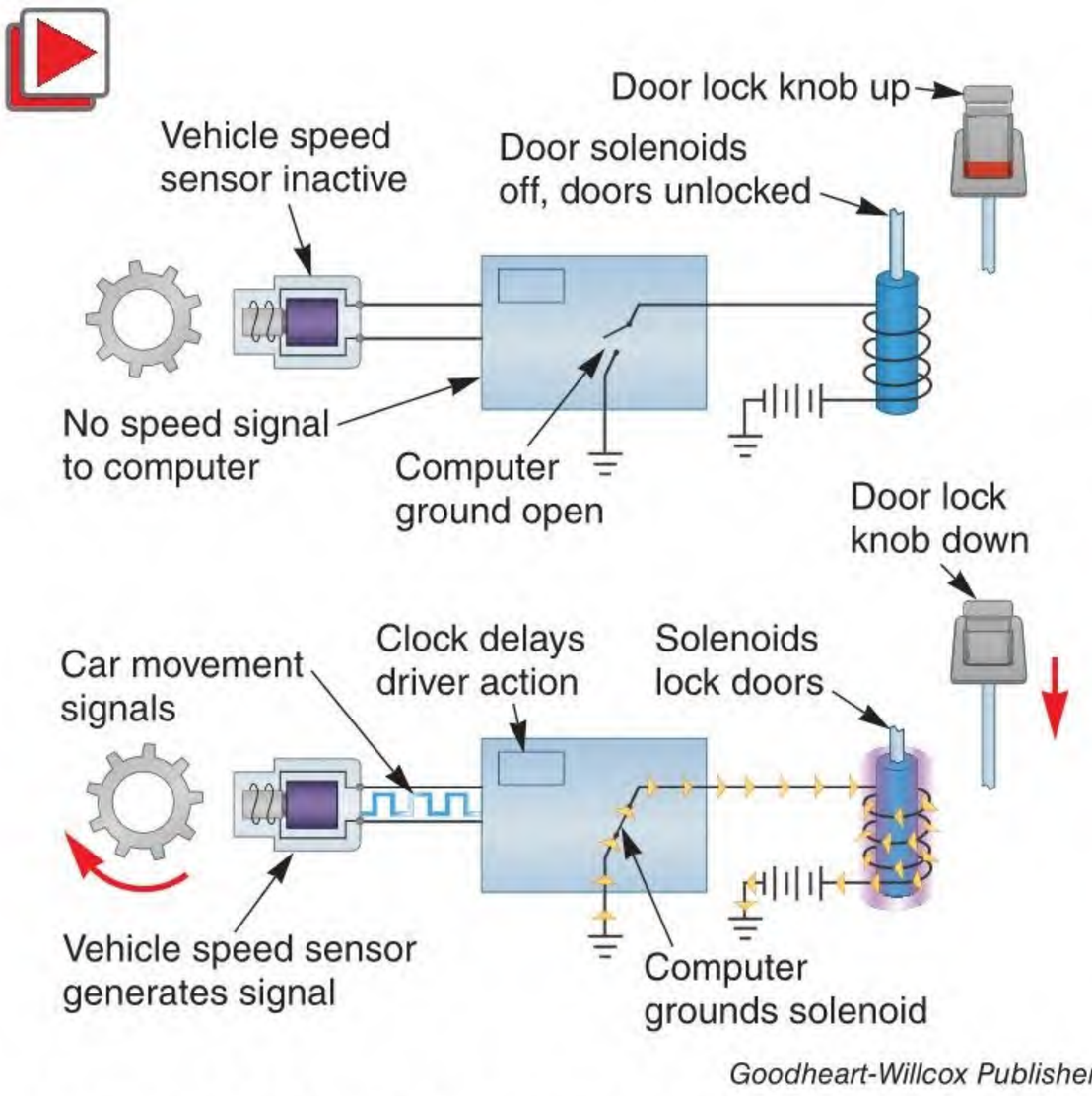
A control module is a small, specialized computer that reacts to input data to control other devices or circuits. The control module often amplifies and/or modifies the input signal to operate actuators by grounding their circuits. An ignition control module is a very common type. An ignition control module operates the ignition coils so high-voltage pulses are sent to the spark plug electrodes. When the hot electric arcs jump across the air gap at each spark plug, combustion begins to operate the engine.

Actuator Operation

When a computer turns on an actuator, it normally provides the device with a ground circuit. Then, current flows through the actuator itself, and the frame ground can operate the actuator. The following sections detail the operation of the three most common actuator types: solenoids, relays, and servo motors.

Figure 23-19 shows how the computer can use a solenoid to lock the vehicle's doors once a certain road speed is achieved. Input from the vehicle speed sensor enters the computer. When the computer detects vehicle travel or forward motion, it grounds the solenoid circuits and current flows through the solenoid windings. This produces a magnetic field in the windings. The magnetic field moves the plunger mounted in the solenoid windings. This plunger move-

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Figure 23-19. Simplified illustration of how sensor inputs can be used by the computer to operate solenoids. When the vehicle speed sensor produces a signal, the computer grounds the door lock solenoid. The solenoid movement is used to lock the car doors automatically.

ment locks the doors.

A relay is often used as an actuator when a high-current load must be controlled by the ECM. The ECM will simply ground the relay coil windings. Then, the relay coil field will pull the mechanical contacts closed, allowing a large current to flow to the load, **Figure 23-20**.

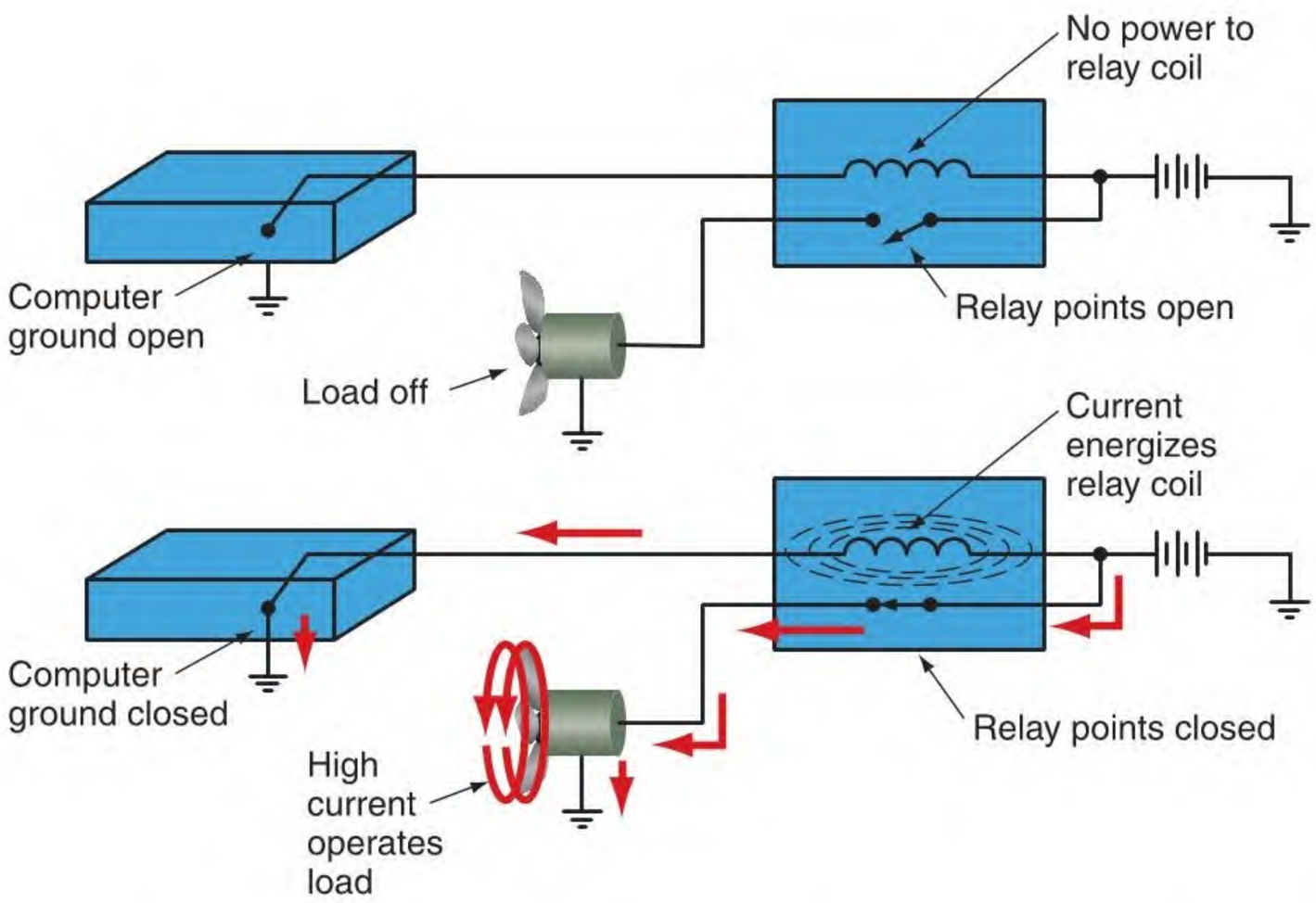
A servo motor provides another way for the ECM to produce an output. The ECM can ground the motor circuit, turning the motor on or off or reversing motor rotation as needed.

Sometimes, the servo motor is simply a reversible dc motor. The motor will turn a threaded mechanism to produce a controlled movement of a part. A good example would be an idle speed motor. Note that some motors also serve as sensors for the computer. They can inform the computer as to their positions. Look at **Figure 23-21**.

Specific Actuators

Some common actuators used on late-model vehicles include the following:

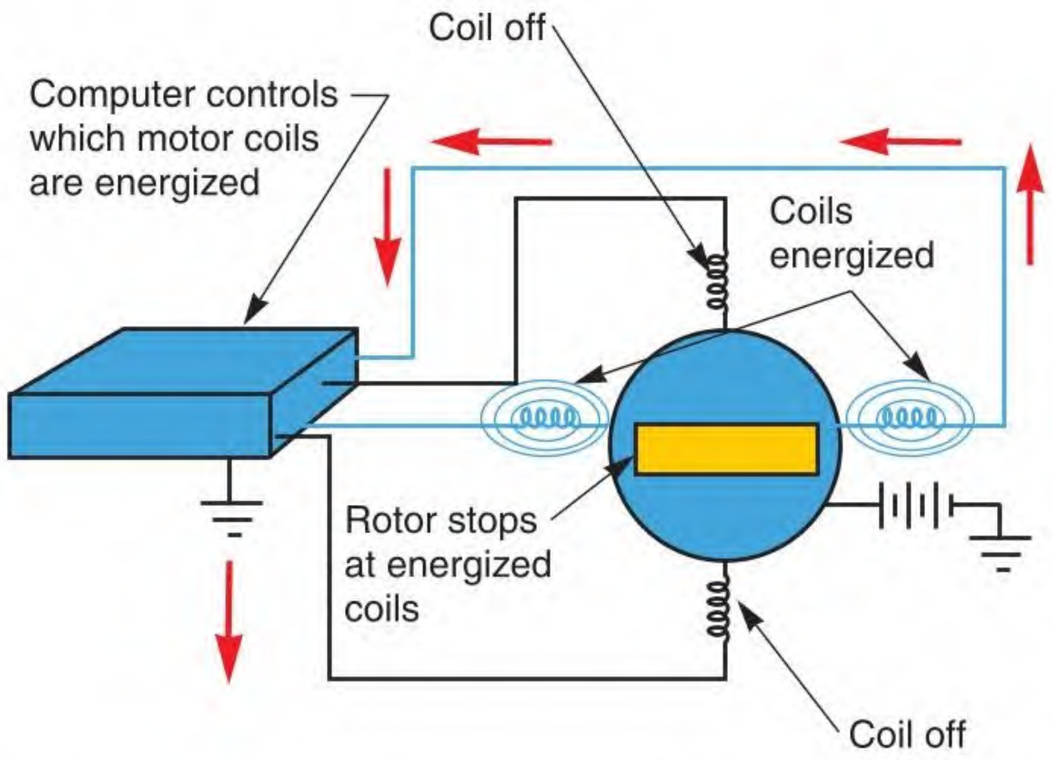
- Fuel injectors—A fuel injector is basically a solenoid valve that controls fuel flow into the engine.
- Fuel pump—An electric fuel pump is a small motor and impeller that forces fuel out of the gas tank and to the engine.
- Idle air solenoid—An idle air solenoid controls airflow into the engine to help control idle speed.
- Idle speed motor—An idle speed motor is a small



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Figure 23-20. A relay can also serve as an actuator to control high current. Low-voltage computer control current is used to close the relay points. Then, high current flows to the load.

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Figure 23-21. A servo, or stepper, motor can be stopped in an exact position. The computer can energize specific coils to attract and stop the armature next to the energized coils.

reversible dc motor that opens and closes the engine throttle valve to control idle speed.

- EGR solenoids—EGR solenoids open and close small ports to control exhaust gas flow back into the engine to control emissions.
- Canister purge solenoids—Canister purge solenoids control vacuum flow to draw fuel vapors into the engine for burning to reduce emissions.
- Door lock motors or solenoids—Door lock motors or solenoids move latch mechanisms to lock or unlock the car doors.
- Electric seat motors—Electric seat motors are reversible dc motors that move the seat into the desired position.
- Ignition coil—An ignition coil uses high current flow to change low voltage into the high voltage that operates the spark plugs.
- Ignition module—An ignition module is an electronic circuit that uses computer signals to control the operation of the ignition coils and spark plugs.

Computer Networks

A ***computer network*** is a series of computers that control different systems but work together to improve overall vehicle efficiency. Also called an integrated computer system, the network allows all the on-board computers to use feedback data from several systems (engine, transmission, braking, suspension, and traction control, for example) to better control all vehicle systems. The term used to describe this computer interaction in vehicles is ***multiplexing***. Multiplexing binary signals between computers avoids the duplication of components, it speeds electronic communication, and it reduces the amount of wiring needed in the vehicle's wiring harnesses.

The computers in the network share common parts, such as wires, input signals, and output signals. They exchange data from sensors to prevent duplication of parts and to reduce wiring.

The wiring used for the network is often referred to as a ***data bus***. The signals traveling through the data bus are coded to indicate which computers the signals are being sent to, and in what order the signals should be processed. This prevents the signals from being processed by the wrong computer or in the wrong order.

Each computer and system needed for vehicle operation has its own default operating or limp-in mode, so the vehicle can be driven home or to a shop for service.

In the near future, fiber optics, which uses light to transmit data, may form the network connections. This will allow faster and simultaneous transmission of data from each computer.

Serial/Parallel Network Communication

Communication between ECMs in a network can be classified as either serial or parallel. ***Serial communication*** uses only one wire to exchange digital data. In this setup, data is transferred one bit at a time. ***Parallel communication*** involves the use of several wires to exchange multiple bits of data simultaneously. See **Figure 23-22**.

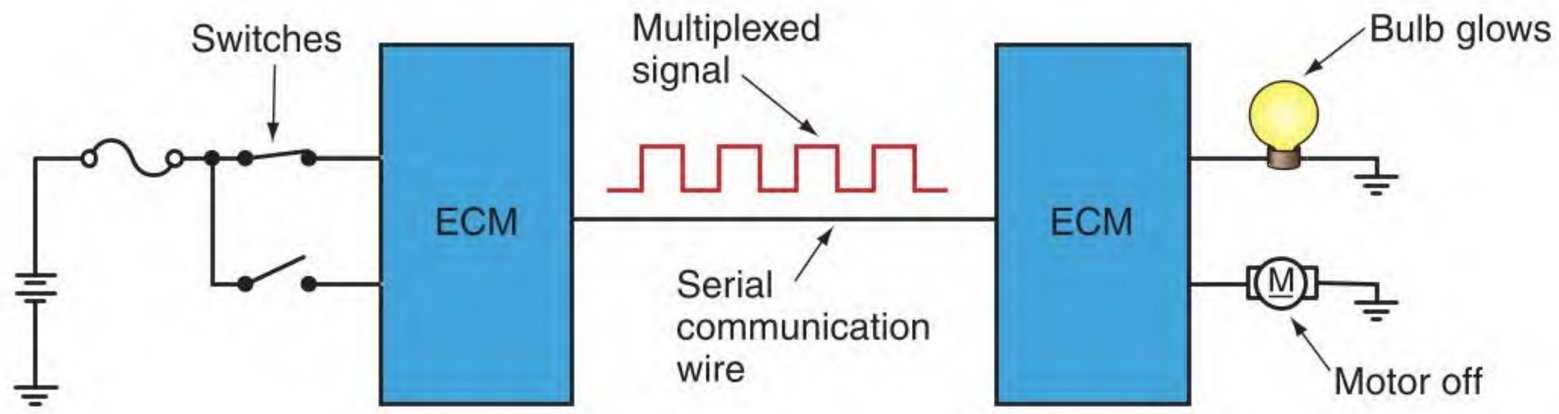
ECM Information Flow

There are several ways that vehicle ECMs communicate or talk with one another. In a ***star configuration***, one main processing ECM and several less complex ECMs work as a network. The smaller ECMs cannot communicate with each other unless data is first sent through the main processing ECM.

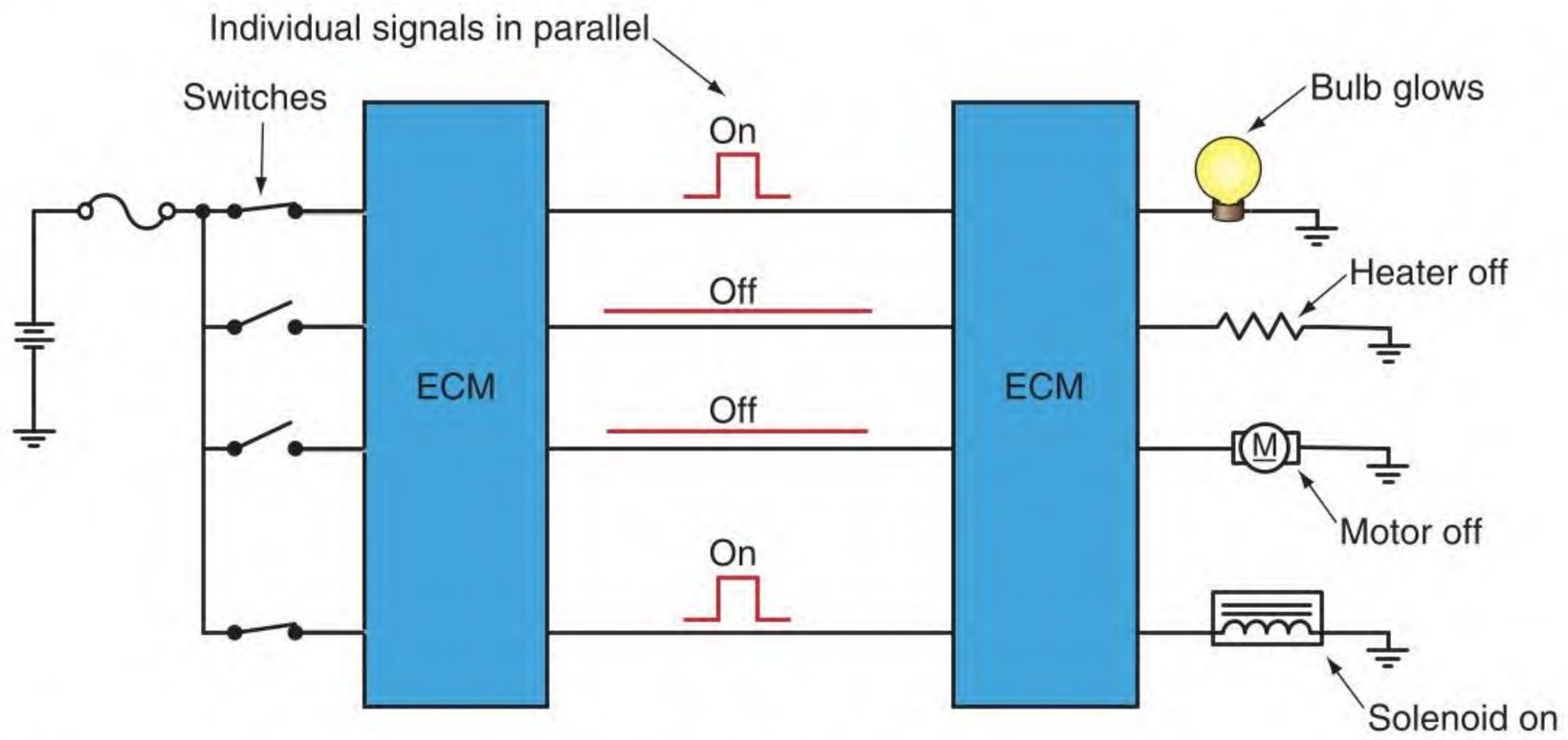
The ***bus configuration*** has several of the vehicle's ECMs wired to a single conductor, or bus. No main processing ECM is used.

A ***ring configuration*** has each ECM wired in series, or in a loop. The signal-transmitting ECM's data flows through each ECM and then back to the source ECM. Again, no main processing ECM is needed. Refer to **Figure 23-23**.

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A **Serial (Multiplexed) Communication**



B **Parallel Communication**

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Figure 23-22. A multiplex communication system has several computers working together to improve overall vehicle efficiency. The computers in the network share a common wire or wires that carry digital data through the network or multiplex.

Network Wiring

There are two basic types of conductors used in a vehicle ECM network to carry data between different components: single-wire conductors and twisted-pair conductors.

A ***single-wire conductor*** is a conventional insulated wire that carries data signals between computers. The insulation in a single-wire conductor may be covered by a braided metal shield to protect the conductor from electromagnetic interference.

A single-wire conductor is the smallest, lightest type of conductor used to provide communication between computers in different vehicle systems. It is adequate for vehicle systems that do not affect vehicle performance and safety, such as the accessory system.

Twisted-pair conductors consist of two insulated wires that are wound, or twisted, into a spiral. Twisting the wires together helps cancel out electromagnetic interference from external sources. Twisted-pair conductors can carry computer data faster than single-wire conductors.

Twisted-pair conductors can be unshielded or shielded. Unshielded twisted-pair conductors are ideal for high-speed communication between computers when the conductor is away from strong sources of electromagnetic interference or when it is located inside a metal body structure of the vehicle.

A ***shielded twisted-pair conductor*** is encased in a metal shield to further reduce electromagnetic interference. Shielded twisted-pair conductors must be used near high-voltage sources in the vehicle, such as the ignition coils or hybrid power cables. If an unshielded conductor is routed near a high-voltage source, current can be induced in the conductor and affect computer communication.

A ***differential voltage signal*** is used with twisted-pair conductors. A differential voltage signal consists of two complementary digital signals with opposing polarities. One of these signals is sent through each wire

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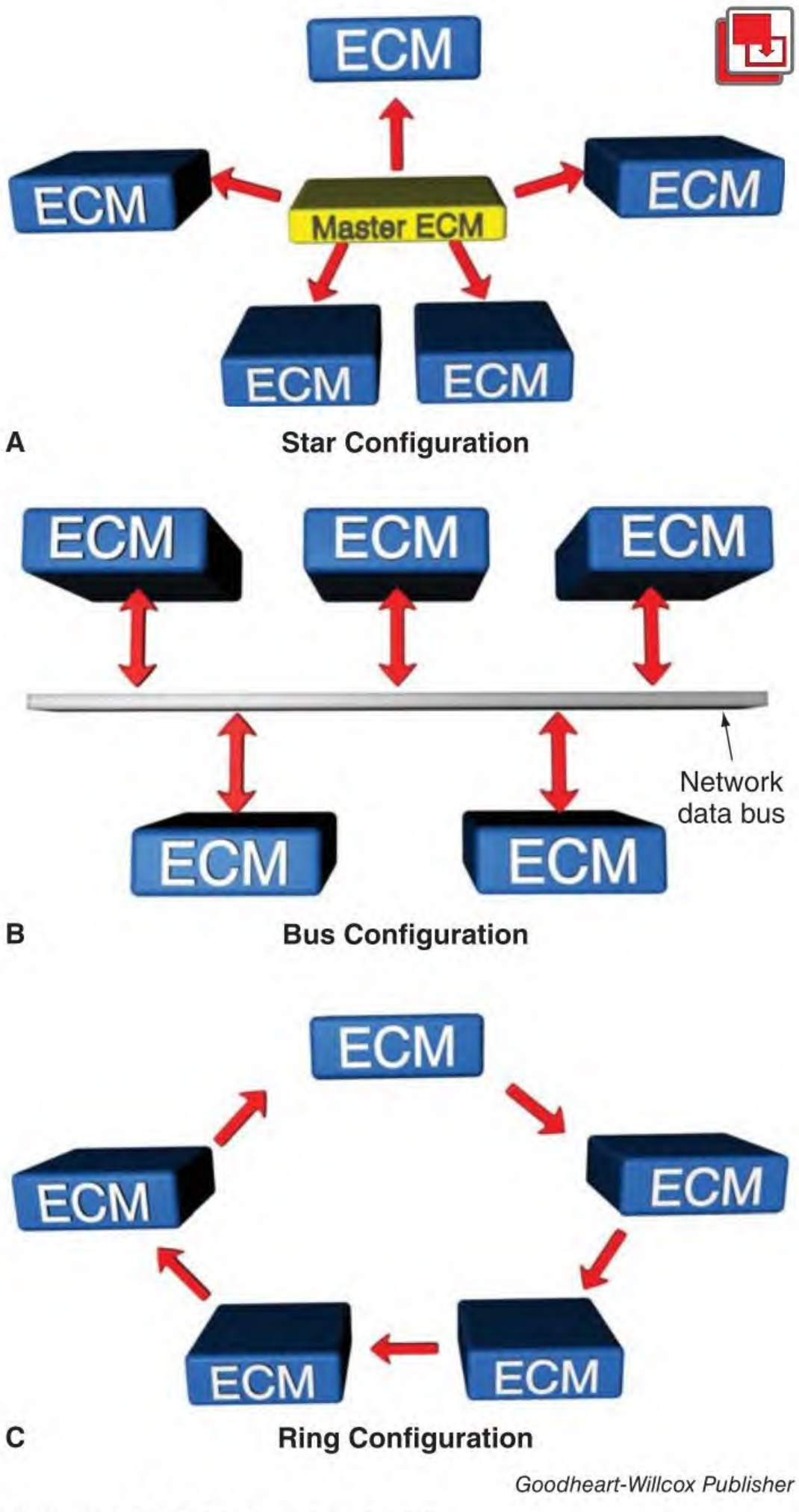


Figure 23-23. Study network styles.

of the twisted pair. The differential voltage signals are synchronized to strengthen the low-voltage communication signals flowing between computers. The signals are combined when they reach their destination.

CAN and LIN Systems

A ***CAN***, or ***controller area network***, is a specific type of high-speed computer data bus. Several computers and sensors can use CAN bus wiring at the same time. Each computer in a CAN system has the ability to send and receive signals. Each CAN signal carries markers that denote where the signal originated, what type of information it contains, the priority of the information in the signal, and the actual information or message.

The signal from one computer in a CAN system is sent to all other computers in the network. Each computer decides whether or not to process the signal based on its marker.

Tech Tip

Starting with the 2008 model year, the diagnostic systems in all new vehicles are CAN compliant.

A ***LIN***, or ***local interconnect network***, is a data bus system that is designed to work in conjunction with CAN. It operates at a relatively low speed and is less expensive to manufacture than CAN. LIN is ideally suited for sensor and actuator networking applications for body control systems, such as climate control, lighting, and door control (power windows, locks, and mirrors). While CAN may be used throughout the vehicle, LIN would be used in one section, such as inside a door. A special CAN-LIN bridge must be used to connect the LIN to the CAN system.

In the Rearview Mirror

In response to the Clean Air Act of 1977, manufacturers began producing "self-adjusting" engines. These engines, which were introduced in 1981, were equipped with feedback fuel-control systems. Early feedback systems consisted of an oxygen sensor to measure the oxygen content in the exhaust gases (an indication of air-fuel ratio), a small computer to analyze the oxygen sensor signal, and a mixture control device to make air-fuel ratio adjustments based on the computer's output signals. These simple systems were the predecessors to the powerful, complex computer systems found on today's vehicles.

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Summary

- A computer is a complex electronic circuit that will produce programmed electrical outputs after receiving specific electrical input signals.
- The term *cybernetics* refers to the study of how electrical-mechanical devices can duplicate the action of the human body.
- The binary numbering system uses only two numbers, zero and one, and is the key to how computers and ECMs operate.
- A gate is an electronic circuit that produces a specific output voltage for given input voltages.
- An integrated circuit is an electronic circuit that has been reduced in size and placed on the surface of a tiny semiconductor chip.
- Digital signals are on-off signals, like those produced by a rapidly flipping switch.
- An analog signal changes in strength (voltage, current, and/or resistance).
- A computer signal, waveform, or wave is a voltage variation over short periods of time.
- A vehicle sensor is a transducer that changes a condition into an electrical signal.
- The computer sends a reference voltage to passive sensors so that a signal can be fed back for processing.
- Circuit sensing involves using the computer itself instead of dedicated sensors to monitor component and circuit operation.
- Output drivers control current flow through the actuators.
- A microprocessor is an integrated circuit capable of analyzing data and calculating appropriate outputs.
- Computer memory uses gates that are capable of storing data as voltage charges.
- The three basic types of computer memory are RAM, ROM, and PROM.
- Actuators allow the computer to alter the operation of other components.
- A computer network is a series of computers that control different systems but work together to improve overall vehicle efficiency.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

active sensor
actuators
adaptive strategy
analog signal
binary numbering system
buffer
bus configuration
CAN (controller area network)
circuit sensing
computer
computer network
computer signal
computer system block diagram
conditioner
cybernetics
data bus
differential voltage signal
digital electronics
digital signal
display devices
duty cycle
electrically erasable programmable read only memory (EEPROM)
erasable programmable read only memory (EPROM)
flash erasable programmable read only memory (FEPROM)
gate
input
integrated circuit (IC)
keep alive memory (KAM)
LIN (local interconnect network)
multiplexing
output
parallel communication
passive sensor
potentiometer
processing
programmable read only memory (PROM)
pulse width
random access memory (RAM)
read only memory (ROM)
reference voltage
relay
ring configuration
serial communication
servo motor
shielded twisted-pair conductor
shielded wire
signal amplitude
single-wire conductor
solenoid
star configuration
storage
transduce
twisted-pair conductors
vehicle sensors
voltage regulator
waveform

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Activities

1. Use the Internet to research CAN systems in modern cars.
2. Look up a specific make and model vehicle with our shop's computer service software. Research the number and names of the electronic control units (ECUs) used on this vehicle. Note their locations and wiring diagrams.

Review Questions

Answer the following questions using the information provided in this chapter.

1. Define the term *cybernetics*.
2. The binary numbering system uses only _____ and _____ and is the key to _____.
3. Describe the five basic types of computer gates.
4. Name and describe the two general sensor classifications.
5. An active sensor requires a reference voltage. True or False?
6. Typically, a reference voltage is about _____.
7. Explain seven types of computers used on a car.
8. What is an EPROM?
9. What is meant by the term *adaptive strategy*?
10. _____ are the hand and arms of a computer network.

ASE-Type Questions

1. Technician A says the term "cybernetics" refers to the study of how chemical-mechanical devices can duplicate the action of the human body. Technician B says the term "cybernetics" refers to the study of how electrical-mechanical devices can duplicate the action of the human body. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Which of the following are known as the "linking cells" of the human brain?
   (A) Neutrons.
   (B) Neurons.
   (C) Protons.
   (D) None of the above.
3. The advantages of computers in late-model vehicles are being discussed. Technician A says computers can compensate for mechanical wear. Technician B says computer systems have on-board diagnostic systems that can detect and record system problems. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. Technician A says digital electronics deals with the way an alternator charges a battery. Technician B says digital electronics deals with the way a computer system uses discrete on and off signals to produce artificial intelligence. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. Technician A says the numbers 1 and 2 are used in the binary numbering system. Technician B says the numbers 0 and 1 are used in the binary numbering system. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Technician A says in computer language a 0 or 1 is called a byte. Technician B says in computer language a 0 or 1 is called a bit. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. Technician A says the term "gate" refers to an electronic circuit that stops current from flowing in a particular direction. Technician B says the term "gate" refers to an electronic circuit that produces a specific output voltage for given input voltages. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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8. Technician A says an AND gate requires voltage at both inputs to produce a voltage at the output. Technician B says an AND gate requires voltage at only one input to produce a voltage at the output. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Technician A says both inputs of a NAND gate must be *on* to produce an output. Technician B says both inputs of a NAND gate must be *off* to produce an output. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. Technician A says an IC is an electronic circuit that has been reduced in size and etched on the surface of a semiconductor chip. Technician B says an IC is a small power transistor, amplifier circuit for increasing output strength. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
11. Technician A says a variable resistor sensor opens or closes the sensor circuit to provide an electrical signal for the computer. Technician B says a variable resistor sensor changes its internal resistance with a change in a condition. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
12. Which of the following is another name for an automotive computer?
   (A) Electronic control unit.
   (B) Electronic control module.
   (C) Electronic control assembly.
   (D) All of the above.
13. Technician A says an automotive computer can be located under the dash. Technician B says an automotive computer can be located in the automobile's engine compartment. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
14. Which of the following memories can be altered in the field to adjust for operating parameters?
   (A) EEPROM.
   (B) XPROM.
   (C) KAM.
   (D) RAM.
15. Technician A says a servo motor is one type of output device used in an automotive computer system. Technician B says a solenoid is one type of output device used in an automotive computer system. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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In the past, massive and expensive engine analyzers were needed to see graphic representations of the engine's operation. Today, a tool with the same diagnostic capabilities fits in the technician's hand.

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Chapter 24
On-Board Diagnostics and Scan Tools

After studying this chapter, you will be able to:

- Discuss the purpose and operation of on-board diagnostic systems.
- Explain the use of scan tools to simplify reading of trouble codes.
- Locate the data link connector on most makes and models of cars.
- Activate on-board diagnostics and read trouble codes with a scan tool.
- Erase diagnostic trouble codes.
- Correctly answer ASE certification test questions concerning late-model on-board diagnostics and scan tool use.

No longer can the untrained "shade tree mechanic" hope to repair modern vehicles. It takes the skill of a well-trained technician versed in on-board diagnostics to troubleshoot and repair today's vehicles. Today, the first thing a technician often does when diagnosing a problem in a computerized system is check for diagnostic trouble codes with a scan tool.

On-board diagnostics refers to a vehicle computer's ability to analyze the operation of its circuits, and to store and output data showing any problems. All late-model cars and light trucks have this self-monitoring feature. To save time and effort finding problems, it is critical that you know how to use this vital troubleshooting aid.

A ***scan tool*** is used to communicate with the vehicle's computers to retrieve trouble codes, display circuit and sensor electrical values, run tests, and give helpful hints for finding problems. This can all be done quickly and easily, without disconnecting wires or removing parts.

This chapter will summarize on-board diagnostic capabilities and explain the fundamental use of any make of scan tool. It will prepare you for other text chapters on troubleshooting and servicing vehicle systems.

Tech Tip

This chapter provides the basics of using scan tools and reading trouble codes. More advanced scan tool functions are explained at the beginning of most service chapters and are covered in detail in later chapters.

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On-Board Diagnostic Systems

Modern automotive computer systems are designed to detect problems and indicate where they might be located. The computer is programmed to detect abnormal operating conditions. It actually scans its input and output circuits to detect an incorrect voltage, resistance, or current.

Today's on-board diagnostics will check the operation of almost every electrical-electronic part in every major vehicle system. A vehicle's engine control module can detect engine misfiring and air-fuel mixture problems. It monitors the operation of the fuel injectors, ignition coils, fuel pump, catalytic converter, and other major components that affect vehicle performance and emissions.

You can scan for problems in the engine and its support systems, the transmission, the suspension system, the anti-lock brake system, and other vehicle systems. This has greatly simplified the troubleshooting of complex automotive systems.

If the on-board computer finds any abnormal values, it will store a trouble code and light a malfunction indicator light on the instrument panel. This will inform the driver and the technician that something is wrong and must be fixed.

Early On-Board Diagnostic Systems

Most early on-board diagnostic systems could check only a limited number of items. Although these older systems are able to detect a major problem in a circuit, they are unable to detect weak or partially failed circuits and components. Also, there was little or no standardization among these early systems. A wide range of connectors and methods were used to retrieve stored trouble codes.

Early diagnostic systems are called ***OBD I (on-board diagnostics generation one) systems***. There are still millions of vehicles on the road that use OBD I systems.

OBD II Systems

A malfunctioning automobile engine can be a significant source of air pollution. For this reason, the Environmental Protection Agency (EPA) recommended and passed vehicle pollution laws. They require on-board diagnostic systems to detect potential problems *before* they result in the production of harmful exhaust emissions. These regulations also require auto manufacturers to standardize the monitoring systems on their cars and light trucks.

OBD II (on-board diagnostics generation two) systems are designed to more efficiently monitor the condition of hardware and software that affect driveability emissions. OBD II systems detect part deterioration (changes in performance), not just complete part failure. For example, if a sensor becomes lazy or remains in the low end of its normal operating range, this problem is stored as a trouble code in the computer memory for retrieval at a later date. Refer to **Figure 24-1**.

OBD II systems are designed to keep the vehicle running efficiently for at least 100,000 miles (160,000 km). The on-board computers used in OBD II systems have greater processing speed, more memory, and more complex programming than computers used in OBD I systems.

OBD II systems can produce over 500 engine-performance-related trouble codes. They check the operation of switches, sensors, actuators, in-system components, wiring, and the computer itself. OBD II systems also have standardized data link connections, trouble codes, sensor and output device terminology, and scan tool capabilities.

Malfunction Indicator Light (MIL)

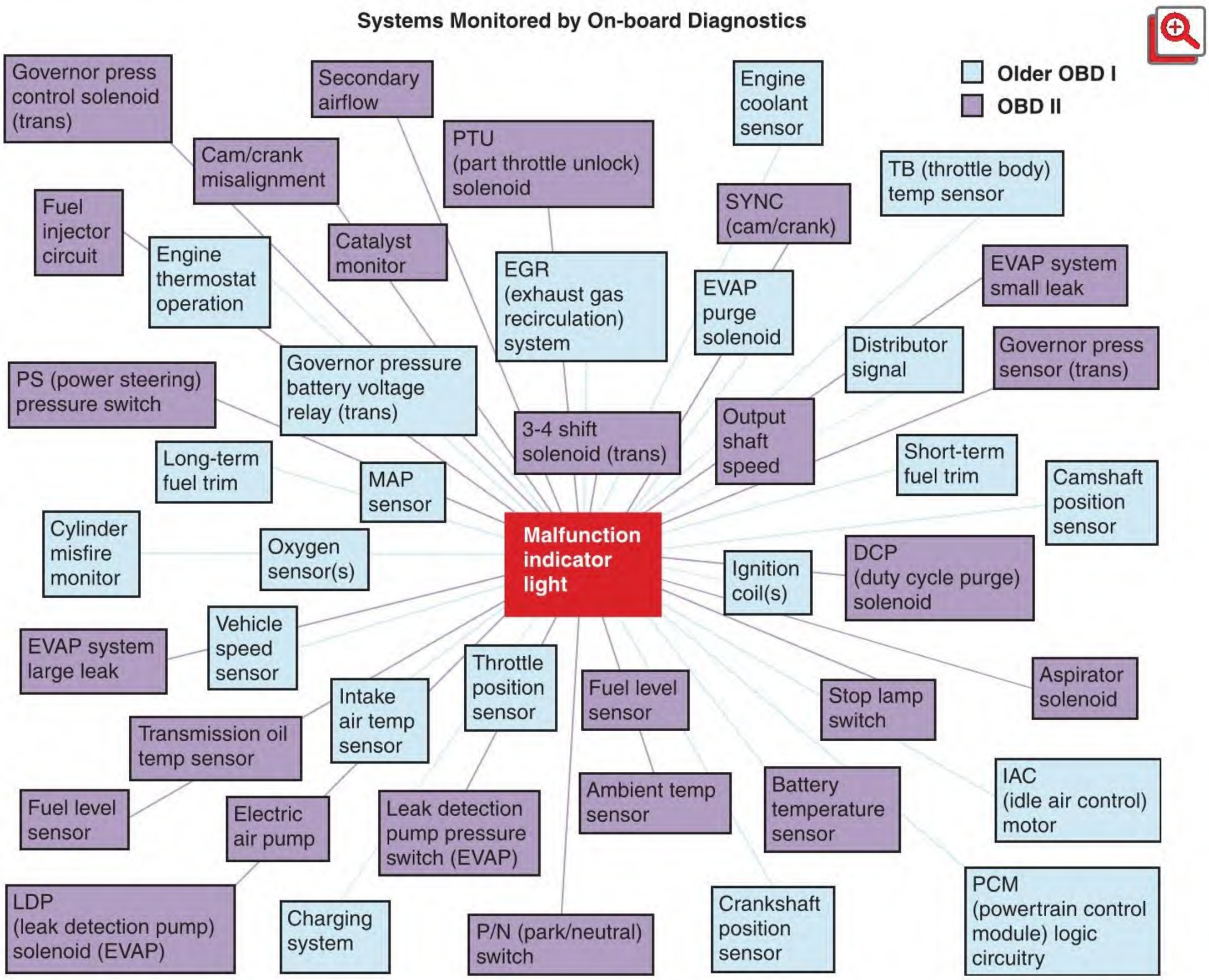
If an unusual condition or electrical value is detected, the computer will turn on a warning light in the instrument panel or the driver information center. The warning light will notify the driver that the vehicle needs service. Some vehicles have a silhouette of an engine on their warning lights.

In OBD II systems, the engine warning light is referred to as a ***malfunction indicator light (MIL)***. If the MIL glows continuously, the trouble is not critical but should be repaired at the vehicle owner's convenience. If the MIL light comes on and then goes out, the problem may be intermittent.

A flashing MIL in an OBD II equipped vehicle means that the trouble could damage the catalytic converter and is, therefore, considered critical. For example, an engine misfire (engine not completely burning fuel mixture) or a fuel system malfunction will generally cause the malfunction indicator light to flash on and off. This warns the driver that the catalytic converter may be overheated and burned if the vehicle is not serviced immediately.

Whenever the MIL is illuminated, drivers should be advised to bring the vehicle in for service as soon as

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Figure 24-1. Compare the OBD I diagnostic system's capabilities with the OBD II system's abilities.

possible. The technician can then use a scan tool to retrieve information about the problem.

A ***trouble code chart*** in a service manual will state what each number code represents. However, most modern scan tools can perform trouble code conversion. ***Trouble code conversion*** means the scan tool is programmed to automatically convert the number code into abbreviated words that explain the potential problem. The technician can then use service information to further isolate the problem.

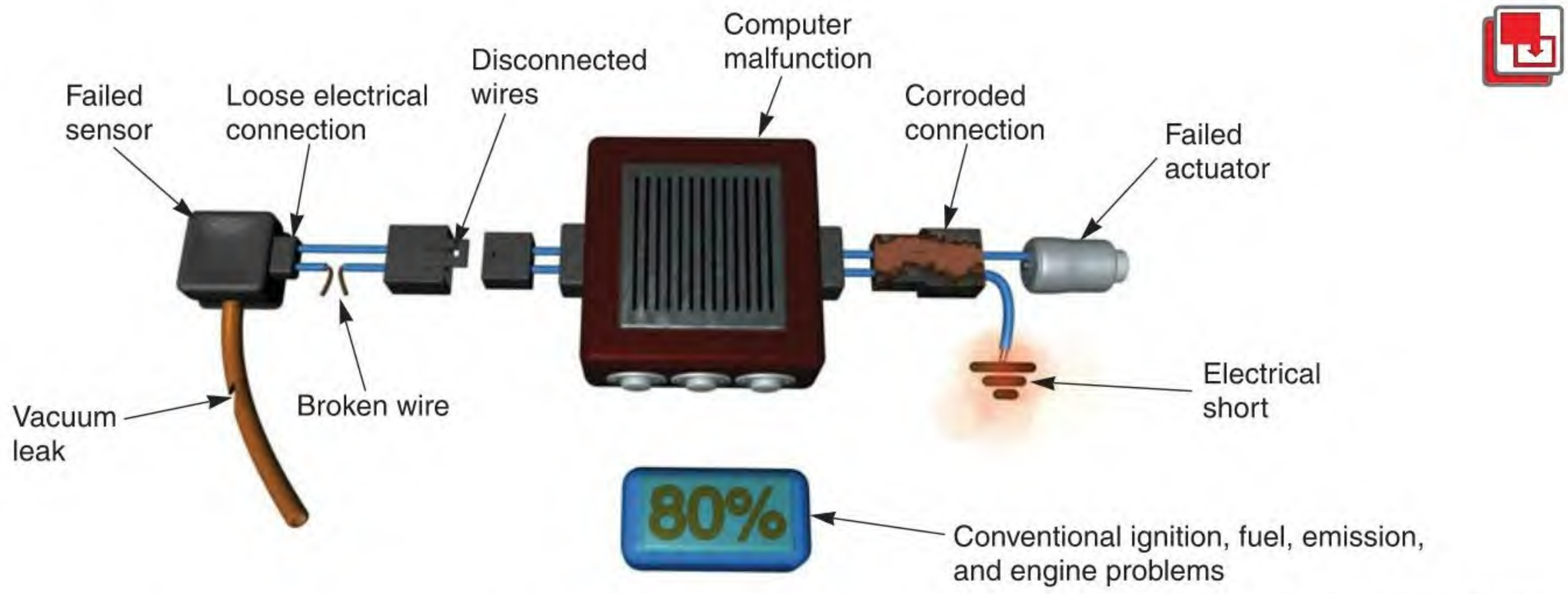
Diagnostic Trouble Codes

Diagnostic trouble codes (DTC) are digital signals produced and stored by the vehicle's computer when an operating parameter is exceeded. An ***operating parameter*** is an acceptable minimum and maximum value. The operating parameter might be an acceptable voltage range from the oxygen sensor, a resistance range for a temperature sensor, current draw from a fuel injector coil winding, or an operational state from a monitored device. In any case, the computer "knows" the operating parameters for most inputs and outputs. This information is stored in its permanent memory chips.

Computer System Problems

Common problems that can affect vehicle performance and cause the computer system to set a code and light the MIL in the dash are shown in **Figure 24-2**. These problems include:

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Figure 24-2. Always remember that about 80% of all performance problems are not caused by the computer, its sensors, or its actuators. Most problems are the result of conventional problems, such as loose connections, broken wires, vacuum leaks, mechanical problems, etc.

- Loose electrical connection—This problem can cause an input signal from a sensor to not reach the computer properly, or an actuator may not respond to the computer's output control current.
- Corroded electrical connection—This problem can result in high resistance in a wiring connector, upsetting sensor input or actuator output.
- Failed sensor—This problem occurs when an opened or shorted sensor or other sensor malfunction prevents normal computer system operation.
- Failed actuator—This involves a solenoid, servo motor, relay, or display that shorted, is open, or does not react to computer signals.
- Vacuum leak—This problem is an engine vacuum leak that reduces engine or system performance.
- Electrical short—This problem occurs when wires touching ground or each other cause a current increase or incorrect current path.
- Ignition system problems—Problems include fouled spark plugs, weak ignition coil voltage, a bad crankshaft sensor, etc. For example, a spark plug misfire causing unburned fuel to enter the exhaust can trick the oxygen sensor into trying to create a leaner mixture. The misfire upsets computer system operation and can be detected in OBD II systems by variations in the crankshaft sensor signal.
- Fuel system problems—Problems include leaking or clogged injectors, bad pressure regulator, faulty fuel pump, or other problems.
- Emission system problems—These are problems with the catalytic converter, EGR valve, vapor storage system, etc. Many emission components are monitored electronically and will set a trouble code if a malfunction occurs.
- Engine problems—These are mechanical problems that cannot be compensated for by the computer modifying system operation. Engine misfire due to mechanical wear will also trip a trouble code on OBD II systems.
- Computer malfunction—This problem results from an faulty or incorrect internal programming, failure of an integrated circuit, or failure of other computer components can disable the computer and alter the operation of related systems.
- Weak or lazy component—This includes any sensor, actuator, or computer that is working slowly or inefficiently. In some cases, a sensor's current, voltage, or resistance values are within specs, but the component is sending weak or incorrect signals to the ECM. A lazy oxygen sensor, for example, can trick the computer system into compensating for an artificial lean or rich condition; it will trip codes on OBD II-equipped vehicles.
- Transmission problems—Electronically controlled transmissions and transaxles are monitored and will trip trouble codes if a problem is detected. Transmission problems include a bad vehicle speed sensor, a faulty shift sensor or shift solenoid, or faulty wiring.

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- Anti-lock brake system problems—Problems include bad wheel speed sensors, faulty wiring, worn brake pad sensor, or a malfunctioning hydraulic unit.
- Air conditioning problems—These problems include faulty pressure and temperature sensors, a loss of refrigerant, or compressor clutch failure.
- Air bag problems—Problems include faulty impact sensors, a malfunctioning arming sensor, or a damaged air bag module.
- Hybrid electric drive train part and circuit malfunctions—These types of problems include an HV battery malfunction, a failed power control module, or faulty HV power cables.



OTC/SPX Corp.

Figure 24-3. A scan tool is now the most important tool of the automotive technician. It will tell you where problems are located.

Tech Tip

Most computer system problems are conventional (loose electrical connection, mechanical problem, etc.). Only about 20% of all performance problems are caused by an actual fault in the computer or one of its sensors. For this reason, always check for the most common problems before testing more complex computer-controlled components.

Scanning Computer Problems

A scan tool is an electronic test instrument designed to retrieve trouble codes from the computer's memory and display these codes as a number and words identifying the problem. It is now the most important tool used by the automobile technician, **Figure 24-3**.

A basic scan tool is designed to read and erase vehicle trouble codes. An advanced scan tool is commonly a wireless, touch screen tablet that has more functions than a basic scan tool, including troubleshooting guides, manufacturer-specific tests, and circuit values. An advanced scan tool can communicate with the vehicle and the internet at the same time.

To use any scan tool, read the operating instructions for the tool at hand. Operating procedures vary slightly. Most scan tools have simple buttons, a scroll wheel, or a touch screen that allow the technician to choose various test functions. With modern scan tools, plug the cord or wireless sending unit into the connector under the dash and follow scanner on-screen instructions.

A wireless sending unit for a diagnostic tablet plugs into the vehicle's diagnostic connector and can send and receive radio signals to and from the tablet. This allows you to take the diagnostic tablet anywhere in the shop while monitoring vehicle operation, data stream values, and trouble codes. **See Figure 24-4**.



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Figure 24-4. Wireless touch screen diagnostic tablets are replacing scan tools. There is no hard wire needed between the vehicle and the tablet. The wireless sending unit is plugged into the vehicle's diagnostic connector.

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Tech Tip

Late-model vehicles are equipped with CAN-compliant computer systems. While the diagnostic techniques for these systems are similar to those for conventional computer systems, a CAN-compliant scan tool must be used to retrieve diagnostic information from CAN-equipped vehicles.

Data Link Connector (Diagnostic Connector)

The ***data link connector (DLC)*** is a standardized multipin terminal used to link the scan tool to the computer. In the past, this connector was identified by a variety of names, including ***diagnostic connector*** and ***assembly line diagnostic link (ALDL)***.

OBD I data link connectors came in various shapes and sizes, and were equipped with a varying number of pins or terminals. With OBD II, the DLC is a standardized 16-pin connector. The female half of the connector is on the vehicle, and the male half is on the scan tool cable.

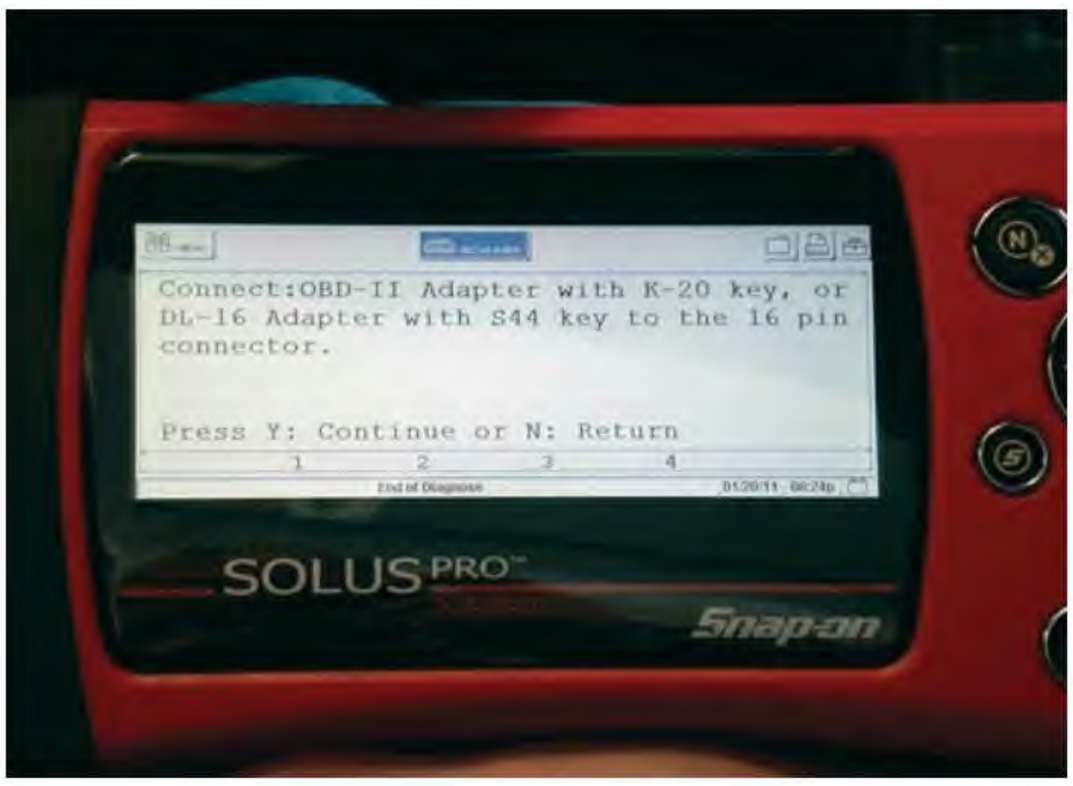
With OBD II diagnostic systems, you should be able to connect a scan tool to the vehicle's data link connector with one hand while sitting in the driver's seat or kneeling outside the vehicle.

Connecting the Scan Tool

In late-model vehicles, the data link connector is mounted under the dash in a location that is easy to access from the driver's seat. The scan tool cable should slide easily into the data link connector, **Figure 24-5**. If not, something is wrong. Never force the two together or you could damage the pins on the tool cable or the data link connector. With an older vehicle, you will need an ***adapter*** so the scan tool connector will fit the vehicle's pre-OBD II pin configurations.

Using Scan Tools

Modern scan tools will give ***prompts***, or step-by-step instructions, in their display windows. The prompts tell you how to input specific vehicle information and run diagnostic tests. These procedures and specifications are programmed into the scan tool circuitry. See **Figures 24-6** and **24-7**.



Snap-on Tool Corp.

Figure 24-6. This advanced scan tool is prompting the user to install an OBD II connector and a specific key adapter.



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Figure 24-5. The OBD II test connector is under the dash. It should be visible as you lean down and look under the dash. A—The OBD II connector has 16 male pins and a power plug to the power scan tool. B—The OBD II connector under the dash has a 16-pin female plug. C—Slide scan tool connector straight into the vehicle data link connector so the pins slide smoothly together.

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Controls vary by manufacturer. This scan tool uses simple yes–no buttons.

Snap-on Tool Corp.

Figure 24-7. Always read the operating manual fully before attempting to use any model of scan tool. A—Scan tool controls vary from one manufacturer to another. B—Note the simple yes-no buttons that allow the user to quickly respond to the scan tool's prompts.

The scan tool may ask you to input VIN information (numbers or letters) from the plate on the top of the dash.

The VIN data lets the scan tool know which engine, transmission, and options are installed on that car or truck. With some makes, however, the on-board computer will contain this data and will automatically download it into the scan tool. Then, you will be able to select the information that you would like the scan tool to give you, **Figure 24-8**.

Some of the information a scan tool can request includes:

- Stored diagnostic trouble codes—This is a number that represents the general area (body, chassis, power train, network) and specific system or part that is not functioning normally in the vehicle.
- Fault description—This explains what each stored diagnostic trouble code means by pinpointing specific fuel injectors, ignition coils, sensors, actuators, or other parts and circuits that are operating out of specification.
- Datastream information—This displays the operating values of all monitored circuits and sensors (engine speed, engine temperature, ignition timing, injector pulse width, and other values).
- Run tests—These read datastream circuit values for sensors and actuators while they are operating. If an actuator fails to move or fire during the run tests, the scan tool will inform you of any problem.



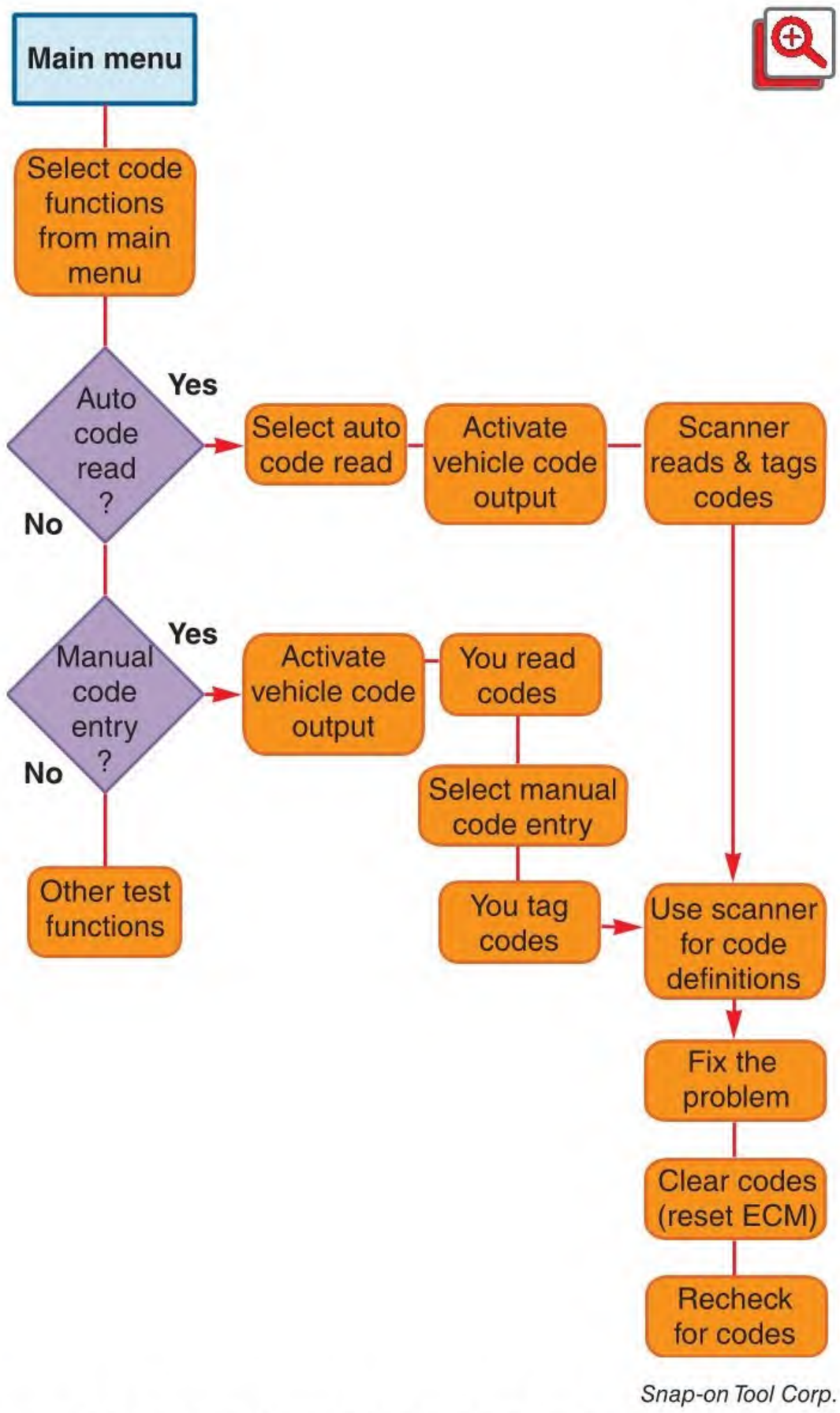
Snap-on Tool Corp.

Figure 24-8. A full-featured scan tool can perform complex testing and troubleshooting procedures. A—This advanced scan tool does not require cartridges. You can quickly navigate to the exact make, model, and year car to be tested. B—Here the scan tool is asking the technician to input VIN information. This lets the tool know how the vehicle is equipped—engine type, transmission type, computer configuration, etc. C—You can then proceed to read stored trouble codes, or erase codes by scrolling through the menu.

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- Oxygen sensor monitoring—This performs detailed tests of the O_2 sensors signals under normal operating conditions. This helps find a weak or sluggish oxygen sensor.
- Failure record—This lists the number of times a particular trouble code has occurred by keystarts or warm-ups. This will help you find intermittent or irregular problems.
- ***Freeze frame***—This takes a snapshot of sensor and actuator values when a problem occurs or when triggered during a test drive. This also helps find problems that do not set hard trouble codes. This records the values from all monitored components so they can be further evaluated, letting you locate and correct intermittent problems more easily.
- Troubleshooting—This feature provides help and instructions for diagnosing faults once you have read a trouble code.

Figure 24-9 gives the general sequence for using a scan tool. You can ask the scan tool to give more information on a trouble code, and the tool will display words that give sensor resistance values, identify common problems, and provide other useful repair information.



Snap-on Tool Corp.

Figure 24-9. This flowchart shows the basic steps for using a scan tool.

Tech Tip

Most technicians check for stored diagnostic trouble codes before performing tests on specific components. This is a quick way to pinpoint any hard failures, so they can be repaired first.

Always correct the cause of the lowest number diagnostic trouble code first. Sometimes, fixing the cause of the lowest code will clear other codes because of component interaction. A trouble code does not mean that a certain component is bad. It simply indicates that a possible problem has been detected in that particular device or its circuit.

Most ECMs count the number of times a trouble code has occurred. This information is stored in a ***failure record***, or failure recorder. The failure recorder in OBD II systems counts the number of times the engine reached operating temperature since the last time the trouble code was set.

Diagnostic Trouble Code Identification

To simplify troubleshooting, OBD II requires all auto manufacturers to use a set of standardized alphanumeric trouble codes. Each trouble code identifies the same problem in all vehicles, regardless of the manufacturer.

OBD II codes contain a letter and a four-digit number. The letter in all OBD II codes indicates the general function of the affected system (power train, chassis, etc.).

The first digit of the number indicates whether the code is a standard trouble code or a nonuniform code. Standard trouble codes, or SAE codes, are indicated by the number *0*. Nonuniform codes (nonstandard OBD II codes that are assigned by the auto manufacturers) have the number *1* after the system letter. The second digit of the OBD II code number indicates the specific function of the system where the fault is located, such as fuel, computer, etc.

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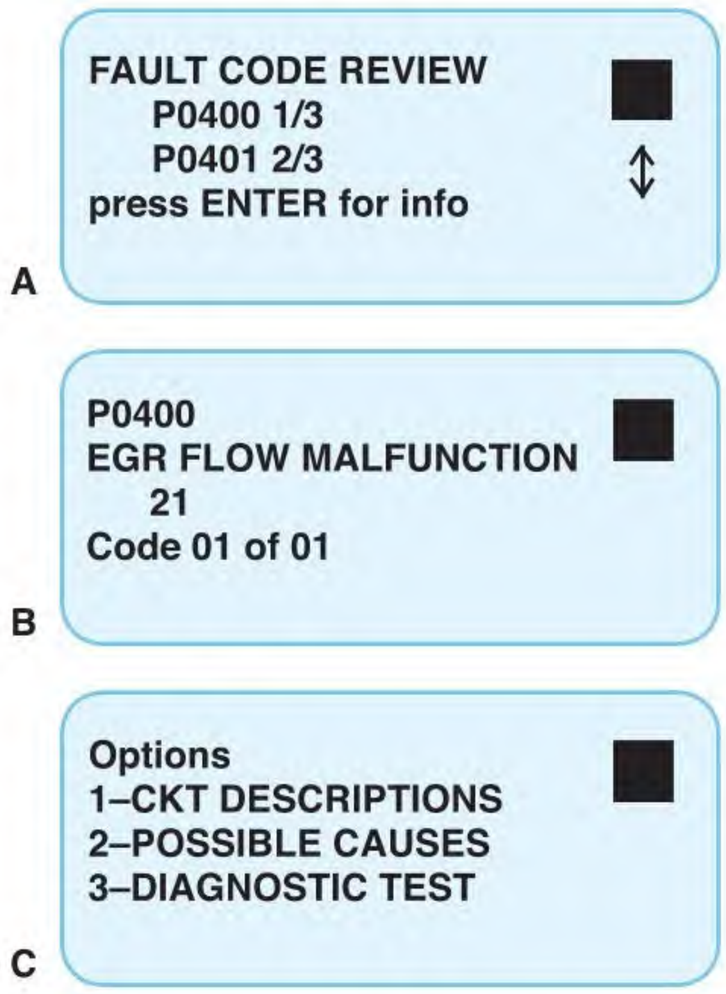
The code's last two digits refer to the specific fault designation. The ***fault designation*** pinpoints exactly which component or circuit of the system might be at fault, as well as the type of problem. Regardless of the type of vehicle being serviced, the standard trouble code numbers will be the same. The scan tool explains the code and, in some cases, describes how to fix the problem.

Figure 24-10 gives a breakdown of the OBD II diagnostic code. Study it carefully. **Figure 24-11** shows the display of a scan tool that has found a stored trouble code.

Failure Types

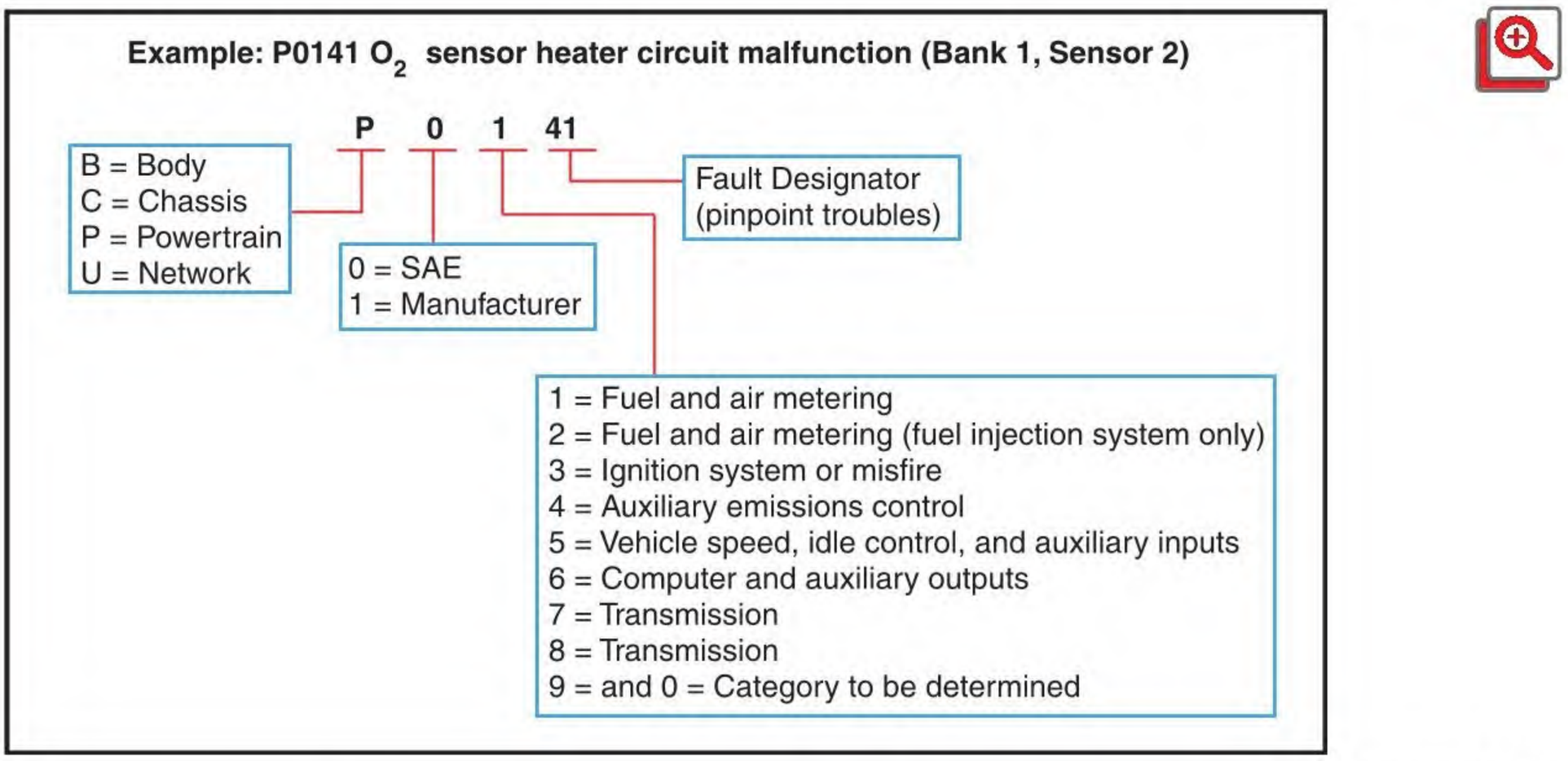
There are two general types of computer system failures: hard failures and soft failures. A ***hard failure*** is a problem that is always present in a computer system. An example of a hard failure is a disconnected wire or another problem that would cause a general circuit failure. A hard failure does not come and go with varying conditions. After the computer memory is cleared, any hard failures will usually reset as soon as the engine is started or the affected system is energized.

A ***soft failure***, or intermittent failure, is a problem that only occurs when certain conditions are present. It might be present one minute and gone the next. Soft failures will usually be stored in memory for 30–50 keystarts or engine warm-ups. An example of a soft failure is a loose terminal that connects and disconnects as the vehicle travels over bumps in the road. Low-input, high-input, and improper range failures are usually classified as soft failures.



OTC/SPX Corp.

Figure 24-11. This is an example of what you might see on the display of a scan tool. A—The scan tool will give you the trouble code numbers. B—If you request information on the stored trouble codes, the tool will explain what each code means. C—Options will allow you to use the scan tool to get detailed descriptions of each code, list possible causes, or perform diagnostic tests.



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Figure 24-10. OBD II trouble codes are alphanumeric. Note what each part of the trouble code means. The first part of the code tells you which system is having problems. The last part of the code identifies the specific problem circuit or component.

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Computer system failure types can be further broken down into four general categories:

- ***General circuit failure***—The circuit or component has a fixed value, no output, or an output that is out of specifications. This is the most severe fault, but it is the easiest to locate. It is caused by disconnected wires, high-resistance connections, shorts, or a component constantly operating out of parameter.
- ***Low-input failure***—A failure that produces a voltage, current, or signal frequency below normal operating parameters. A weak or abnormally low signal is being sent to the on-board computer. This type of failure is often caused by high circuit resistance, a poor electrical connection, a contaminated or failed sensor, or a similar problem.
- ***High-input failure***—This results when the signal reaching the on-board computer has a much higher voltage, current, or frequency than normal. This type of failure is often caused by a faulty sensor, a high charging voltage, or a mechanical fault that is "fooling" the computer system.
- ***Improper range/performance failure***—This occurs when a sensor or actuator is producing values slightly lower or higher than normal. The circuit is still functioning, but not as well as it should under normal conditions. This type of failure can be caused by a contaminated sensor, a partial sensor failure, a poor electrical connection, and similar problems. Improper range/performance failures were not detected in OBD I systems and were often difficult to find. OBD II systems can detect improper range/performance failures.

Datastream Values

Datastream values, or diagnostic scan values, produced by the vehicle's computer give electrical operating values of sensors, actuators, and circuits. These values can be read on a scan tool's digital display and compared to known normal values in the service manual. Datastream values give additional troubleshooting information when trying to locate a problem.

Key-On/Engine-Off Diagnostics

In order to access the ECM data on most vehicles, it is necessary to turn the ignition key on. ***Key-on/engine-off diagnostics*** are performed by triggering the ECM's on-board diagnostic system with the ignition key in the *on* position but without the engine running. This allows you to access any stored trouble codes in the computer's memory chips. Key-on/engine-off diagnostics are usually performed before key-on/engine-on diagnostics. Look at **Figure 24-12**.

If you anticipate working in the key-on/engine-off diagnostic mode for over 30 minutes, connect a battery charger to the vehicle. This will prevent the extended current draw from draining the battery and upsetting the operation of the computer while in the diagnostic mode. False trouble codes could result from a partially drained battery.

Wiggle Test

Many computer system failures, especially intermittent failures, are caused by loose, dirty, or corroded connections, **Figure 24-13**. These failures can be found by performing a ***wiggle test***, or "flex" test.



A



B

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Figure 24-12. Most technicians check for stored trouble codes first. A—This scan tool readout shows a problem with the intake air (air charge) temperature sensor. B—You would then know to check that sensor and its wiring for problems.

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Figure 24-13. The wiggle test involves moving wires and connectors while scanning for trouble codes. If wiggling a wire trips a code, you found the location of the problem.

Service Procedure

To perform a wiggle test:

1. Connect a scan tool to the vehicle and choose the appropriate test options. Refer to the instructions provided with the scan tool.
2. Place the vehicle in the key-on/engine-off diagnostic mode.
3. Flex wires and wiggle harness connectors while scanning for problems.
4. If wiggling a wire or connector produces a new diagnostic trouble code, check the wire or electrical connection more closely. It may be loose, corroded, or damaged.

Some technicians perform a wiggle test while the engine is running. If engine operation changes suddenly (stalls or idles high, for example) when a connector or wire is flexed, the problem is located at or near that point. Be careful when performing a wiggle test on a running vehicle.

You might also want to use a heat gun to heat potentially faulty components during a wiggle test. For example, electronic amplifiers and modules tend to malfunction when hot. This could help find an intermittent problem.

Caution

Exercise care when using a heat gun. The heat generated by the gun can easily melt most plastics and damage electronic components.

Key-On/Engine-On Diagnostics

Key-on/engine-on diagnostics are performed with the engine running at full operating temperature. These tests check the condition of the sensors, actuators, computer, and wiring while they are operating under normal conditions.

Switch Diagnostic Test

A ***switch diagnostic test*** involves activating various switches while using a scan tool. The scan tool will tell you which switch to move and will monitor its operation. The scan tool will quickly indicate if the switch is working normally, **Figure 24-14**.

For example, you might be told to shift the transmission shift lever through the gears, press on the brake pedal, and turn the air conditioning on and off. As each step is performed, the scan tool will indicate if the affected switch is okay and whether or not the ECM is reading the switch input. Refer to the service manual for details of the switch diagnostic test.

Actuator Diagnostic Test

An ***actuator diagnostic test*** uses the scan tool to order the vehicle's computer to energize specific output devices with the engine on or off. This will let you find out if the actuators are working. Most actuator diagnostic tests are considered intrusive tests, since engine or vehicle operation will be drastically affected



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Figure 24-14. Most scan tools will also perform switch and actuator tests. This is sometimes done automatically. You may be prompted to close different switches to make sure each one is working. The scan tool may also be able to perform additional actuator tests.

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while the device is being tested. Actuator diagnostic tests might:

- Fire or prevent the firing of the ignition coil.
- Open and close the fuel injectors.
- Cycle the idle speed motor or solenoid.
- Energize the digital EGR valve solenoids.

You can then watch or listen to make sure these actuators are working. With OBD II, the scan tool will give readouts showing whether there is trouble with any actuators.

Switch and actuator diagnostic tests cannot be performed on all vehicles. Refer to the service manual or scan operating manual for details.

Scanning during a Test-Drive

With a modern scan tool, you can also check for problems while driving the vehicle to simulate the conditions present when the trouble happens, **Figure 24-15**. For example, if the problem occurs only while driving at a specific speed when the engine is cold, you can scan under these conditions. Start the cold engine and drive at the specified speed while scanning for problems. You can then take a snapshot (if the scan tool has this feature) when the problems occur.

Erasing Trouble Codes

Erasing trouble codes, also termed clearing diagnostic codes, removes the stored codes from computer memory after system repairs have been made. In most cases, codes will be automatically erased after 30–50 engine starts or warm-ups. However, codes should be erased after repairs are made to prevent a possible misdiagnosis by the next technician who works on the vehicle. There are various methods used to erase trouble codes from the computer:

- Use a scan tool to remove stored diagnostic codes from the on-board computer. This is the best way to remove old codes after repairs. In OBD II systems, the ECM may retain stored codes for several days without battery power. See **Figure 24-16**.
- Disconnect the battery ground cable or strap. However, this will also erase the digital clock memory, all radio presets, and any adaptive strategy information from the computer.
- Unplug the fuse to the ECM. This will also erase all other information stored in the computer's temporary memory.



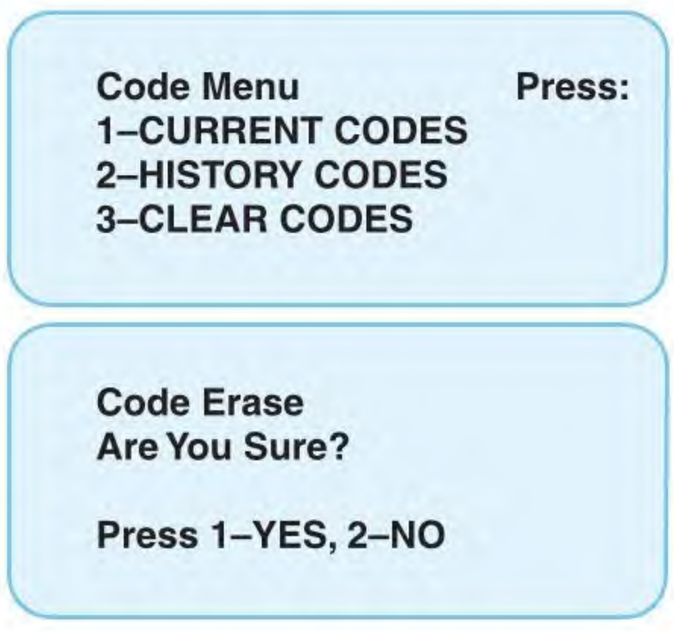
OTC/SPX Corp.

Figure 24-15. Scan tools are sometimes used while test- driving vehicles. This will allow you to check engine and vehicle operating parameters while duplicating the conditions present when the problem occurred.

Caution

Some auto manufacturers warn against unplugging or plugging in the computer harness connector with the ignition key on or the engine running. This could cause a voltage spike that could damage the computer.

After erasing trouble codes, reenergize the on-board diagnostics and check for diagnostic trouble codes. If no trouble codes are displayed, you have corrected the problem.



OTC/SPX Corp.

Figure 24-16. Using a scan tool is the fastest and easiest way to erase stored trouble codes. With most scan tools, simply choose the menu selection to clear codes and then press yes.

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Tech Tip

The OBD II system performs a series of checks, or monitors, to verify the proper operation emissions-related components. Erasing trouble codes may also erase monitor status records stored in the computer's memory. If this occurs, the monitors must be reset before the vehicle is emission tested. This can be done by performing the appropriate OBD II drive cycle or by simply driving the vehicle until all the monitors reset. However, the vehicle may have to be driven 100 miles or more under varying conditions to reset the monitors.

Diagnostic Case Study

Concern: Ms. Figuroa says that a light is glowing in the dash of her 2013 Toyota pickup truck.

Cause: Duff questions Ms. Figuroa as to the nature of the problem, but she says she has noticed nothing wrong other than the glowing light. Duff starts the vehicle and notes that the malfunction indicator light in the dash is glowing. He test-drives the vehicle to try to find problem symptoms. He notices that the vehicle seems to miss slightly and lack normal power. He makes a note of his findings and turns the repair over to the shop's master technician.

After analyzing the symptoms, the technician connects a scan tool to the truck's data link connector. The scan tool readout indicates a misfire in cylinder number one. The technician then performs pinpoint tests to verify the scan tool findings. He first pulls the ignition coil on cylinder number one and checks for a good, "hot," high voltage spark. He finds that the direct ignition coil has a very weak spark. An ohmmeter test of the coil primary shows high resistance.

Correction: The technician installs a new ignition coil in the affected cylinder. He erases the stored trouble codes and then starts the engine and rechecks the system for codes. No problems are found and the MIL light no longer glows. He test drives the vehicle to make sure it is no longer missing and lacks normal power.

Summary

- On-board diagnostics refers to a vehicle computer's ability to analyze the operation of its circuits and output data showing any problems.
- A scan tool is used to communicate with the vehicle's computers to retrieve trouble codes, display circuit and sensor electrical values, run tests, and give helpful hints for finding problem sources.
- OBD I and earlier on-board diagnostic systems could check only a limited number of items.
- OBD II systems are designed to more efficiently monitor the condition of hardware and software that affect emissions. New vehicle diagnostics detect part deterioration and not just complete part failure.
- If an unusual condition or electrical value is detected, the computer will turn on a malfunction indicator light (MIL) in the dash instrument panel or driver information center.
- Code conversion means the scan tool is programmed to automatically convert trouble codes into abbreviated words that explain what might be wrong without referring to a service manual.
- Diagnostic trouble codes (DTCs) are digital signals produced by the computer when an operating parameter is exceeded.
- The data link connector (DLC) is a multipin terminal for reading computer trouble codes or scanning problems.
- A scan tool freeze frame is a snapshot of operating parameters at the time of a malfunction.
- OBD II codes contain a letter and a four-digit number.
- The letter in all OBD II codes indicates the general function of the affected system.
- The first digit of the number in OBD II codes indicates whether the code is a standard trouble code or a nonuniform code.
- The second digit of the number in the OBD II code indicates the specific function of the system where the fault is located.
- The last two digits in the OBD II code refer to the specific fault designation.
- A wiggle test is done by moving wires and harness connectors while scanning to find soft failures.

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Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

actuator diagnostic test
adapter
assembly line diagnostic link (ALDL)
data link connector (DLC)
datastream values
diagnostic connector
diagnostic trouble codes (DTC)
failure record
fault designation
freeze frame
general circuit failure
hard failure
high-input failure
improper range/performance failure
key-on/engine-off diagnostics
key-on/engine-on diagnostics
low-input failure
malfunction indicator light (MIL)
on-board diagnostics
OBD I (on-board diagnostics generation one) system
OBD II (on-board diagnostics generation two) system
operating parameter
prompts
scan tool
soft failure
switch diagnostic test
trouble code chart
trouble code conversion
wiggle test

Activities

1. Demonstrate the proper method for using a scan tool or diagnostic tablet.
2. Videotape a service technician using a scan tool to "check out" an engine performance problem. Ask the technician to explain each step as he or she performs the work. Show the completed video to the class.

Review Questions

Answer the following questions using the information provided in this chapter.

1. What is computer on-board diagnostics?
2. What is the first thing most technicians look at when diagnosing a computer system problem?
3. If an unusual condition or electrical value is detected, most computer systems will turn on a(n) _____.
4. List and summarize 17 types of problems that can affect computer system operation.
5. Only about _____ of all performance problems are caused by the computer, sensors, and actuators.
6. Where is a typical OBD II scan tool connector located?
7. Summarize the OBD II alphanumeric diagnostic code.
8. Which of the following is a standardized OBD II code for a malfunction in the computer or auxiliary outputs?
   (A) P0605.
   (B) P1600.
   (C) P0141.
   (D) P0505.
9. Name the four general types of computer system failures.
10. A(n) _____ is always present and a(n) _____ is intermittent.
11. Explain key-on/engine-off diagnostics.
12. What is a wiggle test?
13. An OBD II vehicle comes in the shop with the engine trouble light glowing. Technician A says to connect a scan tool to the vehicle first to read stored trouble codes. Technician B says to test-drive the vehicle first even with the trouble light ON. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
14. An _____ diagnostic test uses the scan tool to order the vehicle's computer to energize specific output devices with the engine on or off.
15. What are trouble code charts?

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ASE-Type Questions

1. Technician A says an automotive computer can scan its input and output circuits to detect incorrect voltage problems. Technician B says an automotive computer can scan its input and output circuits to detect an incorrect resistance problem. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Technician A says if an automotive computer system detects an abnormal condition, the car's malfunction indicator light will normally be activated. Technician B says if an automotive computer system detects an abnormal condition, the car's low oil warning light will normally be activated. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. The malfunction indicator light in an OBD II system is flashing. Technician A says this means the problem could be damaging the catalytic converter. Technician B says that this simply indicates a soft problem. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. Technician A says a faulty actuator can affect the operation of an automotive computer system. Technician B says a leaking vacuum hose can affect the operation of an automotive computer system. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. Technician A says a spark plug misfire can affect the operation of an automotive computer system. Technician B says an automotive computer system is not affected by a spark plug misfire. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. An automobile has a small fuel tank leak. Technician A says this problem may activate the car's computer system "malfunction indicator light." Technician B says this type of problem has no effect on the car's computer system. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. Technician A says about 50% of all automotive engine performance problems are caused by the computer system. Technician B says about 80% of all automotive engine performance problems are caused by something other than a computer system malfunction. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. A trouble code indicates that there is no activity in an oxygen sensor circuit. Technician A says to test the sensor and its circuit. Technician B says to replace the sensor. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Technician A says the term "hard failure" refers to an intermittent automotive computer problem. Technician B says the term "hard failure" refers to a constant automotive computer problem. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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10. A wiggle test is being performed on an automotive computer system. Technician A performs this test with the engine off and the ignition key off. Technician B performs this test with the engine off and the ignition key on. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
11. All of the following can normally be performed during an automotive computer system actuator self-test *except*:
    (A) open and close injectors.
    (B) fire the ignition coil.
    (C) operate the reed valve.
    (D) activate the idle speed motor.
12. Technician A says a switch diagnostic test involves energizing specific output devices. Technician B says an actuator diagnostic test involves the scan tool giving orders to the vehicle's computer. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
13. Which of the following is used with a wireless diagnostic tablet?
    (A) Jumper wire.
    (B) Sending unit.
    (C) Cartridge.
    (D) PROM.

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Chapter 25
Computer System Service

After studying this chapter, you will be able to:

- Perform a visual inspection of the computer, its sensors, actuators, and the systems they monitor and control.
- Test sensors and their circuits.
- Remove and replace sensors.
- Test and replace actuators.
- Remove and replace a computer.
- Program an EEPROM.
- Demonstrate safe working practices when servicing automotive computers.
- Correctly answer ASE certification test questions on servicing computer system components.

Since almost all vehicle systems now use computer components, you must have a thorough knowledge of computer circuit service methods. Otherwise, you will not fully understand the chapters on the service and repair of fuel injection, ignition, and emission control systems.

This chapter will briefly summarize how to test computer components and circuits and help you develop the skills needed to verify where problems are.

After you have checked the computer for trouble codes, you can find the exact source of the problem by doing pinpoint tests. ***Pinpoint tests*** are more specific tests of individual components. The service manual will normally explain how to do each pinpoint test. It will show specific tests, as well as provide component electrical values and other critical information.

Remember that trouble codes only indicate the area of trouble and sometimes the type of problem, not what part or circuit is at fault. It is therefore imperative that you know how to do basic electrical tests on individual components.

Preliminary Visual Inspection

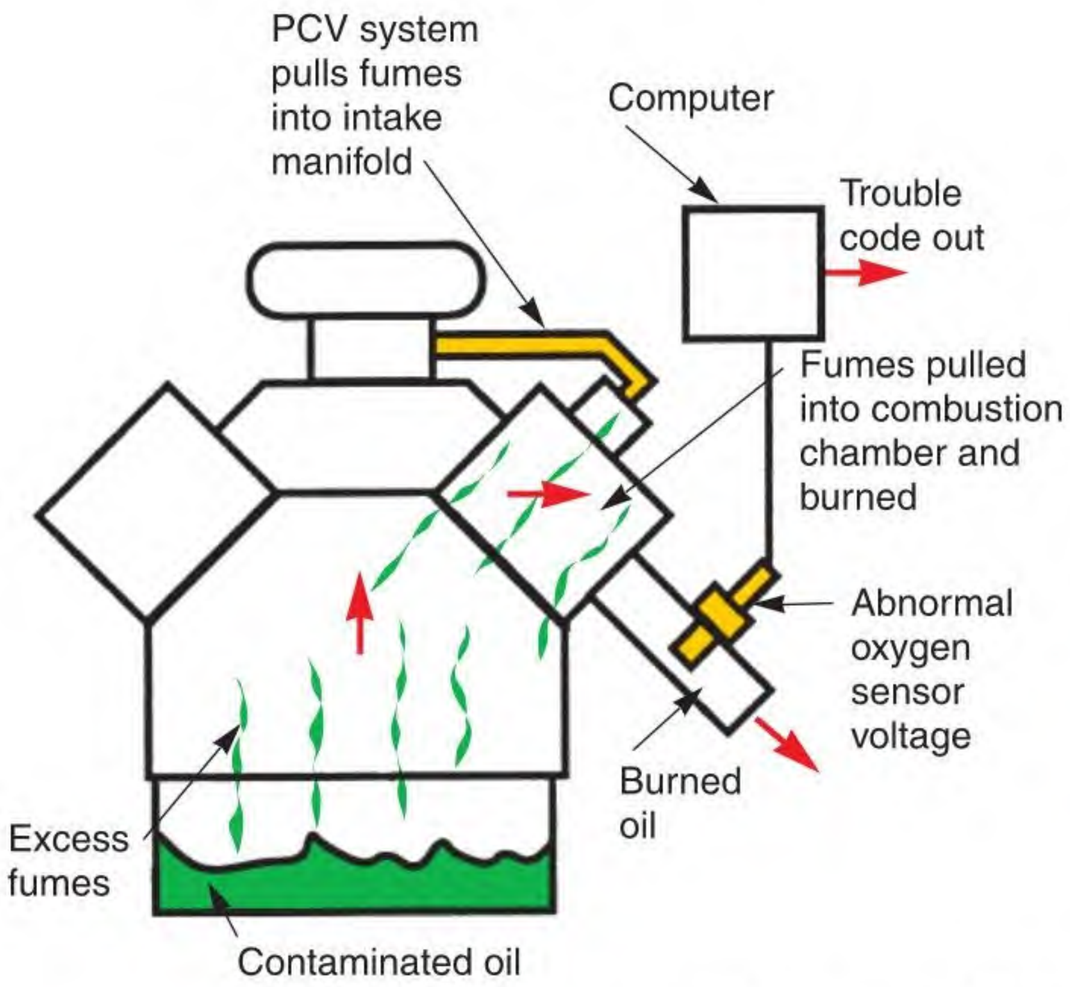
A ***preliminary visual inspection*** involves looking for signs of obvious trouble: loose wires, leaking vacuum hoses, part damage, etc. For example, if the trouble code says there is something wrong in the coolant temperature sensor circuit, you should check the sensor resistance and the wiring going to the sensor. You should also check the coolant level and the thermostat. A low coolant level or engine overheating could also set this code.

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KISS is an acronym that could help you find the source of performance problems on a computer-controlled vehicle. KISS stands for "keep it simple, stupid." This means you should start your troubleshooting with the simple checks and tests. Then, as the common causes are eliminated as the source of the problem, you will move to more complex tests. It is easy for the untrained person to instantly think "computer problem" when an engine runs rough, fails to start properly, or exhibits some other performance problem.

For example, contaminated engine oil can trigger a computer trouble code, **Figure 25-1**. Fumes from the contaminated oil can be drawn into the engine's intake manifold from the crankcase. If these fumes are excessively strong, the oxygen sensor could be tricked into signaling a rich air-fuel mixture. The computer would then lean the mixture to compensate for the crankcase fumes. An oxygen sensor trouble code may be produced and, in some cases, an engine performance problem could result.

As this points out, it is critical that you check for conventional or simple problems first. Start checking for computer problems only after all the conventional causes have been ruled out.



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Figure 25-1. This example shows that a trouble code can be tripped by factors other than a computer system problem. Contaminated engine oil can cause excess fumes to be pulled into the PCV system. When burned in the combustion chambers, the fumes could trick the computer into sensing that something is wrong with the oxygen sensor circuit.

Electrical Component Damage

Semiconductor devices, such as transistors and integrated circuits, are very easy to damage. They can be damaged by static electricity, voltage spikes, heat, and impact shocks. Here are some things to remember when working with semiconductor devices and their wiring:

- When welding on any part of a vehicle, disconnect the battery ground and disarm the airbag system. If welding within 12″ (304.8 mm) of any control module, remove the electronic module from the vehicle to avoid heat and radiation damage.
- Never disconnect the battery cables while the engine is running. In the past, some technicians would do this to see if the alternator was working. This can destroy or weaken electronic circuits, causing failure in a short period of time.
- Do not disconnect or connect wiring, especially the computer wiring, with the ignition key on. This can cause a current surge that can damage the computer.
- Make sure you do not reverse the battery cable connections. This can destroy electronic components.
- Wear an anti-static wrist strap whenever you handle static-sensitive components (removable PROM chips, for example) to protect them from damage.
- Use only high-impedance test lights and meters when checking electronic circuits or their wiring. A conventional test light or meter will draw too much current and destroy electrical components.
- Do not disconnect a scan tool from the data link connector while the ignition key is on. This could create a voltage spike that can damage the computer.

Computer System Circuit Problems

Almost all electrical-electronic problems are actually basic circuit problems. A ***basic circuit problem*** is caused by a problem in a circuit that increases or decreases current, resistance, or voltage. For example, a broken wire could stop current flow or a charging system problem could decrease output voltage and current flow.

Unfortunately, when a minor problem occurs in a complex circuit like a computer control system, it may

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not seem like a minor problem. For example, a poor electrical connection in a positive feed wire to a body ground may cause the computer system or one of the systems it controls to lose power. This can result in a shutdown of the fuel injection system, the emissions control system, the ignition system, or the entire vehicle.

You might think that any of these systems or the computer itself is at fault. Several systems could appear to have a problem. In reality, it is simply a poor electrical connection in one wire that is causing all the problems. It is important for an automotive technician to remain calm when diagnosing electrical problems. If analyzed properly, problems can usually be found and corrected easily.

Locating Computer Problems

The most difficult aspect of making computer system repairs is finding the source of the problem. To find the source of computer problems, you must ask yourself the following types of questions:

- What could be causing the specific symptoms? Mentally picture the parts in the circuit and how they function. Trace through the circuit while referencing a wiring diagram to find out which wires, connections, and components are in the circuit leading to the potential trouble source.
- How many components are affected? If several components are not working, something close to a common power source or ground point is at fault. If only one or two sections of the circuit are faulty, begin your tests at those sections of the circuit.
- Is the problem always present or is it ***intermittent*** (only occurs under some conditions)? If the problem is intermittent, the conditions causing the problem will have to be simulated. For example, a loose electrical connection could open and close with vibration or movement. You might simulate driving conditions by wiggling wires and connectors in the circuit to make the problem occur.
- Is the problem's occurrence related to heat or cold? If it occurs only on a hot day or when the engine is warmed to full operating temperature, heat is related to the problem's occurrence. Electronic circuits (transistors in particular) are greatly affected by heat. In fact, too much heat can ruin an electronic component. You can use a heat gun to simulate the heat in an engine compartment.
- Is the problem's occurrence affected by moisture? If the trouble occurs only on wet or humid days, you have information to use when analyzing the source of a problem. In most cases, moisture cannot enter a sealed electronic component, but it may enter and affect the wire connections and any components exposed to the environment.

Stress testing refers to the use of heat, cold, or moisture to simulate extreme operating conditions of components, like spark plug wires, explained in a later chapter under spark plug wire leakage.

Sensor and Actuator Problems

As with other electrical and electronic components, sensors, actuators, and their circuits can develop opens, shorts, or abnormal resistance or voltage values. When your pinpoint tests find a problem, the sensor or actuator should be replaced or the circuit repaired.

In most cases, a scan tool is used to find the problem circuit and component. A digital multimeter is sometimes used to measure the electrical signal from the component or circuit to verify problems indicated by the scan tool. Then, this value (voltage, resistance, or current) is compared to factory specifications. If the test value is too high or too low, you would know that the sensor or actuator is faulty and must be replaced.

The shop manual will also have a wiring diagram, or schematic, for the computer system. The diagram will show the color codes of the wires and the number of connectors that are used to feed signals from the sensors to the computer and from the computer to the actuators. This can be very helpful when servicing any computer system. The following paragraphs discuss the most frequent circuit problems.

Poor Electrical Connections

Poor electrical connections are the most common cause of electrical-related problems in a computer system. Discussed previously, a wiggle test will help find poor connections and intermittent problems. Always check electrical connections when diagnosing sensors and other electronic components. OBD II scan tools will help you find poor electrical connections, as shown in **Figure 25-2**.

Poor electrical connections can be due to corroded terminals, loose terminal ends, burned terminals, chafed wires, and other problems. Dirt and moisture can get into connectors, causing high resistance. Any of these conditions can prevent a normal sensor signal from returning to the computer. They can also prevent the control current from reaching an actuator.

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Snap-on Tool Corp.

Figure 25-2. The scan tool will usually direct you to the area of the vehicle causing the problem. A—"Read DTC Options" allows you to select stored codes, pending codes (codes that are almost out of normal operating parameters), and manufacturer data. B—The scan tool denotes the vehicle has tripped two trouble codes. C—The scan tool readout explains that the mass or volume airflow sensor circuit is showing low voltage or current input to the computer. D—The scan tool readout shows there is no engine misfire problem, the fuel injection system is working normally, and the catalytic converter is working. E—No signal from the heated catalyst may be due to the engine not warming up completely. The evaporative emission control system is working normally. Air conditioning has no signal because it might not be turned on. F—The scan tool indicates both O_2 sensors are working normally. The EGR system may not have a signal because the engine has not warmed fully.

Vacuum Leaks

Vacuum leaks are frequently caused by deteriorated, broken, or loose vacuum hoses. Vacuum leaks often make a hissing sound. Some vacuum leaks can upset the operation of a computer system and cause a wide range of symptoms. Also, some engine sensors and actuators rely on engine vacuum for operation.

Always check for vacuum leaks when they could be causing a performance problem, **Figure 25-3**. For example, if the trouble code indicates a problem with the MAP (manifold absolute pressure) sensor, check the vacuum lines leading to the sensor. If there is a vacuum leak, the sensor cannot function normally. Also check the intake manifold gasket area, as this is a common location for vacuum leaks.

Air leaks after a mass airflow sensor can also cause problems. The sensor cannot measure the



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Figure 25-3. Always inspect the engine compartment for signs of trouble. A loose or corroded connection or a vacuum leak may be setting trouble codes or tricking the computer system.

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actual amount of air being drawn into the engine, and an incorrect air-fuel mixture will result.

Sensor Service

Sensor service involves testing and, if needed, replacing computer system sensors. Since sensor designs vary and some can be damaged by incorrect testing methods, it is important for you to know the most common ways of checking sensor values.

For testing purposes, you can classify sensors into one of two categories: passive sensors or active sensors. This will help you select a testing method.

Testing Passive Sensors

Since passive sensors do not generate their own voltage, the computer must feed them a reference voltage. A passive sensor can change its internal resistance with a change in system or vehicle condition or operation. This resistance change modifies the reference voltage, which is interpreted and used by the computer to control the engine's various systems.

To test a passive sensor, either measure its internal resistance with an ohmmeter or measure the voltage drop across the sensor with its reference voltage applied. Depending on the sensor or manufacturer, both tests may be performed. You can also read computer data stream values with your scan tool. However, the scan tool cannot isolate the sensor, wiring, or computer for individual tests. Any unusual sensor readings by a scan tool should be verified using a multimeter.

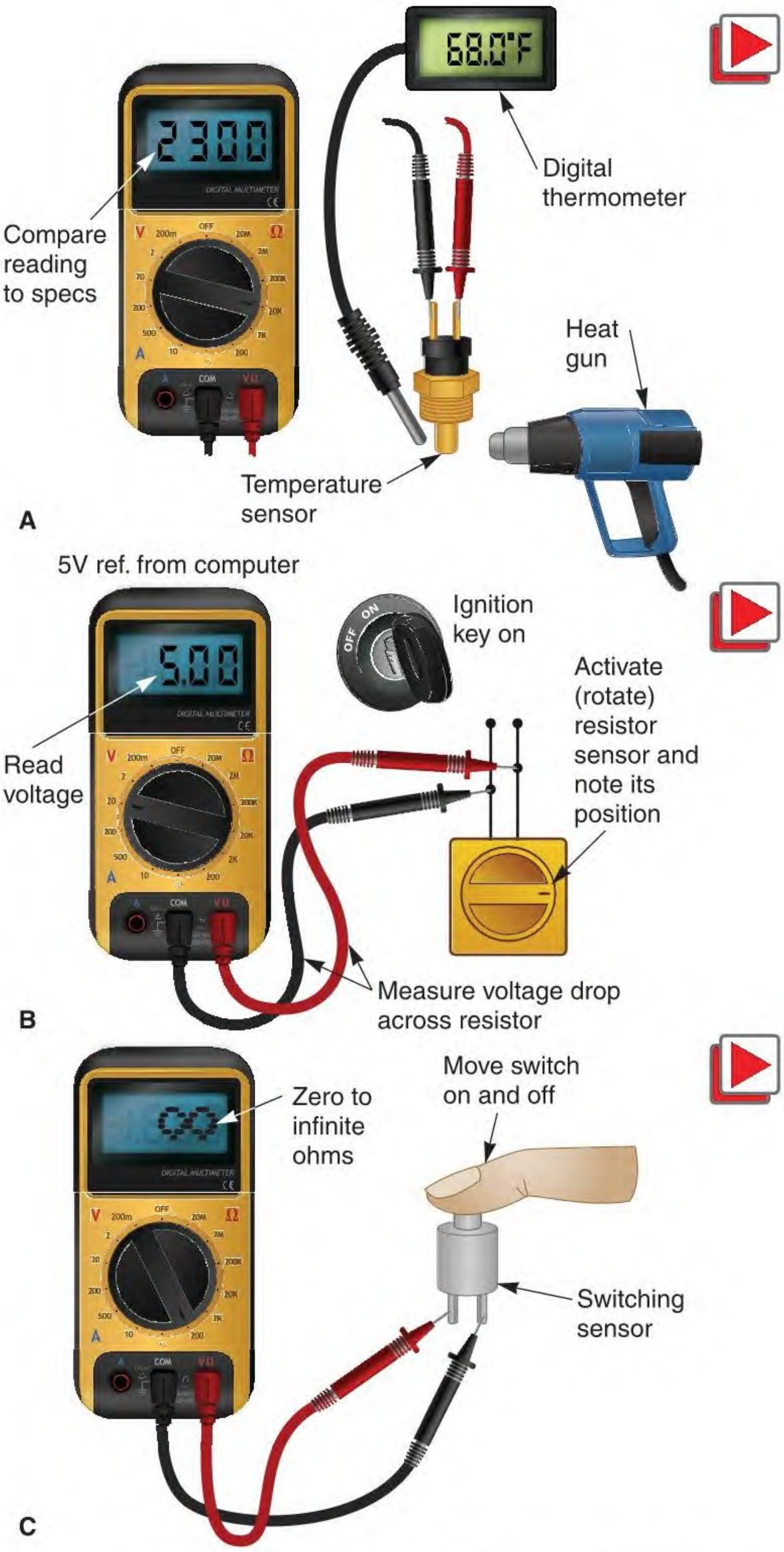
Testing Variable Resistance Sensors

Service Procedure

To test a variable resistance sensor with an ohmmeter:

1. Disconnect the sensor wires.
2. Connect the ohmmeter's test leads to the sensor terminals, **Figure 25-4A**.
3. Compare the ohmmeter reading to the manufacturer's specifications.

The sensor's resistance must be within factory specifications. For example, if you are testing a temperature sensor, connect an ohmmeter to the sensor terminals and then measure coolant temperature with



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Figure 25-4. There are many ways to test passive sensors. A—An ohmmeter can be used to measure internal resistance. Some sensors can be heated with a heat gun while measuring resistance. A digital thermometer may also be used to compare actual temperature with sensor resistance. B—A voltmeter can be used if sensor specifications are given only as a voltage drop. The sensor must have reference voltage while testing occurs. C—Switching sensors may be tested with an ohmmeter or a high-impedance test light. The meter or light should show a change in condition when the switch is turned on and off.

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a digital thermometer. Note the resistance readings at various coolant temperatures and compare these readings to service manual specifications.

If the sensor's resistance is within specifications, check for opens or shorts in the wires going to the sensor. If the wires are good, suspect the computer itself. The service manual will give detailed instructions for testing the computer.

Service Procedure

To check a variable resistance sensor with a voltmeter:

1. Connect the voltmeter in parallel with the sensor. Be sure to leave the computer wires connected to the sensor, **Figure 25-4B**.
2. Measure the voltage drop across the sensor with the computer reference voltage applied.
3. Compare your measurements to specifications.

Testing Switching Sensors

With a switching sensor, such as a power steering pressure switch, you can use an ohmmeter to check that the switch is opening and closing. As shown in **Figure 25-4C**, connect your ohmmeter and move the switch opened and closed. Your meter should register infinite ohms and then zero ohms. Replace the sensor if it is defective. You could also use a high impedance test light to quickly check the operation of a switching sensor.

Note that some auto manufacturers do not give resistance specifications for passive sensors, they only give voltage drops. You may have to use a test harness to connect the meter in parallel with the sensor. You can make or purchase this type of test harness.

Testing Reference Voltage

A reference voltage (typically 5 volts) is fed to passive sensors. Then, when conditions and sensor resistance change, the amount of voltage flowing back to the computer also changes. The reference voltage is needed so a signal returns to the computer.

Service Procedure

To measure reference voltage to a passive sensor:

1. Disconnect the wires leading to the sensor.
2. Connect a digital voltmeter to the wires.
3. Turn the ignition key on and note your readings.
4. Compare your voltage readings to specifications.

Typically, the open circuit voltage should be about 5 volts. Refer to **Figure 25-5**.

If the reference voltage to the sensor is low, check the wiring harness for high resistance, as something is preventing the full reference voltage from reaching the sensor. Low reference voltage would cause a sensor to produce erroneous readings. It is possible for the reference voltage to be too high if a current-carrying wire is shorted into the circuit. High voltage may also be caused by a computer malfunction, but this is rare.

Testing Active Sensors

As mentioned, an active sensor produces its own voltage and sends it back to the computer. The voltage produced by an active sensor is very low, often under 1 volt. This makes sensor wiring harness continuity very critical. One poor electrical connection can keep the low voltage from returning to the computer.

Figure 25-6 shows several ways to test an active sensor. In **Figure 25-6A**, an ohmmeter is connected to a common magnetic sensor. The ohmmeter will measure the resistance of the coil winding. Replace the sensor if the resistance is high or low.

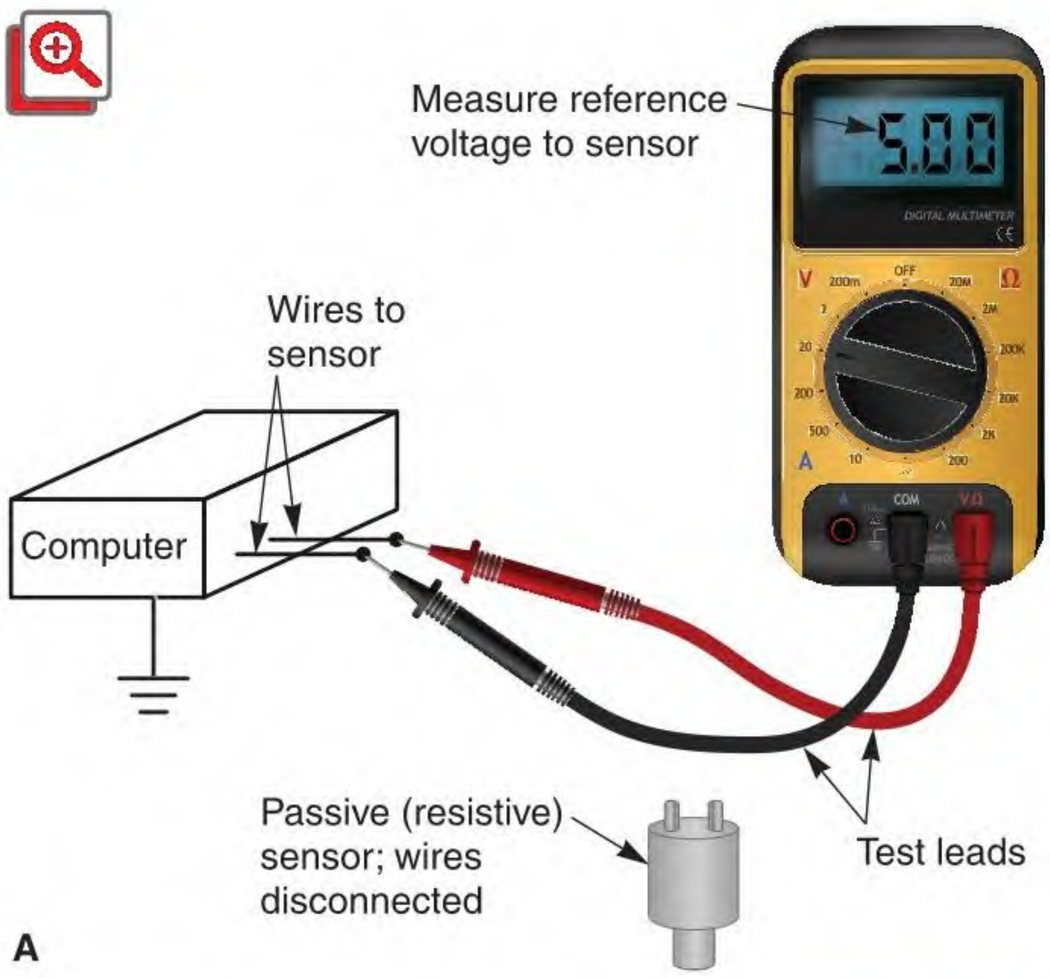
In **Figure 25-6B**, an ac voltmeter is connected to a magnetic sensor. The trigger wheel must be rotated (engine cranked over, wheel or hub in an ABS system turned, etc.) to make the sensor generate voltage. A magnetic sensor should typically produce about 1.5–3 volts ac. A magnet can also be passed by a coil to make it produce a voltage.

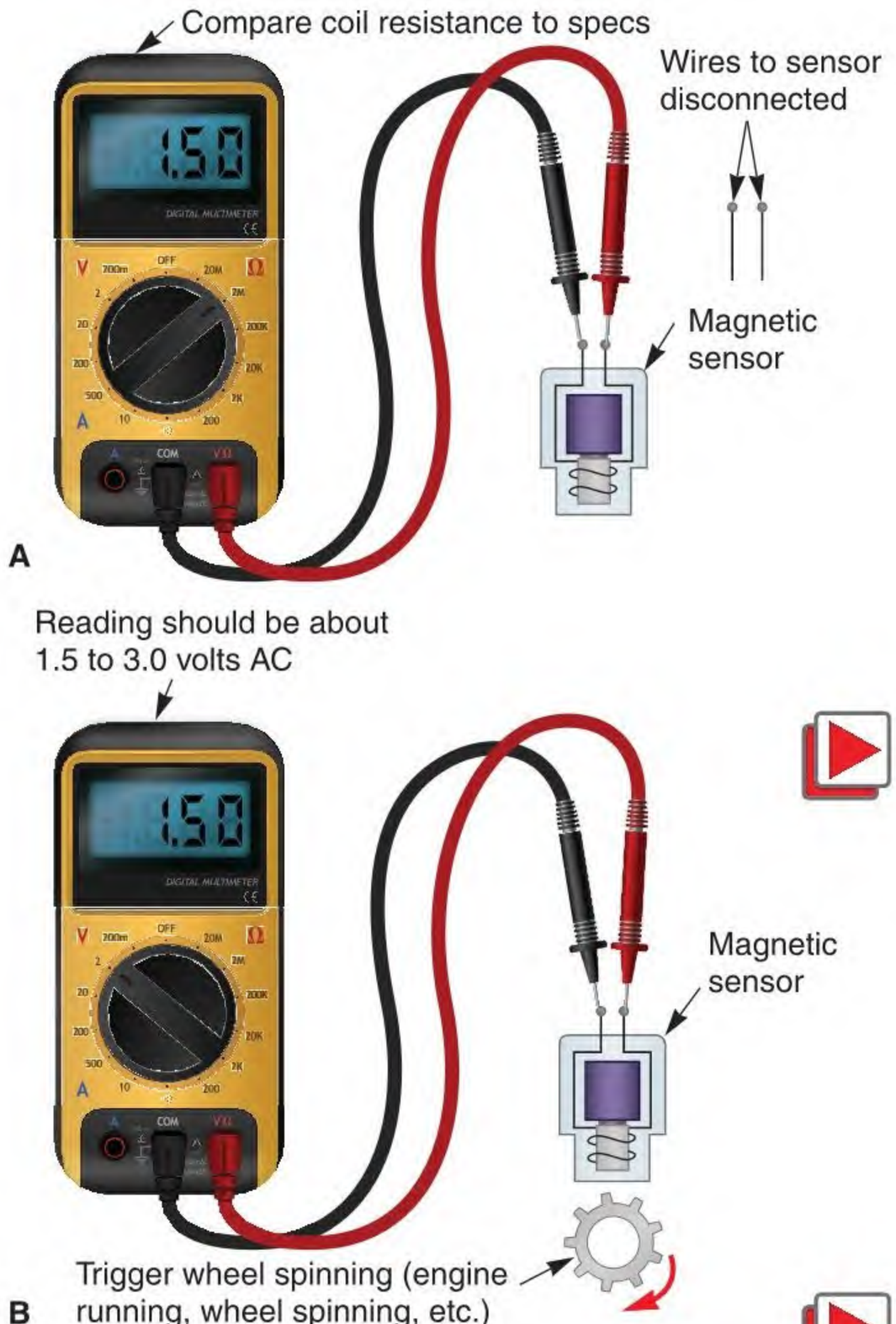
In **Figure 25-6C**, a digital voltmeter is connected to an oxygen sensor. With the engine running in closed loop, the voltmeter should show the sensor's output voltage. If the output voltage from the sensor is low or high, the sensor may require replacement. **Figure 25-7** shows how to use small jumper wires to connect a meter to check a sensor while it is still functioning in the circuit.

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Tech Tip

Whenever a sensor tests good, check the wiring leading to the sensor. Bad wiring may be blocking current flow back to the computer.



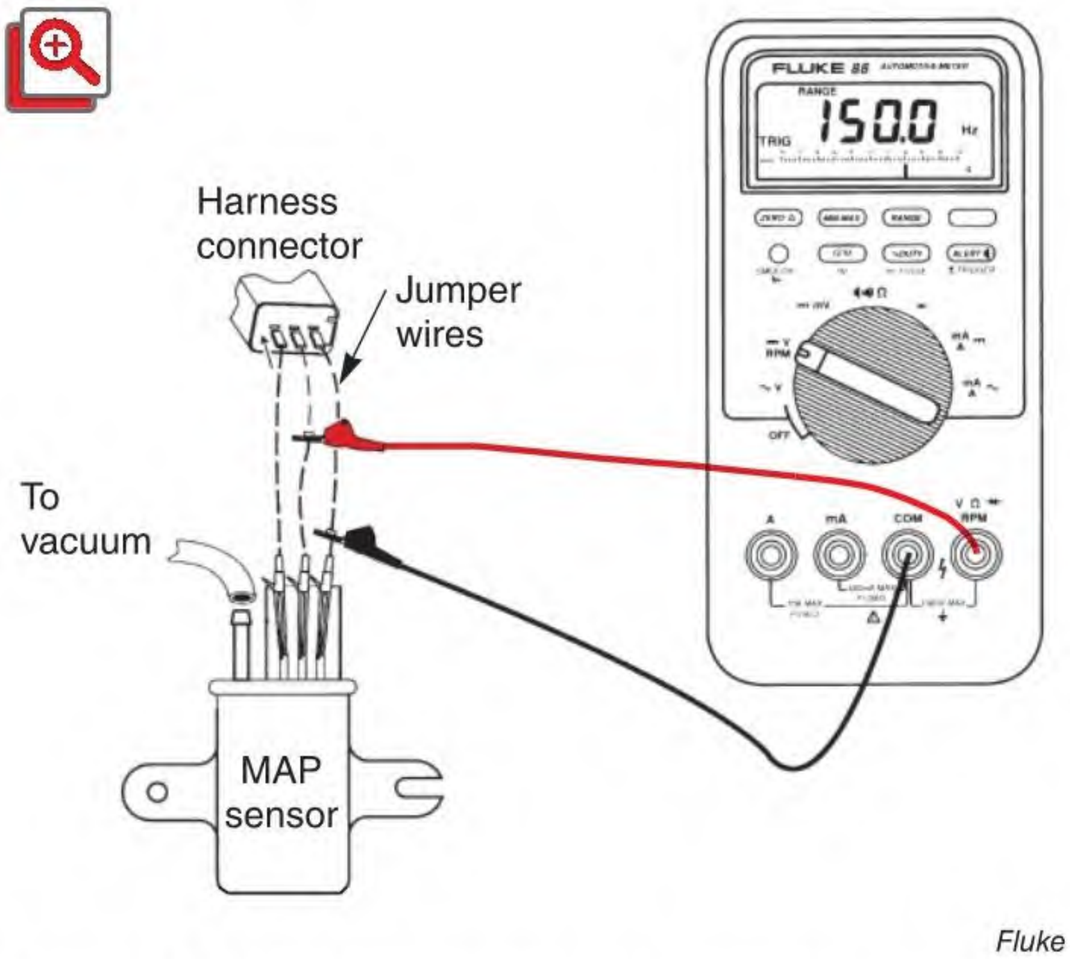


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Figure 25-5. Passive sensors rely on a computer reference voltage for proper operation. A—Use a digital voltmeter to measure the amount of voltage supplied to the sensor. Typical reference voltage might be 5 volts, but refer to the service manual specifications. B—If the reference voltage is not correct, test for voltage at the computer. If the reference voltage at the computer is correct, a problem with the wiring harness is indicated.

Figure 25-6. Since an active sensor generates its own output signal, testing methods for active sensors are slightly different from those for passive sensors. A—Magnetic sensor internal coil resistance can be measured with an ohmmeter. B—An ac voltmeter can be used to check a magnetic sensor while it is operating. With the triggering device moving, an ac voltage signal should be generated. C—Sometimes it is recommended to connect a meter directly to the sensor. You can compare the operating sensor's output to specifications. Be sure to test the harness leading to the sensor.

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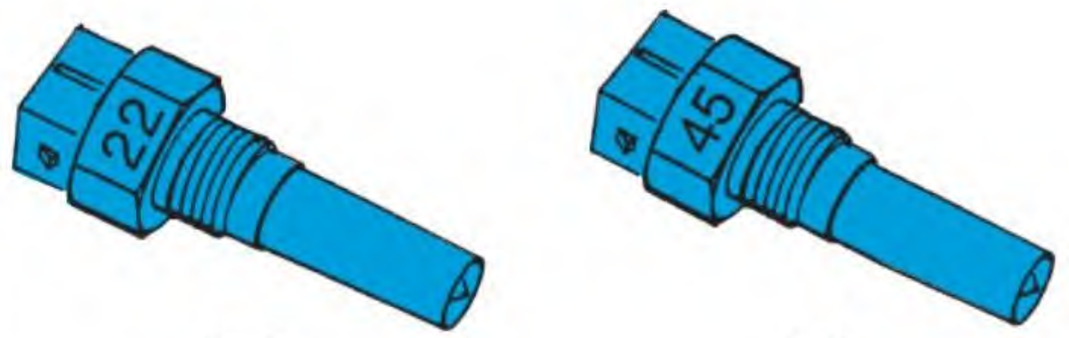
Fluke

Figure 25-7. Small jumper wires are often used when measuring sensor circuit values. Make sure you do not short the jumper wires together or to ground. This test is used to measure the frequency signal in hertz from a manifold absolute pressure sensor.

Replacing Sensors

When replacing a sensor, there are several general rules you should remember:

- Always purchase an exact sensor replacement. Even though two sensors may look identical, their internal resistance or circuitry may be different. See **Figure 25-8**.
- Release the sensor connector properly. Most connectors have positive locks that must be released. If you damage the connector, intermittent problems may result from a loose connection.
- Use special tools as needed. Some sensors, such as oxygen sensors, require the use of a ***sensor socket***. This socket has a deep pocket and a cutout that will fit over the sensor and any wires. Conventional deep sockets may not fit over the wiring or the sensor head.
- Use thread sealant sparingly. If the sensor seals a coolant, oil, or vacuum passage, do not use too much sealant.
- Use thread and engine sealants that are safe for oxygen sensors. Some sealants can poison the oxygen sensors.
- Tighten the sensor properly. Overtightening a sensor can damage it. Undertightening can lead to leaks.



Snap-on Tool Corp.

Figure 25-8. Always make sure the replacement sensor is same as the old one. These two temperature sensors look the same but have different temperature and resistance values. If the wrong one is installed, the vehicle may not function correctly.

- Adjust the sensor, if needed. Some throttle position sensors require adjustment after installation.
- Scan for trouble codes after sensor replacement.

Actuator Service

Actuator service involves testing the actuators for possible electrical or mechanical problems and replacing them, if necessary. If an actuator fails, the computer cannot control the engine and vehicle systems properly.

Testing Actuators

Since actuators are simply relays, solenoids, and motors, they are fairly easy to test. **Figure 25-9** shows several ways to test actuators.

Testing Servo Motors

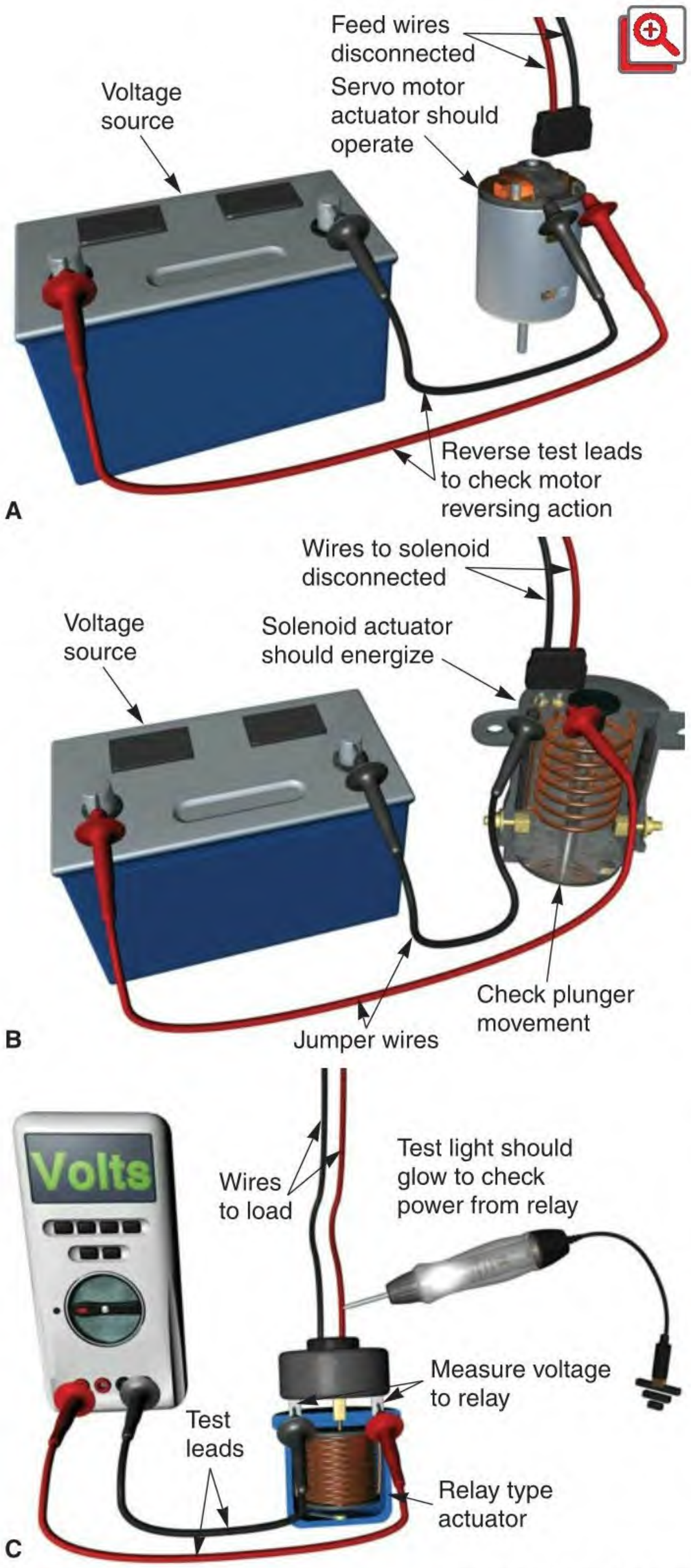
In **Figure 25-9A**, a voltage source has been connected to a servo motor. The wiring harness to the motor has been disconnected. Jumper wires feed current directly to the motor. This is a simple way to check the operation of an electric or servo motor. If the motor begins to function with an external voltage source applied, you should test the wire harness leading to the motor.

Testing Solenoids

In **Figure 25-9B**, a voltage source is being used to check a solenoid. When jumper wires are connected to the vehicle's battery and the solenoid, the solenoid should operate. If the solenoid tests good, you should check the voltage coming to the solenoid through its harness.

An ohmmeter can also be used to test a solenoid. You can use the meter to measure the internal

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Figure 25-9. Actuator testing is straightforward. It is similar to testing a conventional motor, relay, or solenoid. A—Voltage can be jumped to a servo motor. The motor should function when energized by the power source. B—A solenoid can also be tested in the same manner as a servo motor. C—A relay is slightly more complex to test. You must make sure there is an output when voltage is supplied to its input terminals. This can be done using a voltmeter or a high-impedance test light.

resistance of the unit. By comparing resistance readings to specifications in the service manual, you can find out if the actuator must be replaced.

Testing Relays

Figure 25-9C shows how to test a relay. Check the voltage entering the relay and the voltage leaving the relay. It is possible that voltage is applied to the relay but the relay points are not sending voltage out to the controlled device.

Since relays contain movable contact points, they are a common source of computer system problems. The scan tool may indicate a problem with the circuit containing the relay. However, you must test the relay to pinpoint the problem source.

Relays can be located almost anywhere on a vehicle: in the engine compartment, under the dash, under the seat, or in the trunk. The service manual will give exact locations. See **Figure 25-10**.

An integrated ***junction block*** encloses most or all of the vehicle's mechanical relays in a single housing. Some of the relays found in this block are the fuel pump relay, cooling fan relay, wide open throttle relay, air conditioning relay, and a host of others. The junction block is usually mounted in the engine compartment.

When testing a relay, refer to the service manual wiring diagrams for pin numbers and wire color codes. Special ***relay testers*** can be used to quickly test relay operation. They plug into the relay and test the unit automatically.

For information on actuator service, refer to the index in this textbook. You can find instructions on testing fuel injectors, glow plugs, and more specialized actuators.

Replacing Actuators

Actuator replacement will vary with the type and location of the unit. Here are a few rules to follow when replacing an actuator.

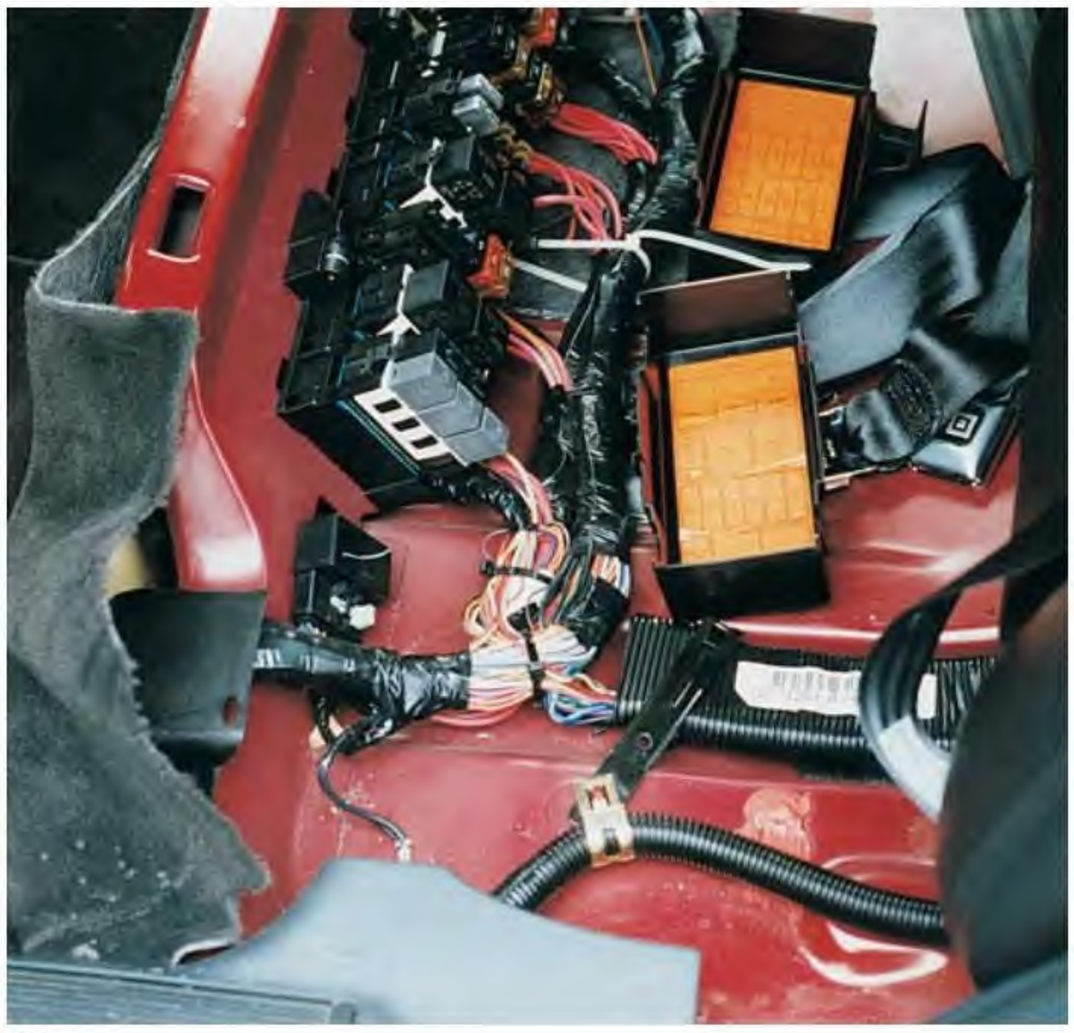
- Do not damage the wire connectors when releasing them. They are made of plastic and will break if forced open improperly.
- Do not drop the actuator mounting screws during removal or installation. If a screws falls into an engine, major problems can occur.
- Make sure you have the correct replacement actuator before attempting installation. Two actuators may look the same, but they will often have different internal construction.

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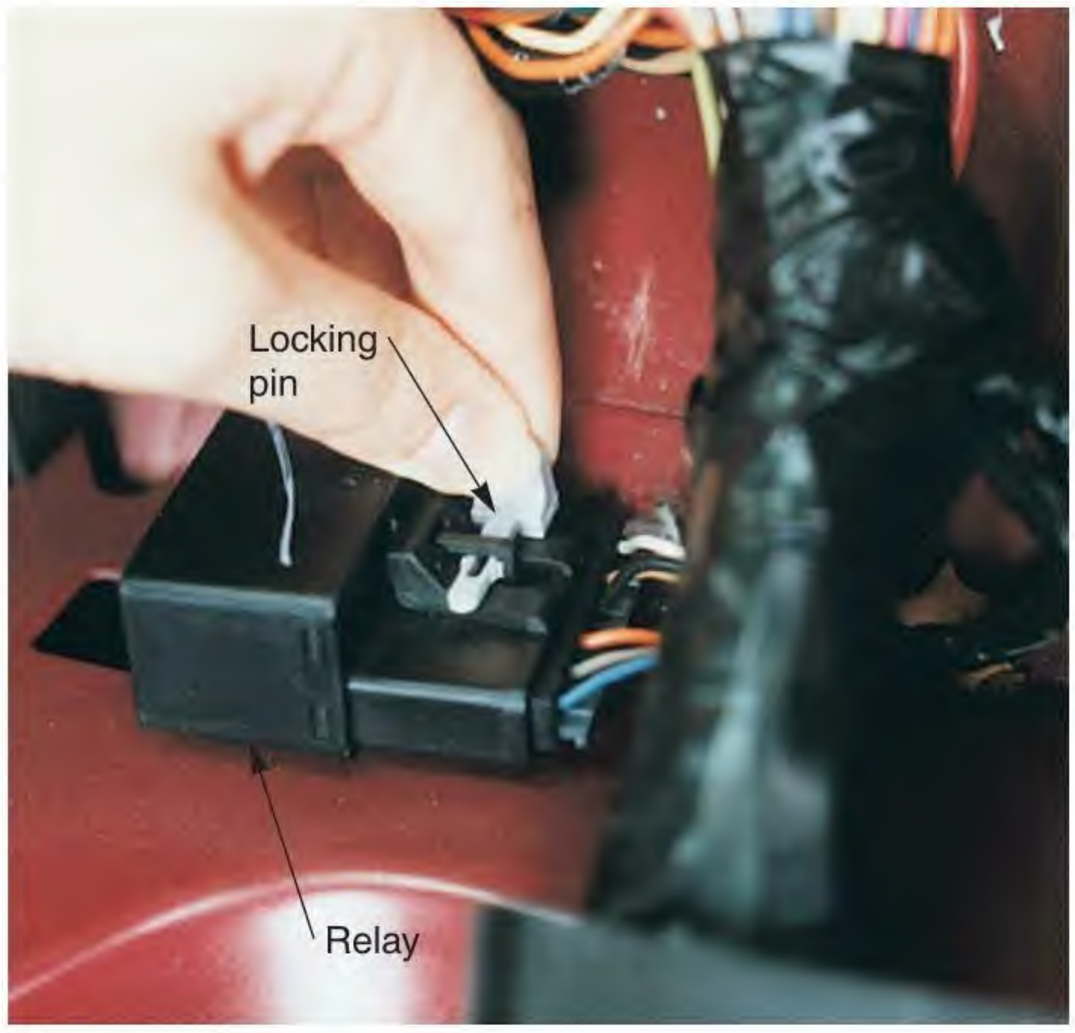
- Check that the actuator is fully seated before tightening the mounting screws.
- Double check actuator operation after replacement.

Computer Service

Computer service involves replacing or reprogramming the computer. The computer is the last component to be suspected of being the problem



A



B



C



D

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Figure 25-10. Relays have moving parts that can fail in service. Relays can be located almost anywhere on the vehicle. A—Technician has removed the rear seat cushion to gain access to the fuses and relays. B—This relay has a locking pin that must be removed before disconnecting the harness. C—Relays can have different internal construction. Make sure the replacement unit is identical to the original. D—The service manual will give relay locations for pinpoint testing and replacement.

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source, only after all other potential sources of trouble have been eliminated. It is sometimes possible for an integrated circuit, transistor, or other electronic part in the computer to fail and upset system operation.

Measuring Computer Output

If the computer is not tested, a defective computer is often identified through the process of eliminating the sensors, actuators, and related wiring as the cause of the problem. In the process of sensor and actuator testing, it was necessary for you to measure the computer's output. A ***computer output*** can be a reference voltage to a sensor or a supply voltage to an actuator.

Use a voltmeter to make sure the correct reference voltage is being sent to a sensor. Most computers produce a reference voltage of about 5 volts. If the reference voltage is not correct, check the wiring before condemning the computer. You can also measure voltage to make sure the correct voltage output is being fed to the actuators.

Each computer input and output passes through an individual metal terminal, or pin, which plugs into the vehicle wiring harness. ***Pin numbers*** identify the location and purpose (electrical value and internal connection) of each terminal in a computer wiring harness connector. You may have to probe computer terminal pins to find the source of complex problems. This will be discussed in a later chapter.

Again, always refer to the service manual for exact procedures when testing a computer system. One wrong electrical connection can destroy the computer.

Caution

Never use an ohmmeter to check a computer, as it will damage the computer's internal circuitry. If it is necessary to use an ohmmeter to check the continuity of a wire or circuit in the computer harness, disconnect all wiring harnesses from the computer before testing.

Saving Memory

Saving memory can be done by connecting a memory saver to the accessory port (lighter port) or the data link connector before disconnecting the vehicle's battery. The ***memory saver*** supplies enough power to keep the clock, stereo, and computer from losing the information stored in their memories. Some memory savers use a 9-volt battery and plug into the vehicle's accessory port. Other memory savers contain a rechargeable 12-volt battery and plug into the vehicle's accessory port or the data link connector. See **Figure 25-11**. In some cases, a battery jump start box can be used as a memory saver. A specially designed cable connects the jump start box to the vehicle's accessory port or data link connector.

Before using a memory saver, turn off all accessories (radio, blower, etc.). The current drain from these devices, combined with even the smallest voltage drop, could cause electronic devices (computer, clock, radio, etc.) to lose their preprogrammed data. You are still disconnecting the vehicle battery for safety. The memory saver cannot supply enough current to cause an electrical fire or operate the starting system.

Computer Replacement

Before disconnecting the battery and removing the computer from the vehicle, you should scan the computer and obtain the PROM identification number or the EEPROM calibration number. This information



OTC/SPX Corp.

Figure 25-11. This memory saver has cables for your vehicle's accessory port and for the data link connector.

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is needed to check for updated PROMs that should be installed and calibration programs that should be downloaded to the new computer. External identification numbers are not always placed on the PROM.

When removing a computer, the ignition key should be off and the vehicle's negative battery cable disconnected. This will prevent voltage spikes from damaging the computer when the harness connectors are removed. Remove any shields or components necessary to access the computer. Unbolt the brackets holding the computer in place and unplug the computer connectors.

Identification information is usually stamped or printed on the computer. Use this data and the year, make, and model of vehicle to order the correct replacement computer. The VIN (vehicle identification number) may be helpful, as well.

Caution

When handling computers, keep one hand on chassis ground and use the other to remove the component. This will prevent a static electrical charge from entering and damaging the electronic circuitry. If available, wear an anti-static wrist strap when working on computer circuits. Static electricity may not instantly ruin an electronic part, but it can reduce the part's useful service life from years to days.

EEPROM Programming Using Computerized Equipment

Most newer computers use Electrically Erasable Programmable Read Only Memory (EEPROM) or Flash Erasable Programmable Read Only Memory (FEPROM) chips that are permanently soldered to the circuit board. These chips must be programmed using electronic equipment. They are often reprogrammed to correct driveability and performance problems.

EEPROMs are programmed using a method referred to as flash programming. Flash programming may be performed by downloading the vehicle's information through a computer, a computerized diagnostic analyzer, or a scan tool. Actual programming details vary between manufacturers, but the basic procedure begins by placing the computer in the programming mode. One of two methods is used to program the computer:

- Direct programming using a service computer or a laptop computer, **Figure 25-12**.
- Remote programming with the computer off the vehicle.

Direct Programming

Direct programming is the fastest and simplest method. The new information is downloaded by attaching a shop recalibration device (usually a laptop computer) directly to the data link connector. The erasure and programming is done by accessing the programming menu and following the instructions as prompted by the computer. Then, the vehicle's operating information and parameters are entered into the vehicle's computer through the connector.

Remote Programming

Remote programming is done with the vehicle's computer removed from the vehicle. This procedure is used when changes need to be made through a direct modem connection to a manufacturer's database computer. It can also be done in cases where direct programming is not practical or possible. Since special connectors and tools are required for this type of programming, this procedure is done only at new vehicle dealerships.

EEPROM Programming Procedure

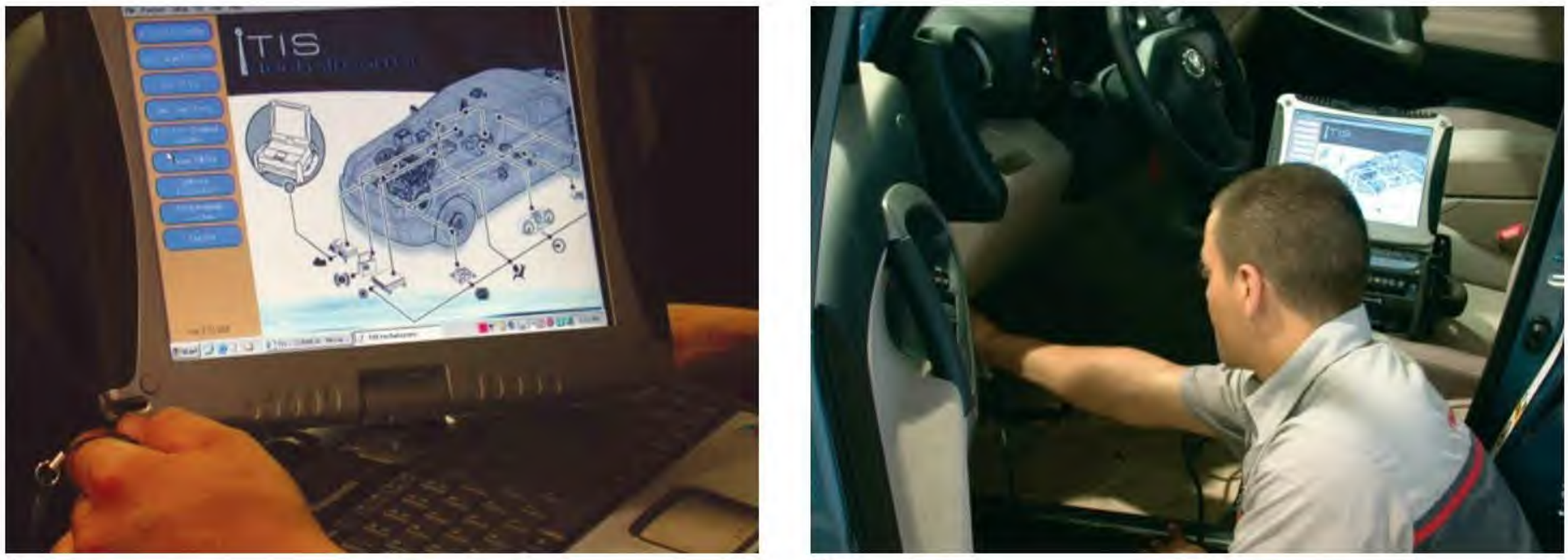
To begin programming the EEPROM-equipped computer, make sure that the vehicle's battery is fully charged. Recharge the battery if necessary. Do not charge the battery during the programming procedure, as damage to the computer will result. Connect the programming computer or scan tool to the data link connector. Make any other vehicle connections as needed before proceeding with the programming sequence.

Caution

Do not disconnect the scan tool or programming computer from the data link connector during the programming sequence. Doing so will damage the vehicle's computer.

To start the programming sequence, the programming computer prompt may ask you to enter the engine type, vehicle type, and vehicle identification number (VIN) in a specific sequence. Once the vehicle information is entered, go to the programming software and follow the directions as prompted.

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A B

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Figure 25-12. Most dealerships now have a dedicated laptop computer for EEPROM reprogramming. A—The laptop is plugged into the diagnostic link so it can download new information into the vehicle's computer. B—Icons on the laptop screen allow the technician to select the correct software for downloading.

Depending on the manufacturer, it may be necessary to turn the ignition switch on or off during the connection and programming procedure. Double-check any instructions on ignition switch position before making any connections or beginning the programming procedure. The next step is to determine the type of programming that is needed.

Programming a New Computer

If a new computer is being installed, program only that computer. In many cases, other on-board computers can be accessed and programmed using the data link connector. While most computers have internal circuitry that protects them from accidental programming, be careful not to program the wrong computer. Do not attempt to program a new computer with information from the old computer or a computer from another vehicle. Any attempt to do this will set a failed programming sequence code in the new computer's memory.

Tech Tip

In some cases, an erasure must be performed on a new computer before initial programming can take place.

Reprogramming a Computer

Computer reprogramming is often needed to solve specific performance or emission related problems. The auto manufacturer will put out a bulletin and provide the modified software to fix vehicle malfunctions. Before reprogramming a vehicle's computer, determine the date that the current programming was downloaded or check the program's calibration number. If the current program is the latest version, no further actions are required. If the latest program has not been downloaded, proceed with the reprogramming sequence.

Before reprogramming most computers, you must first erase the existing information. After this step is complete, select the updated calibration information from the programming computer or scan tool menu. Then download the new information into the computer. On some systems, the erasure step is not necessary since the programming computer or scan tool will erase or overwrite the old information as it loads the new program into the computer.

Tech Tip

If the computer does not accept the new program or cannot be programmed, check all connections first. Ensure that the correct computer is being reprogrammed with the proper information and that all procedures are being followed. If the computer still cannot be programmed, it may need to be replaced.

Allow sufficient time for the programming to take place. Monitor the computer or scan tool to determine when the programming sequence is complete. Do not touch any connections until you are sure the

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programming sequence is complete. After programming is completed, turn the ignition switch to the position called for and disconnect the programming computer. Then, use a scan tool to check the computer and control system operation. While doing this, make sure you have installed the proper program into the computer by checking the program calibration number.

Computer Relearn Procedures

After being serviced, the computer system may have to go through a relearn procedure. A ***relearn procedure*** is a period of vehicle operation during which the computer system adapts to new components and programming information. The computer must receive inputs to formulate adaptive strategies to set some of its output parameters. The relearn procedure can often be done by simply driving the vehicle for several minutes. Some vehicles require a specific relearn procedure. Always check the manufacturer's service literature for exact relearn methods. In a few cases, sensors or actuators may have to be manually adjusted using a scan tool.

Diagnostic Case Study

Concern: Mr. Hayes brought his late model KIA into the shop, complaining of a hesitation, or stumble, when he accelerates the vehicle from a standing start.

Cause: Duff test drives the vehicle to double-check the symptoms and to observe engine performance. He immediately notices a hesitation during acceleration. The vehicle seems to operate normally at cruising speed.

Once back at the shop, Duff connects a diagnostic tablet to the vehicle and finds a trouble code for the throttle position sensor. Using the scope function on the tablet, he slowly opens the throttle and finds a spiking waveform as the throttle is opened. This indicates an internal resistance problem with the throttle position sensor.

Correction: Duff replaces the TPS and rechecks its scope pattern. The new TPS shows a gradual, smooth increase in voltage/resistance as the throttle is moved open. He then test drives the vehicle to make sure the repair fixed the hesitation problem before releasing the vehicle to the customer.

Summary

- Pinpoint tests are specific tests of individual components. They are completed after scanning for trouble codes.
- A preliminary inspection involves looking for signs of obvious trouble: loose wires, leaking vacuum hoses, part damage, etc.
- Semiconductors are very easy to damage. They can be damaged by static electricity, voltage spikes, heat, and impact shocks.
- Stress testing refers to the use of heat, cold, or moisture to simulate extreme operating conditions of components, like an electronic control unit.
- Poor electrical connections are the most common cause of electrical-related problems in a computer system.
- Vacuum leaks are frequently caused by deteriorated, broken, or loose vacuum hoses. Vacuum leaks often make a hissing sound.
- A reference voltage (typically 5 volts) is fed to switching and variable resistance type sensors.
- Sensor sockets have a deep pocket and a cutout for a sensor pigtail (wires).
- Since they contain movable contact points, relays are a common source of computer system problems.
- Computer service usually involves a few tests and computer replacement if needed.
- Some computers use the old PROM (memory chip) during computer replacement, since it stores data for the specific make and model vehicle.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

basic circuit problem
computer output
intermittent
junction block
memory saver
pin number
pinpoint test
preliminary visual inspection
relay tester
relearn procedure
sensor socket
stress testing

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Activities

1. Describe and sketch the procedure you would use to test a temperature sensor for proper operation.
2. Demonstrate two methods of checking a knock sensor—with a multimeter and by manual tapping.
3. Look up vehicle software update on the Internet. Try to find which cars sometimes require computer reprogramming. Write a paragraph on your findings.

Review Questions

Answer the following questions using the information provided in this chapter.

1. What should you look for during a preliminary inspection of a computer system?
2. Explain five questions you should ask yourself when analyzing computer system problems.
3. How can a vacuum leak upset the operation of a computer system?
4. An engine runs poorly only when cold. Symptoms and a trouble code indicate a problem with the engine coolant temperature sensor. Technician A says to measure the engine coolant temperature sensor's resistance with a digital ohmmeter while measuring coolant temperature with a digital thermometer. Technician B says to measure the sensor's ac voltage output while measuring its temperature with a digital thermometer. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. How do you check sensor reference voltage?
6. Explain three ways to test an active sensor.
7. Describe three ways to test an actuator.
8. Relays are a common source of problems in a modern computer system. True or false?
9. How do you save computer memory?
10. The computer must be removed from a late-model vehicle. Technician A says to keep one hand on chassis ground when handling the computer. Technician B says to wear an anti-static wrist strap when handling the computer. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

ASE-Type Questions

1. Technician A says automotive computer system trouble codes are used to detect faulty components in the system. Technician B says automotive computer system trouble codes are used to indicate the general area of trouble in a computer system. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. A trouble code is triggered in an automotive computer system. Technician A says fuel-contaminated engine oil could possibly trigger this trouble code. Technician B says fuel-contaminated engine oil has no effect on computer system operation. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. Technician A says a basic circuit problem is caused by something in the circuit that increases or decreases current. Technician B says a basic circuit problem is caused by something in the circuit that increases or decreases resistance. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. A scan tool indicates a problem with the MAP sensor. Technician A says you should check the operating condition of the MAP sensor. Technician B says you should check for poor electrical connections in the system. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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5. Technician A says a passive automotive sensor is capable of generating its own voltage. Technician B says a passive automotive sensor is not capable of generating its own voltage. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Technician A says that a variable resistance sensor can be tested with an ohmmeter. Technician B says that a variable resistance sensor can be tested with a voltmeter. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. Technician A says a reference voltage of about 12 volts is normally required for an automotive variable resistance type sensor to operate properly. Technician B says a reference voltage of about 5 volts is normally required for an automotive variable resistance type sensor to operate properly. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. A trouble code shows a problem with an active sensor. Technician A says the voltage produced by an active sensor is very low, often under 1 volt. This makes sensor output and wiring harness continuity very critical. Technician B says that active sensor signals are just as strong as passive sensor signals. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. An automobile's oxygen sensor output needs to be checked. Technician A uses a digital voltmeter to check this sensor's output. Technician B uses an analog ohmmeter to check this sensor's output. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. An oxygen sensor tested faulty and must be replaced. Technician A says to use a sealant that is safe for oxygen sensors on the threads. Technician B says to use a sensor socket to prevent sensor damage. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Computer System Sensor and Actuator Diagnosis		
Condition	**Possible Causes**	**Correction**
Hard starting.	1. Faulty coolant temperature sensor. 2. Defective intake air temperature sensor. 3. Maladjusted or defective throttle position sensor. 4. Faulty crankshaft position sensor. 5. Faulty manifold absolute pressure sensor. 6. Bad mass airflow sensor. 7. Faulty idle speed motor. 8. Bad fuel injectors.	Test components and related circuitry. Service or replace as necessary.
Engine stalling.	1. Faulty coolant temperature sensor. 2. Defective intake air temperature sensor. 3. Maladjusted or defective throttle position sensor. 4. Faulty crankshaft position sensor. 5. Faulty manifold absolute pressure sensor. 6. Bad mass airflow sensor. 7. Faulty idle speed motor. 8. Bad fuel injectors.	Test components and related circuitry. Service or replace as necessary.
Rough idle or surging.	1. Faulty coolant temperature sensor. 2. Defective intake air temperature sensor. 3. Maladjusted or defective throttle position sensor. 4. Faulty crankshaft position sensor. 5. Faulty manifold absolute pressure sensor. 6. Bad mass airflow sensor. 7. Faulty idle speed motor. 8. Bad fuel injectors.	Test components and related circuitry. Service or replace as necessary.
Erratic idle speeds.	1. Maladjusted or defective throttle position sensor. 2. Faulty crankshaft position sensor. 3. Bad idle speed motor.	Test components and related circuitry. Service or replace as necessary.
Cold engine warm-up problems.	1. Faulty coolant temperature sensor. 2. Faulty intake air temperature sensor. 3. Faulty manifold absolute pressure sensor. 4. Bad mass airflow sensor. 5. Bad idle speed motor.	Test components and related circuitry. Service or replace as necessary.
Engine hesitation.	1. Faulty coolant temperature sensor. 2. Faulty air temperature sensor. 3. Maladjusted or defective throttle position sensor. 4. Faulty EGR position sensor. 5. Defective or contaminated oxygen sensor. 6. Maladjusted or faulty crankshaft position sensor. 7. Faulty manifold absolute pressure sensor. 8. Bad mass airflow sensor. 9. Bad fuel injectors.	Test components and related circuitry. Service or replace as necessary.

Continued

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Computer System Sensor and Actuator Diagnosis		
Condition	**Possible Causes**	**Correction**
Poor performance and gas mileage.	1. Faulty coolant temperature sensor. 2. Faulty air temperature sensor. 3. Maladjusted or defective throttle position sensor. 4. Faulty EGR position sensor. 5. Defective or contaminated oxygen sensor. 6. Maladjusted or faulty crankshaft position sensor. 7. Faulty manifold absolute pressure sensor. 8. Bad mass airflow sensor. 9. Bad fuel injectors.	Test components and related circuitry. Service or replace as necessary.
Erratic acceleration.	1. Faulty EGR position sensor.	Test sensor and related circuitry. Service as necessary.
Pinging.	1. Bad coolant temperature sensor. 2. Maladjusted or defective throttle position sensor. 3. Defective EGR position sensor. 4. Faulty manifold absolute pressure sensor. 5. Bad mass airflow sensor. 6. Faulty knock sensor.	Test sensors and related circuitry. Service or replace as necessary.
Surging at highway speeds.	1. Bad coolant temperature sensor. 2. Maladjusted or defective throttle position sensor. 3. Defective EGR position sensor. 4. Faulty manifold absolute pressure sensor. 5. Bad mass airflow sensor.	Test sensors and related circuitry. Service or replace as necessary.
Backfiring.	1. Maladjusted or defective throttle position sensor. 2. Faulty manifold absolute pressure sensor. 3. Bad mass airflow sensor.	Test sensors and related circuitry. Service or replace as necessary.
Black exhaust smoke.	1. Bad coolant temperature sensor. 2. Faulty intake air temperature sensor. 3. Faulty oxygen sensor. 4. Faulty manifold absolute pressure sensor. 5. Bad mass airflow sensor. 6. Bad fuel injectors.	Test components and related circuitry. Service or replace as necessary.
No torque converter lockup.	1. Maladjusted or defective throttle position sensor. 2. Faulty EGR position sensor. 3. Faulty manifold absolute pressure sensor. 4. Bad mass airflow sensor. 5. Faulty torque converter lockup solenoid. 6. Faulty or maladjusted brake light switch.	Test components and related circuitry. Service or replace as necessary.
Run on.	1. Defective idle speed motor.	Test motor and related circuitry. Service or replace as necessary.

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ASE

Pinpoint tests can be performed to find the exact source of a computer system problem. This technician is using a DVOM to check the reference voltage being sent to a passive sensor.

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Section 5

Electrical and Electronic Systems Technology

Chapter 26
Hybrid Drive Technology

Chapter 27
Hybrid Drive Systems Diagnosis and Repair

Chapter 28
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Chapter 29
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Chapter 30
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Charging System Diagnosis, Testing, and Repair

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Chapter 36
Lights, Instrumentation, Wipers, and Horns—Operation and Service

Chapter 37
Sound Systems and Power Accessories

Chapter 38
Security and Navigation Systems

Almost every system in a modern vehicle uses some type of electric or electronic component. Electronic ignition, electronic fuel injection, computerized engine management systems, "smart" air bag systems, collision avoidance systems, anti-lock brakes, hybrid drive systems, and other advanced systems require technicians skilled in electricity and electronics. Even specialized technicians need a background in electricity and electronics to fix today's vehicles.

This section details the operation, diagnosis, and repair of the major electrical systems. It opens by explaining the operation and service of hybrid drive systems. It then presents detailed information on both 12-volt and HV batteries before progressing to starting, charging, ignition, and other systems.

Study the information in this section carefully. A technician who is well versed in electricity and electronics is in high demand. The information in this section will help you pass ASE Test A6, Electrical/Electronic Systems, and Test A8, Engine Performance.



Chapter 26
Hybrid Drive Technology

After studying this chapter, you will be able to:

- Identify the major parts common to hybrid gas/electric or all-electric vehicles.
- Compare hybrid design and construction variations.
- Explain the operation of a motor-generator, HV battery, and HV power control module.
- Correctly answer ASE certification test questions on hybrid drive systems.

A ***hybrid electric vehicle (HEV)*** uses two power sources for propulsion: a small gas or diesel engine is used in conjunction with a high-voltage battery and a motor-generator to produce torque for operating the vehicle's drive train and electrical systems.

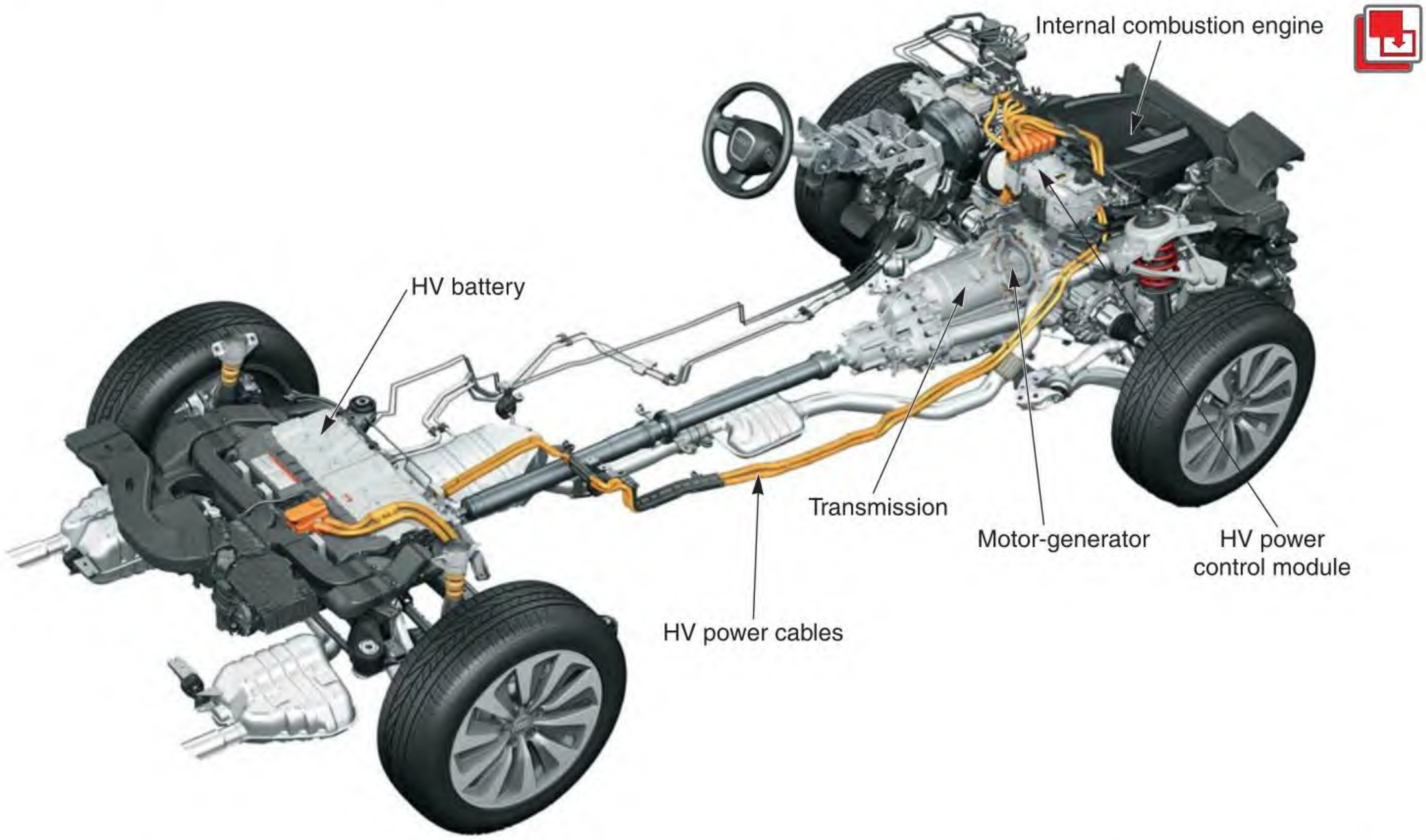
Hybrid electric vehicles are now produced and sold by all major auto manufacturers. Therefore, it is very important that you understand how various hybrid designs differ in their construction and operation. If you understand how any hybrid "is supposed to work," you will more clearly comprehend how to fix hybrid drive train problems.

Hybrid Vehicles

To electricians working on high-voltage transformers and power transmission lines, the abbreviation *HV* means "high voltage." All hybrid vehicles now operate on high voltage, so *HV* is used frequently when referring to the high voltage circuits and components found in hybrid vehicles. For example, the battery used in a hybrid vehicle is commonly called an "HV battery."

Discussed briefly, an HEV uses multiple individual power sources to provide useable energy for propulsion. In an HEV, an internal combustion engine and an electric drive system are combined to make up the vehicle's power train. The power train provides driving force to the wheels. Refer to **Figure 26-1**. Most HEVs on the road today use the electric drive system to assist the engine, especially during acceleration.

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Audi

Figure 26-1. Study the major assemblies of a modern hybrid drive system. An internal combustion engine and a powerful electric drive train are used to propel this vehicle.

Tech Tip

To identify a hybrid vehicle, look for badges on the front fenders, engine cover, trunk, or hood, or open the hood and look for orange HV power cables. See **Figure 26-2**. You can also compare the vehicle's VIN (vehicle identification number) to factory reference information. The 5th, 6th, and 7th characters in the VIN identify hybrid vehicles.

Hybrid Vehicle History

In 1898, Ferdinand Porsche, the founder of Porsche Motor Car Company, designed and built a car that used a small internal combustion engine to spin a direct current (dc) electric generator. The electric generator powered electric drive motors at each drive wheel. No mechanical link, clutch, transmission, or mechanical drive train was used. Huge power cables were used between the electric generator and the electric drive motors. This basic engine electric-driveline principle is used today in locomotives.

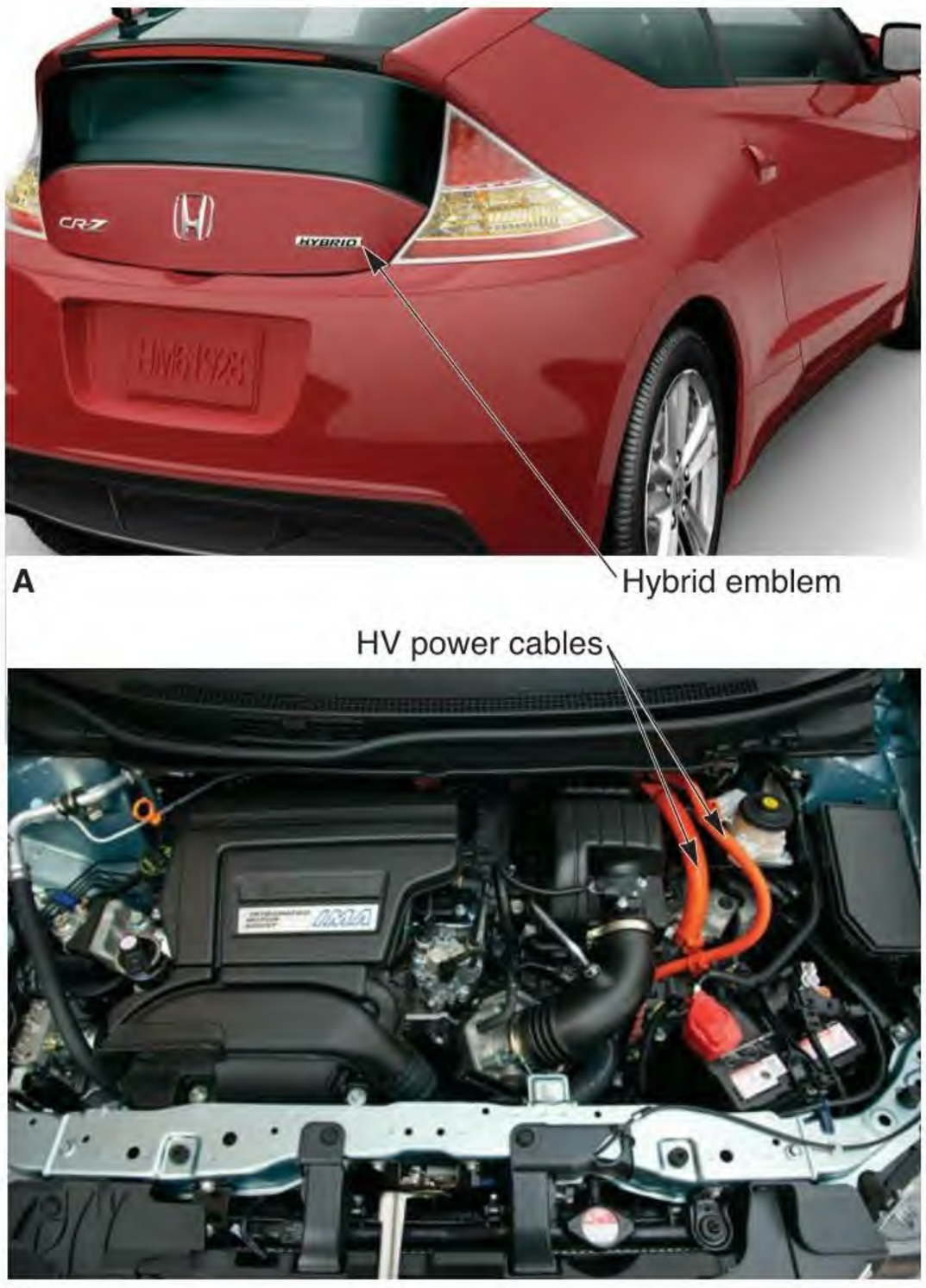
In 1966, the United States Congress passed a bill recommending the development of electric vehicles to reduce air pollution and our dependence on foreign oil. By the 1990s, automakers started perfecting hybrid drive systems to meet these demands.

Currently, all major automakers are building hybrid electric vehicles that are capable of operating on electricity only. When the HV battery is depleted, the gasoline or diesel engine "fires up" to provide propulsion energy and force. Full electric vehicles (no internal combustion engine) are only practical for short trips or city driving, since they require frequent recharging from a home wall outlet.

Tech Tip

In addition to hybrid electric vehicles, automakers are experimenting with fuel cell hybrids, hydraulic hybrids, and pneumatic hybrids.

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Honda

Figure 26-2. Identifying a hybrid vehicle. A—Emblems or badges on the hood, trunk, fenders, or engine. B—The orange cables under the hood denote a high-voltage drive train.

Hybrid Drive Construction

Advances in electric motor, battery, and power transistor technology have allowed automakers to build hybrid vehicles that accelerate as well as, or even better than, conventional gasoline-powered vehicles. Hybrids also greatly reduce the amount of fuel burned in both city and highway driving.

In an HEV, the internal combustion engine and electric drive system work in unison under computer control to propel the vehicle and operate its electrical accessory systems.

When most hybrids come to a stop, both the internal combustion engine and the high-voltage charging system are shut off. This increases fuel economy over cars that keep the engine running when not moving. Since little energy is needed to operate the dash electronics, climate control, and other electrical accessories, a small conventional 12-volt battery is sometimes still used to operate the electrical systems of the vehicle. However, the design of some hybrids replaces the 12-volt battery, conventional starting motor, crankshaft ring gear, and alternator with the electric drive system.

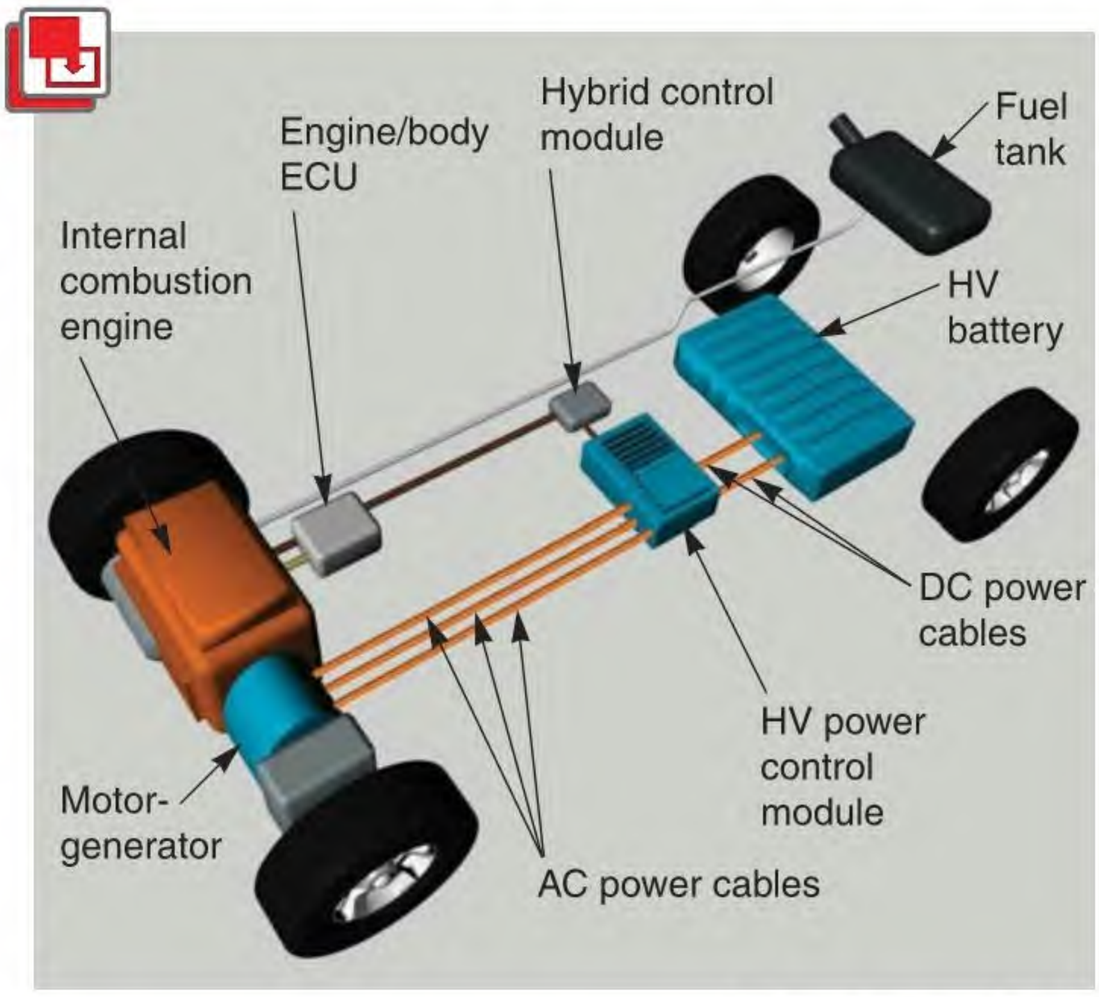
Today's hybrids also use their electric drive system to:

- Almost silently crank the engine over for starting. A conventional 12-volt starting motor and flywheel ring gear are not needed to rotate the engine crankshaft to force air and fuel into the combustion chambers.
- Step-down HV battery dc voltage to 12–15 volts dc to power the lights, instrumentation, and on-board computer circuits with the internal combustion engine running or not.
- Shut off the internal combustion engine when battery charging is not needed. When the vehicle is stopped, it is wasteful to keep an internal combustion engine running and idling. The power reserve of an HV battery is easily capable of powering the car's electrical accessories for hours without being depleted.
- A hybrid drive regenerative braking system helps prevent wear of conventional friction brake pads and brake rotors. The torque needed to spin the motor-generator during the generation of high voltage and current helps slow and stop the vehicle so there is less brake part wear.

There are six major assemblies (**Figure 26-3**) in a hybrid drive system:

- HV battery—An HV battery consists of a large number of voltaic cells wired in series to produce a high-voltage, high-power storage battery.
- Motor-generator—The motor-generator uses a brushless armature and multi-coil stator assembly to function as both an electric drive motor and a generator.
- HV power control module (HV PCM)—This high-voltage circuit controls current flow to the HV battery and motor-generator. It contains high-power transistors, rectifying diodes, large relays, and industrial contactors to change dc to ac or ac to dc while controlling output voltage, current, and frequency. The HV PCM can amplify voltage and current as needed for propulsion or lower voltage and current for HV battery recharging.
- Hybrid control module—This is a small electronic control circuit that monitors driving conditions, battery temperature, system voltages, and current

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Figure 26-3. Review the major parts of a hybrid electric vehicle. Can you explain the purpose of each hybrid assembly?

loads to help control the operation of the HV PCM, battery pack, and motor-generator.

- HV power cables—HV power cables are large insulated conductors that electrically connect the battery pack, HV PCM, and motor-generator together. Two cables extend from the HV battery and three cables extend out of the motor-generator.
- Internal combustion engine—The gasoline or diesel engine propels the vehicle during heavy acceleration and at cruising speeds, and spins the generator to recharge the HV battery and/or power the electric drive train.

Tech Tip

The hybrid motor-generator is sometimes referred to as a "dynamotor." The term *dynamotor* comes from the words *dynamo* and *motor*. The first dynamotor (integral electric generator and motor assembly) was built in the early 1900s.

With most HEVs, a conventional fuel tank, fuel lines, and electronic fuel injection system feed gasoline to an internal combustion engine. Both the motor-generator and the engine work together to provide a dependable and fuel efficient means of transportation.

Warning

Hybrid electric circuits and HV power cables carry dangerous voltage levels (up to 300 volts dc and 600 volts ac). Because of the extremely high voltage and current levels inside a hybrid, you must know how to work safely with very deadly levels of electricity. If you were to accidently grab the metal terminals of any HV power cable with your body grounded, you could be killed.

Types of Hybrid Vehicles

There are several types and classifications of hybrid drive systems. For example, hybrids can be classified by the drive train configuration and by when the vehicle employs the internal combustion system. The following sections outline various hybrid classifications. You should understand their differences and similarities.

Full and Mild Hybrids

A ***full hybrid*** uses a motor-generator to initially accelerate and propel the vehicle. The internal combustion engine runs only when the battery pack becomes discharged, or during heavy acceleration. Full hybrids can accelerate normally (not full throttle) without consuming any fuel or emitting any exhaust emissions.

A full hybrid is propelled by the motor-generator until the HV battery has about a 30% charge remaining. Then, the hybrid control module "fires up" the internal combustion engine to simultaneously propel the vehicle and recharge the battery pack.

A ***mild hybrid***, or ***assist hybrid***, is propelled by its internal combustion engine only. This type of hybrid shuts down its internal combustion engine when the vehicle is coasting, braking, or stopped, and uses an HV starter-alternator to quickly restart the engine when the brake pedal is released. The HV starter-alternator functions as an electrical generator when the engine is running.

Most first-generation mild hybrids have a 36- or 42-volt electrical system that powers electric motors to drive accessory items, such as the power steering pump or the air conditioning compressor. In this way, these components continue to work even when the internal combustion engine is shut down.

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Tech Tip

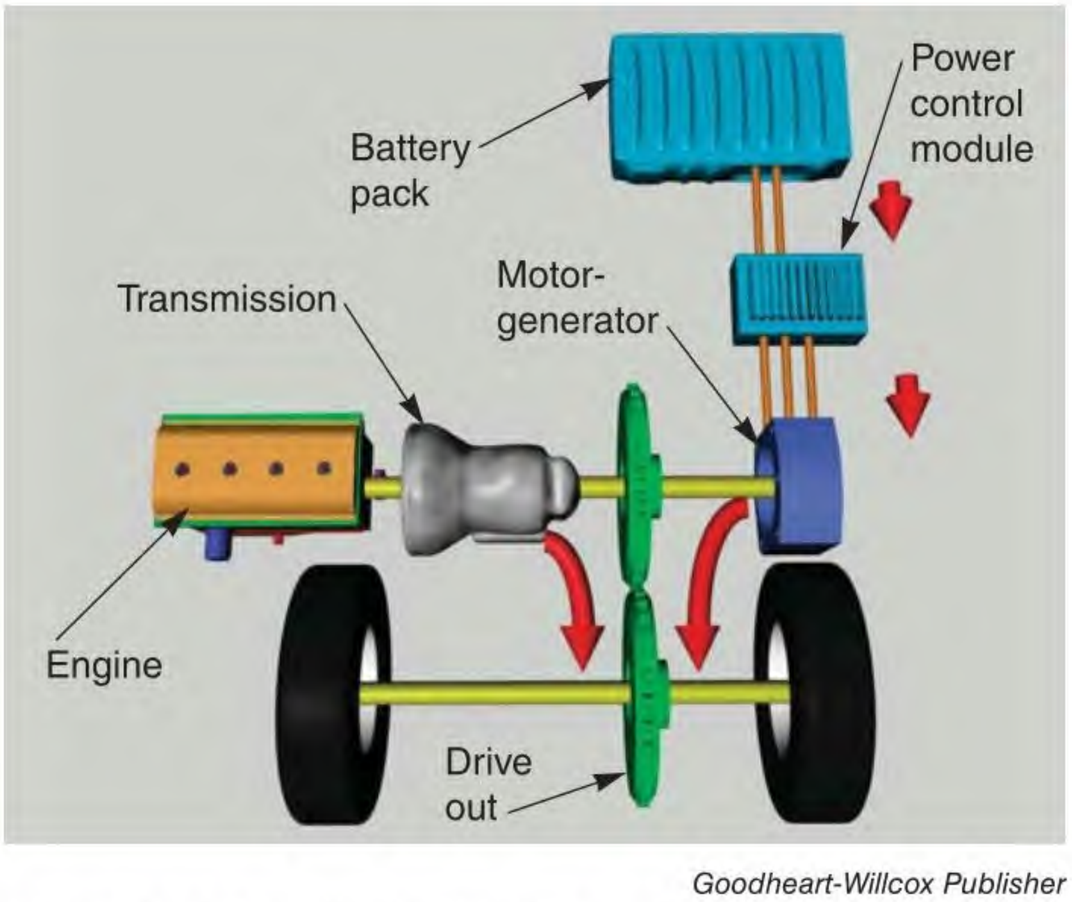
Some late-model mild hybrids use a 115-volt system, allowing the use of a larger starter-alternator that can assist the internal combustion engine in propelling the vehicle from a standstill. This improves fuel economy slightly, but not as much as a full hybrid drive train.

Series Hybrid

In a ***series hybrid*** configuration, an electric motor is the only method used to apply torque to the vehicle's drive train. See **Figure 26-4**. The internal combustion engine has no mechanical connection to the drive train. The series hybrid can operate in the all-electric mode when the battery pack charge is sufficient to propel the vehicle. When the battery pack becomes drained, the internal combustion engine starts and turns a generator to recharge the battery pack.

Parallel Hybrid

A ***parallel hybrid,*** **Figure 26-5**, uses both an internal engine and a motor-generator to apply mechanical torque to the drive train. The engine and motor-generator operate in parallel, or at the same time. During rapid acceleration, both the internal combustion engine and the motor-generator apply torque to the drive train. At low speeds, a parallel hybrid can operate in full-electric mode, with the engine completely shut down.



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Figure 26-5. Parallel hybrid drive configuration.

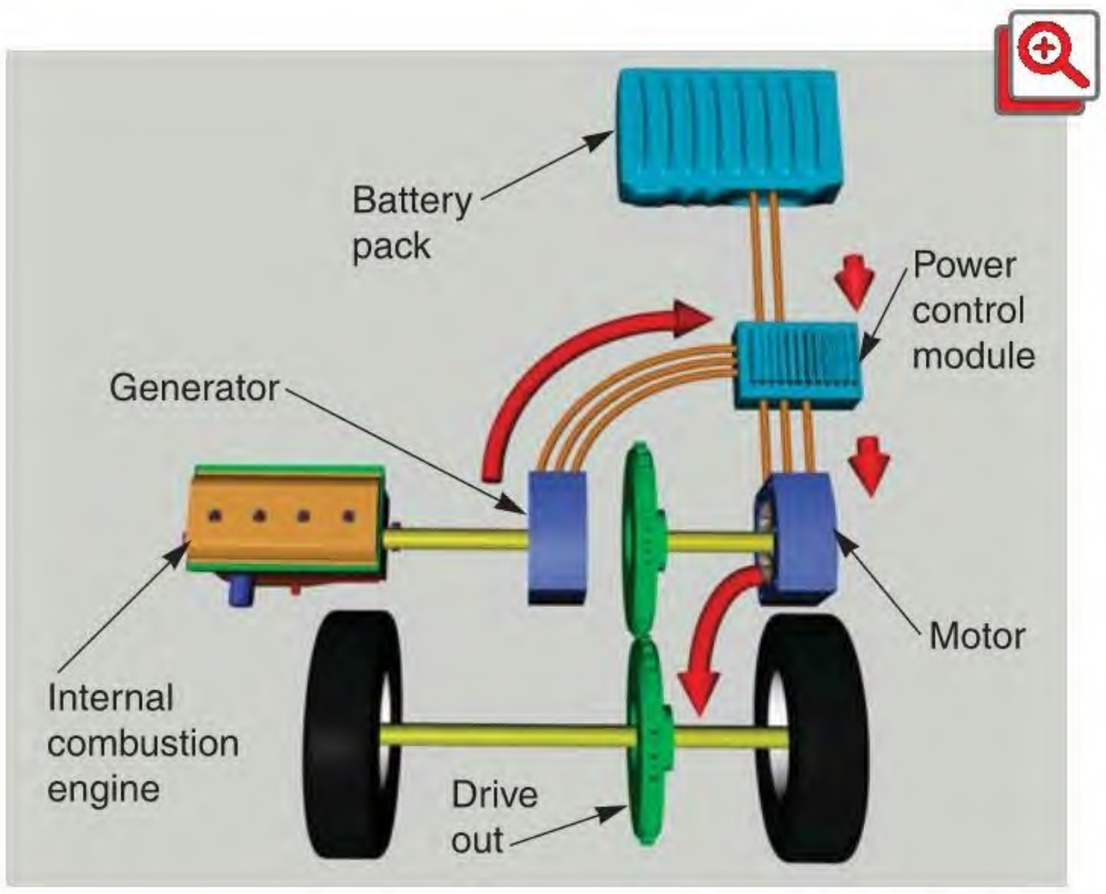
A parallel hybrid provides the advantages of a full-electric vehicle in city driving, but can perform like a conventional vehicle under full acceleration or at highway speeds. The drawback to the parallel hybrid is that the motor-generator cannot drive the vehicle and recharge the battery pack at the same time. This limits the amount of time the vehicle can be driven by the motor-generator.

Series-Parallel Hybrid

The ***series-parallel hybrid*** combines the advantages of a parallel hybrid with those of a series hybrid. Refer to **Figure 26-6**. A series-parallel hybrid can recharge the battery pack even when the electric motor is in use to drive the vehicle. The internal combustion engine can drive the wheels, but it can also be disconnected from the drive train so only the electric drive motor propels the vehicle. The engine can also power the motor-generator, which acts as a generator to recharge the HV battery.

Plug-In Hybrid Electric Vehicles (PHEVs)

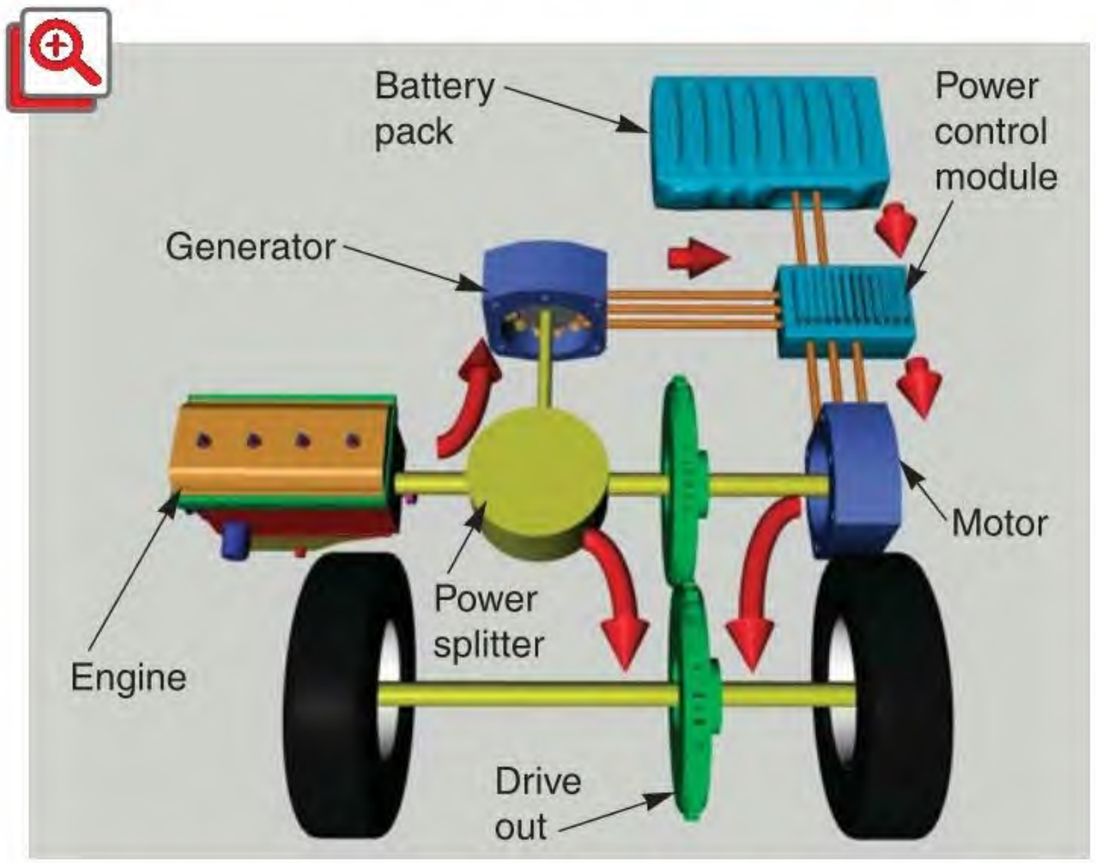
A ***plug-in hybrid electric vehicle (PHEV)*** is designed so the battery pack can be fully recharged when the vehicle is not being driven. A charging station or high-voltage charger that plugs into a home



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Figure 26-4. Series hybrid drive configuration.

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Figure 26-6. Series-parallel hybrid drive configuration.

or garage wall outlet (120 volts ac or 240 volts ac) is used to re-energize the battery. See **Figure 26-7**. New PHEVs can travel 30–40 miles before the gas or diesel engine ever runs. When the engine is running, the electric drive system recharges the HV battery. This prevents the vehicle from ever being stranded without power.

Full-Electric Vehicles

A ***full-electric vehicle*** only has an electric propulsion system and no method of recharging the HV battery when driving. Full-electric vehicles are only practical for city driving. Their driving range, or distance between recharges, is limited to less than 100 miles (160.93 km).

Flywheel Generator Hybrids

An ***HV flywheel generator***, or ***kinetic energy generator***, uses a large, heavy flywheel rotor spinning around a series of electromagnets to store large amounts of electrical energy. After years of development, the flywheel generator is being raced very successfully on international road race courses. A hybrid race car equipped with an HV flywheel generator is shown in **Figure 26-8**.

In this hybrid design, the rear wheels are powered by a gas-burning, six-cylinder, turbocharged engine with direct fuel injection. The front-drive wheels are powered only by the motor-generators. When braking, the motor-generators act as electric generators to help slow the car, and also send electrical energy to the flywheel motor. In a few seconds of ac current flow, the flywheel spins up to around 40,000 rpm, storing a huge amount of kinetic or spinning energy.

When coming out of a turn, the driver can press a small button on the steering wheel for electric boost power to the front wheels. The HV PCM then feeds high levels of electrical energy to the two motor-generators. With over 300 horsepower (223 kW) motor-generators, the car accelerates like a four-wheel drive vehicle, with almost 1000 total horsepower (746 kW). Flywheel generators for passenger vehicles are in development.



General Motors Corp.

Figure 26-7. This PHEV is charging at a solar-powered charging station.

Hybrid Vehicle Operation

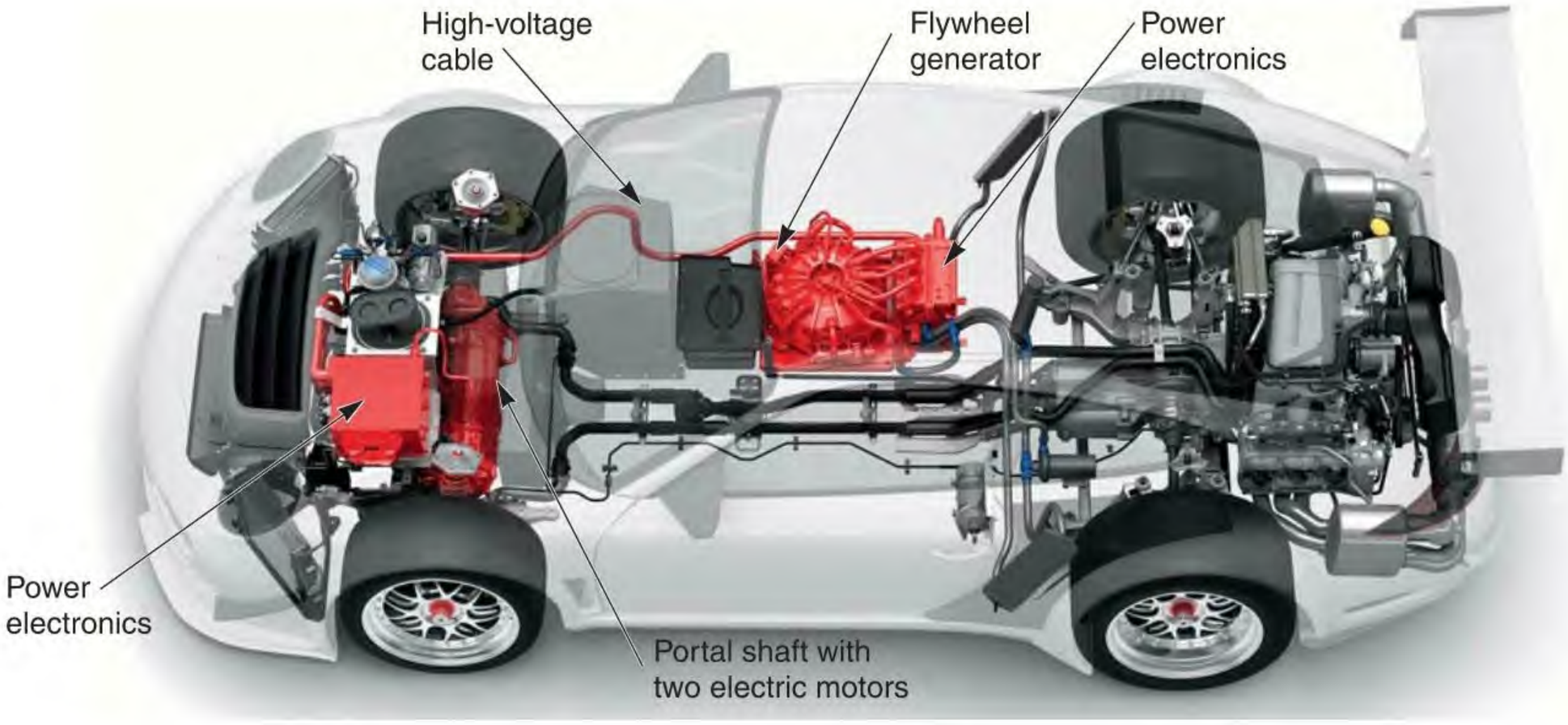
A typical series-parallel hybrid drive system has six basic modes of operation (**Figure 26-9**):

- All-electric drive mode.
- Motor-assist mode.
- Idle stop mode.
- Regenerative braking mode.
- Engine starting mode.
- HV battery recharging mode.

All-Electric Drive Mode

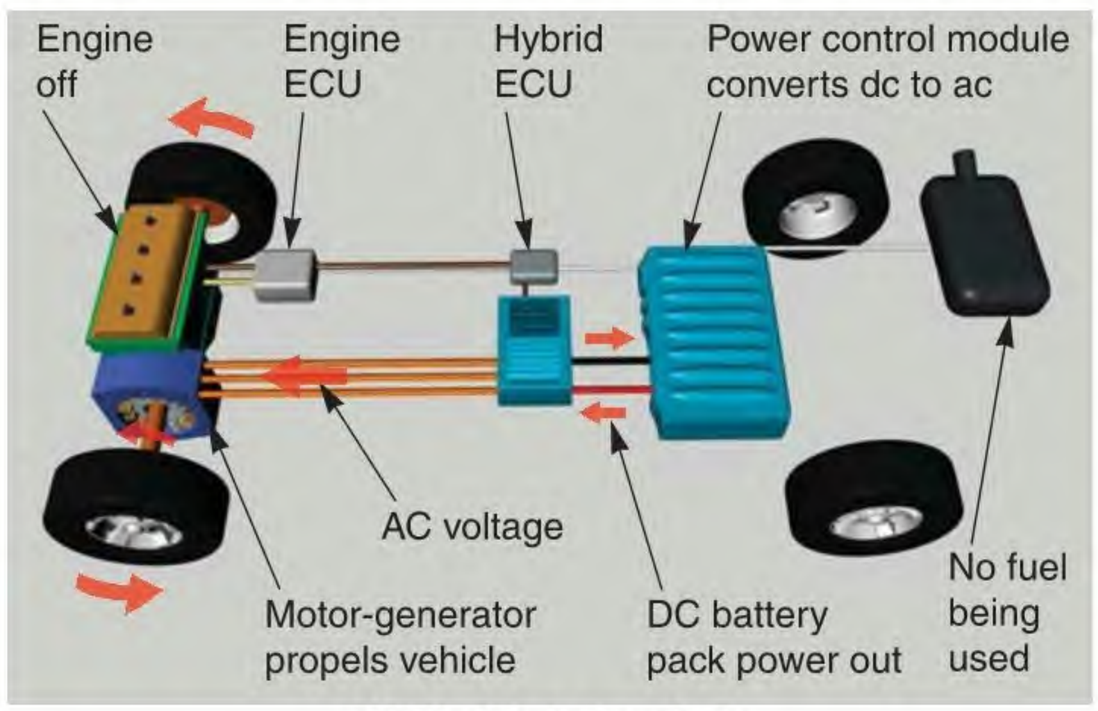
In all-electric drive mode, the hybrid vehicle operates just like an all-electric car. The battery pack provides all the energy needed for city driving, sometimes up to 50 miles. The internal combustion engine is shut off, but is ready to start up when the battery

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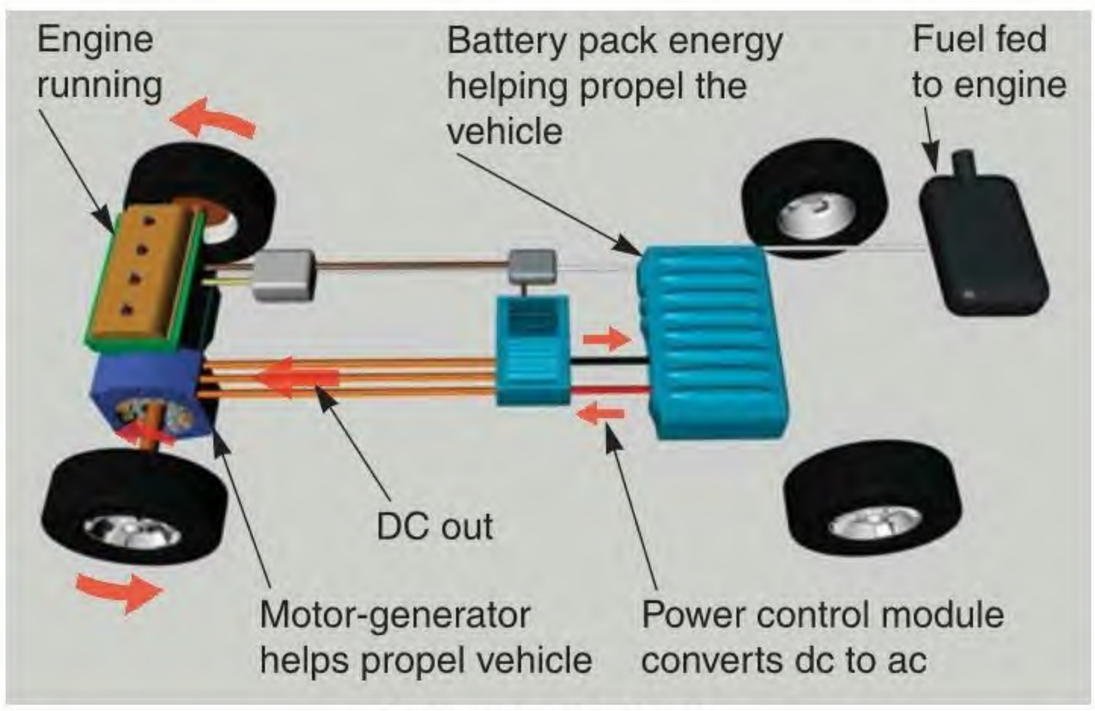


Porsche

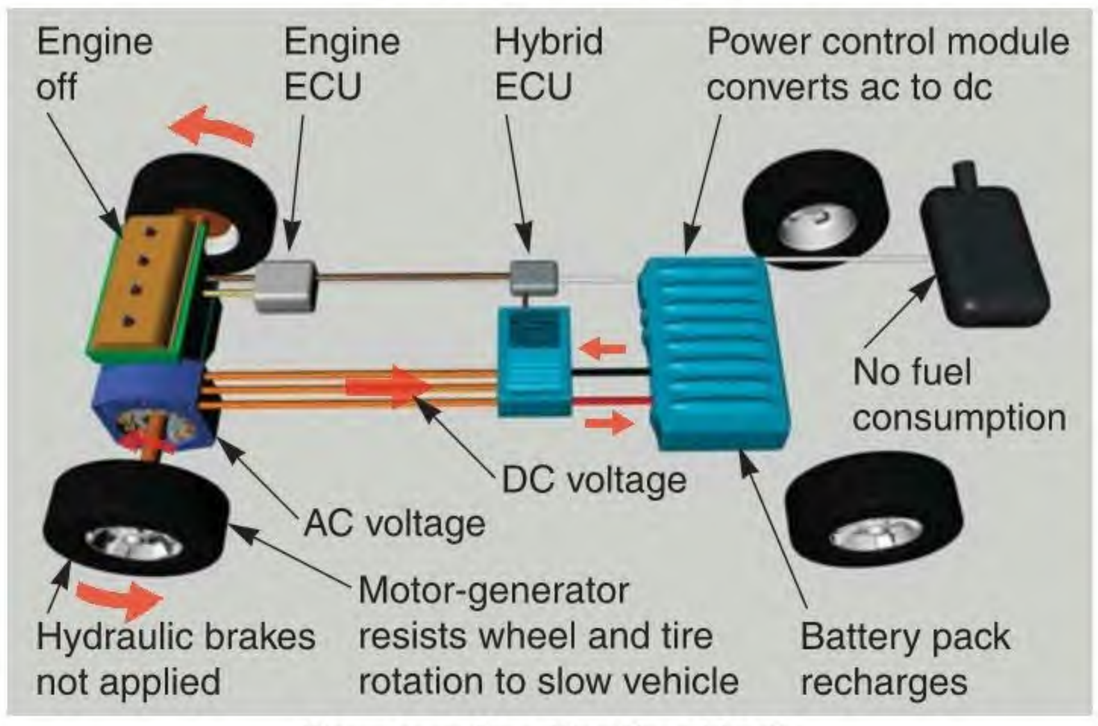
Figure 26-8. The basic layout of an HV flywheel generator hybrid car. The flywheel captures free energy when braking and uses the same energy to help the gas engine in the rear.



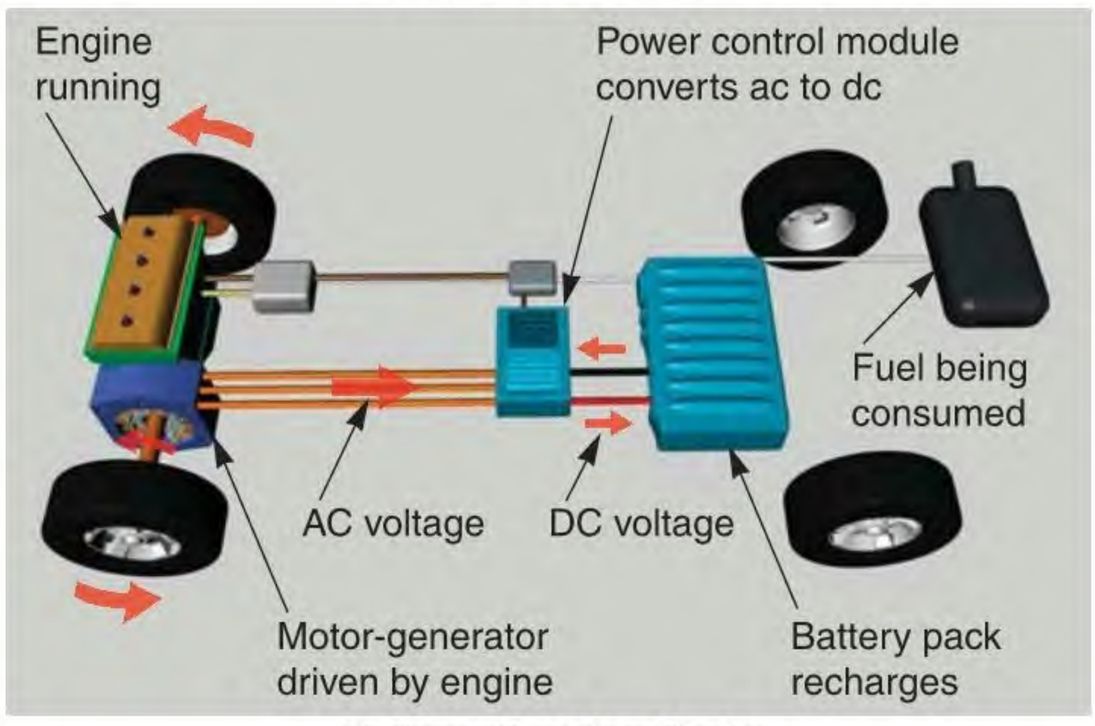
All-Electric Drive Mode



Motor-Assist Mode



Regenerative Braking Mode



Battery Charging Mode

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Figure 26-9. Study the basic modes of hybrid operation carefully. Note the flow of both alternating current and direct current through the components.

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pack becomes discharged or when more power is needed to help propel the vehicle.

Many hybrid vehicles stay in the all-electric mode when accelerating up to 20–40 mph. If the driver accelerates normally, the electric drive system will propel the vehicle up to city speed limits without starting the internal combustion engine. An internal combustion engine is least efficient when operating at very low rpm.

When backing up, most hybrids operate in all-electric mode—the internal combustion engine remains off. When a hybrid runs on electrical energy only, it does not burn fuel or emit hydrocarbons.

Motor-Assist Mode

In the hybrid motor-assist mode, both the motor-generator and the internal combustion engine apply torque to the drive train for propulsion. Some hybrid systems start out using only the motor-generator during acceleration and operate in the motor-assist mode at cruising speeds. Other systems use both the motor-generator and the internal combustion engine during acceleration and while cruising. Motor-assist allows an HEV to accelerate just as quickly as a conventional vehicle.

Idle Stop Mode

In idle stop mode, the system automatically shuts off the internal combustion engine when the vehicle comes to a full stop, and restarts the engine when the vehicle reaches a predetermined speed (about 20–40 mph) or when the HV battery is partially discharged. This conserves energy and reduces exhaust emissions during idle and at other times when the engine is not needed.

Regenerative Braking Mode

Regenerative braking is an electric braking system that works in conjunction with the conventional hydraulic brakes. During regenerative braking mode, the motor-generator serves as an electrical generator—sending high voltage and current through the HV power cables, to the HV PCM, and into the HV battery.

When the brakes are applied, a brake pedal sensor sends a signal to the hybrid control module, prompting the motor-generator to function as a high-current generator. With moderate brake pedal pressure, the conventional hydraulic brakes do not apply the friction pads into the spinning brake discs. Instead, the motor-generator's armature becomes more difficult to rotate. The large armature places a drag on the driveline, wheels, and tires, slowing the vehicle.

When the brake pedal sensor is depressed more for faster stops, the computer system applies the conventional hydraulic brakes and the "electric brakes" (motor-generator) to stop the vehicle. If the vehicle is slowed carefully, almost all the kinetic energy of the moving vehicle is recaptured as electrical energy and forced into the HV battery. The HV battery stores this energy and sends it to the motor during acceleration.

Light braking may feel different in a hybrid vehicle since the motor-generator drag slows the vehicle without applying hydraulic friction brakes.



Tech Tip

In some hybrid systems, the crankshaft of the internal combustion engine is disconnected from the driveline during regenerative braking. This prevents engine compression from slowing the vehicle without recapturing energy.

Engine Starting Mode

In the hybrid engine starting mode, the motor-generator spins the engine crankshaft to start the internal combustion engine. The engine then runs to propel the vehicle at cruising speeds, or to drive the motor-generator when the battery pack becomes partially discharged.

The hybrid ECU energizes transmission solenoids that apply and release clutches in the transmission so the engine crankshaft and motor-generator are locked and turn together. The power control module then sends just enough current to the motor-generator to spin the engine crankshaft at about 300 rpm.

The hybrid ECU also signals the engine ECU to provide "spark and fuel" to the engine. The engine ECU electrically energizes the engine's fuel pumps, electronic fuel injectors, and ignition coils while the motor-generator spins the crankshaft until the engine "fires" and runs on its own power.

Battery Charging Mode

After driving several miles in all-electric mode, the HV battery becomes partially discharged. When the hybrid control module detects the lower voltage (about 70% discharge), it starts the internal combustion engine to propel the vehicle and recharge the HV battery. The

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engine crankshaft spins the motor-generator, which in turn sends electricity to the HV PCM and HV battery.

Hybrid Drive Assemblies

The following sections detail the construction and operation of various hybrid drive assemblies used in series, parallel, and series-parallel hybrid vehicles.

HV Battery

The ***HV battery*** sends high-voltage dc into the HV PCM through the HV power cables. The HV PCM converts this dc to ac, and usually steps the voltage up or down as needed by system circuits. HV battery dc can be converted into three-phase ac to operate the motor-generator. The HV battery and motor-generator can easily propel the vehicle or start the internal combustion engine, as needed.

An HV battery contains several high-efficiency lithium-ion battery modules stacked in a sealed enclosure. The lithium-ion modules are wired in series to produce a very high-voltage power source. Depending on the vehicle make and model, battery voltage can range from about 150 volts dc up to 400 volts dc for newer models.

The HV battery is normally mounted in the rear of the chassis, often behind or under the rear seat or in the trunk area. See **Figure 26-10**. An ***HV battery cover*** encloses the modules and protects them from damage. It also protects people from electric shock. HV battery covers are often held on with machine screws. A few hybrids have the HV PCM and HV battery housed together.



Toyota

Figure 26-10. The HV battery is in the lower trunk area of the vehicle. Note the large orange power cables that connect the HV battery to the HV PCM up near the engine.

Tech Tip

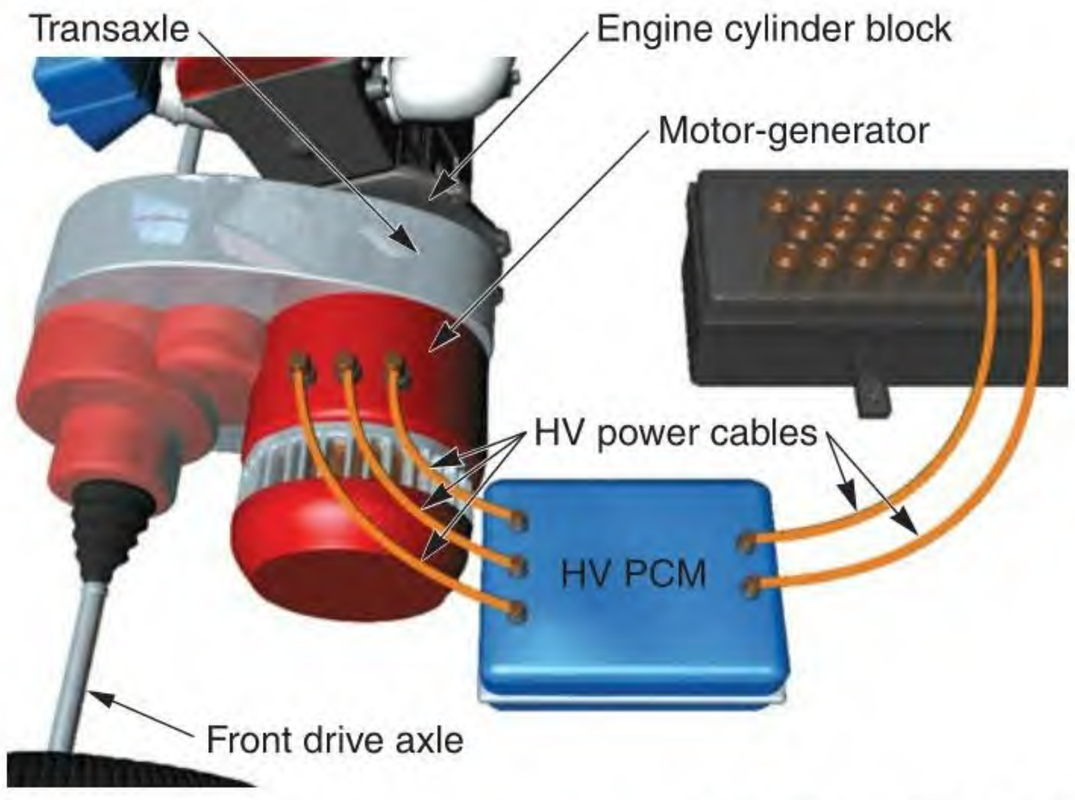
HV battery construction, operation, and service are covered in detail later in this textbook. Refer to the index for specific pages.

Motor-Generator

A motor-generator functions as both a traction motor and as an alternator (ac generator) in the vehicle's power train. The motor-generator has several functions:

- It helps power the drive train and propel the vehicle.
- It recharges the HV battery.
- It cranks the internal combustion engine.
- It helps slow and stop the vehicle.

The motor-generator can be attached directly to rear of the engine, on one side of the transaxle, inside the transmission, or inside the rear axle housing. Look at **Figure 26-11**.



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Figure 26-11. The figure shows the HV battery, the HV PCM, and the motor-generator, which is mounted on the side of the transaxle in this arrangement.

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The basic parts of a motor-generator include the armature, stator, and housing. The basic components of a simplified motor-generator are illustrated in **Figure 26-12**.

The ***armature*** consists of a set of permanent magnets mounted inside a segmented steel or carbon fiber disc. Each magnet is spaced and positioned in the armature so its pole is near the outer edge of the armature. This allows the flux, or field, of each magnet to react with the flux produced by the stator's electromagnets.

Depending on hybrid design, the armature can be mounted on roller bearings or on the engine crankshaft flange, which keeps it from rubbing on the stator coils. In some designs, the motor-generator may also be splined to the transmission input shaft.

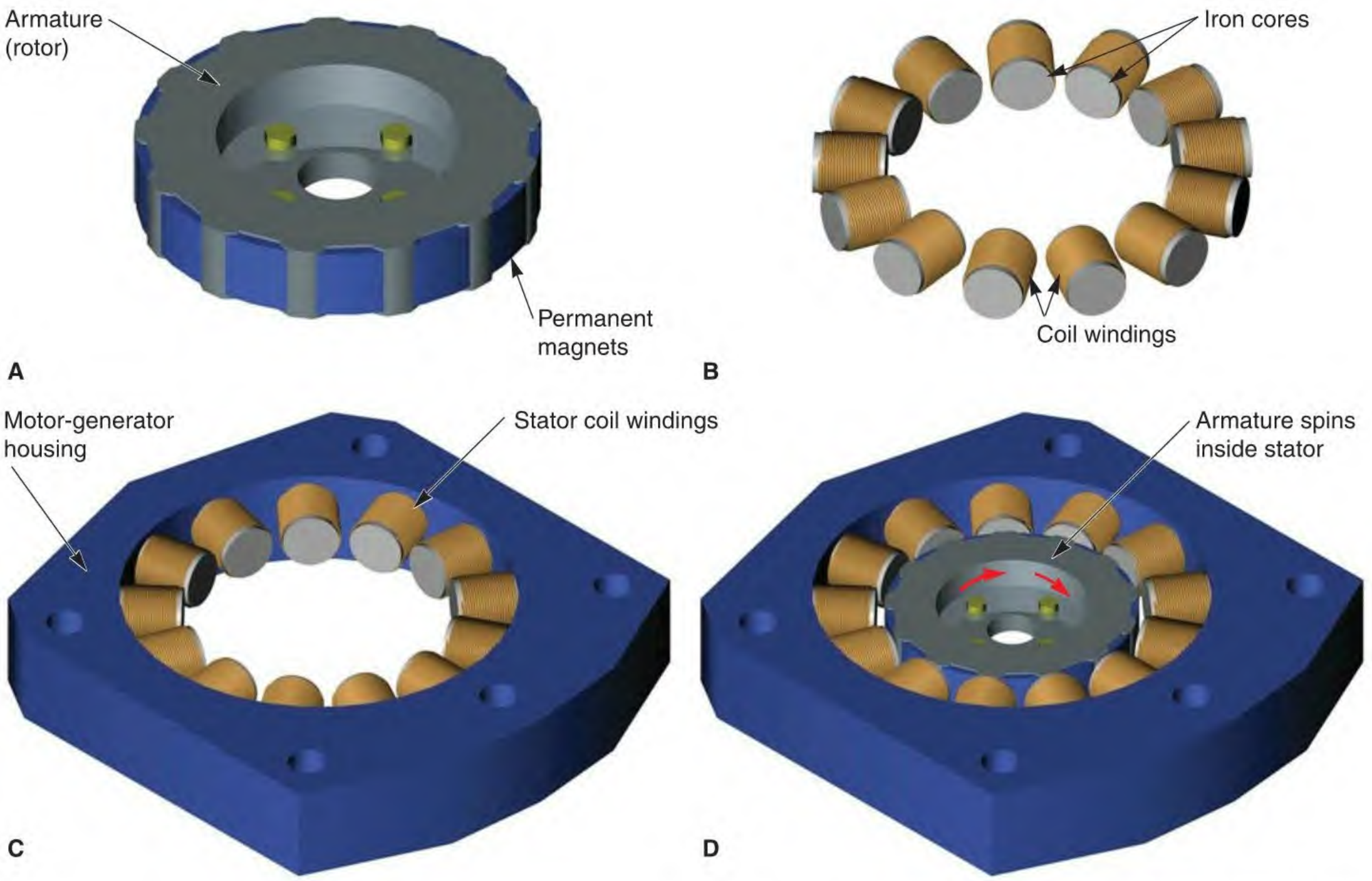
The ***stator*** is a set of stationary coil windings wrapped around iron cores and arranged around the armature. Each stator coil winding is positioned and spaced to match the placement of the armature's permanent magnets.

The housing holds the stator assembly and sometimes the armature in place. It also fastens the motor-generator to the rear of the engine, inside the transmission/transaxle, or in the rear drive axle assembly.

When the motor-generator is assembled, the armature magnets are very close to the stator coil windings. When the armature is rotated by engine power, the magnetic fields produced by the armature magnets cut across the stator winding coils. This induces current and voltage in all the stator coils, generating high-voltage electricity.

Motor-Generator as an HV Motor

When the motor-generator serves as an ***HV motor*** to propel the vehicle, three-phase voltage is applied to the stator windings by the HV PCM. Large amounts of direct current from the two HV power cables are converted into



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Figure 26-12. A simplified drawing of a hybrid motor-generator assembly. A—The armature is a steel or carbon fiber ring with permanent iron magnets imbedded in its outer diameter. B—The stator consists of several sets of coil windings wrapped around iron cores. C—The motor-generator housing holds the stator coils stationary and in perfect alignment. D—The assembly can function as a high-torque motor or a high-wattage ac generator.

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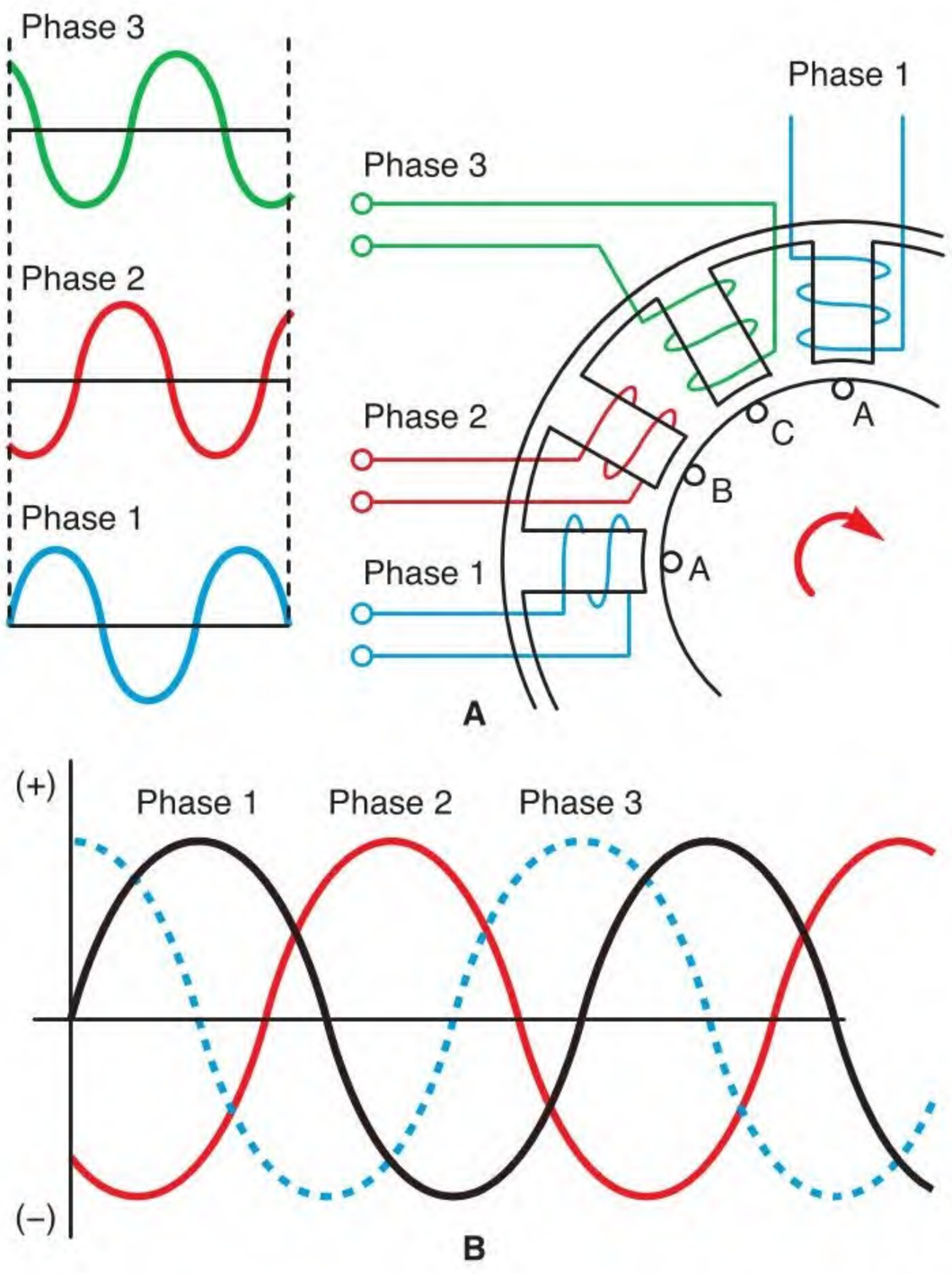
adjustable three-phase ac, flowing out through the three HV power cables going to the motor-generator.

Three-phase ac power consists of three single-phase alternating voltage waves flowing through three conductors at different intervals in time. The positive slope of the first ac sine wave leads the other two ac sine waves by 120° and 240° respectively. This provides 360° rotation of the permanent magnet motor armature as it follows the three voltage waves spaced into three phases of applied ac voltage.

Since the permanent magnets are spaced around the armature in three positions, each ac voltage wave acts on its set of magnets to push and pull the armature for shaft power output. See **Figure 26-13**. The permanent magnets are magnetically attracted and repulsed by the positive and negative voltage waves as they move around the stator coil windings. A north-facing magnet in the armature would be attracted by a south (or negative) wave moving past it. The south-facing waves would attract the armature magnets with their north end exposed to its corresponding stator electromagnet.

To efficiently control a motor-generator, the HV PCM can vary ac frequency, voltage, and resulting current to increase or decrease ***motor torque*** and ***motor speed***. Upon initial acceleration, the HV PCM would feed three-phase ac with a very low "motor start" frequency and moderate voltage to ramp up the motor armature quietly (less motor hum). As vehicle speed and armature speed increase, the HV PCM can increase output voltage, current, and frequency to strengthen the magnetic fields in the stator. The increased voltage and resulting current flow though the stator electromagnets form a stronger electromagnetic field to increase traction motor torque and speed. This progressively stronger stator field strength and increased frequency accelerates the armature and drive train up to an efficient operating rpm.

The HV PCM monitors motor load (current draw), resistance (inductance), and speed (rpm) to maintain an optimum frequency and voltage applied to the stator windings for maximum motor efficiency.



Toyota

Figure 26-13. Three-phase ac flows through the three power cables that run between the motor-generator and the HV power control module. A—Three-phase ac is used to spin the armature in this motor-generator. Phase 1 current attracts armature pole A. Phase 2 attracts armature pole B. Phase 3 attracts armature pole C. B—Three-phase alternating current is simply three single ac phases timed 120° apart. The voltage waves (shown as voltage waveforms) generate magnetic fields that circle inside the motor-generator to make the armature spin.

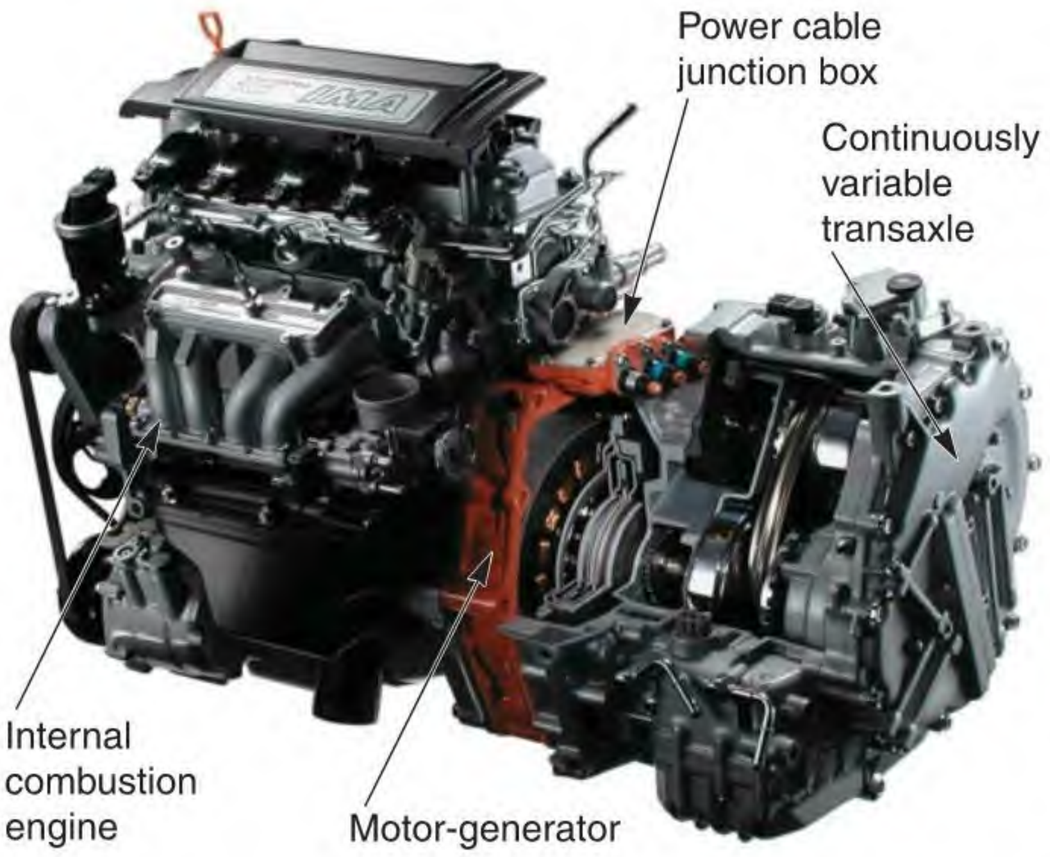
Motor-Generator as an HV Generator

The motor-generator acts as an ac generator (alternator) during regenerative braking and when being driven by the internal combustion engine or transmission. The internal combustion engine or drive train spins the motor-generator's armature to generate high-voltage electricity. The armature's magnetic fields cut through the coil windings in the stationary stator windings. This induces high alternating current in the stator windings, so high current levels are generated at the three power cables going to the HV PCM.

Single Motor-Generator Hybrids

A single motor-generator hybrid uses only one large motor-generator to assist the internal combustion engine. This is a compact design with the motor-generator assembly bolted to the rear of the engine block, in front of the transaxle or transmission. The motor-generator armature is connected to an engine crankshaft and to the transmission input shaft. As shown in **Figure 26-14**, the single motor-generator is the least complex type of hybrid drive train.

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Honda

Figure 26-14. In this parallel hybrid arrangement, the single motor-generator is located between the engine block and transaxle. The motor-generator can assist the internal combustion engine to propel the vehicle or to crank and restart the engine. The motor-generator can also serve as a generator to recharge the HV battery.

Dual Motor-Generator Hybrids

A dual motor-generator hybrid uses two separate motor-generators to provide assist. The two motor-generators are usually located inside the transmission or transaxle. A cutaway view of a rear-wheel drive transmission with two motor-generators is shown in **Figure 26-15**.

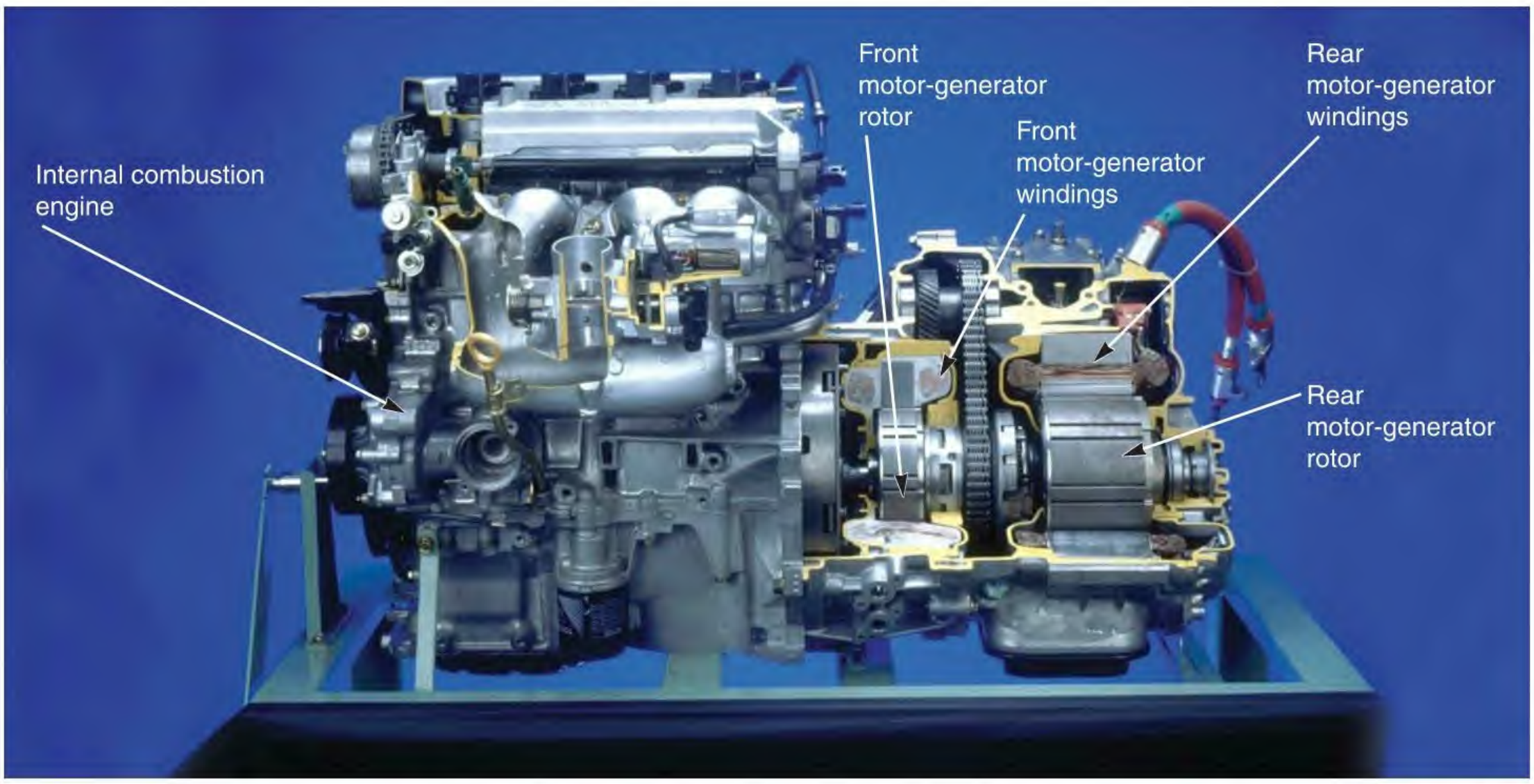
During regenerative braking, both motor-generators act as generators to recharge the battery pack and help drag the drive train to a stop. Both motor-generators act as motors to help propel the vehicle.

Triple Motor-Generator Hybrids

In some cases, three motor-generators are used in a hybrid vehicle, **Figure 26-16**. Two motor-generators are located in the transmission or transaxle, and one is located in the rear drive axle assembly. A triple, or even quad (four), motor-generator arrangement is often used in large four-wheel drive vehicles to help electrically drive all four wheels.

Power Splitter

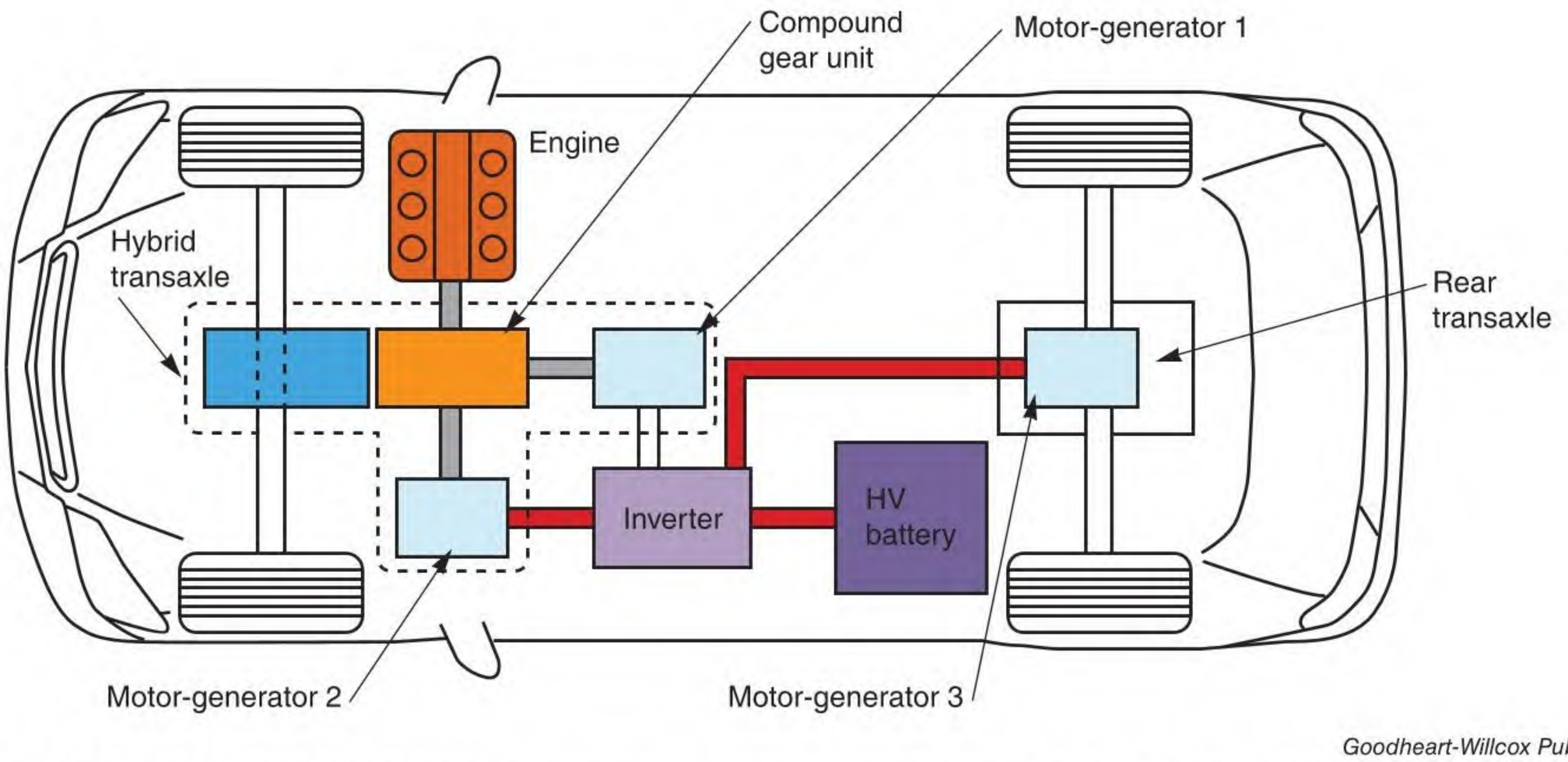
A hybrid ***power splitter*** is a planetary gearset used to control the transfer of power through the hybrid drive train. The hybrid power splitter and transaxle are under computer control.



Toyota

Figure 26-15. In this series/parallel hybrid configuration, the transaxle contains two motor-generators. To improve fuel economy, the internal combustion engine shuts off when braking, when stopped, and when initially accelerating.

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Figure 26-16. This all-wheel drive hybrid drive train uses two motor-generators in the transaxle and a third motor-generator in the rear drive axle assembly.

When the driver moves the gearshift selector in the passenger compartment, an electric signal is sent from the shift lever position sensor to the hybrid control module. The hybrid control module then energizes or shuts off specific solenoids in the transaxle. The solenoids can apply or release friction bands or clutches to hold or release members of the power splitter. By holding or releasing different parts of the power splitter, the solenoids control the planetary gearset(s) and the flow of torque from both the internal combustion engine and the electric drive system. When a motor-generator is operating as a generator, the splitter can transfer driveline torque into the motor-generator armature during braking or coasting.

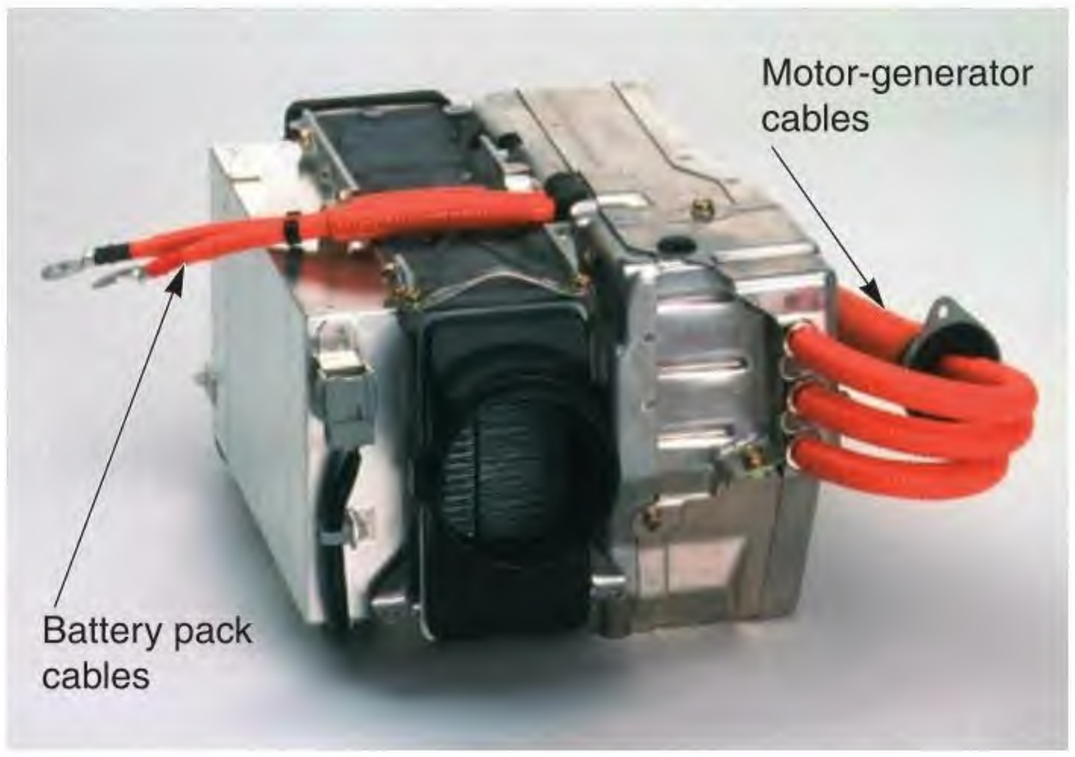
HV Power Control Module

The HV power control module (HV PCM) consists of a set of electronic/electric circuits that feeds voltage (ac and dc) between the HV battery and the motor-generator. See **Figure 26-17**. It controls the amount of ac or dc (0 to 200 amps) that flows through the high-voltage power cables. The HV PCM also controls the speed and torque of the motor-generator by varying ac frequency and ac phase shift.

The HV PCM may be located next to the HV battery, on the transaxle, or on top of the engine. The HV PCM normally contains a converter circuit and an inverter circuit.

The ***converter circuit*** in the HV PCM can step dc voltage up or down. It does not change ac to dc or dc to ac. Hybrid battery pack voltage must usually be stepped up to efficiently drive the inverter circuit and the motor-generator. Battery pack voltage must be stepped down to operate the vehicle's 12-volt or low-voltage circuits.

An ***inverter circuit*** in the HV PCM changes dc to ac and ac to dc. When high-voltage dc is fed into the inverter circuit from the HV battery for electric propulsion, the inverter circuit changes it to high-voltage three-phase ac to run the motor-generator. When



Honda

Figure 26-17. Most hybrid HV power control modules have two orange cables that connect to the HV battery and three large orange cables that connect to the motor-generator.

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three-phase ac is fed into the inverter circuit from the motor-generator, the ac is changed back into high-voltage dc for recharging the battery pack.

Tech Tip

The HV battery, motor-generator, and HV PCM carry tremendous amounts of electrical energy and can become hot from the high current flowing through them. To prevent premature part failure, some provision must be made to carry this heat away from these components. Hybrid cooling system operation and service will be discussed in later chapters.

Hybrid Control Module

The ***hybrid control module*** controls the inverter and converter circuits to efficiently operate the motor-generator(s). The hybrid control module responds to control signals from other vehicle control modules.

The hybrid control module controls the HV PCM to keep the HV battery operating at the optimum temperature and state of charge. It helps utilize power efficiently and properly recharge the HV battery when partially drained by activating the regenerative braking system or generator function of the motor-generator. By keeping the HV battery at optimum charge and temperature, the hybrid control module increases battery service life and fuel economy.

When the accelerator of a hybrid is depressed, a pedal position sensor sends a signal to the hybrid control module. The hybrid control module determines whether to drive in the all-electric mode, start the engine (HV battery partially drained), or use a combination of an internal combustion engine and electric drive based on information in its memory and from sensors.

Hybrid Rotor Sensor

A hybrid ***rotor sensor*** measures armature speed and position to control ac phase shift, which controls motor torque and speed. A rotor on the motor-generator's armature spins inside three sensing coils. The motor-generator sensor produces ac signals that are processed by the HV PCM. Based on the frequency of the rotor sensor signals, the HV PCM can advance or retard the three-phase ac going to the motor-generator electromagnets for efficient traction motor operation and propulsion.

The center sleeve of the motor-generator sensor is splined to the rotor or armature shaft so they rotate together. A steel snap ring often holds the sensor on the motor-generator rotor shaft.

HV Power Cables

HV power cables transfer extremely high voltage and current levels to the components of the electric drive system. The power cables are heavily insulated to prevent these voltages from shorting to ground.

Two large HV power cables connect the battery pack to the HV PCM. Three more large power cables connect the HV PCM to the motor-generator. These three cables are normally routed under the floor pan on the inside of a rocker panel. All the HV power cables have orange insulation to warn technicians of their danger. Look at **Figure 26-1** and **Figure 26-2**.

When a hybrid uses several motor-generators, three HV power cables must be wired to each. For example, if the hybrid has two motor-generators, six HV power cables must be fed to the motors. Two dc power cables must carry current from the HV battery to the HV PCM for a total of eight high-voltage cables connected to the HV PCM.

Hybrid Ground Fault Interrupter

A hybrid ground fault interrupter constantly monitors the system for high-voltage leakage into the metal chassis of the vehicle. If high voltage from the HV battery or motor-generator is shorting to ground, the HV PCM will illuminate a warning light and de-energize the main power relays (contactors) to disconnect the HV battery from its drive circuit.

The main power relays will also open to disconnect the battery during air bag deployment. If the vehicle is in a collision serious enough to trigger an impact sensor, the vehicle control modules will cut power to the HV battery contactors so power cannot enter the HV PCM and other components in the high-voltage system. HV battery contactors are very large, electromagnetic relays with mechanical contact points to close or open the HV battery circuit to the HV PCM.

Impact Sensors

Impact sensors, or inertia switches, open during a severe impact to open the high-voltage circuits, disable the electric fuel pumps for the internal combustion engine, and deploy the air bags. If the air bags have deployed, you must follow manufacturer instructions to replace the air bags and re-energize the electric drive system.

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Hybrid Dash Display

A ***combination meter*** in the dash of a hybrid displays many variables pertaining to the performance and condition of the internal combustion engine and electric drive system. The combination meter contains the speedometer, odometer, fuel gauge, engine gauges, hybrid power display, and the hybrid drive ready light, as well as several warning lights. One design is shown in **Figure 26-18**.

A ***hybrid drive ready light*** often blinks when you press the brake pedal and turn the ignition key to the *Start* position with the gear selector in *Park*. When the electric drive is engaged, the ready light glows continuously to let you know the vehicle is ready to be driven.

A ***hybrid master warning light*** in the combination meter warns if there is a problem in any part of the drive train. If the hybrid ECM detects any abnormal condition in the electric drive circuitry or related components, it will illuminate the master warning light to notify the driver that something is wrong.

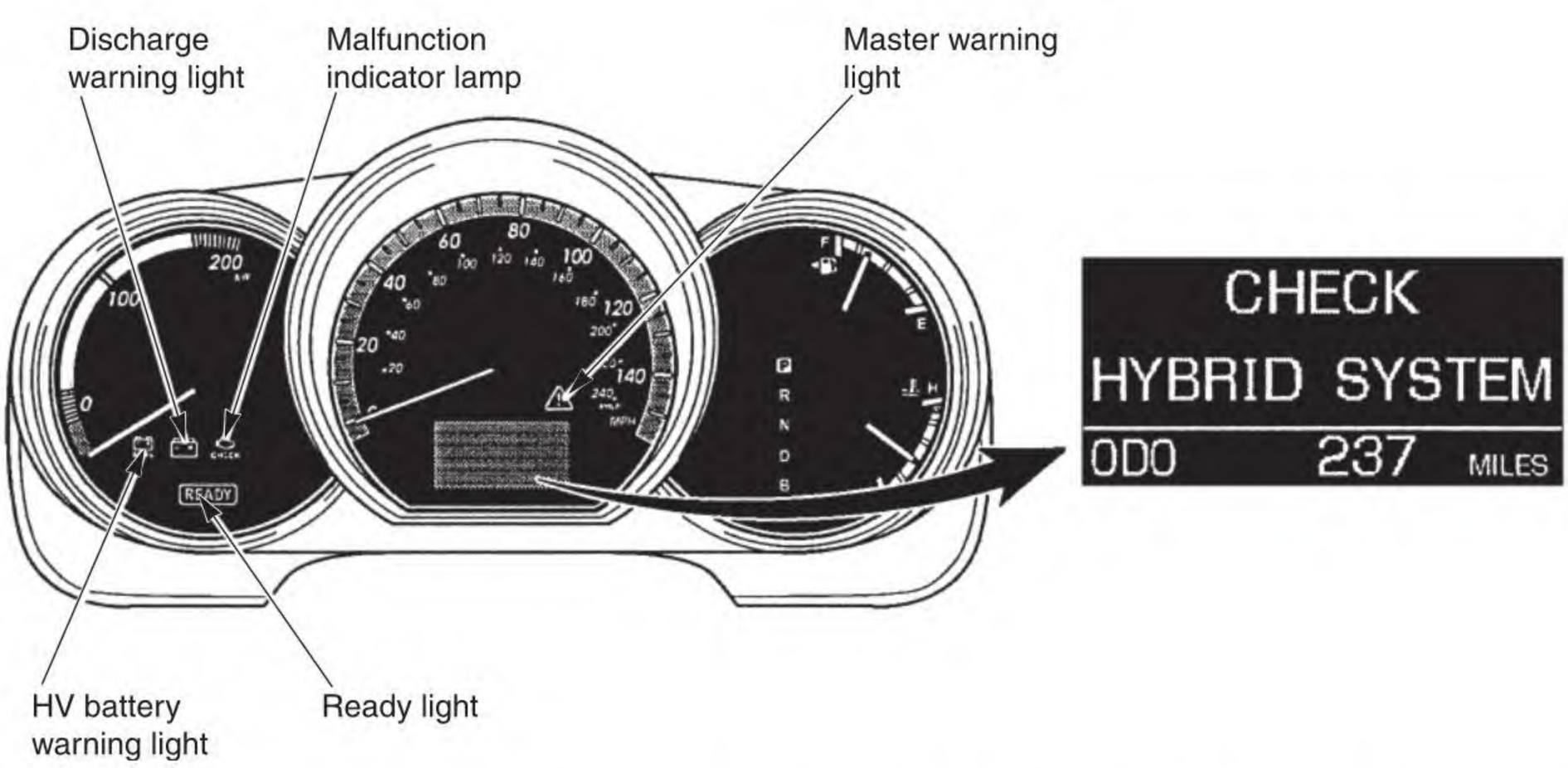
A ***battery pack warning light*** in the instrument cluster illuminates to signal the driver about battery pack problems. This could be caused by running the air conditioning and other high-current draw circuits overnight, several shorted battery cells, or an HV PCM circuit problem preventing the HV battery from being recharged normally. A conventional ***malfunction indicator light (MIL)*** also turns on when any control module detects a vehicle malfunction.

A ***hybrid power display*** informs the driver of the hybrid drive operating conditions. See **Figure 26-19**. Many hybrid displays indicate when the electric "assist" is working, how electrical energy is being used, and how much energy remains in the HV battery. The power display often reads in kilowatts (kW) of power output from the HV battery. This display helps the driver monitor and gauge power usage while driving.



Toyota

Figure 26-19. Note how the hybrid energy monitor in the dash illustrates the flow of energy into or out of the system. Real-time fuel consumption is also indicated.



Toyota

Figure 26-18. The hybrid dash display provides information about the mode of operation and the condition of the electric portion of the drive train.

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Hybrid Tip

A locomotive is considered a hybrid. It uses a diesel engine to spin an electric generator. The generator energizes one or more large, high-torque traction motors to turn the locomotive's steel drive wheels. The operator can adjust diesel engine's speed and the generator's electric current output to control the torque and speed of the traction motor.

Summary

- In an HEV, the internal combustion engine and electric drive system work in unison under computer control to propel the vehicle and operate its electrical accessory systems.
- A typical hybrid drive system has six major assemblies: an HV battery, a motor-generator, an HV power control module, a hybrid control module, HV power cables, and an internal combustion engine.
- A full hybrid is propelled by the motor-generator until the HV battery has about a 30% charge remaining.
- In a series hybrid configuration, an electric motor is the only method used to apply torque to the vehicle's drive train.
- A parallel hybrid uses both the internal engine and a motor-generator to apply torque to the drive train.
- The series-parallel hybrid can recharge the HV battery even when the electric motor is used to drive the vehicle.
- A typical series-parallel hybrid drive system has six basic modes of operation: all-electric drive mode, motor-assist mode, idle stop mode, regenerative braking mode, engine starting mode, and HV battery recharging mode.
- The HV battery sends high-voltage dc into the HV PCM through the HV power cables.
- A hybrid motor-generator functions as both a powerful traction motor and as a high-energy alternator in the vehicle's power train.
- The HV power control module is a set of electronic circuits that feeds voltage between the HV battery and motor-generator.
- The hybrid control module controls the HV PCM and motor-generator to keep the battery pack operating at the optimum temperature and state of charge.
- Hybrid power cables transfer extremely high voltage and current to the components of the electric drive system.
- The dash display of a hybrid presents many variables pertaining to the performance and condition of the internal combustion engine and electric drive system.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

armature
assist hybrid
battery pack warning light
combination meter
converter circuit
full-electric vehicle
full hybrid
HV battery
HV battery cover
HV flywheel generator
HV motor
hybrid control module
hybrid drive ready light
hybrid electric vehicle (HEV)
hybrid master warning light
hybrid power display
inverter circuit
kinetic energy generator
malfunction indicator light (MIL)
mild hybrid
motor speed
motor torque
parallel hybrid
plug-in hybrid electric vehicle (PHEV)
power splitter
regenerative braking
rotor sensor
series hybrid
series-parallel hybrid
stator
three-phase ac power

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Activities

1. Inspect a hybrid vehicle. Locate the HV battery, HV PCM, power display, engine, power cables, and other parts. Make sure you wear insulated gloves and eye protection during your inspection.
2. Use the Internet to look up gas mileage figures for several cars, including conventional and hybrid electric vehicles. Write a report explaining which vehicles get the highest gas mileage and why.
3. Look up service data on a hybrid vehicle. Write a report summarizing what must be done to remove and replace the HV battery, HV PCM, or other parts of the hybrid drive.

Review Questions

Answer the following questions using the information provided in this chapter.

1. How many power sources does a hybrid vehicle use for propulsion?
2. When most hybrids come to a stop, both the internal combustion engine and the high-voltage charging system are shut off. True or False?
3. List the six major assemblies found in a hybrid drive system.
4. Explain the difference between a full hybrid and a mild hybrid.
5. In a(n) _____ hybrid, the internal combustion engine has no mechanical connection to the drive train.
6. What is the drawback to a parallel hybrid?
7. A full-electric vehicle has no method of recharging the HV battery when driving. True or False?
8. List the six modes of hybrid drive system operation.
9. In all-electric drive mode, the _____ provides all the energy to propel the vehicle.
10. During _____ mode, the motor-generator places a drag on the rotating tires, wheels, and drive train to help slow the vehicle.
11. HV battery voltage can range from about _____ to _____ volts dc.
12. The basic parts of a motor-generator include the _____, stator, and housing.
13. Explain the difference in operation when the motor-generator serves as an HV motor versus when the motor-generator acts as an ac generator.
14. A(n) _____ is a planetary gearset used to transfer power through the hybrid driveline.
15. The converter circuit in the HV PCM changes dc to ac and ac to dc. True or False?
16. How many HV power cables connect the HV power control module to the motor-generator?
17. A hybrid _____ monitors the system for high-voltage leaking into the metal chassis of the vehicle.
18. Explain the function of the combination meter.

ASE-Type Questions

1. Manufacturers are experimenting with each of the following hybrid types, *except*:
   (A) pneumatic hybrids.
   (B) hydraulic hybrids.
   (C) fuel-cell hybrids.
   (D) steam-powered hybrids.
2. Technician A says you can identify a hybrid vehicle by the badging on the engine cover. Technician B says you can identify a hybrid by comparing the vehicle's VIN to factory reference information. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. Technician A says all mild hybrids use a small motor-generator to assist the gas engine during acceleration. Technician B says a mild hybrid shuts down its internal combustion engine when the vehicle comes to a stop. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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4. In all-electric drive mode, the energy needed to power the motor-generator is provided by the _____.
   (A) internal combustion engine
   (B) power splitter
   (C) battery pack
   (D) hybrid control module
5. A set of electronic/electric circuits that feeds voltage (ac and dc) between the HV battery and the motor-generator is the:
   (A) HV PCM.
   (B) HEV.
   (C) ECU.
   (D) None of the above.

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Chapter 27
Hybrid Drive Systems Diagnosis and Repair

After studying this chapter, you will be able to:

- Use on-board diagnostics to find the source of problems in a hybrid drive system.
- Recall the safety measures that must be followed when working on high-voltage, high-current hybrid drive systems.
- Perform basic tests to verify hybrid drive trouble codes.
- Carry out proper procedures for safely removing and replacing a battery pack, an HV power control module, HV power cables, control modules, and motor-generator assembly.
- Correctly answer ASE certification test questions about hybrid drive systems diagnosis and repair.

Since hybrid electric vehicles (HEVs) are now produced and sold by many automakers, it is important that you understand how these vehicles operate, and the methods for safely servicing them. The electrical/electronic service methods you learned in previous chapters also apply to hybrid vehicles. The primary concern when working on an HEV drive train is the extremely high voltage and current stored and generated by the electric drive devices and circuits. You must learn how to work safely with up to 600 volts of alternating current (ac) and 300 volts of direct current (dc). It is recommended that you take specialized factory training before attempting to work on a hybrid. For example, if you are going to work on a Ford hybrid, you should attend a certified Ford training program.

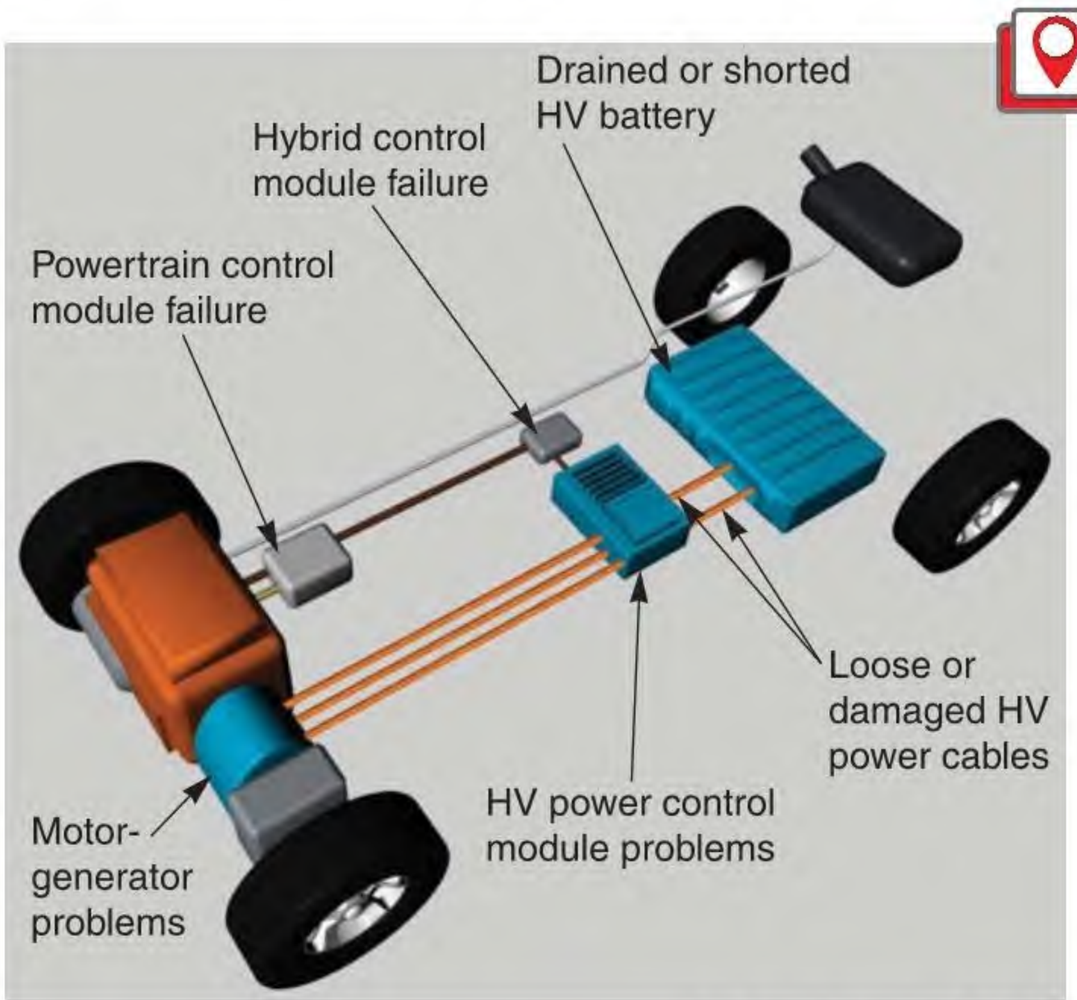
Please remember that the information in this chapter is general and applies to all makes and models of hybrid vehicles. You must refer to factory service instructions to effectively and safely service hybrid vehicles. Even though hybrids can be serviced with conventional tools and equipment, the specifications, part locations, and repair methods vary slightly.

Hybrid Problem Diagnosis

Hybrid vehicles have extensive on-board diagnostic systems that will help you locate the source of system problems. The on-board diagnostic system monitors hundreds of operating conditions and turns on one or more warning lights if any monitored condition is not within specifications. **Figure 27-1** shows a few of the problems that can affect hybrid electric drive operation.

A ***hybrid ground fault interrupter*** constantly monitors the system for high-voltage leakage into the metal chassis of the vehicle. If high voltage from the HV battery pack or motor-generator is shorting to frame ground, the control module illuminates a

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Figure 27-1. Note some of the problems you may encounter when repairing an HEV drive train.

warning light and de-energizes the main power relays (contactors) to disconnect the battery pack from its electric drive circuit.

A glowing malfunction indicator light means that you should use a scan tool to retrieve stored trouble codes. An example of a hybrid drive trouble code index chart is shown in **Figure 27-2**. This chart explains what each code means and where to find instructions for further testing in the service manual.

Hybrid Service Safety

Modern HEV drive systems generate enough electrical energy to cause electrocution. It only takes a couple amps of current through your body to stop your heart and kill you. Most hybrid vehicles conduct almost 600 volts ac and 300 volts dc at hundreds of amps. By comparison, home wall outlet voltage is 120 volts. Therefore, it is important that you work safely when servicing a hybrid vehicle. To work safely, you should:

- Remove your jewelry.
- Wear eye protection.
- Wear insulating gloves.
- Wear rubber-soled shoes.
- Keep a fire extinguisher nearby.
- Follow towing safety procedures.
- Disable the hybrid drive when working.
- Set up a high-voltage buffer zone.
- Remove the high-voltage disconnect.

Remove Jewelry

Remove all jewelry when working on a hybrid's high-voltage circuits. It is easy for a metal watch to short between a high-voltage conductor and ground since high voltage can arc through the air and into the jewelry. The high voltage can instantly make the metal watch glow red hot, burning deep into your wrist or arm. Another potential danger is that the jewelry may come into contact with high-voltage conductors. If a metal necklace or bracelet touches high-voltage conductors in a hybrid, it will weld itself to the conductors. The increased current flow will instantly liquefy the highest resistance point in the jewelry. As a result, the metal in the jewelry will explode.

Wear Eye Protection

Make sure you wear safety glasses, goggles, or better yet, a full-face shield when working on high-voltage components. If an HV power cable shorts to ground, a violent electric arc will occur. The metal end of the shorted cable will melt and may shoot out molten metal. If the molten metal gets in your eyes, you can suffer permanent eye damage, even blindness.

Wear Insulating Gloves

Always wear ***insulating gloves*** rated for high voltage when working on high-voltage components and cables. High voltage and current can arc through cloth gloves, causing serious injury or death. Make sure you use OSHA-approved lineman gloves or approved insulating gloves with an insulation rating value of at least 1000 volts. See **Figure 27-3**.

Always inspect your insulating gloves, especially the fingertips, for tears or splits before using. To check the condition of insulating gloves, grasp a glove by the cusp and fold it over a couple times to seal air inside the glove. With the glove filled with air, check for air leakage and flaws. If the glove leaks air, it can also let voltage in. If your gloves are worn or damaged, discard them and purchase new ones.

Wear Rubber-Soled Shoes

You must wear shoes with rubber soles when working on hybrid vehicles because of the high voltages involved. Rubber soles help insulate your body from earth ground, preventing high voltage from arcing out and into your body while seeking earth ground.

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Keep a Fire Extinguisher Nearby

Always keep a class A, B, C fire extinguisher near the work area when servicing hybrids. A high-voltage electrical short can cause a serious electrical fire. If fire starts, shut off the main contactor or switch for the HV battery, and then put out the fire with a fire extinguisher.

DTC Troubleshooting Index

DTC (IMA System Indicator*1)	Detection Item	IMA System Indicator	Page
P0562 (15)*2	Battery Condition Monitor (BCM) Module System Low Voltage	ON	(see page 12-39)
P0562 (94)*2	Motor Control Module (MCM) System Low Voltage	ON	(see page 12-41)
P0602 (91)*2	Motor Control Module (MCM) Programming Error	ON	(see page 12-43)
P0602 (92)*2	Battery Condition Monitor (BCM) Module Programming Error	ON	(see page 12-43)
P0603 (60)	Motor Control Module (MCM) Internal Circuit Keep Alive Memory (KAM) Error	ON	(see page 12-44)
P0607 (82)	Battery Condition Monitor (BCM) Module Performance Problem	ON	(see page 12-44)
P0A1F (122)	F-CAN Malfunction (Battery Condition Monitor (BCM) Module-Motor Control Module (MCM))	ON	(see page 12-45)
P0A27 (46)	High Voltage Contactor/Bypass Contactor Stays Activated	ON	(see page 12-47)
P0A3C (39)	Motor Control Module (MCM) Overheating	ON	(see page 12-50)
P0A3F (89)	Motor Rotor Position Sensor Circuit Malfunction	ON	(see page 12-51)
P0A5E (24)	U Phase Motor Current Sensor Circuit Low Voltage	ON	(see page 12-55)
P0A5F (25)	U Phase Motor Current Sensor Circuit High Voltage	ON	(see page 12-55)
P0A61 (26)	V Phase Motor Current Sensor Circuit Low Voltage	ON	(see page 12-56)
P0A62 (27)	V Phase Motor Current Sensor Circuit High Voltage	ON	(see page 12-56)
P0A64 (28)	W Phase Motor Current Sensor Circuit Low Voltage	ON	(see page 12-57)
P0A65 (29)	W Phase Motor Current Sensor Circuit High Voltage	ON	(see page 12-57)
P0A78 (32)	Motor Control Module (MCM) Internal Circuit Malfunction	ON	(see page 12-58)
P0A7E (72)	Battery Module Overheating	ON	(see page 12-58)
P0A7F (78)	Battery Module Deterioration	ON	(see page 12-59)
P0A94 (48)	DC-DC Converter Output Low Voltage	OFF	(see page 12-60)
P0A9D (49)	Battery Module Temperature Sensor 1 Circuit Low Voltage	ON	(see page 12-63)
P0A9E (50)	Battery Module Temperature Sensor 1 Circuit High Voltage	ON	(see page 12-65)
P0AA6 (59)	High Voltage Circuit Isolation Problem	ON	(see page 12-68)
P0AA7 (76)	Battery Condition Monitor (BCM) Module Internal Circuit Malfunction	ON	(see page 12-76)
P0AC0 (65)	Battery Current Sensor Circuit Malfunction	ON	(see page 12-77)
P0AC7 (51)	Battery Module Temperature Sensor 2 Circuit Low Voltage	ON	(see page 12-79)
P0AC8 (52)	Battery Module Temperature Sensor 2 Circuit High Voltage	ON	(see page 12-81)
P0ACC (53)	Battery Module Temperature Sensor 3 Circuit Low Voltage	ON	(see page 12-84)
P0ACD (54)	Battery Module Temperature Sensor 3 Circuit High Voltage	ON	(see page 12-86)
P0AE1 (62)	Bypass Contactor Malfunction	ON	(see page 12-89)
P0AEE (109)	Motor Control Module (MCM) Internal Circuit Malfunction	ON	(see page 12-92)
P0AEF (110)	Motor Control Module (MCM) Internal Temperature Sensor Circuit Low Voltage	ON	(see page 12-92)
P0AF0 (111)	Motor Control Module (MCM) Internal Temperature Sensor Circuit High Voltage	ON	(see page 12-93)
P1435 (58)	Charge/Discharge Balance Malfunction	OFF	(see page 12-94)

* 1: These DTCs are indicated by a blinking IMA system indicator when the SCS line is jumped with the HDS.
* 2: To determine the correct troubleshooting procedure for these DTCs, jump the SCS line with the HDS, and read the flash code.

Toyota

Figure 27-2. This chart lists hybrid trouble codes from one automaker. If the scan tool reads code P0562 on this vehicle, go to pages 12–39 in the service manual for further instructions on testing and servicing the battery condition monitor.

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Toyota

Figure 27-3. Wear thick rubber gloves to insulate your skin from the high voltages in a hybrid drive system.

Although you cannot turn off the power stored inside the HV battery, you can disconnect it from the rest of the electrical system.

To disable an HEV for repair, you must first turn the ignition key off. This will cause the hybrid control module to de-energize the relays that connect the high-voltage battery to the rest of the electric drive system. Some manufacturers also require that you disconnect the conventional 12-volt battery to help prevent the high-voltage circuits from accidentally being energized.

Disabling the system is important because a hybrid's drive train may be engaged and ready to accelerate even without the internal combustion engine running. If you leave the key "on" in a hybrid and the shift lever is in gear (*Drive* or *Reverse*), the vehicle can be propelled forward or backward by the motor-generator if you accidentally press the accelerator. This could cause the vehicle to lunge forward or backward and ram into a shop wall or run over coworkers.

Warning

If a collision-damaged lithium ion battery ever catches fire, do *not* spray water on the fire. When water comes in contact with the lithium electrolyte, it produces very explosive hydrogen gas. If a large volume of hydrogen gas ignites, it can explode with the power of several sticks of dynamite!

Tech Tip

If a hybrid is in a severe collision, the hybrid drive system will automatically disable the high-voltage battery pack. Most hybrids automatically disable the HV battery and generator when the air bags deploy in a collision. You will have to repair all damaged systems, check and erase trouble codes before powering up the high-voltage electric drive train.

Follow Towing Safety Procedures

With some hybrids, spinning the wheels and axles can cause the motor-generator to produce high voltage even with the electrical system disabled and the key off. This can be dangerous and may damage the drive system. When towing or moving a hybrid vehicle, the drive wheels engaged to the motor-generator should be raised off the ground so they do not spin when towed.

The front wheels of a front-wheel drive hybrid should be raised when towing. If towing an all-wheel drive hybrid with motor-generators at the front and rear, this type of four-wheel drive hybrid should be towed on a flatbed truck.

Disable the Hybrid Drive when Working

A "hot hybrid" system is one with high and low voltage still present in the electric drive system.

Set Up a High-Voltage Buffer Zone

When working on an HEV, set up a ***high-voltage buffer zone*** of about 3′ (1 m) around the perimeter of the vehicle. You do not want steel workbenches, large metal equipment, co-workers, or any other potential conductors of electricity in the buffer zone. Take the time to move objects or park the hybrid vehicle away from potential conductors.

If you accidentally move your body into a good conductor (such as a steel workbench) with your arm touching a source of high voltage, you could be electrocuted or severely injured as the voltage travels through your body to ground.

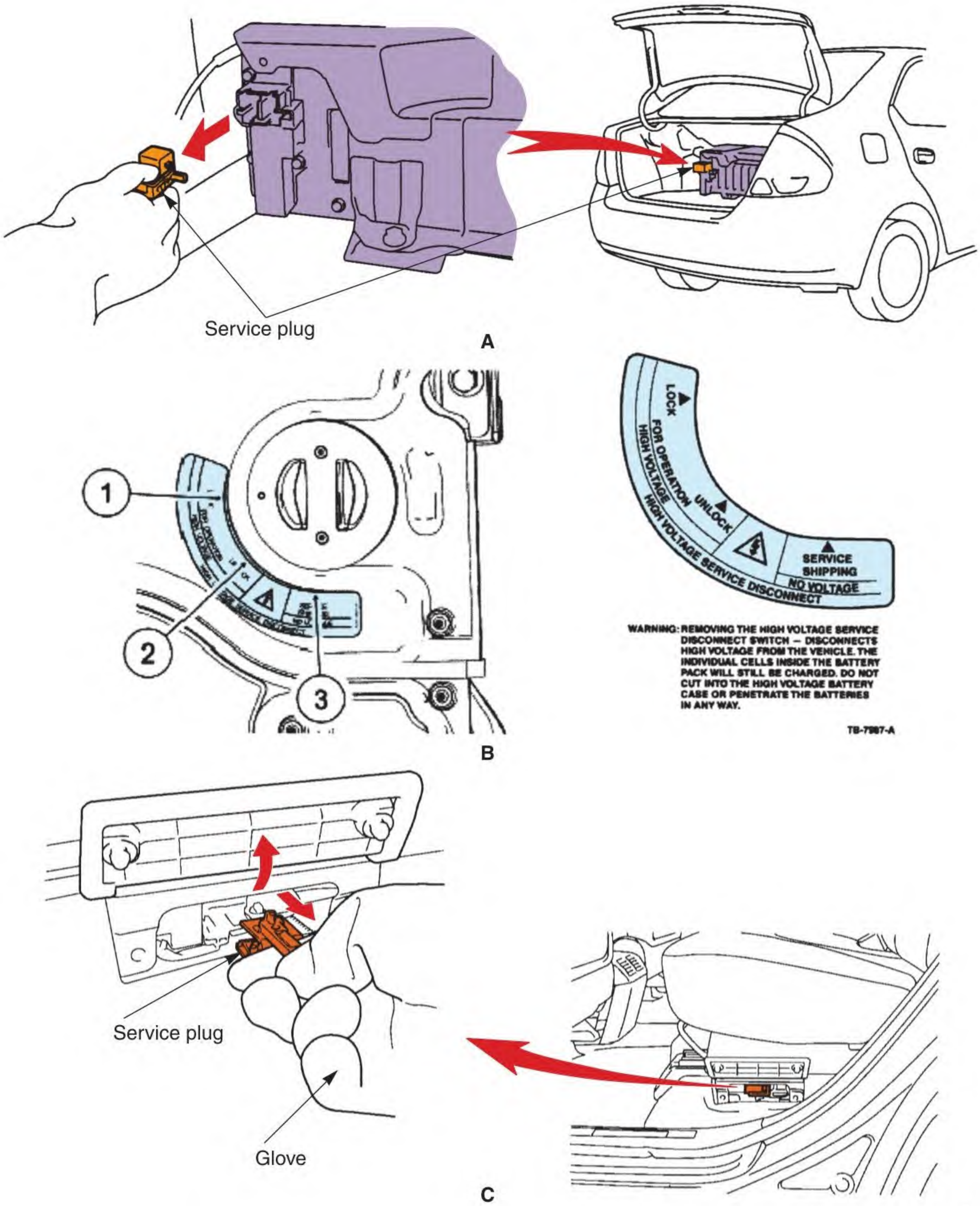
Remove the High-Voltage Disconnect

A ***high-voltage disconnect*** is provided on a hybrid to allow the HV battery to be physically

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disconnected from all vehicle circuits. With many hybrids, you must pull out the disconnect to produce an open circuit between the HV battery cells and the power control module. Refer to **Figure 27-4**. With other designs, you must rotate a high-voltage disconnect switch to provide an open in the HV battery circuit.

Hybrid high-voltage disconnects are usually located near the battery pack in the trunk, under the



Ford and Toyota

Figure 27-4. The hybrid power disconnect can be difficult to find. A—This disconnect is located in the trunk of the vehicle. B—Here you must rotate a locking switch before you can remove the disconnect. C—This hybrid disconnect is located on the side of the rear seat, under a plastic trim piece.

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seat, on the side of a seat under a trim panel, or in other similar locations. Refer to the factory service literature for details.

Warning

To prevent electric shock, wait at least five minutes after removing the high-voltage disconnect before working on the high-voltage circuits. It can take up to five minutes for any high-voltage capacitors in the inverter circuit to fully discharge.

Tech Tip

After you remove a high-voltage disconnect, remove the high-voltage fuse and keep it in your pocket. This will prevent anyone from accidentally reconnecting HV battery power when circuits are being serviced.

HV Battery Service

Hybrid battery packs have a warranty from the vehicle manufacturer. Some automakers offer a full HV battery replacement warranty for up to 8 years or 100,000 miles. HV batteries are very dependable and seldom fail. Nevertheless, they can lose efficiency after a period of extended service. The electrolyte and the metal plates in the HV battery can be depleted after years of operation.

Tech Tip

Remember that hybrid NiMH batteries should not be stored for long periods. When purchasing used HV batteries from recycling yards, find out how long the HV battery has been in storage. If left uncharged for over a year, the battery plates and electrolyte will deteriorate and the HV battery should not be purchased.

Diagnosing HV Battery Problems

Late-model hybrid vehicles have a very extensive on-board diagnostic system that monitors several operating parameters in the high-voltage electric drive system. The hybrid control module will check circuit conditions when the HV battery is discharging while powering the electric drive motor(s) and while it is being recharged by the motor-generator. Trouble codes will be stored in the control module's memory if any electrical value is not within specifications.

Most hybrids have a dash display that shows HV battery charge, temperature, and condition. The display will warn the driver when the on-board diagnostic system detects problems with the HV battery, HV power cables, HV power control module, or other components.

A scan tool will also quickly identify problems with the HV battery, motor-generator, high-voltage electrical connections, hybrid control module, and HV power control module. A scan tool can also be used to compare actual operating voltages to those on the dash display.

If an HV battery fails to accept and hold a charge, a trouble code will be set in memory. The hybrid control module will also trigger a malfunction indicator light in the dash display.

Tech Tip

On some hybrid models, the control module will disable the electric drive train when problems are detected in the battery circuit. When this occurs, the vehicle must be driven under engine power alone until the problem is repaired.

A failed HV battery must be replaced with a new or reconditioned unit. Most shops are not set up to replace individual battery packs. Batteries are sent to a specialty battery repair facility for recycling.

Tech Tip

Detailed information on testing and replacing HV batteries is presented in *Chapter 29, 12-Volt and HV Battery Service.*

Checking HV Battery Relays and Contactors

If the trouble codes and symptoms indicate battery power is okay, but battery power is not reaching the HV power control module (HV PCM), check the

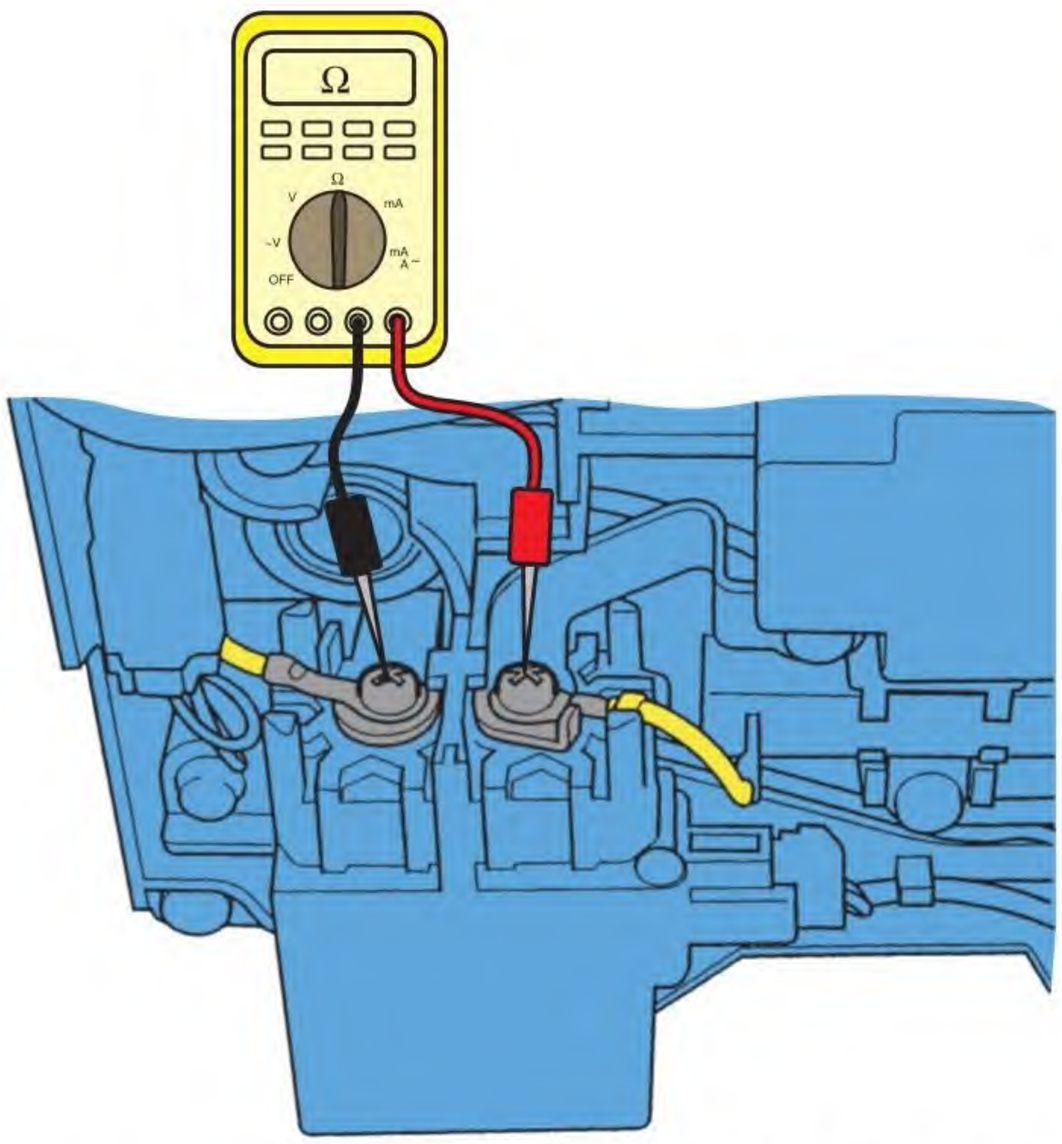
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operation of the battery relays and contactors. Contactors are very large relays with contact points, or lugs. The contactors turn such a high electrical load on and off that their lugs can become burned and pitted. If burned enough, the lugs will develop high resistance and will not be able to carry enough current to the HV PCM and motor-generator. See **Figure 27-5**. Refer to factory service information for relay and contactor test points.

Service Procedure

To make a pinpoint test on a high-voltage contactor:

1. Remove or disconnect the HV battery.
2. Measure the resistance across the closed contactors with the ignition key *On* and then with the ignition key *Off*.
3. If the measurements are not within specifications, replace the contactors.



Goodheart-Willcox Publisher

Figure 27-5. Contactor lugs can become burned and pitted after shutting high voltage on and off thousands of times. If contactor terminals show high resistance when closed (HV battery disconnected from circuit), they should be replaced.

HV Power Cable Service

HV power cables are normally trouble free. However, they can become damaged during a collision, or their metal ends can become loose or corroded. Some HV cables have special watertight terminal ends, **Figure 27-6**. However, most hybrids use an eye-type connector that is secured to a threaded metal stud with a nut.

Service Procedure

To check the HV power cables:

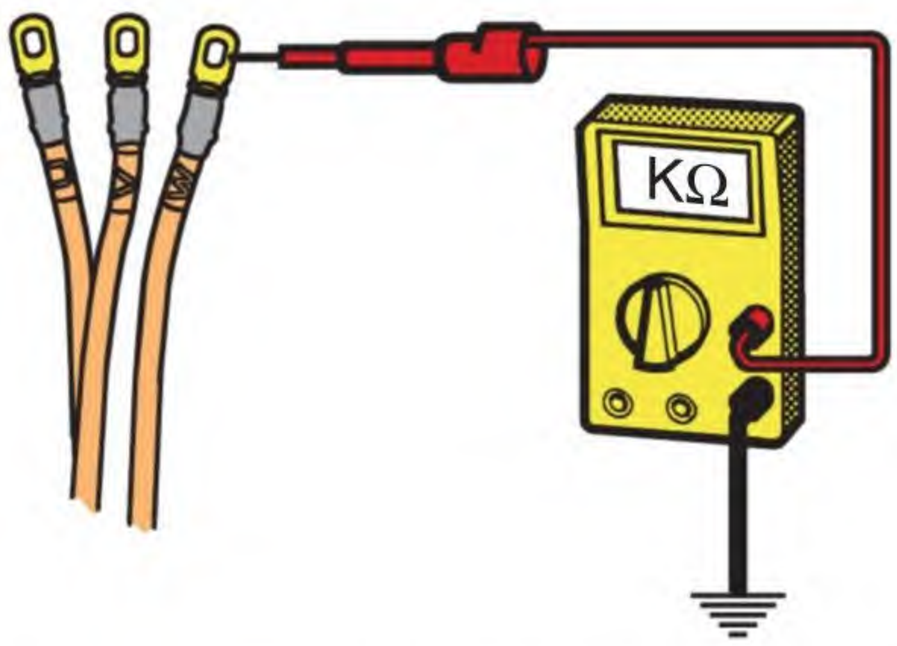
1. Note the conductor resistance values of the high-voltage circuit in the data list display of your scan tool.
2. If the conductor resistance values are not within specifications, tighten or repair the cable ends or replace the HV power cables, if needed.
3. If your scan tool reading shows a ground fault problem with the cables, they may be leaking current to frame or body ground. Touch your ohmmeter test lead on one end of the cable terminal and connect the other meter lead to frame or body ground. See **Figure 27-7**.
4. If the ohmmeter reading is lower than specifications (usually around 350 kΩ), the insulation may be leaking high voltage to ground and the cable should be replaced.



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Figure 27-6. This power cable has a waterproof terminal end. O-ring seals on the HV PCM or the motor-generator housing keep water out of the system.

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Toyota

Figure 27-7. By connecting an ohmmeter between each cable end and ground, you can identify any cable that is leaking voltage. The cable's insulation may have broken down, allowing small amounts of current to leak out of the circuit.

Tech Tip

A high-voltage fuse will open and disconnect the HV battery power if current flow becomes too high due to a short. If this happens and no power is reaching the electric drive system, find out why the fuse burned open. Correct the problem. Then, install a new high-voltage fuse.

A loose cable end can overheat and burn the electrical connection. Always torque the hybrid cable fasteners to factory specifications using a torque wrench to ensure the connection is not too loose or too tight.

Service Procedure

To replace an HV power cable:

1. Disconnect both ends of the cable.
2. Remove the clips that secure the power cable to the vehicle.
3. Install the new power cable in reverse order of removal.

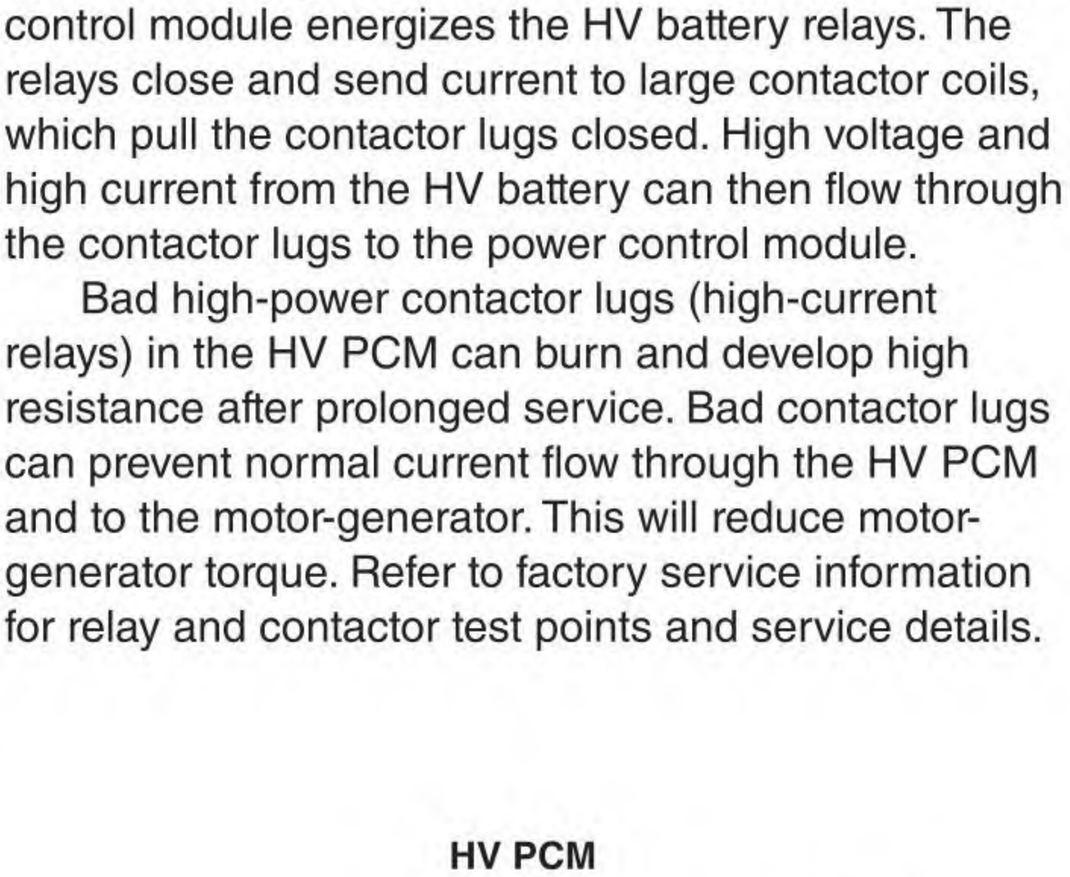
HV Power Control Module Service

The HV power control module (HV PCM) contains several circuits or modules that convert ac to dc and dc to ac. See **Figure 27-8**. The HV PCM also steps voltage up or down using transformers.

A faulty HV PCM can trip various trouble codes, indicating which circuit in the module might be faulty. Sometimes a specific circuit board in the power control module will fail and require replacement. Some hybrid vehicles use separate converter, rectifier, and three-phase circuits. If your scan tool indicates a problem with a specific circuit board, you may be able to order and install just the failed circuit board.

When the ignition key is turned to *Run*, the hybrid control module energizes the HV battery relays. The relays close and send current to large contactor coils, which pull the contactor lugs closed. High voltage and high current from the HV battery can then flow through the contactor lugs to the power control module.

Bad high-power contactor lugs (high-current relays) in the HV PCM can burn and develop high resistance after prolonged service. Bad contactor lugs can prevent normal current flow through the HV PCM and to the motor-generator. This will reduce motor-generator torque. Refer to factory service information for relay and contactor test points and service details.



Chrysler

Figure 27-8. The HV PCM can be located in the engine compartment, on the side of the transmission, or near the HV battery.

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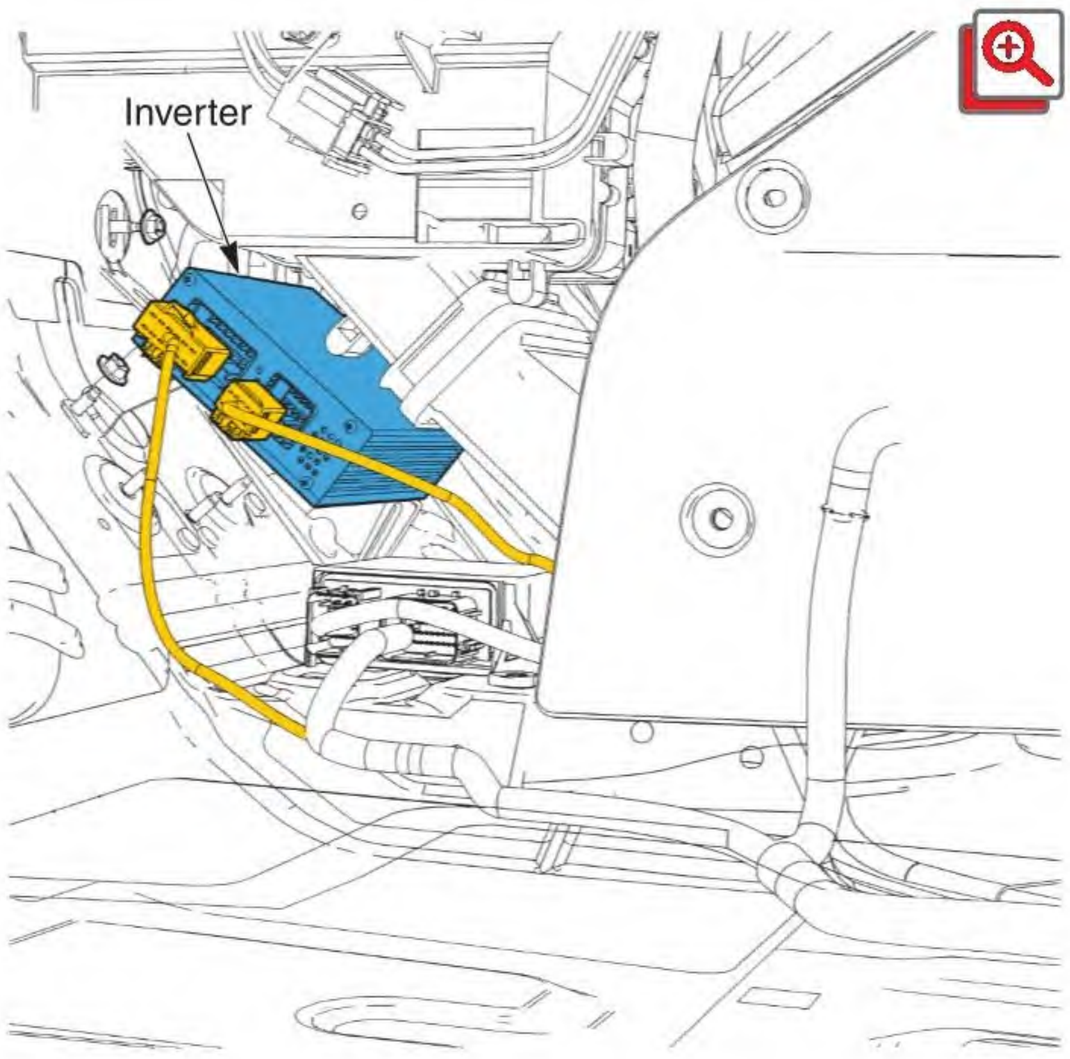
Some hybrid vehicles use discrete (separate) inverters. For example, **Figure 27-9** shows a dc-to-dc inverter that mounts in the engine compartment. If your scan tool indicates internal inverter problems, the defective inverter should be removed and replaced. You can measure actual voltages coming in and out of the unit, but your scan tool will usually pinpoint whether the inverter is bad.

A discrete dc-to-ac inverter is shown in **Figure 27-10**. This unit mounts under a trim panel in the console. Again, your scan tool will help you troubleshoot this converter to determine if it should be replaced.

Sometimes a circuit board in the HV PCM can fail and require replacement. A lack of normal air or coolant flow can cause HV PCM overheating, which will set trouble codes.

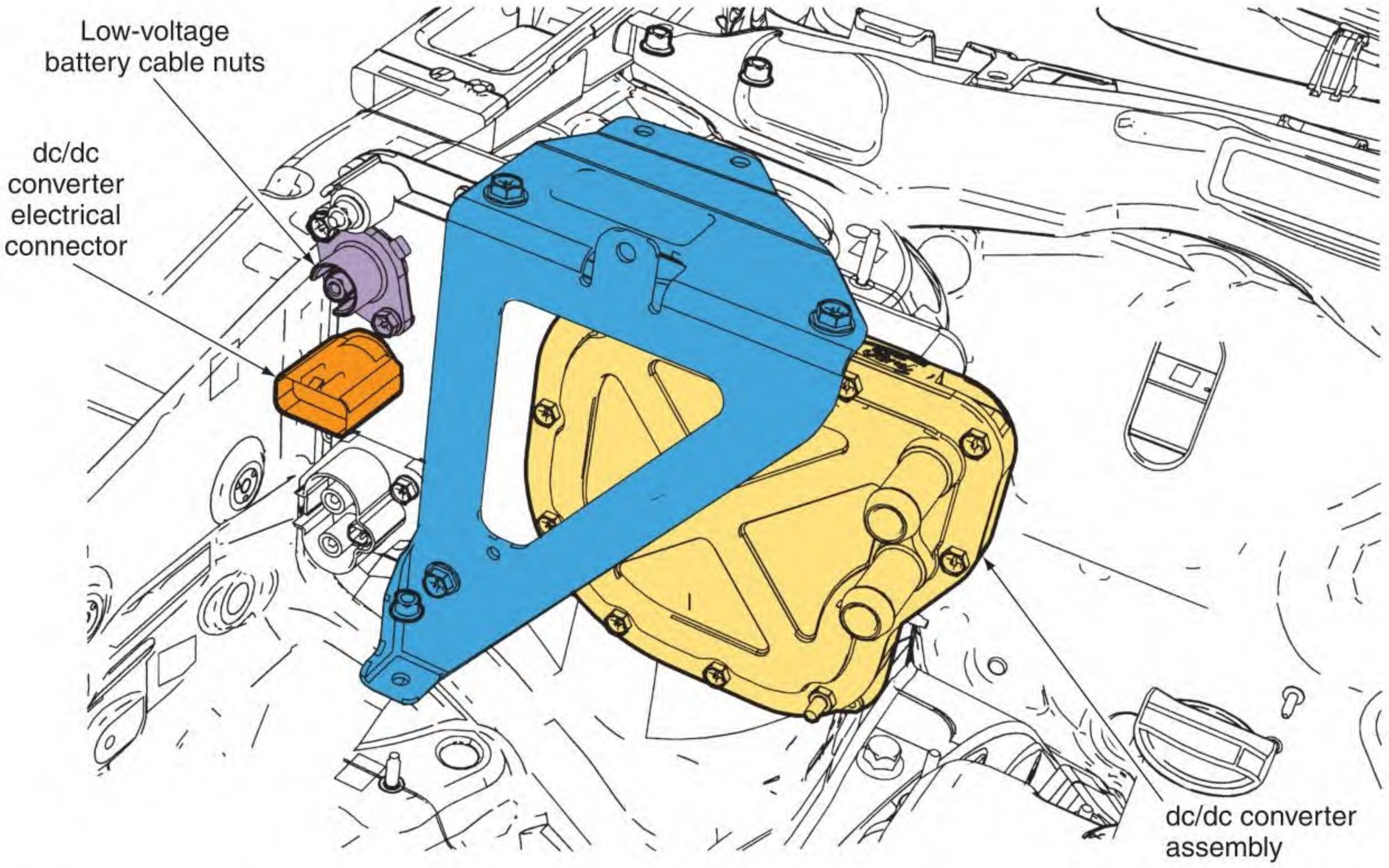
HV Power Control Module Replacement

If your scan tool and pinpoint test indicate a faulty HV PCM, either the affected circuit board or the entire unit must be replaced.



Ford

Figure 27-10. This dc-to-ac inverter mounts under the center console of the vehicle. By removing the trim panels, you can access the electrical connectors and fasteners for unit replacement.



Ford

Figure 27-9. This dc-to-dc inverter is a discrete unit. It mounts in the engine compartment on the firewall of the vehicle.

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Service Procedure

To replace an HV PCM:

1. Make sure you use high-voltage safety gear and tools.
2. Disable the HV battery by pulling its service plug or lug, **Figure 27-4**.
3. Disconnect the low-voltage connections and wiring harness from the HV PCM.
4. Drain the HV cooling system of antifreeze and catch it in a plastic pan.
5. Remove the coolant lines from the side of the HV PCM.
6. Use an insulated socket set to disconnect the five or more high-power cables from the HV PCM. If the cables have special plastic connectors, remove them without damage. Normally, you must depress a small locking lever that secures this type of connection to free the cable end.
7. Wrap electrical tape around each exposed HV battery cable end to prevent a short to ground that can cause a major electrical explosion, injury, and part damage.
8. Remove the hold-down machine screws connecting the HV PCM to the body. They are located around the perimeter of the module.
9. Reinstall the new or reconditioned HV PCM in the reverse order of disassembly.
10. Reconnect the coolant hoses and wiring to the HV PCM.
11. If the high-voltage power cables have fastened or bolted electrical connections, tighten them to factory specs. Use a torque wrench and insulated extension with socket to ensure a good electrical connection.

Caution

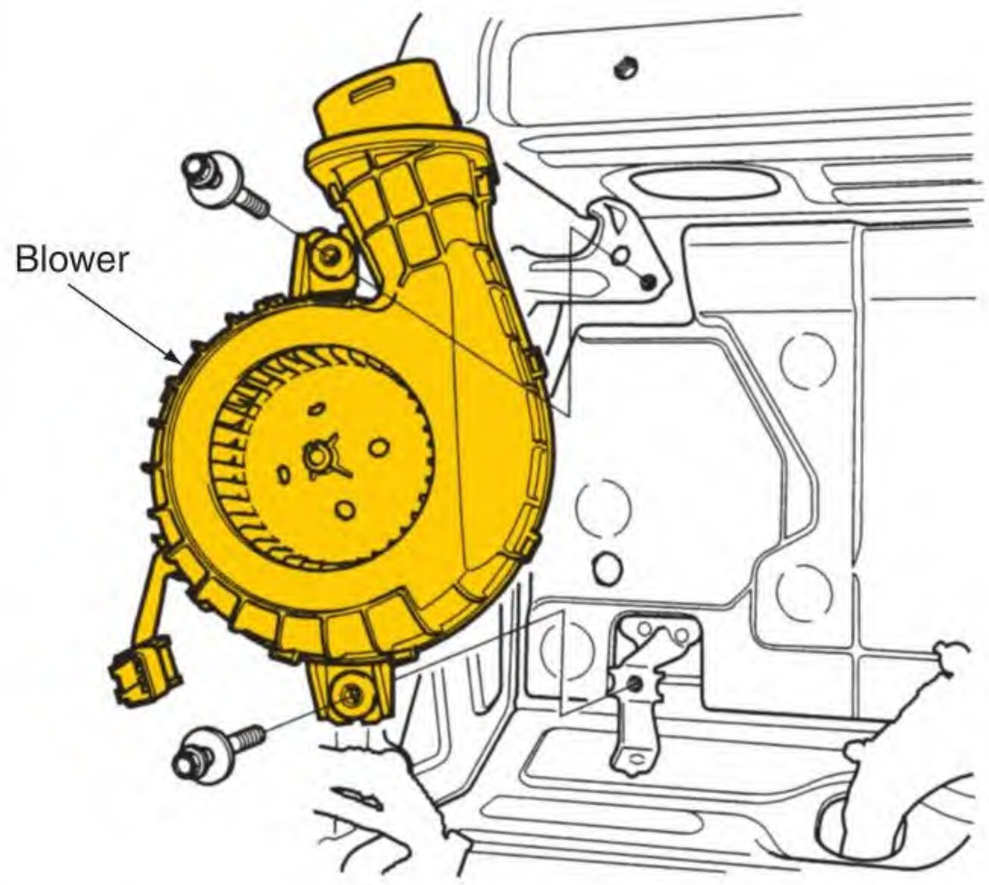
Undertightening the power cables can cause the high current to overheat and loosen the connection even more. Overtightening will strip the fastener threads. Vibration and heat will soon make an overtightened orange power cable connection trip a trouble code.

12. Erase any stored trouble codes and re-scan the hybrid drive system.
13. Double-check high- and low-voltage electrical levels with your scan tool. Check that all voltage and current levels viewed as data stream values are back to normal.
14. Test-drive the vehicle to verify your repairs.

Hybrid Cooling System Service

If the cooling system fails, components in the hybrid drive system can overheat. Trouble codes that indicate the components or circuits at fault will be set. If the system is air cooled, listen for normal operation of the cooling fan. If the system is water cooled, place a stethoscope on the electric pump to determine if it is running when the hybrid is under a high electrical load.

If you find an inoperative cooling fan blower motor, replace it as you would a climate control blower. Disconnect the wires and ducts before removing the fasteners that secure the blower motor to the vehicle. See **Figure 27-11**. With a liquid system, disconnect the hoses and wires going to the pump motor before replacement.



Toyota

Figure 27-11. The air cooling system for the HV battery and HV PCM is serviced the same way you service a climate control fan and wiring. After removing the cover, ducts, and fasteners, the blower motor assembly can be removed for replacement.

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Tech Tip

More information on hybrid cooling system service is presented in *Chapter 48, Cooling System Diagnosis, Testing, and Repair.*

Motor-Generator Service

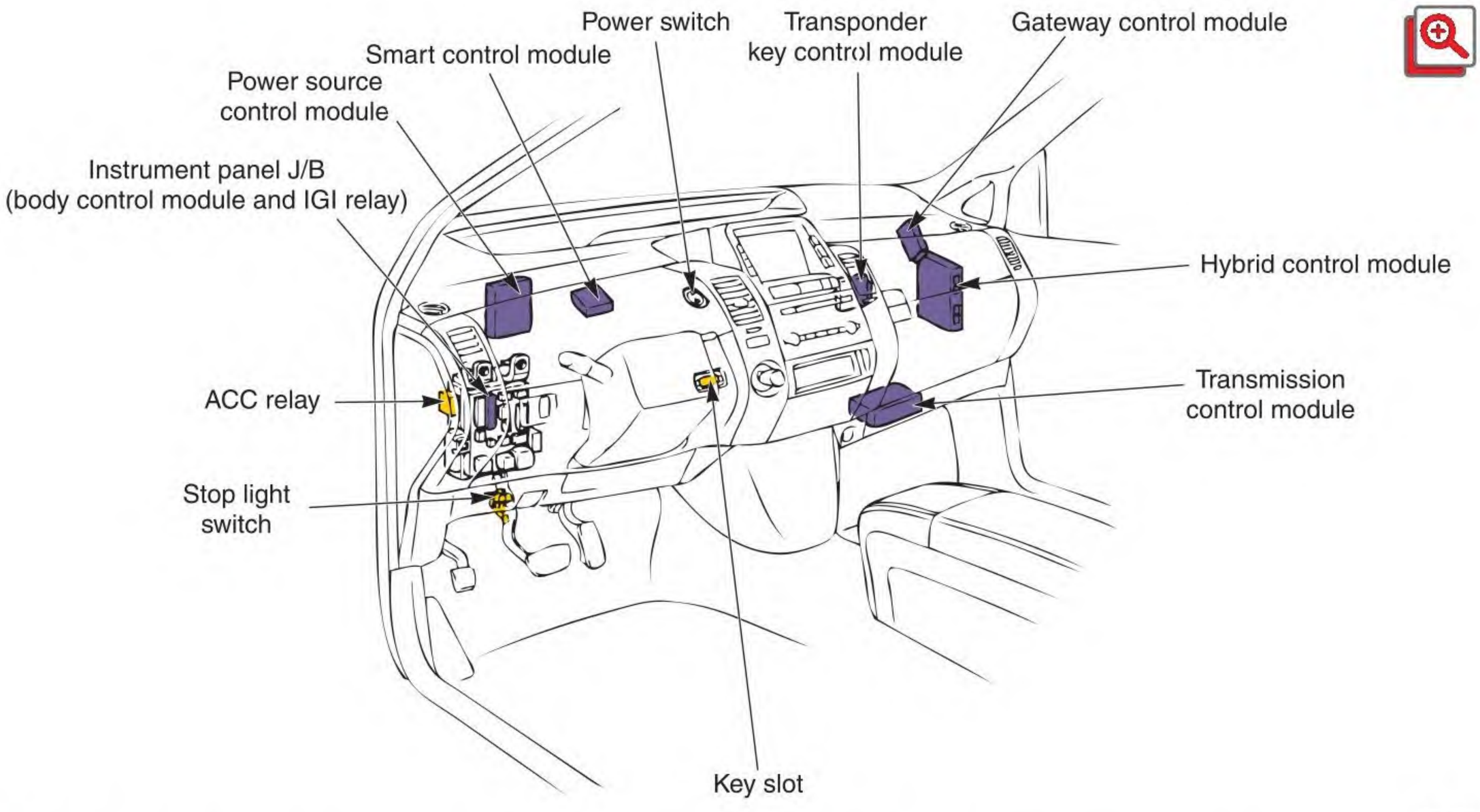
Normally, the motor-generator is trouble free. However, if the car is hit by lightning or used for an extended period, the motor-generator can fail. The stator coil windings in the unit can short or burn open, reducing motor-generator performance. A scan tool will retrieve trouble codes relating to the motor-generator. The instrument panel combination meter will also indicate poor electrical drive performance during all-electric (motor-generator driven) acceleration and regenerative braking.

Refer to the service manual for instructions when replacing a motor-generator, since part locations and procedures vary from one make to another. The most common motor-generator design requires you to remove the transaxle or transmission to access the motor-generator assembly.

A motor-generator trouble code indicates various problems: short coils, poor power cable connections, permanent magnet armature damage, and motor speed sensor failure, among other things. The hybrid control module, engine control module, and HV PCM monitor the condition of the motor-generator and store codes if any of these circuits are operating out of range. If a speed, torque, or temperature sensor signal is not within specs, the location and circuit in question will be tagged with a trouble code. See **Figure 27-12**.

Since transmission and motor-generator bearings can be splash oiled or pressure oiled, their useful service life can vary. In an engine-mounted motor-generator, the magnetic rotor is bolted directly to the rear of the crankshaft. The rear crankshaft main bearing centers the spinning rotor inside its stationary stator coils. This engine bearing seldom wears enough to affect motor-generator operation. The other end of the traction motor shaft is supported by another bearing in the end plate or the clutch of the motor-generator. This bearing can suffer more than the large crankshaft main bearing in the engine block.

With a transmission or transaxle-mounted motor-generator, various configurations are used to mount the motor armature (rotor shaft). Worn motor-generator bearings can cause excessive armature shaft runout.



Toyota

Figure 27-12. This service manual illustration shows locations of ECMs that can affect motor-generator operation.

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With enough bearing wear, the rotating armature can hit and damage the stator windings.

Motor-generator stator problems will trip trouble codes when the circuit resistance, voltage, or current for any stator winding is not correct. If the vehicle has more than one motor-generator, the OBD code will indicate which traction motor or motor-generator is not working properly.

Loose high-voltage connections can trip trouble codes for the motor-generator and HV PCM. The computer only sees that something is preventing normal voltage or current flow in that section of the motor circuit. With a high mileage hybrid, this can be a common problem due to years of vibration, road salt, temperature changes, and such heavy cables. Always inspect, clean, and torque the three ac power cables if trouble codes point to the motor-generator or HV PCM. Refer to **Figure 27-13**.

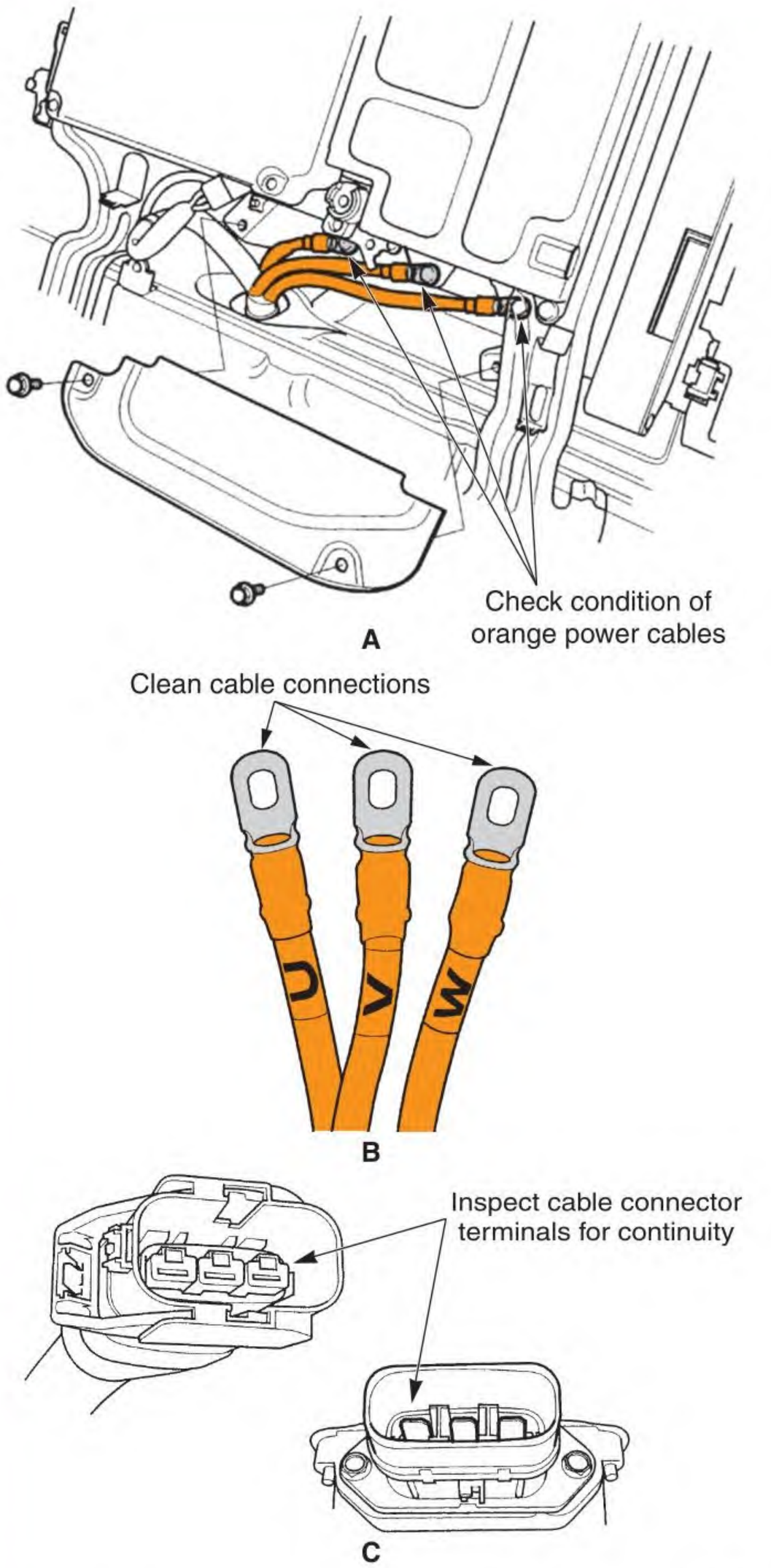
Testing a Motor-Generator

Use an advanced scan tool to perform any live tests of the HV system. Refer to factory service methods to safely perform any drive test or in-shop tests of the high-voltage starting and charging system. Each auto manufacturer has specialized tests that must be performed by following their specific instructions. Usually, the source of any hybrid starting problem can be found using your scan tool.

Service Procedure

To perform a motor-generator resistance test:

1. Wear insulated gloves and safety glasses, and use insulated tools.
2. Disable or disconnect the HV battery from its high-power circuit. Following manufacturer-specific instructions, pull out the high-voltage plug or fuse to disconnect the HV battery.
3. Disconnect the three power cables that connect to the motor-generator. Some plug together, and others are bolted together.
4. Inspect both sets of orange cable conductor terminals for damage from overheating and burning. A high-resistance connection can get very hot and tends to loosen with repeated heating and cooling. If a power cable has a poor electrical connection, the conductors can get hot enough to melt the orange insulation.
5. Connect an ohmmeter to each conductor going to the motor-generator stator windings and to ground.
6. Record and compare your ohmmeter reading for each of the three legs or circuits of the motor-generator. Normally, each leg of the stator windings should have the same reading.



Toyota

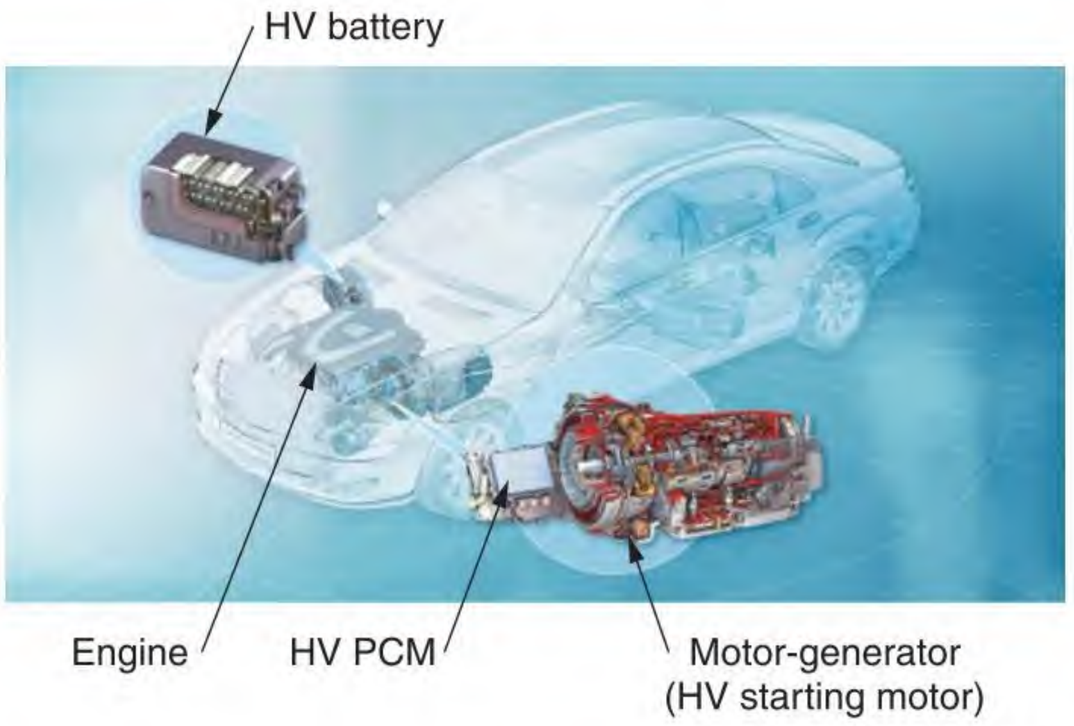
Figure 27-13. Three orange power cables going to the motor-generator must be in perfect condition for normal traction motor operation. Inspect and clean all high-power cable connections if needed or if a trouble code indicates a motor-generator circuit problem.

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When reviewing the ohmmeter readings for each conductor, if one stator leg shows infinite or zero ohms, it is burned open or shorted to ground. Usually, only one phase or grouped set of windings in the motor-generator will fail. Any motor-generator stator winding that has infinite resistance has been burned or broken open, and does not generate its magnetic fields. In this case, motor-generator cranking speed would be slow or the ECM may disable the motor to prevent further damage. Any motor-generator stator winding that has zero resistance to ground might be physically damaged and shorted to ground.

Normal motor-generator stator resistance readings should be approximately 3–10 ohms. Refer to factory specifications if in doubt about normal stator resistance values.

You can also use a stethoscope to listen for motor-generator problems.



Mercedes Benz

Figure 27-14. Some hybrids mount the motor-generator between the transmission and the engine.

Service Procedure

To use a stethoscope to listen for motor-generator problems:

1. Raise the vehicle on a lift so its drive tires are off the ground.
2. Have another technician drive in all-electric mode until the HV battery drains enough for the system to attempt to start the engine.
3. Listen to the operation of the motor-generator during electric propulsion and engine starting.
4. Place a stethoscope against the side of the traction motor when it is running. This will let you hear any mechanical noises that might indicate dry, worn motor bearings, armature runout or wobble, or gear reduction failures.

Warning

The high voltages produced in a hybrid vehicle can cause electrocution. Always wear protective gear and use insulated tools when working around high-voltage hybrid circuits.

Removing and Installing a Motor-Generator

The process of removing a motor-generator varies with the vehicle make and model, and with the location of the motor-generator itself. Look at **Figure 27-14**.

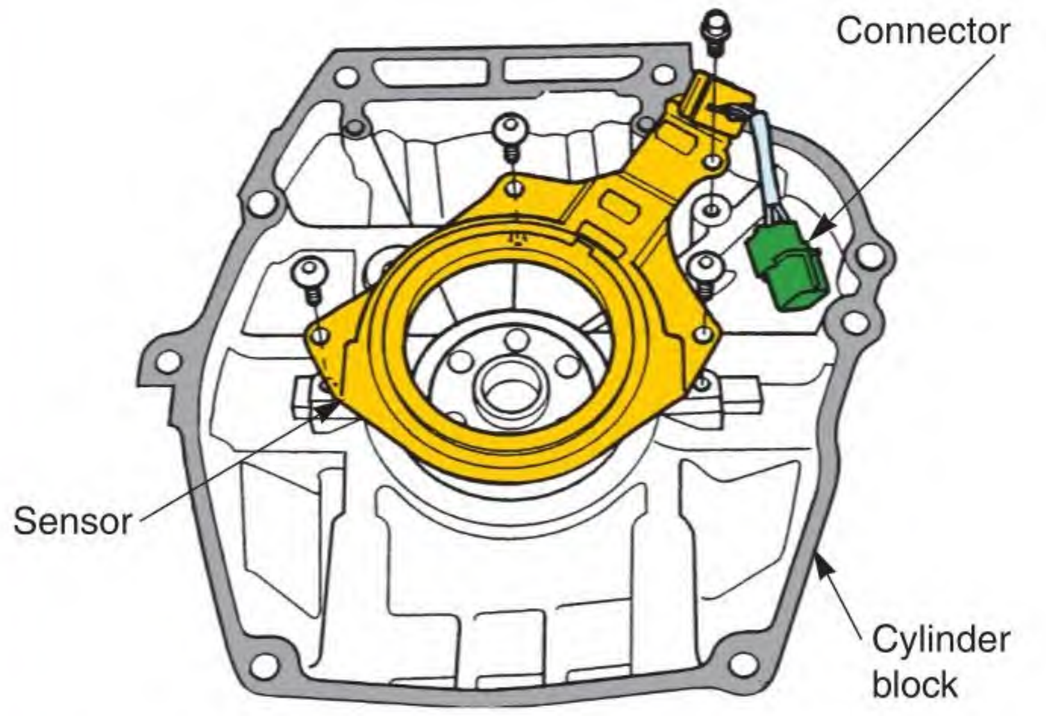
Service Procedure

To remove and install a crankshaft-mounted motor-generator rotor (**Figure 27-15**):

1. Disable the electric drive system and HV battery.
2. Remove the CV axles or drive shaft, wires, fluid lines, linkages, and body-to-transmission mounting fasteners.
3. Remove the transaxle or transmission, following service manual instructions.
4. Disconnect any cooling lines, wires, and flex or end plates from the motor-generator housing.
5. Install a plastic ring tool between the armature and stator. The plastic tool will protect the stator from damage when you unbolt the armature or stator housing. The plastic ring tool will keep the magnets from hitting and damaging the stator during removal.

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6. Remove the armature bolts and pull the armature off the crankshaft flange with a wheel puller.
7. Unbolt and remove the stator housing from the rear of the engine block.
8. Check the resistance and condition of the armature sensor. Many are located under the crankshaft mounted motor-generator. See **Figure 27-16**.
9. Install the new motor-generator in reverse order.
10. Bolt and torque the armature to the crankshaft.
11. Install the plastic spacer ring tool over the armature. It will help protect and center the stator housing over the permanent magnet armature.
12. Torque the stator housing bolts to specs.

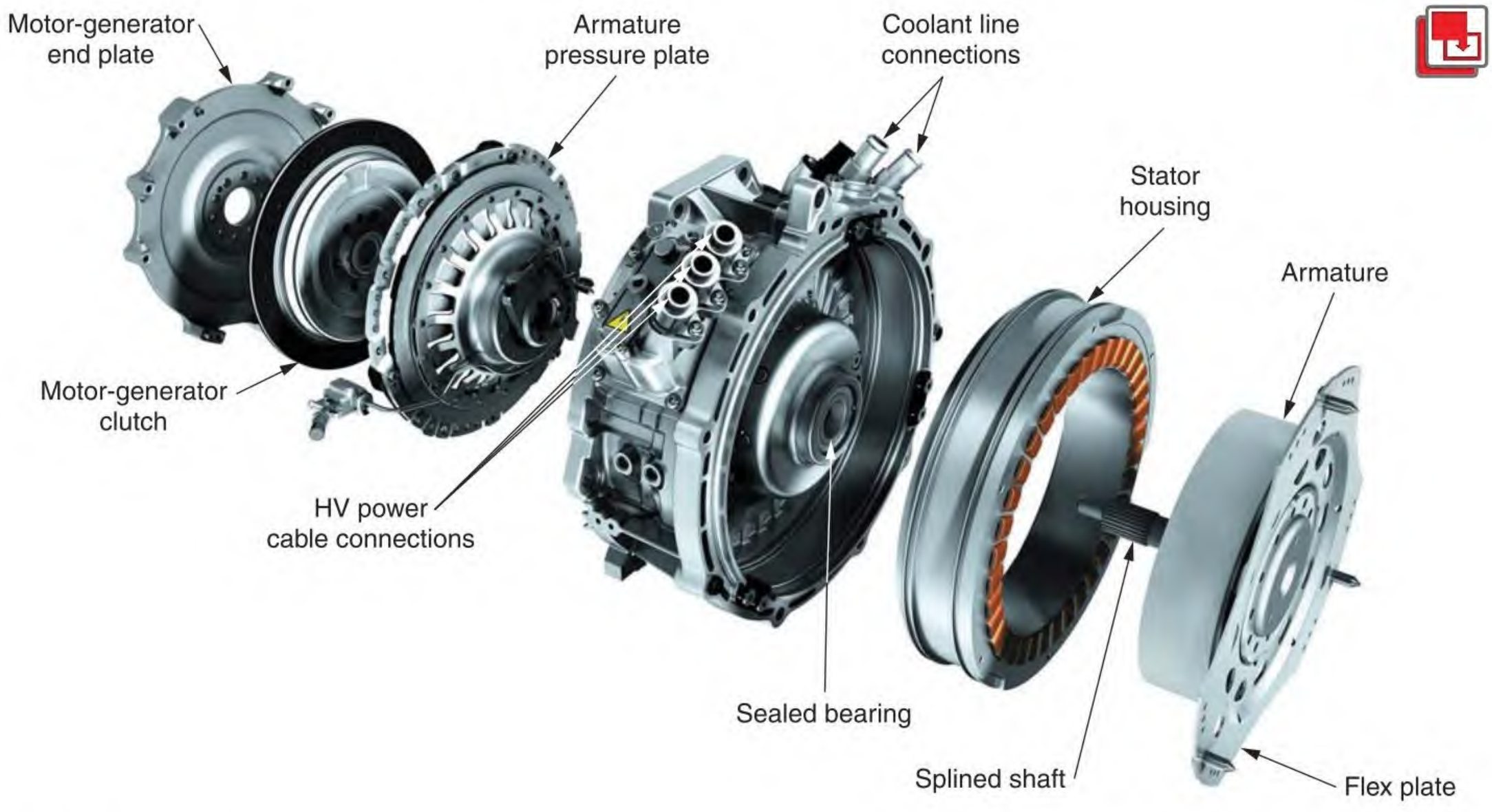


Toyota

Figure 27-16. This particular position sensor for the armature of a hybrid motor-generator is fastened to the back of the cylinder block. The transaxle and motor-generator must be removed to service it.

Figure 27-17 outlines the major steps for removing one motor-generator from one particular vehicle make. After removing the flex plate, a plastic sleeve is installed between the armature and stator to hold them apart during disassembly. This prevents the armature from contacting and damaging the magnets and coils in the stator. A puller is then used to remove the armature, which is press fit into the end of the engine crankshaft.

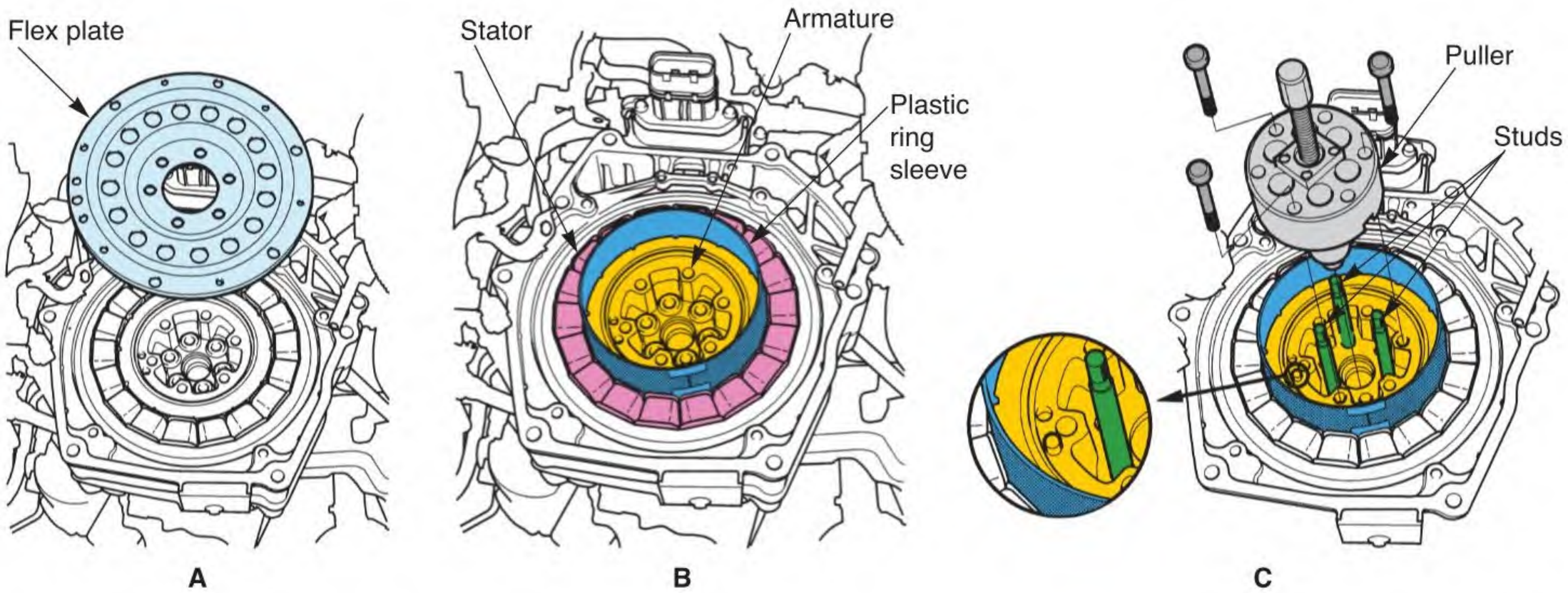
Some hybrids use two or three motor-generators to provide all-electric drive or electric assist. The motor-generators can be located inside the



Porsche

Figure 27-15. Note how a typical engine-mounted motor-generator is constructed so you will understand removal and installation.

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Toyota

Figure 27-17. Note the major steps for removing one type of motor-generator. This particular unit mounts on the rear of the engine and in front of the transaxle or transmission. A—The flex plate over the motor-generator can be removed after removing the cap screws that secure it to the crankshaft flange. B—A plastic sleeve should be installed between the rotor and stator of the motor-generator assembly. It will keep magnetism from pulling the two together when you are trying to remove the rotor. C—A wheel puller is used to force the rotor from the crankshaft. With the puller bolted to the rotor, tighten the puller screw to slowly force off the press fit rotor.

transmission or in the rear drive axle assembly with all-wheel drive vehicles. Refer to manufacturer service information to replace these units.

Tech Tip

Whenever you have to remove a vehicle's transmission, always check to see if you should replace the crankshaft's rear main oil seal. Find out how many miles are on the engine and inspect the seal to detect signs of leakage. If the old seal suddenly fails, you may have to perform the whole repair over to fix an oil leak.

Hybrid Wiring Problems

As with any electrical/electronic circuit, poor electrical connections, broken wire conductors, shorted wires, and similar problems can be difficult to diagnose and repair in a modern hybrid vehicle. When your scan tool shows a problem with a particular component but the component tests good, check for wiring problems in the corresponding circuit. Use factory diagrams, like the one shown in **Figure 27-18**, to locate any electric connector or other component that could be affecting the operation of that circuit.

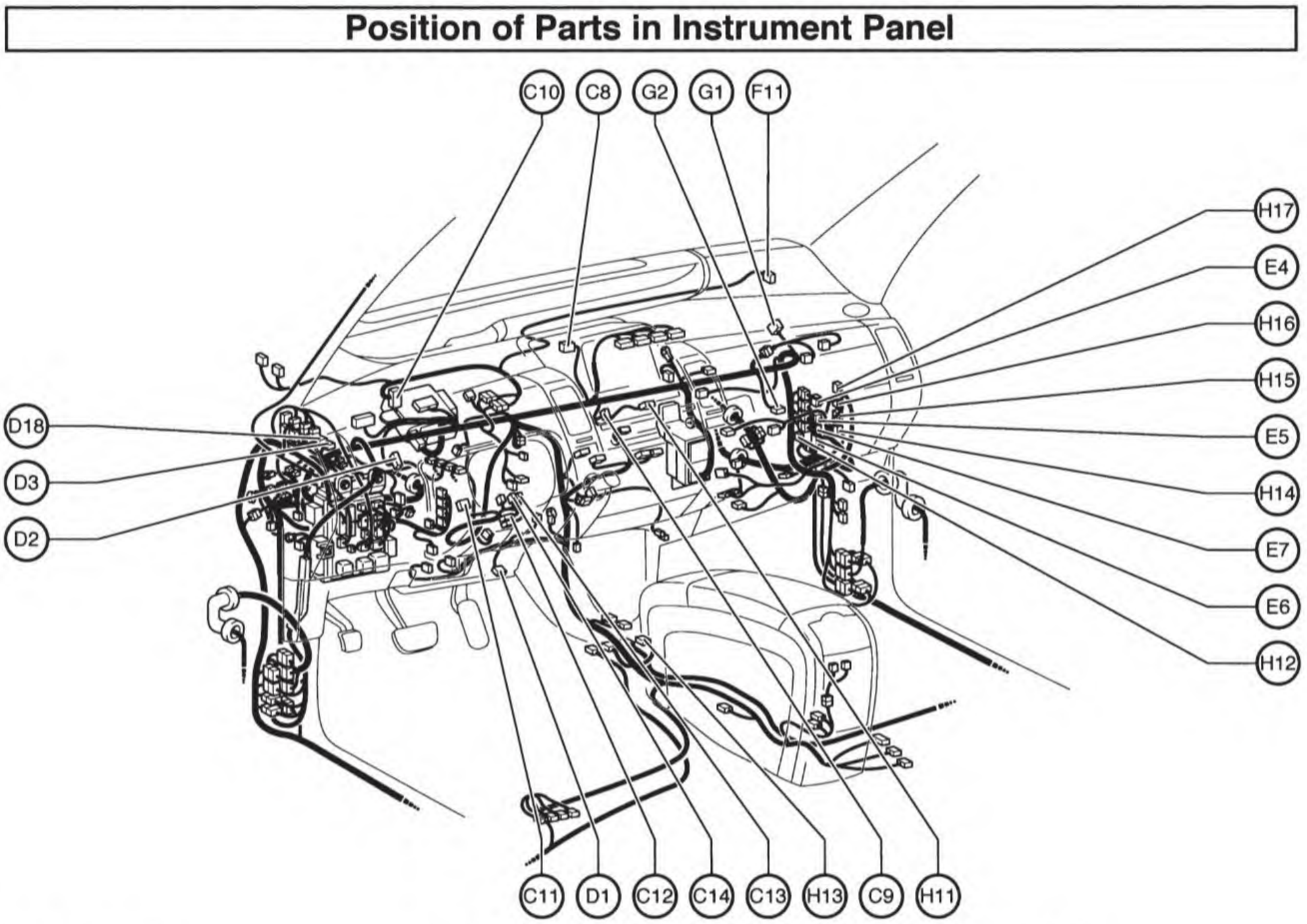


Green Tech

Used Shop Rags

Used shop rags are a source of hazardous waste in automotive shops. If a rag has been contaminated with material considered to be hazardous waste, it must be handled properly. If thrown out, the contaminants on the used rag could do as much damage as the material itself. For example, if the rag has had used automotive fluid applied to it, that fluid could seep off into the soil or into the water and endanger ecosystems. The Environmental Protection Agency expects automotive shops to know how to deal with used shop rags. One option with used rags is to dispose of the rag in the same way as the hazardous waste. Another option is to have the rags taken to an industrial laundry so they can be used again.

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C 8 Center Speaker
C 9 Clock
C 10 Combination Meter
C 11 Combination SW
C 12 Combination SW
C 13 Combination SW
C 14 Combination SW

D 1 Data Link Connector 3
D 2 Daytime Running Light Relay
D 3 Diode (Daytime Running Light)
D 18 Diode (Rear Wiper)

D 4 Engine Control Module
D 5 Engine Control Module
D 6 Engine Control Module
D 7 Engine Control Module

E 4 Engine Control Module
E 5 Engine Control Module
E 6 Engine Control Module
E 7 Engine Control Module

F 11 Front Passenger Seat Belt Warning Light

G 1 Gateway ECU
G 2 Glove Box Light

H 11 Hazard SW
ODO/TRIP SW

H 12 Headlight Beam Level Control ECU
H 13 Heated Oxygen Sensor (Bank 1 Sensor 2)
H 14 Hybrid Vehicle Control ECU
H 15 Hybrid Vehicle Control ECU
H 16 Hybrid Vehicle Control ECU
H 17 Hybrid Vehicle Control ECU

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Figure 27-18. Factory diagrams like this one will help you find loose electrical connectors and other problems in a hybrid drive system.

Summary

- Hybrid vehicles have extensive on-board diagnostic systems that help locate the source of system problems.
- Modern HEV drive systems generate enough electrical energy to cause electrocution. Work safely when servicing a hybrid vehicle.
- Evaluate HV battery condition using the combination meter in the dash battery and a scan tool connected to the diagnostic connector on the vehicle.
- The most common reason for HV battery replacement is physical damage. HV batteries are usually located in the trunk area or under the rear seat cushion or floor pan.
- Other factors to check when troubleshooting HV battery power problems include battery relays and contactors, condition of HV power cables, and an open fuse.
- A faulty HV PCM can trip various trouble codes, indicating which circuit in the module might be faulty. If your scan tool indicates a problem with a specific circuit board, you may be able to order and install just the failed circuit board.

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- If the cooling system fails, components in the hybrid drive system can overheat. If the system is air cooled, listen for normal operation of the cooling fan. If the system is water cooled, place a stethoscope on the electric pump to determine if it is running when the hybrid is under a high electrical load.
- A motor-generator trouble code indicates various problems: short coils, poor power cable connections, permanent magnet armature damage, and motor speed sensor failure, among other things.
- Motor-generator stator problems will trip trouble codes when the circuit resistance, voltage, or current for any stator winding is not correct.
- The process of removing a motor-generator varies with the vehicle make and model, and with the location of the motor-generator itself.
- When a scan tool shows a problem with a particular component but the component tests good, check for wiring problems in the corresponding circuit.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

high-voltage buffer zone

high-voltage disconnect

hybrid ground fault interrupter

insulating gloves

Activities

1. Look up service information for two different make and model hybrid vehicles. For each vehicle, find service instructions for one of the step-by-step service procedures presented in this chapter. Compare all three sets of service instructions and note the differences in procedures, location of components, and general system operation.
2. While wearing insulated gloves and eye protection, inspect a hybrid vehicle. Locate the HV battery, motor-generator, and HV PCM. Trace how each of these components is connected to the others.

Review Questions

Answer the following questions using the information provided in this chapter.

1. What will happen if high voltage from the HV battery or motor-generator is shorting to frame ground?
2. List nine safety rules you should follow when working on high-voltage, high-current hybrid drive systems.
3. To prevent electric shock, wait at least _____ minutes after removing the high-voltage disconnect before working on the high-voltage circuits.
4. What is the common cause of problems with contactors?
5. Describe the steps in a pinpoint test on a high-voltage contactor.
6. What common problems can occur with HV power cables?
7. What should you do if your scan tool shows that resistance values for a power cable are not within specification?
8. What will happen in a hybrid vehicle if current flow becomes too high due to a short?
9. Describe how to replace a high-voltage power cable.
10. What commonly causes a circuit board in the HV PCM to fail?
11. Which components monitor the condition of the motor-generator and store codes if any related circuits are operating out of range?
12. Normal motor-generator stator resistance readings should be approximately _____ ohms.

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ASE-Type Questions

1. Technician A says that most hybrid vehicles conduct 300 volts dc. Technician B says hybrid vehicles only conduct the same voltage as a residential wall outlet. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Technician A says you should remove all jewelry before working on a hybrid's high-voltage circuits. Technician B says you should always wear rubber-soled shoes when working on a hybrid vehicle. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. Technician A says that when working on HV power cables and other high-voltage components, you should wear gloves with an insulation value of 100 volts. Technician B says you should use OSHA-approved "lineman gloves." Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. Technician A says that when towing a front-wheel drive hybrid, the front wheels should be raised off the ground. Technician B says that when towing an all-wheel drive hybrid with motor-generators at the front and rear, all four wheels must be raised off the ground. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. Technician A says that you must wait at least three minutes after removing the high-voltage disconnect before working on the high-voltage capacitors in the inverter circuit. Technician B says that after you remove the high-voltage disconnect, you should remove the high-voltage fuse and keep it in your pocket. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Trouble codes and symptoms indicate battery power is okay, but battery power is not reaching the HV PCM. Technician A says to check the operation of the battery relays and contactors. Technician B says to check the condition of the HV power cables. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. A circuit board in the HV PCM has failed. Technician A says to check the cooling system. Technician B says the failed circuit board should be replaced. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. Technician A says a motor-generator can fail if the car is hit by lightning or used for an extended period. Technician B says a failed motor-generator will not affect drive performance.
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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Chapter 28
12-Volt and HV Battery Technology

After studying this chapter, you will be able to:

- Describe the operation of a basic battery cell.
- Summarize the functions of all types of automotive batteries.
- Explain the construction of a 12-volt battery and how it operates in a car engine.
- Compare battery terminals and connection types.
- Summarize typical 12-volt and HV battery types and ratings.
- Explain how temperature affects battery performance.
- Summarize the operation of both a fuel cell and a flywheel generator.
- Describe the role of capacitor banks in battery operation.
- Correctly answer ASE certification test questions that require a basic knowledge of chemical/electrical and mechanical/electrical storage devices.

Modern passenger vehicles use at least one of two types of automotive batteries: 12-volt or high-voltage. Conventional vehicles use a 12-volt lead-acid battery. Hybrid vehicles are equipped with a high-voltage nickel metal hydride or lithium-ion battery that can produce 100–300 volts of electricity. This type of battery is commonly referred to as an HV battery. Many hybrids use both a 12-volt battery and an HV battery.

Although the operating principles are similar for all automotive batteries, the HV battery found in hybrid vehicles is several times more powerful than the largest lead-acid battery. An HV battery contains as many as 50 kilowatts of potentially deadly energy.

To be a good technician, you must fully understand both 12-volt and HV batteries. Refer to **Figure 28-1**. Both battery types play an important role in the electrical and drive train systems of today's passenger vehicles.

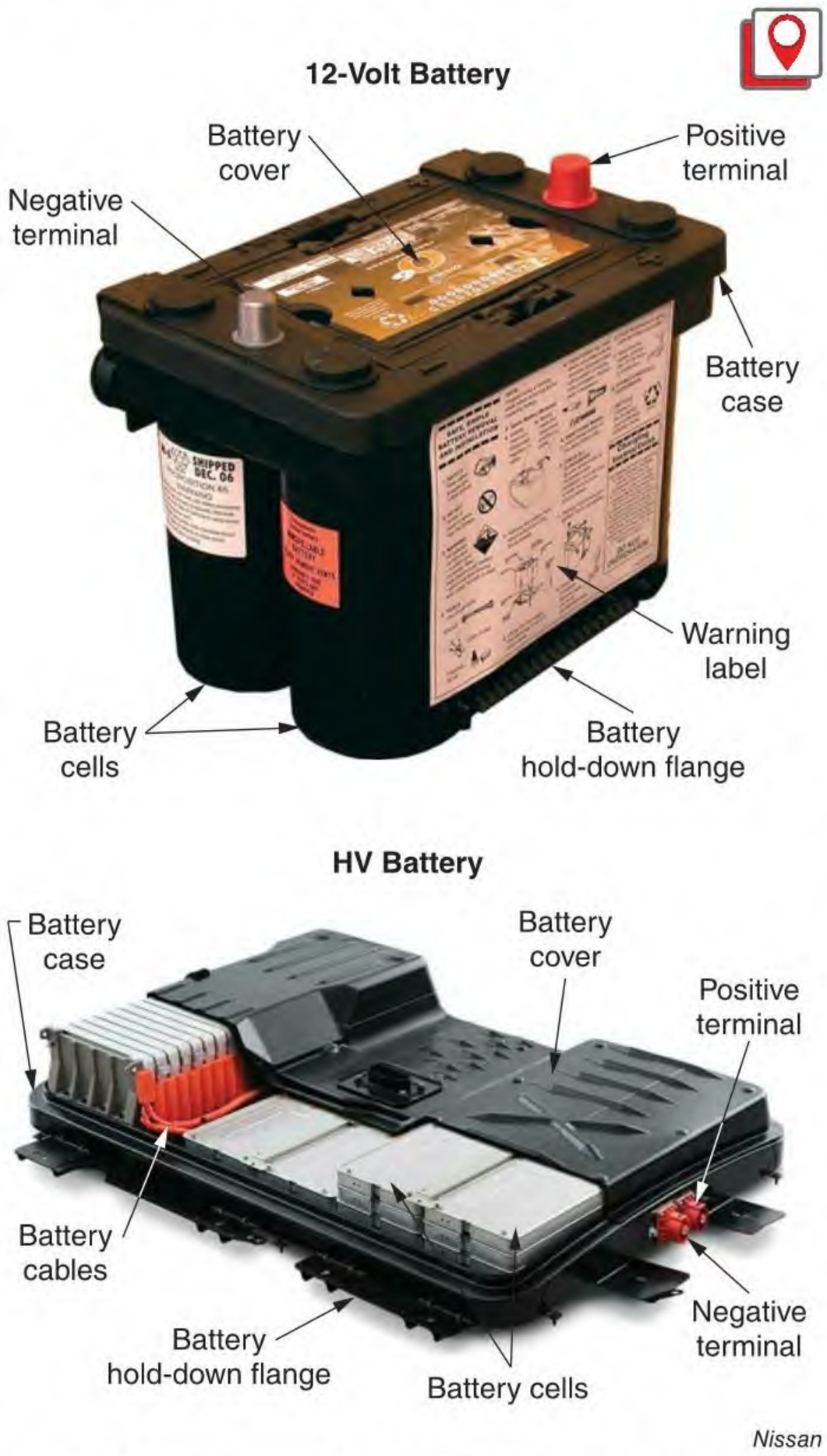
This chapter will briefly explain the theory, construction, and operation of the batteries used in modern passenger vehicles. You will also learn about 12-volt and HV battery cables, terminals, connectors, and ratings. Experimental flywheel generators, ultracapacitors, and fuel cell battery designs will also be discussed. As a result of your study, you will be better qualified to service, troubleshoot, and test any kind of automotive battery.

Battery Principles

A ***12-volt battery***, such as an automotive battery, is an electrochemical device that produces and stores electricity. All batteries produce smooth, direct current (dc), where free electrons move in only one direction through their conductors.

When ***discharging*** (current and electrons flowing out of the cells), the battery changes chemical energy

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Nissan

Figure 28-1. Compare a 12-volt battery and high-voltage battery. Note the large positive and negative terminals on the 12-volt battery that allow high current flow out of the battery. An HV battery encloses several individual battery packs wired in series.

into electrical energy. In this way, the battery releases stored energy.

During ***charging*** (current flowing back into the cells from the charging system), the battery converts electrical energy back into chemical energy. The battery can then store this energy for extended periods of time until needed.

Battery cycling refers to the amount of time between discharging and charging the battery cells. After not being charged for an extended period of time, a 12-volt battery can become almost fully discharged. If it still has enough stored energy to crank and start the engine, engine power will rotate the alternator or motor-generator to recharge the battery. Repeated ***deep cycling*** (going from a very low charge to a full charge) can shorten the service life of a 12-volt battery.

Basic Battery Cell

A simple metal-acid ***battery cell*** consists of a negative plate, positive plate, container, and electrolyte (battery acid). In an HV battery cell, the electrolyte is usually an acidic lithium paste or gel. A lead-acid battery uses liquid sulfuric acid as an electrolyte.

The battery plates are made of two different (dissimilar) metals. The plates are capable of storing a huge supply of free electrons. The battery cell container is usually plastic to resist corrosion.

If a ***load*** (current-using device) is connected to a simple battery cell, current will flow through the load. If the load is a lightbulb, for example, the bulb will glow because of electron movement.

When the battery cell is being charged, the alternator or hybrid motor-generator causes electron flow through the cell. Electron flow through the battery cell causes a positive (+) charge to be deposited on the positive plate and a negative (–) charge to be deposited on the negative plate. This causes the plates to have a difference in voltage potential (electrical pressure, or voltage).

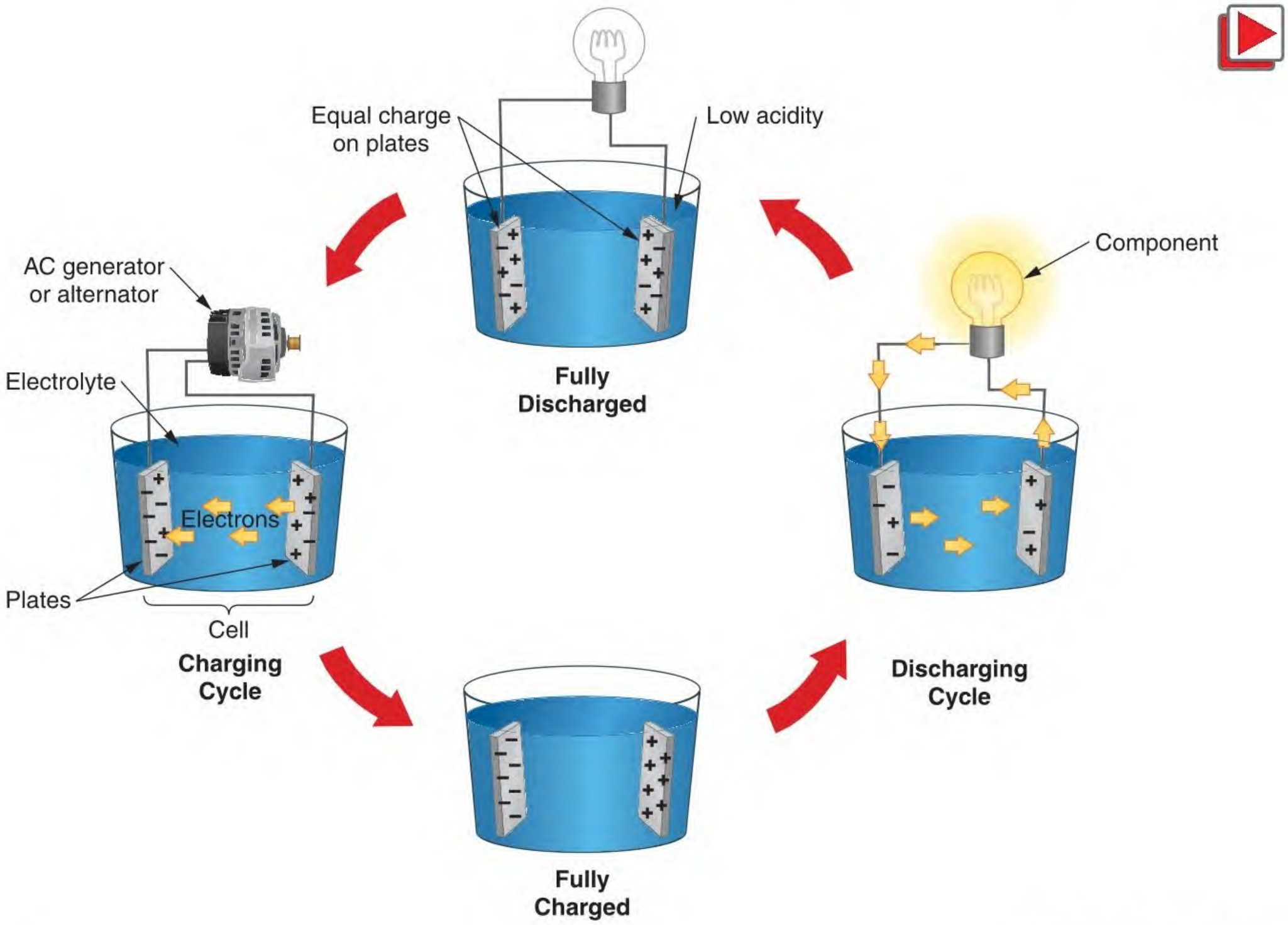
When a load is connected across the battery cell terminals, the resulting current attempts to equalize the difference in voltage potential on the two cell plates. Excess electrons move from the negative plate to the positive plate to cancel out the difference in potential. With enough current flow, the electrolyte will chemically change into water. Complete discharging of the plates results in a dead battery cell with no voltage potential. Refer to **Figure 28-2**.

Battery Functions

A vehicle battery has several important functions. It must:

- Operate the starting motor, ignition system, electronic fuel injection system, and other electrical devices during engine cranking and starting.
- Supply all the electrical power, even electric propulsion, for the vehicle whenever the engine is not running.
- Help provide electricity to the instrumentation and all electric circuits when the vehicle is stopped and the internal combustion engine is not running.

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Figure 28-2. Basic battery cycling.

- Act as a capacitor or filter (voltage stabilizer) that produces smoother dc than the alternator or motor-generator and send the filtered dc through the rest of the electrical system.
- Store huge amounts of potential electrical energy for extended periods.

To illustrate how a battery functions in a conventional vehicle, imagine the following scenario. You are sitting in your car, listening to the radio, but the engine is not running. The battery is supplying the current to operate the radio, any dash indicator lights, and the clock. You don't know it, but your battery is slowly discharging and draining. When you start the engine, the battery provides a tremendous amount of current (approximately 100 amps on a large V-8 engine). This current operates the starting motor and essential engine systems. This, too, drains more current out of the battery.

As soon as the engine starts, the charging system takes over. The alternator recharges the battery and feeds current to other electrical devices.

12-Volt Batteries

Most modern vehicles still use a conventional 12-volt battery and 12-volt main electrical system. A 12-volt battery has six cells, which produce an ***open circuit voltage*** of 12.6 volts.

Some large pickup trucks with diesel engines use two 12-volt batteries connected in parallel. When two batteries are in parallel, their output voltage stays the same, but their current output doubles. Dual batteries are needed to crank and start compression-ignition diesel engines with 12-volt electrical systems.

Caution

When two batteries are connected in series, their output voltage doubles. Keep this in mind when working with batteries. Two 12-volt batteries connected in series produce 24 volts, which could damage electrical devices.

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12-Volt Battery Construction

Automobile batteries are built to withstand severe vibration, extreme temperatures, corrosive chemicals, high current discharge, and prolonged periods without use.

Battery Cell

A 12-volt battery cell is made up of positive plates, negative plates, straps, and separators. Look at **Figure 28-3**. These elements fit into a cell compartment in the battery case.

The ***battery plates*** are made of a grid (stiff mesh framework) coated with porous lead. Several plates are needed in each cell to provide enough battery power. The chemically active material in the negative plates is porous lead. The active material on the positive plates is lead peroxide. Since the lead on the plates is porous, like a metal sponge, the battery acid easily penetrates the material. This aids the chemical reaction and the production of electricity.

Calcium or antimony is normally added to the lead to increase battery performance and decrease ***gassing*** (acid fumes forming during chemical reaction).

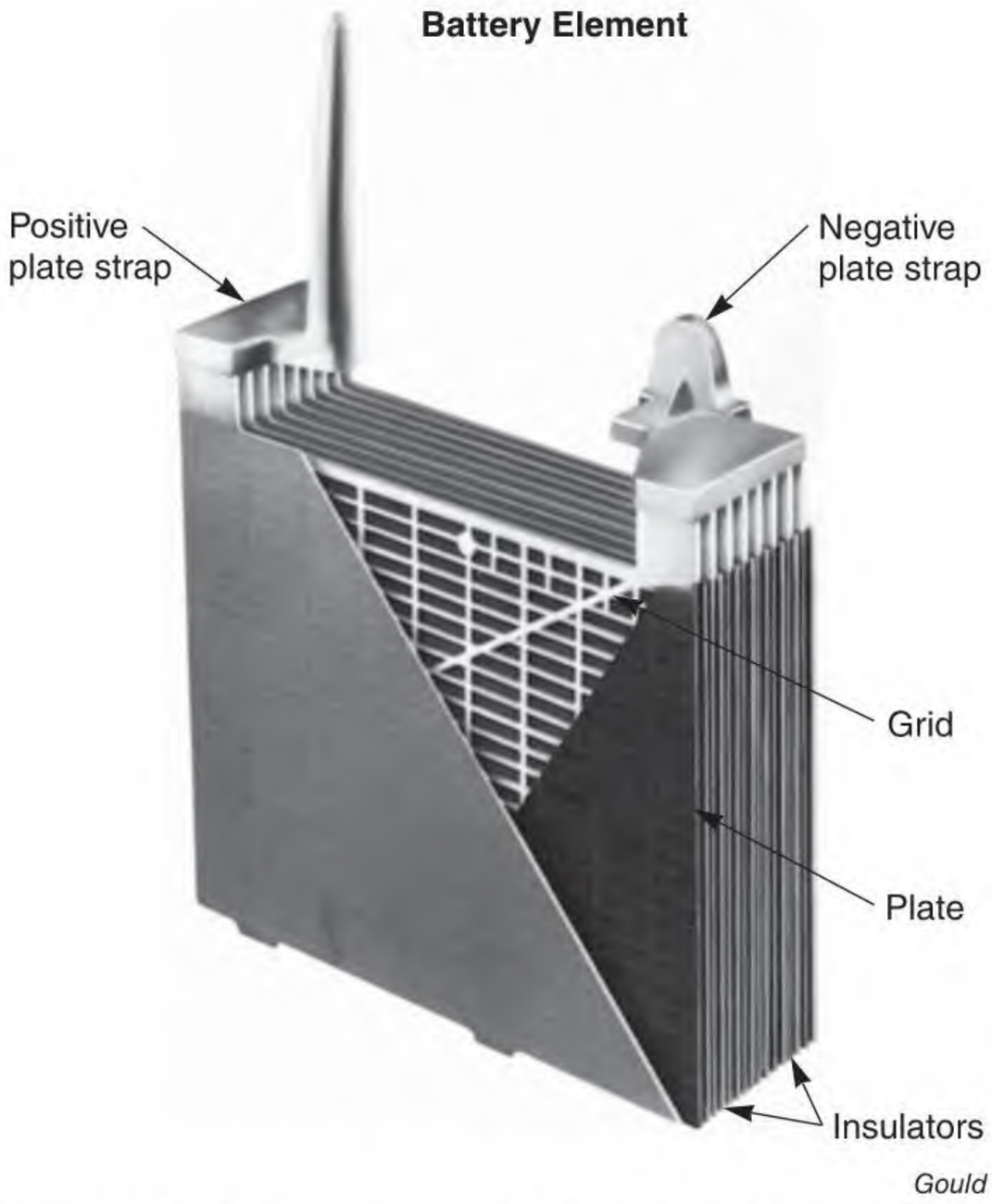


Figure 28-3. A battery element is made up of a positive plate group, negative plate group, separators, and straps. The elements fit into the battery case compartments that hold acid.

Gassing involves the conversion of water in the electrolyte into hydrogen and oxygen. These gases escape from the top of the battery. Gassing results in a loss of water.

Lead ***battery straps***, or ***connectors***, run along the upper part of the battery case to connect the plates. One strap connects the negative plates to form a negative plate group. Another lead strap connects the positive plates, forming the positive plate group. The battery terminals (top posts or side terminals) are constructed as part of one end of each strap.

Separators fit between the battery plates to keep them from touching each other and shorting. The separators are made of insulating material and have openings that allow free circulation of the electrolyte around the battery plates.

A 12-volt battery has six 2.1-volt cells wired in series to produce 12.6 volts dc. A voltmeter should read 12.4–12.6 with a fully-charged 12-volt battery.

Battery Case, Cover, and Caps

The 12-volt ***battery case***, usually made of high-quality plastic, holds the elements and electrolyte. The case must withstand extreme vibration, temperature change, and the corrosive action of the battery acid. Dividers in the case form individual compartments for each element. A compartment and its element make up one cell.

The ***battery cover*** is bonded to the top of the battery case and seals the top of the case. There is an opening above each battery cell for battery caps or a cell cover.

Battery caps snap into the holes in the battery cover. They keep electrolyte from splashing out of the battery. The caps also serve as spark arrestors (keep sparks or flames from igniting gases inside battery). Maintenance-free batteries have a large cap that is not removed during normal service.



Warning

Hydrogen gas can collect at the top of a battery. If exposed to a flame or spark, this gas can explode.

Electrolyte (Battery Acid)

Electrolyte, often called ***battery acid***, is a mixture of sulfuric acid and distilled water. Electrolyte is poured into each cell until the plates are covered. The acid should just touch the split ring in the top of the case.

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Distilled water is used in 12-volt batteries because it does not contain many of the impurities found in tap water. These impurities can contaminate the battery plates and reduce efficiency.

Warning

Take precautions to prevent electrolyte from contacting your skin or eyes. The sulfuric acid in the electrolyte can cause serious burns or even blindness.

Battery Charge Indicator

A ***battery charge indicator***, also called a ***battery eye*** or ***test indicator***, shows the general charge condition of a 12-volt battery. See **Figure 28-4**.

Battery Terminals

Battery terminals provide a means of connecting the battery plates to the car's electrical system. Either two round posts or two side terminals are commonly used on 12-volt batteries. Refer to **Figure 28-5**.

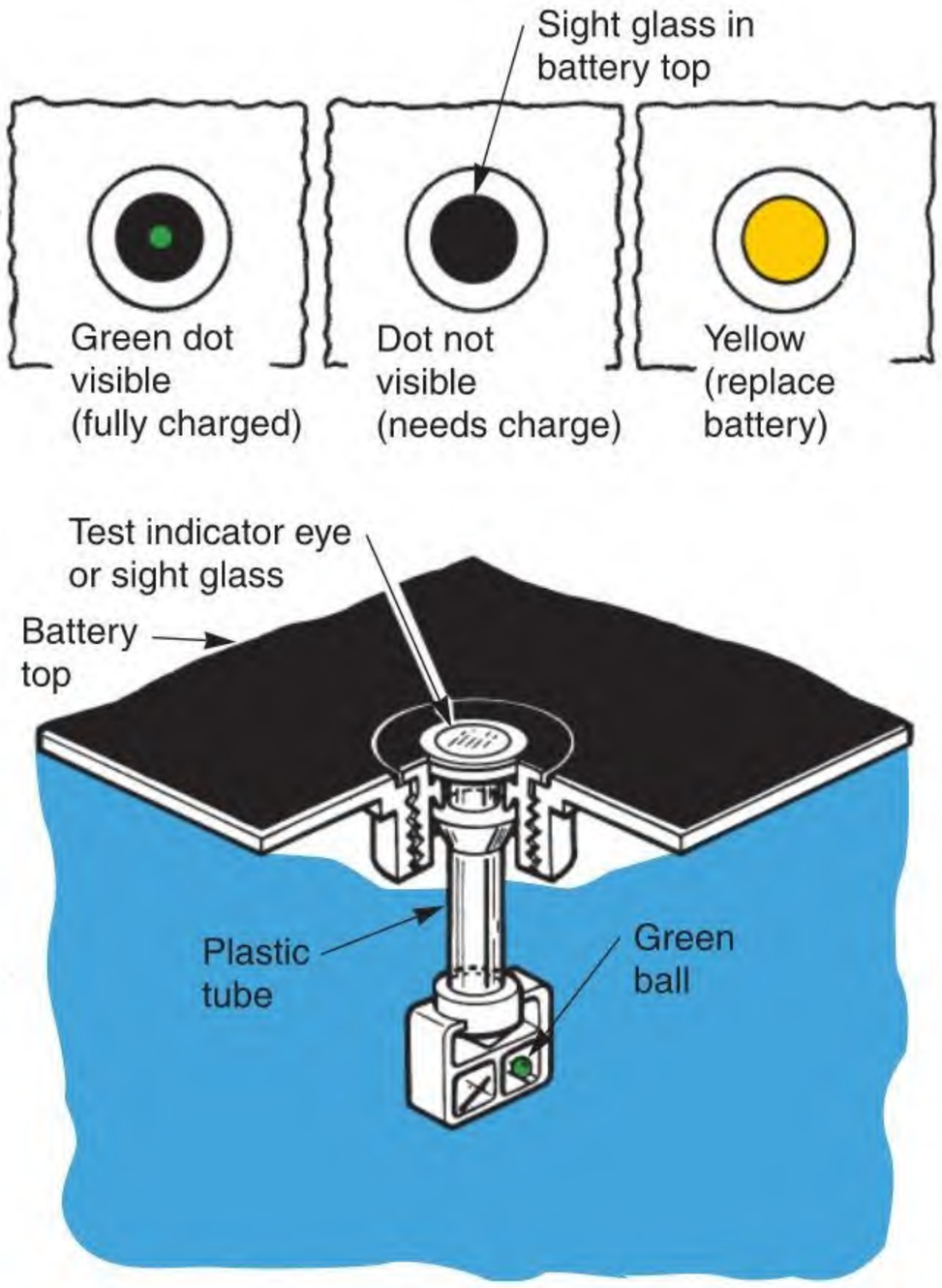
Battery posts are round metal terminals that extend through the top of the battery cover. They serve as male connections for female battery cable ends. The ***positive post*** is larger than the negative post. It may be marked with red paint and has a positive (+) symbol on or near it. The ***negative post*** is smaller than the positive post and may be black or green in color. It normally has a negative (–) symbol on or near it.

Side terminals are electrical connections located on the side of the battery. They have female threads that accept a special bolt on the battery cable end. Side terminal polarity is identified by positive and negative symbols on the battery case.

12-Volt Battery Cables

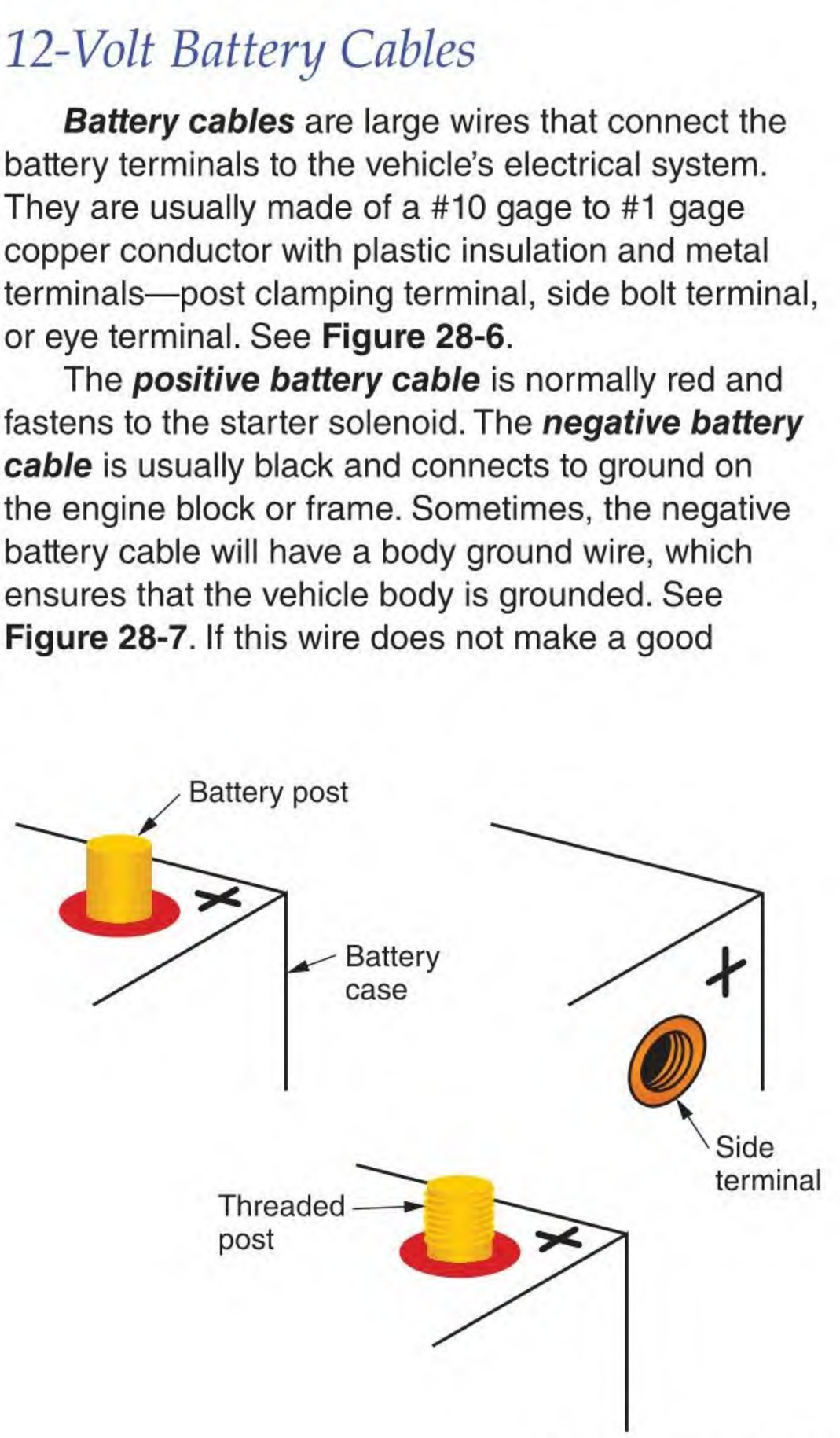
Battery cables are large wires that connect the battery terminals to the vehicle's electrical system. They are usually made of a #10 gage to #1 gage copper conductor with plastic insulation and metal terminals—post clamping terminal, side bolt terminal, or eye terminal. See **Figure 28-6**.

The ***positive battery cable*** is normally red and fastens to the starter solenoid. The ***negative battery cable*** is usually black and connects to ground on the engine block or frame. Sometimes, the negative battery cable will have a body ground wire, which ensures that the vehicle body is grounded. See **Figure 28-7**. If this wire does not make a good



Chrysler

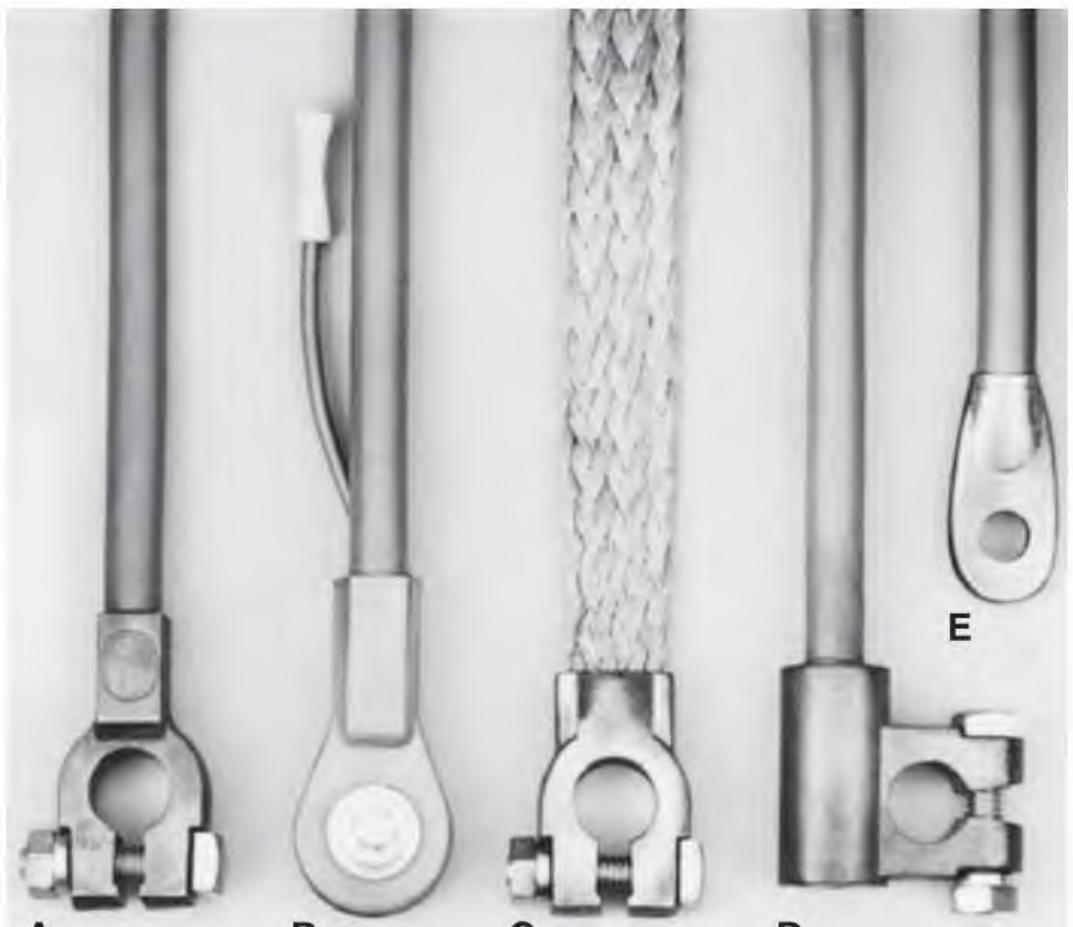
Figure 28-4. A charge indicator provides an easy way of checking battery condition.



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Figure 28-5. Basic battery terminal types. Side terminals are becoming more common because they resist corrosion very well.

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Belden

Figure 28-6. Battery cable types. A—Post-type battery cable. B—Side terminal battery cable with pigtail for ground or accessory connection. C—Braided ground cable. D—90° post-type cable. E—Solenoid-to-starter cable (large conductor size for carrying large amount of current to the starter).

connection, components grounded to the car body may not operate properly. Note that ground cables do not always use insulation.

Battery Tray and Retainer

A ***battery tray*** and ***retainer*** hold the 12-volt battery securely in place. They keep the battery from bouncing around during vehicle movement. The retainer, or ***battery hold-down***, usually consists of a special bracket and fasteners that hold the battery to its tray. Look at **Figure 28-8**. It is important that the tray and retainer be tight and in good condition to prevent battery damage.

In many late-model vehicles, the battery tray houses a ***battery temperature sensor*** that monitors battery temperature. The engine control module uses data from this sensor to determine when to vary the battery charging rate.

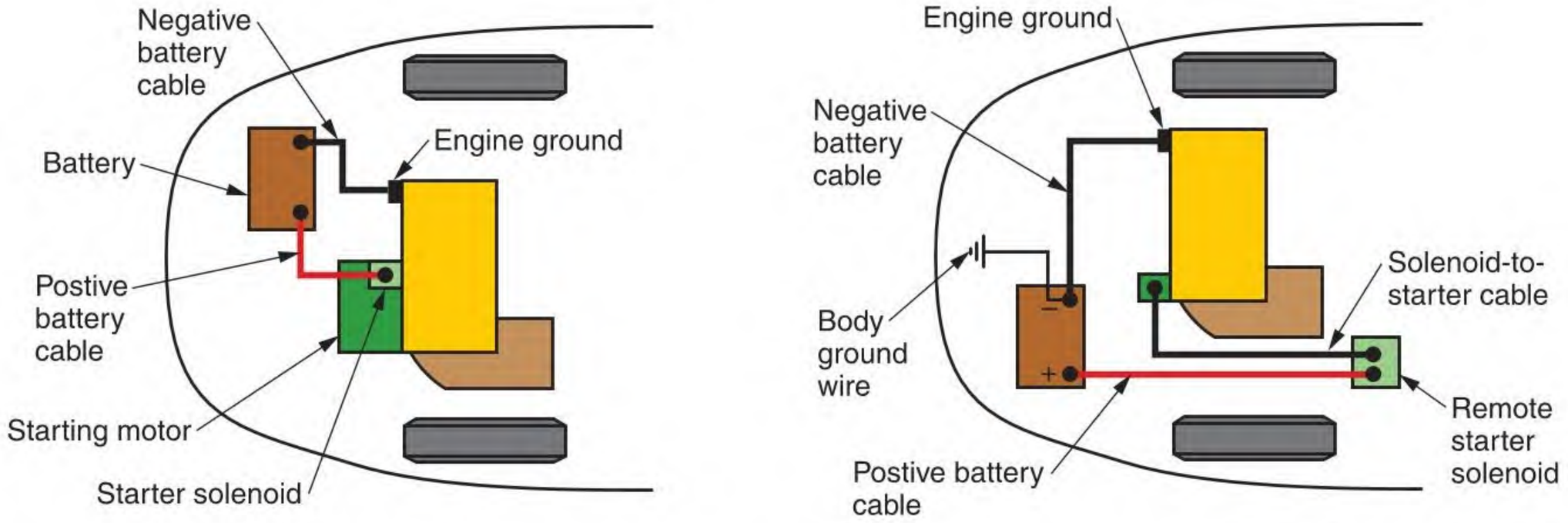
Battery heat shields are designed to keep excess engine heat from damaging the battery. They usually fit over the battery or between the engine and battery case. Always reinstall battery heat shields to ensure normal battery life.

12-Volt Battery Types

Several variations of 12-volt lead-acid batteries are available for today's vehicles. The differences are minor, but you should be aware of them.

A ***maintenance-free battery*** is easily identified because it does not use removable filler caps. The tops of the battery cells are covered with a large, snap-in cover. Calcium is used to make the battery plates, so water does not have to be periodically added to the electrolyte. The calcium in the plates reduces the production of battery gases. As a result, battery gas does not carry as much of the chemicals out of the battery. This increases battery service life and decreases service requirements.

A ***gel battery*** works just like a lead-acid battery, but it does not contain a liquid electrolyte. Instead, the electrolyte in a gel battery has a pastelike consistency.



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Figure 28-7. The battery cable may be connected to the vehicle's electrical system in slightly different ways, depending on the make and model.

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Figure 28-8. The battery retainer connects to the battery tray (under the battery) and holds the battery securely in place.

If the battery case is cracked or broken, the electrolyte will not leak out and the battery will continue to function. Additionally, this type of battery is completely sealed, eliminating gassing and minimizing the risk of explosion.

A disadvantage of a gel battery is that improper charging can burn a void in the electrolyte gel. This can permanently lower the power output of the battery. Therefore, gel batteries require a specific, low charging rate.

An ***absorbed glass mat battery***, or ***AGM battery***, contains fiber matting that absorbs the liquid electrolyte and holds it between the battery plates. Because AGM batteries are sealed, there is no gassing and the risk of explosion is minimized. AGM batteries are not as sensitive to improper charging as gel batteries.

12-Volt Battery Ratings

Battery ratings are set according to national test standards for battery performance. The ratings allow technicians and consumers to compare the cranking power of one battery to another.

The two most common methods of rating lead-acid storage batteries are by the cold cranking rating and by the reserve capacity rating. These ratings were developed by the Society of Automotive Engineers (SAE) and the Battery Council International (BCI).

The battery ***cold cranking rating*** is the amount of current (in amperes) the battery can deliver for 30 seconds at 0°F (–18°C), while maintaining terminal voltage of 7.2 volts (1.2 volts per cell). This rating indicates the battery's ability to crank a specific engine (based on starter current draw) at a specified temperature. For example, one auto manufacturer recommends a battery with 305 cold-cranking amps for a small 4-cylinder engine. A larger engine might require a more powerful battery with 450 cold-cranking amps. Engine size and its compression ratio generally determine the cold cranking rating for a replacement battery.

The ***reserve capacity rating*** is the time needed to lower 12-volt battery terminal voltage below 10.2 volts (1.7 volts per cell) at a discharge rate of 25 amps. Reserve capacity rating assumes that the test starts with a fully charged battery at 80°F (27°C). Reserve capacity is given as a time interval in minutes. For example, if a 12-volt battery is rated at 90 minutes and the charging system fails, the driver has approximately 90 minutes of driving time under minimum electrical load before the battery goes completely dead.

The ***amp-hour rating*** is a measurement of how much current the battery can produce for 20 hours at 80°F (27°C) with battery voltage staying above 10.5 volts. Amp-hour ratings are no longer used because manufacturers used different discharge rates to yield different amp-hour ratings.

Battery Temperature and Efficiency

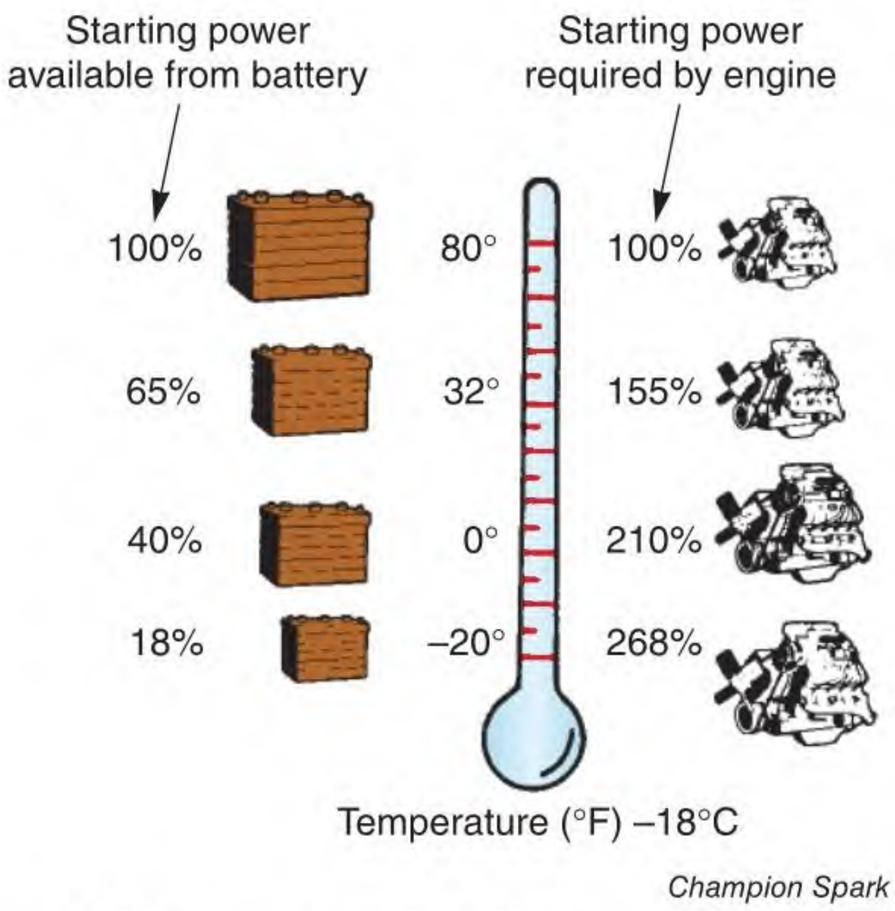
As battery temperature drops, battery power is reduced. At low temperatures, the chemical action inside the battery is slowed. When it is cold outside, a battery will not produce as much current as when the outside temperature is warm. This affects a battery's ability to start an engine in extremely cold weather. Also, when an engine is cold, the motor oil is very thick. This increases the amount of current and torque needed to rotate the crankshaft and slide the pistons in the cylinder block.

Figure 28-9 shows a chart comparing battery efficiency and required starting power. Note that at 0°F (–18°C), a battery has only 40% of its normal cranking power. In addition, starter current draw will be up approximately 200% of its normal value due to the increased viscosity of cold oil. The engine could be very difficult to start on a cold morning. The battery, starter, and electrical connections must be in almost perfect condition for an engine to crank on a cold morning.

HV Batteries

An HV battery, also called a ***battery stack*** or ***battery bank***, stores chemical-electrical energy for starting the internal combustion engine, for full-electric

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Champion Spark Plugs

Figure 28-9. Temperature affects battery power and starter current draw. This is why engines crank slowly in very cold weather.

propulsion, and in some cases to provide 12–15 volts dc for the vehicle's electrical accessories and conventional electric circuits. HV battery technology has changed and improved considerably over the past few years. There have been three major stages of hybrid development: first generation hybrid electric drives, true high-voltage electric driveline, and lithium-ion (Li-ion) HV batteries.

First generation hybrid electric drives were not HV. These vehicles used a bank of 12-volt lead-acid batteries wired in series to produce a 24- or 48-volt battery stack. The electric drive voltage and current output from this setup was minimal. Lead-acid batteries provided minimum motor torque assist and minimum fuel economy gains.

Second generation hybrids connected a true high-voltage electric driveline to the conventional engine, transmission, and differential. These much-improved hybrids use NiMH battery cells to assist the engine with added drive torque.

Some second-generation hybrids use even more powerful lithium-ion (Li-ion) HV batteries, which provide an extended driving range and better fuel economy ratings. Lithium-ion HV batteries are designed to handle high current flow rates during charging and discharging. A lithium-ion battery has a superior weight-to-power ratio than lead-acid and nickel-acid battery designs. HV battery assemblies can weigh about 200 lbs. (91 kg) for electric-assist hybrids to over 600 lbs. (273 kg) for full-electric-drive hybrids.

Tech Tip

HV batteries are wet-charged with a semi-solid electrolyte. A special high-voltage battery charger is needed to recharge the large number of cells wired in series. Refer to the index for more information.

Many hybrids use a ***dual voltage system***: 12 volts for most of the vehicle's conventional electrical/electronic circuits, and high voltage (HV) for the double-ought (00) conductors and HV motor-generator of today's electric drive trains. Both electrical systems are wired separately, but interface through the ECMs and HV power control module. Refer to **Figure 28-10**. In other hybrid designs, the HV battery can be stepped down to provide lower voltages (13–15 volts) for conventional automotive circuits. This eliminates the need for a conventional 12-volt battery to reduce weight and complexity.

HV Battery Construction

The ***HV battery*** is normally mounted in the rear of the chassis, often behind or under the rear seat or in the trunk area. See **Figure 28-11**. Economy vehicles have only one large HV battery. Larger, full-size vehicles and full-electric-drive vehicles can be equipped with two or three HV batteries.

An HV battery is made of many small battery cells inside several battery packs wired in series to produce a high-voltage and current electrical power source. See **Figure 28-12**.

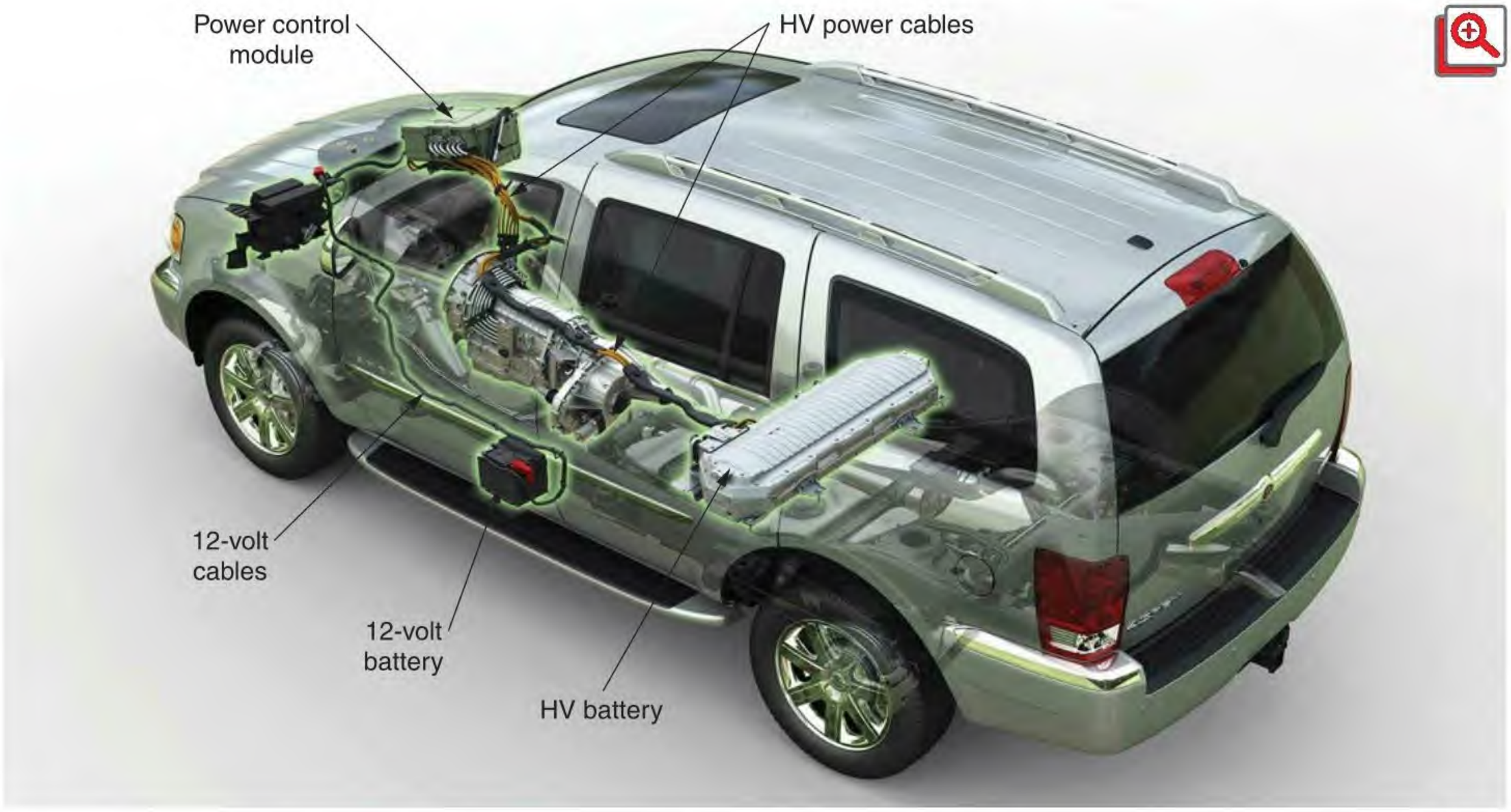
Battery Cells

A ***hybrid battery cell*** is often an individual rechargeable battery similar to those found in laptop computers and flashlights. Each NiMH or lithium-ion cell generates about 1.2–1.6 volts dc. Similar to the common rechargeable battery cells, each is individually sealed to hold its semi-solid electrolyte (acid paste or gel) around the positive and negative plates.

Wires from the positive and negative plate of each cell are soldered or mechanically fastened to adjacent cells in series. HV cells are designed to handle high current flow rates without heat damage during high power recharging and discharging cycles. Since like charges repel and unlike charges attract, a strong and sustained current leaves and re-enters the cell.

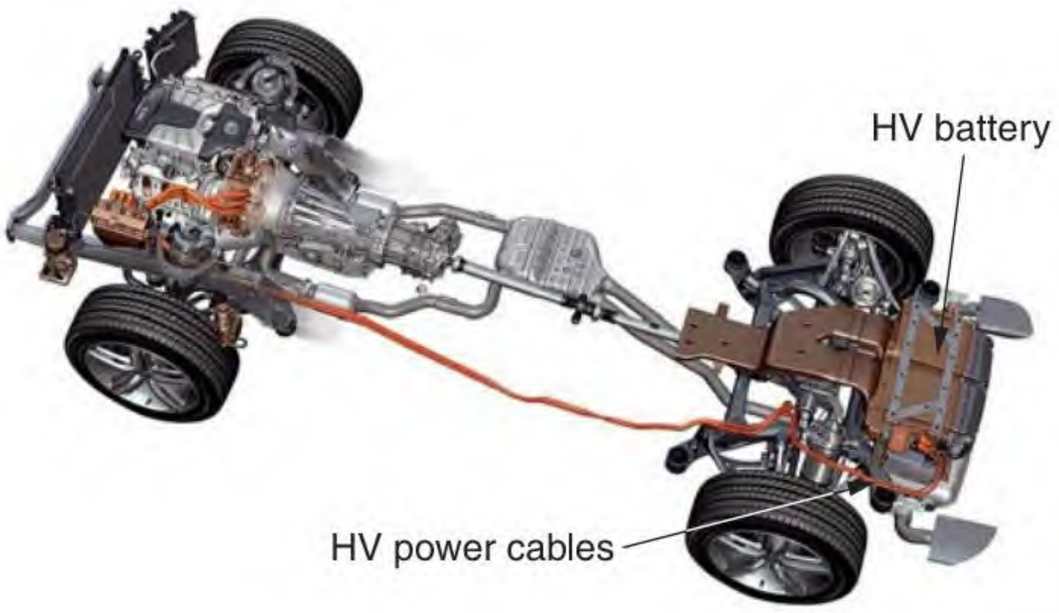
When being recharged, an external electrical power source (engine- or transmission-driven generator)

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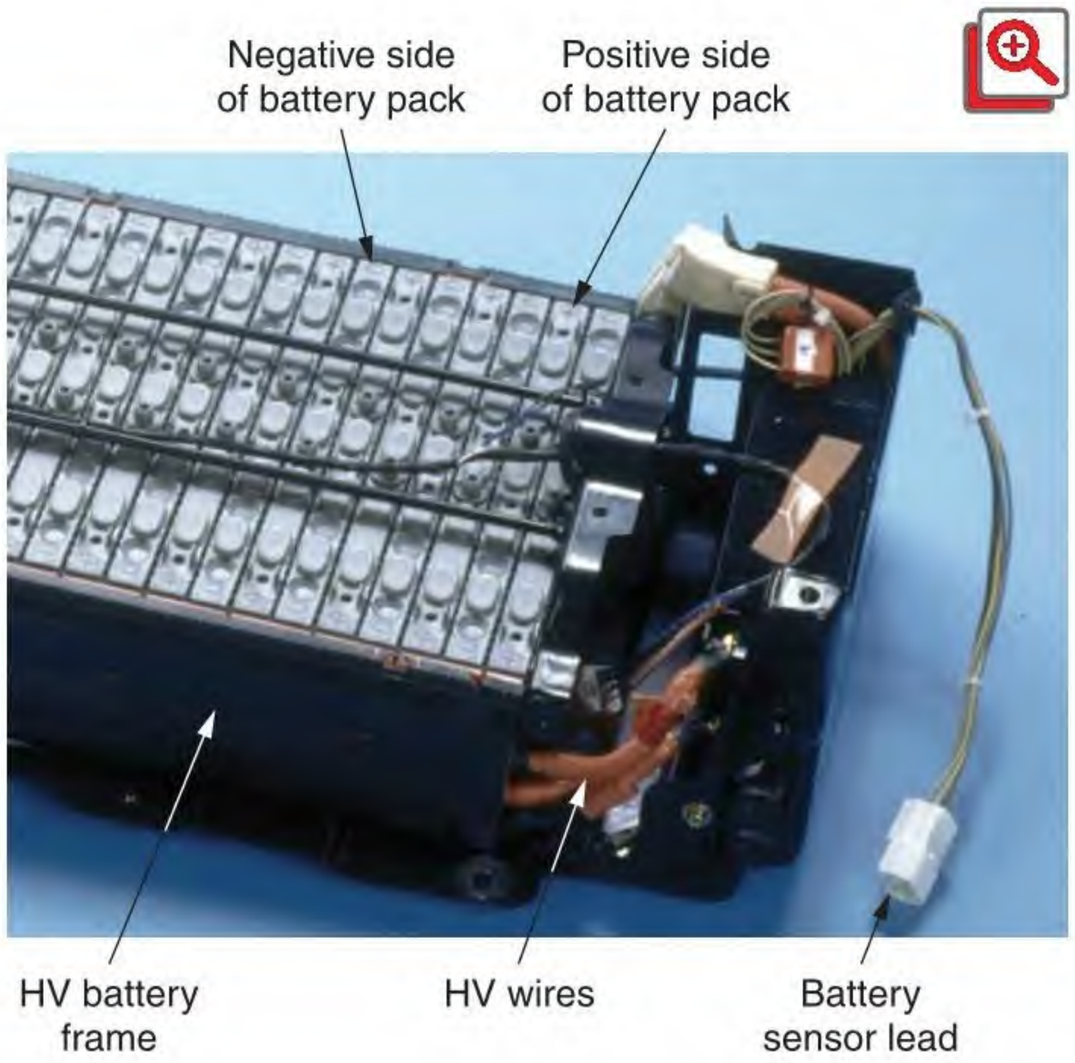
Dodge

Figure 28-10. A large SUV hybrid has a conventional 12-volt battery and an HV battery. Both circuits are isolated from each other.



Volkswagen

Figure 28-11. A large HV battery is often located under the rear seat or in the trunk. Note orange high-voltage cables leaving battery array. Orange cables indicate high voltage and electrocution danger.



Toyota

Figure 28-12. To build a high-voltage hybrid battery, many individual battery packs are wired in series.

applies a regulated voltage to the HV battery pack, forcing the current into the cells in reverse direction.

The electrons (negative charge) or protons (positive charge) then migrate from the positive plate to the negative plate, where they become embedded in the porous electrode materials in a process known as ***intercalation***. Since current flow has caused the

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protons and electrons to embed in the plate material, each has a potential difference trying to push it back out of the battery as stored energy, voltage, and current.

Warning

The electrolyte in lithium-ion HV batteries is very reactive and potentially dangerous. If you accidently pour water on an exposed or damaged lithium battery, a powerful chemical reaction will result. The water and lithium hydroxide acid will react with each other and emit large amounts of explosive hydrogen gas.

Never spray water on a shorted or smoking HV battery to put out a fire. Water will make the battery burn even more violently. If enough hydrogen gas collects in the work area, it could explode like a stick of dynamite.

Battery Packs

An ***HV battery pack*** is a set of low-voltage battery cells wired in series. Refer to **Figure 28-13**. A modern HV battery has approximately 30–40 individual battery packs. For all-electric vehicles, that number is even higher. Each battery pack has six or more battery cells enclosed in a small housing.

Battery pack voltage is 7.2–9.2 volts, depending on the number and types of cells. The battery packs are wired in series to produce a powerful, high-wattage means of storing chemical/electrical energy.

Banks of battery packs are wired in series to produce anywhere from 100–300 volts dc at HV battery cables. For example, an HV battery that has 38 battery packs with 7.2 volts each produces 274 volts dc. An HV battery with 28 7.2-volt battery packs would produce 201 volts dc. Another manufacturer's HV battery might have 30 battery packs of 9.6 volts for a nominal voltage output of 288 volts.

Auto manufacturers are steadily trying to increase HV battery voltages to improve all-electric driving distances without increasing engine operation and fuel consumption.

Battery pack fuses protect against shorts and excessive current draw from each group of cells. Each tiny fuse will overheat and burn open if current flow is too high. A blown fuse will open and isolate the failed battery pack from the rest of the battery. One failed battery pack will lower total HV battery power output slightly, but not significantly.

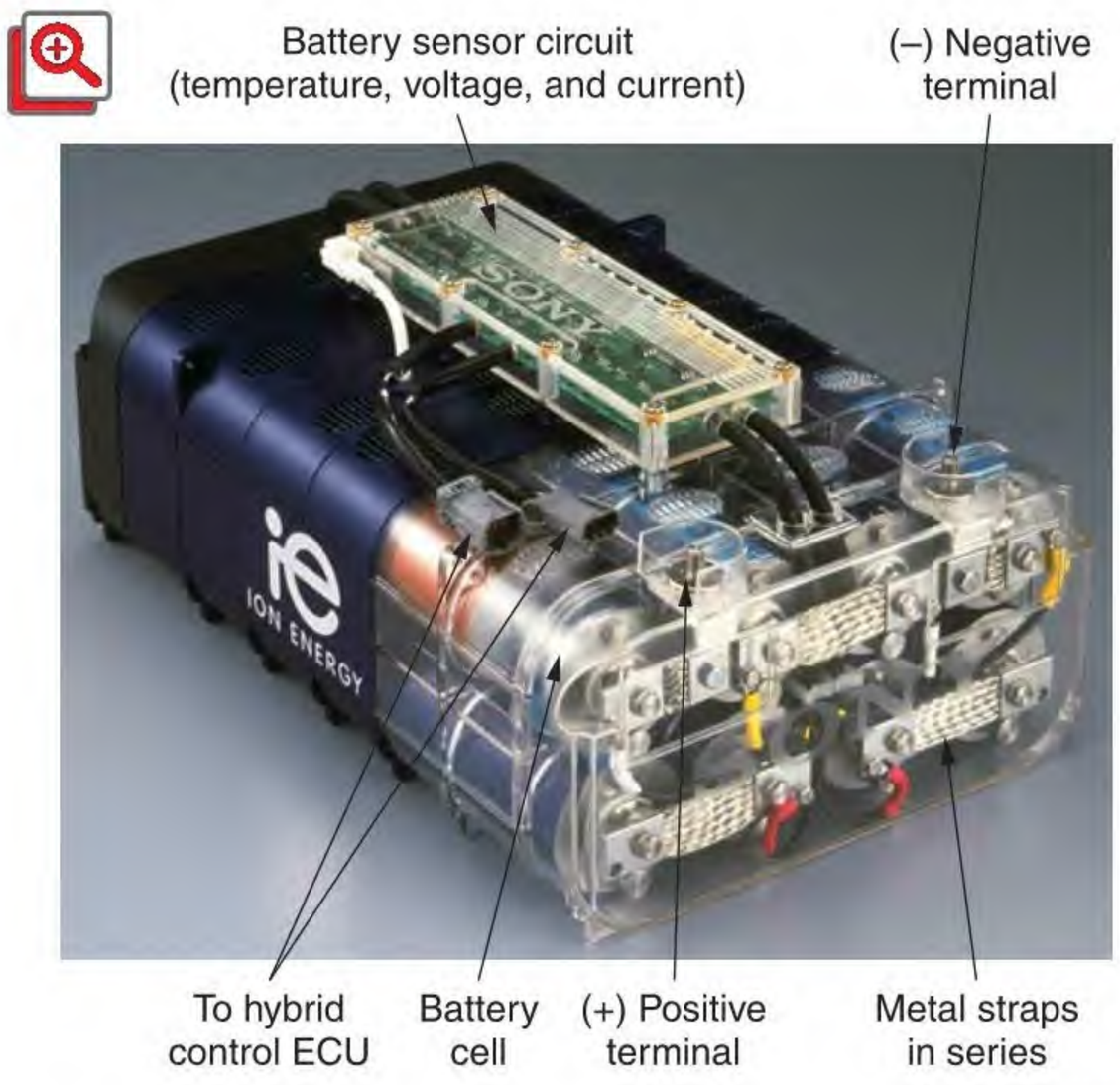


Figure 28-13. Note how small battery cells are wired in series and connected to the sensor circuit on top of this HV battery pack.

Battery Cover and Frame

An ***HV battery cover*** is usually made of plastic. It encloses and protects the individual battery packs. The battery cover also protects against high-voltage dangers from the metal battery pack conductors.

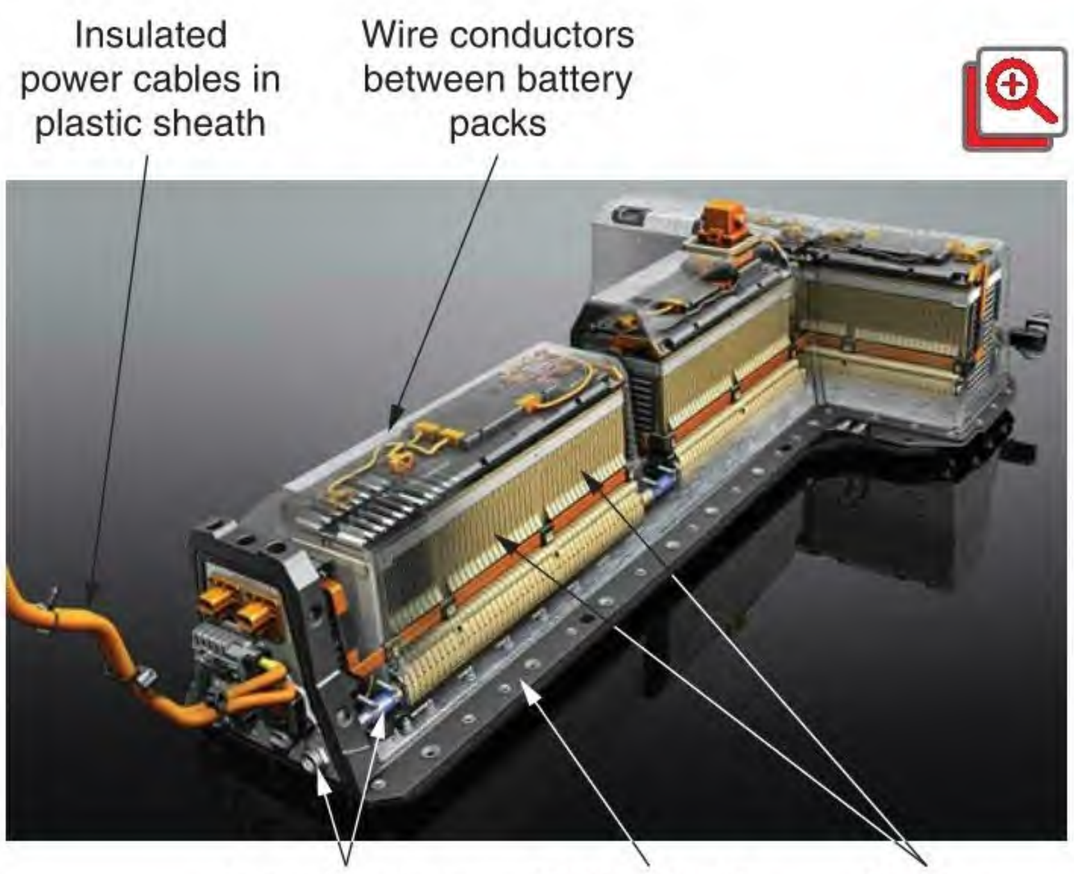
An ***HV battery frame***, usually made of metal, holds the battery packs together and allows the assembly to be bolted to the vehicle's frame. A flange on the HV battery frame provides for mounting the heavy battery assembly securely, protecting the battery in the event of an auto accident. See **Figure 28-14**. Bolting the HV battery to the vehicle frame also provides an excellent frame ground circuit.

Some hybrids do not have a 12-volt battery. Instead, these vehicles employ a step-down transformer and ac-to-dc diode rectifier circuit inside the HV power control module. The transformer-rectifier circuit sends clean 12 volts dc (no ripple in dc waveform) to the low-voltage electronics in the ECMs, electrical accessories, and instrumentation.

HV Battery ECM

An ***HV battery ECM*** is an electronic control circuit that reads signals from HV battery temperature and

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General Motors

Figure 28-14. The hold-down flange on this battery stack runs the perimeter of the battery.

voltage sensors to prevent battery overheating. The HV battery ECM can activate an air, water, or refrigerant cooling system when the battery cells become hot. The HV battery ECM also maintains a preset state of charge on the HV battery by controlling current flow from the motor-generator. Sometimes the HV battery ECM is integrated into the HV battery assembly or the hybrid control module or power control module circuits.

HV battery temperature sensors are used to protect against battery thermal and overcharging damage. A tremendous amount of current flows in and out of the battery when it is being recharged by regenerative braking or when it is powering the electric driveline. If an HV battery temperature sensor detects cell overheating, it will signal the HV battery ECM to disconnect the HV power control module to prevent further overheating.

HV Power Cables

HV power cables include all large-diameter, high-voltage conductors that electrically connect the HV battery, HV power control module, and motor-generator. HV cables consist of large conductors (00 or 000 AWG) coated with bright-orange plastic insulation. The orange insulation serves as a warning of the deadly high voltage being carried by the conductors. Look at **Figure 28-15**. HV power cables



Honda

Figure 28-15. Orange high voltage and wattage cables are clearly visible in this engine compartment. Besides conventional wire insulation, power cables are also protected by thick, flexible plastic sheath.

can carry both high voltage dc and high voltage ac, depending on their location in the electric drive circuit.

HV battery cables are the two large orange conductors that connect dc to the HV power control module. The positive and negative battery cables sometimes extend out of the battery, or a high current/voltage connector is provided for the HV battery cables.

HV motor-generator cables electrically connect three-phase ac from the power control module to the motor-generator. Each motor-generator cable carries a single phase of ac, which is timed 120° from the next ac sine wave.

HV Battery Ratings

HV battery nominal operating voltage is the maximum dc voltage available from the HV battery. Actual HV battery voltage depends on the make and model of the vehicle and the number of cells and packs used in the battery. Nominal HV battery operating voltages can vary from about 150–300 volts dc. Higher nominal voltages increase the efficiency of the electric drive system.

An HV battery is so powerful that it is rated in kilowatts (thousands of watts) of electrical energy. An ***HV battery peak power rating*** might be 100–150 kilowatts (100,000 to 150,000 watts of power). Peak power rating basically determines how much current can be fed to the HV motor for a short period of time. This in turn determines how fast the vehicle can accelerate with full-electric propulsion.

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An ***HV battery continuous power rating*** is the amount of voltage and current that can be safely generated before the battery is fully discharged. A typical value for a late-model HV battery might be 50 kWh (kilowatt hours). The continuous power rating determines how long the hybrid vehicle can be driven in electric mode. An HV battery rating of 50 kWh might allow the vehicle to operate for 40–50 miles per charge. On average, this means one kWh of battery power equals one mile of driving in the full-electric mode.

An ***HV battery amp-hour rating*** compares the electrical power available for one hour of continuous discharge—it is the equivalent of the cold cranking rating. Watt-hour rating basically determines how long the battery can hold its state of charge under full-electric propulsion. As a reminder, watts (power) = voltage × current.

Nickel and lithium HV batteries for hybrids commonly use the watt-hour rating. To convert amp-hour to watt-hour, simply multiply amp-hours by voltage. If an HV battery operates at 300 volts and outputs 50 amps for an hour, then it is producing 15,000 kWh, or 15 kWh of power. Large HV batteries normally produce 50–100 kWh for full-electric drive vehicles. This is a tremendous amount of electrical energy.

Warning

Never allow your skin to contact any conductor on or inside an HV battery. The high voltage and current produced by these batteries can cause severe burns or electrocution.

The charge indicator changes color as the level of battery charge changes. In cars with an electric or hybrid drive train, the battery charge indicator is in the dash display. It will indicate state-of-charge or percent power remaining, power use, gas or energy consumption, and other electrical values.

HV Capacitor Banks

HV capacitor banks are storage devices for electrical energy that do not require an electrolyte or battery acid. As you learned earlier, capacitors are basically made of aluminum foil wrapped around a thin strip of insulating material. Electrical energy flows into a capacitor until it is fully charged. The capacitor stores this energy until needed.

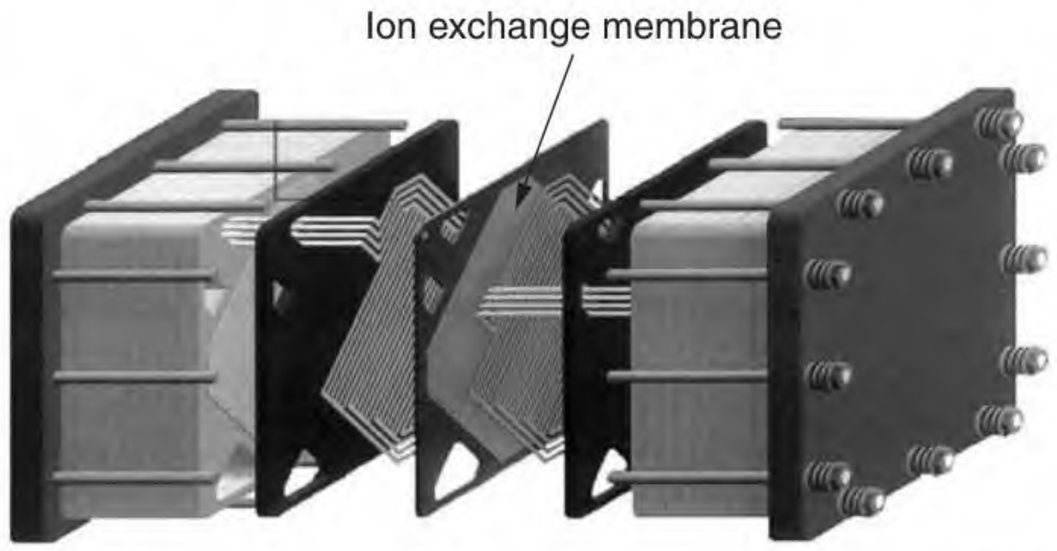
HV capacitor banks are wired in series to aid electric-drive vehicle acceleration. They are ideal for supplementing chemical batteries. Capacitor banks are very light, never wear out, and can accept or output short bursts of high-power electrical energy. Many hybrid buses and trucks now use capacitor banks to improve electric drive train efficiency and power for several seconds of rapid acceleration.

A capacitor will block the flow of alternating current (ac), but stores high voltage and a little current. Start capacitors help the motor start spinning when first turned on and are often used on industrial motors. When a low-resistance motor is connected across the capacitor, stored voltage and current shoot back into the motor windings to help initially spin and rotate the armature until ac current can keep the motor operating. Large capacitors are used in the HV power control module to help start the ac motor begin initial rotation from a standstill.

Fuel Cells

Fuel cells are similar to batteries, but they require an outside fuel source, usually hydrogen, to generate electricity. Like a battery, a fuel cell contains a positive plate (anode), a negative plate (cathode), and electrolyte. See **Figure 28-16**. Two chemical reactions occur in a fuel cell: a fuel is consumed and electrical energy is created.

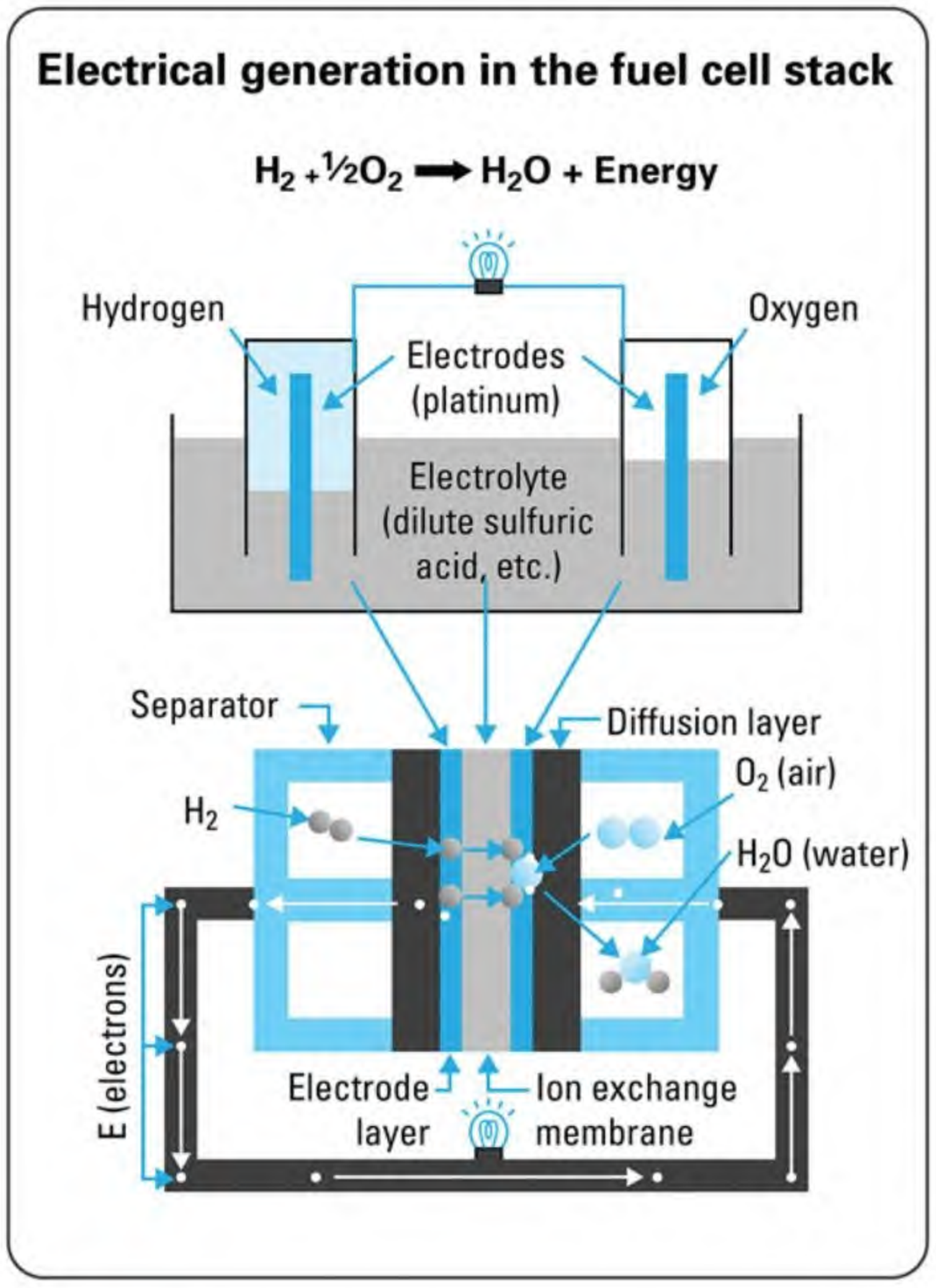
The positive plate oxidizes the fuel (hydrogen) in the fuel cell. This converts the hydrogen fuel into positive-charged ions and electrons. Since the electrolyte in a fuel cell passes ions but blocks electrons, a voltage is generated. Look at **Figure 28-17**. Due to the potential difference in charges, free electrons pass



Honda

Figure 28-16. A fuel cell, like a battery, places its ion exchange membranes in series to generate high voltage levels from a chemical reaction between hydrogen and oxygen.

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Honda

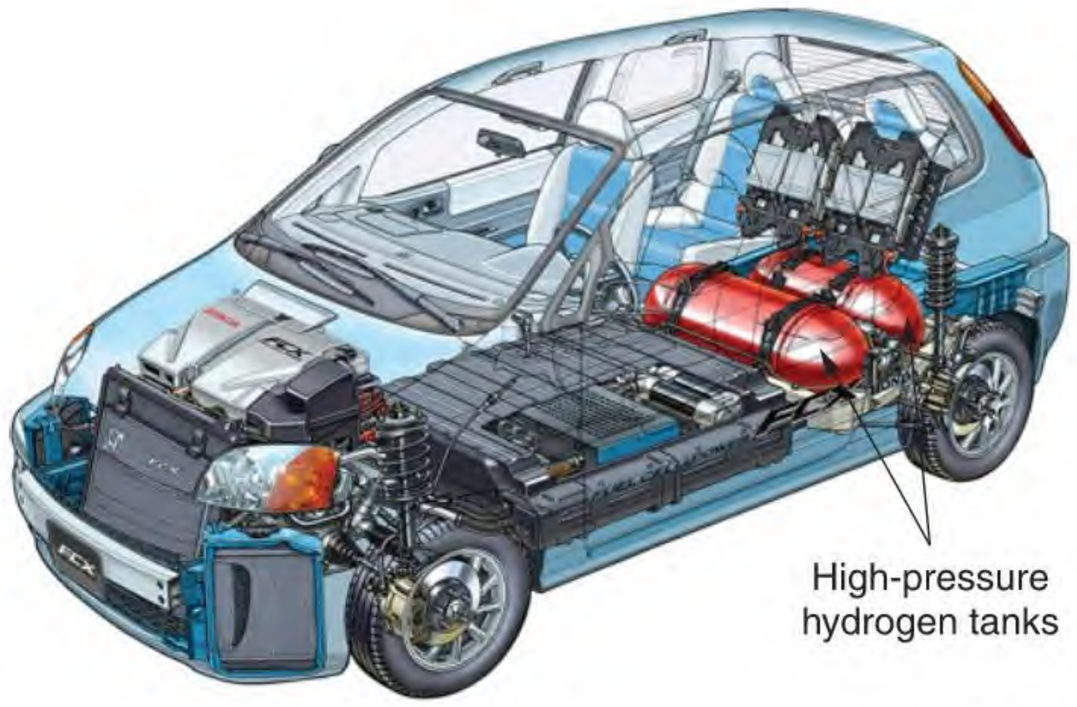
Figure 28-17. Study basic fuel cell physics and how hydrogen atoms and oxygen atoms combine to produce harmless water and electrical energy.

out of the fuel cell as direct current. Once the ions have passed through the electric circuit, they return to the negative plate. The ions then recombine with the electrons, where they react with oxygen to create water and carbon dioxide.

Fuel cell propulsion is very promising technology. However, hydrogen must be stored in high-pressure tanks, and refueling stations are not yet readily available. Refer to **Figure 28-18**.

Flywheel Generator

A ***flywheel generator***, also called a ***flywheel battery***, uses the kinetic energy of a high-speed ac armature (flywheel) to store huge amounts of electrical energy. Permanent magnets are mounted and spaced around the inside circumference of the armature to



Honda

Figure 28-18. This is an advanced fuel cell hybrid vehicle. The fuel cell, HV battery, conventional gasoline engine, and high pressure tanks for hydrogen provide propulsion.

form a stationary stator. The flywheel armature is enclosed in a vacuum chamber or housing, and levitates on a magnetic field to reduce friction.

During flywheel generator charging, three-phase ac is fed into the stator windings to produce reversing polarity magnetic fields at each coil winding. This causes the permanent magnets in the flywheel armature to be attracted or repelled by the stator's magnetic fields. As a result, the flywheel armature is spun up to 50,000–100,000 rpm. The three-phase current that spins the flywheel up to speed comes from the motor-generators during regenerative braking. The motor-generators serve as electric brakes to slow the car while producing large amounts of three-phase ac that is fed to the flywheel generator stator windings.

When spun up to full speed, a typical flywheel battery provides several hundred horsepower of electrical energy for rapid vehicle acceleration. Although still experimental, flywheel battery technology could see commercial use soon.

During flywheel battery discharging, the HV power control module connects the flywheel stator windings to the motor-generators. As the spinning magnets pass each stator coil, voltage and current are induced into the stator windings. Since all of the stator coils are wired together in a "Y" configuration, tremendous current levels flow out of the large power cables. The surge of electrical energy is conducted through the HV power control module and to the motor-generators.

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Summary

- An automotive battery is an electrochemical device for producing and storing electricity.
- A simple metal-acid battery cell consists of a negative plate, positive plate, container, and electrolyte (battery acid, lithium paste or gel, or liquid sulfuric acid).
- A 12-volt battery has six cells, which produce an open circuit voltage of 12.6 volts.
- Battery cables are large wires that connect the 12-volt battery terminals to the vehicle's electrical system.
- Common types of 12-volt batteries include maintenance-free batteries, gel batteries, and AGM batteries.
- The two most common methods of rating lead-acid storage batteries are by the cold cranking rating and by the reserve capacity rating.
- As battery temperature drops, battery power is reduced.
- Many hybrids use a dual voltage system: 12 volts for most of the vehicle's conventional electrical/electronic circuits, and high voltage (HV) for the double-ought (00) conductors and HV motor-generator of today's electric drive trains.
- An HV battery is made of several battery cells wired in series to produce a high voltage electrical power source.
- An HV battery ECM is an electronic control circuit that reads signals from HV battery temperature and voltage sensors to prevent battery overheating.
- An HV battery is so powerful that it is rated in kilowatts (thousands of watts) of electrical energy.
- Capacitor banks can store electrical energy without an electrolyte, battery acid, or a fuel (hydrogen).
- Fuel cells are similar to batteries, but require an outside fuel source, usually hydrogen, to generate electricity.
- A flywheel generator uses the kinetic energy of a high-speed ac armature (flywheel) to store huge amounts of electrical energy.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

12-volt battery
absorbed glass mat battery
AGM battery
amp-hour rating
battery acid
battery bank
battery cables
battery caps
battery case
battery cell
battery charge indicator
battery cover
battery cycling
battery eye
battery heat shields
battery hold-down
battery pack fuses
battery pack voltage
battery plates
battery posts
battery stack
battery straps
battery temperature sensor
battery terminals
battery tray
charging
cold cranking rating
connectors
deep cycling
discharging
dual voltage system
electrolyte
flywheel battery
flywheel generator
fuel cells
gassing
gel battery
HV battery
HV battery amp-hour rating
HV battery cables
HV battery continuous power rating
HV battery cover
HV battery ECM
HV battery frame
HV battery nominal operating voltage
HV battery pack
HV battery peak power rating
HV battery temperature sensors
HV capacitor banks
HV motor-generator cables
HV power cables
hybrid battery cell
intercalation
load
maintenance-free battery
negative battery cable
negative post
open circuit voltage
positive battery cable
positive post
reserve capacity rating
retainer
separators
side terminals
test indicator

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Activities

1. Survey the service managers of at least three businesses that sell and install vehicle batteries. Find out how they dispose of batteries they remove from vehicles.
2. Research the best battery value. Gather information from the Internet or visit stores that sell automotive batteries. Find the cold cranking ratings and prices of comparable-size batteries from different stores, and make a chart of your findings. Which battery will give you the most for your money?
3. Construct a model of a vehicle battery element (cell) for classroom display. Clearly label all components.
4. Ask a dealership to allow your class to visit their shop during HV battery replacement. Make sure you stand several feet away from the vehicle while observing.

Review Questions

Answer the following questions using the information provided in this chapter.

1. What is the typical range of output voltage for HV batteries?
2. A(n) _____ is an electrochemical device for producing and storing electricity.
3. Define the terms “discharging” and “charging” as related to battery operation.
4. Which of the following is *not* part of a basic battery cell?
   (A) Positive plate.
   (B) Negative plate.
   (C) Electrolyte.
   (D) Spark arrestors.
5. List five functions of a car battery.
6. A 12-volt battery has _____ cells that produce an open circuit voltage of _____ volts.
7. Most modern vehicles use 6-volt batteries. True or False?
8. _____ gas can collect around the top of batteries. If this gas is exposed to a flame or spark, it can explode.
9. Electrolyte is a mixture of sulfuric acid and distilled water. True or False?
10. What is the purpose of a battery eye?
11. Describe the difference between battery posts and side terminals.
12. Which of the following is *not* a 12-volt battery rating?
    (A) Hot cranking rating.
    (B) Reserve capacity rating.
    (C) Amp-hour rating.
    (D) Cold cranking rating.
13. How is the power of large battery packs rated?
14. What is the standard color of HV battery cables?
    (A) Red.
    (B) Blue.
    (C) Orange.
    (D) Yellow.
15. HV _____ are storage devices for electrical energy that do not require an electrolyte or battery acid.
    (A) capacitor banks
    (B) fuel cells
    (C) motor-generators
    (D) side terminals
16. A flywheel generator uses the kinetic energy of a high-speed ac armature (flywheel) to store huge amounts of electrical energy. True or False?

ASE-Type Questions

1. An automotive battery produces:
   (A) hydrogen gas.
   (B) voltage.
   (C) direct current.
   (D) All of the above.
2. Battery charging converts:
   (A) atoms into electrolytes.
   (B) electrical energy into chemical energy.
   (C) chemical energy into electrical energy.
   (D) lead oxide into sulfuric acid and water.
3. Which of the following is *not* a battery cell component?
   (A) Eye.
   (B) Battery acid.
   (C) Positive plate.
   (D) Negative plate.

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4. Battery plates are grids that are coated with:
   (A) plastic.
   (B) copper.
   (C) thin steel.
   (D) porous lead.
5. The active material on positive plates is:
   (A) antimony.
   (B) sponge lead.
   (C) lead peroxide.
   (D) None of the above.
6. Which of the following shows the general charge condition of a 12-volt battery?
   (A) Battery charge indicator.
   (B) Test indicator.
   (C) Battery eye.
   (D) All of the above.
7. When testing a battery's charge condition, the indicator shows a visible dark green dot. Technician A interprets this to mean the battery needs to be charged. Technician B feels the dot indicates the battery is fully charged. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. Each of the following provides a means of connecting battery plates to a car's electrical system *except*:
   (A) battery caps.
   (B) battery posts.
   (C) side terminals.
   (D) battery terminals.
9. An HV battery stores chemical-electrical energy that is used to _____.
   (A) start the internal combustion engine
   (B) provide 12–15 volts dc for the vehicle's electrical accessories and conventional electric circuits
   (C) provide full-electric propulsion
   (D) All of the above.
10. Technician A says the HV battery ECM can activate a battery cooling system when the HV battery cells become hot. Technician B says that if the HV battery temperature sensor detects battery overheating, it can prompt the HV battery ECM to disconnect the HV power control module to prevent further overheating. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Chapter 29
12-Volt and HV Battery Service

After studying this chapter, you will be able to:

- Visually inspect a 12-volt battery for obvious problems.
- Perform common tests on 12-volt and HV batteries.
- Charge 12-volt and HV batteries.
- Replace a defective battery or battery pack.
- Describe safety practices to follow when testing and servicing 12-volt and HV batteries.
- Identify the major steps for safely removing and replacing an HV battery.
- Explain how to inspect, clean, and torque HV power cable connections.
- Correctly answer ASE certification test questions on battery service.

A ***dead battery*** (discharged battery) is a very common problem in vehicles with a 12-volt starting system. The engine will usually fail to crank and start. You will often hear a rapid clicking sound (or chatter) as the battery tries to repeatedly engage the solenoid. Even though the lights and horn may work, there is not enough "juice" (current) in the 12-volt battery to operate the starting motor.

Hybrid vehicles seldom suffer from a fully-discharged HV battery. If battery voltage is low, the on-board diagnostics warn the driver and technician of a battery problem. With a modern HV battery, the dreaded clicking noise (starter solenoid chatter) of a dead battery is a thing of the past.

It is important to know how to inspect, test, and service both 12-volt and HV batteries. This chapter covers the most common tasks relating to battery service and replacement. Study this information carefully since later chapters expand on this knowledge.

Warning

Working on high-voltage hybrid circuits is much more dangerous than working on conventional 12-volt circuits. The voltage in a 12-volt electrical system does not generate enough current flow to cause injury. An HV battery can output thousands of amps. Since only 1 amp of electrical current can be fatal, imagine what 1000 amps could do.

12-Volt Battery Maintenance

The average service life of a 12-volt battery is approximately 3–5 years. If a 12-volt battery is not maintained properly, its service life will be reduced.

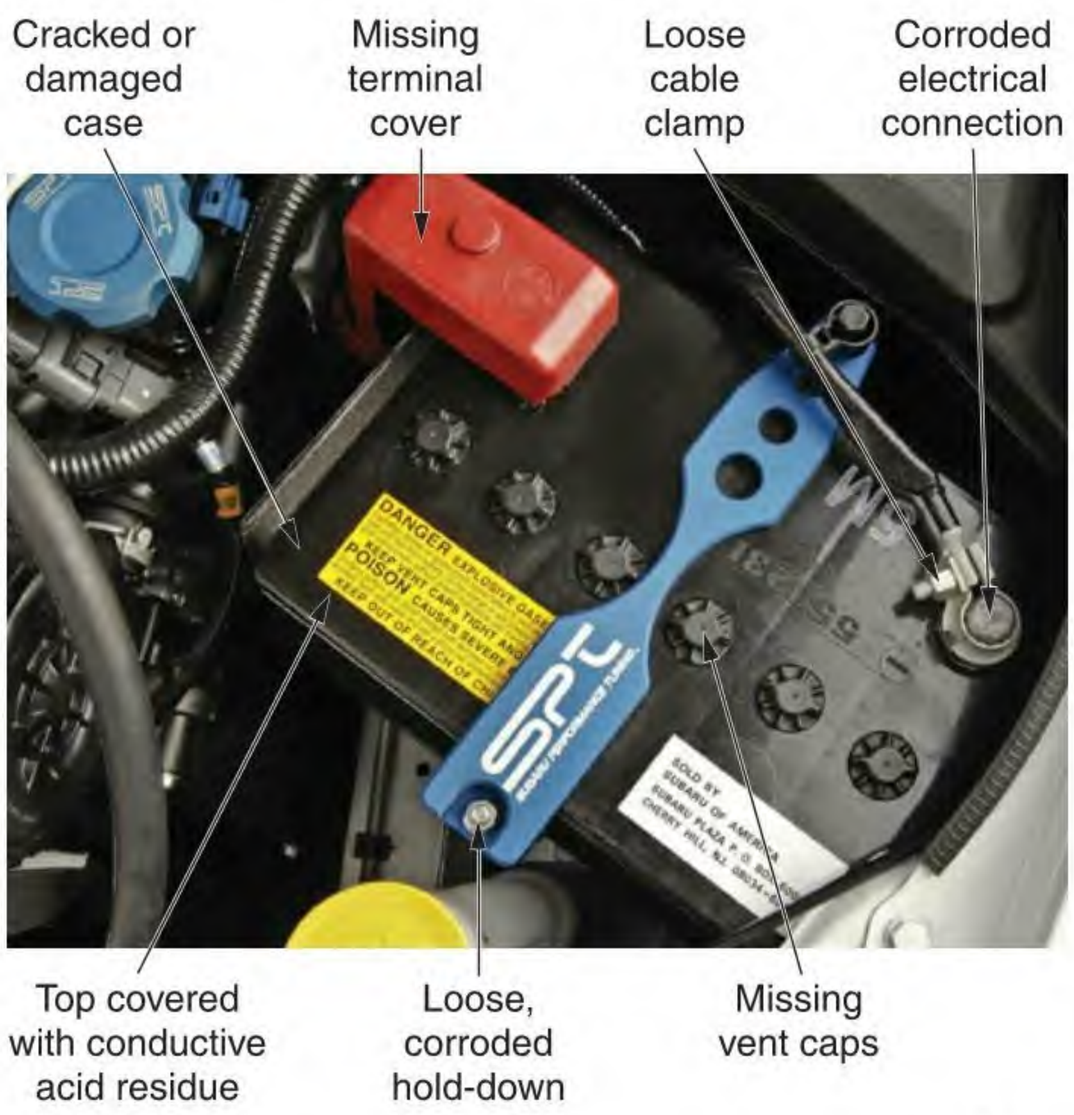
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Battery maintenance should be done periodically—during tune-ups, grease jobs, or any time symptoms indicate battery problems.

12-volt battery maintenance typically includes:

- Inspecting the battery case, battery terminals, battery hold-down, and fasteners on the battery cable ends for corrosion and damage. Look for corrosion buildup on the battery top and electrical connections. Check the case for damage. See **Figure 29-1**. This should be done any time the hood is opened.
- Removing and cleaning the battery terminal connections.
- Washing off the top of the battery case with soap or baking soda and water to neutralize any acid or remove dirt buildup.
- Repairing the battery tray, if rusted or broken.
- Inspecting the electrolyte level. Most new low-current, 12-volt batteries for hybrids have removable vent caps for service. The battery case may also be semi-transparent so you can view electrolyte levels on the sides of the plastic housing.

Since battery connections suffer rapid corrosion from acid and hydrogen fumes, the 12-volt electrical connections can fail quickly, developing high electrical resistance.



Subaru

Figure 29-1. Visually inspect batteries for these kinds of problems. If any problems are found, correct them.

If you can wiggle and turn the cable connections by hand, they must be disassembled and serviced. If a problem is found, get the customer's permission to service the battery.

Warning

Wear eye protection when working around batteries. A 12-volt lead-acid battery contains sulfuric acid, which can cause severe eye burns, even blindness. The dirty film buildup on top of a battery contains acid residue that can attack the electrical connections, as well as your skin.

12-Volt Battery Service

If regular maintenance tasks reveal a problem or do not correct an existing problem with a 12-volt battery, further testing is required to identify the problem and determine the most appropriate and effective solution.

12-Volt Battery Leakage Test

A ***battery leakage test*** will find out if electrical energy is draining and discharging across the top of the battery case. A dirty battery can run down (discharge) when not in use. This can shorten battery life and cause starting problems.

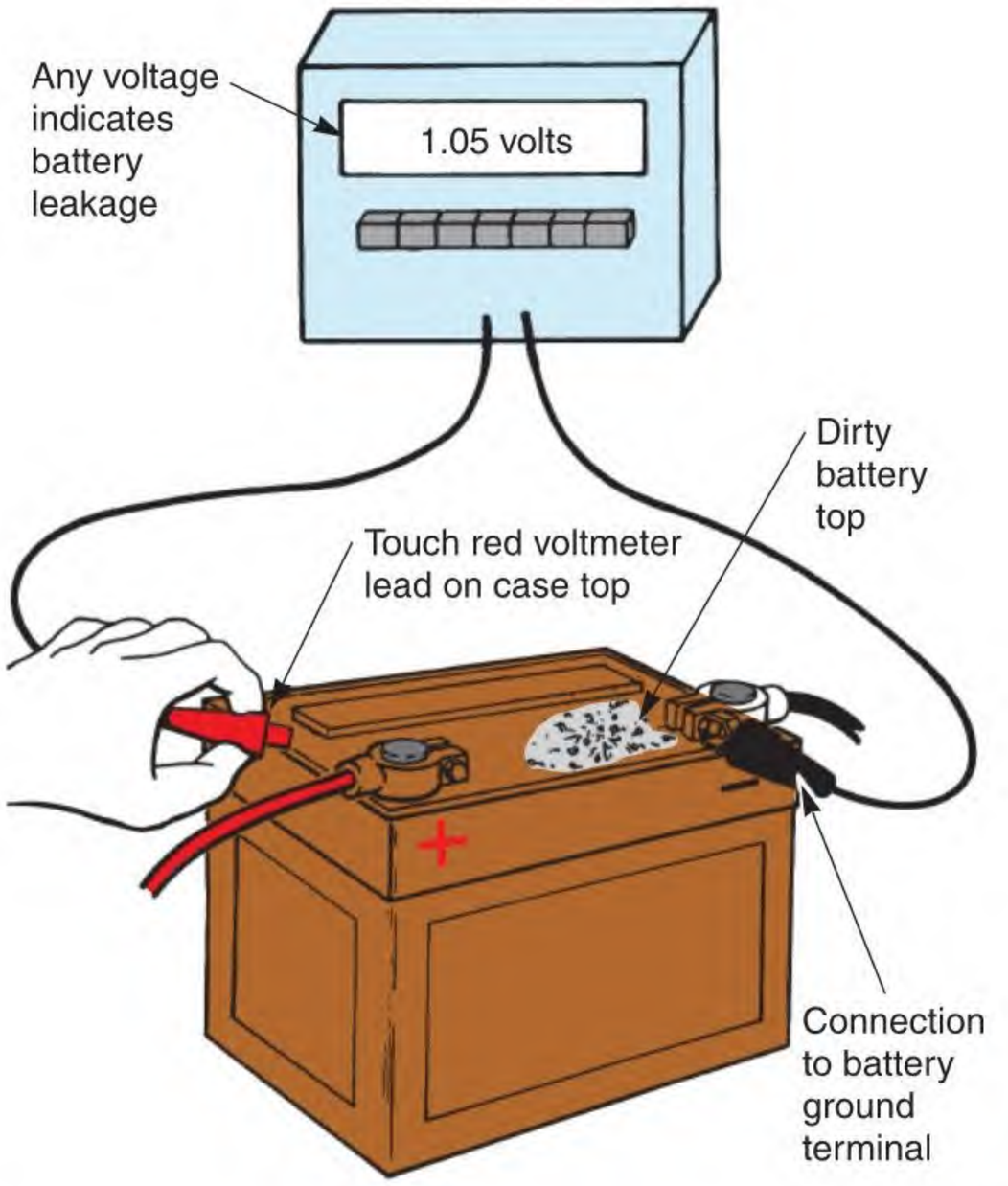
To do a battery leakage test, set a voltmeter to read 12–15 volts dc. Connect the black meter lead to the negative battery terminal and touch the red meter lead on the battery, as shown in **Figure 29-2**. If the meter registers any voltage, a proportional amount of current is leaking constantly out of the battery. You need to clean the battery top to correct this common problem.

If the top of the battery is dirty, wash it with baking soda and water. See **Figure 29-3**. This neutralizes and removes the acid and dirt from the battery case. If battery vent/fill caps are removed, be careful not to let debris enter the filler openings and contaminate the electrolyte.

12-Volt Battery Terminal Test

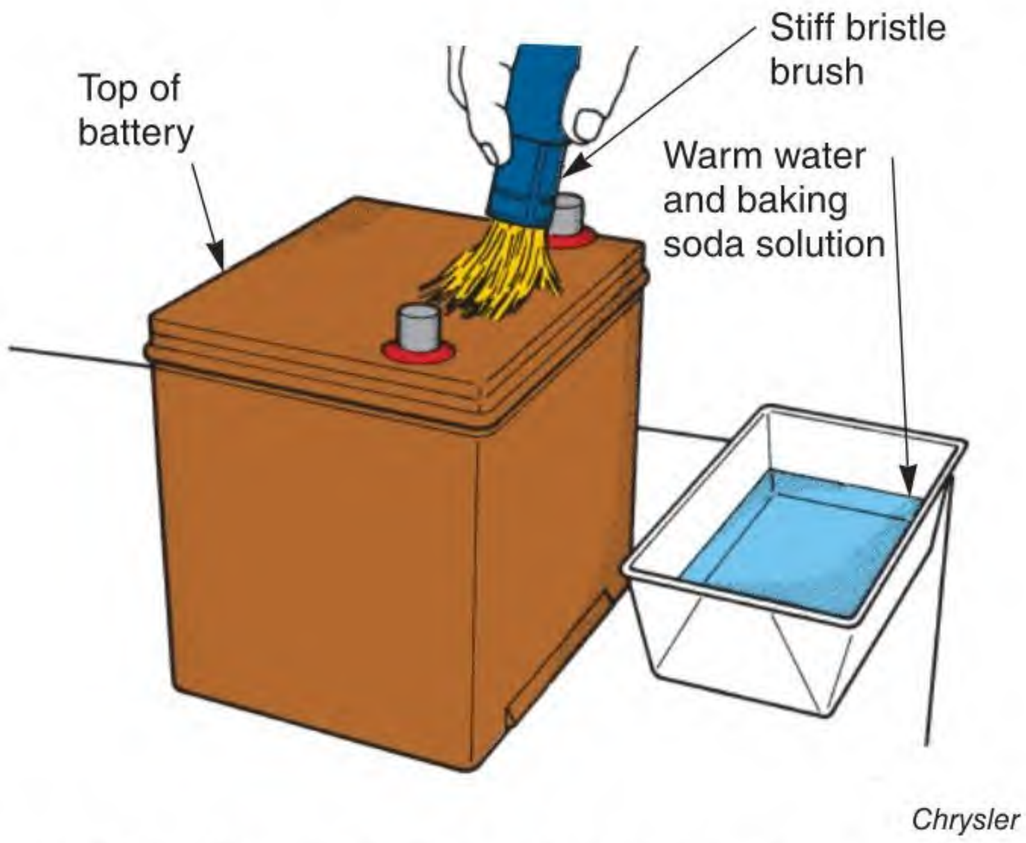
A ***battery terminal test*** quickly checks for a poor electrical connection (high voltage drop) between the battery cables and battery terminals on post-type batteries. A voltmeter is used to measure voltage drop across the cable ends and terminals. See **Figure 29-4**.

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Sun Electric

Figure 29-2. A leak test will quickly show electrical leakage across the top of a battery. If the voltmeter registers any voltage, clean the battery.



Chrysler

Figure 29-3. Clean the battery with a solution of baking soda and water. Keep dirt out of filler openings.

Tech Tip

A battery terminal test cannot be performed on side-terminal batteries because the cable connector completely covers the battery terminal.

Service Procedure

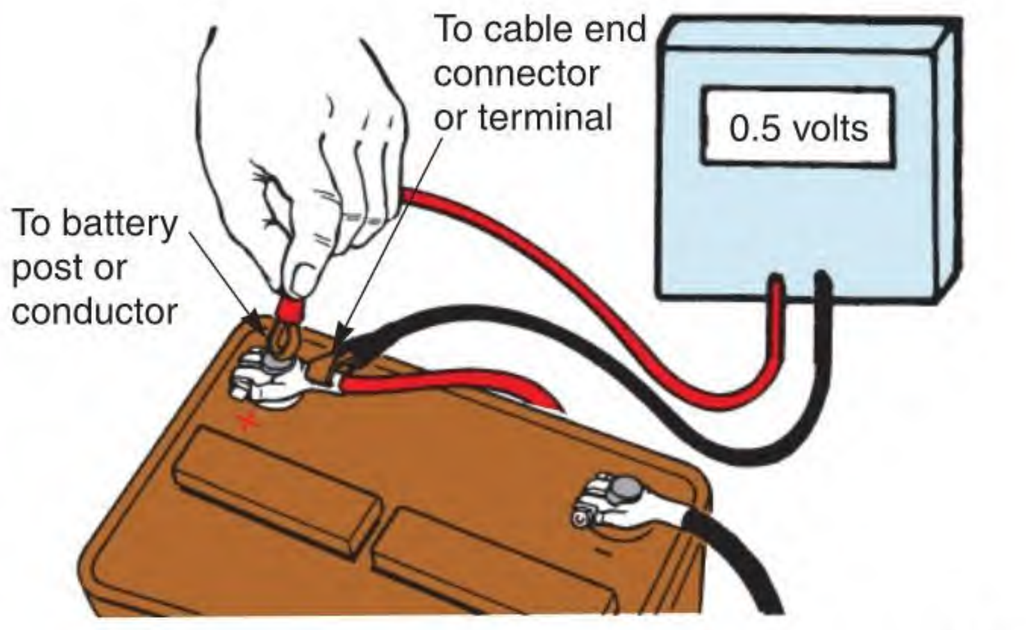
To perform a battery terminal test:

1. Connect the negative voltmeter lead to the cable end.
2. Touch the positive voltmeter lead on the battery terminal.
3. Remove the appropriate fuses to disable the ignition and fuel injection systems so the engine will not start.
4. Crank the engine while watching the voltmeter reading.

If the voltmeter shows 0.5 volts or more, there is a high resistance and poor electrical connection at the cable connection. Remove, clean, and retighten the battery connections. A good electrical connection has less than a 0.5 volt drop at 12 volts dc.

Cleaning 12-Volt Battery Terminals

To clean the terminals, remove the battery cable ends. See **Figure 29-5**. Use a six-point wrench if the bolt or nut is extremely tight. Use battery pliers only on



NAPA

Figure 29-4. To quickly find out if battery terminals need cleaning, measure the voltage drop across the cable-to-terminal connection. Crank the engine with the ignition disabled. A reading over 0.5 volt indicates that the terminal and cable end need cleaning.

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A



B



C

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Figure 29-5. Note methods of removing a battery cable from a battery terminal. Be careful not to damage the post or side terminal. A—An open end wrench should rotate a battery terminal hex nut for cable removal. B—Battery pliers are needed if the hex nut is rusted or corroded so badly that a wrench will no longer fit. C—If the cable end is stuck to the battery post, use a terminal puller to remove the cable end without damaging the post. Most battery posts and straps are made of very soft lead.

spring-type clamps or when the fastener head is badly corroded and rounded off. Be careful not to damage the battery post or side terminal with excess side force.

To clean post-type electrical connections, use a battery cleaning tool to remove surface corrosion from the post and cable. Slide the female end of the battery tool around the post and twist the tool to abrade down to bare metal. See **Figure 29-6**. Slide the male end of the tool inside the cable end and twist the tool to clean the cable end's conductor mating surfaces. Rotate the battery tool until the contact surfaces are a shiny gray color. To clean side terminals, use a small, round wire brush. Twist the brush over the cable ends and the mating surfaces on the battery terminals.

Caution

Do not use a knife or scraper to clean battery terminals. Scraping the conductor surfaces can remove too much metal, roughen the smooth, parallel contact surfaces, and damage the soft metal. Scraping and gouging battery terminals can affect the durability and resistance at the electrical connections.

When reinstalling the 12-volt battery cables, coat the terminals with a conductive, dielectric compound or white grease. Look at **Figure 29-7**. This will keep acid fumes off connections and prevent the connections from corroding again. Tighten the fasteners just enough to secure the connection so it cannot be wiggled by hand. Overtightening can strip the cable bolt threads.

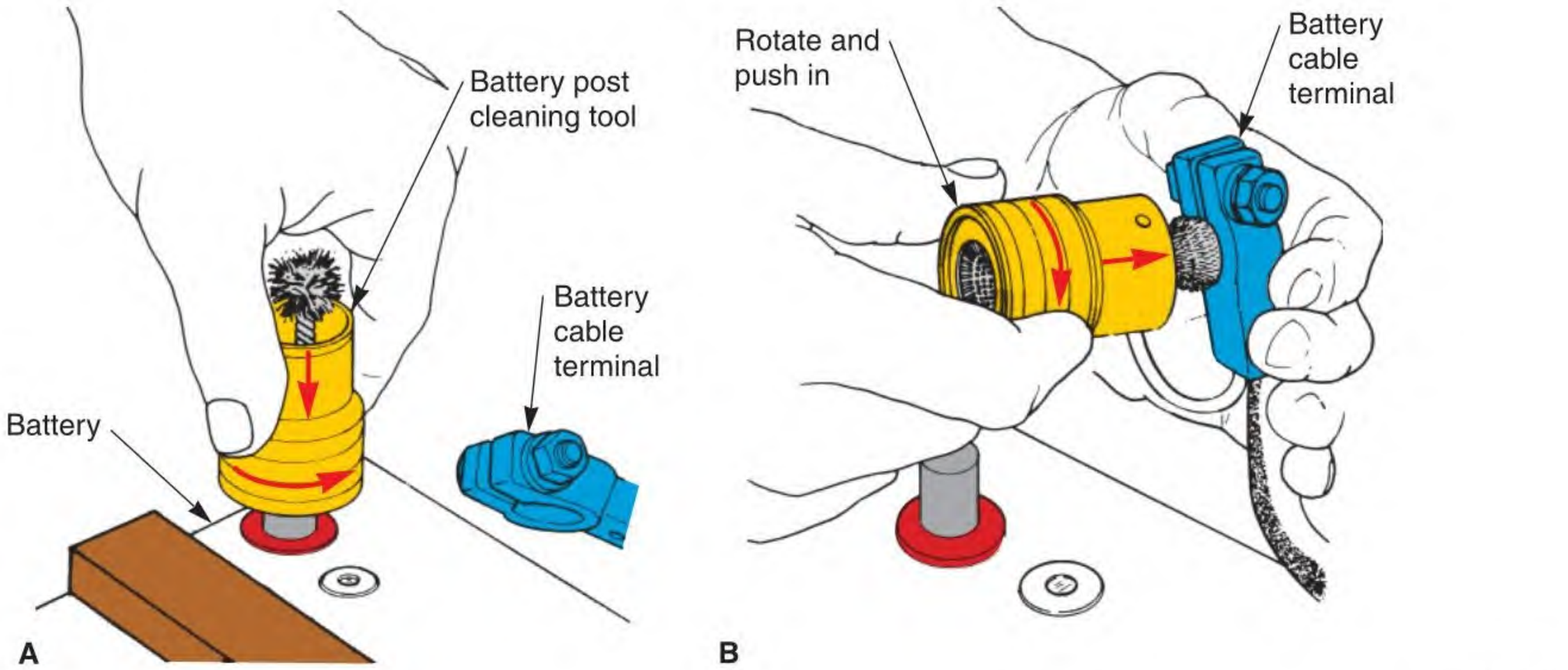
Tech Tip

When disconnecting a 12-volt car battery, consider using a memory saver to provide power to the computer. This will keep all driver-programmed information intact (clock, radio stations, ECM memory, etc.). A memory saver also prevents the computer from having to relearn information, which could temporarily upset drivability.

Checking 12-Volt Battery Electrolyte Level

Maintenance-free batteries do not need periodic electrolyte service. If they are overcharged and lose their electrolyte through gassing, maintenance-free

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Chrysler

Figure 29-6. Note how to properly clean battery posts and cable ends. A—Rotate the female end of the cleaning brush on the post. B—Use the male end of the brush on the cable end. Turn it until all corrosion is abraded off and the metal surface is shiny.

batteries must be replaced. Batteries with removable vent caps, however, should have their electrolyte level checked yearly.

The electrolyte should just cover the top of the battery plates and separators. Most batteries have a fill ring (electrolyte level indicator) inside the filler cap opening. The electrolyte should be even with the fill ring.

If the electrolyte is low, fill the cells to the correct level with ***distilled water*** (purified water). Distilled water should be used because it does not contain many of the impurities found in tap water. Water taken directly out of a water faucet can contain chemicals that reduce battery life. If enough contaminants collect in the battery, the cell plates can short out, ruining the battery.

Warning

The hydrogen gas produced by the chemical reaction in a battery is flammable. Keep all sparks and flames away from the top of the battery, especially during recharging. Batteries can explode if its hydrogen gas is ignited.



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Figure 29-7. Apply dielectric grease before and after the cable is installed to seal all moisture out of the electrical connection.

Checking 12-Volt Battery Charge

When measuring battery charge, you are checking the condition of the battery electrolyte and battery plates. For example, if a vehicle's lights are left on without the engine running, the battery will run down (discharge). Current flow out of the battery steadily reduces available battery energy, or power. There are several ways to measure battery charge.

Some batteries use a charge indicator eye that shows battery condition. This allows you to simply look at the eye in the battery cover to determine its general state of charge.

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12-Volt Battery Voltage Test

A ***battery voltage test*** is done by measuring static battery voltage to determine the general state of charge. Look at **Figure 29-8**. This test provides a quick check of the battery condition. Connect the voltmeter across the battery terminals or posts and turn on the vehicle's headlights or blower motor to provide a small current load. For a fully charged battery under a light current load (less than 5 amps), the voltmeter should read 12.5 volts. The lower the voltage across the battery terminals, the less charge or energy in the battery.

When a battery fails a voltage test, other tests are needed to find or verify the actual problem.

Hydrometer Check

A ***hydrometer*** is used to measure the specific gravity (weight or density) of a liquid. A battery hydrometer measures the specific gravity of the battery electrolyte, which is an indication of the battery's state of charge. See **Figure 29-9**.

Water has a specific gravity standard of one (1.0). Fully-charged electrolyte has a specific gravity of between 1.265 and 1.279. Specific gravity greater than 1.0 indicates that electrolyte is denser (heavier) than water.

As a battery becomes discharged, its electrolyte has a larger percentage of water. Thus, the electrolyte of a discharged battery has a lower specific gravity than the electrolyte of a fully-charged battery.



Fluke

Figure 29-8. A digital voltmeter will check the general charge of a battery. Under a small load, voltage below 12.5 volts generally indicates battery discharge. This battery shows 12.49 volts, which is about 100% of a full charge with a 5-amp load.

Battery Voltage					
Load on battery (Amps)	Specific Gravity (Percent charge)				
	1.265 (100%)	1.250 (95%)	1.230 (75%)	1.200 (50%)	1.175 (25%)
0	12.7	12.6	12.5	12.4	12.2
5	12.5	12.4	12.3	12.1	11.8
15	12.3	12.2	12.0	11.7	11.3
25	12.1	11.9	11.6	11.2	10.7

This is the range in which most vehicle batteries normally operate in customer service.

At 1.180 and below, starting will be unreliable and function of other circuits may be erratic.

Chrysler

Figure 29-9. This chart shows how battery voltage relates to specific gravity (hydrometer readings).

Tech Tip

Maintenance-free batteries do not have removable vent caps and therefore, cannot be tested with a hydrometer.

To use a float-type hydrometer, squeeze the hydrometer bulb and immerse the end of the hydrometer in the electrolyte. Then, release the bulb to draw in the liquid electrolyte. Look at **Figure 29-10**. Hold the hydrometer even with your line of sight. Compare the numbers on the hydrometer float with the top of the electrolyte.

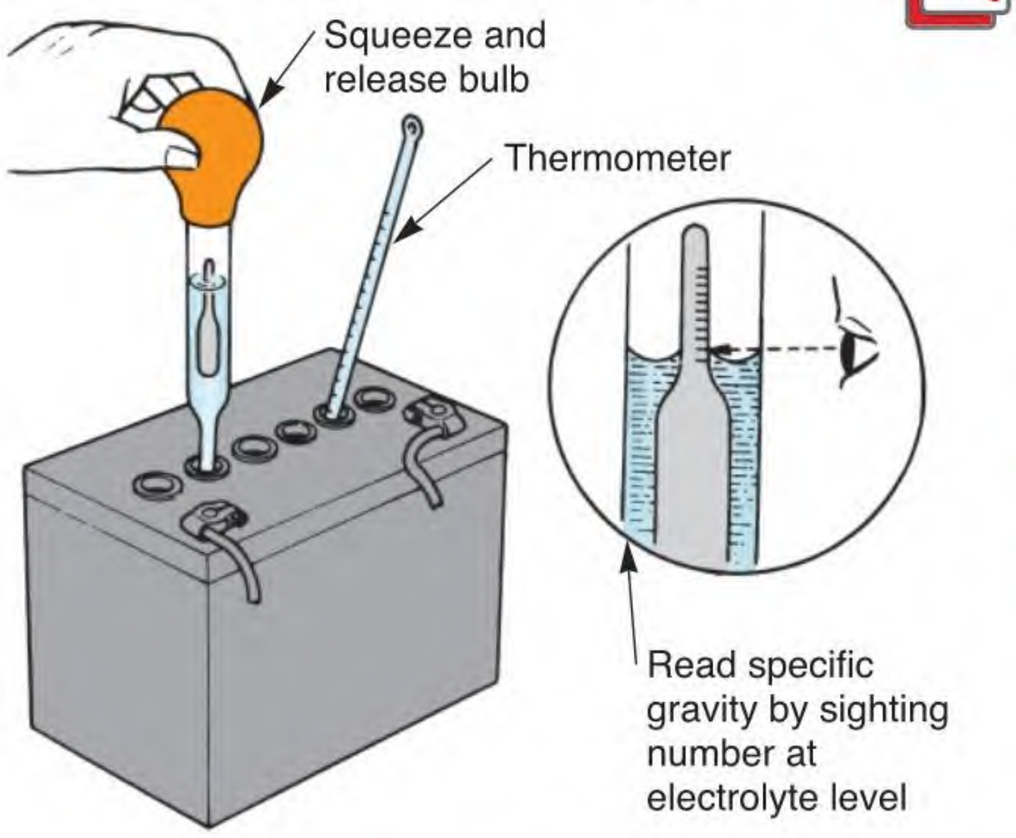
Warning

Wear safety glasses and do not drip electrolyte (sulfuric acid) on anything.

Specific gravity readings will vary somewhat with temperature and most float-type hydrometers are not temperature correcting. However, some models have a built-in thermometer and a conversion chart. This will let you compensate for temperature differences.

To use a ball-type hydrometer, draw electrolyte into the hydrometer with the rubber bulb. Note the number of balls floating in the electrolyte. Instructions on the hydrometer will tell you the battery's state of charge.

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Mazda and Chrysler

Figure 29-10. To check battery charge, draw electrolyte into a hydrometer by squeezing and releasing the bulb.

A needle-type hydrometer uses the same principle as the ball-type. When the electrolyte is drawn into the hydrometer, it causes a plastic needle to register specific gravity.

A fully charged battery should have a ***hydrometer reading*** of at least 1.265. If the reading is below 1.265, the battery needs recharging or it may be defective.

A defective battery can be found with a hydrometer by checking the electrolyte in every cell. If the specific gravity in any cell varies excessively from other cells (more than 0.05), the battery should be replaced. Cells with low readings may have shorted or deteriorated plates. When all the cells have an equal specific gravity, the battery can usually be restored by recharging.

Cell Voltage Test

Just like a hydrometer cell test, a ***cell voltage test*** will indicate if the battery is defective or just discharged.

Service Procedure

To perform a cell voltage test:

1. Set your voltmeter to read low voltage.
2. Ground the black tester lead on the battery negative terminal.
3. Insert the other special cadmium (acid-resistant metal) tip into the cell.
4. Carefully test each cell starting at one end of the battery and working down to the other end.

If cell voltages are low but equal, recharging will usually restore the battery. If cell voltage readings vary more than 0.2 volts, the battery is faulty and should be replaced.

Warning

Make sure you do not drip electrolyte on the vehicle or your skin. The sulfuric acid in the electrolyte will eat through the vehicle's paint or burn your skin.

Discharged 12-Volt Battery

A discharged battery could have several causes:

- Defective battery.
- 1 Cell shorts, low electrolyte, or freezing damage.
- Charging system problem (loose alternator belt, for example).
- Poor cable connections causing high resistance and reduced current flow.
- Engine performance problem requiring excessive cranking time.
- Electrical problem drawing current out of the battery with the ignition key off.

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Parasitic Loads

A ***parasitic load*** is any electric circuit current draw present when the engine and all electrical devices are shut off. This load would include any circuit that requires a small current when the vehicle is not running (clock, vehicle alarm, ECMs, etc.). This results in a continuous current draw on the battery.

If a vehicle sits unused for prolonged periods, the parasitic load can drain the 12-volt battery enough to prevent starting. A battery must be in good condition to withstand prolonged parasitic loads. Parasitic loads are not a problem with hybrids since the HV battery has a huge reserve of stored electrical energy.

Tech Tip

Remember that normal parasitic current load for the clock and computers can discharge a battery if the vehicle sits unused for an extended period (about a month).

Battery Drain Test

A ***battery drain test*** will check for an abnormal current draw (high parasitic load) with the ignition key off. When a battery repeatedly goes dead, you may need to check for an excessive parasitic load. It is possible that there is a short or other problem discharging the battery quickly.

A battery can be discharged if an electrical accessory (an interior light, for example) remains on when the ignition switch is shut off. For example, a short in a switch could cause a glove box light to stay on, even when the glove box door is closed. This could slowly drain the battery and cause a starting problem.

Service Procedure

To perform a battery current drain test:

1. Make the ammeter connections.
2. Close the doors and trunk, and turn off all electric components.
3. Unscrew the underhood lightbulb, if needed.
4. Read the ammeter and compare your reading to specifications.

Tech Tip

To prevent meter damage, do not operate starting motor or any high-current-draw device (blower motor) with the meter connected in series for measuring current drain. High-current draw will blow the meter fuse or damage the meter.

If everything is off (good condition), the ammeter should read almost zero or only a few milliamps—typically 10 mA. However, an ammeter reading above this would point to a drain and a problem. To help pinpoint a drain, pull fuses one at a time while observing the ammeter. Look at **Figure 29-11**. When the ammeter reads zero, the current drain problem is somewhere in the circuit that contained the fuse that was removed.

12-Volt Battery Chargers

When tests show that a battery is discharged, use a ***battery charger*** to re-energize it. The battery charger will force current back through the battery to restore the charge on the cell plates. A battery charger contains a step-down transformer and diode rectifier circuit that changes wall outlet voltage (around 120 volts ac) to a voltage slightly above battery voltage (14–15 volts dc). **Figure 29-12** shows a battery charger.

There are two basic types of battery chargers: slow chargers and fast chargers. Sometimes both are incorporated into one unit.

Slow Charger

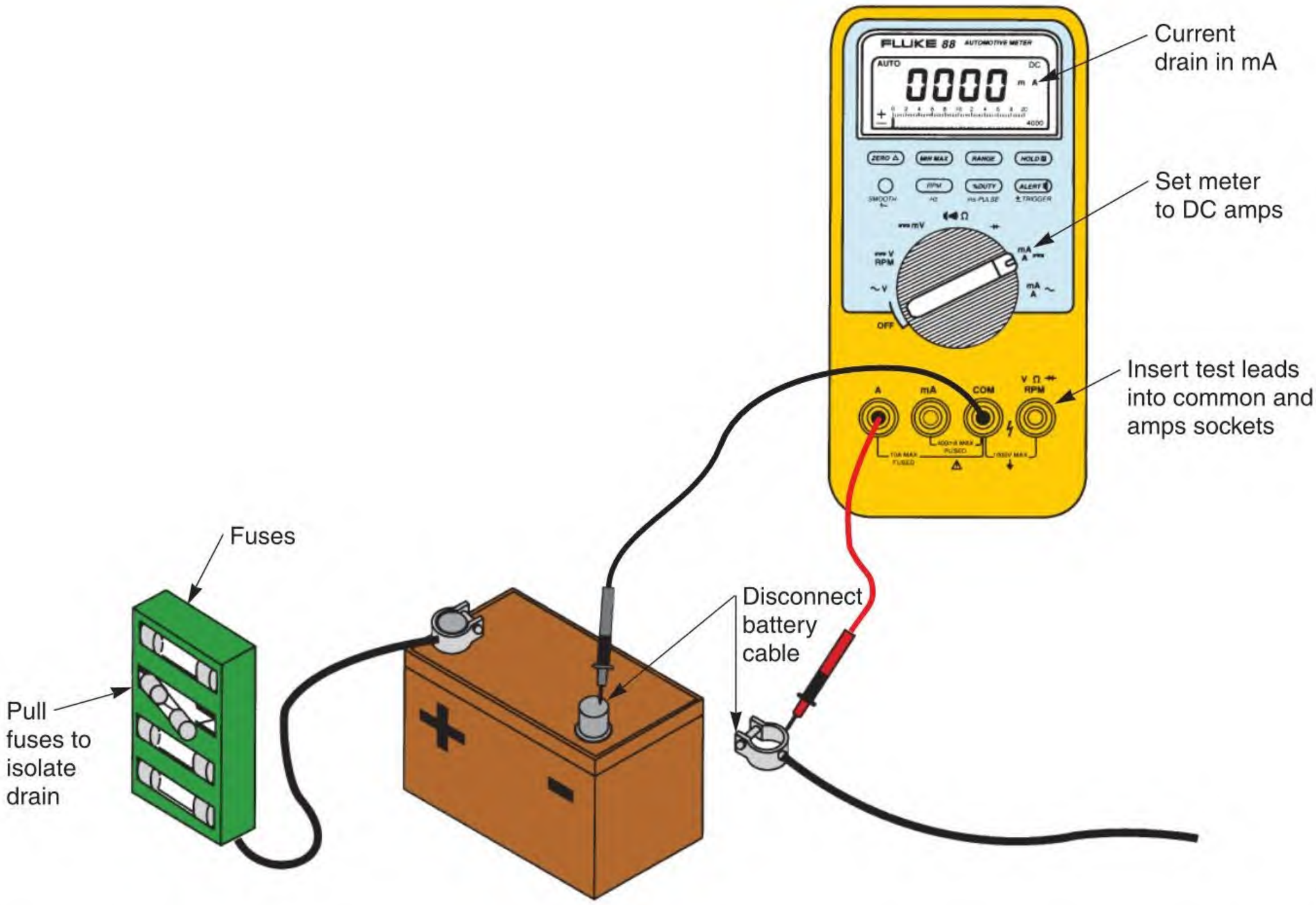
A ***slow charger***, also called a ***trickle charger***, feeds a small amount of current into the battery. When using a slow charger, charging time is relatively long (about 12 hours at 10 amps), but the chemical action inside the battery is improved. During slow charging, the atomic charges are forced back onto the battery plates and electrolyte better than they are with fast charging. When time allows, always use a slow charger for better recharging.

Fast (Quick) Charger

A ***fast charger***, also called a ***quick charger*** or ***boost charger***, forces a high current flow into the battery. When the customer needs the car, time may not allow the use of a slow charger.

Fast charging will usually allow engine starting in a matter of minutes. If possible, slow charging is recommended after fast charging.

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Fluke

Figure 29-11. To perform a battery drain test, connect an ammeter in series with the negative cable. If current flowing out of the battery with everything turned off exceeds specifications, an electrical problem is discharging the battery. By pulling fuses, you can isolate the problem circuit.

Warning

Before connecting a battery charger to a battery, make sure the charger is turned off. Also, check that the work area is well ventilated. If a spark ignites any battery gas, the battery could explode. Wear eye or face protection when working on a car battery.

Caution

Make sure you do not accidentally reverse the cable connections when connecting a battery charger. Hooking a battery charger backward could burn diodes in the charging system and also destroy other delicate electronic circuits in the vehicle.

Charging a 12-Volt Battery

To use a battery charger, connect the red charger lead to the positive battery terminal. Connect the black charger lead to the negative terminal of the battery. With side terminal batteries, use adapters if needed to connect the large alligator clamps from the charger.

After correctly connecting the red and black cables to the battery, set the battery charger controls and turn on the power.

When fast charging, do not exceed a charge rate of 35 amps. Also, battery temperature must not exceed 125°F (52°C). Exceeding either charge rate or temperature could ruin the battery.

If you suspect a battery is frozen or has ice in it from extremely cold weather, do not charge it.

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Schumacher Electric Corp.

Figure 29-12. A battery charger forces current through the battery to restore the charge on its plates. The charging voltage should be above battery voltage, usually 14–15 volts.

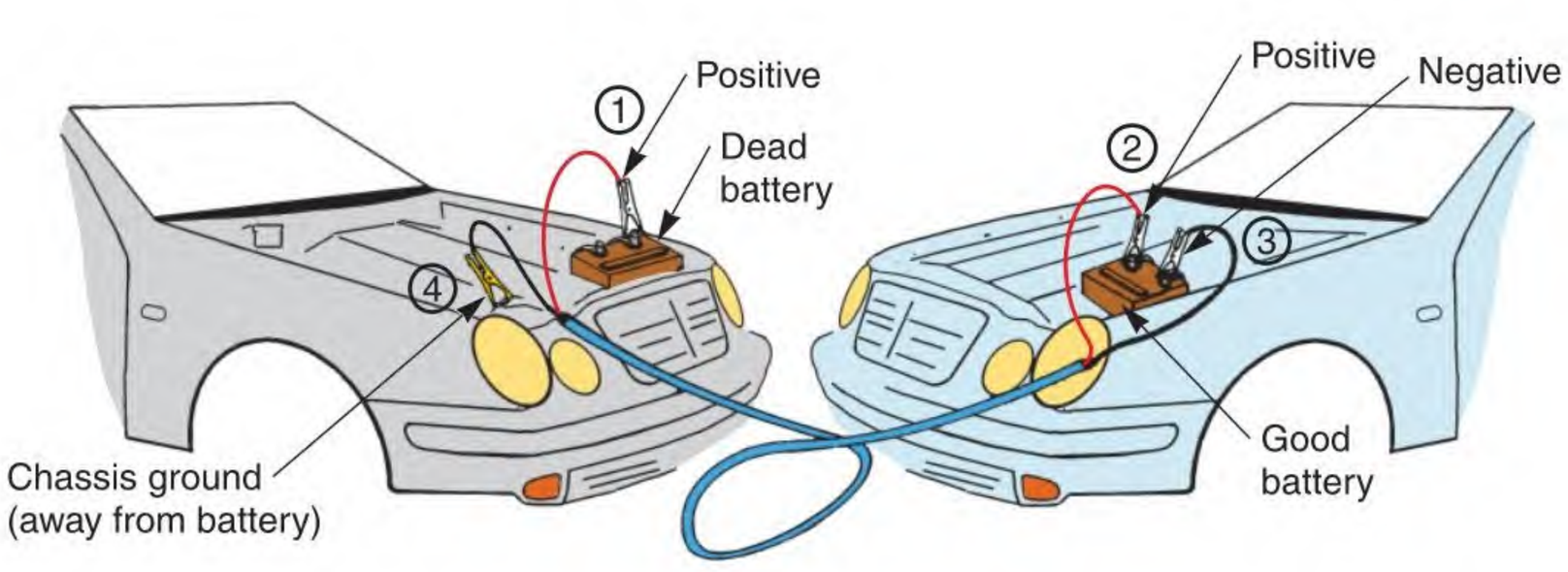
Charging a frozen battery can rupture the case and cause an explosion. A frozen battery will usually have plate and cell damage from ice expansion.

12-Volt Jump Starting

In emergency situations, it may be necessary to ***jump start*** an engine by connecting another battery to the discharged battery. Look at **Figure 29-13**. The two batteries are connected positive-to-positive and negative-to-negative. Connect the red jumper cable to the positive terminal of both batteries. Then, connect one end of the black jumper cable to the negative terminal of the good battery. Connect the other end of the black jumper cable to a good ground, away from the dead battery. See **Figure 29-14**. By connecting the last negative jumper cable to a ground away from the discharged battery, any spark that occurs when making the final connection will be far away from the explosive battery gas.

Caution

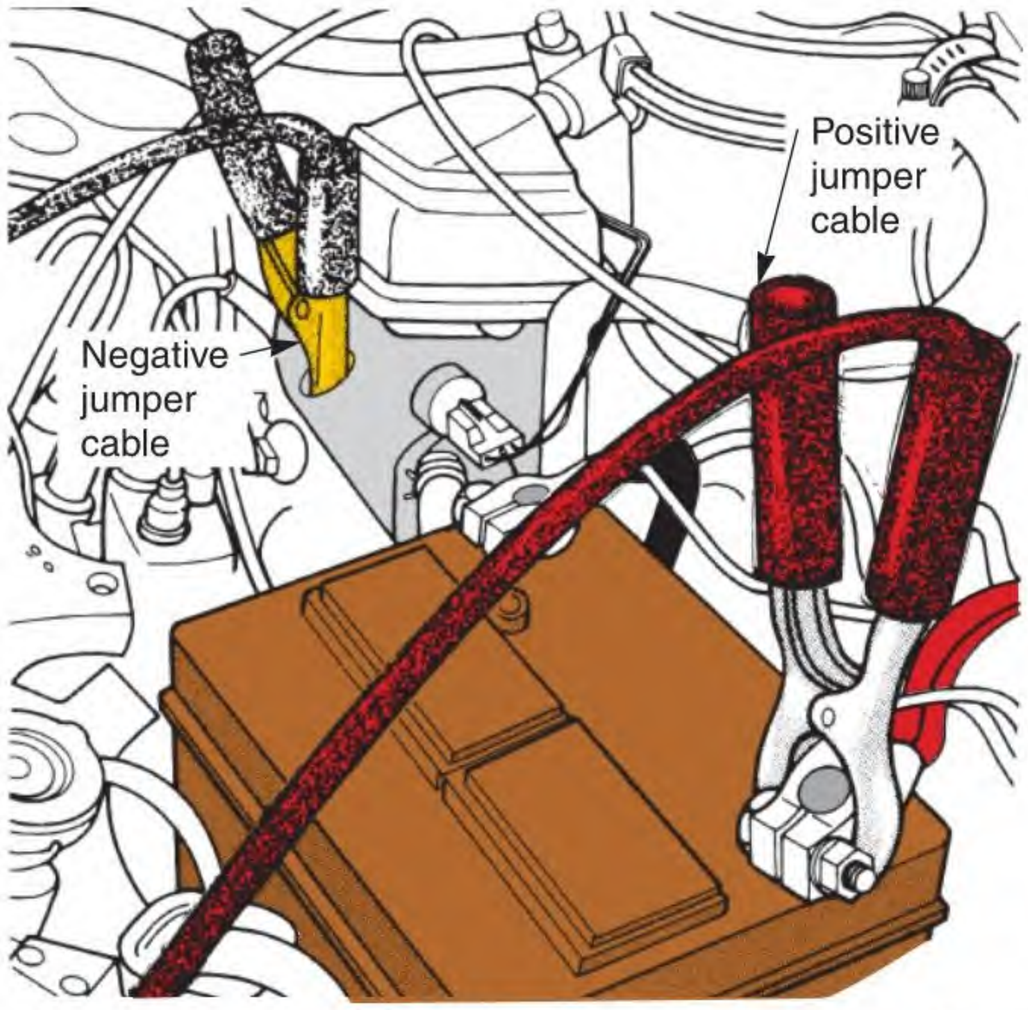
Do not short jumper cables together or connect them backward (positive to negative). This could cause serious damage to the vehicle's electronic systems. Diodes in the alternator and ac-to-dc rectifier circuits can be ruined by improper jumper cable connections.



Belden

Figure 29-13. Jumper cables can be used to start a vehicle with a dead battery. 1—Connect one end of the red jumper cable to the positive terminal of the dead battery. 2—Connect the other end of the red jumper to the positive terminal of the good battery. 3—Connect one end of the black jumper cable to the negative terminal of the good battery. 4—Connect the other end of the black jumper to a good ground on the disabled vehicle, away from the dead battery. Run the engine in the car with the good battery while starting the vehicle with the dead battery.

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Chrysler

Figure 29-14. Close-up of jumper connections shows the connection of the negative (black) jumper to chassis ground. A spark near the dead battery could make battery gases explode.

12-Volt Battery Load Test

A ***battery load test***, also termed a battery capacity test, tests the battery under full-current load. A battery load test is one of the best methods of checking the condition of a 12-volt battery.

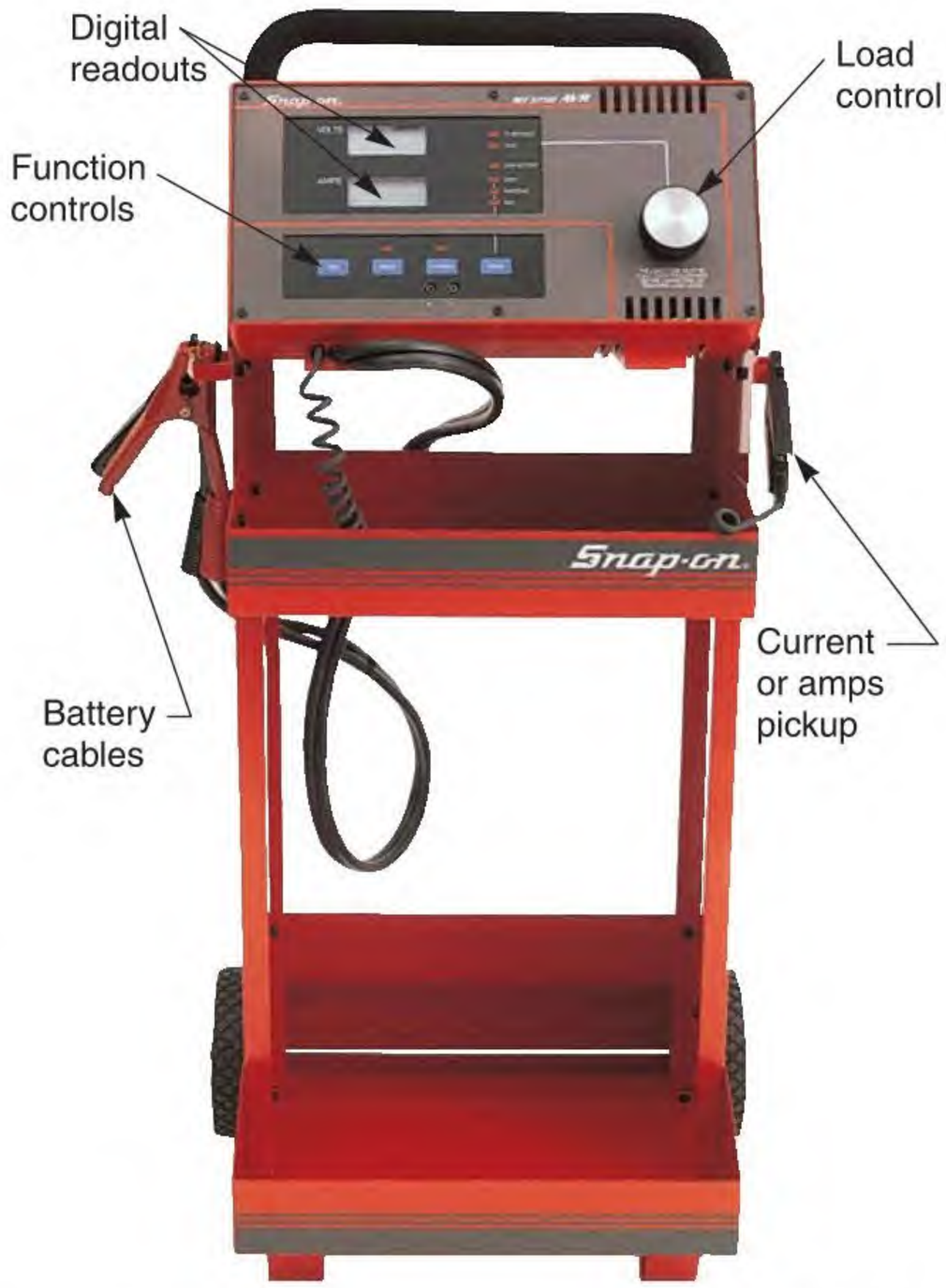
The hydrometer and voltage tests are general indicators of battery condition. The battery load test, however, actually measures the current and voltage output and overall performance of the cells. It is one of the most common and informative battery tests used in modern shops. Refer to **Figure 29-15**.

Connecting a Load Tester

Connect the load tester to the 12-volt battery terminals properly: positive-to-positive and negative-to-negative. Clamp the inductive amp pickup over the negative battery cable so it can measure magnetic field and current. Look at **Figure 29-16**. If the tester is not inductive, you must connect the ammeter in series with the load tester cables.

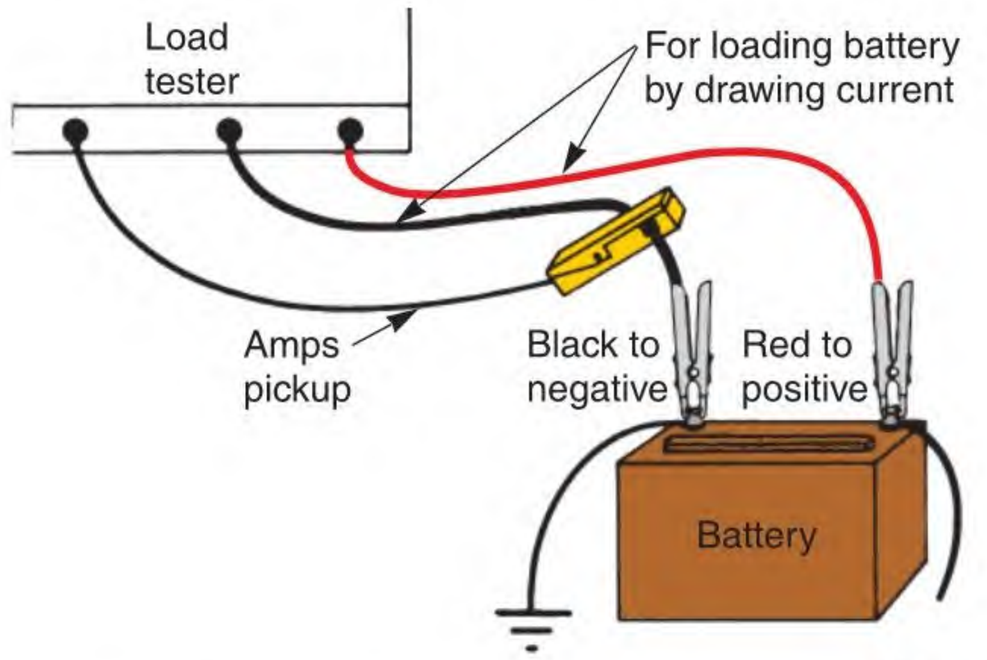
Tech Tip

Read and follow the operating instructions provided with the battery load tester.



Snap-on Tool Corp.

Figure 29-15. A load tester can be used to accurately determine battery condition. It is a commonly used testing device that measures actual battery performance.



Marquette

Figure 29-16. Load testers are connected as shown. Clamp the large cables to the battery. Clip the inductive amps pickup around the negative tester cable.

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Before load testing a 12-volt battery, it is best to slow-charge the battery overnight. A partially charged battery will fail its load test. Adjust the load control on the testing machine to draw 50 amps for 10 seconds. This will remove any surface, or false static, charge from the battery. Then, check no-load battery voltage (also called open circuit voltage, or OCV), by reading the voltmeter.

A fully-charged battery should have a no-load voltage of 12.4 volts or higher. If battery voltage is below 12.4 volts, charge the battery before load testing. The battery is bad if it does not have almost 12.6 volts after a second charging and no-load voltage measurement.

Determine 12-Volt Battery Load

Before load testing a 12-volt battery, calculate the load test value (amp load) that should be applied to the battery. If the amp-hour rating is given, load the battery to three times its amp-hour rating. For example, if the battery is rated at 60 amp-hours, load test the battery at 180 amps ($60 \times 3 = 180$).

Many 12-volt batteries are now rated in SAE cold cranking amps (CCA), rather than amp-hours. To determine the load test values for these batteries, divide the cold cranking amps rating by two. For instance, a battery with a 400-cold cranking amps rating should be loaded to 200 amps ($400 \div 2 = 200$).

Figure 29-17 shows load test values for various battery ratings. A ***load conversion chart*** is normally provided with the load testing equipment. Refer to this material when in doubt.

Loading the 12-Volt Battery

After checking the battery charge and finding the amp load value, you are ready to test the battery output.

Service Procedure

To test the output of a 12-volt battery:

1. Double-check that the load tester cables and leads are connected properly (positive-to-positive and negative-to-negative).
2. Turn the load control knob until the ammeter reads the correct amp load for your battery.
3. Hold the load for 15 seconds to draw high current out of the battery.
4. Read the voltmeter while the load is applied.
5. Turn the load control completely off so the battery will not be discharged or drained fully.

If the voltmeter reads 9.5 volts or more at room temperature, the battery is good. This voltage value is based on a battery temperature above 70°F (21°C). A cold battery may show a lower voltage. You will need a temperature compensation chart, like the one in **Figure 29-18**, to determine the correct voltage value at temperatures below 70°F.

If the voltmeter reads below 9.5 volts at room temperature, battery performance is poor. This shows that the battery is not producing enough current to properly run the starting motor.

Activating Dry-Charged 12-Volt Batteries

There is no difference in the materials used in wet- and dry-charged lead-acid batteries. The difference is in how the batteries are prepared for service.

Battery ratings			Load test amps
Cold cranking current	Amp-hour (approx.)	Watts	
200	35–40	1800	100 amps
250	41–48	2100	125 amps
300	49–62	2500	150 amps
350	63–70	2900	175 amps
400	71–76	3250	200 amps
450	77–86	3600	225 amps
500	87–92	3900	250 amps
550	93–110	4200	275 amps

Marquette

Figure 29-17. This chart shows different battery ratings and calculated current values for load testing.

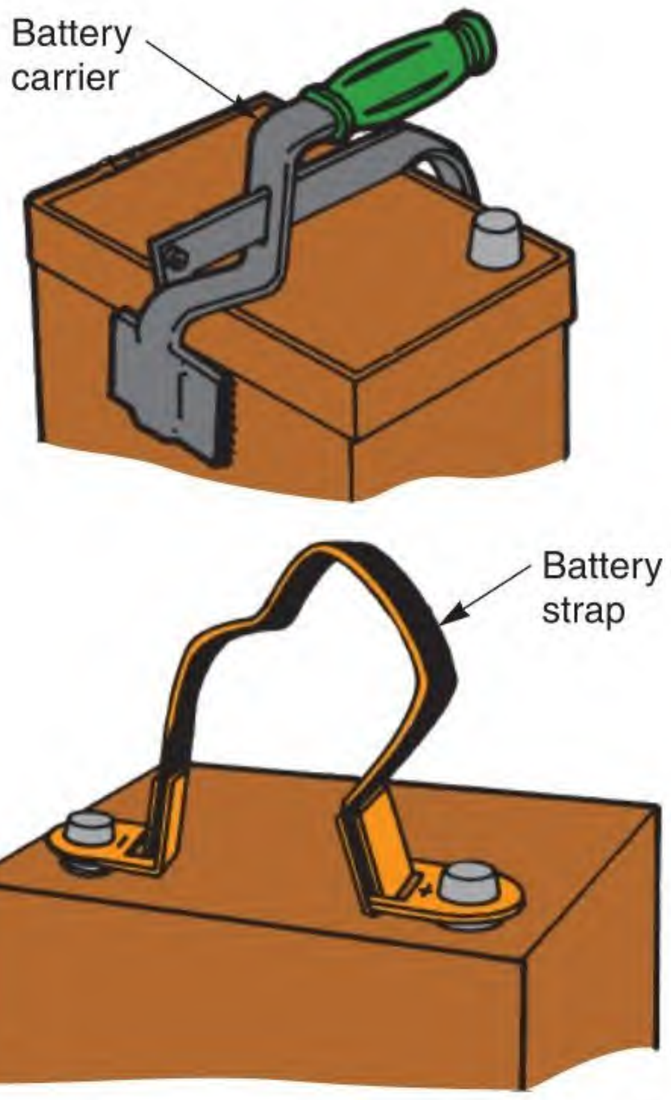
Approximate electrolyte temperature		Minimum acceptable voltage under load for good battery
60°F	(16°C)	9.5
50°F	(10°C)	9.4
40°F	(4°C)	9.3
30°F	(–1°C)	9.1
20°F	(–7°C)	8.9
10°F	(–12°C)	8.7
0°F	(–18°C)	8.5

Snap-on Tool Corp.

Figure 29-18. If the voltage reading is below the values presented in the chart for the specific battery temperature, the battery is probably bad.

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A ***wet-charged battery*** is filled with electrolyte and charged at the factory. The battery is then tested and placed in stock, ready for service. A ***dry-charged battery*** contains fully-charged elements, but it does not contain electrolyte. It leaves the factory in a dry state. Before use, you must fill the battery with sulfuric acid. A dry-charged battery has a much longer shelf life than a wet-charged battery.



Florida Dept. of Voc. Ed.

Figure 29-19. If you lose your grip and drop a battery, acid could splash out and cause eye or skin injury. Always use a battery strap or carrier and wear eye protection for safety.

Service Procedure

To activate new dry-charged battery before installation:

1. Put on safety glasses and rubber gloves.
2. Remove the cell caps or covers.
3. Using a plastic funnel (acid will eat into a metal funnel), pour electrolyte into each cell. Pour in enough electrolyte to just cover the plates and separators.
4. Replace the caps.
5. Charge the battery as recommended by the manufacturer.
6. After charging, recheck the electrolyte level.

Removing and Installing a 12-Volt Battery

To remove a battery, disconnect its cable end clamps and loosen and remove the battery hold-down. Use a ***battery strap*** or ***battery carrier***, **Figure 29-19**, to carefully lift the battery out of the vehicle.

Tech Tip

A replacement battery should have a power rating at least equal to factory recommendations. If an ***undersized battery*** (lower watt or amp rating) is installed, starting motor performance and ***battery service life*** may be reduced.

Warning

Always wear safety glasses when carrying a battery. If you drop a lead-acid battery, electrolyte (sulfuric acid) can squirt out of the vent caps or a broken case and into your face and eyes.

To install a battery, gently place the battery into its clean tray or box. Check that the battery fits properly in the vehicle. The old and new batteries should be the same size (height, width, and depth). The tray edge must not cut through the plastic battery case, as this would allow electrolyte to leak out. Tighten the hold-down and install the cables. See **Figure 29-20**.

HV Battery Service

HV batteries for electric propulsion must be serviced differently from conventional 12-volt batteries. Since a large number of battery packs are wired together in series, the large cables leading out of the HV battery can carry 300 volts dc or more. You must learn many new techniques to safely service and replace an HV battery used in today's electric drive trains.

HV battery service life averages about 150,000 miles (240,000 km). Some HV batteries have failed in as few as 60,000 miles (100,000 km), but many last almost 10 years and/or 200,000 miles (320,000 km). An HV battery normally has a warranty from the

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Figure 29-20. When installing a battery, do not overtighten cable terminals or you could strip the threads. Make sure the hold-down is secure.

vehicle manufacturer. One automaker, for example, offers an HV battery replacement warranty for up to 10 years or 100,000 miles (160,000 km).

HV batteries are very dependable and seldom fail. Nevertheless, even an HV battery can lose much of its electrical storage and output after years of extended service. The electrolyte and the plates can deteriorate and become depleted after years of recharging and discharging.

If the hybrid drive system is functioning normally, the motor-generator and HV power control module should keep the HV battery at a normal, or nominal, ***state-of-charge***. The hybrid dash display will inform you if the HV battery has a low state-of-charge or other problem.

Hybrid Jump-Starting

Avoid jump-starting a hybrid vehicle unless it has a 12-volt battery *and* a 12-volt starting motor. Some late-model full-electric drive trains cannot be jump-started. Full hybrids or full-electric vehicles must be towed to a service facility if they have a dead or discharged HV battery.

When a full hybrid fails to start, it is seldom because the battery is fully discharged. Another electrical problem is probably keeping the HV power control module from starting the engine or the electric drive system. A faulty HV power control module can sometimes cut power to every circuit, even low-voltage circuits.

Some vehicles use a starter/alternator instead of a 12-volt starting motor and 12-volt battery. The larger starter/alternator is actually a small motor-generator. It can be driven by the HV power control module to crank the engine over with its ribbed drive belt. When the engine is running, spinning the small motor-generator armature generates electricity for all electrical systems in the vehicle.

Connect your jumper cables from a good 12-volt battery to the dead battery. Connect the jumpers normally—positive-to-positive and negative-to-ground. Make the last jumper cable connection away from the dead battery.

Tech Tip

If a hybrid has a 12-volt battery, the cell plates might not be designed to handle the high current draw (100 amps or more) pulled by a conventional starting motor. Many hybrid gel and absorbed glass mat 12-volt batteries are designed to power only low-load circuits (instrumentation, lights, stereo, and ECMs) and are not powerful enough to operate the motor-generator as an engine starting motor.

Some hybrid designs have a rectifier and step-down transformer circuits built into the HV power control module. The two sets of windings of a large step-down transformer reduce HV battery voltage to a smooth 12–15 volts dc. A smaller gauge wire from the HV power control module feeds the low voltage to the vehicle's fuse panel. The fuses and circuit breakers then feed 12–15 volts dc to all conventional electrical circuits in the vehicle.

Warning

Never connect two HV batteries together with battery jumper cables. If one HV battery is totally discharged, a powerful electric arc can jump between the cable ends when connected. Thousands of amps can try to flow into the dead HV battery, making a loud pop. The resulting electric arc can instantly burn and destroy the metal ends of the HV power cables. You could be temporarily blinded by the bright light and burned by the molten metal shooting from the cable ends. If an HV battery is fully discharged, it must be recharged with an automatic HV battery charging machine or a recharging station.

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Checking HV Battery Condition

Use the vehicle's dash display and/or a scan tool to observe the vehicle's HV battery readings. See **Figure 29-21**.Hybrid drive trains have an HV battery control module with extensive, built-in, high- and low-voltage monitoring capabilities. Some hybrids have a separate HV battery control module, while others have it built into the HV power control module.

To check general HV battery performance, connect a scan tool to the diagnostic connector on the vehicle and test drive the hybrid. Watch the combination meter in the dash display as you accelerate and brake. Also, use regenerative braking to try to recharge the HV battery. The live readings on your scan tool should be the same as those shown in the dash display.

The ***HV battery control module*** will usually monitor battery pack temperatures, current input and output levels, recharge and discharge voltages, and battery state-of-charge. The vehicle's hybrid control module will convert these values into a percent of charge for the driver, technician, and scan tool data readings. Either the hybrid dash display or an advanced scan tool and the HV battery control module will let you determine the condition of the HV battery.

HV battery state-of-charge should be at least 80% of maximum voltage rating after a full recharge (300-volt batteries would show about 240 volts dc). The hybrid control module or the HV battery control module uses the HV power control module to make the engine and motor-generator recharge the HV battery whenever its state-of-charge goes below 20–30%.



Chrysler

Figure 29-21. Most hybrids will provide an in-dash display of the vehicle's electric drive conditions. This display shows battery level, or state-of-charge, in a graph form. Note the HV battery has 75% of its full charge.

You must refer to the vehicle specifications to determine HV battery voltage and state-of-charge after the vehicle has been driven in all-electric mode.

A bad HV battery will have a state-of-charge that is lower than specifications. If the HV battery state-of-charge drops below a preset level, the hybrid control module will start the internal combustion engine and motor-generator until the battery is almost fully charged.

Testing HV Battery Voltage

To properly test HV battery voltage, fully recharge the battery using a plug-in charger station or HV battery charger, **Figure 29-22**. Preferably, charge the HV on slow charge (or low amps) setting for at least eight hours.



Honda

Figure 29-22. Proper charging will take from 8 to 12 hours, and will allow the vehicle to operate in all-electric mode for up to 50 miles before the gas engine has to take over.

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Tech Tip

Never use a conventional digital or analog test instrument to measure the voltages and current levels in a high-voltage electric power train. The high voltage will instantly "arc and spark" inside the instrument, shorting out and badly burning internal meter circuits. Use only a high-voltage VOM with an insulation rating of 1000 volts or more when testing hybrid drive circuits.

To measure HV battery voltage, connect a high-voltage voltmeter across the two HV battery cables. Look at **Figure 29-23**. Compare your meter reading to the known acceptable voltages of a fully-charged HV battery and to the dash display.

A fully-charged HV battery should show voltage levels to within 60–75% of specifications. For instance, if your meter reads 150 volts dc across the terminals of a fully charged battery rated at 288 volts dc, the battery has lost some of its power. The low voltage reading would indicate that some of the battery packs in the HV battery have failed or that there is a problem in the charging system.

If a plug-in hybrid originally had an all-electric driving range of 50 miles, a weak HV battery might only be able to propel the car for 25 miles before the gas engine starts to assist the HV battery.

Charging an HV Battery

A hybrid battery charger uses a step-up transformer to force high voltage back into the HV battery to re-energize all of its cells. Follow the battery charger's and vehicle manufacturer's instructions for safely connecting the charger cables to the HV battery. Procedures vary by hybrid vehicle make and model.

Service Procedure

To charge a hybrid HV battery:

1. Set up a buffer zone around the vehicle by moving all carts, tools, and equipment away from the car body.
2. Plug in the hybrid battery charger. The charger will require either 120 volts ac or 240 volts ac. Refer to the charger's manual for the correct voltage.
3. Connect the hybrid charger leads to the hybrid vehicle. See **Figure 29-24**. A charging connector is usually provided on late-model hybrids so you can easily plug in the hybrid battery charger.
4. Set the battery charging rate and turn the charger on. Charge the HV battery overnight, if possible.

If voltage has not increased to within minimum levels, the battery has failed and should be replaced.

HV Battery Load Test Drive

An HV battery load test drive measures current and voltage levels into and out of the large battery pack while driving or during simulated driving. An HV battery can be load-tested during a vehicle test drive or by placing the car on jack stands with the drive wheels and tires off the ground.

Warning

Never attempt to use a conventional battery load tester to check an HV battery. The load-carrying capability of a conventional 12-volt load tester is insufficient. The kilowatts of power of an HV battery will burn the carbon pile in the tester.

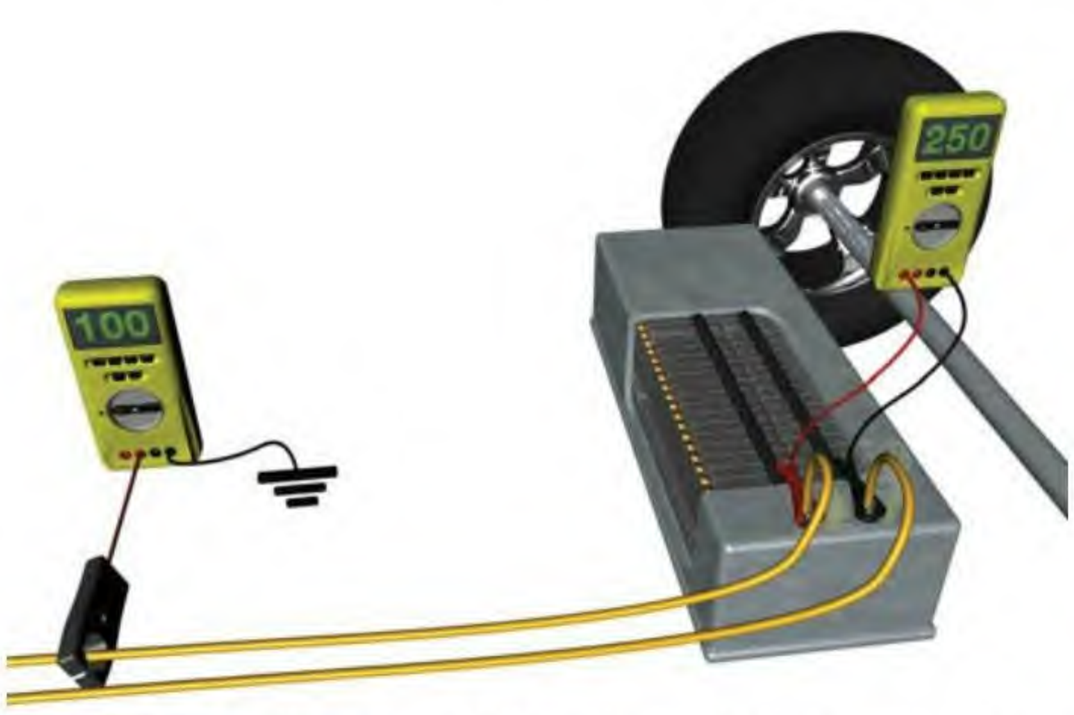
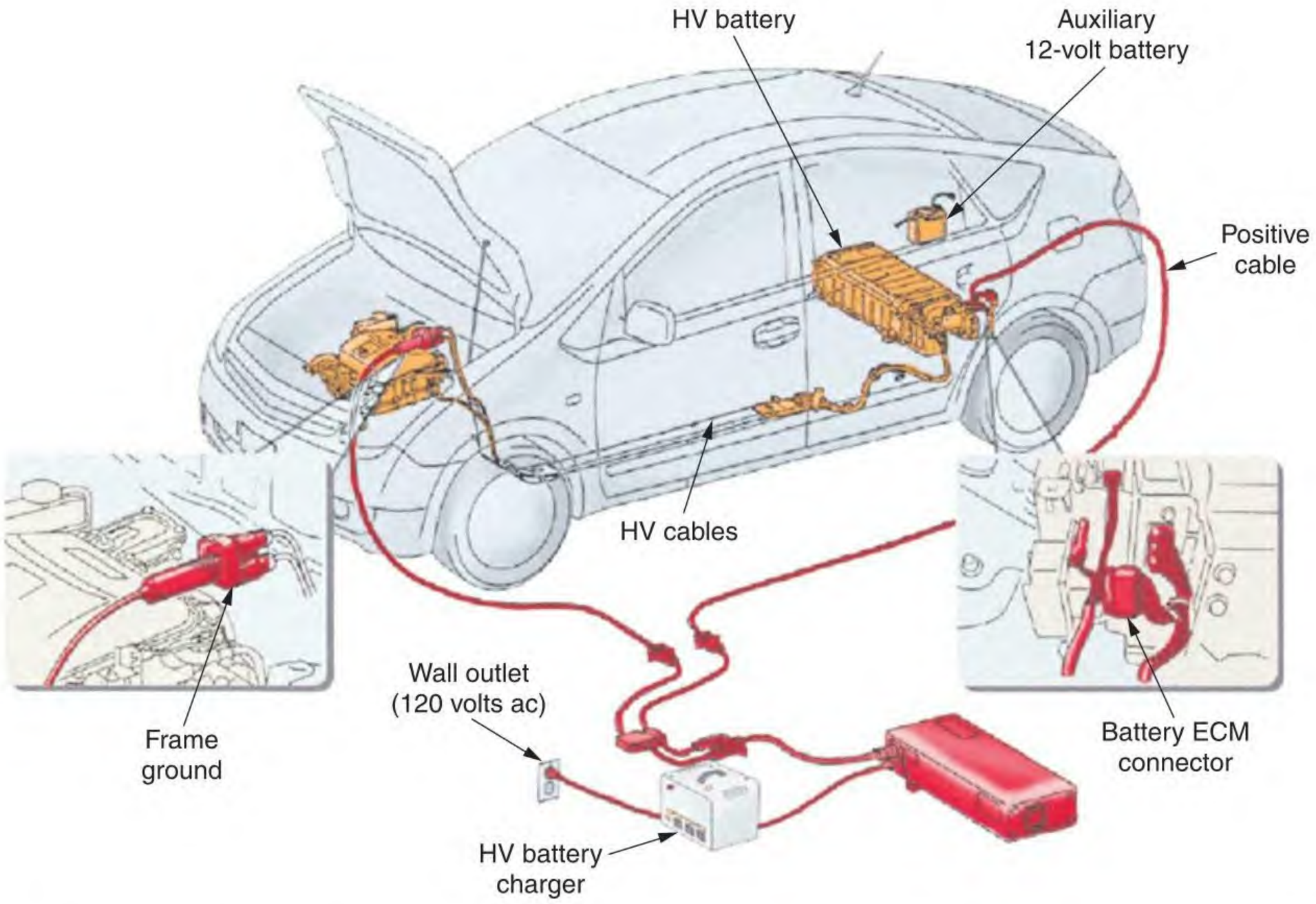


Figure 29-23. If the dash OBD system indicates an improperly charged HV battery, measure battery voltage with a high-voltage meter. If the battery is supposed to have 288 volts and it shows only 250 volts, you can calculate its percent of charge (87%).

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Toyota

Figure 29-24. A high-voltage battery charger is connected to ground and to the battery pack positive at special service connectors.

Service Procedure

To perform a battery load test drive:

1. Fully recharge the HV battery with an external battery charger, or plug the battery into an HV charging station.
2. Connect your laptop or scan tool to the vehicle's diagnostic connector.
3. Adjust your diagnostic tool to take live readings of the HV battery.
4. Test drive the vehicle while recording live data on the laptop or advanced scan tool.

If the battery load test drive indicates poor battery capacity, the entire HV battery must generally be replaced. HV batteries are usually sent to a specialty shop for refurbishing.

In-Shop HV Battery Load Test

If you need to load test the HV battery in the shop, secure the vehicle on jack stands so the drive tires are several inches off the ground. Place your jack stands under the control arms to prevent drive axle damage. This positioning will let the HV battery and traction motor spin the CV axles and wheels without binding and resulting in CV joint noise. Place blocks or chocks under the nondriving tires that are still on the ground so the vehicle cannot move.

Service Procedure

To perform an in-shop HV battery load test:

1. Make sure the HV battery is fully recharged.
2. Connect an inductive ammeter around the positive battery cable.
3. Attach the voltmeter leads to the HV battery as shown in **Figure 29-25**.
4. Press the electric drive train *Start* button and put the transmission in *Drive*.
5. Press the accelerator pedal gently to slowly spin the drive wheels. This normally makes the HV battery send high current to the motor-generator for full-electric propulsion.

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Tech Tip

You may need to have a co-worker activate the electric drive train while you observe meter readings.

6. If possible, keep the vehicle in full-electric mode to increase current draw on the motor-generator and pull more current from the HV battery.
7. Compare the battery performance (live scan tool or voltmeter and ammeter readings) to that of a known good battery or to specifications.

Normal battery voltage but low current might point to HV control module or a motor-generator problem. Low voltage and low current may indicate a bad HV battery.

HV Battery Removal and Replacement

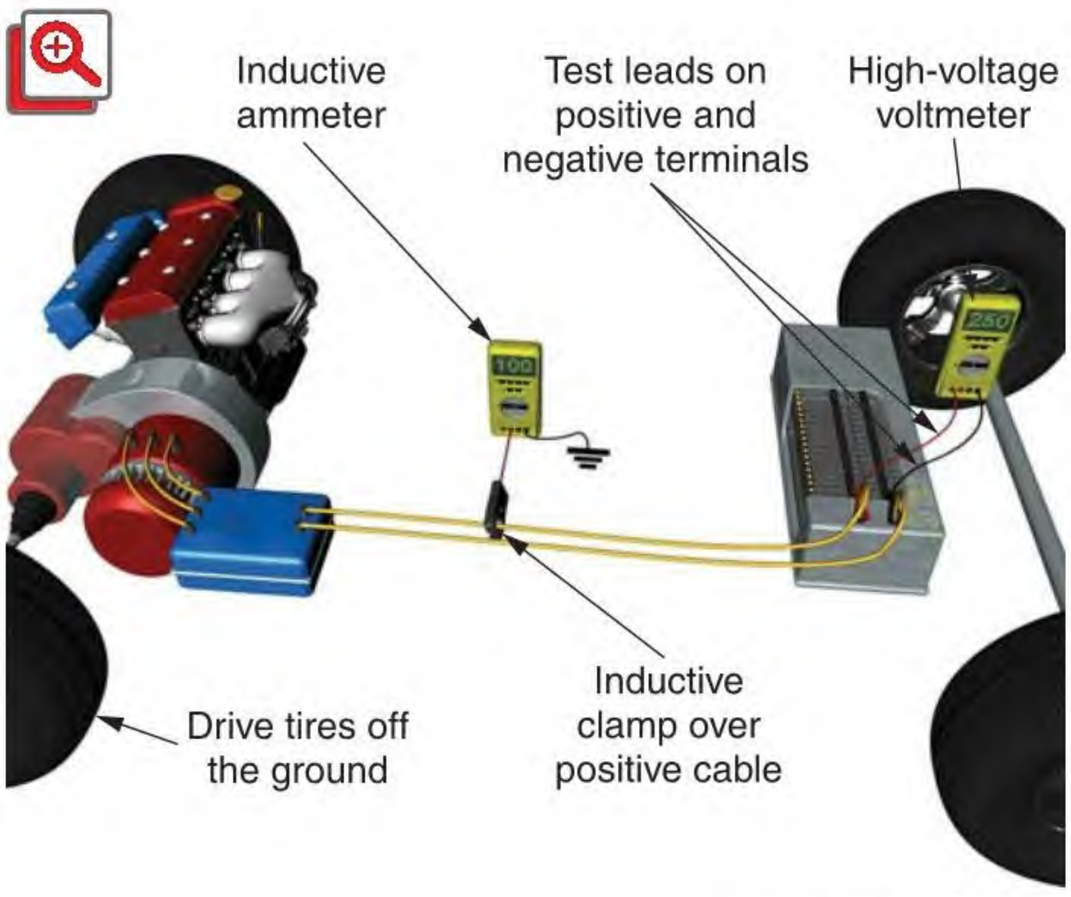
The most common reasons for HV battery replacement are age and physical damage. A severe collision can rupture the battery pack elements. This can penetrate the cell insulation, allowing cell plates to short out.

Before removing the battery, depower the electrical system according to the vehicle manufacturer's instructions. Normally, you must pull a safety disconnect plug or move a battery disconnect switch to disconnect the HV battery from its electrical system, **Figure 29-26**.

Refer to factory service information showing battery location, electrical connections, and mounting. HV batteries may be located in the trunk area, under a rear seat cushion, under the hood, or under the vehicle body. If the HV battery is mounted under the rear seat, remove the interior trim, seats, and carpeting over the top of the battery. If the battery is in the trunk, remove any carpet, spare tire, or cover over the HV battery. Look at **Figure 29-27**. If the battery is water cooled, remove a lower hose on the reservoir to drain the coolant out of the system.

While wearing insulated rubber gloves and appropriate eye protection, remove the large fasteners or connectors that secure the HV power cables to the HV battery. To prevent a high-voltage short, wrap electrical tape around the metal terminals on the ends of the HV power cables. You do not want them to accidentally contact anything and conduct high-voltage electricity into anyone or anything.

Unbolt the HV battery hold-down flange from the vehicle frame. A mild hybrid battery assembly can weigh 100–300 lbs. (45–136 kg). An HV battery for a full-electric drive vehicle can weigh over 1000 lbs. (454 kg). If the battery is very heavy, use an engine crane and nylon straps to raise the large assembly up and out the vehicle. The battery should be handled carefully since it contains a tremendous amount of stored chemical-electrical energy.



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Figure 29-25. For an in-shop load test of an HV battery, connect an inductive ammeter around the positive battery cable and attach the voltmeter leads to the HV battery, as shown.



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Figure 29-26. The main battery disconnect can be under the seat, on the side of the HV battery, or in the trunk of the vehicle.

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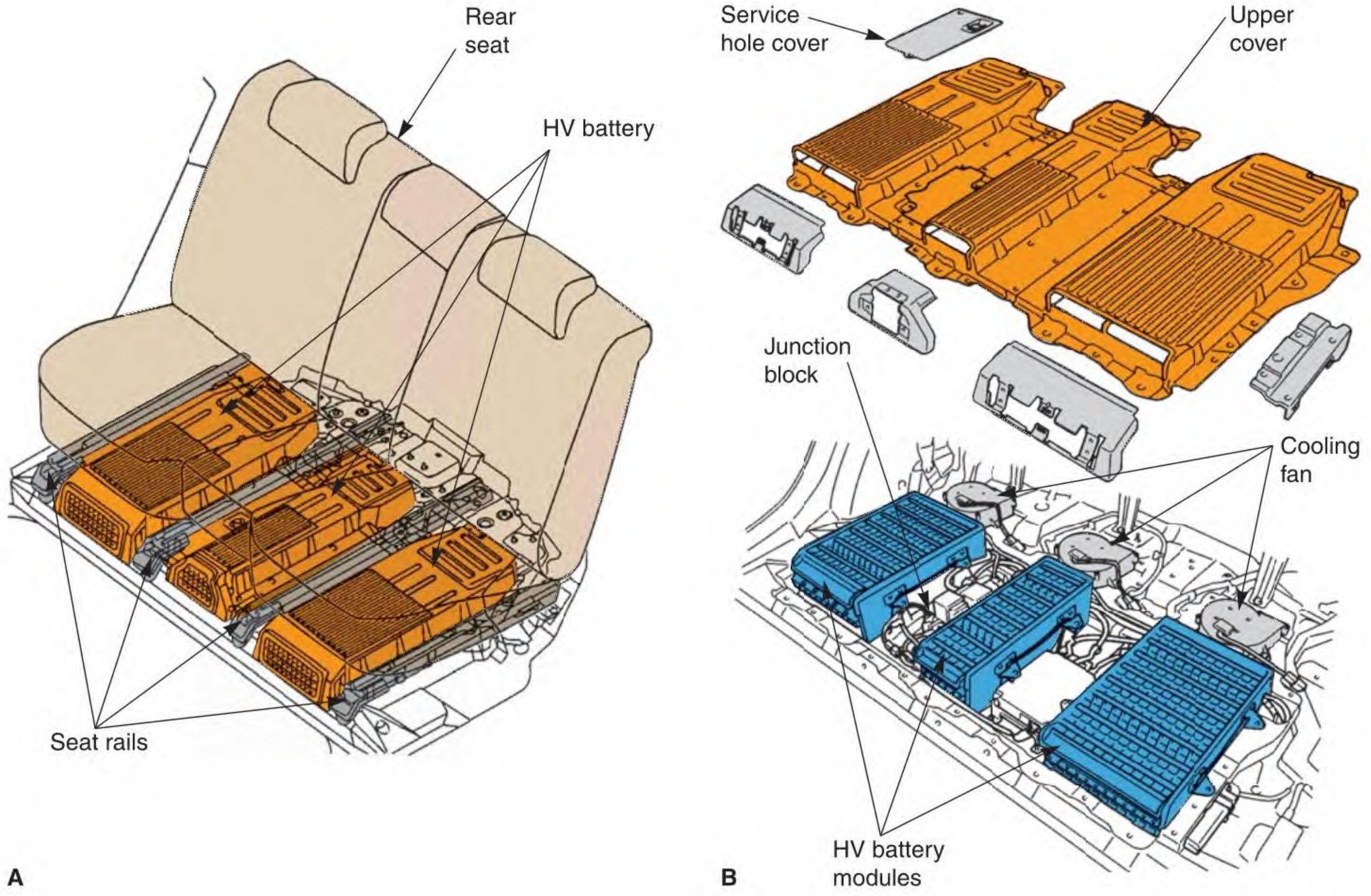


Figure 29-27. These HV batteries are located under rear seat cushion. A—Remove the rear seat and trim panels to gain access to the batteries. B—Remove the cover over the batteries to access the batteries, HV battery control module, cooling fans, and other units that affect battery performance.

Warning

When removing the HV battery cover, never lay tools or test equipment on top of the battery packs. These items could easily touch a metal conductor and cause a small electrical explosion and total destruction of the tool or test instrument.

Some electric and gas-electric power trains have the HV battery located under the center console of the vehicle. The battery fits into the center hump under the floor pan and bolts to the metal frame. Locating the heavy battery in this position lowers the vehicle's center of gravity. It also isolates battery heat and any hydrogen gas outside the passenger compartment for driver and occupant safety.

Service Procedure

To remove an HV battery that is mounted under the floor pan:

1. Raise the vehicle on a two- or four-post lift. A single-post lift will not let you access the battery.
2. Unfasten and disconnect any wires, hoses, or ducts that prevent battery removal.
3. Place a transmission jack or an HV battery jack under the HV battery.
4. Position the lifting arms on the jack so they balance and support the weight of the unit.
5. Remove the bolts or nuts that secure the heavy battery to the unibody structure.
6. Two workers are needed to slowly lower the HV battery to the ground.

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If you accidentally drop an HV battery, especially a lithium-ion battery, it can rupture several of the lithium cells and short them out. The damaged HV battery cells can start to smoke and hiss, as if catching fire. The smoke is acidic and should not be inhaled or make contact with your skin. Open the shop overhead doors and stay clear of the damaged HV battery for a few minutes until it stops smoking.

Warning

Never spray or pour water on a smoking modern lithium-ion battery pack. The exposed lithium acid and plates will pull hydrogen atoms out of the water in large quantities, resulting in the emission of pure hydrogen in a gas form. If enough hydrogen gas is ignited at once, a powerful explosion could result.

Place the HV battery assembly on a wooden pallet for shipment to an authorized recycler. Wrap electrical tape over the battery cables or connectors. Cover the battery with a thick plastic box and place it in a shipping container. Place warning labels on the outside of the battery module or shipping container to warn others of the high voltage and chemical dangers inside.

To replace an HV battery, use the same procedures used during removal. Make sure the battery is secured to the lift and will not fall. Only raise the HV battery high enough to clear the car body. Also, make sure the battery terminals are covered and insulated so you cannot be shocked and killed.

Use a torque wrench to tighten any HV power cable fasteners to specifications, and make sure all electrical connectors are fully engaged and reconnected. Reinstall any air ducts that connect to the HV battery housing. If water cooled, refill the HV battery cooling system with antifreeze or a factory recommended coolant liquid.

Use your scan tool to erase any battery trouble codes, and recharge the battery by connecting an HV battery charger or connect the battery to a charging station. Test-drive the car to check for proper electric assist or full-electric propulsion, if available.

HV Cable Connections Service

Since HV power cables in the electric drive train system carry tremendous amounts of current, it is critical that all cables and their connections are in good condition. See **Figure 29-28**. A poor power cable connection with just a few extra ohms of resistance will greatly affect electric drive train performance. A bad connection can cause cable overheating, reduced current flow, lowered motor-generator torque, and overall reduced electrical efficiency.



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Figure 29-28. Inspect HV power cables for looseness, signs of overheating, rust, and corrosion.

To check for a poor HV battery connection, inspect all fasteners and terminals closely. If the power cable end bolts to the HV battery or motor-generator, try to wiggle each connection by hand (while wearing insulating gloves). All orange cable connections must be tight enough that you cannot move them by hand.

Check HV power cable ends closely for signs of overheating and corroding. A poor current connection will become extremely hot and tends to loosen cable ends even more during heating/cooling cycles.

If a power cable end is loose, rusted, or damaged, remove the cable. Clean off the cable end with a wire brush or stiff scuff pad. Coat the cable ends with dielectric grease to protect them from moisture and corrosion.

Use a torque wrench to tighten each HV cable fastener to specifications. If a power cable connection is loose, the cable can overheat. If you overtighten the cable connection, you can damage the threads on the HV battery, HV power control module, and motor-generator.

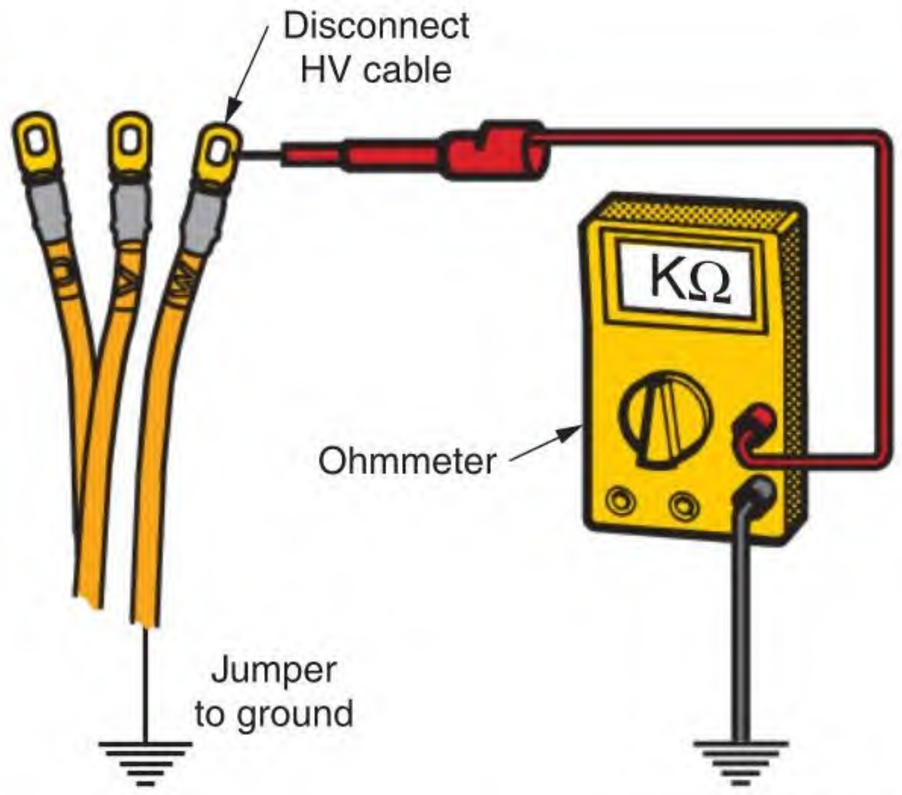
If the HV power cables use factory plastic connectors, use a small wire brush (known as a rifle brush) to clean inside the large round terminals. Remove any rust or corrosion that could affect the cable's electrical conduction. Coat both the male and female high-voltage terminals with dielectric grease to protect them and prevent corrosion.

If you suspect that an HV power cable is restricting current flow, measure its resistance with an ohmmeter. Connect one end of the power cable to ground and the other end of the power cable to your

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grounded ohmmeter. Refer to **Figure 29-29**. ***HV power cable resistance*** should be less than 0.001 ohm (1 milliohm) per 10 feet of cable. If the cable is only 5 feet long, the maximum resistance specification should be half, or 0.0005 ohm (0.5 milliohm). When measuring HV power cable resistance, add approximately 0.025 ohm per electrical connection.

To check for ***HV power cable leakage*** or bad orange insulation, disconnect the cable at both ends and measure its resistance to ground. With the ohmmeter grounded, touch the test lead on the metal end of the cable. If the HV power cable insulation is good, your meter should read infinite resistance. Any resistance reading indicates deteriorated cable insulation allowing unwanted current leakage to ground. If the HV power cable shows any electrical leakage, replace it and any others with poor insulation.

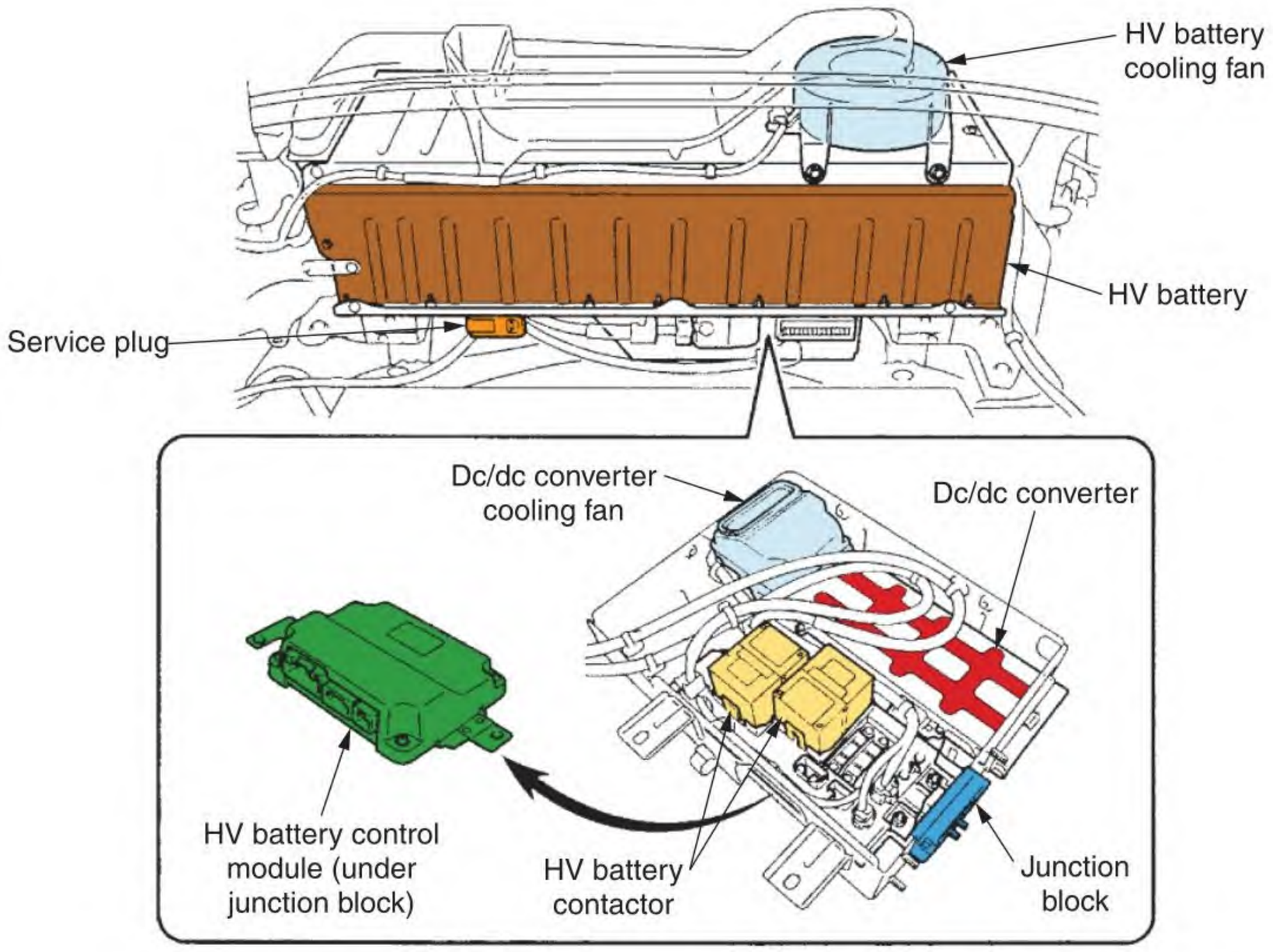


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Figure 29-29. Use an ohmmeter to check HV power cable resistance. Generally, a power cable should not have over about 0.001 ohm, or one milliohm, per ten feet of length.

HV Battery Control Module Service

A bad HV battery control module usually trips a trouble code. Your scan tool will flag any problem with this component and its wiring. Sometimes the HV battery control module is located inside the HV battery. It can also be mounted next to or away from the HV battery, depending on the vehicle make and model. See **Figure 29-30**.



Toyota

Figure 29-30. A bad HV battery control module can prevent normal charging. It is often mounted under, near, or inside the HV battery enclosure.

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Diagnostic Case Study

Concern: Mr. Nagdamoor drives his 2011 Toyota Camry to the shop, complaining that his new battery keeps going dead and that he has to jump start the car every morning.

Mr. Nagdamoor explains to Duff that the vehicle's battery is less than three months old and that it seemed fine for several weeks. For the last few days, however, he had to jump start the vehicle after it sat overnight. The car generally starts fine after the initial jump start.

Cause: Since the battery is new and the problem occurs after the vehicle sits overnight, the symptoms seem to point to a battery drain, or parasitic loss, problem rather than a charging or starting system problem. Duff thinks an electrical component might be staying on after the vehicle is turned off, draining the battery.

Duff relays the information he gathered to the shop's electrical technician. The technician first turns off all the vehicle's electrical accessories and removes the lightbulb under the hood. He then connects an ammeter in series with one of the battery cables. The ammeter shows a 2-amp draw, confirming Duff's suspicion that something is draining the vehicle's battery. The technician pulls fuses to see which circuit is causing the current drain—the ammeter stops registering when the fuse to the circuit containing the drain is removed. The problem is narrowed down to the accessory lighting system. The technician begins removing bulbs from the accessory lighting circuit while watching the ammeter. He discovers that the current draw stops when the trunk bulb is removed and the trunk is closed. Further tests show that the switch in the trunk lighting circuit is shorted closed, supplying power to the trunk light even when the trunk is closed. This slowly drains the battery whenever the vehicle sits unused for an extended period.

Correction: After changing the trunk light switch, the technician again connects the ammeter to check for excessive current draw. Not finding any other problems, the technician charges the battery and performs a charging system output test. The charging system shows an output of 13.8 volts with all electrical accessories turned off. The technician returns the vehicle to Mr. Nagdamoor, assuring him that the problem has been corrected.

Summary

- 12-volt battery maintenance tasks should be performed regularly to ensure optimal service life.
- A battery leakage test will find out if current is discharging across the top of the battery case.
- A battery terminal test quickly checks for a poor electrical connection between the battery cables and terminals.
- Clean battery terminals and coat with a conductive, dielectric compound or white grease before reinstalling the battery cables.
- When measuring battery charge, you are checking the condition of the battery electrolyte and battery plates.
- A parasitic load is any electric circuit current draw present when the engine and all electrical devices are shut off.
- A battery charger forces current back through the battery to restore the charge on the cell plates.
- A battery load test actually measures the current and voltage output and overall performance of the battery cells.
- A fully charged battery should have an OCV (no-load, open circuit voltage) of 12.4 volts or higher.
- HV battery service life averages about 150,000 miles.
- Full hybrids or full-electric vehicles cannot be jumped and must be towed to a service facility if they have a dead or discharged HV battery.
- Use a scan tool and the combination meter in the dash display to evaluate HV battery condition.
- HV battery state-of-charge should be at least 80% of maximum voltage rating after a full recharge.
- An HV battery load test drive measures current and voltage levels into and out of the large battery pack while driving or during simulated driving.
- The most common reasons for HV battery replacement are age and physical damage.
- When removing an HV battery, refer to factory service information showing battery location, electrical connections, and mounting.
- A poor HV power cable connection can cause cable overheating, reduced current flow, lowered motor-generator torque, and overall reduced electrical efficiency.

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Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

battery carrier
battery charger
battery drain test
battery leakage test
battery load test
battery service life
battery strap
battery terminal test
battery voltage test
boost charger
cell voltage test
dead battery
distilled water
dry-charged battery
fast charger
HV battery control module
HV power cable leakage
HV power cable resistance
hydrometer
hydrometer reading
jump start
load conversion chart
parasitic load
quick charger
slow charger
state-of-charge
trickle charger
undersize battery
wet-charged battery

Activities

1. Get permission from several classmates to conduct a 12-volt battery maintenance inspection on their vehicles. Check for the points listed in the *12-Volt Battery Maintenance* section of this chapter. Create and complete a simple checklist or write a short report for each vehicle inspected. Give the form or report to the vehicle owner.
2. Select any make and model hybrid vehicle. Look up the operating specifications in the service literature for the vehicle. While wearing insulated gloves, but without touching the power cables, trace the path of the two dc orange cables from the battery pack to the power control module. Then, trace the three ac cables from the power module to the motor-generator. Make a top view sketch of component placement and hybrid power cable routing.

Review Questions

Answer the following questions using the information provided in this chapter.

1. List the five tasks typically involved in 12-volt battery maintenance.
2. A(n) _____ test will determine whether current is discharging across the top of the 12-volt battery case.
3. If a voltmeter shows a 0.8 volt drop across the 12-volt battery post-to-cable connection during a battery terminal test, what should be done?
4. A knife or scraper is a good tool for cleaning corroded 12-volt battery terminals. True or False?
5. When measuring _____, you are checking the condition of the 12-volt battery electrolyte and plates.
6. The voltmeter reading for a 12-volt battery under a light current load should be _____ volts.
7. List six possible causes for a discharged 12-volt battery.
8. A customer complains that her battery goes dead when the car is not driven for an extended period. A new battery has been installed and tested by another shop. Technician A says that starting motor current draw should be measured. A shorted starting motor could be draining the battery. Technician B says that a battery drain test should be done. An electrical short could be discharging the battery, even with the ignition key off. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. When using a 12-volt battery charger, connect the red lead to positive and the black lead to negative. True or False?
10. When fast charging a 12-volt battery, you should never exceed a charge rate of _____.
11. Explain how to safely connect jumper cables.
12. A(n) _____ test is one of the best methods of checking the condition of a 12-volt battery.
13. Explain how to load test a 12-volt battery.
14. If a 12-volt battery shows less than _____ volts during a load test at 70°F (21°C), the battery is bad.
    (A) 9.9 volts.
    (B) 9.5 volts.
    (C) 9.7 volts.
    (D) 10.0 volts.

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15. HV battery service life averages about _____ miles.
16. Explain how to check the condition of an HV battery.
17. A mild hybrid battery assembly can weigh over 1000 lbs. True or False?
18. Identify three problems that can be caused by a bad HV power cable connection.

ASE-Type Questions

1. 12-volt battery maintenance and inspection should be conducted:
   (A) during tune-ups.
   (B) during grease jobs.
   (C) any time symptoms point to battery problems.
   (D) All of the above.
2. Which of the following will neutralize and remove an acid-dirt mixture from a 12-volt battery case?
   (A) Sulfur and water.
   (B) Baking soda and water.
   (C) White grease and a solvent.
   (D) Distilled water and gasoline.
3. Each of the following can be performed using a voltmeter *except:*
   (A) battery plate test.
   (B) battery voltage test.
   (C) battery leakage test.
   (D) battery terminal test.
4. A discharged 12-volt battery can be caused by a(n):
   (A) defective battery.
   (B) starting system problem.
   (C) engine performance problem.
   (D) All of the above.
5. Charging time for this device with a 12-volt battery is about 12 hours.
   (A) Fast charger.
   (B) Slow charger.
   (C) Quick charger.
   (D) Boost charger.
6. Technician A feels the best test to determine 12-volt battery current output and performance is the battery load test. Technician B feels hydrometer testing is the best choice. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. A fully charged 12-volt battery should have an open circuit voltage of:
   (A) 5.5 volts.
   (B) 12.4 volts or higher.
   (C) 25.0 volts or higher.
   (D) None of the above.
8. Technician A says that a good hybrid HV battery should show a voltage reading of almost 100% of maximum charge. Technician B says that most hybrids only charge their battery packs to about 80% of maximum charge. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Technician A says that you should never put any kind of grease on HV power cable connections. Technician B says that dielectric grease prevents electrical corrosion and the resulting bad connections that can burn up cables and components. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. Technician A says to use live readings from a scan tool or laptop computer to read HV battery voltage, current output while driving, battery temperature, and other readings to evaluate battery condition. Technician B says to use a conventional 12-volt battery load tester by connecting it to the HV power cables. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
11. Which of the following should *not* be done when servicing an HV battery?
    (A) Use a crane to lift the heavy battery.
    (B) Wrap electrical tape over the battery cables or connectors.
    (C) Pour water on smoldering lithium-ion electrolyte.
    (D) Wear rubber gloves and use insulated tools.

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Chapter 30
Engine Starting Systems

After studying this chapter, you will be able to:

- Explain the principles of 12-volt dc and high-voltage ac electric motors.
- Describe the construction and operation of conventional 12-volt and high-voltage starting motors and circuits.
- Sketch a simple computer-controlled starting system circuit.
- Explain the operation and location of starting motor solenoids and HV contactors.
- List and describe the purpose of major starting circuit components.
- Compare different types of starting motor drive mechanisms.
- Describe starting system safety features, especially with high-voltage hybrid starting systems.
- Compare 12-volt engine starting circuits with HV starting circuits.
- Correctly answer ASE certification test questions that require a knowledge of both 12-volt and HV starting system fundamentals.

An ***engine starting system*** must crank or spin the engine until fuel combustion forces the pistons down and the engine begins to operate on its own power. When the driver turns the ignition key or presses the start button, electrical energy is sent to the starting circuit to energize the 12-volt starting motor mounted on the engine block. A small gear on the starting motor engages and rotates a large gear on the engine flywheel. This spins the engine crankshaft, pulls air into the cylinders, and operates the spark plugs to fire up the engine.

The starting system in today's hybrids and ECM-controlled starting circuits can also shut the engine off when it is not needed. This feature saves a tremendous amount of gasoline that is normally wasted when a car is sitting idle at stoplights or intersections.

The starting system has helped make the modern automobile a reliable and convenient means of transportation. It provides an effortless method of cranking and starting multi-cylinder engines. Few car owners would be physically capable of starting a multi-cylinder engine using a hand crank. The electric starting motor is designed to crank the engine with the simple turn of a key or press of a button.

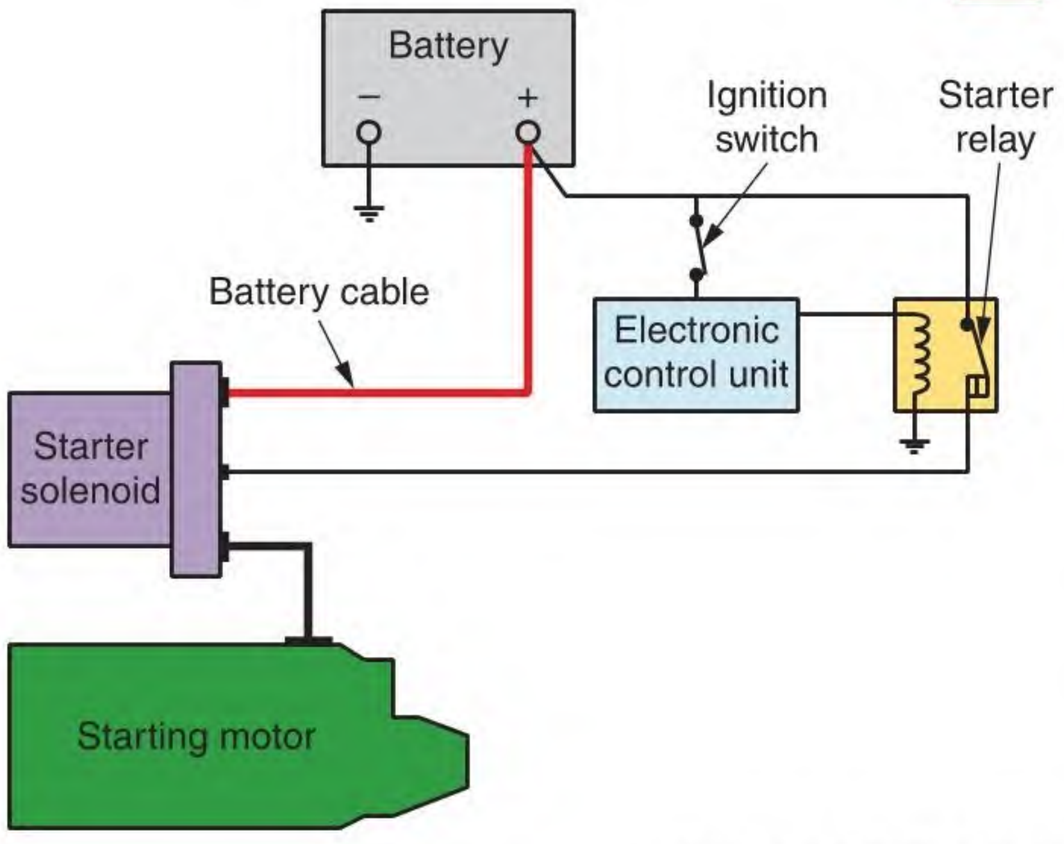
This chapter provides the information needed to understand how any starting system is supposed to function. You will learn about the operation of conventional 12-volt starting circuits before studying more complex hybrid high-voltage starting systems. You will also learn about electronic starter disengagement systems.

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12-Volt Starting System Principles

The ***12-volt starting system*** uses battery power and an electric motor to turn the engine crankshaft for engine operation. The main parts of a starting system include:

- Battery—The ***battery*** is a source of electrical energy for the starting circuit.
- Ignition switch—The ***ignition switch***, or ***start switch***, allows the driver to control starting system operation.
- Starter solenoid—The ***starter solenoid*** is a high-current contactor for connecting the battery to the starting motor.
- Starter relay—The ***starter relay*** is a low-current relay that operates the starter solenoid.
- Starting motor—The ***starting motor*** is a high-torque electric motor for turning the gears at the engine flywheel.
- Engine control module—The ***engine control module (ECM)*** reacts to the voltage of the starter button or ignition key to energize the starter relay. See **Figure 30-1**.



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Figure 30-1. Note the basic starting system operation. The start switch energizes the engine ECM. If conditions are correct for sensors and switches, the ECM will energize the starter relay and solenoid. The solenoid then energizes the starting motor. The motor turns the flywheel gear for engine starting.

Starting System Action

When you turn the ignition key or press the start button, current flows through the ECM and starter relay. This closes the relay and solenoid contacts, connecting the positive battery cable directly to the starting motor windings. The starter pinion gear is pushed into and meshes with the flywheel ring gear. The motor-driven pinion gear turns the flywheel and crankshaft until the engine starts, or fires, and runs on its own power.

On many cars, when the engine starts, you have to release the ignition key to disengage the 12-volt starting motor. The ignition switch then cuts power to the solenoid and starting motor. The starting motor stops spinning, and the pinion gear is pulled away from the flywheel gear.

Starting Motor Fundamentals

The starting motor converts electrical energy from the battery into mechanical energy to crank the engine. It is similar to other electric motors. All electric motors (wiper motors, fan motors, fuel pump motors, etc.) produce a turning force through the interaction of magnetic fields inside the motor assembly.

Simple Electric Motor

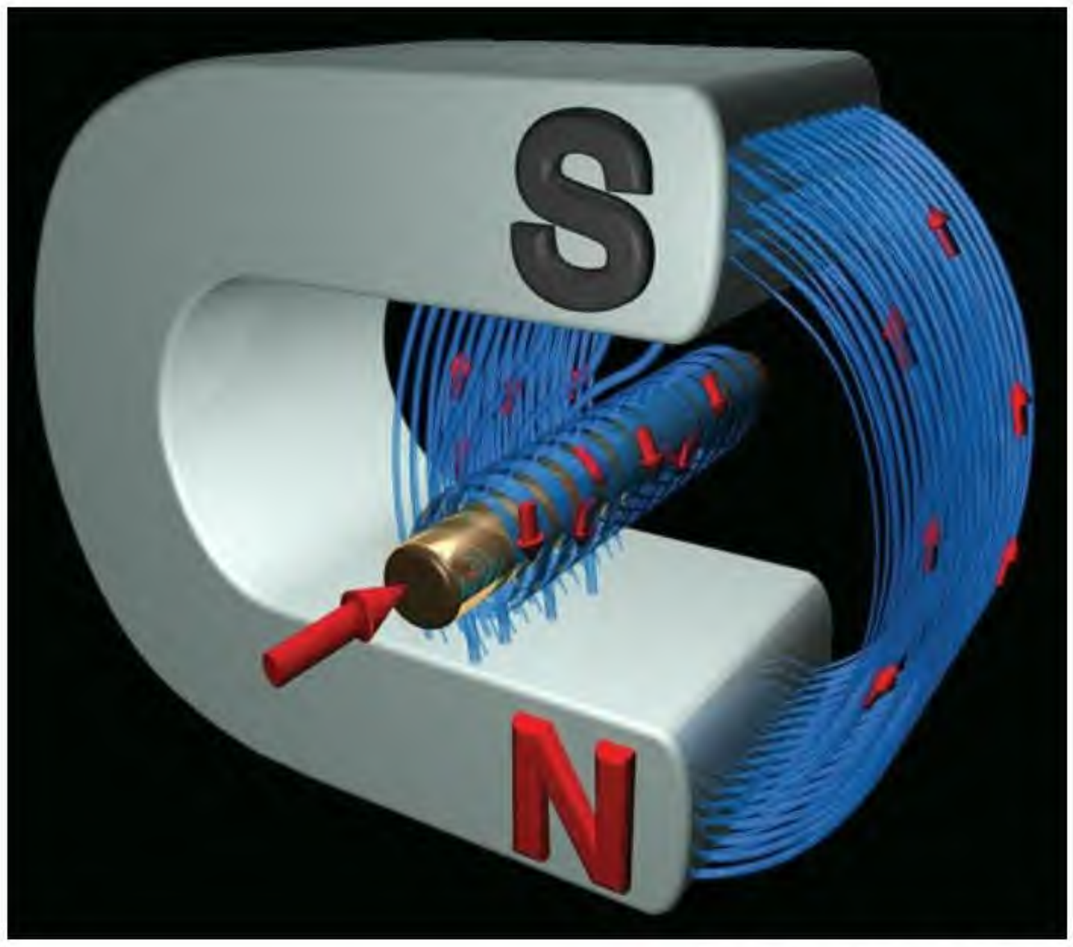
As explained in earlier text chapters, a ***magnetic field*** is made up of invisible magnetic lines of force. The lines of force flow between the poles of a permanent magnet. They also flow around the outside of a wire that is carrying current.

Since ***like charges*** (fields) repel each other and ***unlike charges*** attract each other, magnetic fields can be used to produce motion. Look at **Figure 30-2**. Note how the lines of force in the magnet and the lines of force around the conductor act upon each other. This principle is used in electric motors.

To build a simple electric motor, you would start by bending a piece of wire into a loop. When current is passed through the wire loop (winding), a magnetic field forms around the wire.

Pole shoes, or pole pieces, are needed to make the loop of wire move. A magnetic field is set up between the pole shoes.

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Figure 30-2. Magnetic fields from magnets and the fields around a current-carrying conductor can be used to produce motion. Note how the fields interact.

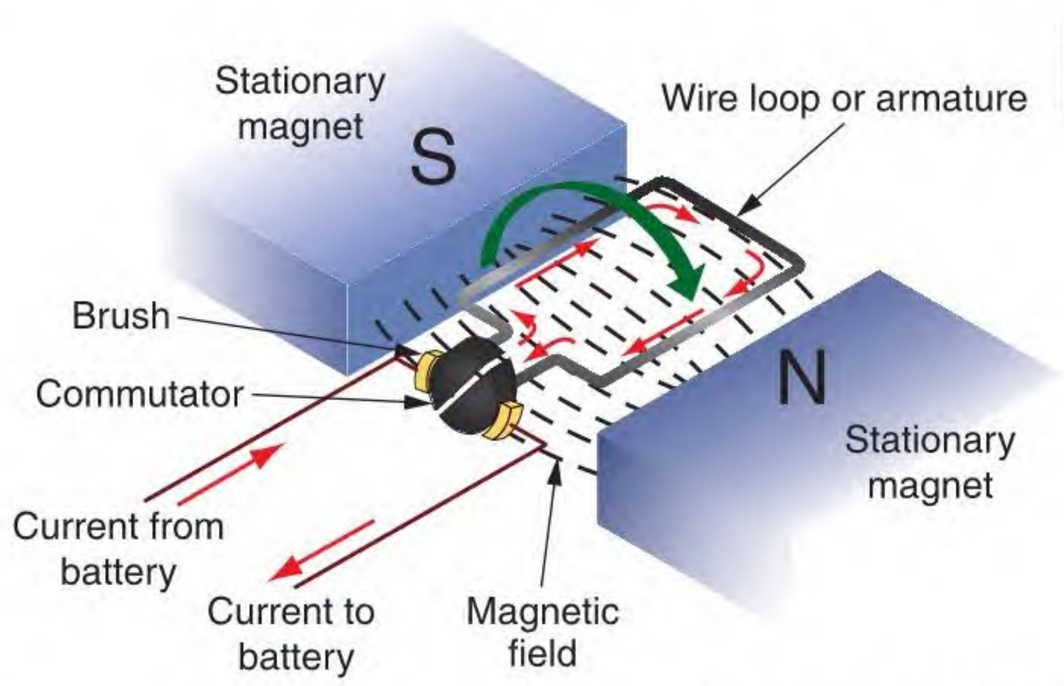
Changing Electricity into Motion

Electric current can be changed into a strong rotating motion by placing the winding between the pole shoes. When current passes through the winding, the magnetic field around the winding and the field between the pole shoes act on each other. This causes the winding to move toward a vertical position. A commutator and brushes are used to keep the electric motor spinning. The ***commutator*** serves as a sliding electrical connection between the armature winding and the brushes. It is divided into segments, which are insulated from each other. The ***brushes*** slide on the commutator to carry battery current to the spinning winding.

As the winding rotates away from the pole shoes, the commutator reverses the electrical connection between the brushes and the winding. This reverses the magnetic field around the winding. Then the winding is pulled around and passes the other pole shoe. The constantly changing electrical connection keeps the motor spinning. A push-pull action is set up as the winding moves around inside the pole shoes. See **Figure 30-3**.

Increasing Motor Power

Several windings (loops of wire) and a commutator with many segments are used to increase motor power and smoothness. Each winding is connected to its own segment on the commutator. This provides current flow through each winding as the brushes contact each segment. As the motor spins, many windings contribute to the motion. This produces a constant and smooth turning force. See **Figure 30-4**.

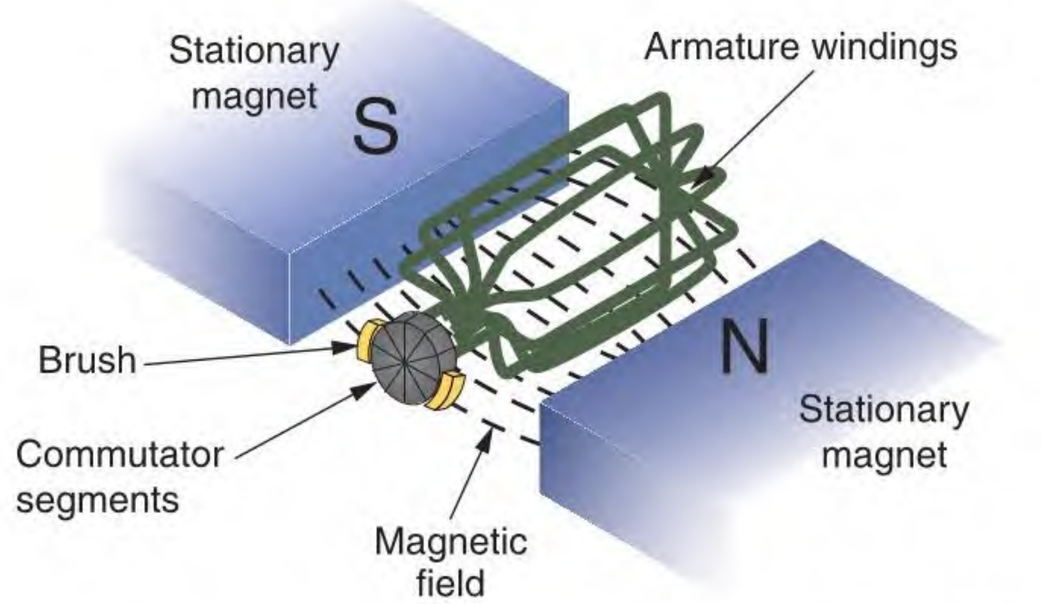


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Figure 30-3. A simple electric motor consists of a winding (loop of wire), located inside stationary pole shoes. The magnetic field around the winding and the magnetic field between the pole shoes act upon each other to make the winding rotate.

12-Volt Starting Motor Construction

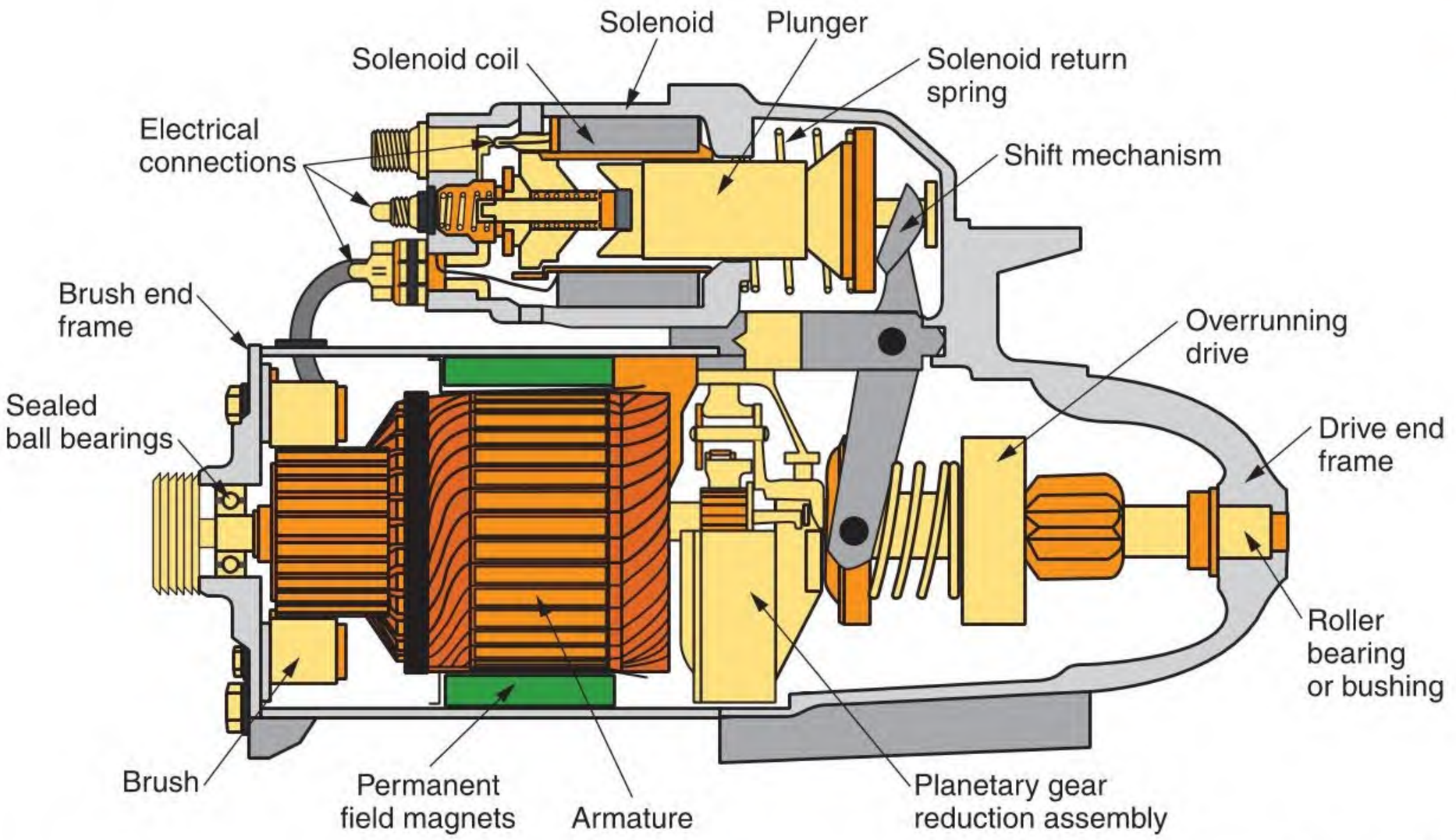
The construction of all 12-volt starting motors is very similar. There are slight variations in design, however. A typical starting motor is shown in **Figure 30-5**.



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Figure 30-4. A starting motor would not have enough power with only a single winding. Instead, many windings are used to increase power and smoothness. Note that each winding is connected to a separate commutator segment.

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Figure 30-5. Observe a cutaway of a typical starting motor. Note that this motor uses permanent magnets instead of field windings.

Refer to this figure as you study the main parts of a starting motor covered in the following sections.

Armature

A starting motor must produce very high torque (turning force) and relatively high speed. Therefore, a system to support the windings and increase the strength of each winding's magnetic field is needed.

A ***starter armature*** consists of the armature shaft, armature core, commutator, and armature windings. The ***armature motor shaft*** supports the armature as it spins inside the starter housing. The commutator is mounted on one end of the armature shaft. The ***armature core*** holds the windings in place. The armature core is made of iron to increase the strength of the magnetic field produced by the windings.

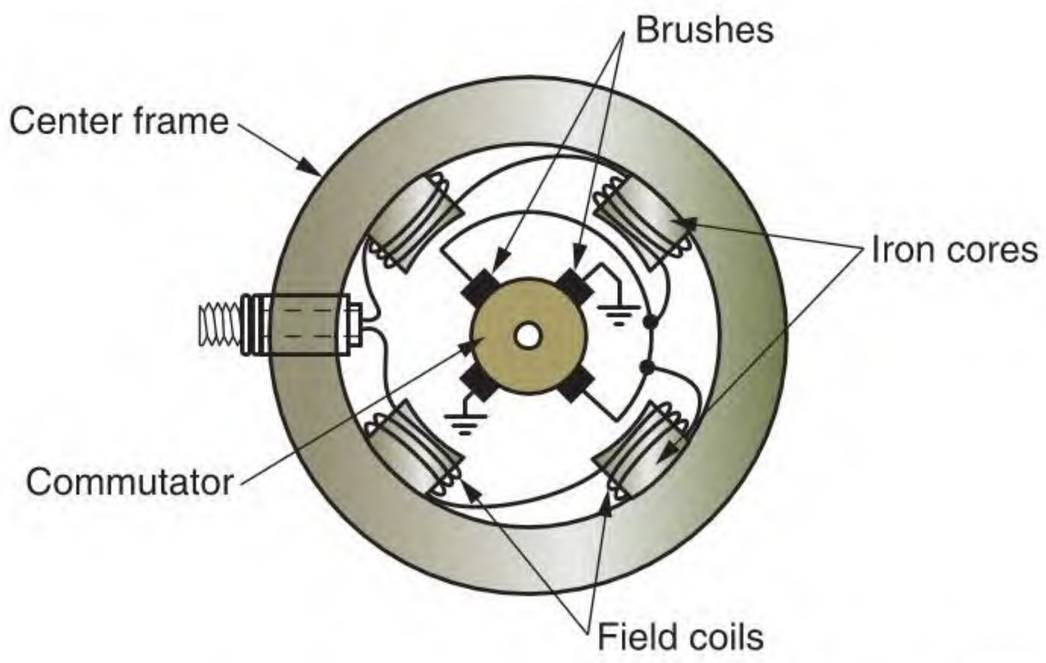
Field Windings

Field windings are stationary insulated wires wrapped in a circular shape around iron pole shoes located inside the starting motor housing, **Figure 30-6**.

When current flows through the field windings, the magnetic field between the pole shoes becomes very large. It can be 5–10 times that of a permanent magnet. As the magnetic field between the pole shoes acts against the field developed by the armature, the motor spins with extra power and torque.

Field Magnets

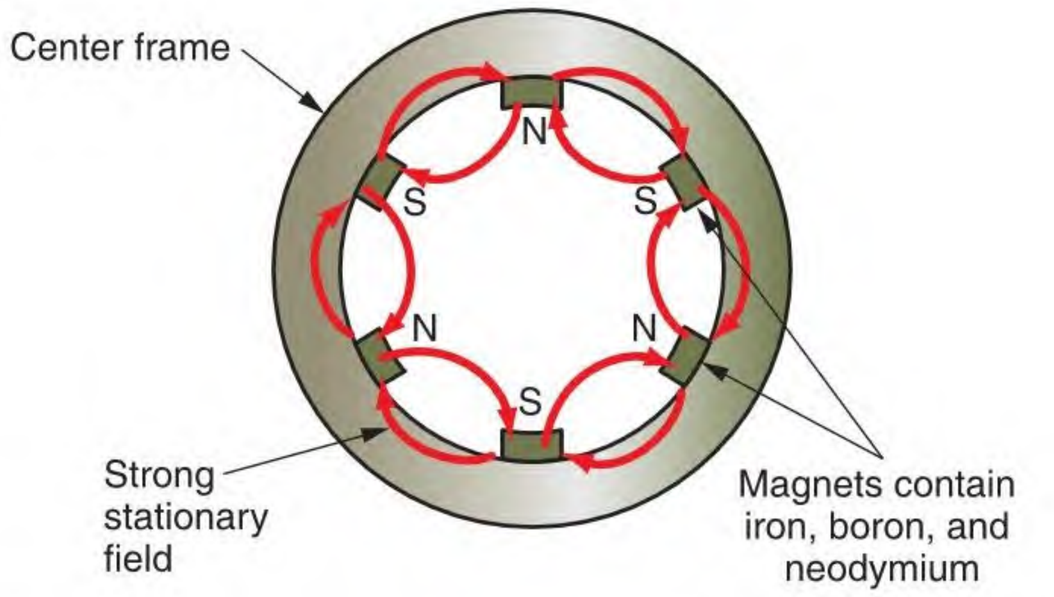
Some starting motors use special high-strength magnets instead of conventional field windings. The magnets produce a strong magnetic field capable of rotating the armature with enough torque to crank the engine. See **Figure 30-7**. Starting motors that use field magnets are referred to as ***permanent-magnet starters***.



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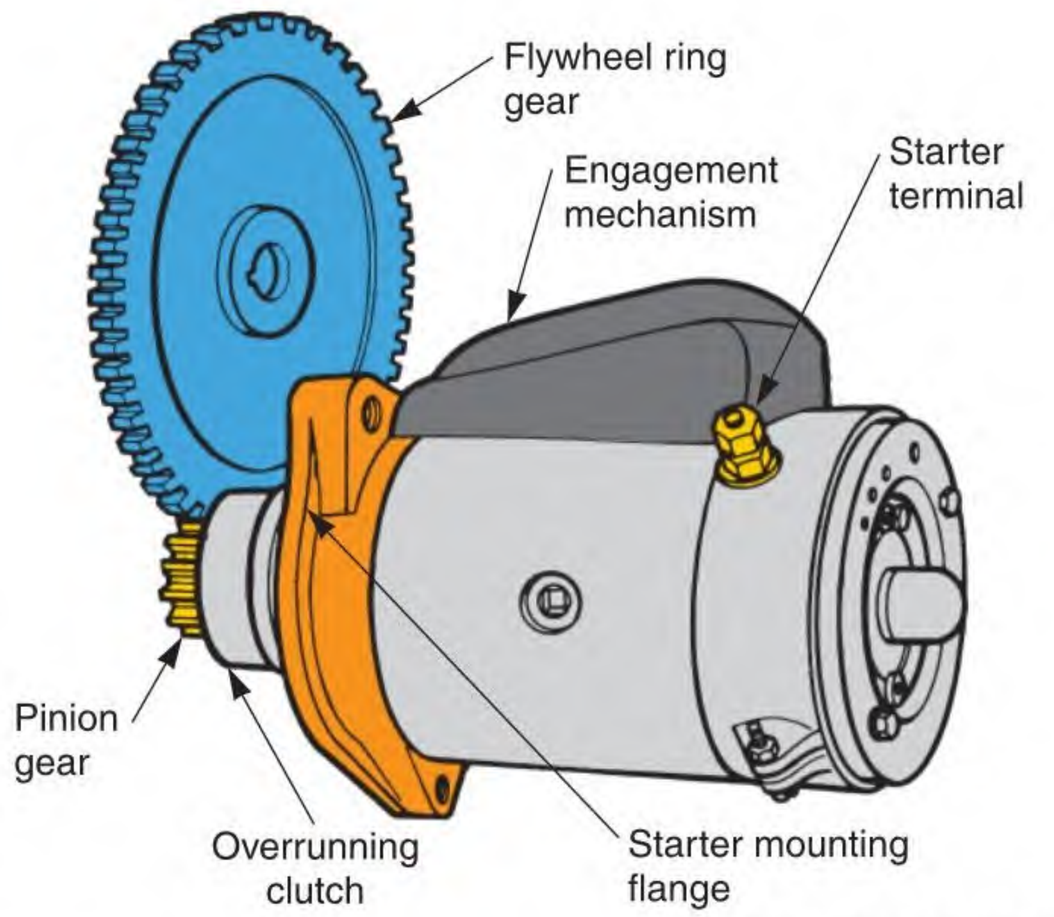
Figure 30-6. This starter uses field windings wrapped around iron pole shoes. Current through the coils produces a powerful magnetic field that acts on the armature.

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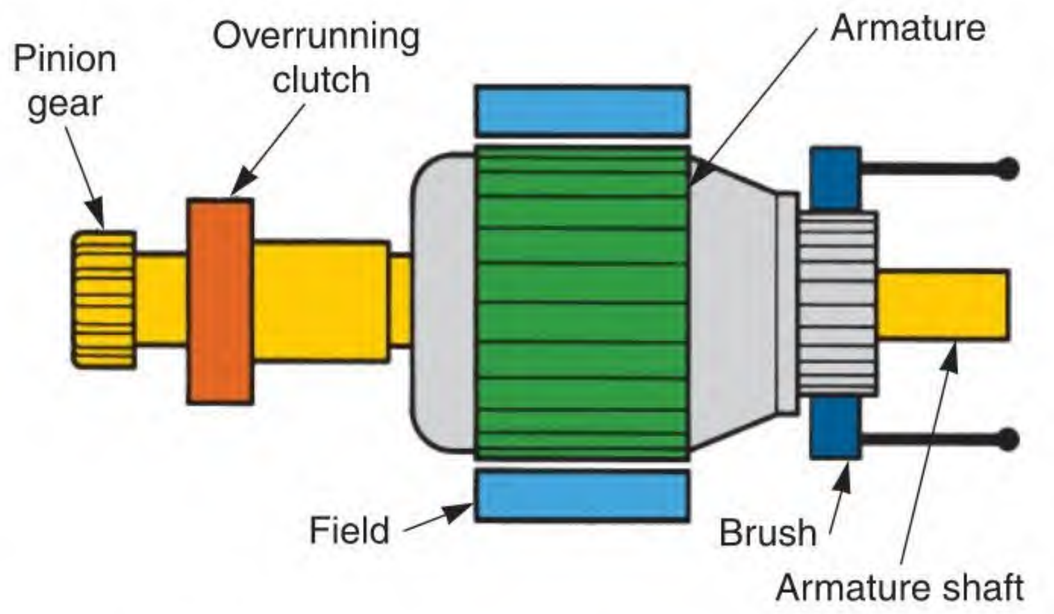
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Figure 30-7. This starter does not need field windings. It uses permanent magnets that are strong enough to rotate the armature.



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Figure 30-8. The starter pinion gear meshes with the large ring gear on the engine flywheel.



Robert Bosch

Figure 30-9. The pinion gear clutch assembly slides onto one end of the armature shaft. Note the other parts.

Frames

The frames, or housings, are the three main sections of the starting motor. The frames hold the other components. The center frame, or field frame, is the large steel cylinder that holds the field windings or field magnets. The two end frames fasten to each end of the center frame.

The drive end frame is the housing around the starting motor pinion gear. The drive end frame contains a bushing for the armature shaft. The shaft spins inside this bushing. The drive end bushing helps keep the pinion gear properly meshed with the flywheel ring gear.

The brush end frame usually holds the brushes and brush springs around the armature commutator. It bolts to the end opposite the drive gear. Two long bolts commonly fit through the brush end frame and thread into holes in the drive end frame. This holds both end frames securely onto the center frame.

Pinion Gear

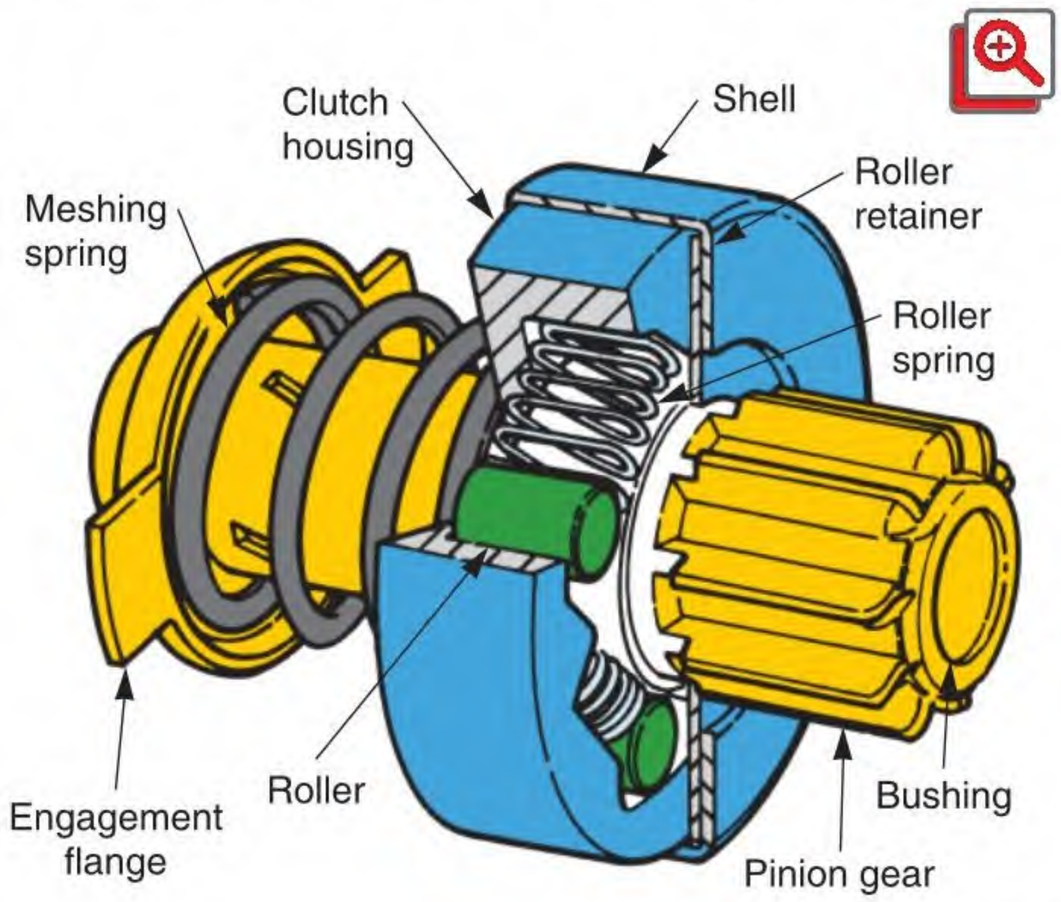
A ***pinion gear*** is a small gear mounted on the armature shaft that engages a large ring gear on the engine flywheel. It moves into and meshes with the flywheel ring gear any time the starter is energized. Most pinion gears are made as part of a pinion drive assembly (pinion gear, overrunning clutch, and housing). The pinion drive assembly slides over one end of the armature shaft, **Figures 30-8** and **30-9**.

A starting motor must produce high torque to start an engine. The pinion gear is much smaller than the flywheel ring gear. Therefore, the starting motor armature turns at a relatively high speed. This helps prevent stalling of the motor. The difference in gear size also increases turning force applied to the crankshaft.

The ***overrunning clutch*** locks the pinion gear in one direction and releases it in the other. This allows the pinion gear to turn the flywheel ring gear for starting. It also lets the pinion gear freewheel when the engine begins to run. Refer to **Figure 30-10**.

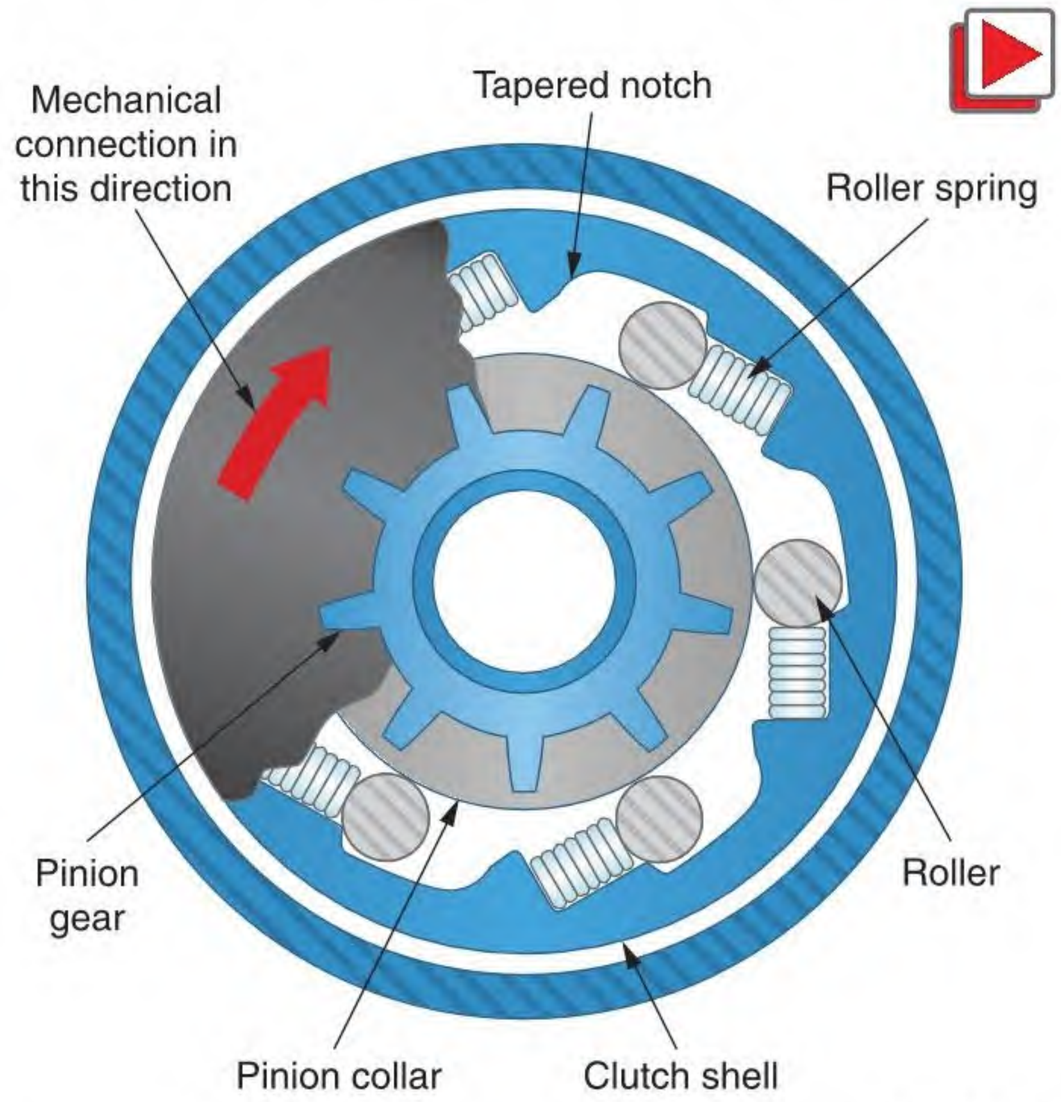
Small spring-loaded rollers are located between the pinion gear collar and the clutch shell, **Figure 30-11**. These rollers wedge into the notches in the shell in the driving direction. They slide back and release when driven in the other direction (freewheeling direction).

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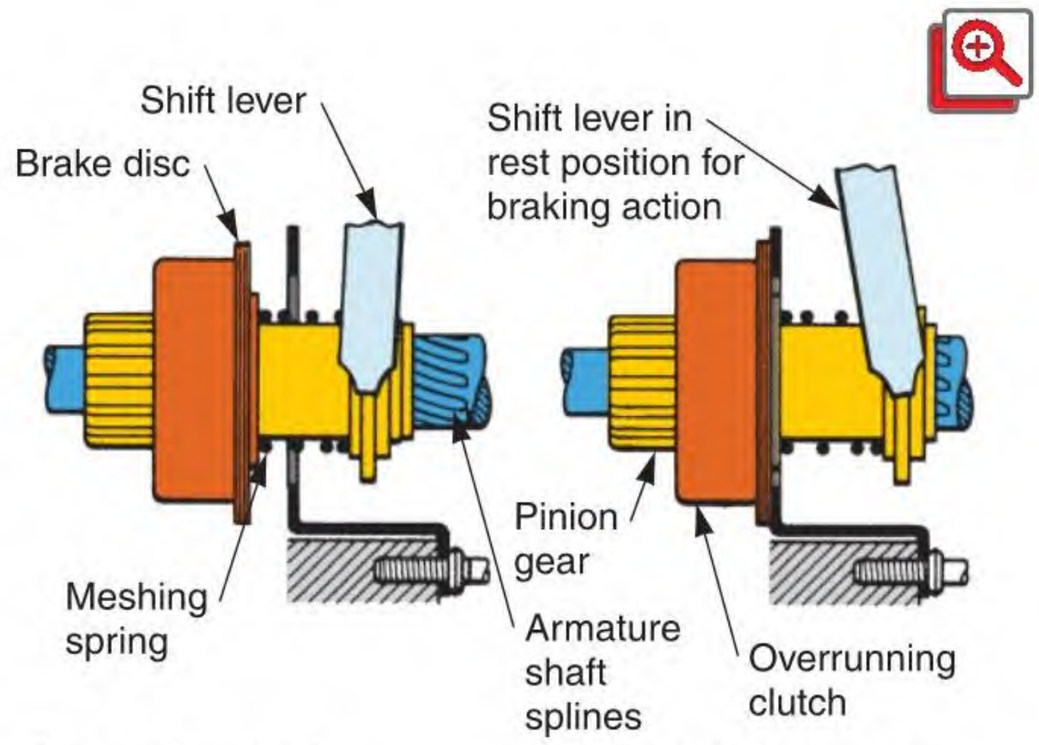
Figure 30-10. Study the construction of the starter overrunning clutch. It is simply a one-way clutch. It locks the flange to the pinion gear in one direction and releases in the other direction.



Robert Bosch

Figure 30-11. This cutaway shows how rollers fit in the clutch. Rollers jam and lock units together one way. Going the other way, they release, allowing the pinion to freewheel.

Spiral grooves on the armature shaft and the inside diameter of the clutch force the shaft and pinion drive assembly to turn together. They also allow the pinion drive assembly to slide on the armature shaft. Refer to **Figure 30-12**.



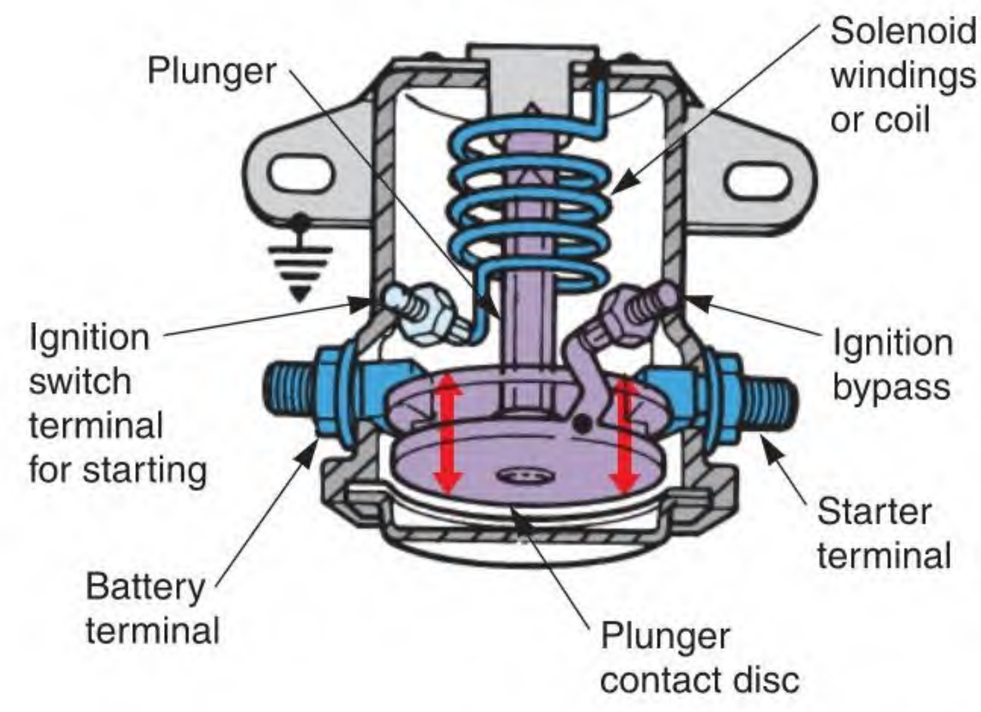
Robert Bosch

Figure 30-12. The pinion gear assembly is splined to the armature shaft. This makes the pinion gear assembly turn with the shaft. It also lets pinion gear slide on the shaft for engagement with the flywheel gear. Note how this unit also has a disc brake for stopping the pinion after disengagement.

Starter Solenoid

The starter solenoid is a high-current relay. It makes an electrical connection between the battery and the starting motor. The starter solenoid is similar to other relays but is capable of handling much higher current levels. See **Figure 30-13**.

The starter solenoid may be located on the starting motor or away from it. When mounted on a body panel (away from starter), the solenoid simply makes and breaks



Ford

Figure 30-13. Study the construction of a 12-volt starter solenoid. One small terminal connects to the ignition start switch. Larger terminals connect to the battery and starting motor. The plunger movement pulls the disc into contact with two battery contactor terminals to activate the starter.

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electrical connections. When mounted on the starter, it also slides the pinion gear into the flywheel ring gear.

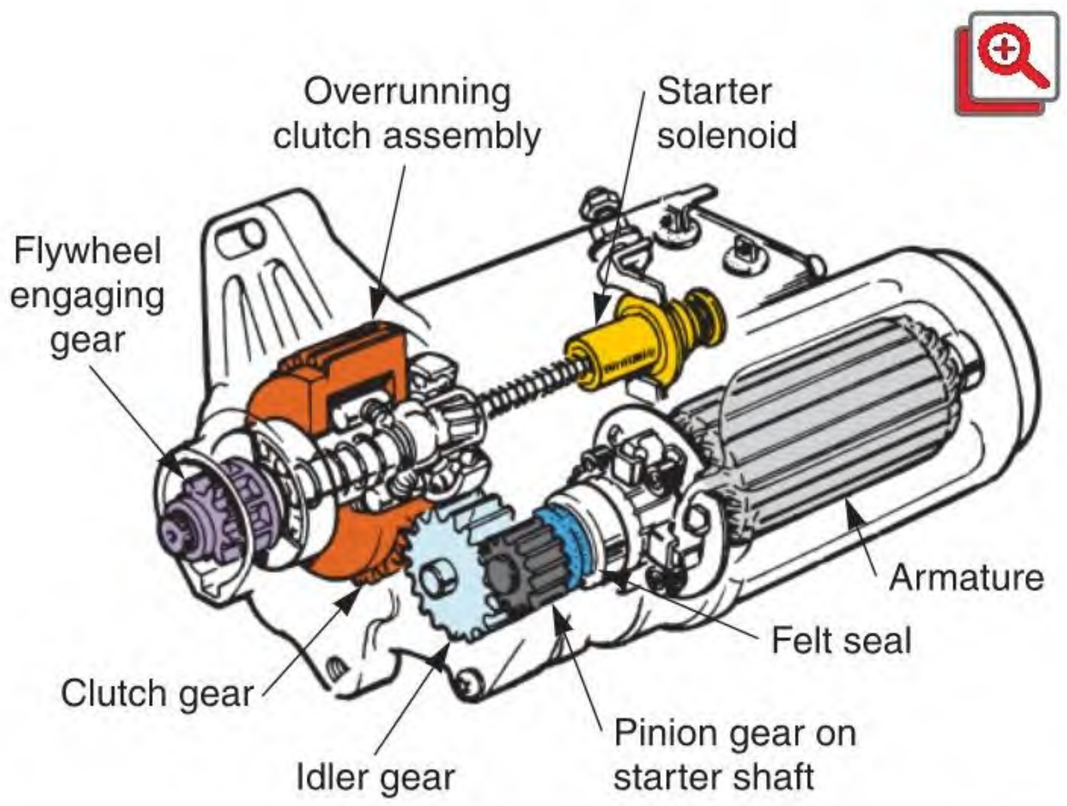
With the ignition key in start position, a small amount of current flows through the ***solenoid windings***. A magnetic field is produced that pulls the solenoid plunger and disc into the coil windings. This causes the ***solenoid disc*** to touch both of the high-current terminals, completing the battery-to-starter circuit. A current of 150–200 amps flows through the solenoid to the starter.

When the ignition key is released, current is disconnected from the solenoid windings. The magnetic field collapses, and the plunger is free to slide out of the windings. This opens the disc-to-terminal connection. The open connection stops current to the starter, and the starter motor shuts off.

Reduction Gearing

The planetary gearset is used to provide reduction. A ***reduction starter*** is sometimes used to further increase the rotating force applied to the engine flywheel. It uses an extra set of gears to improve the gear reduction, as in **Figure 30-14**.

The 12-volt starter pinion gear drives an idler gear. The idler gear drives a larger gear on the overrunning clutch assembly. This allows higher armature speed and higher torque output to the flywheel. More constant engine cranking speeds are produced by a reduction starter.



Honda

Figure 30-14. A reduction starter uses extra gears to increase motor torque. A gear on the armature shaft turns the idler gear. The idler turns a larger gear on the clutch for gear reduction. The exposed gear turns the flywheel gear.

12-Volt Starting Motor Types

Starting motors are classified by type of pinion gear engagement. There are two main 12-volt starter types: movable pole shoe starting motors and solenoid-actuated starting motors. Both types are illustrated in **Figure 30-15**.

A ***movable pole shoe starting motor*** uses a drive yoke to move the pinion gear into contact with the flywheel gear. The drive yoke is hinged on the starter frame and links a movable pole shoe to the pinion gear, **Figure 30-15A**.

When the starter is activated, the magnetic field of the motor pulls the movable pole shoe downward. Then, lever action of the drive yoke pushes the pinion gear outward on its shaft. This causes pinion gear engagement as the armature begins to spin. When the motor is shut off, a spring moves the pinion gear and pole shoe into the released position.

A ***starter-actuated solenoid*** has a plunger that moves a shift lever to engage the pinion gear. The solenoid is mounted on the side of the starter field frame. With this starter design, the solenoid completes the battery-to-starter circuit and also operates the pinion gear. See **Figure 30-15B**.

12-Volt Neutral Safety Switch

A ***neutral safety switch*** prevents the engine from cranking unless the shift selector is in neutral or park. It keeps the starting system from working when the transmission is in gear. The switch provides a safety feature to prevent the car from starting while in gear.

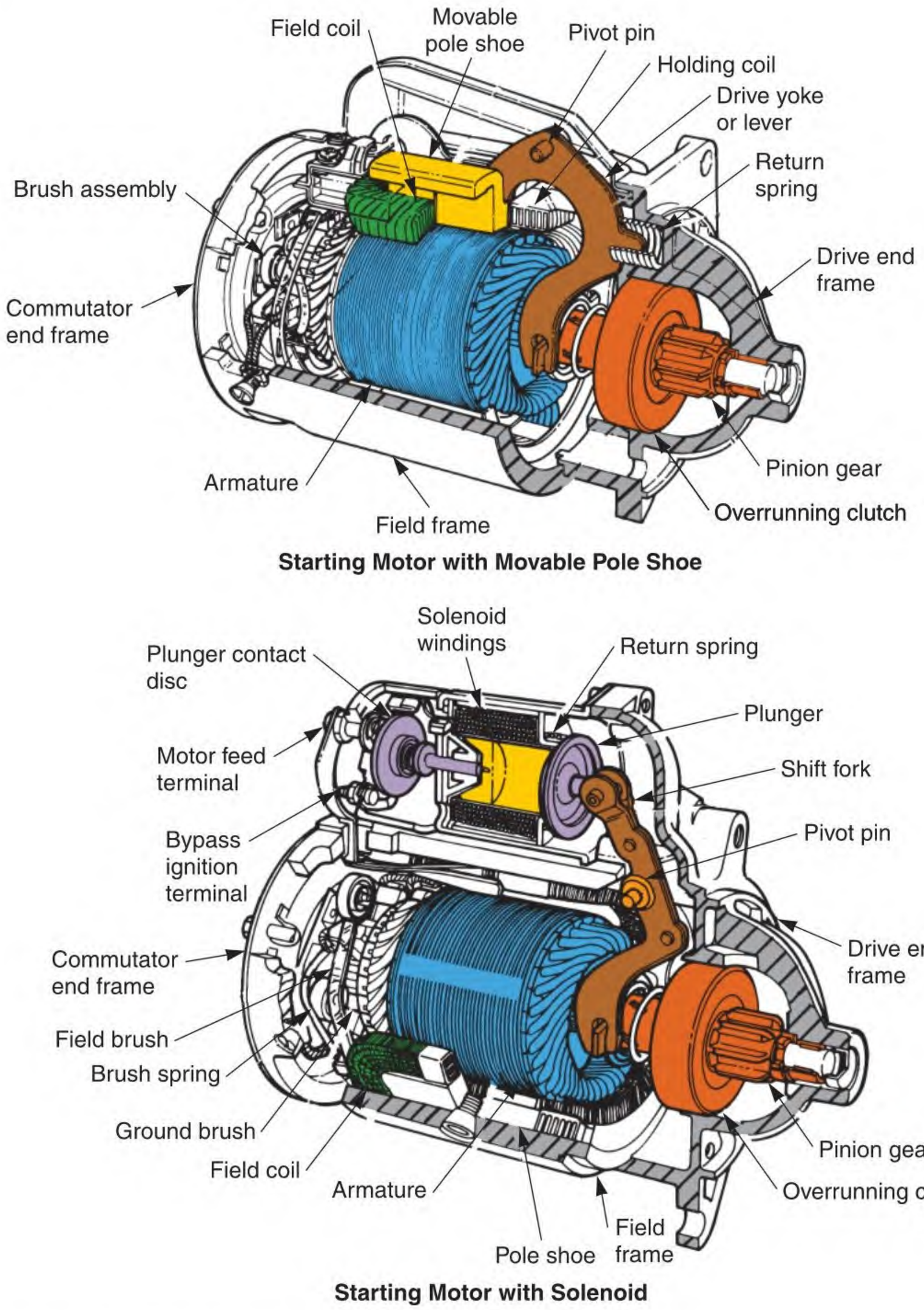
Cars with automatic transmissions commonly have a neutral safety switch. The switch may be mounted on the shift lever mechanism or on the transmission.

Neutral Safety Switch Operation

The neutral safety switch is wired into the circuit going to the 12-volt starter solenoid. When the transmission is in drive or reverse, the neutral safety switch is open (disconnected). This prevents current from activating the solenoid and starter when the start switch is turned to start.

With the transmission in park or neutral, the neutral safety switch is closed (connected). Current can flow to the 12-volt starter when the start switch is turned.

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Ford

Figure 30-15. Compare two common types of 12-volt starting motors.

Tech Tip

In most late-model cars, the brake light switch is wired into the same control circuit as the neutral safety switch. You must have the transmission in park (or neutral) and press the brake pedal for the starting motor to energize.

12-Volt Starter Relay

A ***relay*** is a device that opens or closes one circuit by responding to an electrical signal from another section of a circuit. Most modern starting systems use a relay between the ignition switch (start button) or the ECM and the 12-volt starter solenoid.

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A starter relay uses a small current flow from the start switch or ECM to control a slightly larger current flow to the starter solenoid. This further reduces the load on the ignition key switch. A 12-volt starter relay circuit is shown in **Figure 30-16**.

Starter Relay Operation

When the ignition switch is turned to start, current flows into the relay. This closes the relay contacts. The contacts complete the circuit to the solenoid windings and the starting system operates.

When the key is released, the relay opens. This stops the solenoid current to disengage the starting motor.

ECM-Controlled 12-Volt Starting Circuit

An ***ECM-controlled starting circuit*** automatically energizes and de-energizes the 12-volt starting motor as soon as engine sensors detect fuel combustion and the resulting rapid increase in crankshaft rpms (speed sensor signal). The engine control module and body control module operate the 12-volt starting circuit automatically.

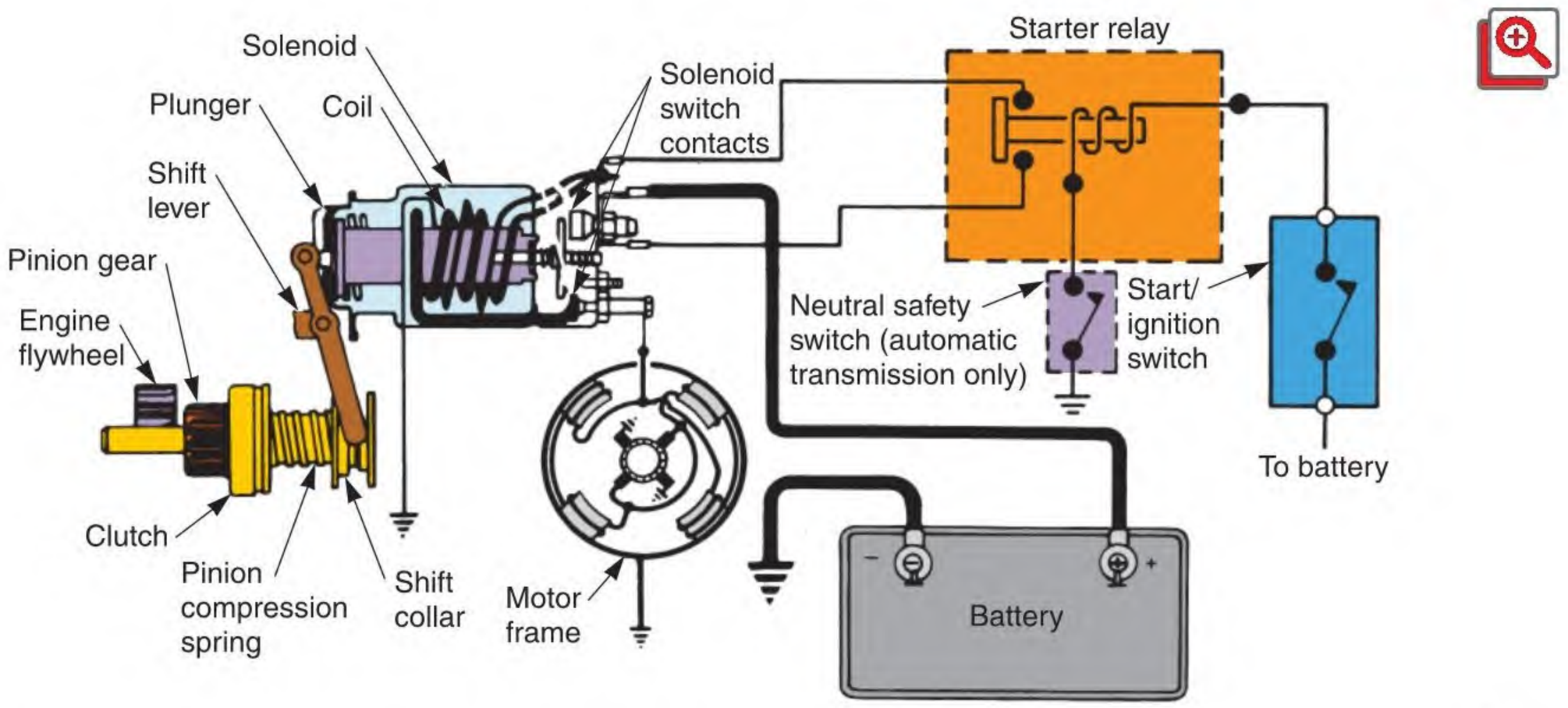
If a driver accidently holds the start key or start button too long, newer hybrids protect the starter pinion gear from damage caused by excessive speed. Most late-model starting systems are programmed to open the circuit between the ignition switch and the starter solenoid whenever the engine is running. This prevents the driver from accidentally engaging the starting motor and grinding its pinion gear into the flywheel gear when the flywheel gear is spinning at high speeds.

Hybrid Starting Systems

Early-model hybrids used a 12-volt starting system and a separate high-voltage propulsion system. Since this design added weight and complexity to the vehicle, most late-model hybrids use the motor-generator to crank the engine for starting.

A late-model hybrid starting system includes the following components:

- Motor-generator—The motor-generator serves as a high-torque motor for rotating the engine crankshaft.
- HV power cables—Three HV power cables connect the HV power control module to the motor-generator. Two HV power cables connect the HV battery to the HV power control module.
- Hybrid control module—The hybrid control module detects a need to start or stop the engine.
- HV power control module—The HV power control module converts dc into three-phase ac for the motor-generator. If the vehicle does not have a separate hybrid control module, the HV power control module determines when the engine should be started and sends three-phase ac to operate the motor-generator for engine startup.
- Engine control module (ECM)—The engine control module activates the fuel and ignition systems so the engine will start and run.



Chrysler

Figure 30-16. Study the complete manual starting system circuit. This circuit has a 12-volt starter relay. The relay further decreases the amount of current flowing through the ignition start switch. Also note how the relay winding is wired to the neutral safety switch.

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The motor-generator armature (rotor) can be attached directly to the engine crankshaft. Refer to **Figure 30-17**. The motor-generator can also be connected to the engine through the transmission or transaxle. In this arrangement, the HV power control module and the hybrid control module must lock the torque converter clutch and the transmission motor-generator clutch so the motor-generator can spin the engine crankshaft for starting.

Motor-generators easily spin the engine crankshaft. Many hybrid starting systems are very quiet when engaged. When driving, it is difficult to tell when the HV starting system fires up the engine.

Hybrid Starting System Operation

In a hybrid, the internal combustion engine runs only when it is needed. The engine will be shut off when braking, coasting, going downhill, or when the vehicle is stopped. It is wasteful to run the internal combustion engine when its power is not needed.

The hybrid control module monitors operating conditions to determine when the internal combustion engine should be started. If the hybrid control module determines that the engine should be started, it signals the HV power control module to start the engine for propulsion and HV battery recharging. It also signals the engine control module to provide fuel and spark for engine starting and running. The HV power control module then applies voltage to the stator windings of the motor-generator to rotate the armature and the engine crankshaft.

Common reasons for starting the engine include a need to recharge the HV battery, a demand for more power during acceleration, high-speed operation, or an engine that has not been started for an extended period of time (too much driving in all electric mode).



Honda

Figure 30-17. In many hybrid designs, the motor-generator rotor is mounted directly onto the engine crankshaft flange. If three-phase current is fed to the stator coils by the HV power control module, the rotor magnets, armature, and crankshaft will be spun easily until the engine fires.



Green Tech

Recycling Batteries

Today's lead-acid batteries typically contain a large percentage of recycled materials. This is because lead-acid batteries are recycled and some of their materials can be reused. Less new material needs to go into a new battery. Several automotive shops collect and send dead batteries to off-site recycling facilities. Used batteries can be stored for up to a year before being recycled. It is best to store used lead-acid batteries inside, away from the drainage system and any source of ignition. Cracked batteries should be contained, and any spills from a battery crack should be cleaned up as quickly as possible.

Summary

- A 12-volt starting system uses battery power and an electric motor to turn the engine crankshaft for engine starting.
- A starting motor converts electrical energy from the battery into mechanical or rotating energy to crank the engine.
- A commutator serves as a sliding electrical connection between the motor windings and the brushes.
- A field winding is a stationary set of windings (insulated wire wrapped in circular shape).

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- A permanent-magnet starter uses special high-strength magnets in place of conventional field windings.
- A starter pinion gear is a small gear on the armature shaft that engages a large ring gear on the engine flywheel.
- A starter overrunning clutch locks the pinion gear in one direction and releases it in the other.
- A starter solenoid is a high-current relay that makes an electrical connection between the battery and starting motor.
- A reduction starter is sometimes used to further increase the rotating force applied to the engine flywheel.
- A neutral safety switch prevents the engine from cranking unless the shift selector is in neutral or park.
- A 12-volt starter relay uses a small current flow from the start switch to control a slightly larger current flow to the starter solenoid.
- An ECM-controlled starting circuit automatically energizes and de-energizes the 12-volt starting motor as soon as the engine sensors detect fuel combustion and the resulting rapid increase in crankshaft rpms (speed sensor signal).
- A hybrid starting system includes a motor-generator, HV power cables, hybrid control module, HV power control module, and engine control module (ECM).
- The HV power control module converts dc into three-phase ac for the motor-generator. If a vehicle does not have a separate hybrid control module, the HV power control module determines when the engine should be started and sends three-phase ac to operate the motor-generator for engine startup.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

12-volt starting system
armature core
armature motor shaft
battery
brushes
commutator
ECM-controlled starting circuit
engine control module (ECM)
engine starting system
field windings
ignition switch
like charges
magnetic field
movable pole shoe starting motor
neutral safety switch
overrunning clutch
permanent-magnet starters
pinion gear
pole shoes
reduction starter
relay
solenoid disc
solenoid windings
start switch
starter-actuated solenoid
starter armature
starter relay
starter solenoid
starting motor
unlike charges

Activities

1. If possible, obtain an unserviceable 12-volt starter motor from a shop or junkyard. Carefully disassemble and clean the components. Mount and label them for a classroom display.
2. Research the advantages and disadvantages of installing a rebuilt 12-volt starter (rather than a new one) in a vehicle. Report to the class.
3. Inspect a hybrid vehicle's starting system. Find out if it uses a 12-volt starting motor or the hybrid motor-generator to crank the engine for starting. Write a report on the hybrid starting system using factory service information as a reference.

Review Questions

Answer the following questions using the information provided in this chapter.

1. List and describe the six major parts of a 12-volt starting system.
2. What is the purpose of the starting motor?
3. Which of the following is *not* part of a starting motor?
   (A) Armature.
   (B) Field winding.
   (C) Commutator.
   (D) Slip ring.
4. List the four parts of a starter armature.
5. The housing around the starting motor pinion gear is called the _____.
   (A) center frame
   (B) brush end frame
   (C) drive end frame
   (D) field frame
6. What is the function of the starter pinion gear?
7. The _____ allows the pinion gear to turn the flywheel ring gear for starting.

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8. The _____ is a high-current relay that completes the circuit between the battery and the starting motor.
9. Describe how a movable pole shoe starting motor operates.
10. A starter-actuated solenoid has a(n) _____ that moves a shift lever to engage the pinion gear.
11. Why is a reduction starter sometimes used?
12. The _____ keeps the engine from cranking unless the shift selector is in neutral or park.
13. List the five major components of a hybrid starting system.
14. Three HV power cables connect the HV power control module to the motor-generator. True or False?
15. Which of the following detects a need to start or stop the engine in a hybrid starting system?
    (A) Motor-generator.
    (B) ECM.
    (C) Hybrid control module.
    (D) None of the above.

ASE-Type Questions

1. Which of the following converts electrical energy from the battery into mechanical or rotating energy to crank the engine?
   (A) Solenoid.
   (B) Pinion gear.
   (C) Starting motor.
   (D) All of the above.
2. Which of the following serves as a sliding electrical connection between motor windings and brushes?
   (A) Solenoid.
   (B) Armature.
   (C) Pole piece.
   (D) Commutator.
3. A starter armature consists of each of these *except:*
   (A) shaft.
   (B) flange.
   (C) windings.
   (D) commutator.
4. Which device locks a pinion gear in one direction and releases it in the other?
   (A) Roller retainer.
   (B) Starter solenoid.
   (C) Flywheel ring gear.
   (D) Overrunning clutch.
5. When reviewing starter motor classifications, Technician A says starters are grouped by type of pinion gear engagement. Technician B says starters are grouped by type of armature. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Which of the following uses a plunger to move a shift lever that engages the pinion gear?
   (A) Reduction starter.
   (B) Movable pole shoe.
   (C) Starter-actuated solenoid.
   (D) Permanent-magnet starter.
7. Technician A says a neutral safety switch prevents the starting system from operating when the transmission is in gear. Technician B says the neutral safety switch is often wired into the same control circuit as the brake light switch. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. Which of the following uses a small current flow from the ignition switch to control a larger current flow to the starter solenoid?
   (A) Clutch.
   (B) Starter relay.
   (C) Reduction starter.
   (D) None of the above.
9. While discussing hybrid starting systems, Technician A says the hybrid control module activates the fuel and ignition systems so the engine will start and run. Technician B says the HV power control module converts dc into three-phase ac to operate the motor-generator for engine startup. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. Technician A says a motor-generator armature can be attached directly to the engine crankshaft. Technician B says that a motor-generator armature can be connected to the engine through the transmission or transaxle for engine starting. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Chapter 31
Starting System Diagnosis, Testing, and Repair

After studying this chapter, you will be able to:

- Diagnose common 12-volt starting system troubles.
- Perform 12-volt starting system tests.
- Explain typical procedures for basic 12-volt starting system repairs.
- Remove and install a starting motor.
- Recall the general procedure for diagnosing hybrid starting system problems.
- Correctly answer ASE certification test questions on starting system diagnosis, service, and repair.

This chapter introduces the steps for diagnosing, testing, and repairing common starting system problems in both conventional 12-volt and hybrid HV starting systems. By studying this chapter, you will learn to recognize the symptoms of specific starting system problems. You will also learn the general procedures for effectively removing and replacing faulty components.

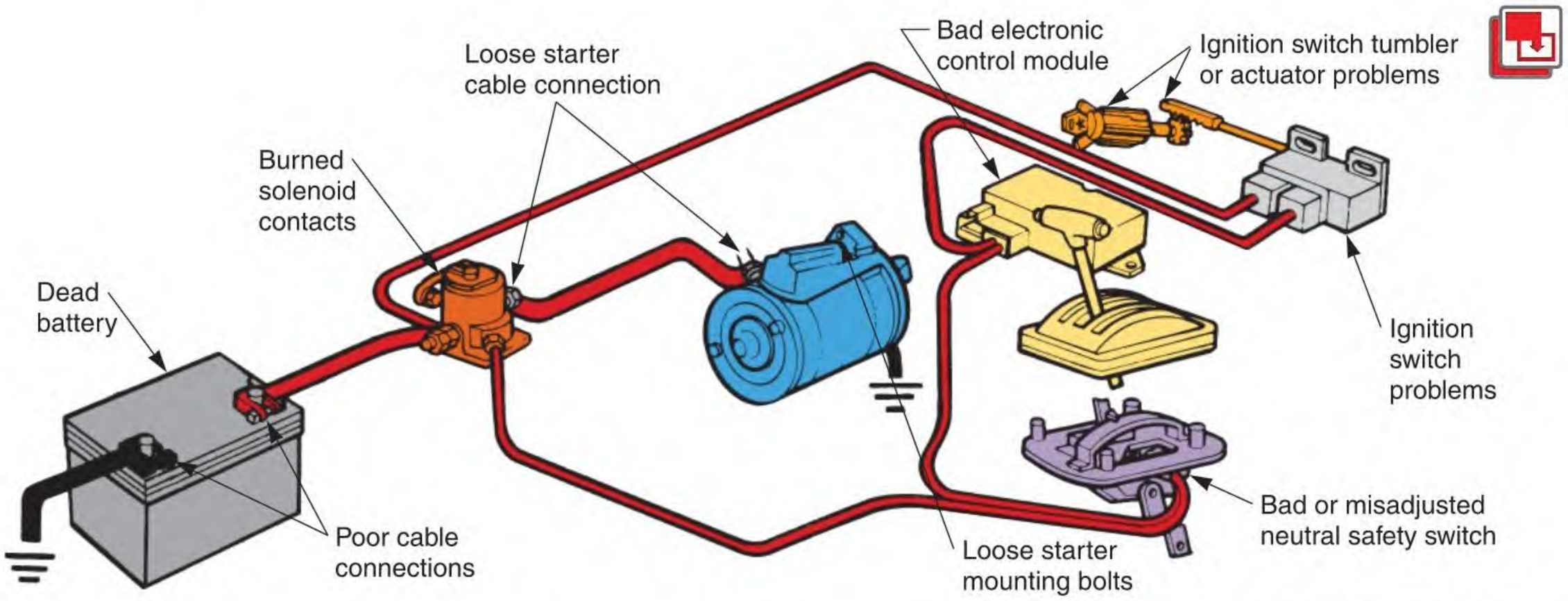
Remember that modern hybrids do not use a conventional 12-volt starting system. Instead, they use the motor-generator to crank the engine over for starting. If an HV starting system fails to function normally, voltage and current draw tests may be needed to isolate the problem location.

Starting System Diagnosis

The starting system used to be one of the simplest systems to troubleshoot and repair. The conventional starting circuit has only a few major components that can cause problems. With hybrid electric drive technology, however, finding out why the engine fails to start, or "crank," is a little more complicated.

If a 12-volt or HV starting system is not working properly, modern on-board diagnostics will provide trouble codes for most components. If any starting-related part has higher- or lower-than-normal resistance, physical damage, or wear, the car engine may not crank when the ignition key is turned or the start button is pressed. For better comprehension of starting system diagnosis and repair, this chapter will cover 12-volt starting systems before HV starting systems, **Figure 31-1**.

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Figure 31-1. During initial inspection, check for these kinds of starting system troubles. A loose connection or discharged battery could keep the engine from cranking.

Common 12-Volt Starting System Problems

With a ***no-crank problem***, the engine crankshaft does not rotate when the ignition key or start button is activated. The most common causes are a dead battery, poor electrical connection, or faulty system component.

A ***slow-cranking condition*** occurs when the engine crankshaft rotates at speeds that are lower than normal. This condition is usually caused by low battery voltage, a bad starting motor, a poor battery connection, or mechanical problems.

If a buzzing or clicking sound (engine not cranking) occurs when the key is turned to start, the battery may be discharged or the battery cable connections may be poor. Low current flow causes the solenoid plunger to rapidly kick in and out, making a clicking or buzzing sound. A single solenoid click sound without engine cranking may point to a bad starting motor, burned solenoid contacts, a partially discharged battery, or engine mechanical problems, such as a locked or frozen engine. The click is usually the solenoid closing or the pinion gear contacting the flywheel gear.

A humming sound that occurs after momentary engine cranking may be due to a bad overrunning clutch or a worn pinion gear unit. Pinion gear wear can make the gear disengage from the flywheel gear too soon. This will allow the motor armature spin rapidly, producing a humming sound.

A metallic grinding noise may be caused by broken flywheel teeth or worn pinion gear teeth. The grinding may be caused as the gears clash against each other.

Normal cranking without starting is not usually caused by the starting system. There may be trouble in the fuel or ignition systems. With a diesel engine, check engine cranking speed. If cranking speed is low, the diesel may not start.

Service manual troubleshooting charts should be used when the causes of problems are hard to find. These charts are designed for the exact circuit and will often reduce the list of causes.

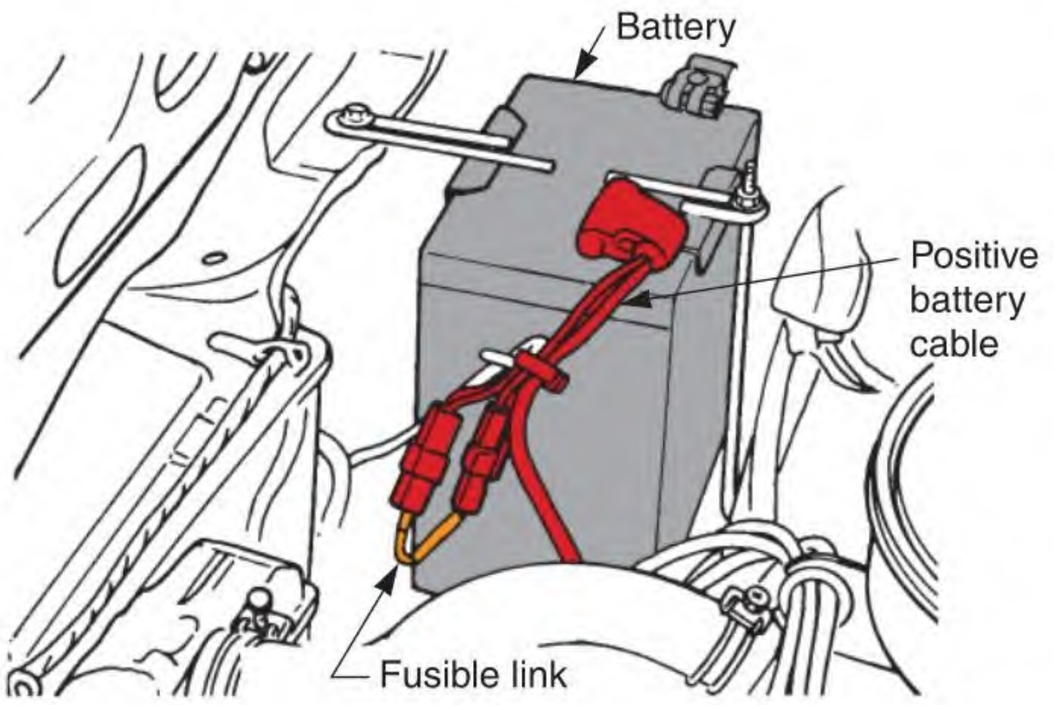
12-Volt Starting Headlight Test

A ***starting headlight test*** will quickly indicate the causes of trouble in a starting system. Turn on the headlights and try to start the engine. Note any sounds and watch the brightness of the headlights.

No cranking with no headlights points to a dead battery or an open in the electrical system. The battery connections may be bad. A burned fusible link will also kill power to most systems. A main feed wire to the fuse box could also be broken or disconnected, **Figure 31-2**.

If the headlights go out when cranking, the battery may be weak. The starting motor may be shorted. The engine could also be at fault. Dimming headlights indicate heavy current draw or poor current supply from the battery.

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Mazda

Figure 31-2. The battery and its cables are the most common cause of improper cranking. Note the fusible link attached to the positive battery cable. It can burn during a short to protect the electrical system. If major components (lights, horn, starting system) are dead, check the fusible link.

If the lights stay bright but the engine does not crank properly, a high resistance or an open in the starting circuit is likely. The problem could be in the ignition switch, wiring, solenoid, starter cable connections, or relay.

The results of the starting headlight test will give you a general idea of the problem's cause. Further testing will be needed to pinpoint the source of the trouble. Depending on what the headlights and starter do when testing, you can decide what further tests are needed.

Checking the 12-Volt Battery

A dead or discharged 12-volt battery is one of the most common reasons the starting system fails to crank the engine properly. The starting motor draws much more current (over 200 amps with large engines) than any other electrical component. A discharged or poorly connected battery can operate the lights, but it may not have enough power to operate the starting motor.

If needed, load-test the battery as described in the chapter on battery service. Make sure the battery is in good condition and is fully charged. A starting motor will not function without a fully charged and well-connected battery.

12-Volt Starter Current Draw Test

A ***starter current draw test*** measures the current used by the starting system. It will quickly tell you about the condition of the starting motor and other system parts. If current draw is higher or lower than specifications, there is a problem.

To perform a current draw test, connect meters to measure the battery voltage and the current flow out of the battery. A load tester may also be used. See **Figure 31-3**.

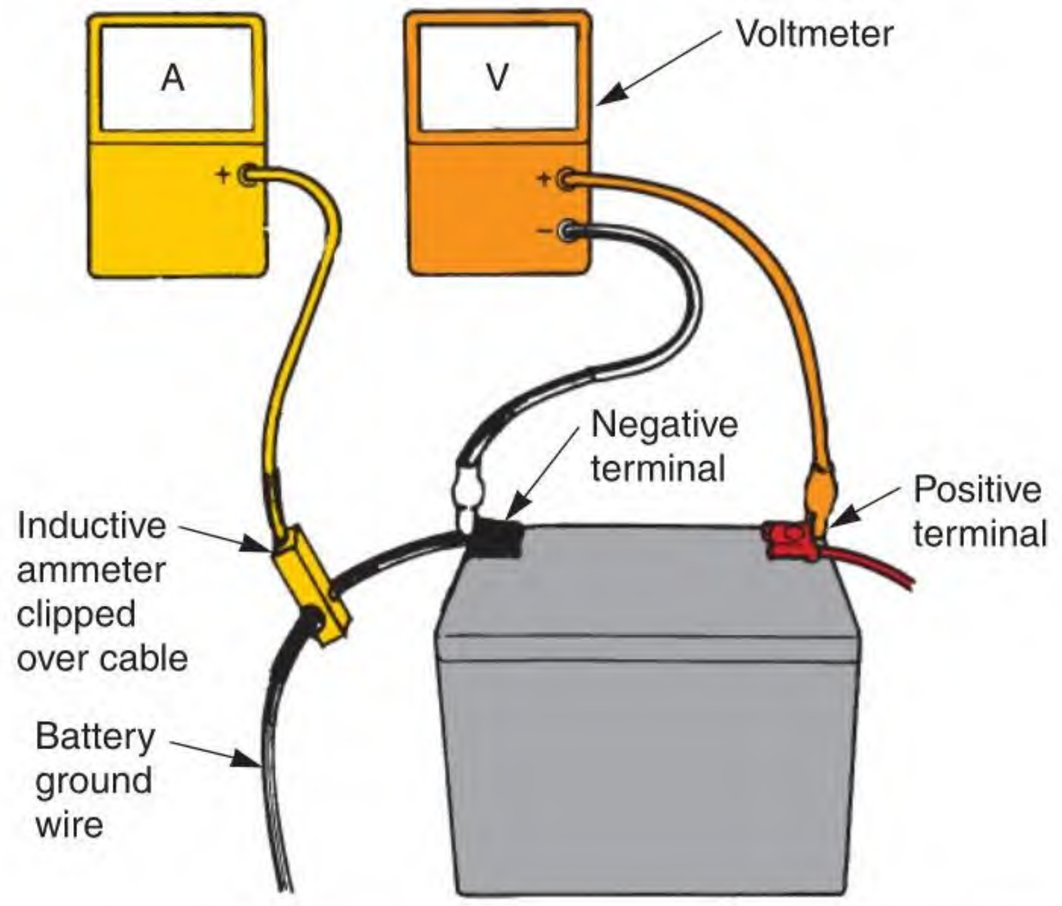
To keep the engine from starting during the test, disconnect the coil primary supply wire or ground the coil wire, **Figure 31-4**. You can also pull the fuse for the electric fuel pump if this is easier (direct ignition systems).

With a diesel engine, you must disable the injection system. You may have to disconnect the fuel shutoff solenoid. Check a shop manual for details.

Caution

Do not crank the engine for more than 15–30 seconds, or starter damage may result. If cranked too long, the starter could overheat. Allow the starter to cool for a few minutes if more cranking time is needed.

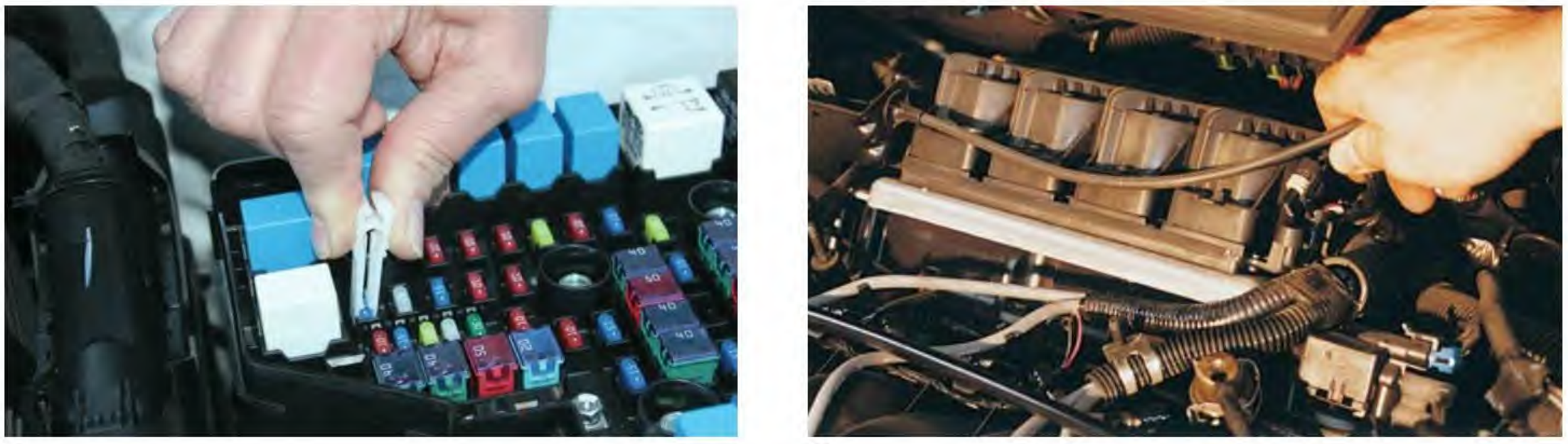
Crank the engine and note the voltage and current readings. If they are not within specifications, something is wrong in the starting system or the engine.



Honda

Figure 31-3. A voltmeter and an ammeter can also be used to measure starter current draw. A voltmeter reading is needed to compare different battery conditions. If current draw is not within specifications, there are starting system troubles.

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A B

Honda

Figure 31-4. To keep the engine from running during a starter current draw test, disable the fuel or ignition system. A—To disable the fuel system, remove the fuel pump fuse. B—With a coil pack, disconnect the primary wires to disable the ignition system.

Further tests are needed. **Figure 31-5** contains a troubleshooting chart and lists the average current draw values for various engine sizes.

Average Current Draw	
Engine Displacement	**12-Volt System Max. Current**
Most 4–6 cylinders	125–175 amps
Under 300 C.I.D.	150–200 amps
Over 300 C.I.D.	175–250 amps

Cranking Circuit Troubleshooting Chart		
Cranking Voltage	**Cranking Amps**	**Possible Problem**
Voltage okay	Current okay	System okay
Voltage okay	Current low, engine cranks slowly	Starter circuit connections faulty
Voltage low	Current low, engine cranks slowly	Battery low
Voltage low	Current high	Starter motor faulty

Marquette

Figure 31-5. This chart shows typical current draw values for different engine sizes. Ignore initial readings until the engine has cranked for a few seconds. Then current draw will stabilize. Study meter readings and the trouble chart.

12-Volt Starting System Voltage Drop Tests

Voltage drop tests quickly locate a part with higher-than-normal resistance. These tests provide an easy way of checking circuit condition. You do not need to disconnect wires and components to perform voltage drop tests. See **Figure 31-6**.

Insulated Circuit Resistance Test

An ***insulated circuit resistance test*** checks all parts between the positive battery terminal and the starting motor for excess resistance.

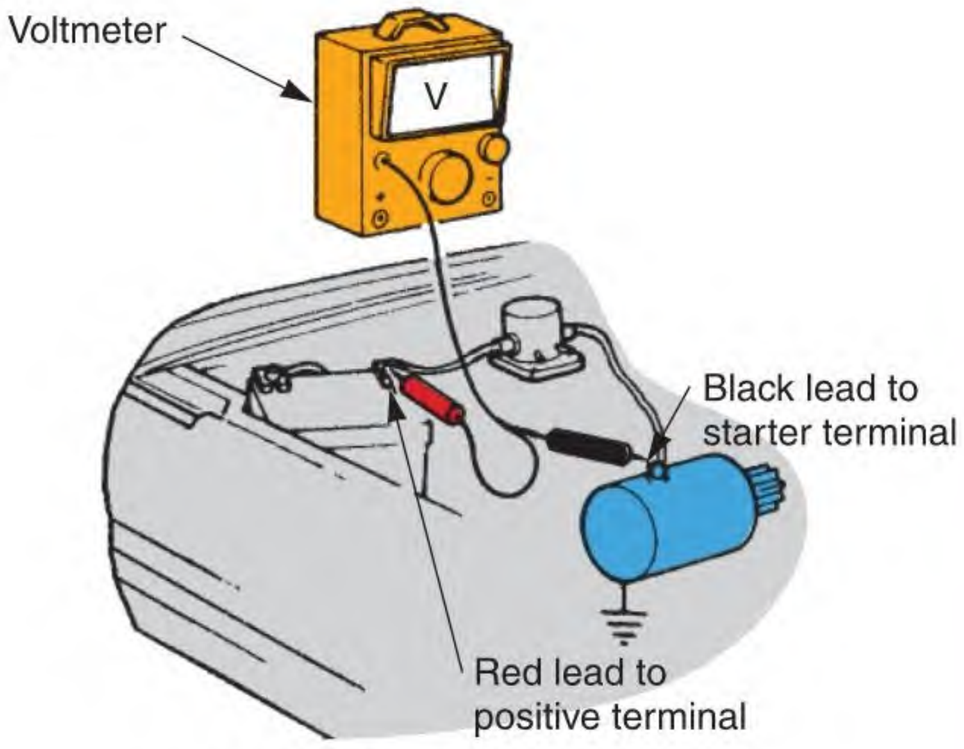
Service Procedure

To perform an insulated circuit resistance test:

1. Touch your voltmeter probes on the positive battery terminal and the starting motor input terminal.
2. Disable the ignition or injection system.
3. Crank the engine and observe the voltmeter reading.

The voltmeter should not read over 0.5 volts. If voltage drop is greater than 0.5 volts, there is excess resistance in the circuit. There may be loose electrical connections, burned or pitted solenoid contacts, or other problems. Test each part individually.

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Insulated Circuit Resistance Test

Starter Ground Circuit Test

A ***starter ground circuit test*** checks the circuit between the starting motor ground and the negative battery terminal.

Service Procedure

To perform a starter ground circuit test:

1. Touch the voltmeter leads to the battery negative terminal and the starter end frame.
2. Crank the engine and note the meter reading.
3. If the reading is higher than 0.5 volts, check the voltage drop across the negative battery cable. The engine may not be grounded properly.
4. Clean, tighten, or replace the cable as needed.

12-Volt Battery Cable Service

A battery cable problem can produce symptoms similar to those caused by a dead battery, bad solenoid, or weak starting motor. If the cables do not allow enough current flow, the starter will turn slowly or not at all.

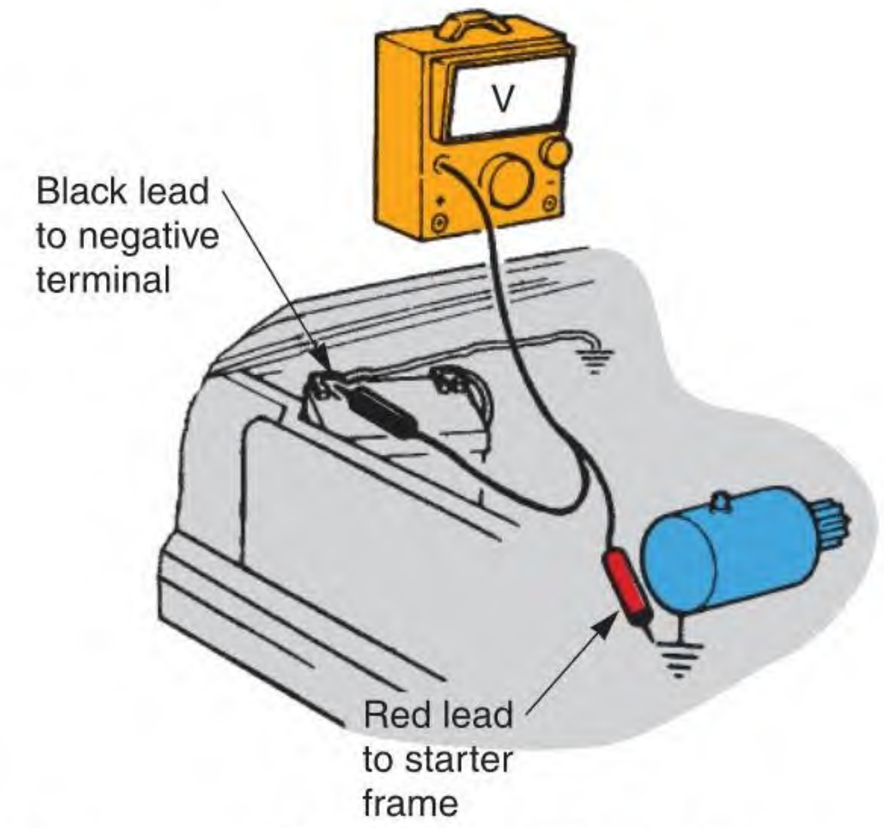
Testing Battery Cables

Battery cables can be damaged by acid corrosion, road salt, improper maintenance, and overtightening of electrical connections. Corrosion between the battery cable connectors and the battery terminals can add resistance in the starting motor circuit. Poor connections between the cable connectors and the battery terminals can also prevent the charging system from sending current through the battery cells for regeneration or recharging.

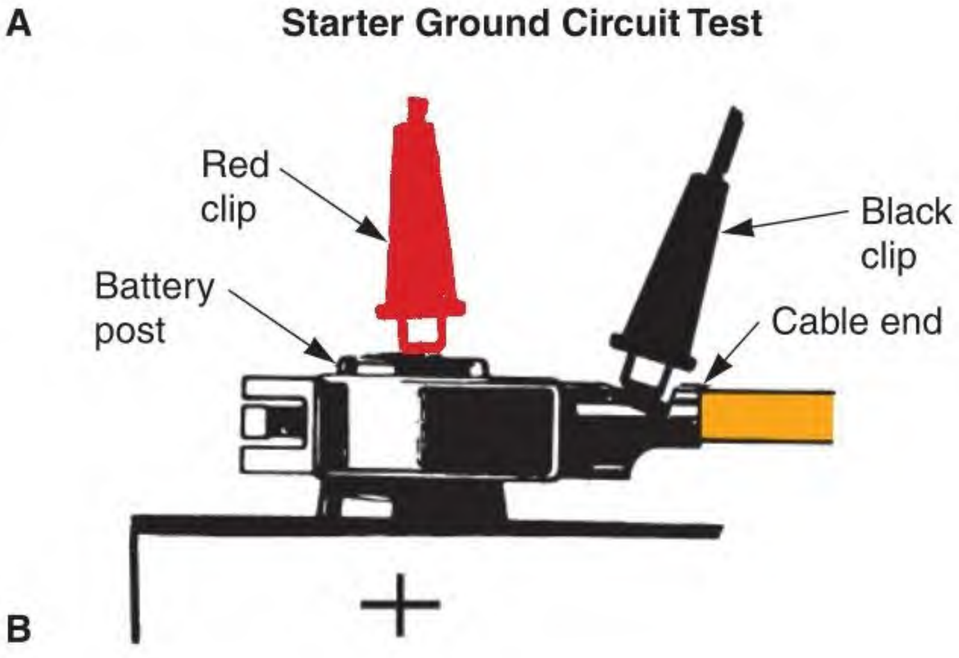
Inspect the battery cables and the cable connectors. While wearing work gloves, grab and try to wiggle the battery cable connections. Vibration, heat, and corrosion will often loosen the battery connections and cause a wide array of symptoms.

To test a battery cable on the vehicle, connect a voltmeter lead between the cable connectors. Do not allow the test leads to touch the battery terminals or ground, or a false reading will result. If necessary, use small alligator clips to secure the leads to the cable end connectors.

Crank the engine and note the voltage drop reading across the cable. Good battery cables will show



A **Starter Ground Circuit Test**



B

Chrysler

Figure 31-6. Voltage drop tests are a quick way of checking circuit resistance without disconnecting wires. A perfect electrical connection would have zero ohms. A—Voltage drop measurements provide a fast way of finding poor electrical conditions. B—Check battery terminals for corrosion and high resistance by measuring voltage drop.

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less than a 0.1 volt drop. If the voltage drop is 0.1 volt or more, there is a high resistance between the cable and the cable connector.

To test a battery cable that has been removed from the vehicle, thoroughly clean the metal surfaces of the cable end connectors. Cleaning will ensure accurate meter measurement. Set your meter to measure resistance. Connect the meter leads between the two cable end connectors. A large-diameter battery cable should show almost no resistance, typically less than 0.2Ω per foot at room temperature. Refer to a wire resistance chart for the size of the battery cable being tested. A higher reading might be due to poor cable end connections adding resistance to the battery cable.

Repair or replace a battery cable if it shows more than a few ohms of resistance. Cleaning and resoldering the battery cable end connectors will often fix a poorly conducting battery cable.

A battery cable connection test checks for high resistance between the battery cable end connector and the battery post.



Service Procedure

To do a ***battery cable connection test***:

1. Connect a voltmeter to the battery post and to the cable end connector.
2. Measure the voltage drop across the connections while cranking the engine.
3. If any cable shows a high voltage drop (above 0.3 volts) during cranking, clean and tighten its connections.
4. Retest the connection. If the voltage drop is still high, repair or replace the cable.

Replacing Battery Cables

When replacing battery cables, make sure the new cables are the same as the old ones. Compare cable length and diameter. Lead terminals are better than steel terminals. The soft lead will more easily conform to the shape of the battery terminal.

When tightening the connections on the ends of battery or starter cables, only snug down the fasteners. Many of the threaded studs, bolts, and nuts are made of soft metal. They can strip and break easily.

Starter Solenoid Service

A bad starter solenoid can cause a variety of problems, including no cranking (with or without a click) or slow cranking. It can also keep the engine and starting motor running or prevent the starting motor from disengaging from the engine.

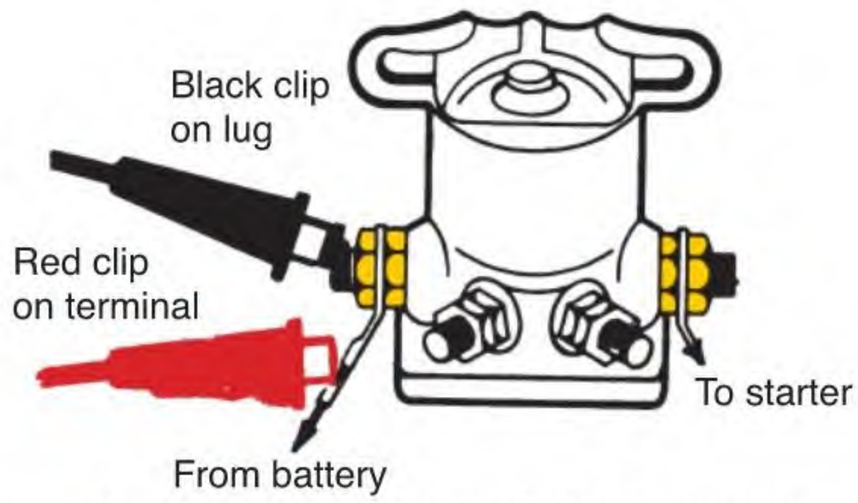
Usually, the large disc-shaped contact will burn and pit. The contact can develop high resistance that reduces current flow to the starter. An open or shorted solenoid winding can keep the contact from closing. No click will occur, and the engine will not crank.

Testing the Starter Solenoid

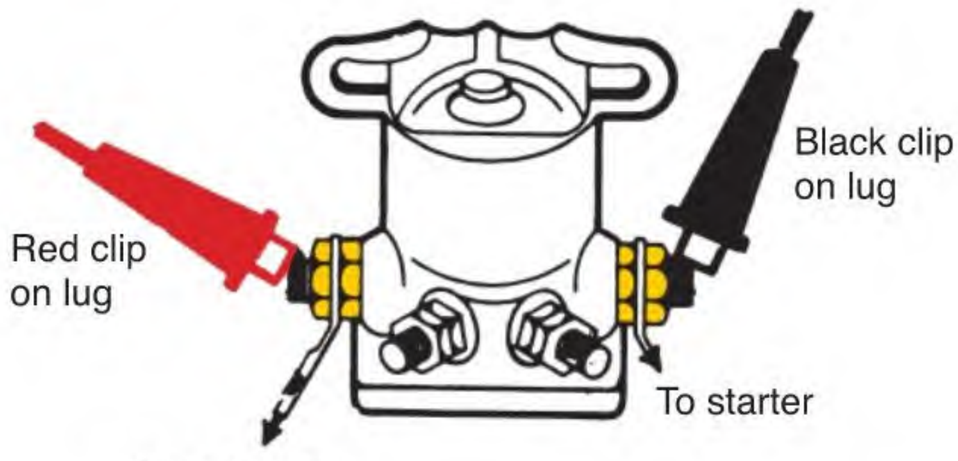
To test the solenoid, connect a voltmeter as shown in **Figure 31-7**. This will measure the voltage drop and resistance of the solenoid lugs and contacts. Crank the engine and note the voltmeter readings. If either voltage measurement is above 0.3 volts, tighten the cable connections or replace the solenoid.

Replacing the Starter Solenoid

To replace a solenoid that is mounted away from the starter, simply remove the cables and wires. Unbolt the solenoid from the fender well and install the new one.



Check Solenoid Lug-to-Cable Connection



Check Disc Contact and Terminal Condition

Marquette

Figure 31-7. Check the starter solenoid as shown.

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If the solenoid is a starter-mounted unit, the starter must be removed from the engine. Then, the solenoid can be unscrewed from the starting motor and replaced. The procedures for removing, assembling, and installing a starter are covered later.

Warning

Before disconnecting the positive cable from a starter solenoid, make sure the battery has been disconnected. If you short this cable to ground, a powerful electric short will result. This could damage parts or cause burns.

Ignition Switch Service

A bad ignition switch (starter feed section of switch) can prevent the starter solenoid from working normally. It can also keep the solenoid from releasing. The contacts in the ignition switch can wear or burn, causing either an open (no-cranking problem) or a short (engine cranks all the time).

Testing the Ignition Switch

To test an ignition switch, touch a test light to the starter solenoid start (S) terminal. See **Figure 31-8**. If the ignition switch is good, the test light will glow when the key is turned to start the engine. The test light should go out when the key is released.

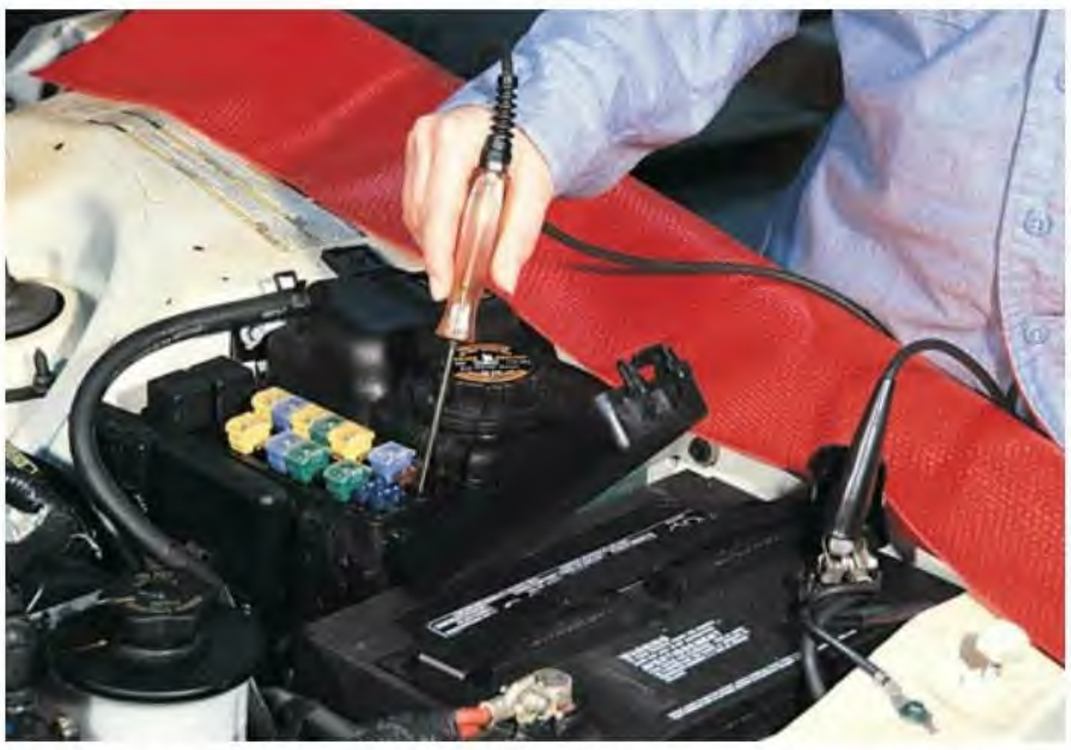


Figure 31-8. Use a test light to quickly check for power in an electric circuit. Connect the alligator clip to ground and touch the tip to the circuit. The light will glow if there is power in the circuit. To prevent component damage, do not use a conventional test light on an electronic circuit.

If the test light on the solenoid does not glow, either a wire in the ignition switch circuit is open or the ignition switch is defective. Test the wires coming out of the ignition switch to eliminate the possibility of a bad wire.

If the test light on the solenoid glows in both the start and run positions, the ignition switch is probably shorted. The engine would crank all the time.

These are simplified tests. You will need to use your own judgment and a service manual to perform more detailed tests.

12-Volt Starter Relay Service

A bad starter relay will keep power from the starter solenoid. This will prevent engine cranking. The winding or the contact points in the relay could be faulty. If the relay is bad, you will not hear the solenoid click and engage.

To test a starter relay, use a test light to check for voltage going into and coming out of the relay terminals. Refer to a wiring diagram for test points. Replace the relay if needed.

Neutral Safety Switch Service

A misadjusted or bad neutral safety switch can also keep the engine from cranking when the key is turned to start. If the neutral safety switch is open, current cannot flow from the ignition switch to the starter solenoid.

Before testing the switch, move the transmission gear shift lever into various positions while trying to start the engine. The switch may close, letting the starter operate. If the starter begins to work, the neutral safety switch may only need adjustment.

Warning

Make sure to press down on the vehicle's brake pedal when checking a neutral safety switch. If the switch is worn or faulty, the engine could try to start while the vehicle is in drive or reverse. If this happens, the brakes would be needed to keep the vehicle from moving.

Testing the Neutral Safety Switch

To test a neutral safety switch, touch a 12-volt test light to the switch output wire connection while moving the transmission shift lever. The light should glow as the shift lever is slid into *Park* and *Neutral*. The test light should not glow when the shift lever is in other positions. If the neutral safety switch does not complete its circuit in *Park* and *Neutral*, but does complete its circuit in other gear positions, it may be defective.

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Before condemning the neutral safety switch, check the mechanism that actuates the switch. There should be a prong or other device that operates the neutral safety switch. If the actuating mechanism is working properly, try to adjust the switch as outlined in the following section. If the switch still will not work properly, it must be replaced. After replacing a defective neutral safety switch, the new unit must be adjusted.

Adjusting the Neutral Safety Switch

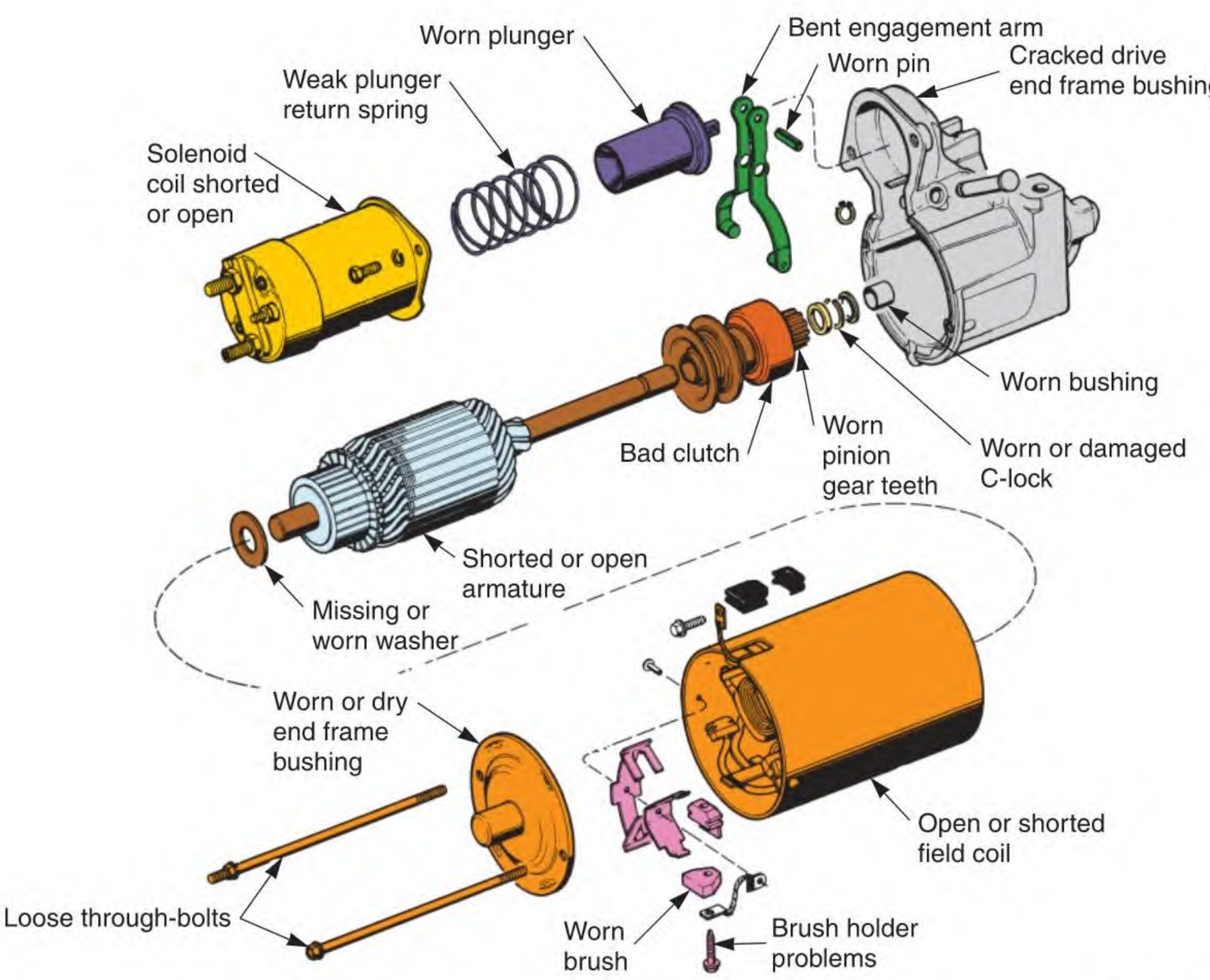
To adjust a neutral safety switch, loosen the fasteners holding the switch. The switch may be located on the steering column, shift lever, or transmission. With the switch loosened, place the shift selector into park. While holding the ignition switch to start, slide the neutral switch on its mount until the engine cranks. Without moving the switch, tighten its hold-down screws. This should allow the engine to start only with the shift lever in park or neutral. Check operation after adjustment.

12-Volt Starter Service

A faulty starting motor can cause a wide range of symptoms: slow cranking, no cranking, overheating of starter cables, and abnormal noises while cranking. If the battery, cables, solenoid, and other starting system parts are good but the engine does not crank properly, the starter may be bad. See **Figure 31-9**. A current draw test and other tests will help you determine whether the starting motor should be removed for further inspection and testing.

12-Volt Starting Motor Removal

Before deciding to remove the starting motor, inspect it closely for problems. Check that the starter-to-engine bolts are tight. Loose starter bolts can upset motor operation by causing a poor ground or incorrect pinion gear meshing. Make sure all wires on the motor and solenoid are tight. If no obvious problems are found, the starter should be removed.



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Figure 31-9. Study the kinds of problems that require repair versus replacement of a starting motor. Solenoid and pinion gear problems can be repaired. Motor problems normally require a new or rebuilt starting motor.

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Service Procedure

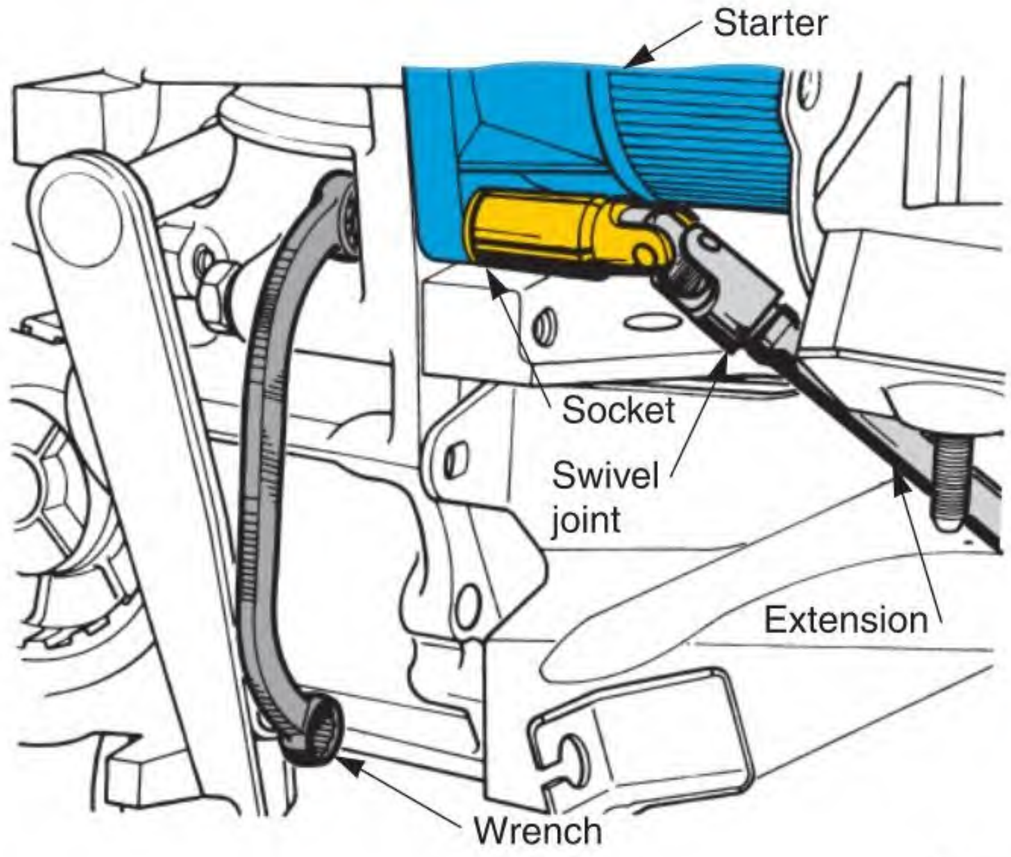
To remove a starter:

1. Disconnect the negative cable on the battery to avoid accidental cranking.
2. Unbolt the battery cable, solenoid wires (starter-mounted solenoid type), and any braces on the starting motor. See **Figure 31-10**.
3. Unscrew the mounting bolts while supporting the weight of the motor. Look at **Figure 31-11**.

Starter shims may be used to adjust the space between the pinion gear and the flywheel ring gear. During starter removal, always check for shims. They must be returned to the same place during reassembly. If the shims are not replaced, the pinion and flywheel gears will not mesh properly. A grinding noise will result, and the pinion and flywheel gears may be damaged.

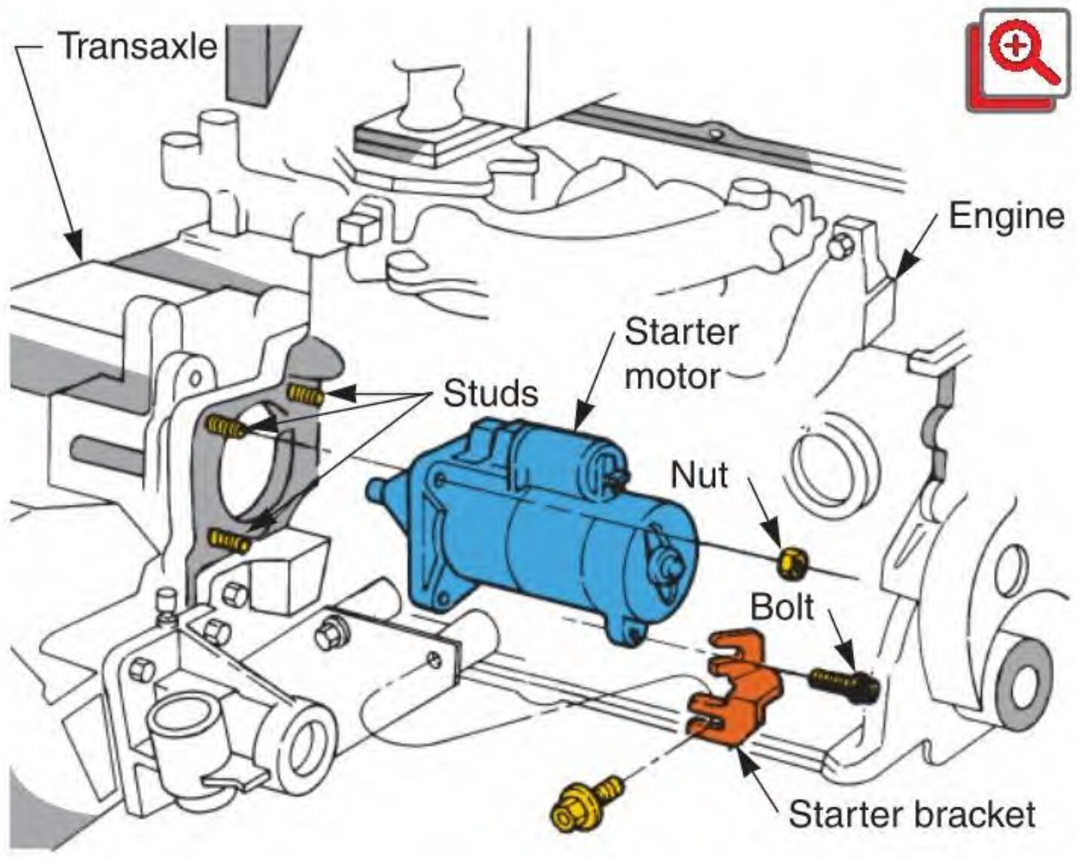
Tech Tip

In a few late-model engines, the starting motor is located under the engine intake manifold. You must remove the manifold to service the starting motor on these engines. Usually, only a few easy-to-reach bolts secure the intake manifold.



Chrysler

Figure 31-10. When starting motor fasteners are hard to reach, a swivel, extension, and ratchet may help.



Chrysler

Figure 31-11. To remove a starter, remove fasteners, wires, and brackets or heat shields. Hold the starter firmly because it is fairly heavy.

12-Volt Starting Motor Rebuild

A ***starting motor rebuild*** typically involves:

1. Disassembling the starting motor.
2. Cleaning parts and inspecting them for wear or damage.
3. Replacing brushes, bushings, and other worn or damaged parts.
4. Polishing or turning the commutator.
5. Lubricating, reassembling, testing, and installing the starting motor.

Many shops do not rebuild starting motors. Instead, they purchase and install new or factory-rebuilt units. The cost of labor is too high to make in-shop rebuilding economical. Also, the factory-rebuilt units will have a limited warranty.

Tech Tip

When the starter must be repaired, you may only need to disassemble a section of the starter. For example, a worn pinion gear can make the starter disengage before engine start-up. The clutch will freewheel before the engine has cranked. The pinion gear assembly can be replaced without complete starting motor disassembly. By removing only the drive end frame and a C-lock, the brushes and the other end of the motor can usually be left together.

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12-Volt Starting Motor Installation

Install the starter in the reverse order of removal. Make sure that any spacer shims are replaced between the motor and the engine block. If these shims are left out, the pinion gear may not mesh with the flywheel gear properly.

If the starter has a solenoid on it, connect the wires on the solenoid before bolting the starter to the engine. Torque the starter mounting bolts to specifications. Replace any brackets or shields and reconnect the battery. Crank the engine several times to check starting motor operation.

Hybrid Starting System Diagnosis

Late-model hybrids have an extensive list of trouble codes for the main components of the engine starting system. OBD systems will indicate problems with the motor-generator, HV power control module, HV battery, and many other components. Usually, stored trouble codes will indicate which circuit is not functioning normally. See **Figure 31-12**. The

OBD II Hybrid Propulsion Diagnostic Trouble Codes (P0AXX)

Diagnostic Trouble Code	Description	Diagnostic Trouble Code	Description
P0A00	Motor electronics coolant temperature sensor circuit	P0A15	Engine mount control circuit low
P0A01	Motor electronics coolant temperature sensor circuit range/performance	P0A16	Engine mount control circuit high
P0A02	Motor electronics coolant temperature sensor circuit low	P0A17	Motor torque sensor circuit
P0A03	Motor electronics coolant temperature sensor circuit high	P0A18	Motor torque sensor circuit range/ performance
P0A04	Motor electronics coolant temperature sensor circuit intermittent	P0A19	Motor torque sensor circuit low
P0A05	Motor electronics coolant pump control circuit/open	P0A20	Motor torque sensor circuit high
P0A06	Motor electronics coolant pump control circuit low	P0A21	Motor torque sensor circuit intermittent
P0A07	Motor electronics coolant pump control circuit high	P0A22	Generator torque sensor circuit
P0A08	DC/DC converter status circuit	P0A23	Generator torque sensor circuit range/ performance
P0A09	DC/DC converter status low input	P0A24	Generator torque sensor circuit low
P0A10	DC/DC converter status high input	P0A25	Generator torque sensor circuit high
P0A11	DC/DC converter enable circuit/open	P0A26	Generator torque sensor circuit intermittent
P0A12	DC/DC converter enable circuit low	P0A27	Battery power off circuit
P0A13	DC/DC converter enable circuit high	P0A28	Battery power off circuit low
P0A14	Engine mount control circuit/open	P0A29	Battery power off circuit high

Chrysler

Figure 31-12. Study this partial list of SAE diagnostic trouble codes relating to a hybrid propulsion system.

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instrument panel combination meter will also indicate poor electrical drive performance during all-electric (motor-generator driven) acceleration and regenerative braking.

Your scan tool will indicate the source of the problem if any starting circuit voltage, current, or resistance is not within specifications. If HV battery voltage, motor-generator current draw, HV power control module voltage, or current output is low or high, the OBD system will tell you where to start your tests.

Motor-Generator Problems

Late-model hybrid vehicle HV starting systems are very dependable. They use industrial-sized three-phase motor-generators that can crank an engine using a fraction of their rated motor horsepower. Since motor-generators are designed to propel the weight of the whole vehicle at highway cruising speeds, they seldom cause an engine no-start problem. However, after several hundred thousand miles of operation, motor-generator bearings can wear and fail in service.

Motor-generator clutch problems can keep the HV motor from cranking the engine, even if the motor is functioning normally. If a transaxle clutch is used to link the motor armature to the engine crankshaft, the traction motor can require reduction gears to multiply torque. This will allow smaller traction motors to easily rotate the engine reciprocating assembly for starting. Failure of the motor-generator clutch and these transmission gears can also appear to be a motor-generator failure.

Hybrid control module and HV power control module problems can sometimes prevent the HV starting system from cranking the engine for starting. Trouble codes will direct you to the failed control module circuit for further tests.



Diagnostic Case Study

Concern: Mr. Figueroa stopped by the shop with a question about his car. "My engine just won't turn over," he says. "It will click, but nothing happens!" Duff explains that it is impossible to diagnose the problem without looking at the vehicle. Mr. Figueroa agrees to have the vehicle towed to the shop for a proper diagnosis.

Cause: After pushing the car into the shop, Duff turns the key to start in an attempt to verify the problem. As Mr. Figueroa explained, the starter clicks but the starting motor does not turn the engine over. Duff suspects that the problem is a faulty solenoid on the starting motor and assigns the job to one of his apprentice technicians.

The apprentice technician uses a stethoscope to verify Duff's initial diagnosis. He places the stethoscope on the starter solenoid and is able to hear the solenoid closing when the key is turned to start. This tells him that current is reaching the solenoid from the ignition switch. The technician then checks the voltage drop across the solenoid terminals while the key is turned. The voltage drop is excessive, indicating a faulty solenoid.

Correction: The technician removes the starter and solenoid. He notices that a few teeth on the flywheel ring gear are worn but knows that this problem would not cause the starter to fail. After disassembling the starter, the technician finds that the large round contact inside the solenoid is burned, preventing current flow from the battery to the starting motor windings.

The technician calls Mr. Figueroa to get his approval before making the repairs. He explains that a faulty solenoid is causing the no-crank problem but warns Mr. Figueroa that a few teeth on the flywheel ring gear are worn down and may cause further cranking problems. Mr. Figueroa tells the technician to replace the starter and solenoid, but he does not okay flywheel ring gear replacement because of the added cost.

The technician installs a new starter and solenoid. He then starts the vehicle several times to make sure the problem has been fixed. As he prepares Mr. Figueroa's invoice, the technician notes that he warned the customer about the ring gear wear. He also notes that Mr. Figueroa chose not to have the repair done.

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Summary

- In a no-crank problem, the engine crankshaft does not rotate properly with the ignition key at start. The most common causes are a dead battery, poor electrical connection, or faulty system component.
- A solenoid buzzing or clicking sound, without cranking, is commonly due to a discharged battery or poor battery cable connections.
- A starting system humming sound, after momentary engine cranking, may be due to a bad starter overrunning clutch or a worn pinion gear unit.
- A starter metallic grinding noise may be caused by broken flywheel teeth or pinion gear teeth wear.
- A dead or discharged battery is one of the most common reasons the starting system fails to crank the engine properly.
- A starter current draw test measures the current used by the starting system. This will tell you about the condition of the starting motor and other system parts.
- Voltage drop tests will quickly locate a part with higher-than-normal resistance.
- An insulated circuit resistance test checks all parts between the positive battery terminal and the starting motor for excess resistance.
- A starter ground circuit test checks the circuit between the starting motor ground and the negative battery terminal.
- A battery cable problem can produce symptoms similar to a dead battery, bad solenoid, or weak starting motor.
- A bad starter solenoid can cause a range of symptoms, including no cranking (with or without a click) or slow cranking. It can also keep the engine or starting motor from shutting off.
- A bad ignition switch (starter feed section of switch) can prevent the starter solenoid from working normally.
- A misadjusted or bad neutral safety switch can keep the engine from cranking when the key is turned to start.
- If the battery, cables, solenoid, and other starting system parts are good but the engine does not crank properly, the starter may be bad. A current draw test and other tests will help determine whether the starting motor requires further inspection and testing.
- Starter shims may be used to adjust the space between the pinion gear and the flywheel ring gear. During starter removal, always check for shims.
- A starting motor rebuild typically involves disassembly of starting motor; cleaning and inspection for part wear or damage; replacement of brushes, bushings, and any other worn or damaged parts; polishing or turning of commutator; lubrication, reassembly, testing, and installation of starting motor.
- OBD systems will indicate problems with hybrid components, including the motor-generator, HV power control module, and battery stack. Stored trouble codes will usually indicate which circuit is not functioning normally.
- You must use high-voltage, high-current tests to pinpoint the problem when a hybrid engine fails to crank and start.
- Motor-generator clutch problems can keep the HV motor from cranking the engine, even if the motor is functioning normally.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

battery cable connection test
insulated circuit resistance test
no-crank problem
slow-cranking condition
starter current draw test
starter ground circuit test
starter shims
starting headlight test
starting motor rebuild
voltage drop tests

Activities

1. Demonstrate the use of a voltmeter in making voltage drop tests to detect excessive resistance in starting system components.
2. Make a video recording to show a procedure that would be hard to demonstrate for a class, such as starting motor removal and installation. Narrate the finished video and play it for the class.

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Review Questions

Answer the following questions using the information provided in this chapter.

1. What are the most common causes of a no-crank problem?
2. List two causes of a buzzing or a clicking sound from the starter solenoid.
3. List two causes of a humming sound after momentary engine cranking.
4. What commonly causes a metallic grinding noise during starting?
5. Summarize how a starting headlight test is performed.
6. Why is a starter current draw test used?
7. A high voltage drop in the starting system could indicate:
   (A) high resistance.
   (B) a loose electrical connection.
   (C) a corroded or burned terminal.
   (D) All of the above.
8. How do you test the battery cables?
9. List two symptoms of a bad starter solenoid.
10. A bad ignition switch can keep the starting motor from working and can also make the engine crank all the time. True or False?
11. How do you adjust a neutral safety switch?
12. Motor-generator clutch problems can keep the HV motor from cranking the engine. True or False?

ASE-Type Questions

1. A metallic grinding noise can be caused by each of the following *except:*
   (A) clashing gears.
   (B) broken flywheel teeth.
   (C) pinion gear tooth wear.
   (D) broken main feed wire.
2. After performing a starting headlight test, Technician A says the resulting bright lights and no-crank condition indicate starting circuit high resistance. Technician B says the test results suggest an open starting circuit. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. Which of the following tests measures the number of amps used by a starting system?
   (A) Starter current draw test.
   (B) Starter ground circuit test.
   (C) Insulated circuit resistance test.
   (D) All of the above.
4. A battery cable problem produces symptoms similar to each of the following *except:*
   (A) bad solenoid.
   (B) dead battery.
   (C) weak starter motor.
   (D) brush holder problem.
5. Which of the following is not an indication of a bad starter solenoid?
   (A) Slow cranking.
   (B) Clicking without cranking.
   (C) Cranking without starting.
   (D) No cranking and no clicking.
6. When removing a starter motor, which of the following should be done first?
   (A) Disconnect the battery.
   (B) Mark the end frames.
   (C) Unbolt the battery cable from the starter.
   (D) Remove any solenoid fasteners.
7. An ignition switch is being tested with a test light. When connected to the solenoid start terminal, the light glows when the key is in the start position and the run position. Technician A says the switch is working properly. Technician B says the ignition switch is most likely shorted. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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8. Technician A says a bad starter relay will keep power from the starter solenoid. Technician B says a faulty neutral safety switch can prevent current from flowing from the ignition switch to the starter solenoid. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Technician A says a starter rebuild generally involves replacing brushes, bushings, and other damaged parts. Technician B says the commutator is typically polished or turned during a starter rebuild. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. The HV starting system in a hybrid vehicle will not crank the engine for starting. Technician A says the problem could be caused by a faulty HV power control module. Technician B says the problem could be caused by a faulty hybrid control module. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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Chapter 32
Charging System Technology

After studying this chapter, you will be able to:

- Describe the construction of major 12-volt charging system components.
- Explain charging system indicators and instrumentation.
- Explain the construction and operation of hybrid charging systems.
- Compare the operation of a 12-volt charging system to that of a hybrid charging system.
- Correctly answer ASE certification test questions that require a knowledge of charging system fundamentals.

In previous chapters, you learned how a 12-volt starting motor or a hybrid motor-generator uses battery power to crank the engine. The starting motor consumed electricity and partially discharged the battery.

In this chapter, you will learn how the charging system re-energizes the battery and supplies electricity for all the car's other electrical systems. This chapter will prepare you for the next chapter on testing and repair of 12-volt and hybrid charging systems.

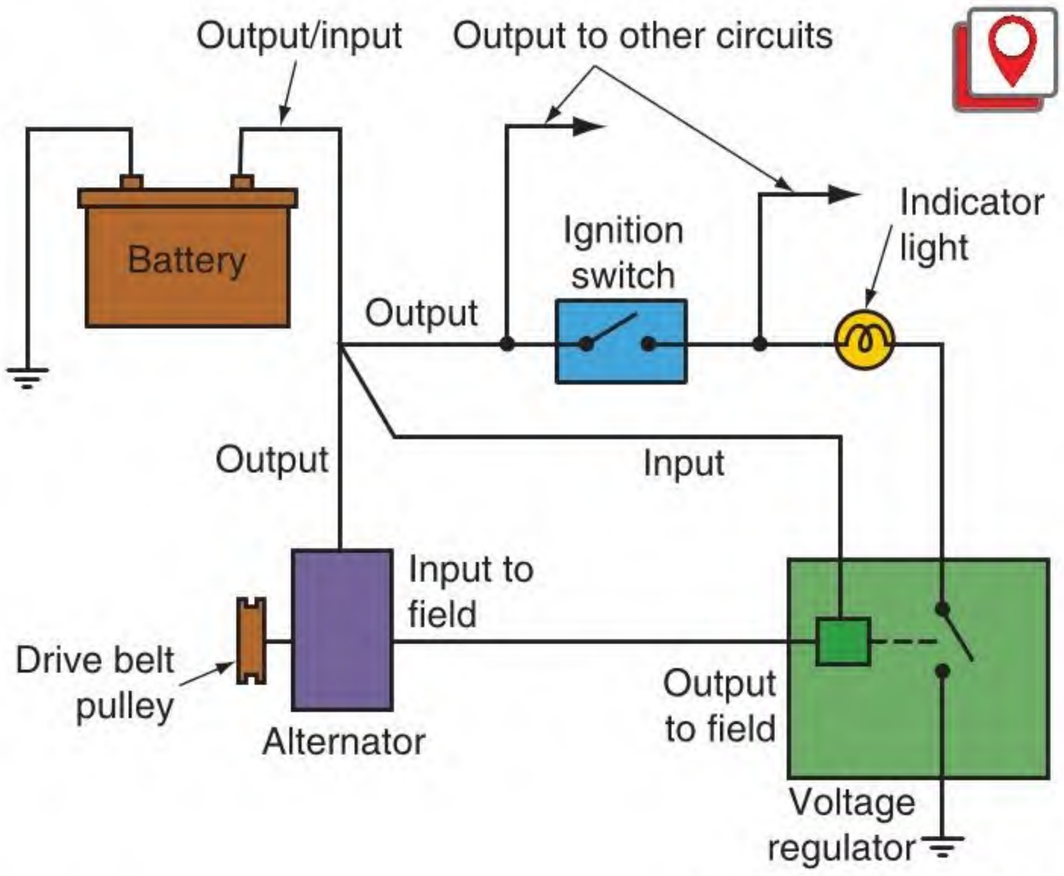
12-Volt Charging System Functions

The ***charging system*** performs several functions:

- It recharges the battery after engine cranking or after the use of electrical accessories with the engine shut off.
- It supplies all the vehicle's 12-volt electricity when the engine is running.
- It provides a 13-15 volt output, which is slightly higher than a battery fully-charged at 12.6 volts.
- It changes current and voltage output to meet different electrical loads.
- It provides smooth dc for the proper function of all of the vehicle's electronic circuits.

A basic 12-volt charging circuit is shown in **Figure 32-1**. When the engine is not running, the battery feeds current to the vehicle's electrical system. When the engine starts, a belt spins the alternator, causing the alternator to produce an electrical output. Current then flows back to the battery and into other electric circuits of the vehicle.

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Figure 32-1. This is a basic charging circuit. The alternator output is wired to the battery and to the vehicle's electrical system.

12-Volt Charging System

The major parts of a typical 12-volt charging system include:

- ***Alternator***—An alternator is an ***ac generator*** that uses mechanical (engine) power to produce electricity.
- ***Voltage regulator***—A voltage regulator is an electronic device that controls the voltage and current output of an alternator. The engine control module serves as the voltage regulator on late-model vehicles.
- ***Drive belt***—The drive belt links the engine crankshaft pulley with the alternator pulley to drive the alternator.
- ***Charge indicator***—A charge indicator often includes an ammeter, voltmeter, or warning light that informs the driver of problems with the charging system.
- ***Charging system harness***—The charging system harness is wiring that electrically connects the components together.
- ***Battery***—A 12-volt battery provides current to initially energize and smooth dc current output from the alternator.
- ***ECM***—The ECM usually monitors 12-volt charging voltage to alter rotor field strength and alternator current output to prevent overcharging and battery damage.

During engine cranking, the battery supplies all the electricity used by the automobile. Then, when the engine starts running, the charging system takes over to provide current to the vehicle's electrical systems.

The engine crankshaft pulley and alternator drive belt spin the alternator pulley. This turns the alternator and causes it to produce electricity. See **Figure 32-2**.

The voltage regulator keeps alternator output at a preset ***charging voltage*** (13–15 volts). Since this is higher than battery voltage (12.6 volts), current flows back into the battery and recharges it. Current also flows to the ignition system, electronic fuel injection system, on-board computers, radio, navigation, cell phone, or any other device that uses electricity.

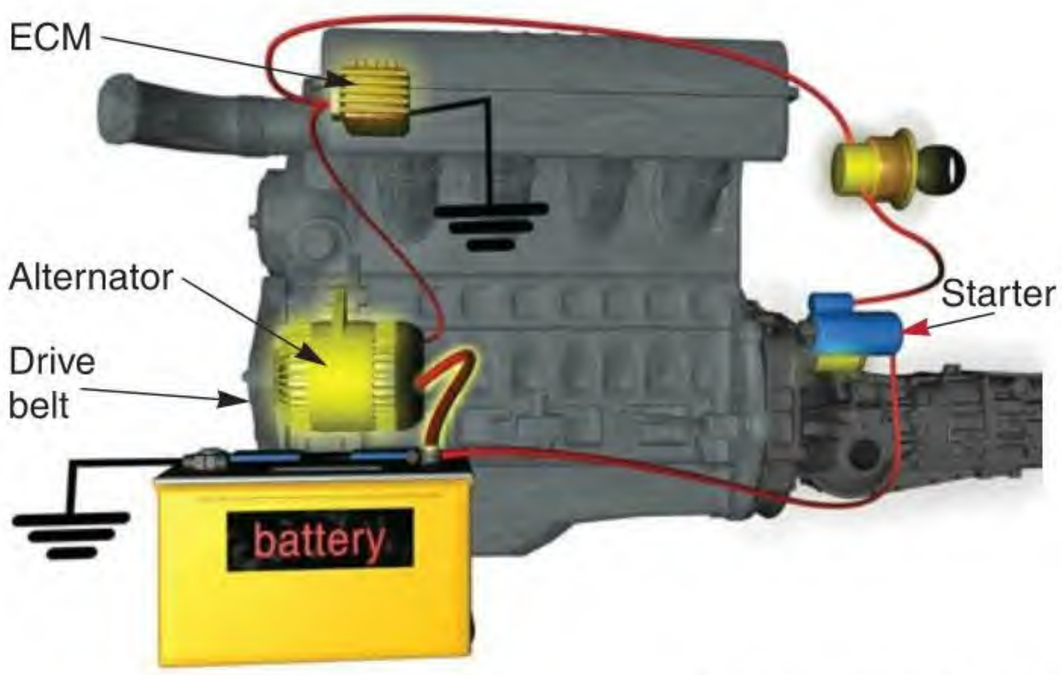
Alternator

It is very important that you understand alternator construction and operation. This information is essential to properly diagnose, test, and repair 12-volt starting systems.

The two main parts of a simplified alternator are the rotor and stator. The rotor is located in the center of the alternator housing. It creates a rotating magnetic field. The alternator drive belt turns the rotor, making the field rotate.

The stator is a stationary set of windings that surrounds the rotor. It is the output winding in the alternator. When the rotor spins, its strong magnetic field cuts across the stator windings. This induces current in the stator windings. If the stator windings are connected to a load (a lightbulb, for example), the load would operate (glow).

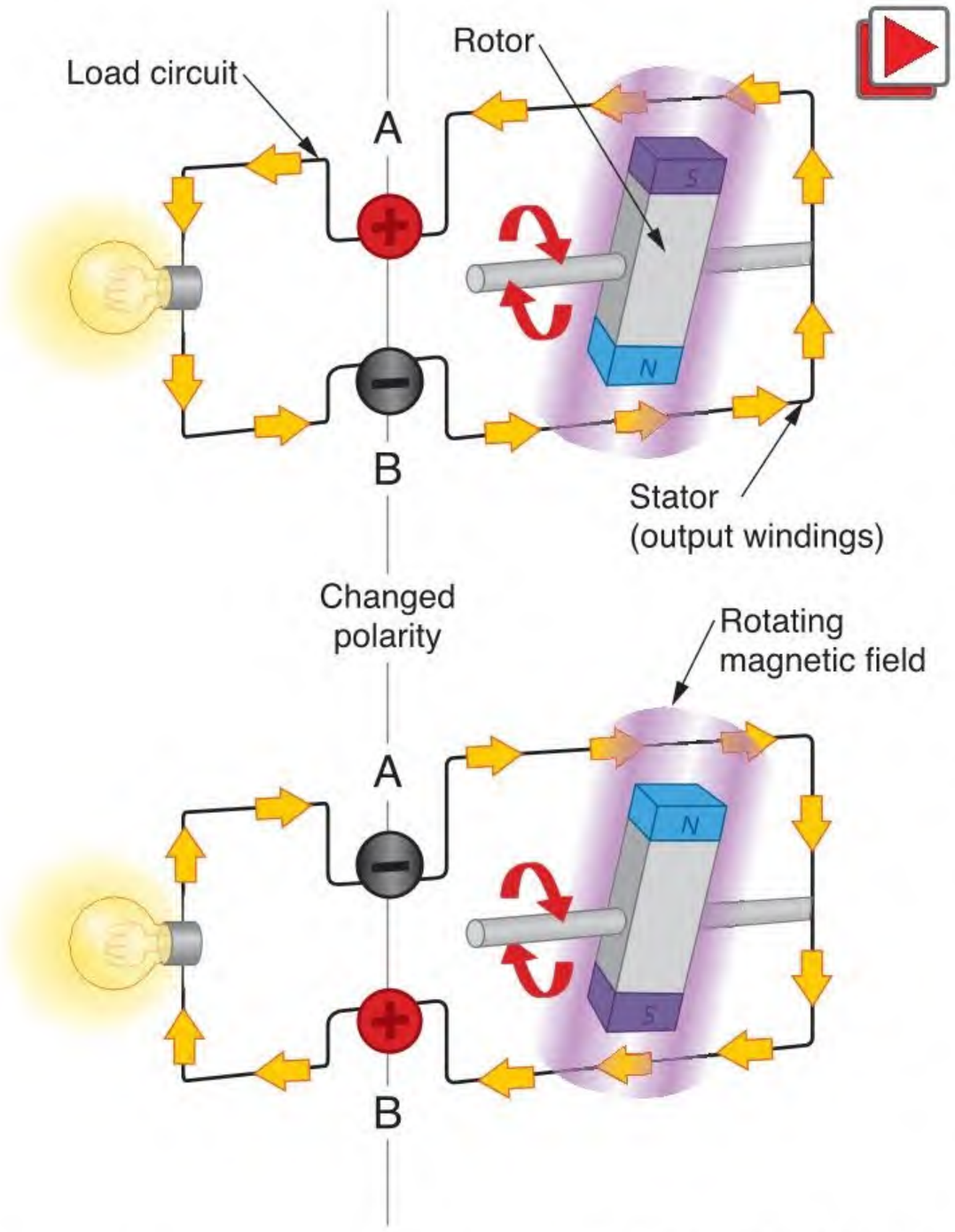
The simple alternator shown in **Figure 32-3** produces an alternating current (ac) output. Alternating current flows one way, and then the other. As the rotor turns into one stator winding, current is induced in one direction. Then, when the same rotor pole moves into



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Figure 32-2. The charging system recharges the battery and supplies electricity when the engine is running.

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Figure 32-3. A basic alternator operation shows a rotating magnetic field moving across the stationary windings. Current is induced in the windings and out to the load. When the rotating field turns one-half turn, the polarity of the windings is reversed. This causes current to flow out to the load in the opposite direction. Alternating current is produced.

the other stator winding, current reverses and flows out in the other direction. See **Figure 32-4**.

An automobile electrical system is designed to use direct current (dc), which flows in one direction only. It cannot use the alternating current as it comes out of the alternator's stator. Therefore, the alternator current must be rectified (changed) into direct current before entering the vehicle's electrical system.

Discussed in earlier chapters, a diode is an electronic device that allows current flow in only one direction. It serves as an "electric check valve." When a diode is connected to a voltage in such a way that current passes through the diode, the diode is said to be forward biased.

A ***forward-biased diode*** acts as a conductor. When a diode is connected to a voltage in such a way that current does not pass through, it is said to be reverse biased. A ***reverse-biased diode*** acts like an insulator. **Figure 32-5** illustrates diode action.

If a diode were placed on the stator output of our simple alternator, current would only flow out through the circuit in one direction.

A single diode would not use all of the alternator's output, however. Also, it would result in pulsing direct current, not smooth current flow. Therefore, an alternator uses several diodes connected into a rectifier circuit.

The main components of a typical alternator, pictured in **Figure 32-6**, include:

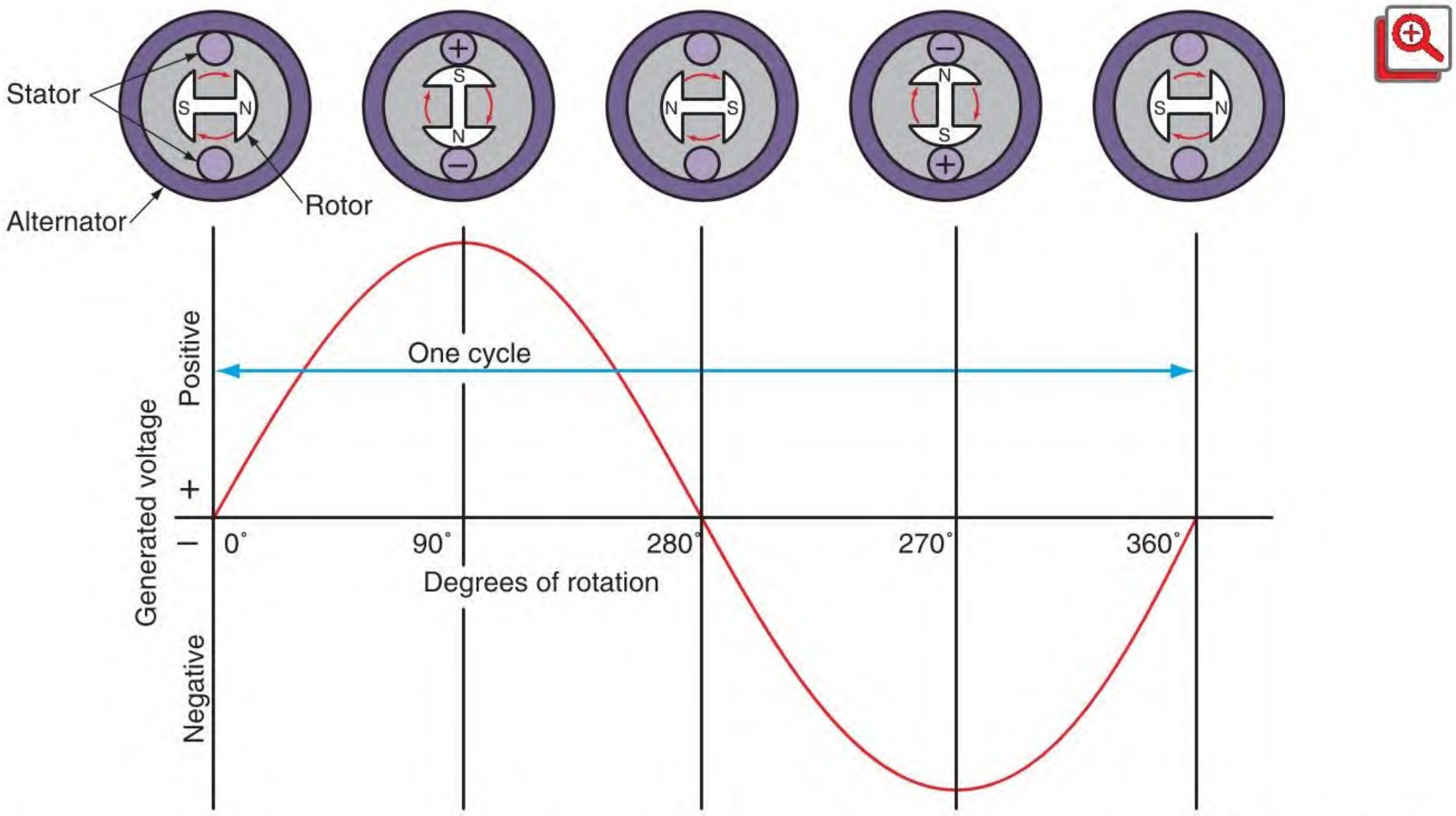
- Rotor—A rotor assembly consists of field windings, claw poles, rotor shaft, and slip rings.
- Brush assembly—The brush assembly includes the brush housing, brushes, brush springs, and brush wires.
- Rectifier—The rectifier assembly consists of diodes, a heat sink or diode plate, and electrical terminals.
- Stator—The stator assembly has three stator windings (coils), a stator core, and wires for the rectifier circuit.
- Alternator housing—The alternator housing is made up of the drive end frame, slip ring end frame, and end frame bolts.
- Fan and pulley—A fan and pulley assembly includes a fan, spacer, pulley, lock washer, and pulley nut.
- Voltage regulator—The voltage regulator is an electronic, small-voltage control circuit chip mounted in or on the rear housing of an alternator. In some cases, the engine control module serves as the voltage regulator.

Alternator Rotor Assembly

An ***alternator rotor assembly*** consists of field windings mounted on a shaft. Two claw-shaped pole pieces surround the field windings to increase the magnetic flux or the magnetic field strength.

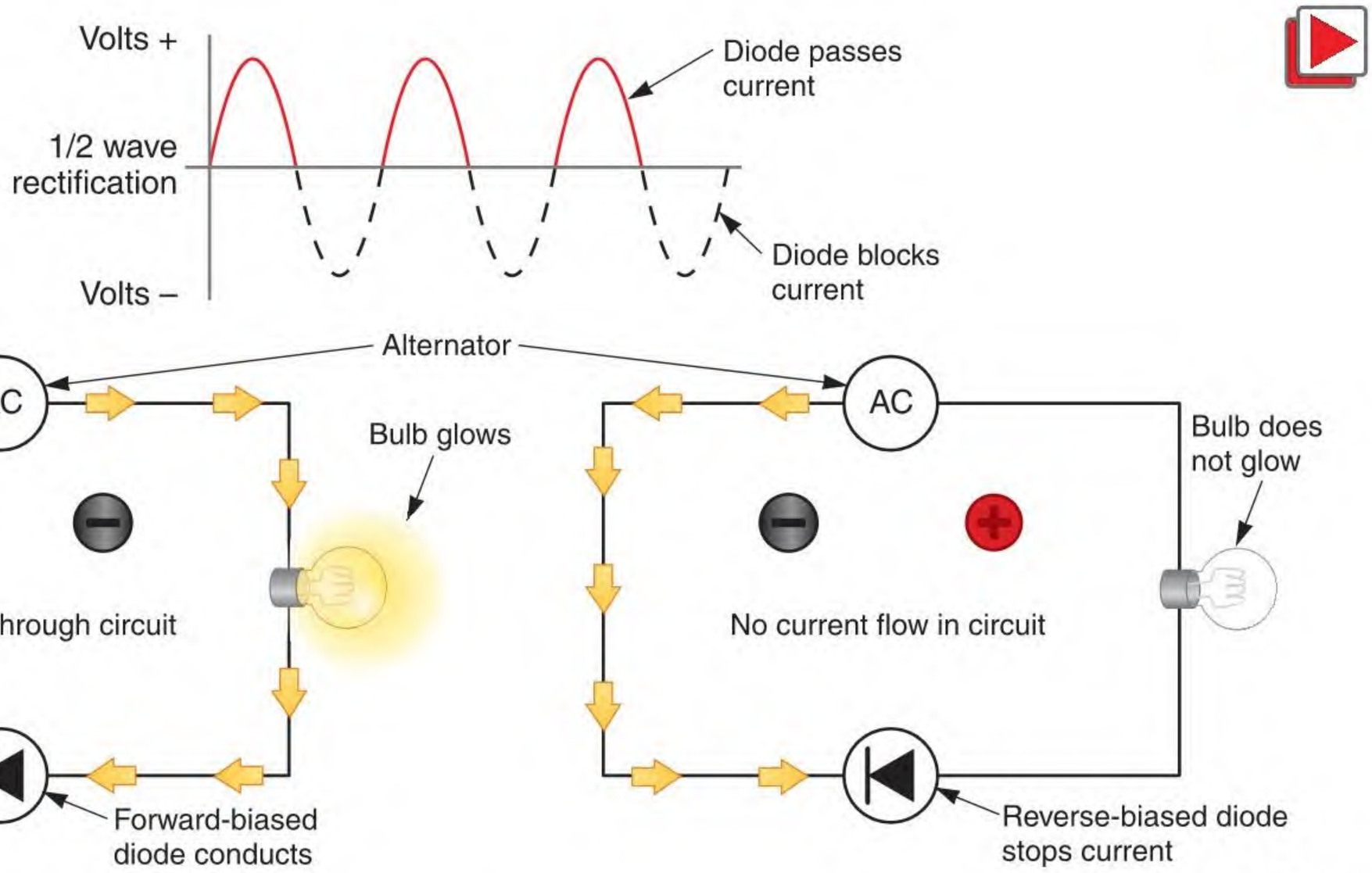
The fingers on one of the pole pieces produce S (south) poles. The fingers on the other pole piece form N (north) poles. As the rotor spins inside the alternator, the alternating polarity (north-south-north-south) produces an alternating current. This is illustrated in **Figure 32-7**.

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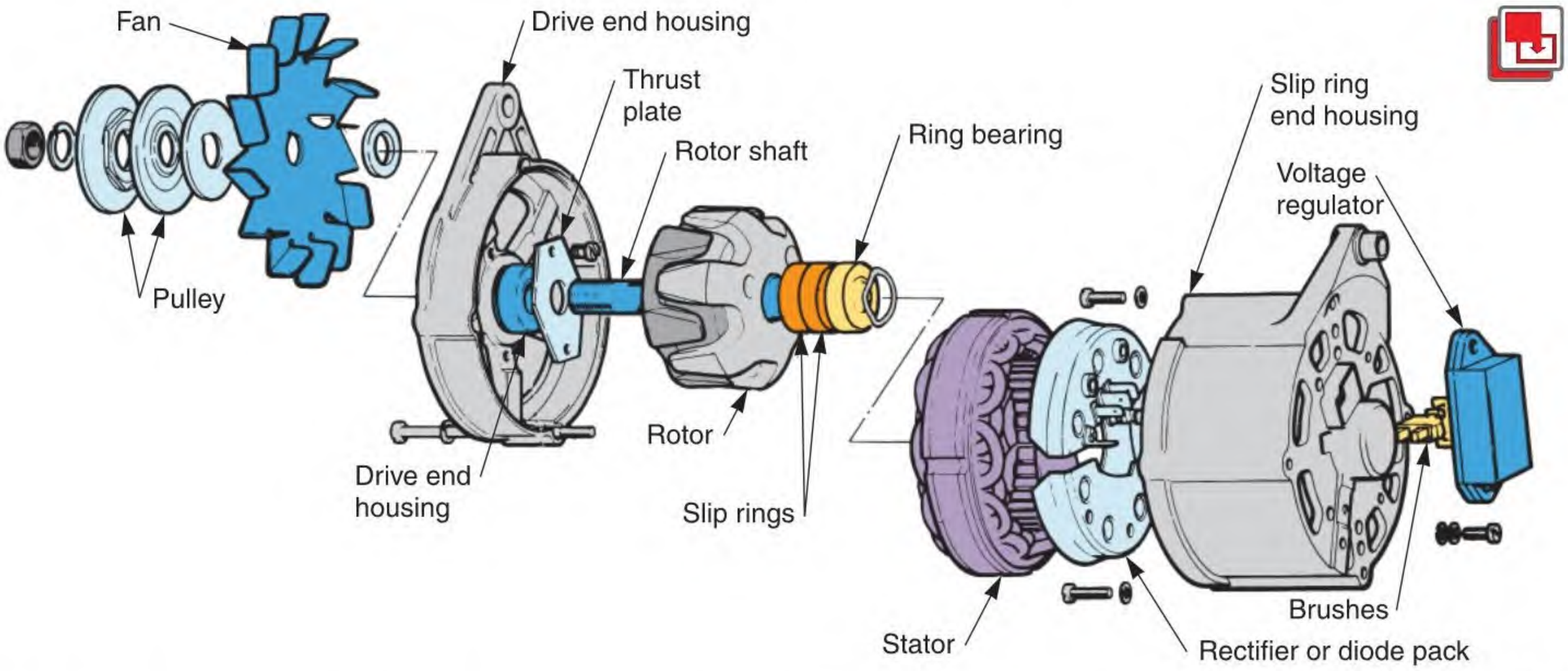
Figure 32-4. The spinning magnetic field induces current into the stationary windings of the stator. As the north and south poles of the spinning field cut across the stationary windings, an output current is generated. The sine wave represents the reversing polarity or reversing current flow.



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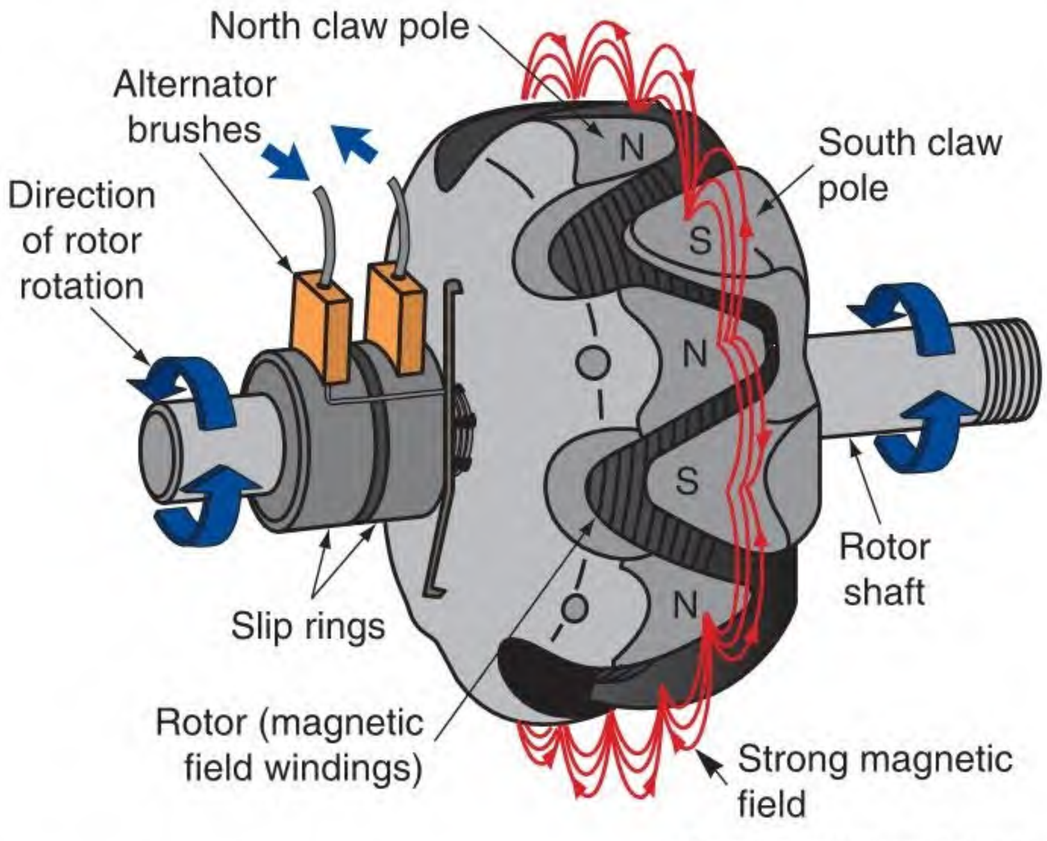
Figure 32-5. This simple circuit shows action of a diode. When the alternator output places forward bias on diode, current passes through circuit. With reverse bias, the diode prevents current flow. The bulb would only glow on the positive output wave from the alternator.

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Figure 32-6. This exploded view shows the major parts of an alternator. Study the names of the parts and the general construction.



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Figure 32-7. The rotor has claw poles that surround its windings. This produces a strong magnetic field that induces current into the stator. Note the north and south poles of the claws.

Alternator Bearings

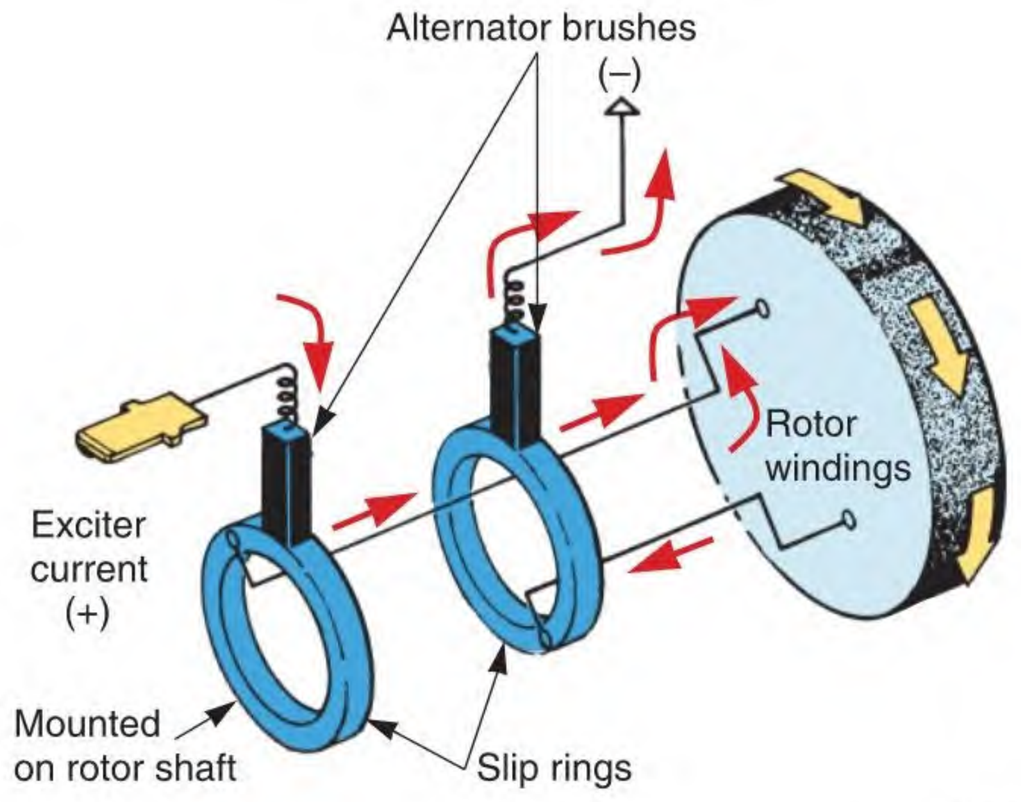
Alternator bearings (needle or ball types) are commonly used to produce a low-friction surface for the rotor shaft. These bearings support the rotor shaft as it spins inside the stator and alternator housing.

The alternator bearings are normally packed with grease. The front bearing is frequently held in place with a small plate and screws. The rear bearing is usually press-fit into place. The average service life of alternator bearings is about 10 years or 100,000 miles (160,934 km).

Slip Rings and Brushes

Alternator slip rings are mounted on the rotor shaft to provide dc current to the rotor's field windings. Each end of the field windings connects to one of the slip rings. Battery voltage is needed to excite the field windings, producing a magnetic field. See **Figure 32-8**.

Alternator brushes ride on the slip rings to make a sliding electrical connection. The brushes feed battery current into the slip rings and field windings. Small ***brush springs*** hold the brushes in contact with the slip



Motorola

Figure 32-8. Brushes and slip rings allow current to be fed into rotor windings. This excites windings to produce a rotating magnetic field.

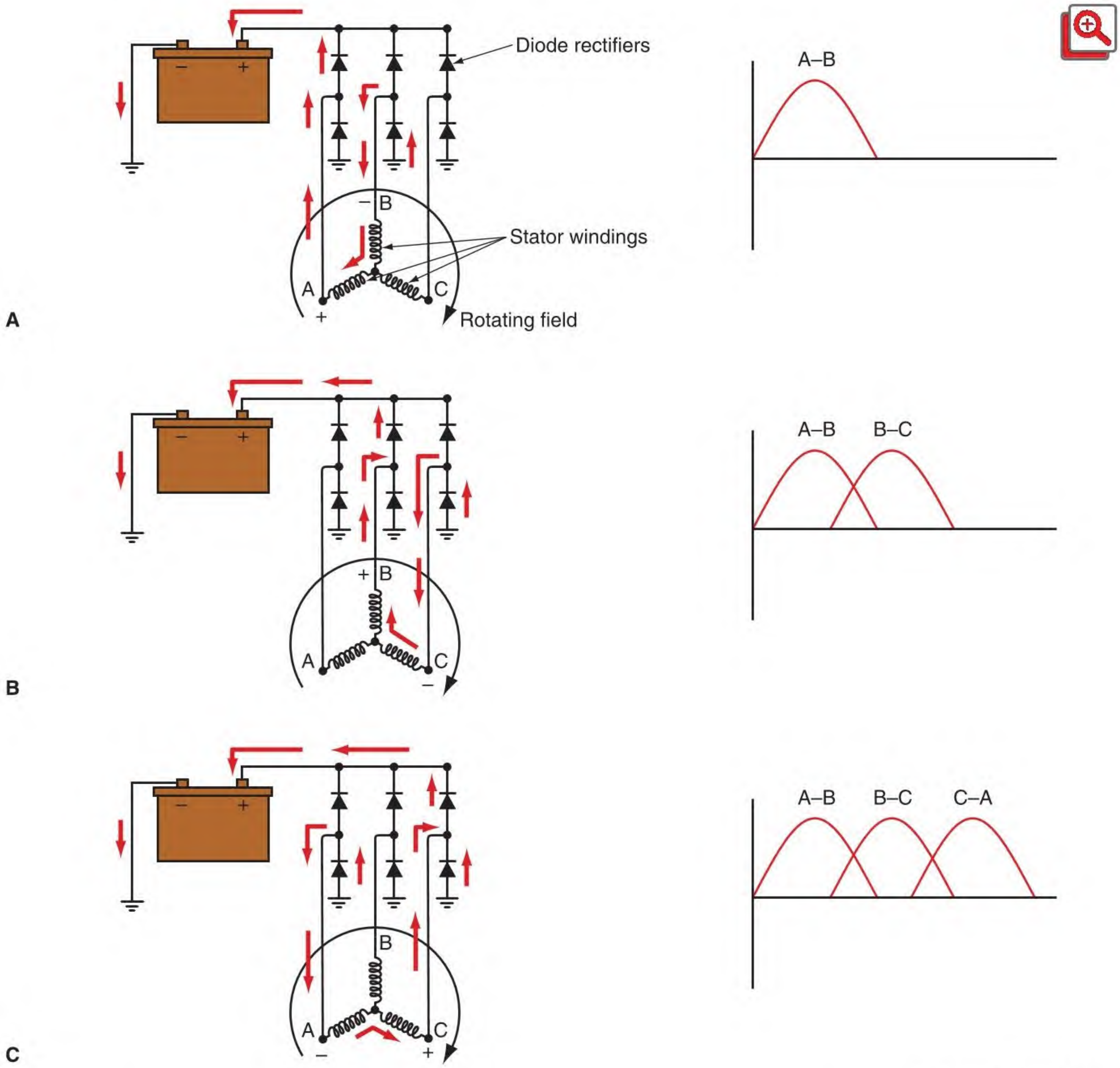
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rings. Current flow into the field windings is low. Therefore, the brushes are small compared to motor brushes.

Alternator Rectifier

An ***alternator rectifier***, also called a ***diode assembly***, commonly uses six diodes to convert stator current (alternating current) to direct current. The diodes are usually wired as shown in **Figure 32-9**. The rectifier provides ***full-wave rectification*** (changes both positive and negative polarities into direct current) as the north and south poles of the rotor claws pass the stator windings.

A ***diode trio*** may be used to supply current to the rotor field windings. In a diode trio, three diodes are



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Figure 32-9. These diodes convert ac into dc. As the rotor turns, only two stator windings and two diodes are active at a time. A—Winding A and B are active and form a series circuit. Current flows from winding A, through one diode, and to the positive post of the battery. It returns through one diode to winding B. B—Current flows from winding B, through one diode, and to the positive post of the battery. It returns through one diode to winding C. C—Current flows from winding C, through one diode, and to the positive post of the battery. It returns through one diode to winding A.

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connected to the field windings through a connection in the voltage regulator. The stator output feeds the diode trio.

The ***rectifier diodes*** are mounted in a ***diode frame*** or ***heat sink*** (metal mount for removing excess heat from electronic parts). Three positive diodes are press-fit in an insulated frame, and three negative diodes are mounted in an uninsulated or grounded frame. A stator with an attached rectifier is shown in **Figure 32-10**.

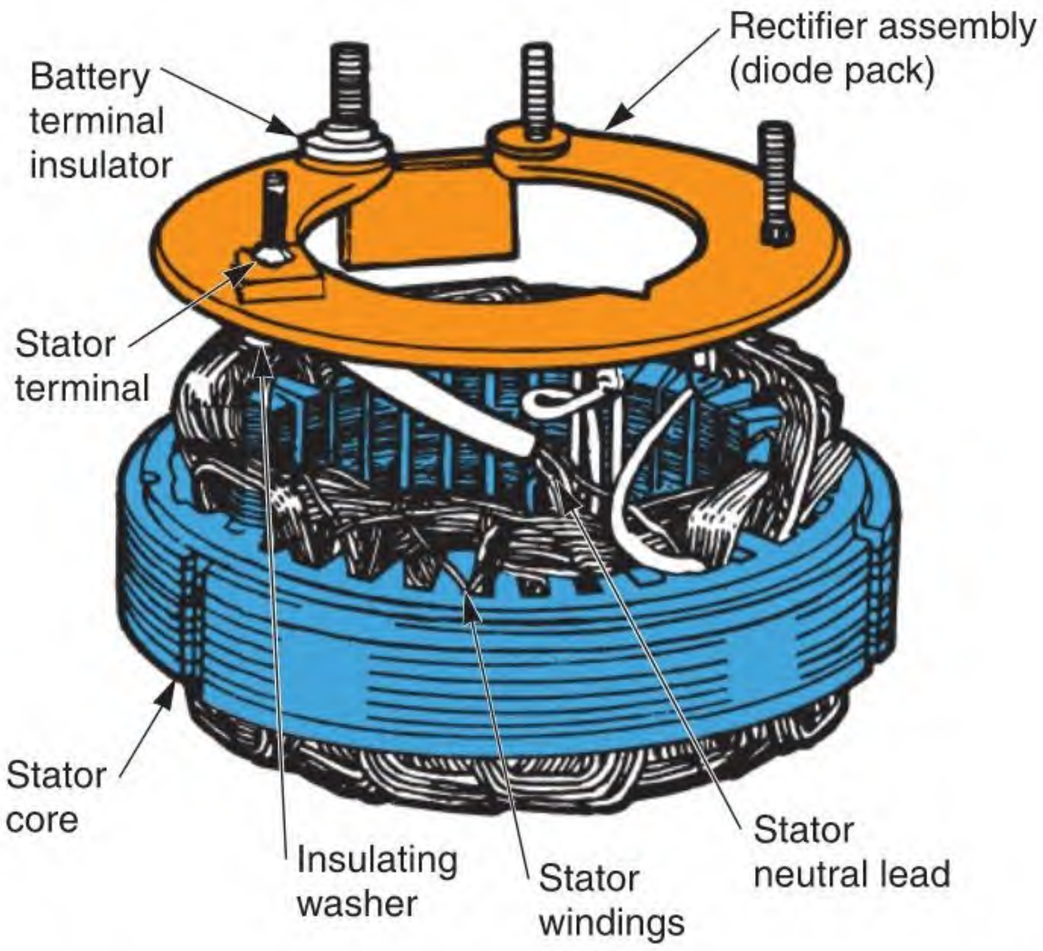
Alternator Stator

The ***alternator stator*** consists of three sets of windings. Each set is wrapped around a laminated iron core. The iron core is used to concentrate and strengthen the field around the stator windings. The stator produces the electrical output of the alternator. The stator windings connect to the rectifier.

Alternator Fan

To provide forced-air cooling for the alternator, an ***alternator fan*** is mounted on the front of the rotor shaft. Normally, the fan is located between the pulley and the front bearing. Look at **Figure 32-11**.

As the rotor and shaft spin, the whirling alternator fan helps draw air through and over the alternator. This cools the windings and diodes to prevent overheating and damage.

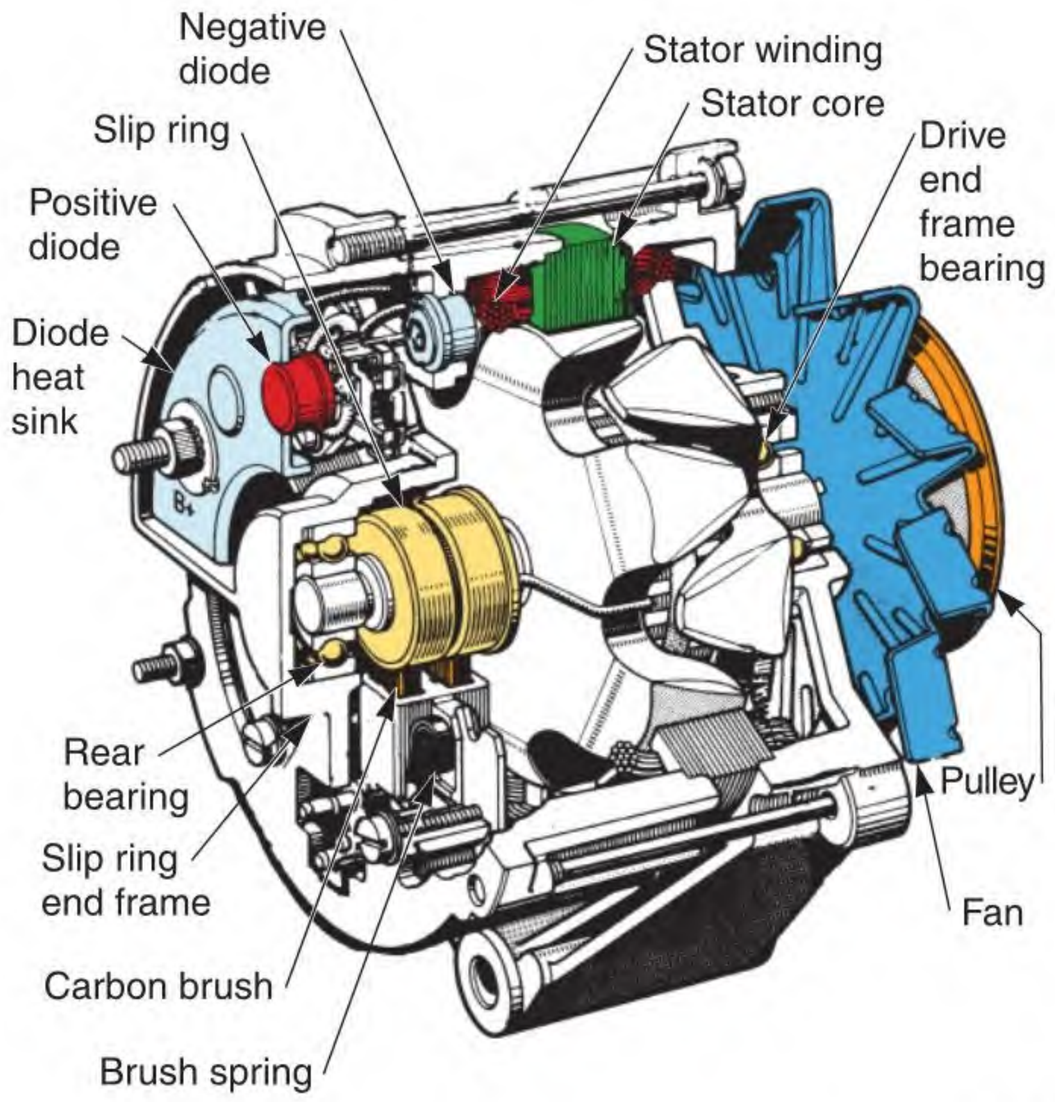


Ford

Figure 32-10. The rectifier assembly consists of six diodes in heat sink. Wires from the stator windings connect to the rectifier. An iron core around the stator windings increases induction.

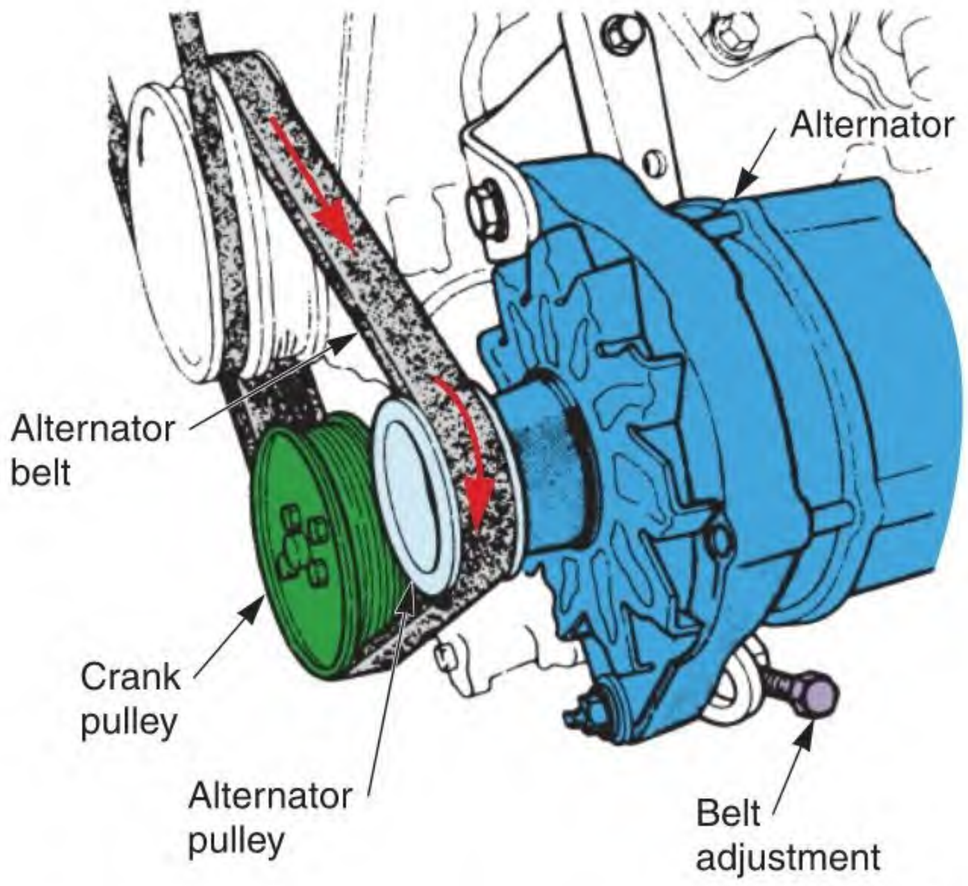
Alternator Pulley and Belt

An ***alternator pulley*** provides a means of spinning the rotor through the use of a belt. The pulley is secured to the front of the rotor shaft by a large nut. See **Figure 32-12**.



Bosch

Figure 32-11. This cutaway view shows many of the parts already discussed. Note the construction.



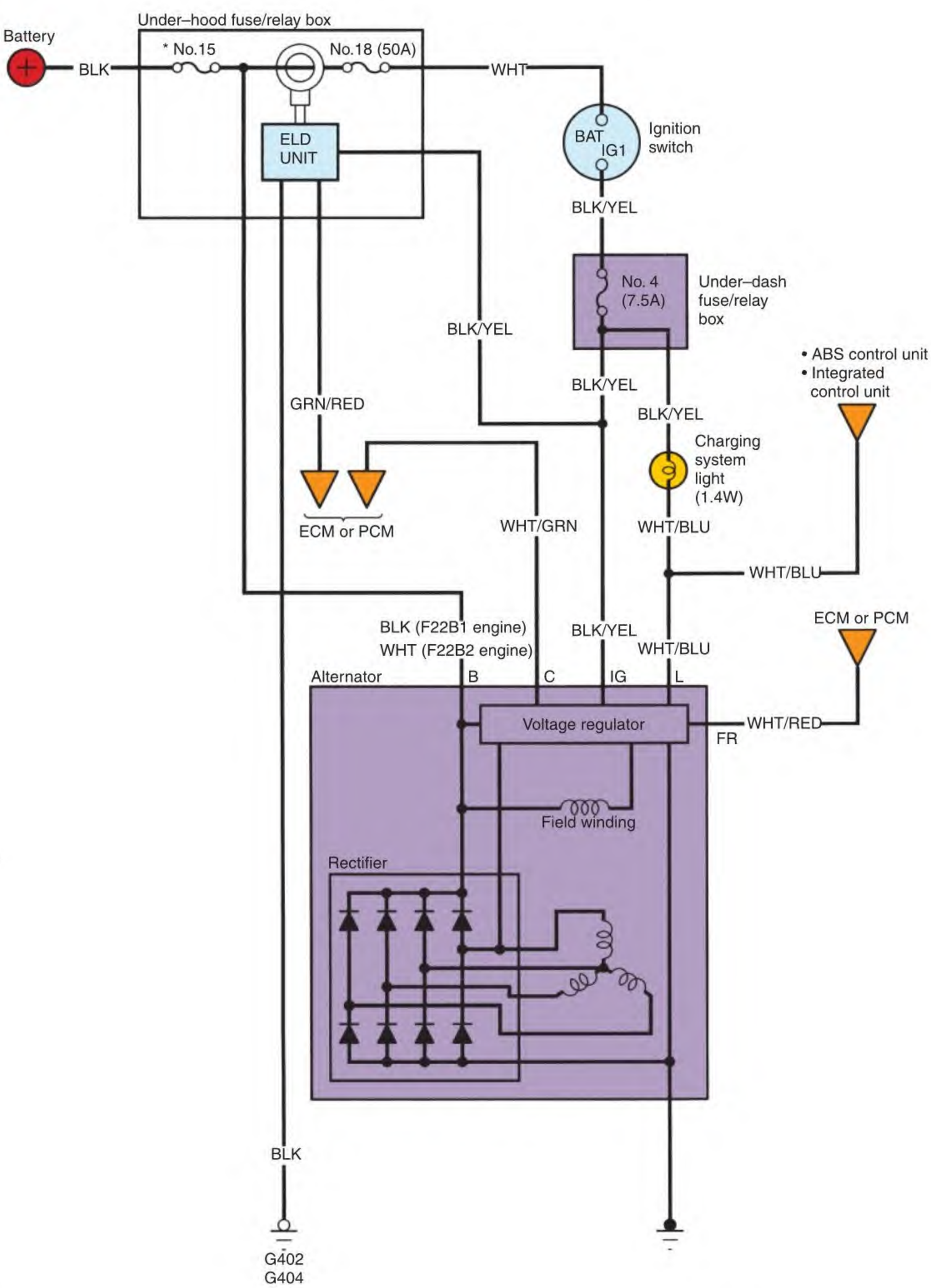
Sun Electric

Figure 32-12. The crankshaft pulley turns the alternator belt. The belt powers the alternator. This is a ribbed belt.

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Voltage Regulator

A voltage regulator uses an electronic circuit to control alternator output by changing the amount of current flowing through the rotor's field windings. Any change in field winding current changes the field strength acting on the stator (output) windings. In this way, the voltage regulator can maintain a preset charging voltage of 13–15 volts. See **Figure 32-13**. The regulator can be mounted inside or on the back of the alternator.



Honda

Figure 32-13. Charging system schematic diagram. The voltage regulator is an unserviceable miniature electronic circuit. Note other connections.

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An electronic voltage regulator is a sealed unit and cannot be repaired. The electronic circuit must be sealed because it can be damaged by moisture, excessive heat, and vibration. Usually the circuit is surrounded by a rubber-like gel for protection.

An ***integral voltage regulator*** is mounted inside or on the rear of the alternator. It is the most common type used on today's vehicles. The integral regulator is small, efficient, and dependable. In many cases, the engine control module serves as the voltage regulator.

Voltage Regulator Operation

To increase alternator output, the voltage regulator allows more current into the rotor's field windings. This strengthens the magnetic field around the rotor. More current is then induced in the stator windings, increasing alternator output.

To reduce alternator output, the voltage regulator places more resistance between the battery and the field windings. Magnetic field strength drops and less current is induced in the stator windings.

Alternator speed and electrical load determine whether the regulator increases or decreases charging output. If the load is high or the rotor speed is low (engine idling), the regulator will sense a drop in system voltage. The regulator then increases field winding current until a preset output voltage is obtained. If the load drops or rotor speed increases, the opposite occurs.

ECM Charging System Monitoring and Control

The engine control module or the power train control module is sometimes used to supplement or replace the conventional voltage regulator to more precisely control the charging circuit.

The control module can monitor charging system output and react to changing operating conditions. For example, the module can shut the alternator off at wide-open throttle for better vehicle acceleration, saving several horsepower. It can more accurately control charge rate, allowing the use of a smaller, lighter battery. The module can also monitor system operation to simplify diagnosis and repair by producing trouble codes and problem descriptions.

Basically, the computer controls the duty cycle of the alternator's field. The ***duty cycle*** is the percentage of time that current is fed to the alternator's field windings. A duty cycle of 50% is normal. With a large electrical load, the duty cycle would be high (long) to make the alternator produce high output. At low engine and alternator speeds with a high load, the regulator may use a 90% duty cycle (on time) to produce an output to meet the high load.

Modern electronic voltage regulators, either integral or in-computer types, can also progressively switch on charging voltage. If the full load of the alternator were to come on instantly, it could lug the idling engine down. Voltage regulator switching is very fast (about 400 cycles per second) to help prevent radio noise.

Battery Thermistor

In some systems, a ***battery thermistor*** is used to measure battery temperature so the charging system can alter charging output as needed. Generally, a cold battery requires more voltage for recharging than a hot battery. The battery thermistor is often mounted on the positive battery cable. It rests against the battery so it can measure battery temperature.

Fail-Safe Circuit

Some late-model charging systems have ***fail-safe circuits***, which disconnect alternator output if voltage levels become too high. This protects all the on-board electronics from being damaged by high voltage. The fail-safe circuit is designed into the voltage regulator. If the alternator stops working for no apparent reason, suspect this circuit, which is located in the electronic voltage regulator chip.

Alternator Drive Belt

An ***alternator drive belt***, powered by the crankshaft pulley, turns the alternator pulley and rotor. One of three belt types may be used: V-belt, cogged V-belt, or ribbed belt. These are pictured in **Figure 32-14**.

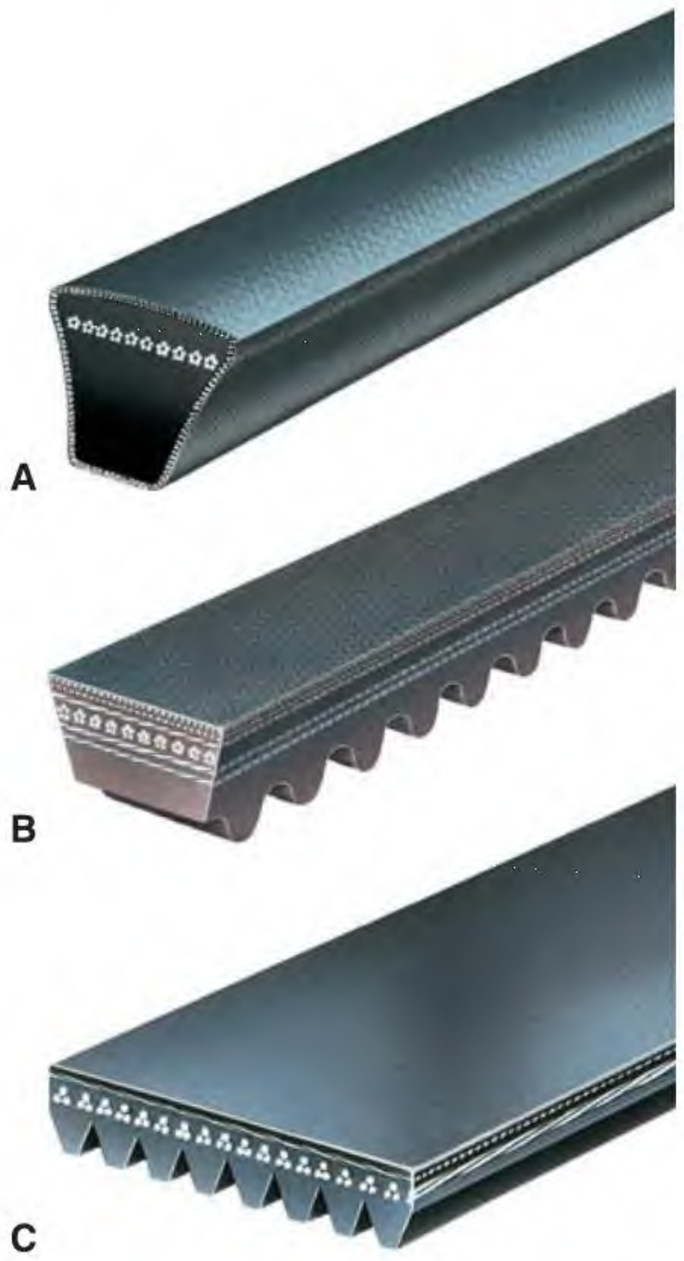
Covered in other chapters, these types of belts are also used to drive the power steering pump, air conditioning compressor, water pump, and other units.

Charge Indicators

A charge indicator informs the driver of the operating condition or output of the charging system. There are three basic types of charge indicators:

- ***Warning light***—A warning light glows if alternator output is below a specified level.
- ***Voltmeter indicator***—The voltmeter measures voltage output of alternator.

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Gates

Figure 32-14. There are three types of belts. A—Conventional V-belt. B—Cogged V-belt. C—Ribbed belt.

- ***Ammeter indicator***—The ammeter measures current flow to and from the battery.

These indicators are mounted in the dash or instrument cluster of the car. Normally, all cars have at least a charge indicator light that signals a failed charging system.

Alternator Warning Light

An ***alternator warning light*** is wired into the charging system so that it will glow when alternator output drops to a specified level. **Figure 32-15** shows one circuit using an alternator warning light.

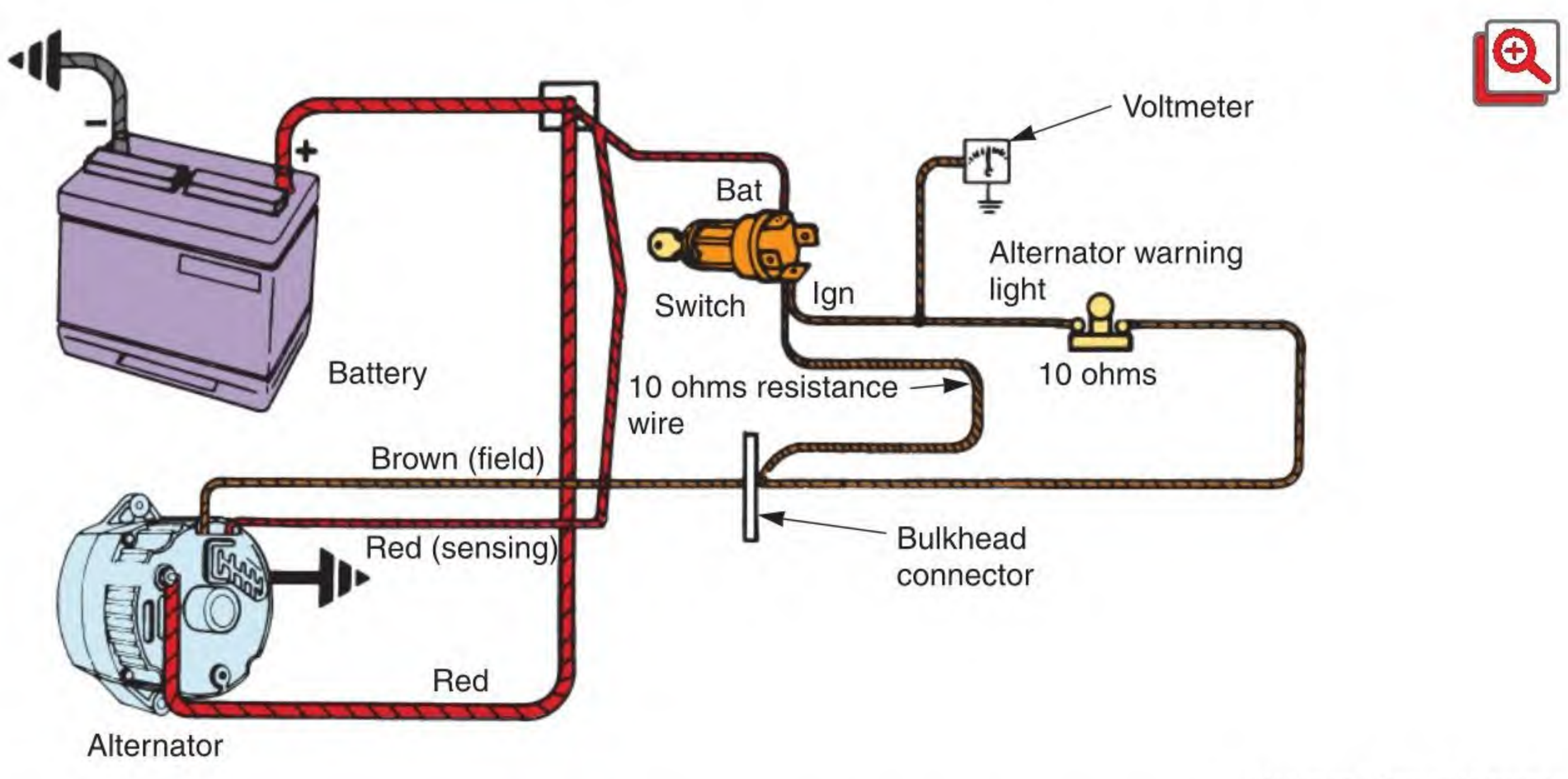
If problems develop in the charging system, the field current, trying to increase alternator output, will increase enough to light the indicator bulb. If the charging system is in good operating condition, current flow through the field will be too low to light the bulb.

Voltmeter Indicator

A voltmeter indicator can also be used to warn the driver of charging system problems. The voltmeter reads the system voltage when the engine is running.

A battery has 12.6 volts when fully charged. To recharge the battery, alternator output must be higher than the battery voltage. Alternator output is normally 13–15 volts.

The voltmeter indicator simply shows voltage, which is an indicator of current output and charging system condition. If the voltmeter reading drops to battery voltage or below, the charging system has problems. If the voltmeter reading is too high, overcharging can occur. ***Overcharging*** results when excess current



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Figure 32-15. The charging circuit shows connections for an alternator warning lamp and voltmeter.

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is forced through the battery. Battery overheating damage can result after extended overcharging. This problem is often due to a faulty voltage regulator.

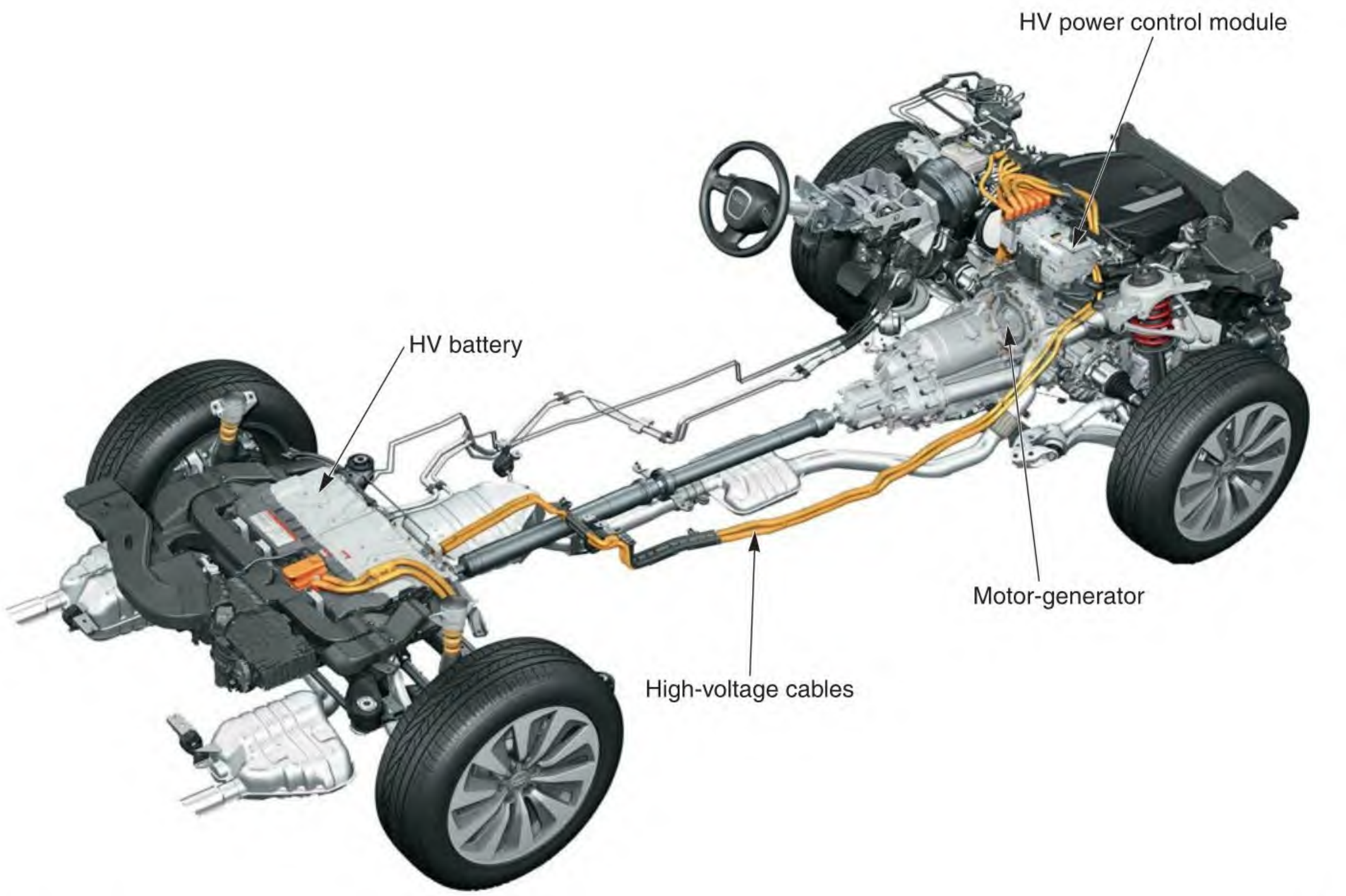
Hybrid Charging Systems

Many hybrid vehicles do not have a conventional alternator. Instead, these vehicles use the motor-generator to recharge a high-voltage battery and, sometimes, a conventional 12-volt battery.

The major parts of a hybrid charging system, **Figure 32-16**, include:

- Motor-generator—A motor-generator uses braking energy or engine power to produce electricity.
- Hybrid instrumentation—This instrument panel display shows the battery state of charge, power regeneration, power remaining, etc.
- HV power control module—The HV power control module converts high-voltage ac to 12 volts dc, and controls ac charging current from the motor-generator.
- HV battery—The HV battery provides huge amounts of stored electrical energy for engine starting and propulsion.
- Hybrid control module—The hybrid control module coordinates information flow from the HV power control module and other computers to control the hybrid charging systems.

When a hybrid vehicle has been driven its maximum range on electric power alone, it will start the internal combustion engine to partially recharge the battery, propel the car, and operate conventional 12-volt circuits. The hybrid control module will signal the HV power control module to harness the energy from the engine-powered motor-generator and route it to the HV battery. The HV power control module rectifies the alternating current coming out of the motor-generator and outputs smooth dc through the orange power cables to the HV battery. Today's HV power control modules also step down and rectify the high-voltage ac.



Audi

Figure 32-16. Hybrid charging system components.

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In the Rearview Mirror

Until the late 1960s, motor cars used large mechanical contact-point voltage regulators to control alternator voltage and current output. These large sheet-metal-encased components used a coil, a set of relatively large contact points, and resistors to control generator or alternator output. This type of regulator has long been replaced by electronic units. Back then, if the system was not charging, you could often tap on the side of the voltage regulator to free the points and get the system charging again.

Summary

- The major parts of a 12-volt charging system include: an alternator, voltage regulator, drive belt, charge indicator, charging system harness, battery, and ECM.
- The battery provides current to initially energize and smooth dc current output from the alternator.
- An alternator is an ac generator that uses mechanical (engine) power to produce electricity.
- The alternator rotor assembly is located in the center of the alternator housing, and creates a rotating magnetic field.
- The alternator stator is a stationary set of windings that surrounds the rotor that carries the current generated.
- The voltage regulator keeps alternator output at a preset charging voltage (13–15 volts). An ECM is sometimes used to supplement or replace the conventional voltage regulator to more precisely control the charging circuit.
- A charge indicator can be an ammeter, voltmeter, or warning light. Indicators inform the driver of the operating condition or output of the charging system.
- The major parts of a hybrid charging system include a motor-generator, hybrid instrumentation, HV power control module, HV battery, and hybrid control module.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

ac generator
alternator
alternator bearings
alternator brushes
alternator drive belt
alternator fan
alternator pulley
alternator rectifier
alternator rotor assembly
alternator slip rings
alternator stator
alternator warning light
ammeter indicator
battery
battery thermistor
brush springs
charge indicator
charging system
charging system harness
charging voltage
diode assembly
diode frame
diode trio
drive belt
duty cycle
ECM
fail-safe circuits
forward-biased diode
full-wave rectification
heat sink
integral voltage regulator
overcharging
rectifier diodes
reverse-biased diode
voltage regulator
voltmeter indicator
warning light

Activities

1. Vehicles from different manufacturers use various belt arrangements to drive the alternator. Identify at least three different belt arrangements and sketch them. Label each sketch with vehicle make and engine type.
2. A diode is sometimes called “an electrical check valve.” Make sketches to show why it received that name.

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Review Questions

Answer the following questions using the information provided in this chapter.

1. What are four of the functions of a 12-volt charging system?
2. List and explain the seven major parts of a 12-volt charging system.
3. The alternator is a device for changing mechanical energy into _____ energy.
4. Explain the function of alternator's rotor and stator.
5. What is a *diode*?
6. What are *forward-biased diodes* and *reverse-biased diodes*?
7. List and describe the seven main components of an alternator.
8. An alternator _____ consists of field windings mounted on a shaft.
9. Alternator brushes ride on _____ to feed current to the field windings.
10. The alternator _____ changes alternating current into direct current.
    (A) transistor
    (B) rectifier
    (C) stator
    (D) regulator
11. An alternator _____ consists of three groups of windings and produces the electrical output of the alternator.
12. A voltage regulator controls alternator output by changing the amount of current flowing through the _____.
13. The voltage regulator keeps alternator output at a preset charging voltage of approximately _____ to _____ volts.
14. A(n) _____ voltage regulator is an electronic unit mounted inside or on rear of alternator.
15. Alternator _____ and electrical _____ determine whether the regulator increases or decreases charging output.
16. A(n) _____ may be used to measure battery temperature so the charging system can alter charging output as needed.
17. List and describe two types of charge indicators.
18. Name the major parts of a hybrid charging system.

ASE-Type Questions

1. Technician A believes that once an engine starts running, the engine crankshaft pulley powers the alternator to supply electricity to a car's electrical systems. Technician B feels a battery is a car's sole electrical supplier. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
2. Charging system voltage is approximately:
    (A) 12.6 volts.
    (B) 13–15 volts.
    (C) 16–19 volts.
    (D) 20–25 volts.
3. Which of the following is *not* a component of a typical 12-volt charging system?
    (A) Voltage regulator.
    (B) Drive belt.
    (C) Battery.
    (D) Ignition switch.
4. The component that is turned by the alternator drive belt and creates a rotating magnetic field is the:
    (A) rotor.
    (B) stator.
    (C) rectifier.
    (D) diode trio.
5. Alternator design is being discussed. Technician A says the stator is a stationary set of windings that is surrounded by the rotor. Technician B says the stator is the output winding in the alternator. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
6. To reduce alternator output, the voltage regulator places more resistance between the:
    (A) battery and the field windings.
    (B) rotor and the stator.
    (C) alternator pulley and the stator.
    (D) alternator brushes and slip rings.
7. Which of the following is *not* a type of alternator belt?
    (A) V.
    (B) Ribbed.
    (C) Cogged V.
    (D) Integrated.

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8. When fully charged, an automotive battery has:
   (A) 12.6 volts.
   (B) 13–15 volts.
   (C) 16–19 volts.
   (D) 20–25 volts.
9. Which of the following components do hybrid vehicles use to recharge the HV battery?
   (A) HV power control module.
   (B) Motor-generator.
   (C) Alternator.
   (D) Battery thermistor.
10. Which of the following components steps down and rectifies the high-voltage ac used in hybrid charging systems?
   (A) HV power control module.
   (B) Hybrid control module.
   (C) Motor-generator.
   (D) Voltmeter.

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Chapter 33
Charging System Diagnosis, Testing, and Repair

After studying this chapter, you will be able to:

- Inspect a 12-volt and high-voltage (HV) charging system to locate obvious troubles.
- Diagnose 12-volt charging system troubles.
- Test 12-volt charging system with a voltmeter, load tester, and scope.
- Remove and reinstall an alternator.
- Diagnose high voltage hybrid charging system problems.
- Correctly answer ASE certification test questions on charging system service.

This chapter begins by summarizing the types of troubles that occur in 12-volt charging systems. You will learn how to perform fundamental tests that help locate problems. Then, the chapter covers parts removal, disassembly, repair, and reassembly. This should give you a sound background in the most common types of charging system service and repair jobs.

In addition to being able to service conventional 12-volt charging systems, you should know how to troubleshoot and repair the charging systems found in hybrid vehicles. Remember, the hybrid's HV charging system uses voltage produced by the motor-generator to recharge the HV battery, and steps down HV battery voltage to 12 volts dc for use in conventional circuits. Refer to **Figure 33-1**.

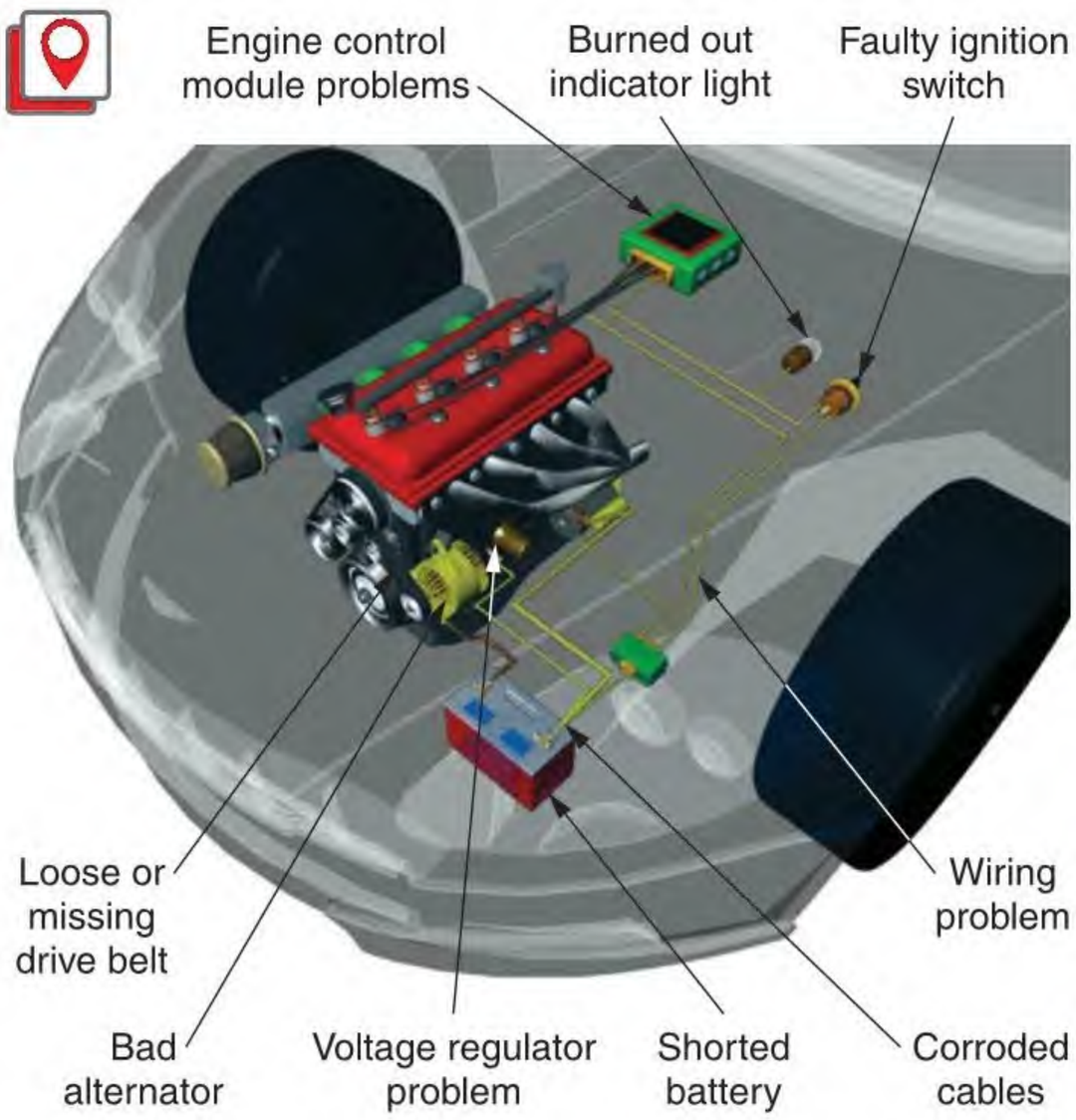
12-Volt Charging System Diagnosis

Although a 12-volt charging system has only two major parts (alternator and regulator), troubleshooting can be difficult. Sometimes, another system's fault (bad starting motor, defective battery, computer failure, or faulty wiring) will appear to be caused by problems in the charging system.

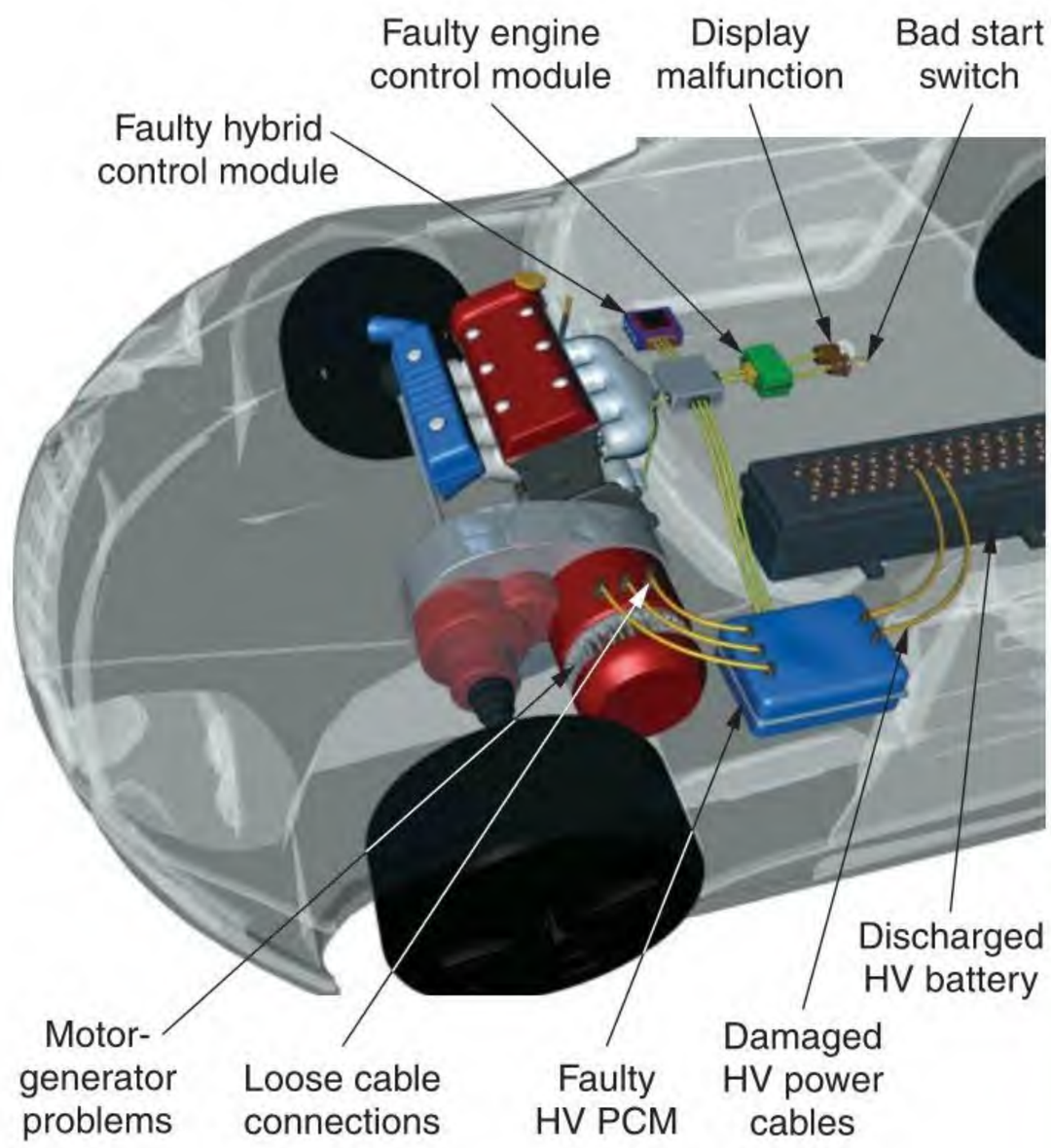
There are four common symptoms of charging system problems:

- Dead battery—A dead battery will crank the engine slowly or it will not crank the engine at all.
- Overcharged battery—An overcharged battery is rare, but occurs when the battery has a low electrolyte level or gets too hot from current flow back through the battery.
- Abnormal noises—Abnormal noises include dry alternator bearing noise, belt squealing, and solenoid buzzing when trying to start the engine with a discharged battery.

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12-Volt Charging System Problems



Hybrid Charging System Problems

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Figure 33-1. Note common problems in 12-volt and HV charging systems. Some of these could be found during your initial visual inspection and test drive.

- Indicator shows problem—An indicator will glow or otherwise signal a problem when there is an incorrect charge voltage reading.

Verify these problems by starting or trying to start the engine. It is possible that the symptoms have been misinterpreted by the service writer or customer. For example, a problem described as a no-charge condition may really be a shorted starting motor, parasitic battery drain, bad battery, or other trouble.

Warning

Some late-model cars are equipped with a heated windshield. When the windshield is being heated, the alternator produces 110 volts ac. This is enough voltage to cause electrocution. Keep this in mind when working on this type system.

Preliminary Inspection

A preliminary inspection of the components and connections will help determine the source of the charging system problem.

Service Procedure

To perform a preliminary inspection of the charging system:

1. Open the hood and visually inspect the parts of the 12-volt charging system.
2. Check for battery-related problems, such as loose battery cables, a discharged battery, corroded terminals, a low water level, or a damaged battery case.
3. Make sure the belt tension is adjusted to specifications. A loose alternator drive belt may squeal or flap and prevent normal charging.
4. Check the condition of the alternator drive belt. Look for cracks, glazing (hard, shiny surface), grease or oil contamination, and deterioration, **Figure 33-2**.
5. Check for loose or corroded electrical connections, shorted wires (missing insulation), and other wiring problems. In particular, check the electrical connections on the back of the alternator.

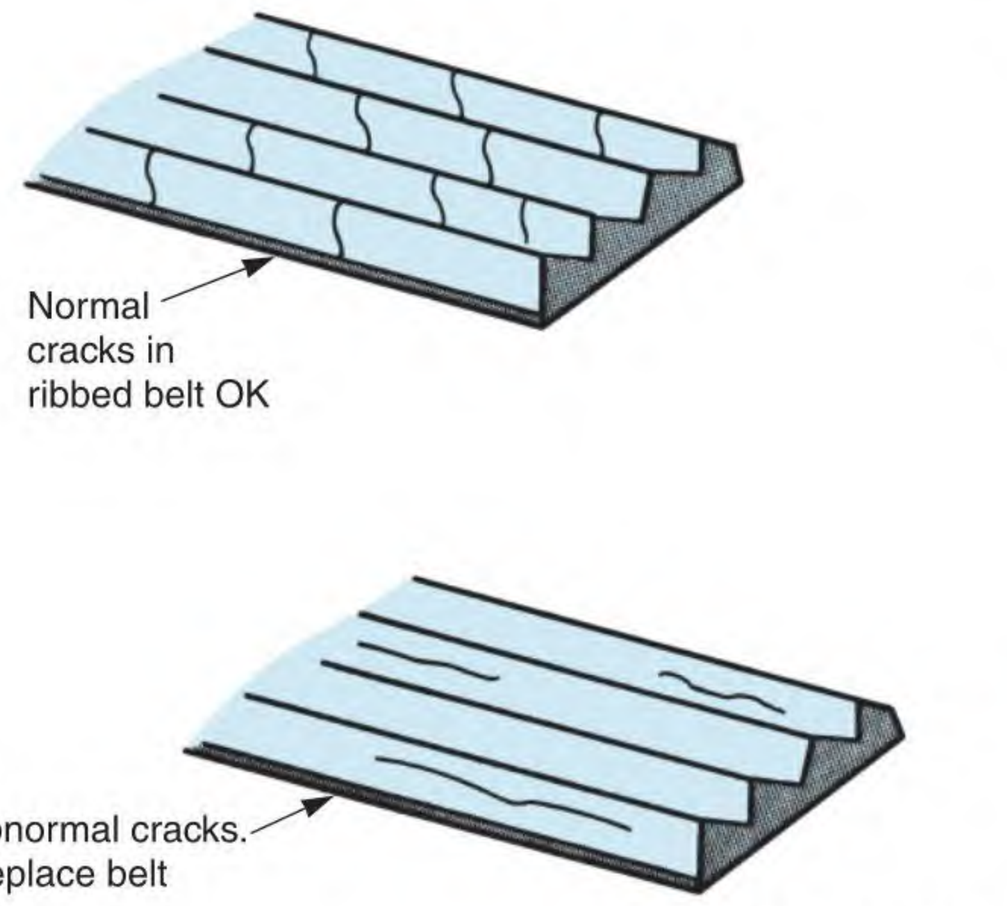
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6. Wiggle the wiring harness from the alternator to the firewall or ECM while the engine is running. If the indicator light goes out or the indicator gauge begins to read properly when a wire is moved, the problem is in that area of the wiring.

Tech Tip

Connect a voltmeter across the battery terminals while wiggling charging system wires. If the meter fluctuates to a higher voltage when a wire is wiggled, you have found the bad electrical connection.

7. With the engine running, listen closely for abnormal noises in the alternator. If necessary, use a stethoscope to listen for dry, noisy alternator bearings. Try to detect internal grinding (worn, dry bearings), whining (leaking diodes or overcharging), or any other unusual sounds.



Snap-on Tool Corp.

Figure 33-2. Inspect belts closely for wear, deterioration, and damage. Replace belt, if needed.

Scanning 12-Volt Charging Systems

On most vehicles with self-diagnostic systems, you can connect a scan tool to the vehicle to aid in troubleshooting. The scan tool will display charging voltage, battery temperature, and other data useful in finding problems. Capabilities vary with each model; refer to the service manual or scanner instructions for details.

12-Volt Charging System Precautions

Observe the following rules when working on a charging system. These precautions will help prevent possible damage to electrical/electronic systems.

- Disconnect the battery before removing any charging system component. If a ***hot wire*** (current-carrying wire) touches a ground, parts could be ruined.
- Disconnect the battery before connecting it to a battery charger. A voltage surge or high voltage can damage electronic components in the alternator, regulator, and other computerized systems.
- Never reverse polarity. If the battery or jumper cables are connected backwards, serious electrical damage can occur. Reversing polarity can damage the diodes in the alternator, ruin regulator circuitry, and burn electronic components in other computer systems.
- Do not operate the alternator with the output wire disconnected. If the alternator is operated with the output wire disconnected, alternator voltage can increase above normal levels. Alternator or charging circuit damage could result.
- Never short or ground any charging system terminal unless instructed to do so by a shop manual. Some circuits can be grounded or shorted without damage; others will be seriously damaged. Refer to a service manual when in doubt.

12-Volt Charging System Tests

Charging system tests should be done when symptoms point to low alternator voltage and current. These tests will quickly determine the operating condition of the charging system. There are several common charging system tests, including the following:

- Scan tool test—This test allows charging system voltage values to be viewed using the scan tool's datastream capabilities.
- Load test—This test involves using a load tester to check the current and voltage output of the charging system.

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- Scope tests—These tests involve using a scope to analyze voltage waveforms produced by the charging system.
- Voltmeter test—This test is used to quickly check the general output of a charging system.
- Circuit resistance tests—These tests measure resistance in insulated and ground circuits of the system.

Scan Tool Test

With modern OBDII vehicles, you can access alternator charging voltage values with your scan tool or diagnostic tablet. Start and idle the engine. Turn on all electrical accessories (headlights, AC, stereo, interior lights) to load the alternator. Use the scan tool menu to access datastream values and scroll to the alternator or charging system live voltage readings. With all accessories on, an alternator output of at least 13 volts indicates normal operation. If the output reading drops to 12.6 volts or less, the alternator is bad and is not producing enough current to keep the battery charged.

Tech Tip

Most modern laptop computers and diagnostic tablets have a scope function. The scope function will convert datastream voltage readings into live scope waveforms for advanced troubleshooting. Remember that smooth DC is required for the proper operation of ECMs and their sensor circuits.

Load Test

A ***load tester*** provides the most accurate method of checking a charging system. See **Figure 33-3**. It will measure both system current and voltage while applying a load to the system.

Before testing the charging system, it is common practice to check the condition of the battery. Although charging system problems often show up as a dead battery, you must not forget that the battery itself may be bad. Measure the battery's state-of-charge and perform a battery load test. This will ensure that the battery is not affecting your charging system tests.

A ***charging system load test*** measures alternator/regulator current and voltage output under its maximum load.



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Figure 33-3. Modern, digital load testers may or may not have an inductive, clip-on current clamp.

Service Procedure

To check charging system output with a load tester:

1. Connect the tester leads, as described by the manufacturer. With modern testers, fasten the two large alligator clips to the battery terminals (red to positive, black to negative). With some loader testers, you must clip an inductive (clip-on) amps pickup around the insulation on the negative battery cable.

Tech Tip

Procedures differ with each tester design. Check the tester's operating instructions when in doubt.

2. Set the load tester controls to their proper positions and values.
3. Attach a vent hose to the exhaust and start the engine.
4. Set the load control on the tester until the ammeter displays the alternator's rated amperage. Do not exceed the alternator's output rating in amps. Do not let the voltage drop below the full battery voltage of 12.6 volts. (You do not want to load the battery, just

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the alternator. At 12.6 volts, current flow into and out of the battery will be minimal.)
5. Note the alternator output current (amps) at 12.6 volts.
6. Turn off the load control and evaluate your readings.

Compare the test amps reading to the alternator's output specifications. If alternator output current is low, suspect a bad alternator/regulator assembly.

Alternator output current specifications for charging systems depend on the size (maximum amp rating) of the alternator.

Tech Tip

Alternator current specifications are sometimes stamped on the alternator housing. If not, look up the alternator specifications in the service manual.

Scope Tests

A charging system ***scope test*** involves analyzing the alternator voltage waveform for signs of abnormal ripple, interference, and "dirty dc." Abnormal voltage ripple is an indication of bad alternator diodes.

Service Procedure

To scope a 12-volt alternator charging system:
1. Connect the red scope test lead to the alternator battery (output) terminal.
2. Ground the other scope lead.
3. Start the engine and observe the scope trace (waveform). The charging system should produce a relatively smooth dc voltage trace with minimum ripple. Look at **Figure 33-4**.

Voltmeter Test

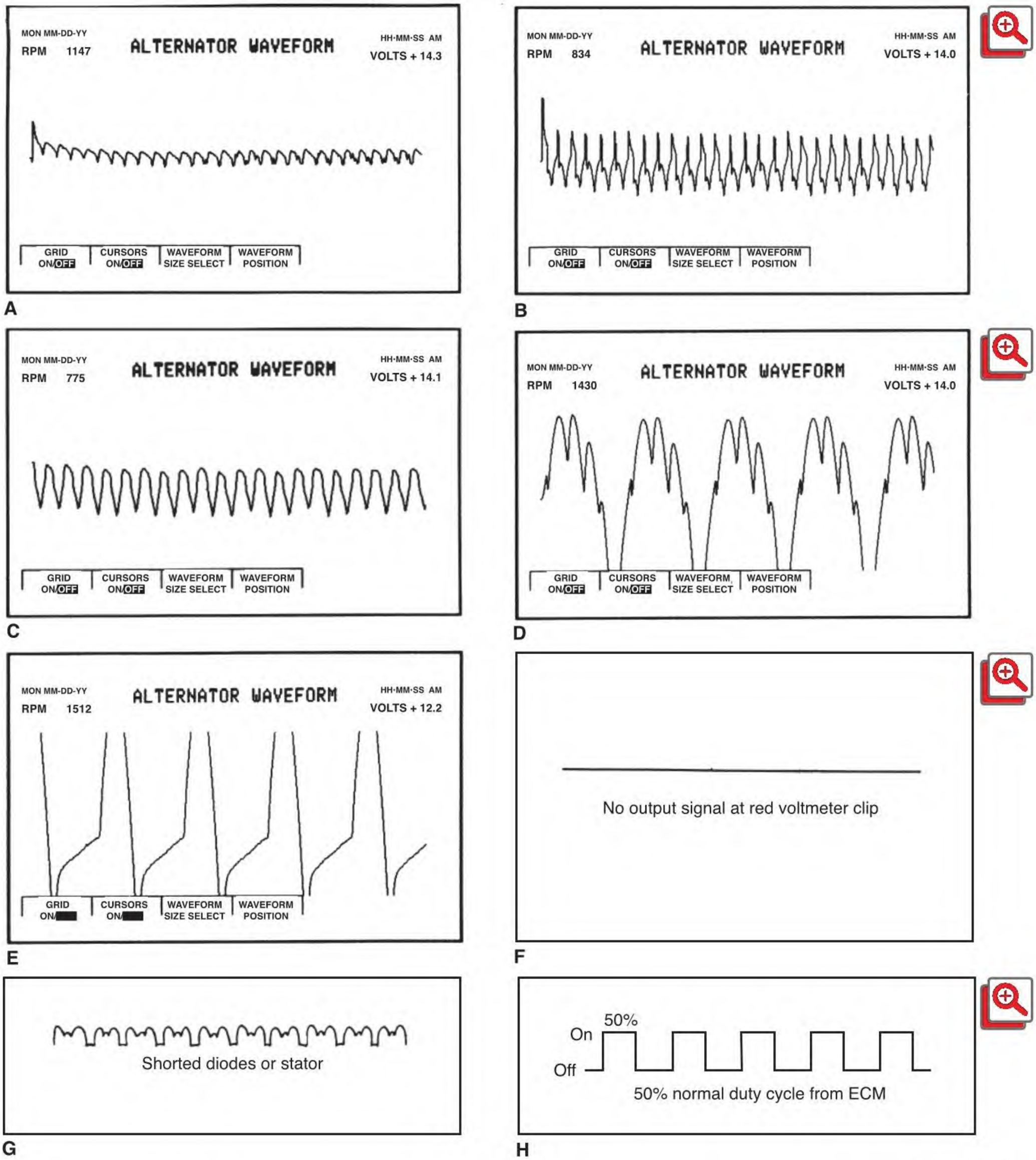
A voltmeter can also be used to quickly test the general output of a charging system. It will measure charging system voltage with a vehicle accessory load (all electrical accessories *on*). The voltage reading will be a good indicator of system condition. If charging system output voltage is not above battery voltage, the battery is not being recharged and a problem exists. Typical charging system voltmeter tests are shown in **Figure 33-5**.

Service Procedure

To use a common voltmeter to test a charging system:
1. Charge the battery, if it was drained before testing.
2. Set the voltmeter to read low voltage.
3. Connect the voltmeter test leads across the battery terminals.
4. Measure and record battery ***base voltage*** (battery voltage with everything off). This reading will compensate for any variation in the condition of the battery and accuracy of your meter. With a good, fully-charged battery, the base voltage reading should be around 12.6 volts. Look at **Figure 33-6**.
5. Start the engine and record the ***no-load voltage***. The no-load voltage is the battery voltage with the engine running and the electrical accessories off. The voltmeter reading should increase from the base reading, but not by more than 2–3 volts. For example, if your base voltage is 12.5 volts, your no-load voltage reading should be 13–14.5 volts. If the no-load voltage is more than 2–3 volts higher than base voltage, the alternator is overcharging the battery. Either the voltage regulator, ECM, or wiring is bad.
6. Turn on all electrical accessories (air conditioning, blower, stereo, headlights, etc.) to load the charging system, and record the load voltage. The ***load voltage*** test shows if the charging system is providing current for all the electrical units and still has enough current to recharge the battery.
7. Calculate ***charge voltage*** using the formula: Load voltage – base voltage = charge voltage. So, 14.5 volts – 12.6 base volts = 1.9 volts dc.

Charge voltage should be at least 0.5 volts with the engine at warm idle. The load voltage must be higher than the base voltage for battery charging. No-load voltage must be within specifications.

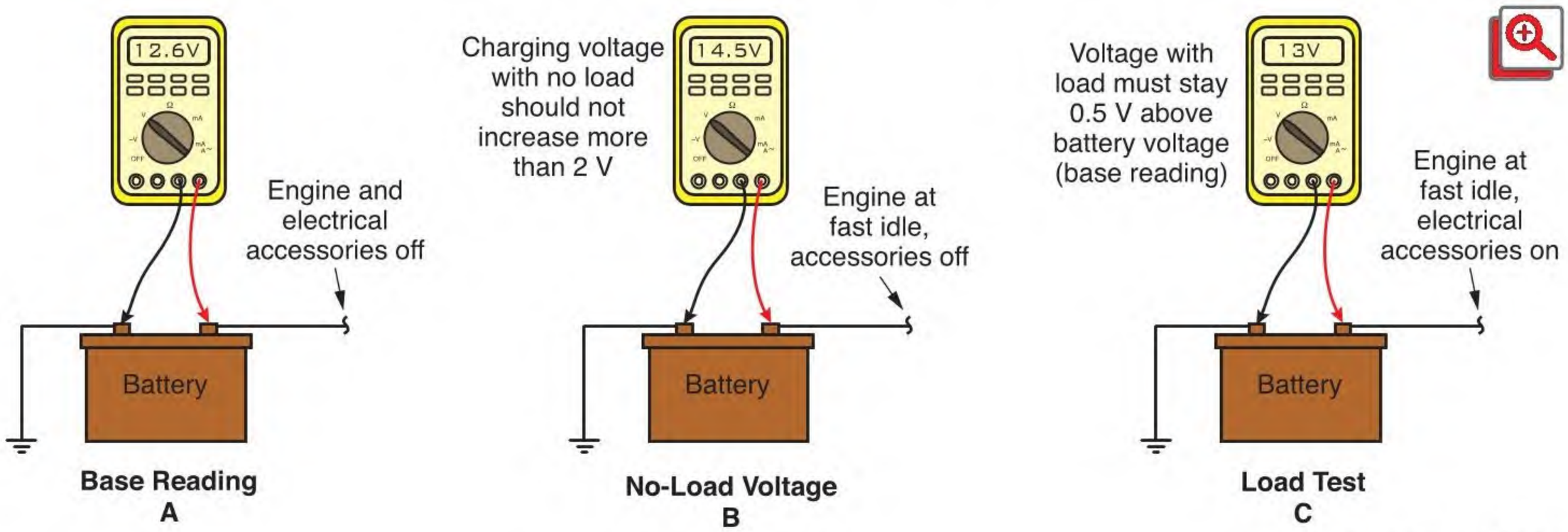
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Snap-on Tool Corp.

Figure 33-4. An oscilloscope can be used to check for faulty diodes and other problems before alternator removal. A—Normal alternator waveform with typical output. Note the small, regularly spaced, even ripples. B—This is a normal light-load alternator waveform for some electronic regulators using duty cycles to control output. Slightly higher inductive peaks and spikes can be normal with other systems. C—Normal alternator waveform with heavy load. It is similar to A, but has a higher amplitude ripple from increased current output. D—This alternator waveform shows an open diode causing high spikes. E—This waveform is due to one open diode and one shorted diode. F—A solid straight line at zero on the scope screen indicates no output from the alternator. G—This waveform indicates shorted diodes or shorted stator windings. H—Duty cycle from ECU to alternator field windings can be checked with a scope. High load, applied from the load tester, should make the duty cycle show more "on" time. If not, suspect the computer or ECM.

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Figure 33-5. A volt-ohm-millimeter, or VOM, allows for a quick check of the general condition of a 12-volt charging system. A—Connect the meter across the battery with the engine off to check battery base voltage. Battery voltage should be almost 12.6 volts if the battery is good. B—Start the engine with all accessories *off* to take a no-load voltage reading, which should be higher than battery voltage. C—Turn on all electrical accessories and read the voltmeter again. Charge voltage must remain above battery voltage. If readings are below battery voltage, the charging system is not working.

Circuit Resistance Tests

Circuit resistance tests are used to locate wiring problems in a charging system, such as loose connections, corroded terminals, partially burned wires, and similar troubles. Resistance tests should be performed when symptoms point to problems other than the alternator or regulator. For example, if the dash indicator flashes on and off erratically or the system charges one minute then stops working, suspect a poor ground or electrical connection between the alternator, regulator, and engine or body ECM. Two common circuit resistance tests are the insulated-circuit resistance test and ground-circuit resistance test. See **Figure 33-7**.



Fluke

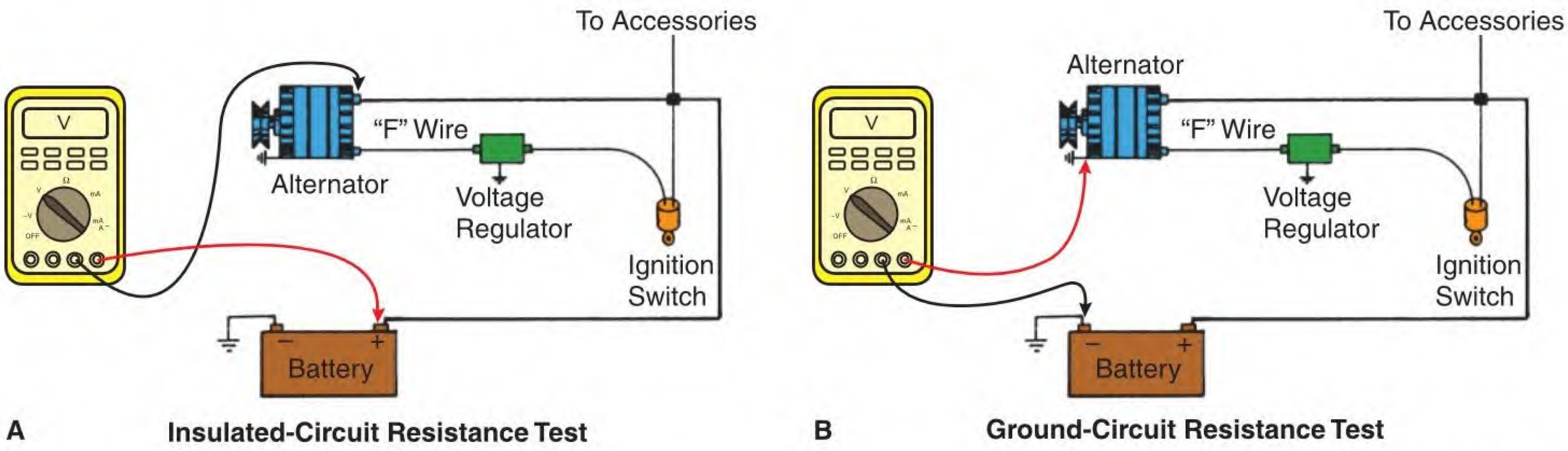
Figure 33-6. This digital voltmeter shows a base voltage reading of 12.49 volts, which is about 100% of a full charge.

Service Procedure

To do an ***insulated-circuit resistance test*** on a charging system:

1. Connect the tester across the alternator (battery) output terminal and the positive battery terminal.
2. With the vehicle running at a fast idle, set the load control to obtain a 20 amp current flow. All lights and accessories should be off.
3. Read the voltmeter. If the circuit is in good condition, the voltmeter should not read over about 0.7 volts (0.1 volt per electrical connection). If the voltage reading is higher than 0.7 volts, circuit resistance is high and a poor connection exists in that section of the charging circuit.

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Figure 33-7. Voltage drop or resistance tests will find problems in wiring. A—Connections for an insulated circuit resistance. B—Connections for a ground circuit resistance test. A voltage reading above 0.1 volts per connection indicates a resistance problem.

A ***ground-circuit resistance test*** is similar to the insulated-circuit resistance test. However, the voltmeter is placed across the negative battery terminal and alternator housing.

The voltmeter should not read over 0.1 volt per electrical connection. If the voltmeter reading is higher, look for corroded or loose connections, a burned plug socket, damaged wiring harness, or similar problems.

Alternator Service

A bad alternator will show up during your tests as a low output or unclean dc problem. Although most shops simply replace alternators that exhibit these symptoms, a few will rebuild faulty units. The following sections outline the steps for removing, rebuilding, and installing an alternator.

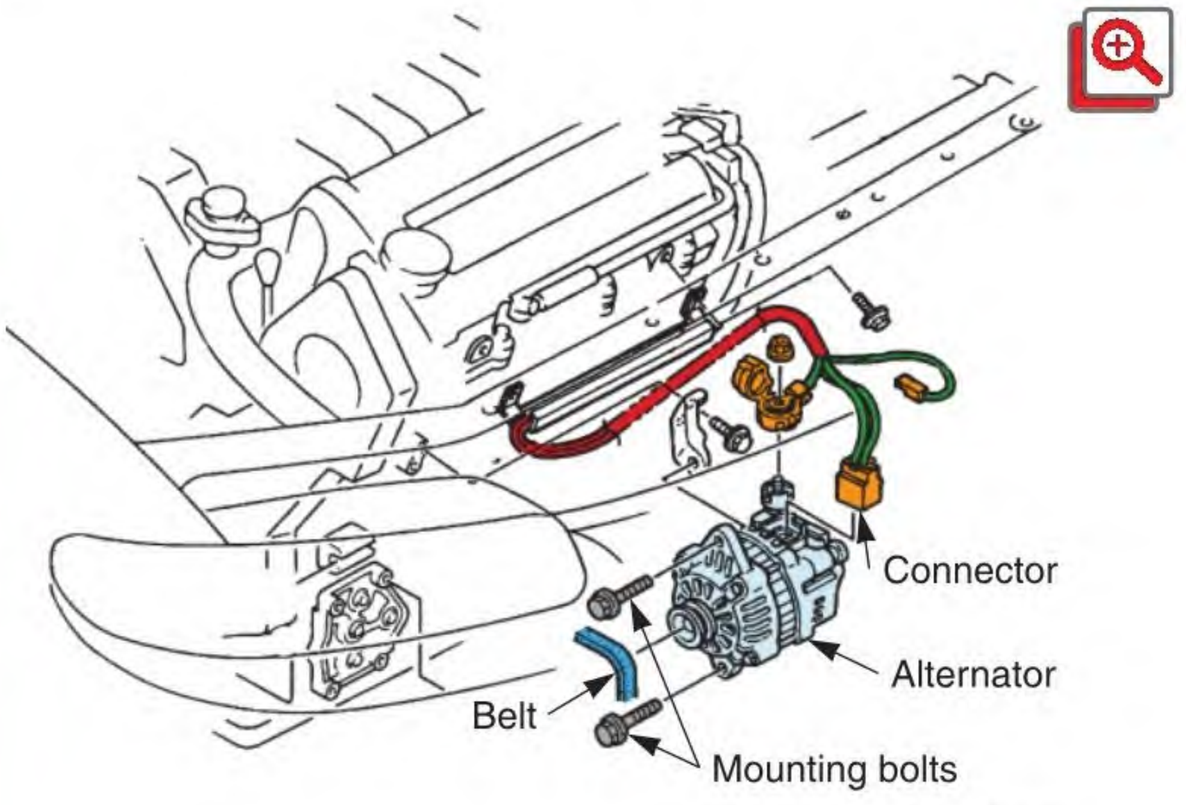
Alternator Removal

Service Procedure

To remove an alternator:

1. Disconnect the battery to prevent a major electrical short and wiring harness fire.
2. Remove the alternator belt from the drive pulley by retracting the belt tensioner with a breaker bar and socket. Try to keep the belt over and inside the other engine pulleys to simplify reinstallation.
3. Disconnect the wiring harness from the rear of the alternator. When removing the wires from the alternator, note their location and whether special insulating washers are used.
4. Remove the bolts that secure the alternator to its mounting brackets and remove the alternator from the vehicle. Sometimes it is easier to remove the alternator wires after the unit has been unbolted from the engine. See **Figure 33-8**.

Depending on vehicle design, the alternator may come out from the top, side, or bottom of the engine compartment. If it must be removed from the bottom, you may need to remove a splash shield to gain access to the bolts securing the alternator to



Mazda

Figure 33-8. When removing an alternator, first remove the belt and any parts that block access to the alternator mounting bolts. Then disconnect the wires and remove the mounting bolts.

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its mounting brackets. If the alternator comes out from the side of the engine compartment (transverse engine mounting), you may have to remove the inner fender apron to gain access to the alternator.

Alternator Rebuild

An alternator rebuild typically involves the following steps:

1. Disassembling the alternator.
2. Inspecting and testing the rotor.
3. Inspecting and testing the stator.
4. Testing the diodes.
5. Replacing the rotor, stator, or diodes if they are defective.
6. Replacing the bearings.
7. Replacing the brushes.
8. Reassembling and testing the alternator.

As mentioned previously, most shops do not rebuild alternators. Instead, they purchase new or rebuilt units. The cost of labor is generally too high to make in-shop rebuilding economical. Alternator rebuild parts are often no longer available. Also, rebuilt units will have a limited warranty.

Alternator Installation

With the battery still disconnected, fit the alternator onto the engine. Install the alternator mounting bolts, torque them to specifications, and reconnect the wiring harness.

Check the condition of the alternator belt and replace it, if needed. Slip the belt over the engine and alternator pulleys, making sure the belt is aligned properly on each pulley.

Hybrid Charging System Service

In a high-voltage hybrid electrical system, the HV power control module (HV PCM) normally generates different voltage levels for the various vehicle electrical systems. It will often have connectors for outputting 13–15 volts dc for conventional circuits, 45–110 volts dc for heated windshield circuits, and a voltage slightly higher than HV battery voltage for recharging the HV battery. Proper operation of the hybrid charging system can often be verified by studying the diagnostic information displayed by the vehicle's dash instrumentation. See **Figure 33-9**.

Scanning Hybrid Charging Systems

Depending on the make and model of the vehicle, your scan tool, laptop computer, or diagnostic tablet will indicate problems in the HV charging system. Diagnostic codes will indicate problems with any high-voltage component or circuit that is affecting HV battery charging voltage.

Late-model hybrid vehicles will output hundreds of trouble codes for almost every circuit, ECM, and component in the entire electrical/electronic system. The following are the most common problems with an HV charging system:

- Bad HV PCM—The HV PCM can have problems in its converter circuits, inverter circuits, high-power relays (contactors), transformers, diodes, and power transistors. Since the HV PCM performs so many electrical functions, it will sometimes trip trouble codes. Most scan tool readouts will indicate which circuit in the HV PCM is not functioning normally.
- Bad motor-generator—The motor-generator can fail to output normal 3-phase voltage and trip various trouble codes. For example, if one stator coil winding breaks open, the motor-generator will still work, but will not generate adequate voltage in that phase. Normally, the hybrid control module will completely disable the electric drive train when any problem with the motor-generator is found.
- Failed hybrid control module—The hybrid control module will generate trouble codes indicating something is wrong with the control module itself or its connecting circuits.
- Loose or corroded HV power cables—Faulty HV power cables, a common problem, can affect charging system performance and trip motor-generator, HV battery, or HV PCM codes. Loose HV cable connections can overheat and burn, increasing circuit resistance even more. Bad HV cable connections can affect motor-generator or electric drive performance.
- Bad HV battery—Late-model hybrids can detect a weak HV battery and will trip a trouble code if the HV battery fails to take or hold a proper electrical charge.

When test driving a hybrid vehicle in the electric mode, it is best to drive up a small hill. This will increase the load on the motor-generator and draw more current from the HV battery. Compare electric

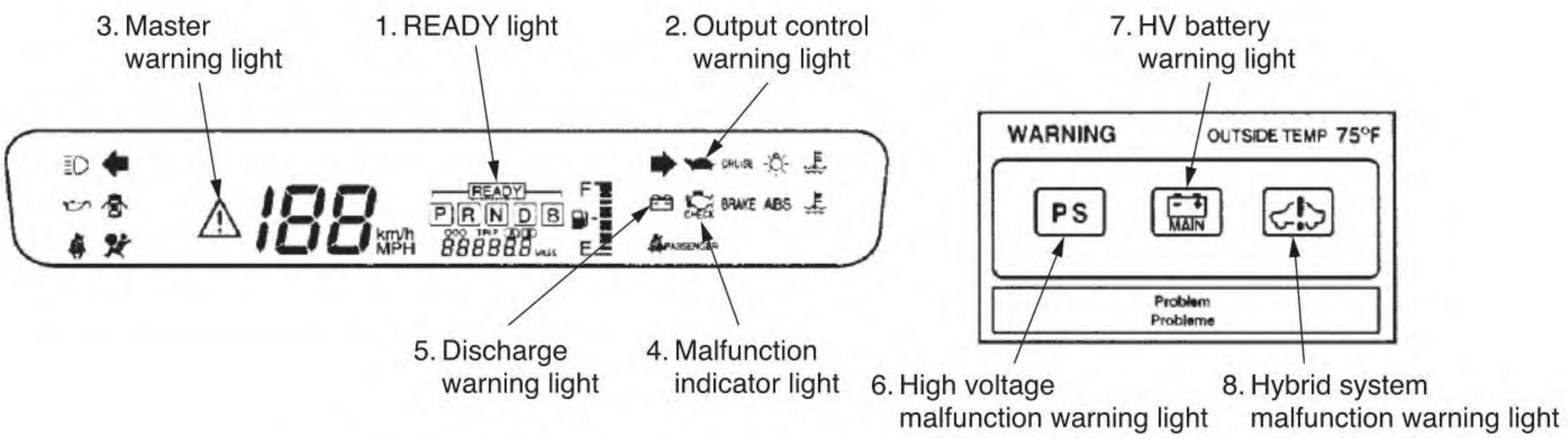
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drive and charging circuit performance to that of a known good vehicle and system. If the battery of a hybrid or electric vehicle is not being recharged normally with a home charger or by driving in the recharge mode, further tests are needed to verify diagnostic trouble codes in vehicle memory.

Tech Tip

To become properly trained to diagnose and repair a hybrid charging system, you should attend factory training courses or read manufacturer instructions on the specific make and model of hybrid vehicle. Hybrid vehicle designs, operation, and repair procedures vary.

Instrument Cluster



Center Meter **Multi Information Display**

1. READY Light	Turns on when the ignition switch is turned to START to indicate that the vehicle is ready to drive.
2. Output Control Warning Light	Turns on when the remaining HV battery charge becomes insufficient at R range or when there is an abnormal temperature rise in the HV battery due to continuous driving under heavy loads. It may also light when the HV battery temperature is low (after starting at low temperatures). The hybrid system output is limited while this light is on. • Travel at reduced speeds (avoid sudden acceleration) while the light is lit.
3. Master Warning Light	Turns on with buzzer sounding by linked operation with warning lights "6" to "8" on the center display.
4. Malfunction Indicator Light	Turns on when there is a malfunction in the engine control system.
5. Discharge Warning Light	Turns on when there is a malfunction in the 12 V charging system (converter assembly). • If it turns on together with the master warning light and hybrid system warning light, check the diagnostic code.
6. High Voltage Malfunction Warning Light	Turns on when there is a malfunction in the HV power control module.
7. HV Battery Warning Light	Turns on when the HV battery is discharged to the lower limit.
8. Hybrid System Warning Light	Turns on when a malfunction in motor-generator, HV power control module, HV battery, or hybrid control module is detected.

Toyota

Figure 33-9. Modern hybrid and electric vehicles provide an abundance of diagnostic information through the dash instrumentation. Note all the indicator lights on this instrument cluster.

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Diagnostic Case Study

Concern: Mr. Howard brings his 2011 Ford Mustang to the shop, complaining that it has to be jump started every time he wants to drive it. He adds that he bought and installed a new battery to correct the no-start problem, but the car still will not start properly after a couple of days of driving.

Cause: Duff inspects the alternator belt, the alternator, the alternator wiring, and the battery connections. Not finding a problem during the visual inspection, Duff turns the repair over to the shop's electrical technician.

The technician charges the battery in preparation for electrical tests. He connects a voltmeter across the battery terminals. The meter shows a base voltage reading of 12.6 volts, indicating that the battery is fully charged.

The technician then checks no-load voltage. He starts the engine, makes sure all the electrical accessories are off, and runs the engine at fast idle. At fast idle, the voltmeter still reads 12.6 volts, indicating that the charging system is not functioning properly. Further testing shows that the alternator is not putting out the required voltage.

Correction: The technician removes the bad alternator and orders a rebuilt unit. He then reinstalls the alternator and rechecks charging system voltage. After determining that the system is working properly, he releases the vehicle to the customer.

Summary

- Sometimes, another system's fault (bad starting motor, defective battery, computer failure, or faulty wiring) will appear to be caused by problems in the charging system.
- There are four common symptoms of charging system problems: dead battery, overcharged battery, abnormal noises, and an indicator showing a problem.
- A preliminary inspection of the components and connections will help determine the source of the charging system problem.
- Take the necessary precautions when working on a charging system to prevent possible damage to electrical/electronic systems.
- Charging system tests should be done when symptoms point to low alternator voltage and current. Common charging system tests include the scan tool voltage readings, load test, scope tests, voltmeter test, and circuit resistance tests.
- A bad alternator will show up as a low voltage and current output problem during charging system tests. This may be caused by a bad alternator rotor, bad alternator stator, bad alternator diodes, worn alternator bearings, or worn alternator brushes.
- The most common problems with an HV charging system include the following: bad HV PCM, bad motor-generator, failed hybrid control module, loose or corroded HV power cables, and a bad HV battery.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

base voltage
charge voltage
charging system load test
charging system tests
circuit resistance tests
ground-circuit resistance test
hot wire
insulated-circuit resistance test
load tester
load voltage
no-load voltage
scope test

Activities

1. Make a poster for classroom display showing the steps involved in checking a charging system with a voltmeter.
2. Using the Internet, price a new or rebuilt alternator for a vehicle of your choice. Then, use a flat rate manual to determine how many hours of labor a customer should be charged to replace the alternator on the vehicle chosen. Assuming a shop labor rate of $60 per hour and a part markup of 15%, prepare an estimate showing the total parts and labor charges for replacing the alternator.

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Review Questions

Answer the following questions using the information provided in this chapter.

1. Name four common symptoms caused by charging system problems.
2. List and explain five 12-volt charging system service precautions.
3. List and explain five common 12-volt charging system tests.
4. All of the following are steps in a charging system visual inspection *except:*
   (A) checking battery terminals for corrosion.
   (B) listening for abnormal noises in the alternator.
   (C) checking the condition of the alternator drive belt.
   (D) checking the operation of the neutral safety switch.
5. Alternator current specifications can be found in service literature or are sometimes stamped on the _____.
6. A scope test on a charging system involves analyzing an alternator voltage waveform for signs of abnormal ripple or interference. True or False?
7. What is the purpose of charging system circuit resistance tests?
8. When measuring the battery base voltage with a voltmeter, the vehicle engine should be _____ and all the accessories should be turned _____.
   (A) fast idling; on
   (B) running; on
   (C) off; off
   (D) running; off
9. All of the following steps may be part of an alternator rebuild *except:*
   (A) testing the diodes.
   (B) resurfacing the clutch plate.
   (C) replacing the brushes.
   (D) inspecting and testing the rotor.
10. List five common problems that occur in HV charging systems.

ASE-Type Questions

1. When working on charging systems, all of the following precautions should be taken *except:*
   (A) never reverse polarity.
   (B) always polarize the alternator.
   (C) never short system terminals.
   (D) detach the battery before part removal.
2. Each of these is a common 12-volt charging system test *except:*
   (A) scan tool charging voltage test.
   (B) circuit resistance tests.
   (C) alternator mounting test.
   (D) charging system load test.
3. Charging system tests are performed using a(n):
   (A) VOM.
   (B) scope.
   (C) load tester.
   (D) All of the above.
4. During a 12-volt charging system voltmeter test, all electrical accessories are *on* when checking:
   (A) base voltage.
   (B) load voltage.
   (C) no-load voltage.
   (D) All of the above.
5. When recording no-load voltage, the voltmeter reading should increase from the base reading by no more than:
   (A) 1–2 volts.
   (B) 2–3 volts.
   (C) 5–6 volts.
   (D) 8–10 volts.
6. To check a HV charging system, Technician A says to use on-board diagnostics and a scan tool, laptop, or diagnostic tablet. Technician B says to check data stream values to gain more information on the performance of the HV charging system. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. What is the best way to be trained to service a specific HV charging system?
   (A) Attend factory or manufacturer classes and read their service instructions.
   (B) Search the Internet for service information.
   (C) Read posts from hybrid vehicle forums on the Internet.
   (D) Read service magazines that discuss hybrid repairs.
8. Hybrid vehicle charging system problems are being discussed. Technician A says that an HV battery that will not hold a proper electrical charge will set a diagnostic trouble code. Technician B says that loose HV cable connections will not affect electric drive train performance. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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Charging System Diagnosis

Condition	Possible Causes	Correction
No charge.	1. Alternator drive belt loose or broken. 2. Voltage regulator fusible link blown. 3. Sticking or worn commutator brushes. 4. Loose or corroded connection. 5. Rectifiers open. 6. Charging circuit open. 7. Open circuit in stator winding. 8. Field circuit open. 9. Defective field relay. 10. Defective voltage regulator. 11. Open isolation diode. 12. Open resistor wire. 13. Slipping drive pulley. 14. Oil soaked brushes. 15. Corroded or loose brush connections. 16. Seized bearings.	1. Tighten or replace belt. 2. Install new fusible link. 3. Free or replace brushes. 4. Clean and solder connections. 5. Correct cause and replace rectifiers. 6. Correct as needed. 7. Replace stator. 8. Test and correct as required. 9. Replace relay. 10. Replace voltage regulator. 11. Replace diode. 12. Replace resistor wire. 13. Install new key and tighten. 14. Replace brushes. 15. Clean and tighten connections. 16. Replace bearings. Check shaft for damage.
Low or erratic rate of charge.	1. Loose drive belt. 2. Open stator; grounded or shorted turns in stator windings. 3. High resistance in battery terminals. 4. High resistance in charging circuit. 5. Engine ground strap loose or broken. 6. Loose connections. 7. Defective rectifier. 8. Dirty, burned slip rings. 9. Grounded or shorted turns in rotor. 10. Brushes worn. Brush springs weak.	1. Tighten belt. 2. Replace stator. 3. Clean and tighten terminals. 4. Repair cause of high resistance. 5. Tighten or replace strap. 6. Tighten connections. 7. Replace rectifier. 8. Turn slip rings. 9. Replace rotor. 10. Replace brushes and/or springs.
Excessive rate of charge.	1. Faulty voltage regulator ground. 2. Defective voltage regulator. 3. Alternator field winding grounded. 4. Open rectifier. 5. Loose connections.	1. Ground regulator properly. 2. Replace regulator. 3. Repair grounded field winding. 4. Replace rectifier. 5. Tighten connections.
Noise.	1. Drive belt slipping. 2. Drive pulley loose or misaligned. 3. Mounting bolts loose. 4. Worn bearings. 5. Dry bearing. 6. Open or shorted rectifier. 7. Sprung rotor shaft. 8. Open or shorted stator winding. 9. Alternator fan dragging. 10. Excessive rotor end play. 11. Out-of-round or rough slip rings. 12. Hardened brushes.	1. Tighten belt. 2. Tighten or align pulley. 3. Tighten mounting bolts. 4. Replace bearings. 5. Lubricate or replace as required. 6. Replace rectifier. 7. Install new rotor. 8. Test. Replace stator as needed. 9. Adjust fan clearance. 10. Adjust for correct end play. 11. Turn slip rings. 12. Replace brushes.

Continued

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Charging System Diagnosis

Condition	Possible Causes	Correction
Undercharged battery.	1. No charge or low charge rate. 2. Excessive use of starter. 3. Defective battery. 4. Excessive resistance in charging circuit. 5. Defective alternator. 6. Defective regulator. 7. Electrical load exceeds alternator rating. 8. Electrical draw in system. 9. Excessive starter motor draw.	1. See *No charge or Low or erratic rate of charge*. 2. Recharge battery. Advise owner. 3. Replace battery. 4. Test circuit and remove resistance. 5. Rebuild or replace alternator. 6. Replace regulator. 7. Reduce load or install higher capacity alternator. 8. Test. Remove source of electrical draw. 9. Rebuild or replace starter motor.
Overcharged battery.	1. Excessive resistance in voltage regulator circuit. 2. Regulator-alternator ground wire loose or open. 3. Defective battery. 4. Defective regulator.	1. Clean and tighten connections. 2. Tighten or replace wire. 3. Replace battery. 4. Replace regulator.

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Chapter 34
Ignition System Technology

After studying this chapter, you will be able to:

- Explain the operating principles of any type of automotive ignition system.
- Sketch the primary and secondary circuits of an ignition system.
- Identify and describe the function of major ignition system components.
- Compare ignition coil, spark plug, and ignition circuit variations.
- Distinguish between coil pack and direct ignition systems.
- Explain the need for accurate ignition timing control.
- Correctly answer ASE certification test questions that require knowledge of ignition system theory and design.

In recent years, different types of ignition systems have been developed to enhance performance, increase efficiency, improve dependability, and reduce the emissions of gasoline engines. Ignition systems in late-model vehicles use a crankshaft position sensor and a computer or an ignition control module (ICM) to determine when to fire each spark plug.

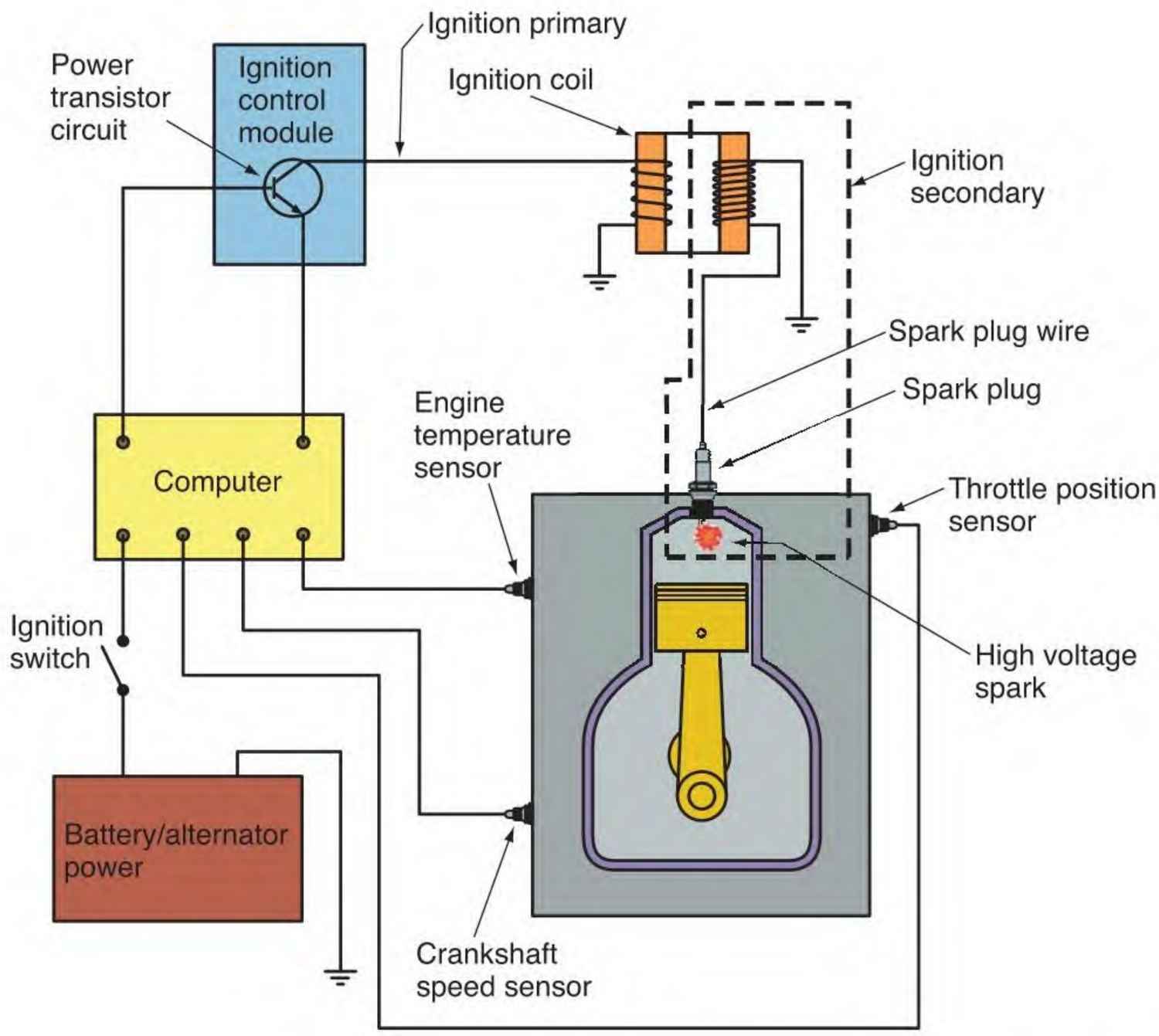
Ignition System Fundamentals

An ***ignition system*** amplifies battery voltage (12.6 volts) or charging system voltage (13 to 15 volts) to over 40,000 volts and delivers this voltage to the spark plugs at the right time. Refer to **Figure 34-1**. Gasoline engines need an ignition system to initiate combustion on the power stroke. Diesels are compression ignition engines and do not need an ignition system to start combustion.

The following are the basic parts of an ignition system:

- Crankshaft position sensor—A crankshaft position sensor is usually a magnetic pickup coil that detects engine speed to "fire" the ignition coil properly.
- Primary wires—The primary wires feed low voltage to components in the ignition system.
- Ignition control module—An ignition control module is an electronic circuit used with the crankshaft position sensor to make and break current to the ignition coil.
- Ignition coil—The ignition coil serves as a step-up transformer that increases battery voltage to 100,000 volts or more.

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Figure 34-1. These are the basic parts of an ignition system. The crankshaft speed sensor sends a low voltage signal to the computer and other engine sensors. The computer then signals the ignition control module, which amplifies the signal to make and break current flow to the ignition coil. When the amplifier shuts off the current to the ignition coil, the ignition coil fires and produces high voltage for the spark plug.

- Spark plugs—The spark plugs convert high-voltage current into an electric spark, or arc, in the engine combustion chamber to burn the engine's fuel.
- Secondary wires—The secondary wires have thick insulation for carrying high-voltage current to the spark plugs without arcing or leaking to ground.
- Ignition switch—The ignition switch is the key-operated or push-button switch that feeds battery voltage to the ECM, ignition coil(s), and other components.

Ignition System Operation

The ignition system supply voltage is fed to the ignition system by the battery or alternator. The battery provides electricity for starting the engine. After the engine is running, the alternator supplies a slightly higher voltage to the battery and the ignition system.

When the driver turns the ignition key to the *Start* position, current is fed to the ignition coils by the ignition control module. The current energizes the coil windings with a strong magnetic field. The starting motor turns the crankshaft, trying to make the engine fire and run. This causes the position sensor to produce voltage signals that correspond to engine speed.

The ***ignition control module (ICM)*** uses signals from the engine control module and the crankshaft position sensor to determine when to stop (and start) the current flow through an ignition coil. When the ICM stops the current, the ignition coil feeds high-voltage current to the spark plug. This causes an electric arc between the spark plug electrodes, igniting the air-fuel mixture in the combustion chamber. Combustion makes the engine start, and the driver or ECM can then cut power to the starting motor. This stops and disengages the starting motor, but still allows ignition system operation. When the driver turns the key to the *Off* position, the current is shut off to the ignition module and coil, and the engine stops running.

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As you will learn, an actual ignition system is much more complex than the one just described. Automotive engines have multiple cylinders, and the timing of the sparks must vary with operating conditions.

Primary and Secondary Circuits

The two main sections of an ignition system are the primary and secondary circuits. In **Figure 34-1**, the primary circuit includes all the components and connections outside the dotted box.

The ***primary circuit*** consists of all the components and wires that operate on low 12-volt dc from the battery, alternator, or current from the HV power control module. Small, conventional wires carry primary currents.

The ***secondary circuit*** includes all the parts that carry high-voltage current. It consists of the wires and parts between the coil output windings and the spark plug ground. The secondary wiring must have thick insulation to prevent leakage or arcing of the high secondary operating voltage. The ***secondary operating voltage*** of the ignition system ranges from 4,000–100,000 volts, depending on the system design.

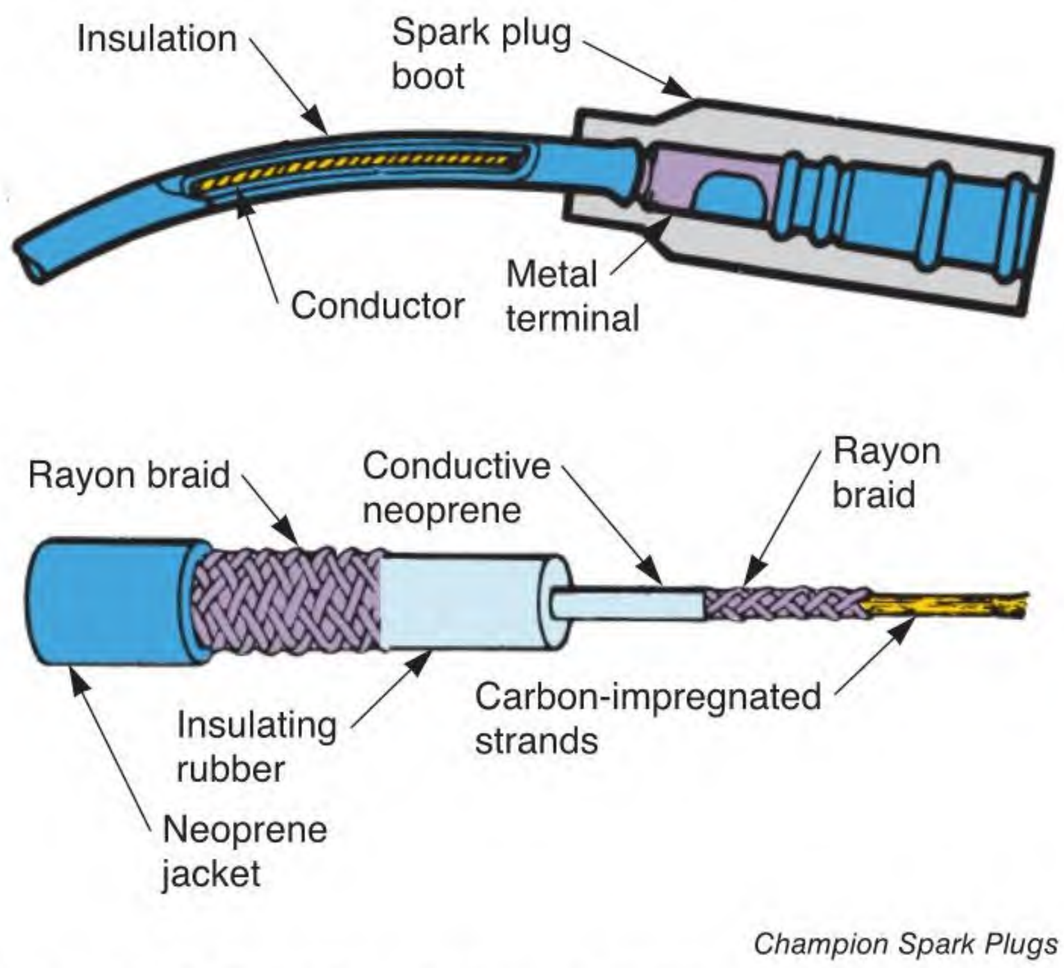
Ignition System Supply Voltage

The ***ignition system supply voltage*** is fed to the ignition system by the battery, alternator, ignition ECM, or HV power control module. On late-model vehicles, these sources feed voltage through the engine control module or the power train control module. The 12-volt or HV battery provides electricity for starting the engine. After the engine is running, the alternator or HV power control module supplies a slightly higher voltage to the electrical and ignition system.

Secondary Wires

Secondary wires, or ***spark plug wires***, carry the high-voltage current produced by the ignition coils. Insulated ***boots*** usually fit over both ends of the secondary wires to protect the metal connectors from corrosion, oil, and moisture.

Resistance wires are now used for secondary wire applications because they contain internal resistance, which helps prevent radio interference. Resistance wires consist of carbon-impregnated strands and rayon braids. Look at **Figure 34-2**. Also called ***radio suppression wires***, resistance wires have about 10,000 ohms of resistance per foot.



Champion Spark Plugs

Figure 34-2. Secondary wire has very thick insulation. Spark plugs contain carbon-impregnated strands that increase internal wire resistance, to prevent radio interference noise in the stereo speakers.

Tech Tip

Most late-model engines have one ignition coil mounted directly to each spark plug. This eliminates the need for secondary wires and improves ignition system dependability. A short resistance spring often conducts high voltage from the direct ignition coil to the spark plug center electrode.

Spark Plugs

Spark plugs use ignition coil high voltage to ignite the fuel mixture. A secondary voltage between 4,000 and 28,000 volts is needed to make current jump the gap at the spark plug electrodes. This is much lower than the coil's output voltage potential discussed earlier.

The following are the basic parts of a spark plug:

- ***Center terminal (center electrode)***—The center terminal (center electrode) conducts electricity into the combustion chamber.
- ***Grounded side electrode***—The grounded side electrode causes the electricity to jump the gap and return to the battery through frame ground.
- ***Ceramic insulator***—The ceramic insulator keeps the high voltage at the plug wire from shorting to ground before producing a spark in the engine cylinder.

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- ***Steel shell***—The steel shell supports the other parts of the plug and has threads for screwing the plug into the engine cylinder head.

Spark Plug Reach

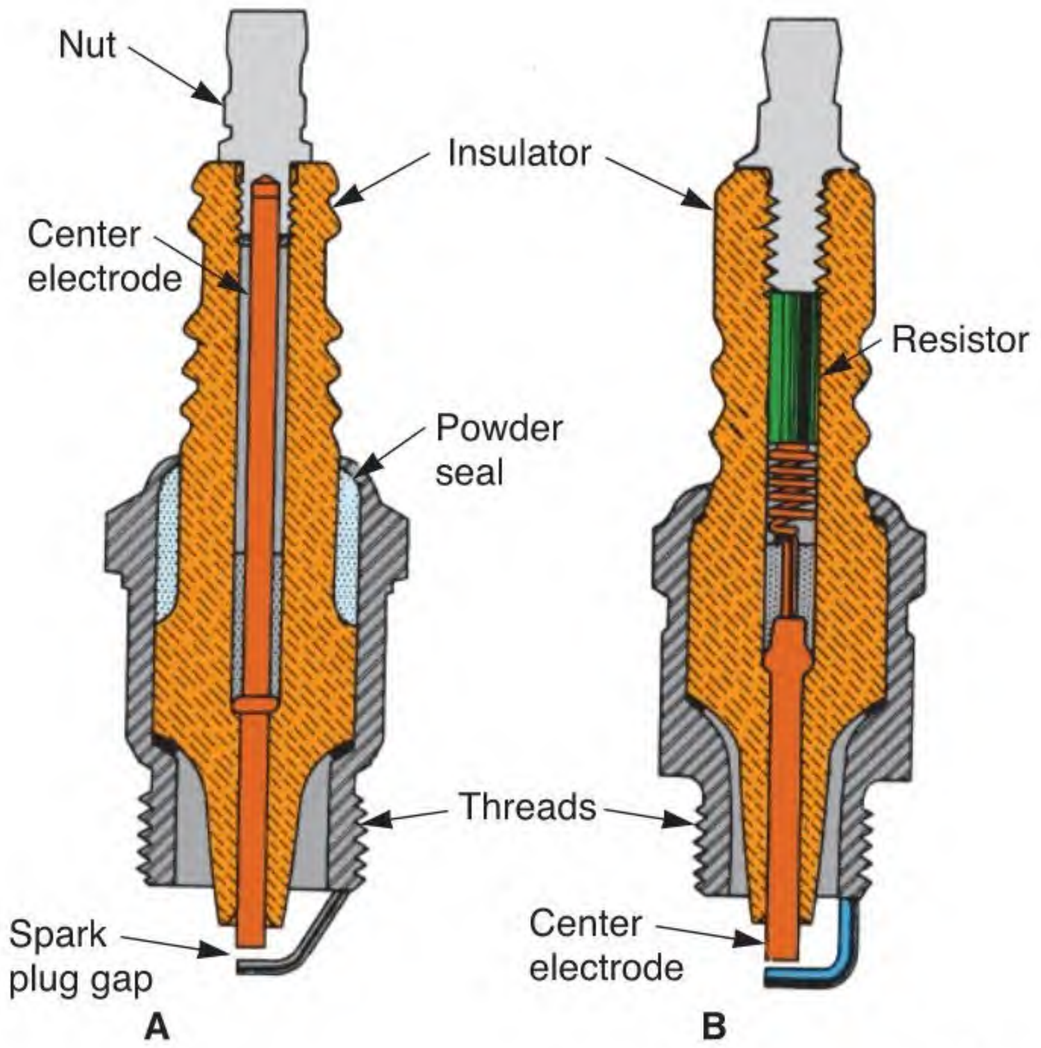
Spark plug reach is the distance between the end of the plug threads and the seat or sealing surface on the plug shell. Refer to **Figure 34-3**. Spark plug reach determines how far the spark plug extends through the cylinder head.

If spark plug reach is too long, the plug electrode may be struck by the piston at top dead center (TDC). If reach is too short, the plug electrodes may not extend far enough into the chamber, and combustion efficiency may be reduced.

Resistor and Non-Resistor Spark Plugs

A ***resistor spark plug***, like a resistance secondary wire, has internal resistance (around 10,000 ohms) to reduce static in radios and television sets. Most vehicles require resistor plugs.

A ***non-resistor spark plug*** has a solid metal rod that forms the center electrode. This type of plug is not commonly used, but it is found in some racing and off-road applications. Refer to **Figure 34-4**.

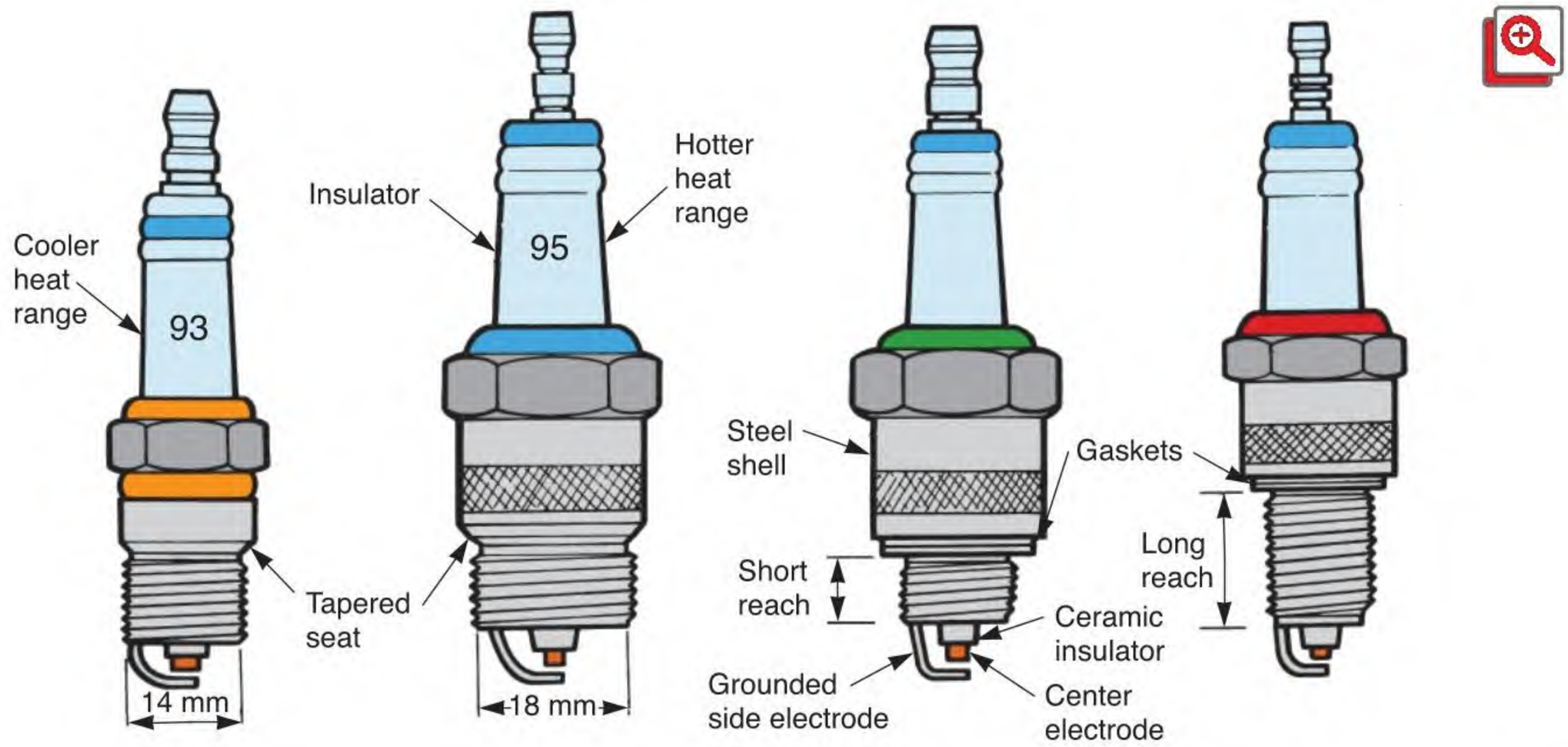


Ethyl Corp.

Figure 34-4. Cutaway shows the internal parts of racing and street spark plugs. A—Non-resistor spark plugs have a solid metal center electrode for a hotter spark, and are used for off-road racing. B—Resistor spark plugs have a small radio-suppressing resistor between a two-piece center electrode. Resistance plugs are required to avoid inducing a clicking sound into nearby car stereos.

Spark Plug Gap

Spark plug gap is the distance between the center and the side electrodes. Normal gap specifications



Chrysler

Figure 34-3. Compare spark plug variations. Small 14 mm plugs are commonly used in today's engines. Larger 18 mm plugs are used in older engines. Spark plug reach is the length of the plug threads.

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range from 0.030″–0.080″ (0.76 mm–2.0 mm). Smaller spark plug gaps are used on older cars. Larger spark plug gaps are used with electronic and computerized ignition systems to produce a "hotter spark."

Spark Plug Heat Range

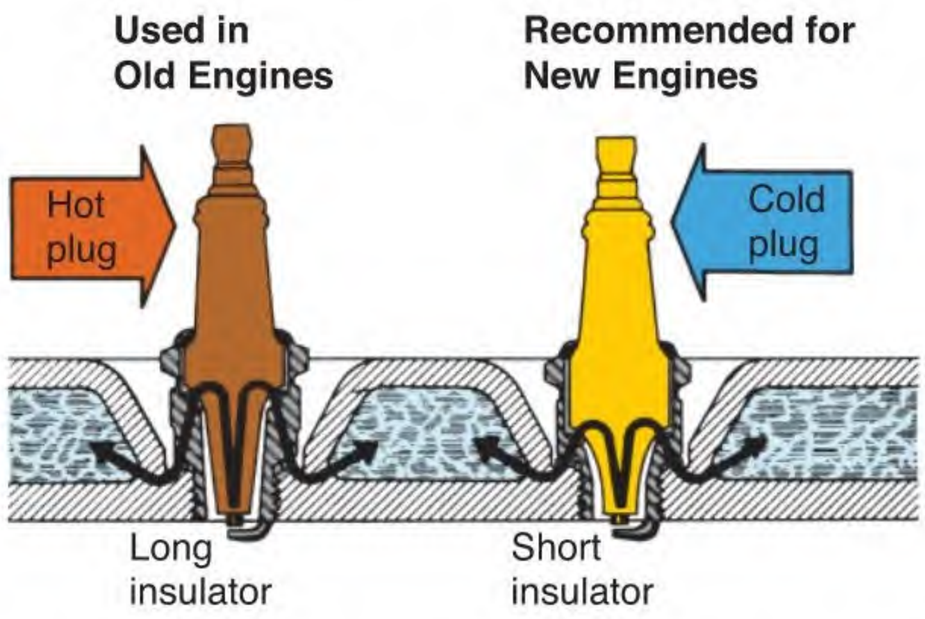
Spark plug heat range is a rating of the operating temperature of the spark plug tip. Plug heat range is basically determined by the length and diameter of the insulator tip, and the ability of the plug to transfer heat into the cooling system. Refer to **Figure 34-5**.

A ***hot spark plug*** has a long insulator tip and tends to burn off deposits. This provides a self-cleaning action.

A ***cold spark plug*** has a shorter insulator tip; its tip operates at a cooler temperature. A cold plug is used in engines that operate at high speeds. The cooler tip helps prevent tip overheating and preignition.

Auto manufacturers normally recommend a specific spark plug heat range for their engines. The heat range is normally coded and given as a number on the plug insulator. Generally, the larger the number on the plug, the hotter the spark plug tip. For instance, a 52 plug would be hotter than a 42.

The only time you should deviate from plug heat range specifications is when abnormal engine or driving conditions are encountered. For example, a hotter plug may be installed in a worn out, oil-burning engine. The hotter plug helps burn off oil deposits, which prevents spark plug oil fouling.



Ethyl Corp.

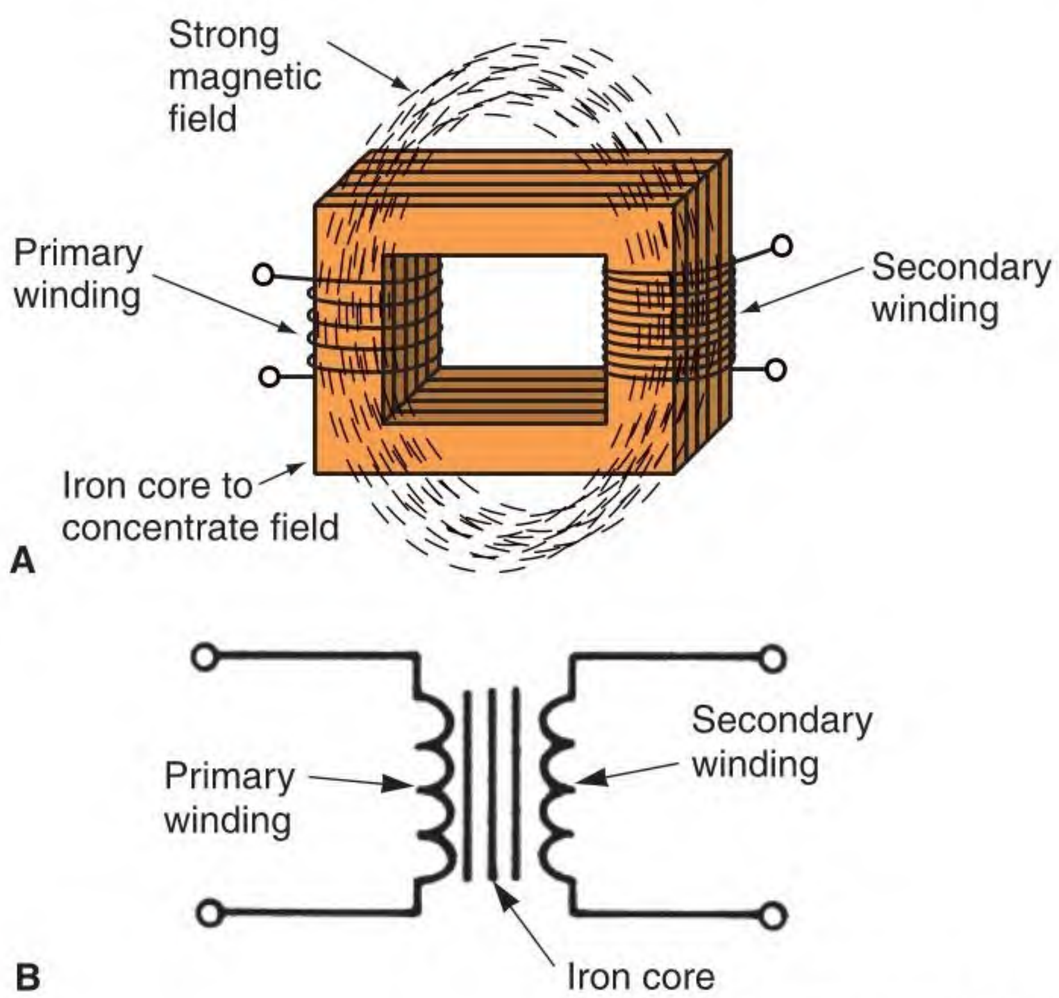
Figure 34-5. A hot plug has a long insulator that prevents heat transfer into the water jackets. It will burn off oil deposits in high-mileage engines. A cold plug has a shorter insulator for high-speed operation and higher cylinder temperatures.

Ignition Coils

The ***ignition coil*** is a pulse-type transformer capable of producing the short bursts of high-voltage current that pass through the secondary wires (if used) and jump the spark plug gaps. It contains two sets of ***windings*** (insulated wire wrapped in circular pattern). The ***primary windings*** are made up of several hundred turns of heavy wire wrapped around or near the secondary windings. The ***secondary windings*** consist of several thousand turns of very fine wire located inside or near the primary windings. Both windings are wrapped around an iron core and are housed inside the coil case. See **Figure 34-6**.

The ignition systems in older engines contain spark plugs with relatively small gaps. These systems operate at about 4,000–8,000 volts. With today's wider spark plug gaps and leaner fuel mixtures, more voltage is needed to make the electricity surge through all parts of the ignition system. Ignition systems in late-model vehicles operate at about 15,000 volts, depending on ignition system design and condition.

If everything is in good condition, the ignition coil operates below its potential maximum output voltage. This keeps some voltage in reserve. The ***ignition coil open-circuit voltage*** (maximum voltage potential) ranges from 40,000–100,000 volts in late-model designs.



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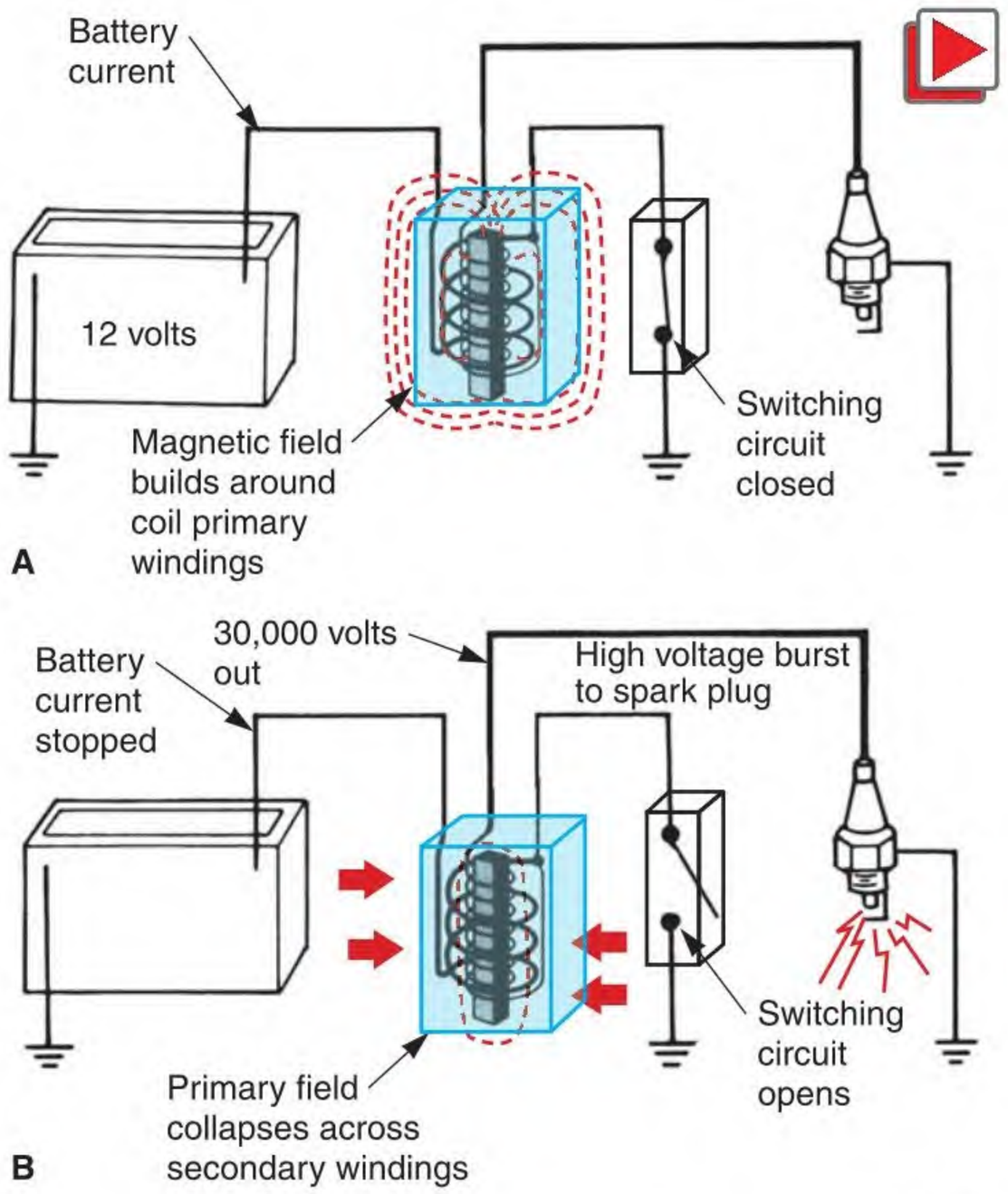
Figure 34-6. Study an ignition coil. A—The ignition coil is a step-up transformer that can increase a 12-volt input into an output of almost 100,000 volts. B—Note how the schematic symbol for an ignition coil relates to its construction.

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Ignition Coil Operation

When battery current flows through the ICM and primary windings of the ignition coil, a strong magnetic field is generated. The action of the iron core helps concentrate and strengthen this field. Look at **Figure 34-7**.

When the current flowing through the coil's primary windings is interrupted by the ICM, the magnetic field collapses across the secondary windings. Since the secondary windings have more turns than the primary windings, up to 60,000 volts is induced in the secondary windings. High voltage shoots out of the high-voltage terminal of the coil, traveling through the secondary circuit to a spark plug.

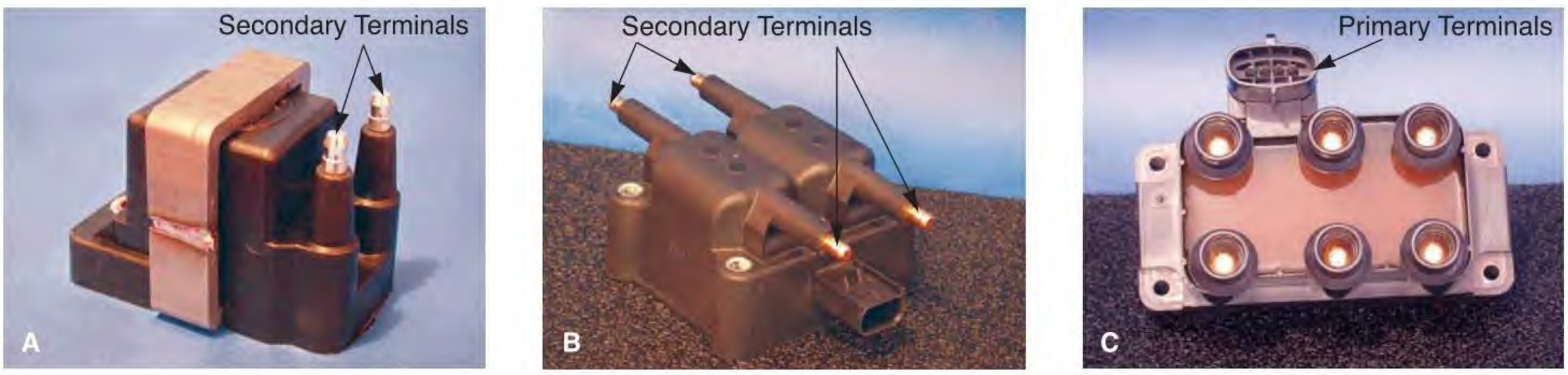


Saab

Figure 34-7. Study the operation of a typical ignition coil. A—With the switching device (electronic circuit or contact points) closed, current flows through the ignition coil primary windings. A strong magnetic field builds around both coil windings and the iron core. The primary magnetic field saturates secondary windings with magnetic energy. B—When the switching device opens, current flow stops and the magnetic field collapses through the secondary windings. This induces a high-voltage surge of electricity in the secondary windings. When the high-voltage surge reaches the spark plug, it arcs across the plug's gap to the ground electrode.

Ignition Coil Designs

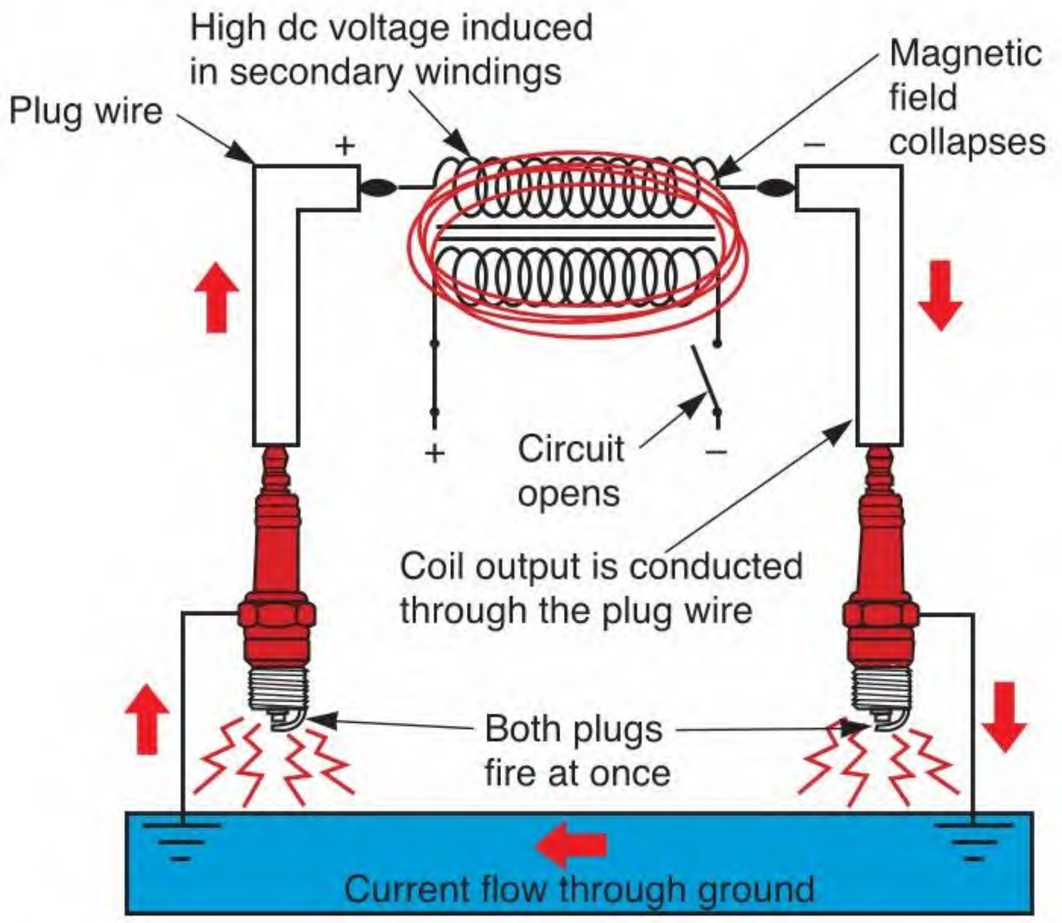
With today's computer-controlled ignition systems, ignition coils can be more complex than those used in the past. Depending on ignition system design, an engine can have one or more ignition coils. Very old ignition systems have one coil that serves all engine cylinders. Coil pack ignition systems have one coil for every two engine cylinders. Direct ignition systems have one coil for every engine cylinder. A ***coil pack*** consists of several ignition coils combined into one assembly, **Figure 34-8**. As you will learn, this type of coil is used in coil pack ignition systems. No coil wire is needed with a coil pack. The spark plug wires are connected from the coil pack to the spark plugs. Each coil in the coil pack is wired so that it fires two spark plugs at the same time. As illustrated in **Figure 34-9**, each end of the coil's secondary winding is connected to a spark plug wire. Then, when the primary magnetic field collapses across the secondary winding, a high-voltage, low-current surge is induced in both spark plug wires. Current flows across each spark plug gap



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Figure 34-8. Common oil pack designs. A—An ignition coil that has two secondary terminals for firing two spark plugs at once. B—An ignition coil with four high-voltage output terminals. C—A coil pack with six high-tension terminals for a V-6 engine.

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Figure 34-9. Waste-spark ignition coils are wired so they fire two spark plugs simultaneously. One spark plug starts combustion on the power stroke. The other spark plug produces a wasted spark. It does nothing since the electric arc or spark occurs during the engine exhaust stroke.

with the opposite polarity. The engine ground connects the two spark plugs.

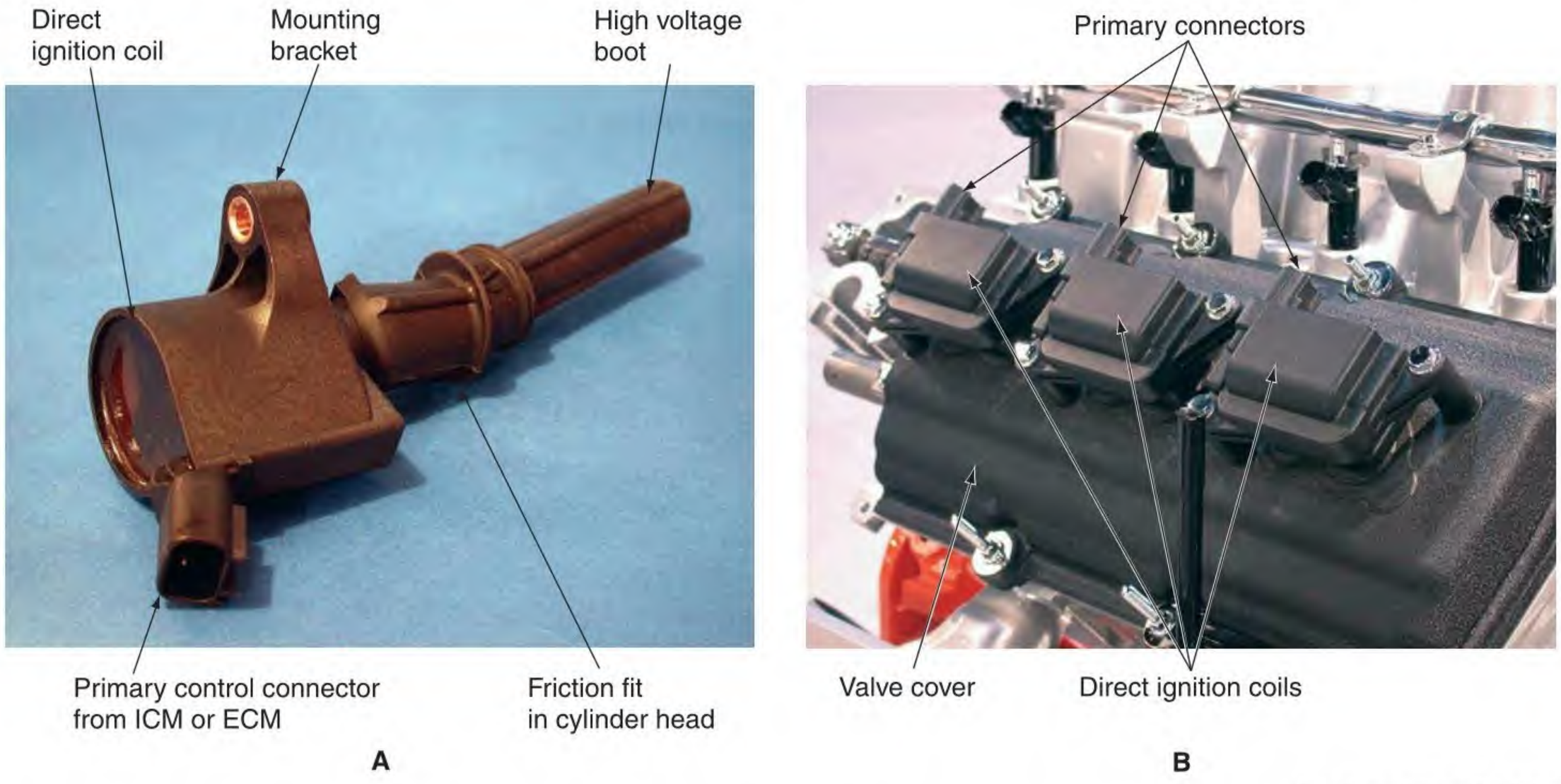
The ***direct ignition coil*** bolts directly over the top of the spark plug on top of the engine. A direct ignition coil fires only on the power strokes for maximum voltage and combustion efficiency. One direct ignition coil is required for each spark plug. Two wires connect to each direct ignition coil from the ICM or directly from the engine ECM. Refer to **Figure 34-10**.

Coil Pack Ignition System

A ***coil pack ignition***, also called a distributorless ignition system or a computer-coil ignition system, uses multiple ignition coils, a coil control unit, engine sensors, and a computer (engine control module) to operate the spark plugs. See **Figure 34-11**.

An ***electronic coil module*** consists of two or more ignition coils and a coil control unit (electronic circuit) that operates the coils. Each coil in the coil module serves two cylinders. Therefore, a four-cylinder engine would have a coil module with two ignition coils and a six-cylinder engine would need a coil module with three ignition coils.

The coil control unit performs about the same function as the ignition control module in an electronic



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Figure 34-10. A direct ignition coil is designed to operate only one spark plug. A—The direct ignition system has ignition coils mounted directly on top of the spark plugs. One coil is used for each spark plug. No plug wires or conductor strips are needed. B—Note how the direct ignition coils bolt to the valve cover of this engine.

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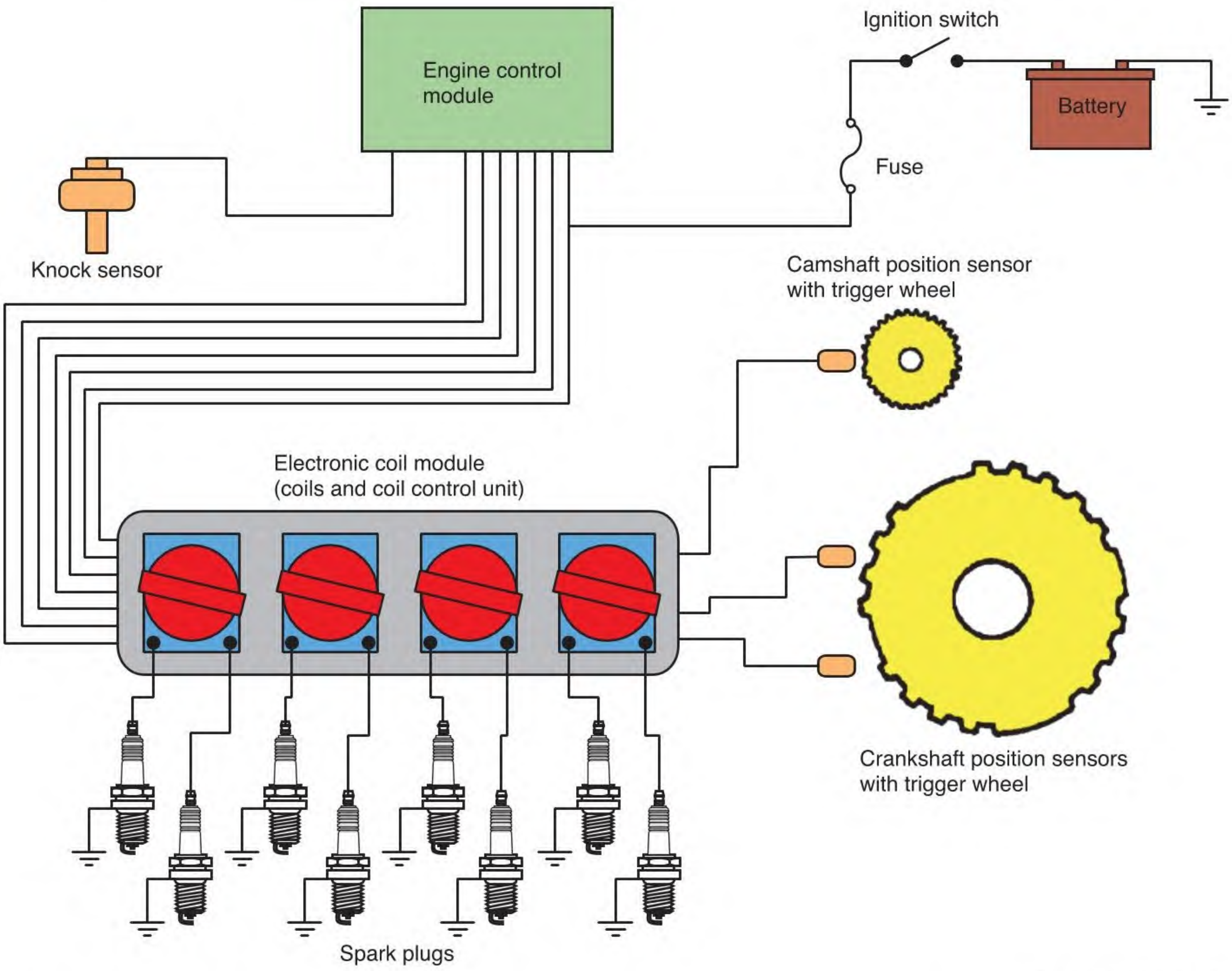
ignition. It is more complex, however, because it must analyze data from engine sensors and the computer.

A camshaft position sensor sends electrical pulses to the coil control unit, providing data on camshaft and valve position. The crankshaft position sensor feeds pulses to the control unit that show engine speed and piston position. A knock sensor may be used to allow the system to retard timing if the engine begins to ping or knock.

Figure 34-12 illustrates how a coil pack ignition system works. The on-board computer (engine or ignition control module) monitors engine-operating conditions and controls ignition timing. Sensor data is also fed to the coil control unit.

When the computer and sensors (including the crankshaft position sensor) send correct electrical pulses to the coil control unit, the control unit fires one of the ignition coils. Since the secondary output of each coil is wired to two spark plugs, both plugs fire. One spark plug arc produces the power stroke. The other arc does nothing (waste-spark) because its cylinder is on the exhaust stroke—burned gases are simply being pushed out of the cylinder. Because the arc in the cylinder on the exhaust stroke has no effect on engine operation, coil pack ignition systems are often called ***waste-spark ignition systems***.

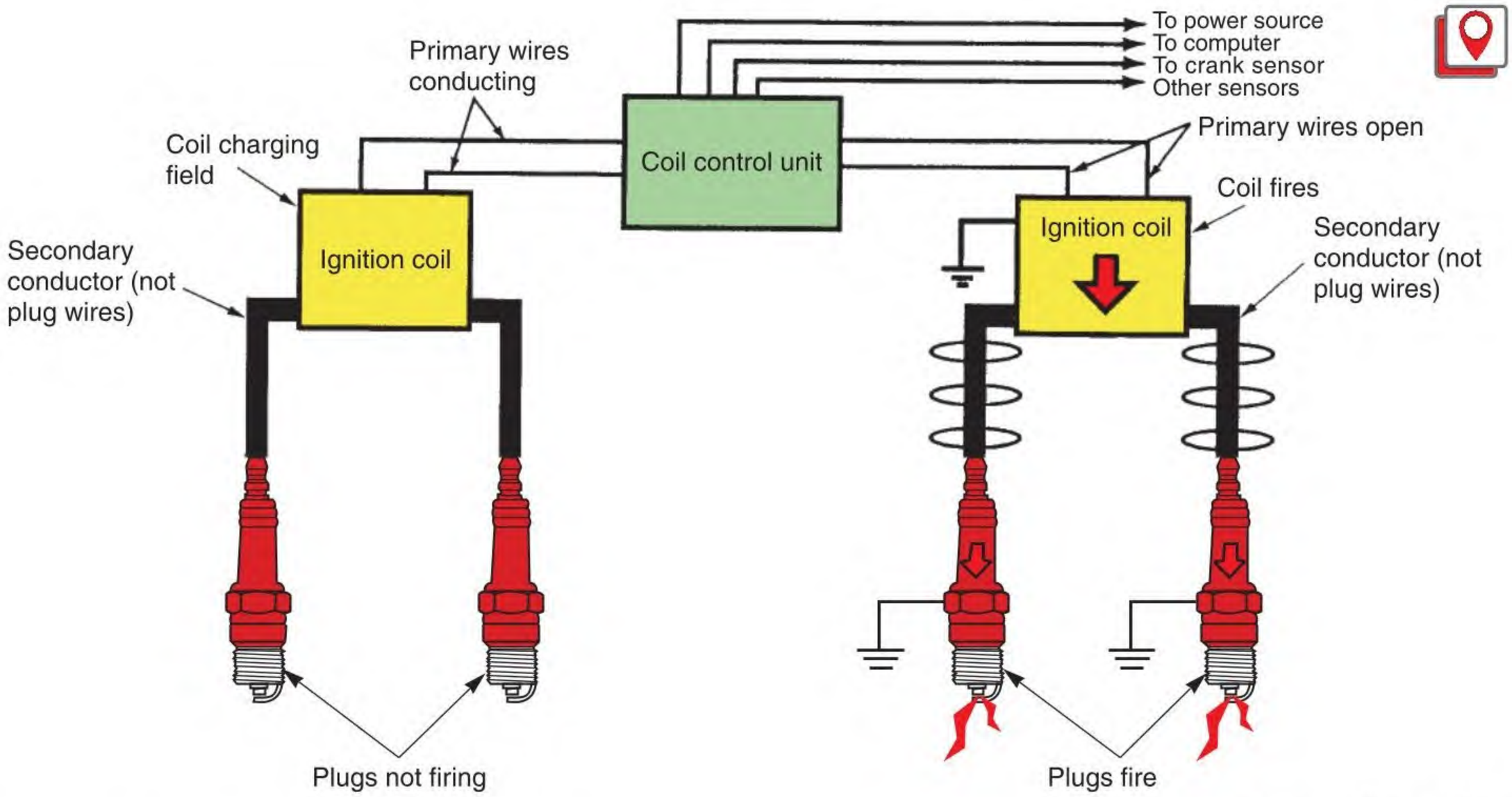
When prompted by the computer and sensors, the coil control unit or engine ECM fires the next ignition coil. Another two spark plugs arc, producing one more power stroke. This process is repeated over and over as the engine runs.



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Figure 34-11. A coil pack ignition system has multiple coils and a coil control unit. Crankshaft and camshaft position sensors feed data to the control unit. Each ignition coil fires two spark plugs.

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Figure 34-12. Simplified illustration of a coil pack ignition. The coil control unit uses various sensor inputs to determine when to fire one of the ignition coils. When one coil fires, two spark plugs fire. One plug produces a power stroke and the other does nothing since its cylinder is on the exhaust stroke. Two coils operate the ignition for a four-cylinder engine. Three coils are needed for a six-cylinder engine.

Direct Ignition System

In a ***direct ignition system***, one coil assembly is mounted directly above each spark plug, **Figure 34-13**. This eliminates the need for spark plug wires. It also allows the use of smaller ignition coils. The other components in a direct ignition system (ECM, sensors, etc.) are the same as those used in a coil pack ignition system.

There is some confusion in the industry about the terms *coil pack ignition* and *direct ignition*. A coil pack ignition system has secondary wires between the coils and spark plugs. In a direct ignition system, one ignition coil is mounted over the top of each spark plug. There is no need for spark plug wires, just a short secondary conductor from the coil secondary output to the spark plug terminal. Study the direct ignition system wiring diagram in **Figure 34-14**.

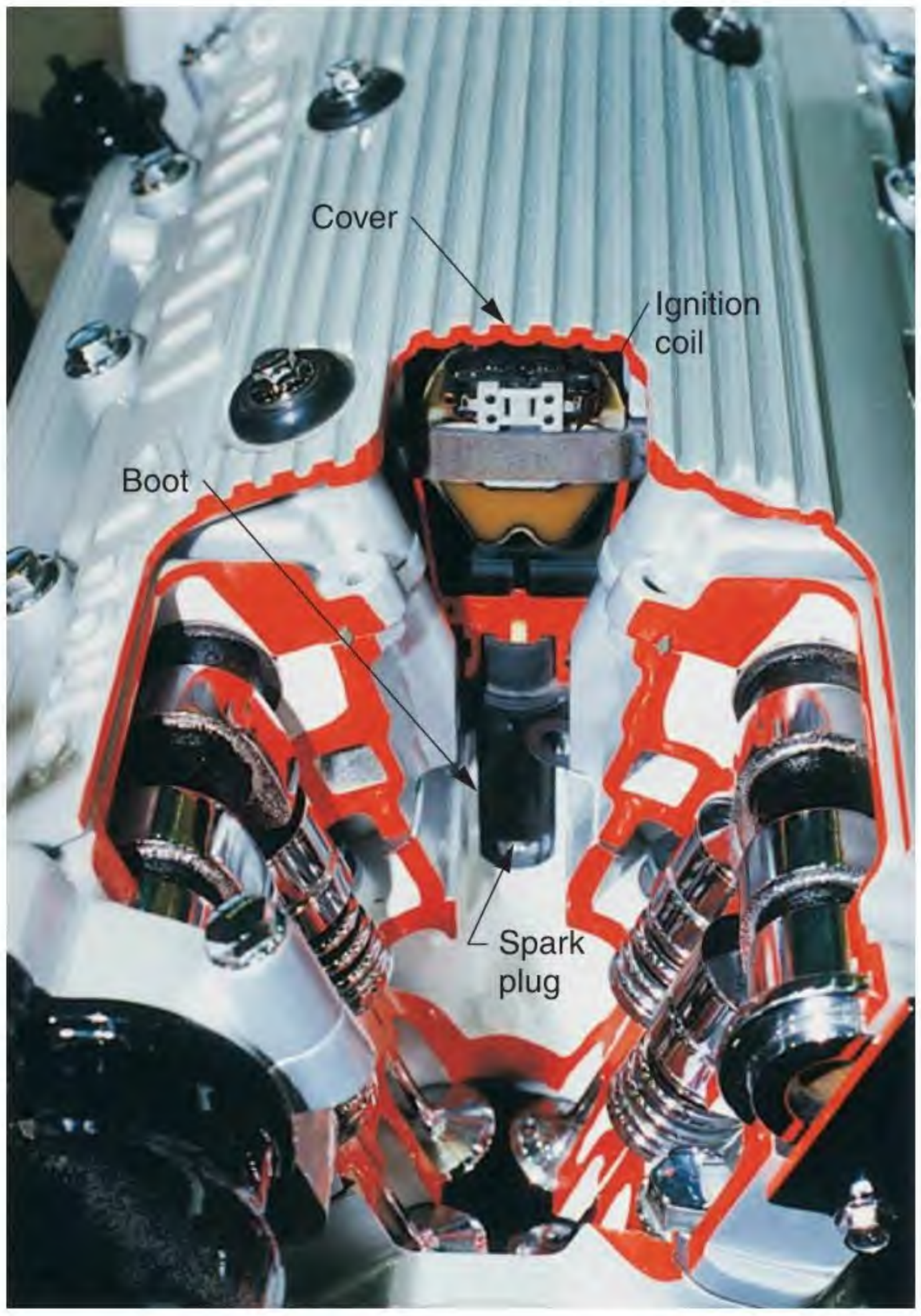
Tech Tip

In some multi-coil ignition systems, the engine control computer measures the time needed to charge each ignition coil. Charge time varies with each coil's resistance/inductance and with the output voltage from the alternator or HV power control module. The ECM uses this charge time to determine the ignition coil on-time for optimum spark plug arc duration and spark timing.

Ionization Knock Sensing

In some cases, an ***ionization knock sensing*** system is used to detect abnormal combustion and knocking. In these systems, the coil computer prompts the ignition coil to send a low-voltage discharge across the spark plug gap immediately following combustion. The quality of combustion affects the resistance across the plug gap by varying the degree of ionization (process by which atoms gain or lose electrons) in the gases between the plug's electrodes.

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Figure 34-13. This engine cutaway shows a coil mounted over a spark plug.

Consequently, the quality of combustion influences the strength of the discharge across the gap. The computer uses feedback from the discharge to determine if the spark advance or the supercharger or turbocharger boost should be modified to reduce knocking. A conventional knock sensor is not needed on an engine with an ionization knock sensing system.

Dual Spark Plug Ignition

A few engines have a ***dual spark plug ignition system***. In this type of system, two spark plugs are used in each cylinder. For instance, a four-cylinder engine would use eight spark plugs. One plug is located near the intake valve and the other is near the exhaust valve. Dual plugs help ensure better ignition and combustion of the air-fuel mixture.

In some dual spark plug systems, one ignition coil is used to fire both spark plugs in a given cylinder at the same time, similar to a coil pack ignition. Other systems contain a separate coil for each plug. This results in two very powerful electric arcs that can ignite and burn fuel more completely, especially at high engine speeds and boost levels.

Multiple Discharge Ignition

A ***multiple discharge ignition system*** fires the spark plugs more than once during each power stroke. By producing a series of sparks, the multiple discharge system helps ensure more complete burning of the fuel charge. This type of ignition system is commonly used on racing engines and on some late-model engines with direct fuel injection. Each ignition coil can be fired hundreds of times or more per power stroke.

Distributor Ignition Systems

An ignition distributor is used in older ignition systems. An ignition distributor, **Figure 34-15**, typically has several functions:

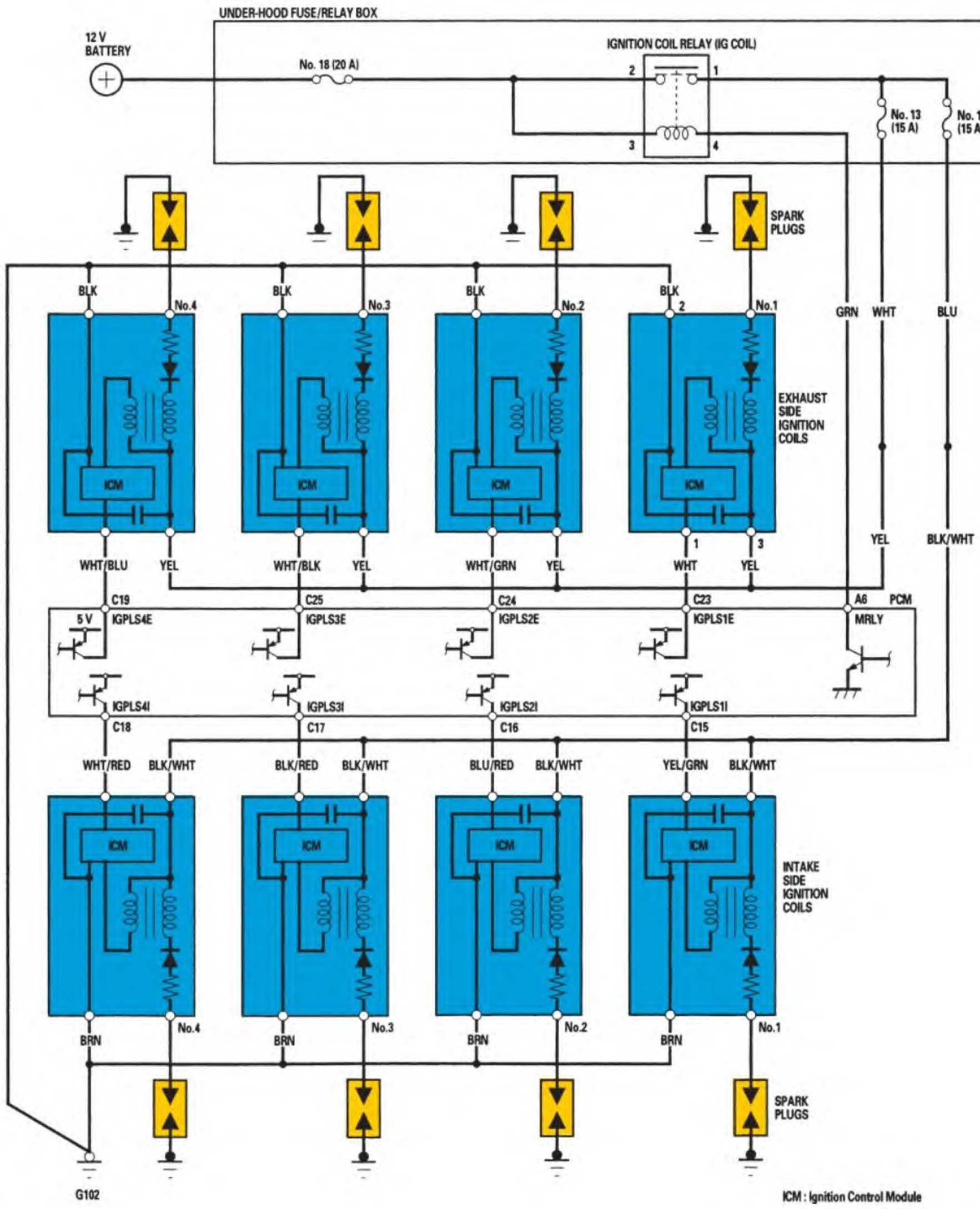
- It actuates the *on*/*off* cycles of current flow through the ignition coil primary windings.
- It distributes the coil's high-voltage pulses to the spark plug wires.
- It causes the spark to occur at each plug earlier in the compression stroke as engine speed increases and vice versa.
- It changes spark timing with changes in engine load. As more load is placed on the engine, the spark timing must occur later in the compression stroke to prevent spark knock (abnormal combustion).
- Sometimes, the bottom of the distributor shaft powers the engine oil pump.
- Some distributors (unitized distributors) house the ignition coil and electronic switching circuit in one assembly.

Engine Firing Order

Engine firing order refers to the sequence in which the spark plugs fire to cause combustion in each cylinder. A four-cylinder engine may have one of two firing orders: 1-3-4-2 or 1-2-4-3. The cylinders are numbered 1, 2, 3, and 4, starting at the front of the engine. In this way, you can tell which cylinders will fire in sequence. Firing orders and cylinder numbers for V-6 and V-8 engines vary. See **Figure 34-16**.

The engine firing order is sometimes cast into the top of the intake manifold. When not on the manifold, the firing order can be found in a service manual.

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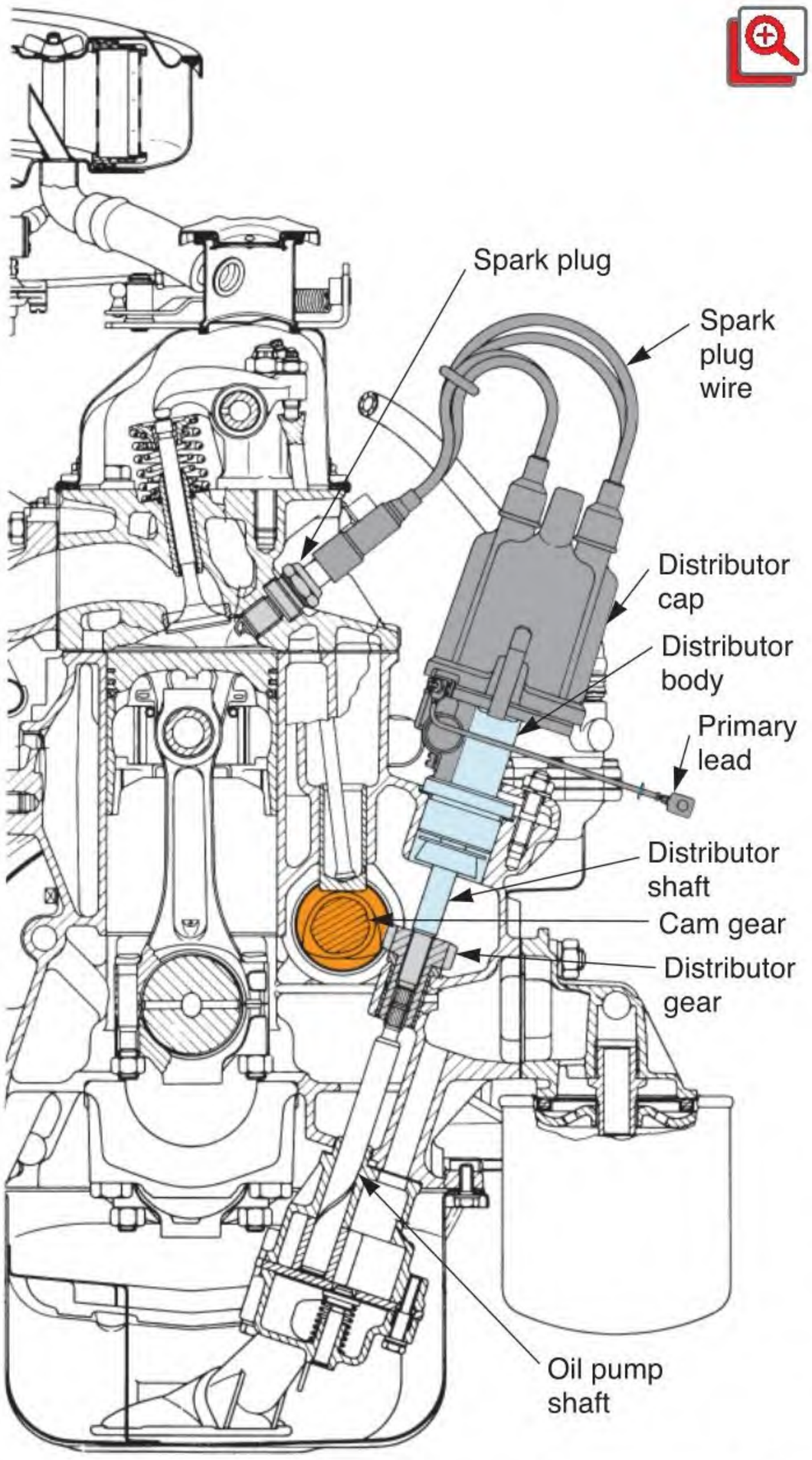
Figure 34-14. This ignition system is for a four-cylinder engine used in a hybrid vehicle. The intake-side ignition coils fire spark plugs near the intake valves, and the exhaust-side ignition coils fire spark plugs near the exhaust valves.

Ignition Timing

Ignition timing, also called ***spark timing***, refers to how early or late the spark plugs fire in relation to the position of the engine pistons. Ignition timing must change with changes in engine speed, load, air-fuel mixture, and temperature.

Timing advance occurs when the spark plugs fire sooner during the engine's compression strokes. The timing is set several degrees before top dead center (TDC). Even more timing advance is needed at higher engine speeds to give combustion enough time to develop pressure on the power stroke. See **Figure 34-17**.

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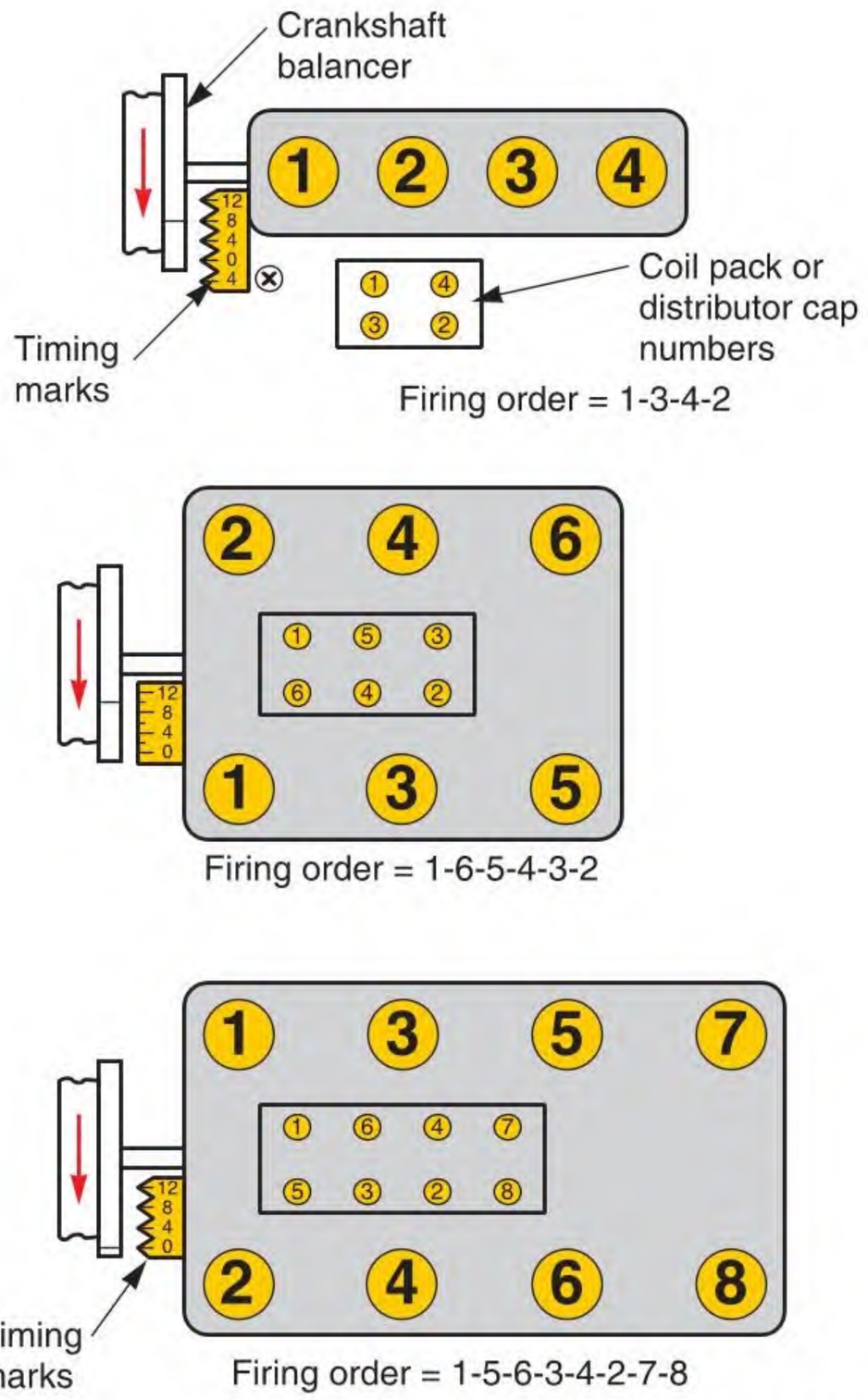


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Figure 34-15. The ignition distributor is usually driven by the engine camshaft. A small gear on the camshaft drives the gear on the distributor a one-half engine speed. The main purpose of the distributor is to feed coil voltage to the spark plugs.

Timing retard occurs when the spark plugs fire later during the compression strokes—opposite of timing advance. Timing retard is needed at lower engine speeds and under high load conditions. Timing retard prevents the fuel from burning too much on the compression stroke, causing a spark knock or ping (abnormal combustion).

The spark advance systems found on late-model vehicles use engine sensors, an ignition control module, and/or an engine or power train ECM to adjust ignition timing.



Mitchell Manuals and Echlin

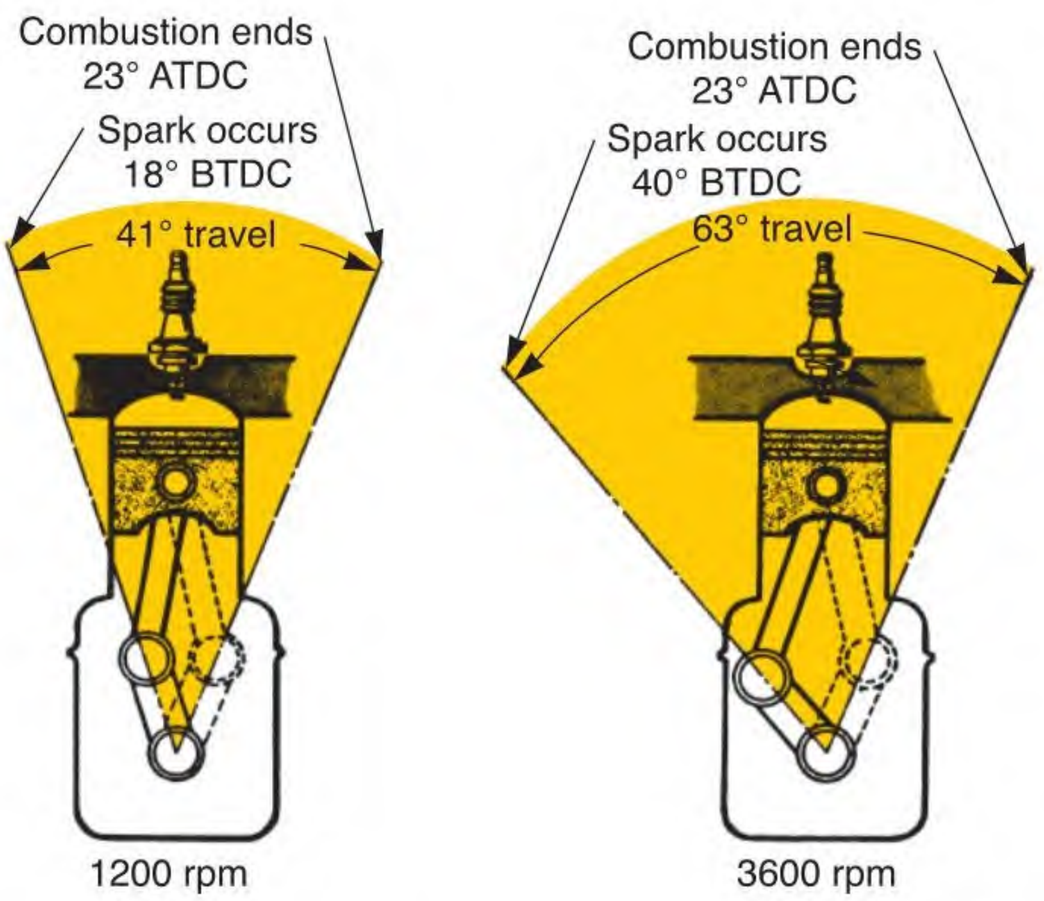
Figure 34-16. Firing order is the sequence in which the spark plugs fire inside the engine. Firing order information is used when installing plug wires, checking ignition timing, and other operations.

The ***engine sensors*** check various operating conditions and send electrical data representing these conditions to the computer. The computer can then analyze the data and change ignition timing for maximum engine efficiency.

Sensors that influence ignition timing include:

- ***Crankshaft position sensor***—Reports engine rpms to the computer.
- ***Camshaft position sensor***—Tells the computer which cylinder is on its power stroke.
- ***Manifold absolute pressure sensor***—Measures engine intake manifold vacuum, an indicator of load.
- ***Intake air temperature sensor***—Checks temperature of air entering the engine.

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Sun Electric Corp.

Figure 34-17. Study how ignition spark timing is altered with changes in engine rpms and other conditions. Since each combustion flame period takes about the same amount of time, the electric spark at the air gap must start combustion sooner as engine speed increases. This will ensure that all the fuel is burned on the power stroke and that sufficient pressure acts on the piston.

- ***Engine coolant temperature sensor***—Monitors the operating temperature of the engine by measuring the temperature of the engine coolant.
- ***Knock sensor***—Allows the computer to retard timing when the engine pings or knocks.
- ***Throttle position sensor***—Notes the position of the throttle.

The ECM receives input signals (different current or voltage levels) from these sensors, and it can measure battery voltage to compensate for voltage variations due to battery state-of-charge, accessory loads, etc. It is programmed (preset) to adjust ignition timing to meet different engine operating conditions. The ECM may be mounted under the dash, on the air cleaner, on the fender inner panel, or under a seat.

For an example, imagine a car or light truck traveling down the highway at 55 mph (88 km/h). The crankshaft sensor detects moderate engine rpms. The throttle position sensor detects part throttle. The intake air and coolant temperature sensors detect normal operating temperatures. The manifold absolute pressure sensor detects high vacuum. The sensors send signals representing these values and conditions to the ECM.

Based on the sensor signals, the ECM circuitry calculates that the engine needs almost maximum spark advance. It then advances timing so the spark occurs several degrees before TDC on the compression stroke. This ensures that the engine attains high fuel economy on the highway. There is enough time for all the fuel to burn and produce maximum pressure on the downward motion of the pistons.

If the driver began to pass a car and pressed down on the accelerator to open the throttle valve more, engine intake manifold vacuum would drop. A manifold absolute pressure sensor signaling this drop in intake manifold vacuum would be sent to the computer. The throttle position sensor would detect wide open throttle (WOT). Other sensor outputs would stay about the same. Based on the signals from the manifold absolute pressure sensor and the throttle position sensor, the computer would retard ignition timing to prevent spark knock or ping.

Since computer systems vary, refer to a service manual for more information. The manual will detail the operation of the specific ignition system for that make and model vehicle.

Summary

- An ignition system amplifies battery voltage (12.6 volts) or charging system voltage (13 to 15 volts) to over 40,000 volts, and delivers this voltage to the spark plugs at the right time.
- The primary circuit of the ignition system consists of all the components and wires that operate on low 12-volt dc from the battery, alternator, or current from the HV power control module.
- The secondary circuit of the ignition system includes all the components that carry high-voltage current.
- The secondary operating voltage of the ignition system can range from 4,000–100,000 volts, depending on system design.
- The spark plugs use ignition coil high voltage to ignite the fuel mixture.
- An ignition coil is a pulse-type transformer capable of producing the short bursts of high-voltage current that pass through the secondary resistance wires (if used), and jump the spark plug gap.
- A coil pack ignition system, also called a distributorless ignition, uses multiple ignition coils, a coil control unit, engine sensors, and a computer (engine control module) to operate the spark plugs.

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- In a direct ignition system, one coil assembly is mounted directly above each spark plug, eliminating the need for spark plug wires.
- In a dual spark plug ignition system, two spark plugs are used in each cylinder.
- A multiple discharge ignition system fires the spark plugs more than once on each power stroke, which ensures more complete burning of the fuel charge.
- An ignition distributor is used on older ignition systems to distribute the coil's high-voltage pulses to the spark plug wires.
- Engine firing order refers to the sequence in which the spark plugs fire to cause combustion in each cylinder.
- Ignition timing must change with changes in engine speed, load, and temperature.
- An electronic spark advance system uses engine sensors, an ignition control module, and/or a computer (engine or power train ECM) to adjust ignition timing.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

boots
camshaft position sensor
center terminal (center electrode)
ceramic insulator
coil pack
coil pack ignition
cold spark plug
crankshaft position sensor
direct ignition coil
direct ignition system
dual spark plug ignition system
electronic coil module
engine coolant temperature sensor
engine firing order
engine sensors
grounded side electrode
hot spark plug
ignition coil
ignition coil open-circuit voltage
ignition control module (ICM)
ignition system
ignition system supply voltage
ignition timing
intake air temperature sensor
ionization knock sensing
knock sensor
manifold absolute pressure sensor
multiple discharge ignition system
non-resistor spark plug
primary circuit
primary windings
radio suppression wires
resistor spark plug
secondary circuit
secondary operating voltage
secondary windings
secondary wires
spark plug gap
spark plug heat range
spark plug reach
spark plug wires
spark plugs
spark timing
steel shell
throttle position sensor
timing advance
timing retard
waste-spark ignition system
windings

Activities

1. If you have access to a computer with a CAD or drawing program, use it to make a cross-sectional drawing of a resistor-type spark plug. Label the components and then output the drawing to a printer, if available.
2. Make a list of the various engine sensors used with an electronic spark advance system. Describe the purpose of each sensor.
3. Using a computerized service information system, identify the firing order of the spark plugs for two different makes of four-, six-, and eight-cylinder engines.
4. Make a wall chart comparing coil pack and direct ignition system types.

Review Questions

Answer the following questions using the information provided in this chapter.

1. List and explain each of the basic parts of an ignition system.
2. Define the terms *primary circuit* and *secondary circuit*.
3. An ignition system _____ is used to ignite the air/fuel mixture in the engine combustion chamber.
4. A secondary voltage between _____ and _____ volts is needed to operate a spark plug.

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5. Why do most vehicles require resistor spark plugs?
6. Spark plug gap is the distance between the center electrode and side electrode. True or False?
7. A cold spark plug might be beneficial in an older engine that burns some oil. True or False?
8. A modern ignition coil is capable of producing an open-circuit voltage of:
   (A) 7,000–9,000 volts.
   (B) 10,000–15,000 volts.
   (C) 40,000–100,000 volts.
   (D) None of the above.
9. The primary windings of an ignition coil are several hundred turns of heavy wire. True or False?
10. When the current flowing through the ignition coil is interrupted, the magnetic field collapses and induces high voltage into the _____ windings of the coil.
11. A(n) _____ ignition system has one coil for every two engine cylinders.
12. A waste-spark ignition coil fires two spark plugs at once. True or False?
13. One coil assembly is mounted above each spark plug in the engine in a(n) _____ system.
14. An ionization knock sensing system is used to detect abnormal combustion and knocking. True or False?
15. Explain the difference between coil pack ignition and direct ignition systems.
16. All of the following are functions of a distributor in a distributor ignition system *except:*
   (A) analyzes sensor data to advance spark timing.
   (B) changes spark timing with changes in engine load.
   (C) actuates *on/off* cycles of current flow through ignition coil primary windings.
   (D) distributes the coil's high-voltage pulses to the spark plug wires.
17. The sequence in which the spark plugs operate to cause combustion in each cylinder is called _____.
18. Timing retard is needed at _____ engine speeds and under _____ load conditions.
19. An electronic spark advance system uses engine sensors, an ignition control module, and/or a computer to adjust _____.
20. Explain how an electronic spark advance system functions.

ASE-Type Questions

1. An ignition system uses this to change battery voltage into high secondary voltage:
   (A) spark plug.
   (B) bypass circuit.
   (C) ignition coil.
   (D) spark advance system.
2. Which of the following provides voltage to the battery and ignition system *after* an engine is running?
   (A) Alternator.
   (B) Condenser.
   (C) Primary circuit.
   (D) None of the above.
3. Ignition system wires that operate at battery voltage are considered part of the:
   (A) ignition coil.
   (B) primary circuit.
   (C) secondary circuit.
   (D) primary windings.
4. Which of the following spark plug components causes electricity to jump the gap and return to the battery through frame ground?
   (A) Shell.
   (B) Insulator.
   (C) Side electrode.
   (D) Center terminal.
5. Technician A says that with modern ignition coils, open-circuit voltage can reach 100,000 volts. Technician B says that average operating voltages for an ignition system are about 15,000 volts. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Technician A says that no coil wire is needed with an ignition coil pack. Technician B says that an eight-cylinder engine equipped with a coil pack system uses two ignition coil packs. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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7. A direct ignition system uses:
   (A) spark plug wires.
   (B) a distributor.
   (C) one coil per spark plug.
   (D) All of the above.
8. Technician A says a multiple discharge ignition system fires the spark plug during each of the engine's four-cycle strokes. Technician B says that a dual spark plug ignition system ensures better ignition and combustion of the air-fuel mixture than a single spark plug per cylinder system. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Technician A says late-model vehicles keep ignition timing the same under varying conditions and engine speeds. Technician B says that most late-model vehicles require non-resistor spark plugs. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. Which of the following is *not* a typical electronic spark advance ignition system sensor?
   (A) Vehicle height sensor.
   (B) Knock sensor.
   (C) Manifold absolute pressure sensor.
   (D) Crankshaft position sensor.

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Chapter 35
Ignition System Diagnosis, Testing, and Repair

After studying this chapter, you will be able to:

- List the symptoms produced by faulty ignition system components.
- Diagnose typical ignition system problems.
- Describe common tests used to find ignition system troubles.
- Explain how to replace or repair ignition system parts.
- Describe safety practices to follow when testing or repairing an ignition system.
- Correctly answer ASE certification test questions on the diagnosis and repair of ignition systems.

An ignition system is required to ignite an engine's fuel in a gasoline or flex-fueled engine, although not in a diesel engine. If a problem exists in the ignition system, engine performance and emissions will suffer. As a service technician, you must be able to quickly and accurately correct any ignition system troubles.

Complete ignition system part failure can prevent the engine from starting. Problems caused by spark plugs, secondary wires, ignition coils, ECMs, and related wiring manifest themselves in a variety of ways (glowing indicator light in the dash, engine missing, poor fuel economy, engine spark knock, etc.). If the malfunction indicator light (MIL) is on, it should be noted on your shop's repair order so you would know to scan the vehicle first to verify the problem source before performing other tests. See **Figure 35-1**.

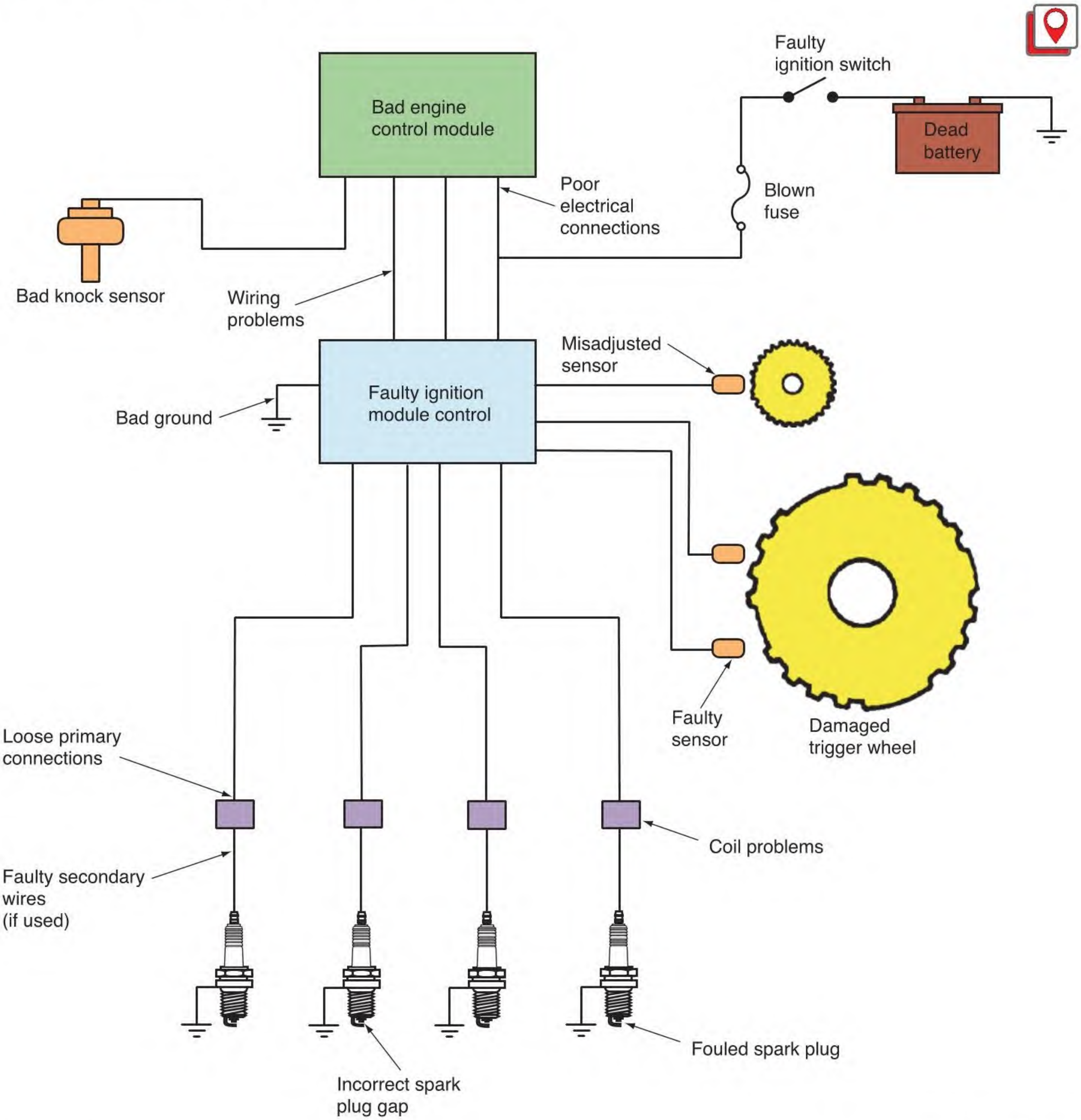
Ignition System Diagnosis

To start diagnosis, visually inspect the ignition system with and without the engine running. Look for obvious problems, such as loose primary connections to ignition coils, a disconnected spark plug, loose direct ignition coil fasteners, deteriorated secondary wire insulation, a damaged coil pack, burned ignition system control module fuse, and other troubles. See **Figure 35-2**. At the same time, look over other engine systems and try to find anything that could upset engine operation.

Scanning Ignition System Problems

After inspection is complete, connect a scan tool to the vehicle's diagnostic connector under the dash to find many ignition-related problems. Look at **Figure 35-3**.

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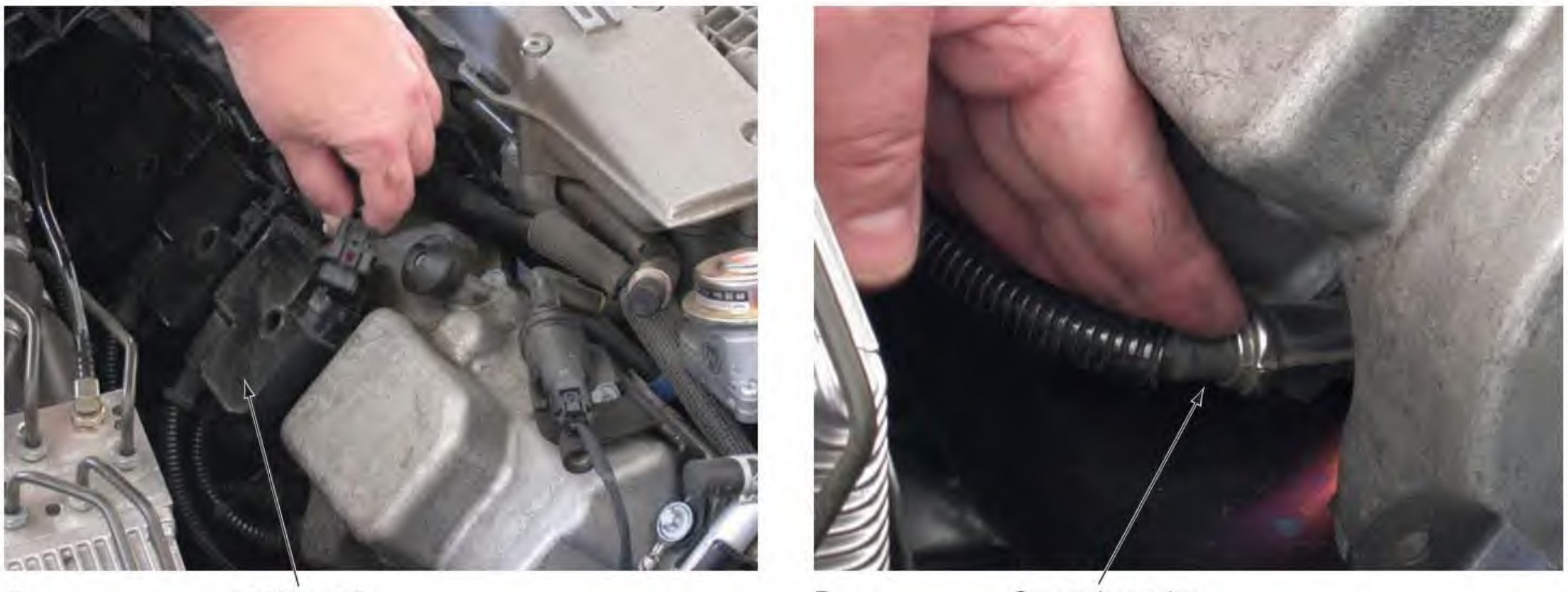
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Figure 35-1. Note some of the problems you will find in a modern ignition system.

The scan tool can detect troubles in the following ignition system circuits, components, and conditions:

- Crankshaft position sensor.
- Camshaft position sensor.
- Knock sensor.
- Ignition coil(s) primary circuit.
- Ignition coil(s) secondary circuit.
- Timing reference signal and timing advance circuit.
- Spark plug and coil secondary wire radio interference.
- Engine misfire (on-board computer conclusion from analyzing crank speed fluctuations, spark duration, and other circuit values and frequencies).

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A Ignition coil **B** Secondary wire

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Figure 35-2. Visually inspect the ignition system with and without the engine running. A—Loose electrical connections can cause problems in the ignition system. This technician is securing a loose connector to the coil module on a direct ignition system. B—Check that the secondary wires are fully locked onto their spark plugs.



Snap-on Tool Corp.

Figure 35-3. Scan tools can find problems with ignition system sensors, ignition coils, spark plugs, engine valves, piston rings, pistons, and can even tell you which engine cylinder is missing and not firing its fuel.

Start your pinpoint tests at the component or circuit indicated by the scan tool readout. You might test the component first and then its circuit. This will depend on the specific circumstances of the symptoms, part location, and vehicle design.

If your scan tool readout displays a ***misfire code***, the engine has failed to ignite and burn its air-fuel mixture properly. Engine misfire increases exhaust emissions, fuel consumption, and engine vibration, while reducing engine power.

A misfire code indicates which engine cylinder is not producing combustion normally. Misfire can be caused by problems in the ignition system, the fuel injection system, the emission control system, or the engine itself (low compression, for example). Additional tests and more specific scan tool data are needed to pinpoint the cause of the misfire condition.

Start your meter tests at the engine cylinder indicated by the scan tool trouble code. If, for example, your scan tool indicates a misfire in the number three cylinder, check that cylinder's spark plug or direct ignition coil first.

Caution

A computerized ignition system can be seriously damaged if the wrong wire is shorted to ground, or if a meter is connected improperly. Always follow manufacturer's testing procedures.

Spark Intensity Testing

A ***spark intensity test***, or ***spark test***, checks the strength of the electric arc (spark) produced by the ignition system. It is a quick and easy way to check the general condition of the ignition system.

The spark intensity test is often used when an engine cranks, but will not start. The test will tell you

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whether the trouble is in the fuel system ("no fuel" problem) or the ignition system ("no spark" problem). It may also be used to check the condition of the spark plug wires, ignition coils, and other secondary components.

Tech Tip

When testing a direct ignition system, it may be helpful to remove the coils and connect conventional spark plug wires between the coil output terminals and the spark plugs. This will let you connect a spark tester, an inductive tachometer, and other test instruments to the system.

Spark Test Procedures

A ***spark tester*** is a device that is used to check ignition system output voltage. It looks like a spark plug with a large air gap and an alligator clip test lead.

Service Procedure

To perform a spark intensity test:

1. Remove one of the secondary wires from a spark plug or from a suspect direct ignition coil.
2. Insert the spark tester into the wire or the coil's secondary conductor terminal.
3. Ground the spark tester by connecting the alligator clip to a good ground on the engine or unibody (frame).
4. Crank or start the engine and observe the spark at the tester's air gap. Refer to **Figure 35-4**.

Caution

Only run the engine for a short period of time with a spark plug wire or direct ignition coil off its spark plug. Unburned fuel from the dead cylinder could foul and ruin the catalytic converter after prolonged engine operation.



Snap-on Tool Corp.

Figure 35-4. A bright arc should jump the gap in the spark tester. No spark or a weak spark indicates ignition system troubles. This tests the general high voltage output of the ignition coil and any plug wire.

Spark Test Results

A strong spark (wide, bright, snapping electric arc) should jump the tester's air gap. This shows that ignition system primary and secondary voltages are good. A strong spark also indicates that the ignition coil, crankshaft position sensor, ignition control module, and other ignition system parts are functioning. If a strong spark is present, the engine no-start problem may be due to oil-fouled spark plugs, fuel system problems, ignition switch or engine troubles.

A weak spark or no spark indicates that something is wrong inside the ignition circuit. If the spark is weak at all the spark plug wires, the problem is common to all the cylinders . If you are not getting a good, hot spark, you may want to check the coil supply voltage. If a coil is not getting full battery voltage or if the coil windings partially fail, the ignition system will not produce a secondary arc at the plug tip or the arc will be too weak to start combustion.

Checking for a Dead Cylinder

A ***dead cylinder*** is an engine combustion chamber that is not igniting and burning its fuel-air mixture on that cylinder's power stroke. There may be ignition system troubles or problems in the engine itself, the fuel system, starting system, or another system.

Symptoms of a dead cylinder include a very rough idle and a puffing noise at the engine's exhaust tailpipe. A dead cylinder is considered an extreme misfire condition because none of the fuel is "firing" and burning.

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To check for a dead cylinder in a direct ignition system, pull off the suspect cylinder's ignition coil primary connector. With older ignition designs, pull off one secondary coil or spark plug wire. On a "live" or firing cylinder, disabling the high-voltage source to one spark plug will cause engine speed to drop and the idle to become rougher. With a dead cylinder, idle smoothness and engine speed will *not* change when the high-voltage source for that cylinder is removed.

After locating the dead cylinder, check for spark and study the spark plug's condition. Also measure for low cylinder compression pressure. Today's OBD systems automatically check for engine misfire and dead cylinders by reading abnormal speed signals from the crankshaft and camshaft sensors and will set a trouble code. A dead cylinder causes the crankshaft to momentarily slow down during a few degrees of rotation when the bad cylinder is not firing and helping to spin the crankshaft.

High-Voltage Leakage Test

After prolonged service, the secondary or high-voltage ignition circuit can fail. This usually occurs due to internal high-voltage arcing that eventually burns circuit conductors. You will often find burned secondary connections inside direct and indirect (with spark plug wire) ignition coils. The insulation can burn and harden from the heat of unwanted electrical sparks in the conductors.

Service Procedure

To check an ignition system for high-voltage leakage:

1. Place a hood cover over the engine compartment to fully darken your inspection area, which will help you view any electric sparks on ignition components, **Figure 35-5**.
2. Install a vent hose over the vehicle's tailpipe.
3. Chock the wheels, put the transmission in *Park*, and set the emergency brake.
4. Start the engine.
5. While wearing rubber gloves and eye protection, place your head under the hood cover to inspect for high-voltage leakage.
6. Move the primary and secondary conductors in their connectors while looking for small sparks jumping off of components.
7. Ground a non-powered test light and move it over secondary wires and conductors. The metal probe on the test light will attract any electrical leakage and will glow.
8. Replace any components that show electrical leakage.
9. If the engine has a direct ignition, you must remove each ignition coil to inspect its high-voltage connection to its spark plug.



OTC/SPX Corp.

Figure 35-5. To check for high-voltage leakage in the ignition secondary, you must block outside light from the engine compartment. This technician is using a special cover so the area around the engine is dark. This will make small sparks easy to find.

Tech Tip

Many late-model ignition systems apply full-battery voltage to the ignition coil primary terminal. The ignition coil primary voltage is grounded by the ignition or engine electronic control module power transistor circuits.

Ignition Primary Voltage Testing

The ***ignition primary voltage test*** checks the voltage being fed to the ignition coil. If the ignition system fails a spark test, an ignition primary voltage test may help you locate the source of the problem.

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Service Procedure

To check for proper primary voltage to the ignition coils in a direct ignition system:

1. Disconnect the primary connector to one of the ignition coils on the engine.
2. Install test jumper wires between the harness connector and the coil connector.
3. Connect your high-impedance meter leads to the bare metal conductors on the jumper wires.
4. Measure the voltage applied to the ignition coil with the ignition switch in the *Run* position. Compare the reading to specifications.

If the voltage across the ignition primary is too low or too high, you could have a problem in the coil windings. You could also have a circuit problem in the ignition module or engine module affecting applied ignition coil voltage or ECM applied ground for the ignition coil primary circuit.

Ignition Circuit Scope Testing

An oscilloscope, or scope, precisely measures the operating voltages of analog and digital signals present in a modern ignition system over specific time intervals. Study **Figure 35-6**.



OTC/SPX Corp.

Figure 35-6. A handheld scope is handy for advanced ignition system testing. It gives voltage, current, and resistance readings, and shows scope waveforms for advanced troubleshooting of the ignition system and other systems.

Often built into advanced scan tools and laptop diagnostic software, the scope uses a display screen to show slight changes in voltage over small periods of time. The technician can compare actual ignition system voltage over time, and also compare them with known good patterns. Any variance from spec voltage levels and signals in the ignition system will pinpoint problems to components or computer systems (ignition control module, engine control module, or coil control modules).

Evaluating Ignition System Test Results

After performing preliminary ignition system tests, you must evaluate the test results and narrow down the possible causes. Use your knowledge of system operation, a service manual troubleshooting chart, basic testing methods, and common sense to locate the trouble.

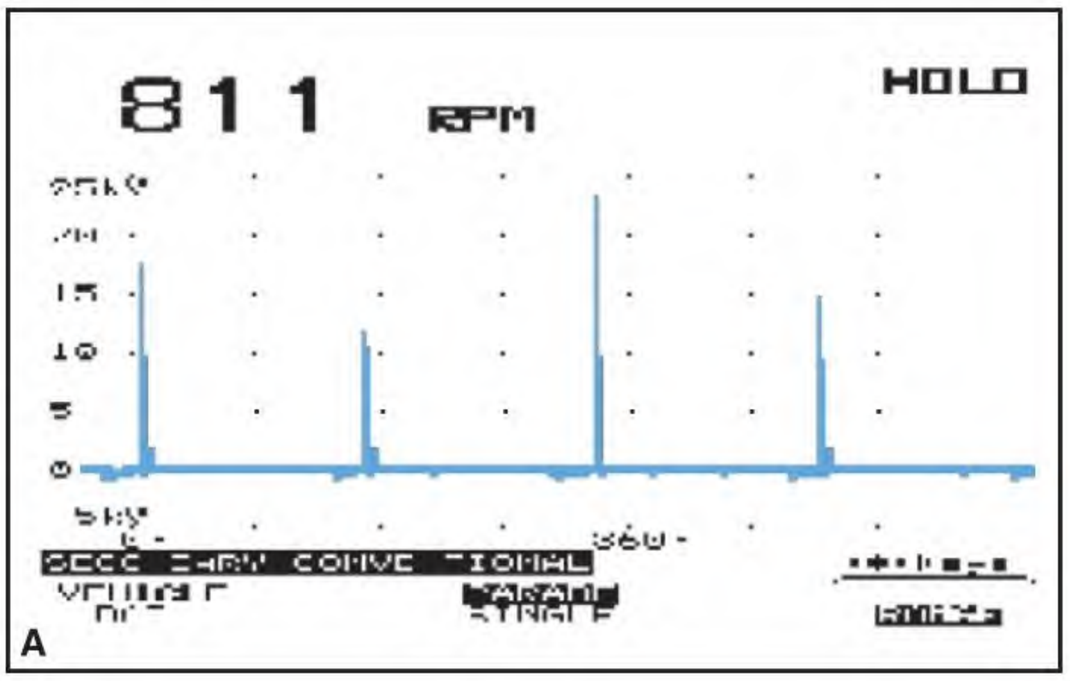
Spark Plug Service

Bad spark plugs can cause a wide range of problems, including misfiring, lack of engine power, poor fuel economy, exhaust odor, and hard starting. With a high-mileage engine, the spark plug tip can become coated with ash, oil, and other substances. This may allow high voltage to flow over the deposits and to ground without arcing or sparking. The engine may miss and stumble upon rapid acceleration.

The spark plug electrodes can also be etched away by prolonged use. The millions of electric arcs that have occurred after prolonged service tend to erode the metal inside the spark plug gap, widening the air gap. This will make it more difficult for the ignition system to produce an arc between the electrodes. Wider spark plug gaps require an increased secondary voltage, which can burn other ignition system parts (ignition module, ignition coil, etc.).

To test the spark plugs, use an oscilloscope or scan tool misfire readings. Bad plugs will show up as abnormal scope waveforms (trace or pattern) or as a misfire code. Refer to **Figure 35-7**. If a scope or advanced scan tool is not available, remove the plugs and inspect their condition.

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Fluke

Figure 35-7. Secondary ignition system patterns can provide information on spark plug condition. A—Uneven firing lines are commonly caused by worn spark plugs. B—A short firing line is often caused by a fouled spark plug.

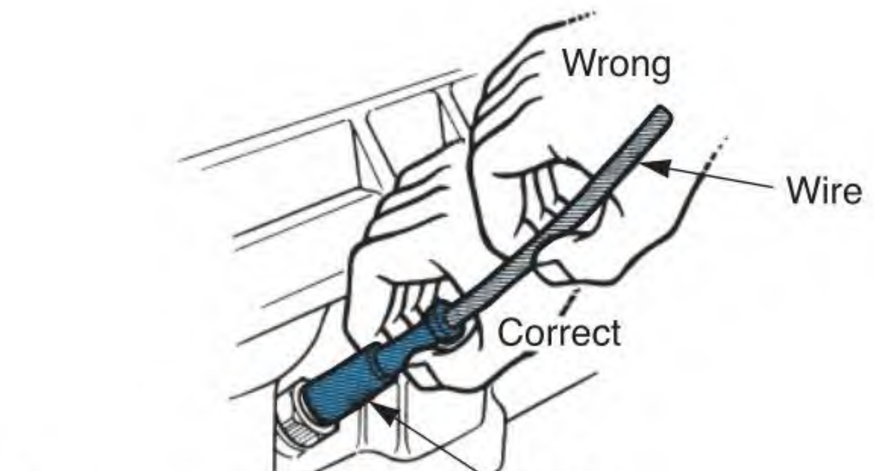
4. Use a blow nozzle to clean off any debris that has collected on top of the engine. Never allow small rocks and other debris to accidentally fall into the spark plug holes and engine cylinders.
5. Unscrew each spark plug using a spark plug socket, an extension, and a ratchet (as needed), **Figure 35-9**.
6. As you remove the plugs, lay them in order on the fender cover or the workbench. Do not mix up the plugs.
7. After all the plugs have been removed, inspect the color and condition of the electrodes to help diagnose the condition of the engine and fuel system.

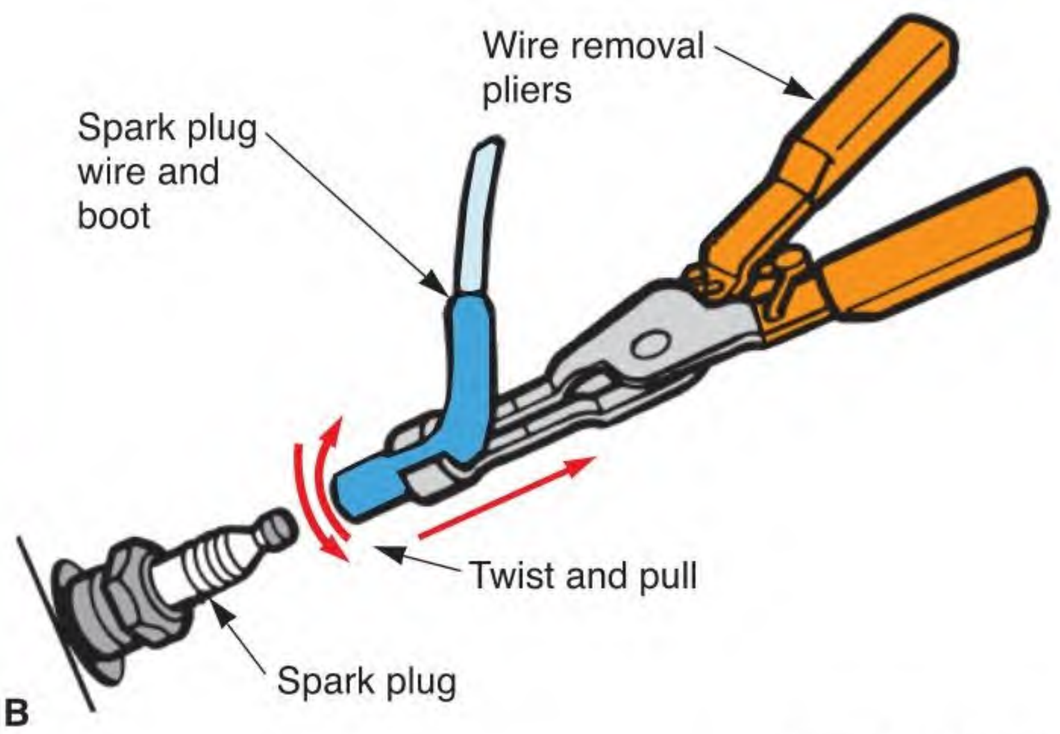
Spark Plug Removal

Service Procedure

To access the spark plugs, you must remove the ignition coils, the coil module, or the spark plug wires:

1. If the engine is equipped with direct ignition coils or a coil module, remove the screws that secure the coils or module to the engine.
2. Wiggle the coil or module while pulling it straight up. This will free each coil terminal from its spark plug terminal.
3. If the engine is equipped with spark plug wires, make sure they are numbered or located correctly in their clips. Grasp a spark plug wire by the boot and pull to disconnect it from its spark plug. See **Figure 35-8**. Twist the boot back and forth if it is stuck on the plug.

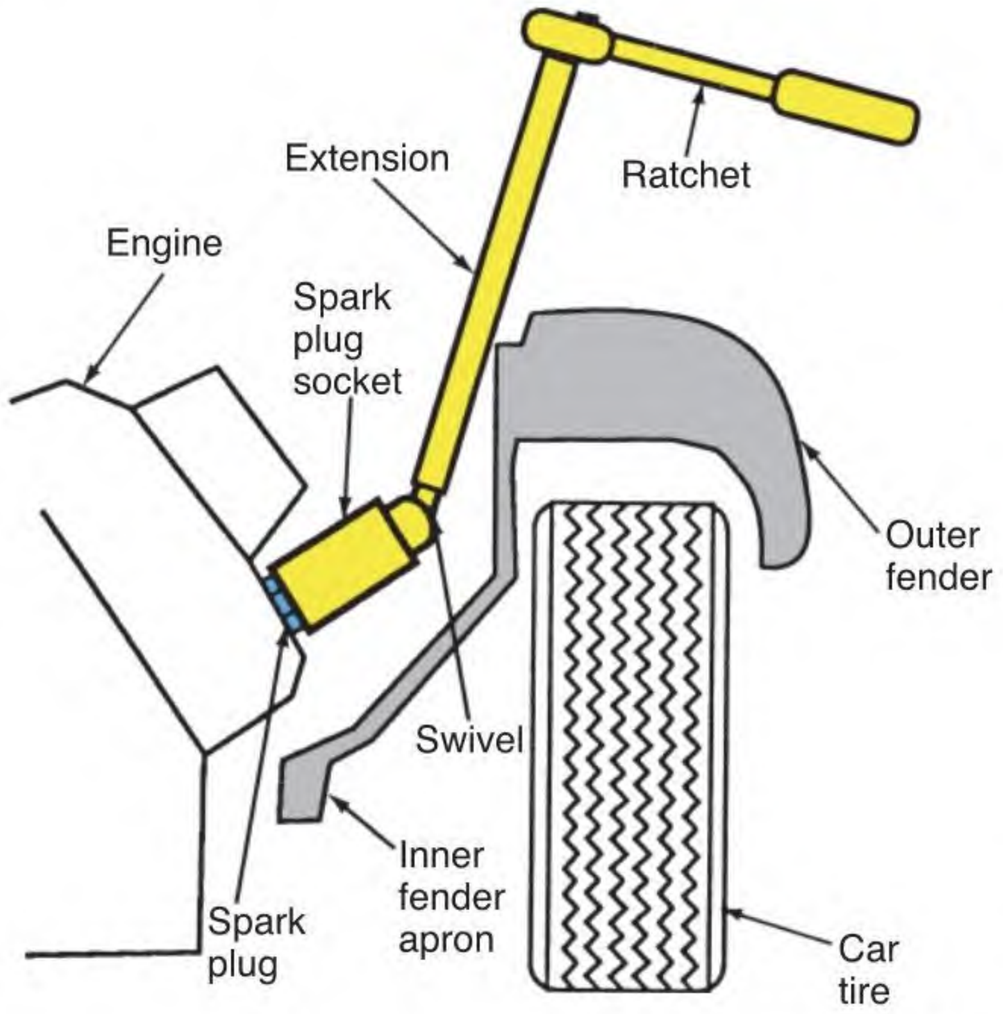




Toyota and Chrysler

Figure 35-8. When removing a spark plug wire, pull on the boot, never on the wire because its powdered carbon conductor can easily break. This would ruin the wire and cause the engine to miss after the repair. A—Sometimes you have to use your fingers to remove a spark plug wire. B—If you have enough clearance for them, use special pliers to grasp and pull on the boot.

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Figure 35-9. With today's cramped engine compartments, there is little room to reach spark plugs. A common fix is to use a swivel-type spark plug socket on a short 3/8th extension. The socket with the extension can reach around obstructions to easily remove or install spark plugs.

Reading Spark Plugs

To read a spark plug, closely inspect and analyze the condition of its tip and insulator, **Figure 35-10**. This will give you information on the condition of the engine, fuel system, and ignition system.

A properly burning plug should have a brown to grayish-tan color. A black or wet plug indicates that the plug is not firing or that there is an engine problem (worn piston rings and cylinders, leaking valve stem seals, low engine compression, or rich fuel mixture) in that cylinder. Study the spark plugs in **Figure 35-11**.

Gapping Spark Plugs

Obtain the correct replacement plug (heat range and reach) recommended by the manufacturer. Then, set the spark plug gap by spacing the side electrode the correct distance from the center electrode. If the new spark plugs have been dropped or mishandled, the gap may not be within specifications.

A wire feeler gauge should be used to measure spark plug gap. Slide the specified size feeler gauge



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Figure 35-10. Read spark plugs by inspecting the condition of insulators and electrodes.

between the electrodes. The gauge should drag lightly as it is pulled in and out of the gap. See **Figure 35-12**.

If needed, bend the side electrode until the feeler gauge fits snugly, **Figure 35-13**. Spark plug gaps vary from approximately 0.030″ (0.76 mm) on older engines to over 0.080″ (2.03 mm) on late-model, high-energy ignition systems.

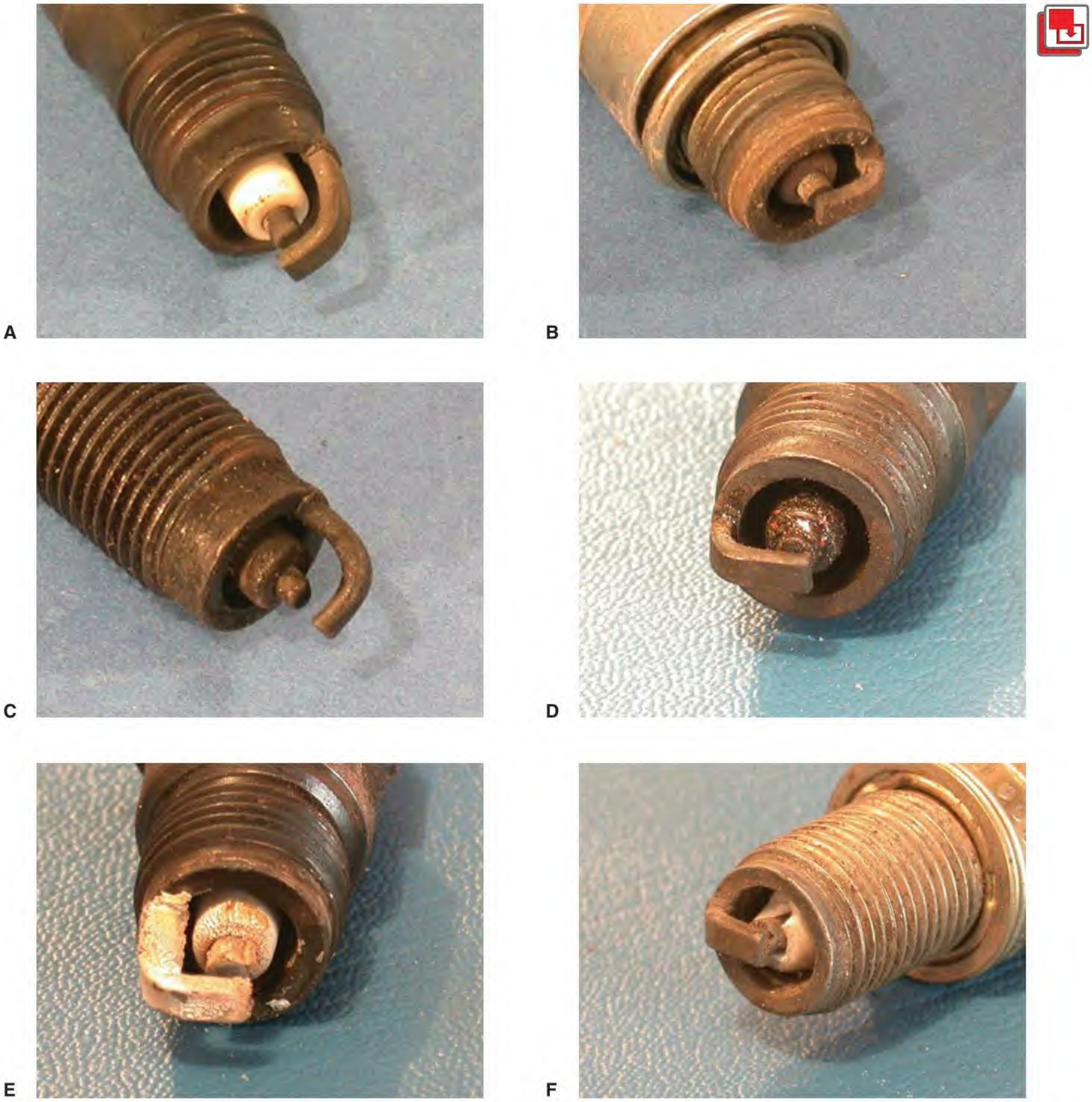
Tech Tip

Wider spark plug gaps (above 0.045″) are needed to burn lean fuel mixtures required by many late-model vehicles. Smaller spark plug gaps (around 0.025″ to 0.030″) are recommended in high-horsepower, turbocharged, and supercharged engines. An electric arc or spark cannot jump a wide air gap when extreme boost and compression pressure builds in the cylinder. A smaller spark plug gap will allow the high voltage to arc to ground to start combustion more easily, even with extreme cylinder boost pressures.

Installing Spark Plugs

Spark plugs that are set to the correct gap are ready for installation. Use your fingers, a spark plug socket, or a short piece of vacuum hose to start the plugs in their holes. Study **Figure 35-14**.

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Figure 35-11. Read the spark plugs by observing the condition of their insulators and electrodes. A—A properly burning plug has minimal deposits and is grayish-tan color. B—This carbon-fouled plug is the result of a prolonged rich air-fuel mixture. C—This high-mileage plug shows erosion at the gap. D—An oil-fouled plug is shiny and dark gray or black in color. E—An ash-fouled plug can result from burning low-quality gasoline. F—The physical damage on this spark plug indicates an internal engine failure. The piston, a broken valve, or foreign matter struck the tip of the plug.

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Figure 35-12. Use a wire feeler gauge to measure gap. Both electrodes should just touch gauge.



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Figure 35-13. If needed, bend the side electrode with a gapping tool to achieve correct electrode spacing. Then recheck the spark plug gap.

Caution

Do not use the ratchet to start the plug in its hole because the plug and cylinder head threads can be cross-threaded and damaged. This is particularly critical when starting plugs in aluminum cylinder heads.



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Figure 35-14. Always start spark plugs with your fingers so you can feel the threads go into the cylinder head without binding. Never use a ratchet or impact wrench to initially thread in spark plugs because they can easily cross-thread in the aluminum cylinder head. If this happens, you might have to remove and replace the damaged cylinder head for free!

After threading the spark plugs into the head a few turns by hand, turn them in the rest of the way with your ratchet. Tighten the spark plugs to specifications. Some manufacturers specify a spark plug torque. Others recommend bottoming the plugs on the seat and then turning them an additional one-quarter to one-half turn. Refer to the appropriate service information for exact procedures.

Secondary Wire Service

A faulty secondary wire can have a burned or broken conductor or deteriorated insulation. Most secondary wires have a resistance conductor that is easily damaged. If the conductor is broken, voltage and current cannot reach the spark plug.

If the secondary wire insulation is faulty, current may leak (or arc) through the insulation to ground or to another wire instead of reaching the spark plugs.

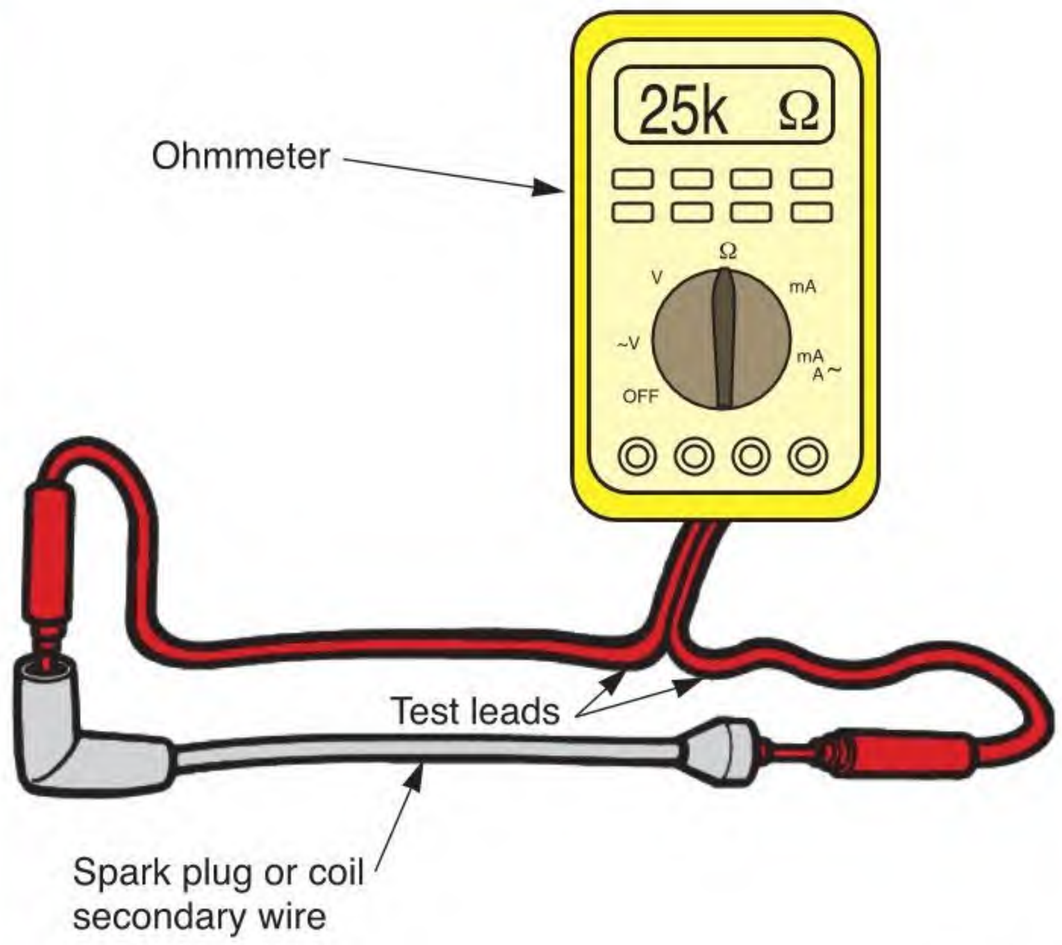
A ***secondary wire insulation test*** is used to check for sparks arcing through the insulation to ground. An ohmmeter test will not detect bad insulation.

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Service Procedure

To check secondary wire insulation:

1. Darken the shop or place fender covers over the sides of the vehicle's hood to block out light.
2. Start the engine and visually inspect each wire for sparks of electric arcing leakage. Large ignition secondary leakage can make a popping or clicking sound as the electricity flows through the air faster than the speed of sound.
3. If arcing is not evident during the visual inspection, move a high-impedance test light or a grounded screwdriver along the length of each wire. Hold the tip of the tool about 1″ from the wire insulation.
4. If an arc jumps through the insulation and onto the test light probe or the screwdriver, the wire is bad and must be replaced.



Chrysler

Figure 35-15. To check the conductor in a secondary wire, measure the wire's resistance with an ohmmeter. If the resistance is too high, the conductor or terminal is broken and the wire must be replaced.

Tech Tip

Secondary wire insulation leakage will usually show up when it rains or in damp weather. The moisture will cause excessive leakage, and the engine may miss or not start.

Secondary Wire Resistance Test

A ***secondary wire resistance test*** can be used to check the condition of a secondary wire conductor. This test is commonly used to check for a bad wire when an oscilloscope is not available or handy.

Typically, secondary wire resistance should not be over approximately 12,000 ohms per foot or about 50,000 ohms for long wires. Since specifications vary, always check an appropriate service manual for the exact value. A bad spark plug wire will often have almost infinite (maximum) resistance.

Replacing Secondary Wires

Installing new secondary wires is simple, especially if one wire is replaced at a time. Compare the length of the old wire with the length of the new wire. Replace each wire with one of equal length. Make sure the new wire is fully attached on the plug and in the coil module. See **Figure 35-16**.

Service Procedure

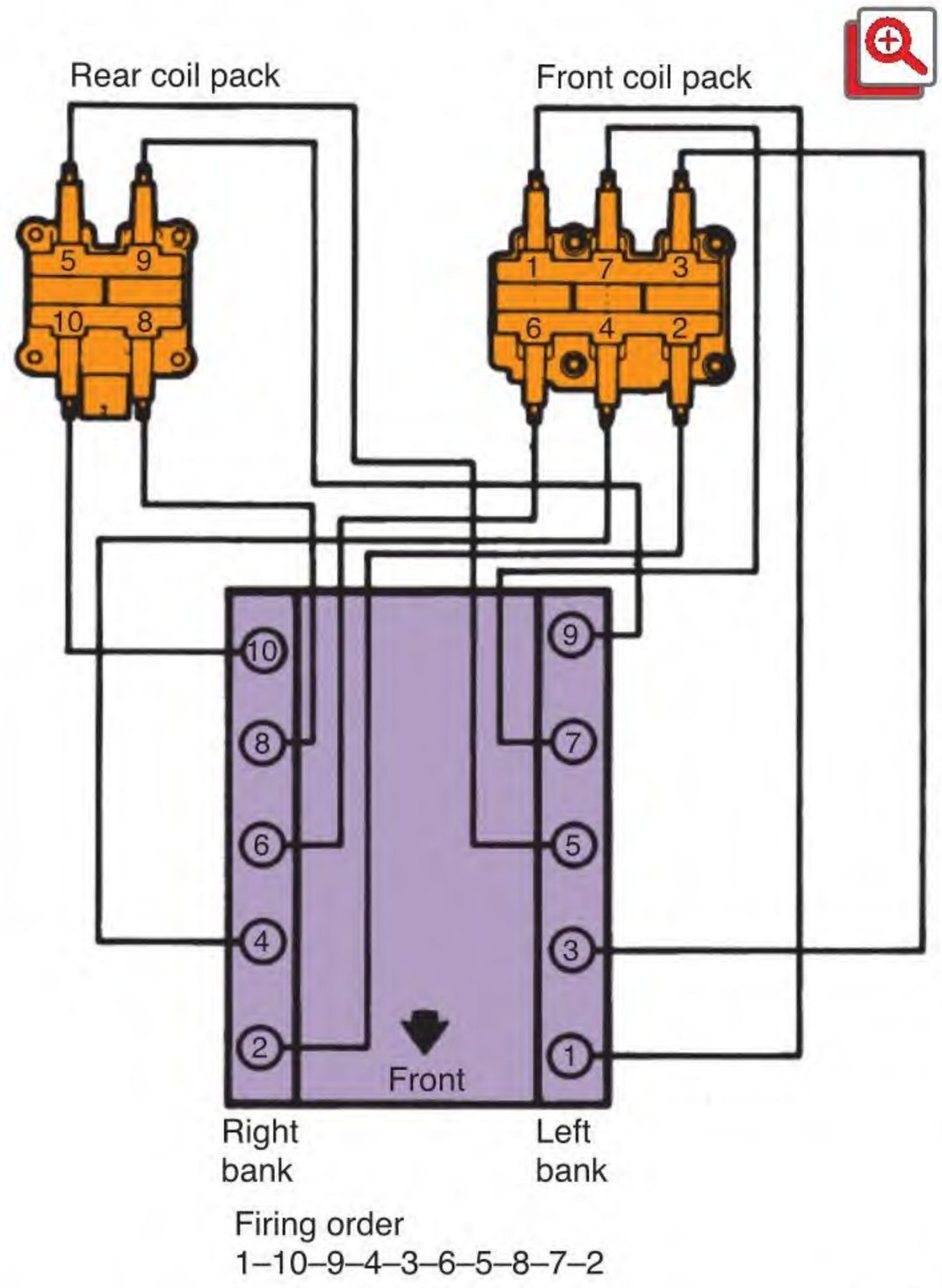
To perform a wire resistance test:

1. Remove each wire from its spark plug and from the coil pack.
2. Connect an ohmmeter to each end of the secondary wire. The meter will measure the wire's internal resistance in ohms. Look at **Figure 35-15**.
3. Compare your reading to specifications.

Tech Tip

Some sensor circuits use lower-than-normal reference voltages (1.5 volts dc). This can make them more susceptible to interference from outside magnetic fields. To prevent induced voltage from entering these sensor wires, always keep secondary wires in their clips.

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Chrysler

Figure 35-16. If all the spark plug wires have been removed, locate a service manual illustration (like this one) for your engine. Then, trace and install the wires from the correct ignition coil tower to the proper spark plug.

Ignition Timing Service

Proper ignition timing is critical to the performance of an engine. If ignition timing is incorrect, the engine is not firing the spark plugs at the right time in relation to engine crankshaft position. If the ignition timing is off by even 1° of crankshaft rotation, fuel economy and power can drop considerably.

With ***over-advanced ignition timing***, the engine will suffer from spark knock or ping, caused by abnormal combustion. A light metallic-like pinging sound may result when the engine is accelerating or is under a high-torque load. The ping will sound like a small hammer tapping on the engine. Causes for spark knock include carbon on piston heads, low octane fuel for piston compression ratio, an overheated engine, a bad engine knock sensor, a turbocharger over-boost problem, or a partial failure of ignition control module or engine control module.

With ***retarded ignition timing***, the engine will have poor fuel economy and lack power, especially during acceleration. If timing is extremely retarded, combustion flames blowing out of the open exhaust valves can overheat and crack the exhaust manifolds. A worn or stretched timing chain or belt is a common cause of retarded spark timing on high-mileage engines.

Measuring Ignition Timing

Ignition timing should be checked if the engine is experiencing poor fuel economy or performance problems, spark knock, or exhaust manifold and catalytic converter overheating. Always obtain the exact timing specifications from the engine emission control sticker or a service manual.

After a technician connects it to the vehicle diagnostic connector, a scan tool will display ignition timing as live data so it can be compared to specifications. Scan tool live data of spark timing shows when high voltage is being sent to the spark plugs in relation to piston position and camshaft position (with variable valve timing).

Check ignition timing at idle and at various engine speeds to verify that the computer advance is operating properly. Generally, the timing reading should go up as engine speed increases. Compare your scan tool timing readings at specific engine speeds to determine if there is a computer or programming problem.

In late-model vehicles, ignition timing cannot be adjusted mechanically. If timing is incorrect, the ECM or another component affecting timing must be replaced or updated (reprogrammed). Today's engines rely on the camshaft position sensor, crankshaft position sensor, and MAP sensor to provide data for electronically adjusting ignition timing. As a result, a worn engine timing chain or stretched timing belt can cause trouble codes and symptoms related to ignition timing and these sensors.

With difficult-to-locate problems, compare the signals from the camshaft and crankshaft position sensors with scan tool live timing data to get more information that will help you find ignition timing-related problems.

Reprogramming ECM and Ignition Timing

The engine control module (ECM) must be reprogrammed to change the ignition timing of late-model

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vehicles. Make and model specific software on a personal computer or laptop must be downloaded into the engine ECM. This can be done to change the ignition timing curve with speed, load, engine temperature, air temperature, and other variables. Sometimes software fixes are provided by the manufacturer for vehicles that experience ignition timing problems, such as spark knock or ping.

Ignition Coil (Coil Pack) Service

A faulty ignition coil may result in a weak spark, an intermittent spark, or no spark at all. The engine may miss or stall. In some cases, the engine will not start at all. The windings inside the coil can break, producing high resistance or an open in the coil circuit. In some cases, heat from the engine can make the coil windings expand and open, with a resulting loss of high-voltage output. The engine will stop running when the coil heats up.

A bad coil pack may only affect two cylinders. The other coils in the assembly may continue working normally. If you find misfiring or dead cylinders that correspond to one coil in a coil pack, suspect the coil pack.

Testing Ignition Coil

A coil test may be needed when the ignition system fails the spark test, but proper supply voltage is found. Since coil designs are different, testing procedures vary.

Generally, an ohmmeter is used to measure the internal resistance of the coil windings. Follow the manufacturer's instructions to check the resistance of both the primary and secondary windings. A reading that is out of specifications indicates a faulty ignition coil.

With a coil pack, test the windings of the coil having the spark problem. If, for example, the number two cylinder is not firing, the coil for that cylinder should be checked first. Normally, a bad coil pack winding will show infinite resistance, or open.

Direct ignition coils mount directly over the top of the spark plug. A short conductor inside a rubber insulator boot carries high voltage to the spark plug center electrode. A direct ignition coil is tested like other ignition coils. Measure both primary and secondary winding resistance. Also, make sure primary voltage is getting to the coil.

After years of service, the rubber boot on the direct ignition coil can harden and crack. This can allow moisture to enter the spark plug hole and short high voltage to engine ground, preventing the spark plug from firing. Keep this in mind when one or more cylinders misfire and trip a misfire code.

Replacing Ignition Coils

When an ignition coil or coil pack is mounted on the engine, coil replacement involves disconnecting the wires, removing the bolts securing the old coil, and lifting the coil from the engine. To install a new coil, simply bolt the coil in place and reconnect all the wires. Make sure the direct ignition coil fully snaps over the spark plug.

Ignition Switch Service

A bad ignition switch can cause several problems: the engine may not crank or start, the engine may not shut off when the ignition key is turned off, or the starter may not disengage when the ignition key is returned to run. When these types of problems occur, a faulty ignition switch may be the cause.

Testing Ignition Switch

A test light can be used to check the action of an ignition switch. When a test light is touched to the start terminal on the back of the switch, the light should glow only when the key is turned to *Start*. The test light should not glow when the key is released to the *Run* position.

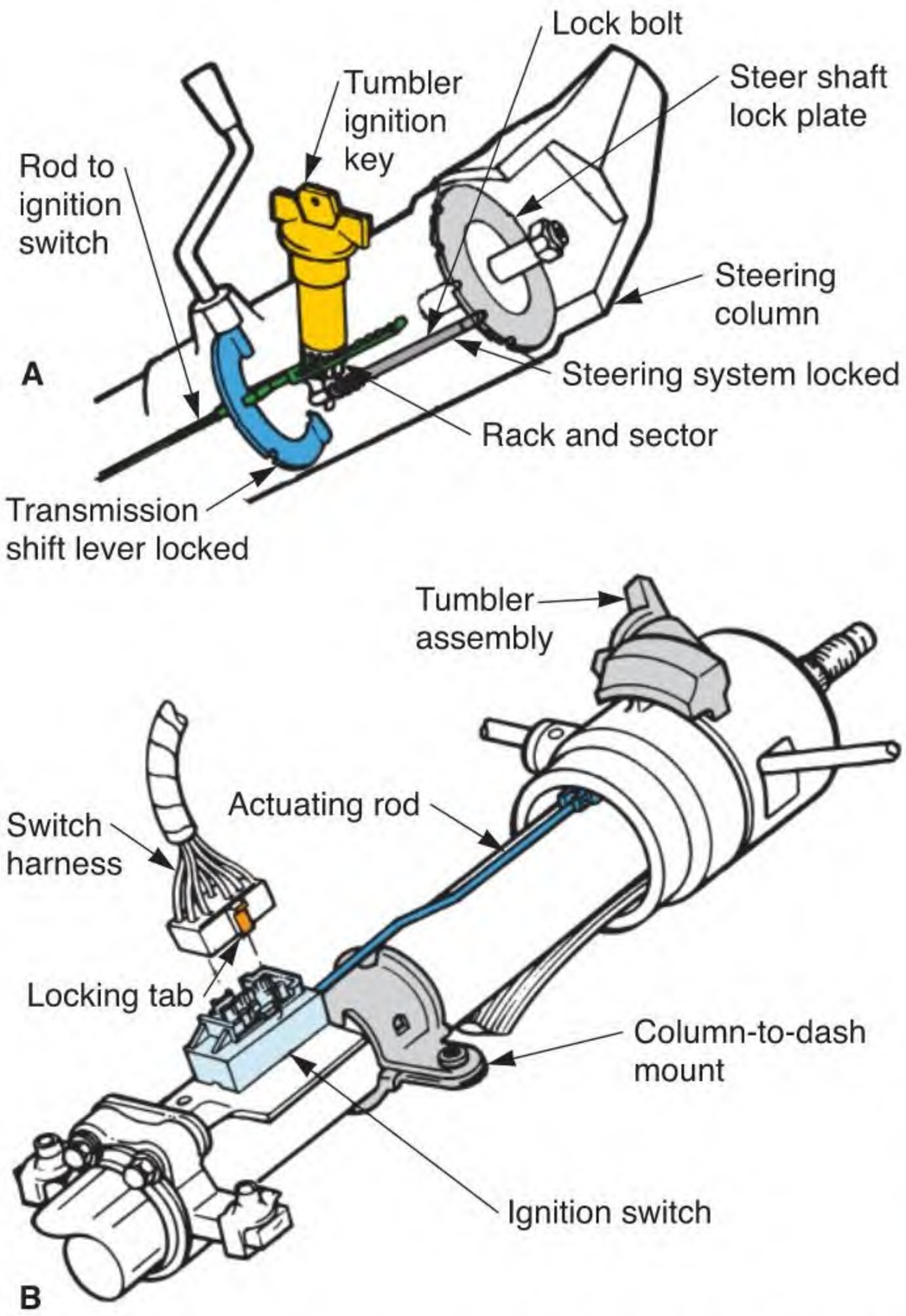
In the *Run* position, the test light should glow when touched on the *Run* terminal of the switch. With the ignition key in the *Off* position, neither terminal (*Start* or *Run*) should make the test light glow.

Replacing Ignition Switch

If the ignition switch is defective, it must be replaced. Before removing a dashboard-mounted switch, the ***tumbler*** (lock mechanism) must be removed from the switch. For most vehicles, plastic covers and the wiring harness fasteners must be removed to install a new ignition switch.

A steering column-mounted ignition switch is separate from the tumbler, **Figure 35-17**. It is normally about halfway down and on top of the steering column. To remove this type of switch, remove the fasteners holding the steering column to the dash.

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Figure 35-17. Most cars have the ignition switch and key tumbler in the steering column. A—Construction of a typical steering lock mechanism. B—A small rod runs down the column to the ignition switch. To remove the switch, remove the column-to-dash fasteners to drop the column. Then, remove the small nuts holding the switch to the top of the column.

This lets the steering column drop down so you can replace the ignition switch.

Ignition Control Module Service

A faulty ignition control module can produce a wide range of problems: engine stalls when hot, engine cranks but fails to start, engine misses at high or low speeds, etc. Quite often, an ignition control module problem will show up after a period of engine operation because engine heat soaks into the module and raises its temperature. The heat upsets the operation of electronic components in the unit.

Fixed and Variable Dwell

With modern computer-controlled ignition systems, the dwell time (number of degrees of crankshaft rotation that the circuit conducts current to the ignition coil) is controlled by the ignition control module and varies with vehicle make and model. Modern systems electronically vary the dwell and ignition timing with changes in engine speed and load.

Fixed dwell means that the dwell time should remain the same at all engine speeds. Some vehicles can be set to a fixed dwell for testing purposes.

Variable dwell means the ignition control module alters ignition coil dwell time with engine speed. If a system fails to alter dwell when it should, the ignition control module has a problem and should be replaced.

Current-limiting dwell means the ignition control module sends high current through the ignition coil windings until a strong magnetic field is developed around the windings. Once the module senses a ***saturated ignition coil*** (coil's magnetic field is fully formed), it reduces the amount of current sent through the coil windings. Reducing the current avoids overheating and possibly prevents burning the small conductors in the primary coil windings.

Testing Ignition Control Module

Many shop manuals list the ignition control module as one of the last components to test when troubleshooting an ignition system. If all the other components are in good working order, then the problem might be in the ignition control module.

If a specialized tester is available, it may be used to quickly determine the condition of the ignition control module. Unplug the wires going to the module and connect the tester to the module. The tester will indicate whether an ignition control module fault exists.

Heating Ignition Control Module

The microscopic components (transistors, diodes, capacitors, resistors) inside the ignition control module are very sensitive to high temperatures and vibration.

When testing the control module, many technicians use a heat gun or heat lamp bulb to warm the unit. This simulates the temperature in the engine compartment after the engine has been running. The heat may make the ignition control module act up and allow you to find an intermittent problem.

Do not apply too much heat to an ignition control module or it may be ruined. Only heat the unit to a temperature equal to its normal operating temperature.

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Replacing Ignition Control Module

Replacing an ignition control module is a simple task.

Service Procedure

If the control module is mounted in the engine compartment or under the dash:

1. Carefully unplug the wiring harness without damaging the small terminal pins and plastic connectors.
2. Unbolt and remove the old ignition or engine control module.
3. Install the new unit.
4. Reconnect the wiring harness.

In many cases, the bottom of the ignition control module must be coated with a special grease (silicone grease, dielectric heat-transfer compound, or heat-sink compound) before installation. This grease helps heat transfer away from the circuits, protecting the module from overheating and damage. See **Figure 35-18**.

Make sure you have the correct ignition control module. The new control module may look identical to the old one, but it may have internal circuit differences. Even cars of the same year and make can require different ignition control modules.



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Figure 35-18. Some manufacturers recommend that a heat-sink compound be applied to the bottom of the ignition control module before installation. This will allow the module to dissipate heat properly.

Ignition System Sensor Service

Testing procedures for many of the parts in a computerized ignition system (spark plugs, secondary wires, ignition coils, etc.) have been covered earlier in this chapter. However, the computerized ignition system also contains engine sensors that must be tested and serviced when troubleshooting these systems.

Replacing Crankshaft Position Sensor

The crankshaft position sensor, which is used to monitor engine speed in many modern ignition systems, can be mounted on the front, side, or rear of the engine.

Most crankshaft position sensors simply lock into place and are not adjustable. However, a few require adjustment. Crankshaft position sensor air gap is the distance from the tip of the sensor to an unnotched area on the trigger wheel. This gap must be correct for proper sensor signal output.

Service Procedure

To adjust crankshaft position sensor air gap:

1. Loosen the mounting screws that hold the sensor in place.
2. Fit a flat feeler gauge between one of the teeth on the crank trigger wheel and the sensor tip.
3. Adjust the sensor position so there is a slight drag on the feeler gauge.
4. Tighten the crank sensor mounting screws so that they remain the correct distance from the trigger wheel on the crankshaft.

Knock Sensor Service

A knock sensor is used to detect abnormal combustion, or ping. When it "hears" pinging or knocking, the sensor retards ignition timing or lowers turbo boost with the turbo waste gate. A bad knock sensor can upset ignition timing and affect turbocharger boost pressure. Many computers store a trouble code if there is a potential problem with the knock sensor.

To check knock sensor operation, start the engine and allow it to reach operating temperature. Lightly tap on the engine block or on a bracket with a wrench or small

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hammer. This simulates pinging or knocking, and should make the computer retard the ignition timing. Light taps should make the engine speed drop slightly. You might need to prop open the throttle to increase engine speed slightly so timing is advanced and will retard.

If tapping on the engine has no effect on timing and engine speed, check the sensor with a VOM or scope. Refer to the manual for recommendations. Remember to check the wiring that leads to the knock sensor before removing or replacing the sensor.

Camshaft Position Sensor Indexing

Camshaft position sensor indexing involves installing the sensor with the number one piston at TDC on the compression stroke. Use a breaker bar to rotate the crankshaft snout until air is pushed out of the number one cylinder (hold thumb or finger over the spark plug hole). Then continue rotating the crankshaft until the dampener or flywheel timing marks line up at zero. If no timing marks are provided, use a dial indicator with a long extension rod and rotate the crankshaft back and forth until the number one piston is at TDC.

The camshaft position sensor is normally mounted on the cylinder head or front timing cover. Make sure the rubber O-ring is fully in its groove on the sensor and that any spacer is placed under the sensor before installation.

A special plastic alignment tool may be required to hold the sensor in correct orientation as you slide the sensor into place before securing it. The tool may have an arrow that must face toward the front of the vehicle or engine. Since procedures vary, always refer to your service information for the year, make, and model car being repaired if in doubt. Also check for any software updates or reprogramming that may be required when replacing the camshaft position sensor.

An incorrectly indexed camshaft position (CMP) sensor may be difficult to diagnose since it can slightly affect fuel injection timing and ignition timing. The engine might have poor fuel economy or drivability problems, and the MIL may illuminate. Surging, hesitation, missing upon acceleration, or a lack of engine power may result.

Tech Tip

Most modern camshaft position sensors do not require indexing. They will only go into the engine one way. Only early model camshaft position sensors require indexing.

Diagnostic Case Study

Concern: Mrs. Kim drives her 2011 Honda Accord with 100,000 miles on the odometer into the shop complaining of low engine power and a rough idle. She says an engine warning light in the dash is glowing.

Cause: Duff questions Mrs. Kim about the exact nature of the problem. She explains that the problem occurs more at initial engine startup with the engine cold. She admits that she has never changed the spark plugs.

Correction: The technician connects a scan tool to the vehicle and notes a misfire code for cylinder number three. He removes cylinder three's direct ignition coil and the spark plug. Inspecting the spark plug, he finds that the air gap is three times greater than specifications. The spark plug has been run so long that the air gap has opened enough to prevent an arc from jumping the gap. New spark plugs are installed in the engine to correct the poor engine performance problem. After checking engine power and idle smoothness on a test drive, the technician releases the vehicle back to the customer.

Summary

- Problems caused by spark plugs, secondary wires, ignition coils, ECMs, and related wiring manifest themselves in a variety of ways.
- To start diagnosis, visually inspect the ignition system with and without the engine running.
- Connect a scan tool to the diagnostic connector under the dash to find many ignition-related problems.
- A spark intensity test (spark test) checks the strength of the electric arc (spark) produced by the ignition system.
- A dead cylinder is an engine combustion chamber that is not igniting and burning its fuel-air mixture on that cylinder's power stroke.
- Bad spark plugs can cause a wide range of problems, including misfiring, lack of engine power, poor fuel economy, exhaust odor, rough idle, and hard starting.
- To read a spark plug, closely inspect and analyze the condition of its tip and insulator.

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- Set the spark plug gap by spacing the side electrode the correct distance from the center electrode.
- A faulty secondary wire or spark plug wire can have a burned or broken conductor or deteriorated insulation.
- Proper ignition timing is critical to the performance of an engine. If the ignition timing is off by even 1° of crankshaft rotation, fuel economy and power can drop considerably.
- A faulty ignition coil may result in a weak spark, an intermittent spark, or no spark at all. The engine may miss or stall. In some cases, the engine will not start at all.
- A bad ignition switch can cause several problems: the engine may not crank or start, the engine may not shut off when the ignition key is turned off, or the starter may not disengage when the ignition key is returned to run.
- An ignition control module problem often shows up after a period of engine operation because engine heat soaks into the module and raises its temperature.
- When a knock sensor "hears" pinging or knocking, it retards ignition timing or lowers turbo boost with the turbo waste gate.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

current-limiting dwell
dead cylinder
fixed dwell
ignition primary voltage test
misfire code
over-advanced ignition timing
retarded ignition timing
saturated ignition coil
secondary wire insulation test
secondary wire resistance test
spark intensity test
spark test
spark tester
tumbler
variable dwell

Activities

1. Demonstrate the use of a wire feeler gauge to measure the gap of a spark plug. Then, demonstrate the method used to set the gap to specifications.
2. Use a scan tool to check the timing at idle on two or three engines. Compare your findings with the appropriate service manual specifications to determine if timing is "within specs" for each engine.

Review Questions

Answer the following questions using the information provided in this chapter.

1. Explain how to use a scan tool to detect problems in an ignition system. What problems can a scan tool typically detect?
2. A(n) _____ test checks the strength of the electric arc produced by the ignition system.
3. Which of the following is commonly used to check ignition system output voltage?
   (A) Voltmeter.
   (B) Ohmmeter.
   (C) Spark tester.
   (D) Ammeter.
4. Define the term *dead cylinder.*
5. Burned secondary connections inside direct and indirect ignition coils can indicate high voltage leakage. True or False?
6. What does an oscilloscope measure?
7. A(n) _____ spark plug is shiny and dark gray or black in color.
8. Which of the following pertains to setting spark plug gap?
   (A) Wire feeler gauge.
   (B) Bend side electrode.
   (C) Space between center and side electrode.
   (D) All of the above.
9. When screwing a spark plug into the cylinder head, a socket, an extension, and a ratchet should be used to start the plug threads. True or False?
10. With _____ ignition timing, the engine will suffer from spark knock or ping, caused by abnormal combustion.
11. Normally, a bad ignition coil pack will measure infinite resistance on an ohmmeter. True or False?

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12. If the engine does not shut off when the ignition key is turned off, a technician should suspect a(n) _____ as the probable cause.
    (A) parasitic battery load
    (B) bad knock sensor
    (C) faulty ignition switch
    (D) All of the above.
13. In an ignition system, the crankshaft position sensor fits all of these descriptions *except:*
    (A) monitors spark plug voltage.
    (B) can be replaced if faulty.
    (C) measures engine speed.
    (D) mounts on the front, side, or rear of the engine.
14. Why do ignition control module problems often show up after a period of engine operation?

ASE-Type Questions

1. In an engine with a dead cylinder, the problem could be a bad:
    (A) ignition system.
    (B) fuel system.
    (C) starting system.
    (D) All of the above.
2. Which device will properly measure ignition system operating voltages over time?
    (A) Oscilloscope.
    (B) Dynamometer.
    (C) Spark tester.
    (D) All of the above.
3. Which of the following is *not* a problem that can be caused by bad spark plugs?
    (A) Misfiring.
    (B) High idle speed.
    (C) Hard starting.
    (D) Lack of power.
4. A properly burning spark plug should be:
    (A) grayish-tan.
    (B) black.
    (C) white.
    (D) yellow.
5. Each of the following can be used to start spark plugs in their holes *except:*
    (A) a ratchet.
    (B) your fingers.
    (C) a spark plug socket.
    (D) a short piece of vacuum hose.
6. While conducting a secondary wire resistance test, Technician A states that wire resistance should be approximately 12,000 ohms per foot. Technician B says that a direct ignition coil boot can deteriorate over time. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
7. Ignition modules are being discussed. Technician A says that the module may be adversely affected by excessive heat and vibration. Technician B says that a specific car company's ignition modules will be identical across all the vehicle makes and models they manufacture. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
8. Direct ignitions systems are being discussed. Technician A says that service procedures for these systems are very similar to procedures used on contact point distributor ignition systems. Technician B says that when replacing this type of coil, the new coil requires a 1″ air gap with the spark plug. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
9. Which of the following is the ignition switch locking mechanism?
    (A) Tumbler.
    (B) Steering column.
    (C) Actuating rod.
    (D) Suppressor shield.
10. A car equipped with a coil pack ignition enters the shop with two dead cylinders. Technician A says to check to see if the dead cylinders are operated by the same ignition coil pack. Technician B says there is no need for this step as one coil pack fires all engine cylinders in this system design. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Ignition System Diagnosis

Condition	Possible Causes	Correction
No spark.	1. Breaker points defective or misadjusted (point ignition). 2. Distributor pickup defective or misadjusted (electronic ignition). 3. Defective condenser. 4. Discharged battery. 5. Faulty coil or primary circuit resistor. 6. No primary current to points. 7. Defective coil high tension lead. 8. Defective rotor and/or distributor cap. 9. Defective plug wires. 10. Moisture in distributor cap and on points. 11. Breaker plate not grounded. 12. Defective ignition control module. 13. Loose, corroded, or open electronic control module ground lead. 14. Loose, corroded, or disconnected primary connections. 15. Defective distributor electronic pickup. 16. Trigger wheel positioned too high. 17. Incorrect trigger wheel-to-pickup air gap. 18. Defective cam or crankshaft sensor.	1. Install new points. 2. Replace or adjust as needed. 3. Replace condenser. 4. Charge battery. 5. Replace coil or resistor. 6. Check ignition switch, coil, resistor, wiring. 7. Replace lead. 8. Replace cap and rotor. 9. Replace plug wires. 10. Dry cap and points. 11. Replace or tighten ground wire. 12. Replace ignition module. 13. Tighten, clean, or connect as needed. 14. Clean, cover with special, protective grease and shove firmly into distributor. 15. Replace pickup unit. 16. Reposition correctly. 17. Set correctly. Use nonmagnetic feeler gauge. 18. Replace defective sensor.
Weak or intermittent spark.	1. Breaker points defective (where used). 2. Defective condenser (where used). 3. Point dwell set incorrectly. 4. Discharged battery. 5. Loose or dirty primary wiring connections. 6. Weak coil. 7. Defective primary circuit resistor. 8. Burned rotor and cap contacts. 9. Defective resistance spark plug wires. 10. Insufficient system voltage. 11. Weak breaker spring pressure (point ignition only). 12. Worn distributor bushings or bent shaft. 13. Worn distributor cam (point ignition only). 14. Breaker arm sticking (point ignition only). 15. Loose spark plug wires. 16. Defective distributor electronic pickup. 17. Trigger wheel pin sheared. 18. Shorted primary wiring. 19. Loose wiring harness connectors.	1. Install new points. 2. Install new condenser. 3. Set dwell correctly. 4. Charge or replace battery. 5. Clean and tighten connections. 6. Replace coil. 7. Replace resistor. 8. Replace cap and rotor. 9. Replace resistance wires. 10. Adjust regulator. 11. Increase spring pressure. 12. Replace bushings or shaft. 13. Replace cam. 14. Free and lubricate bushing. 15. Clean and tighten connections. 16. Replace pickup. 17. Replace pin. 18. Replace wire and relocate. 19. Tighten connections.

Continued

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Condition	Possible Causes	Correction
Missing at idle or low speed.	1. Weak or intermittent spark at plugs. 2. Fouled spark plugs. 3. Spark plug gaps too narrow. 4. Improper plug heat range. 5. Damaged plugs. 6. Defective distributor electronic pickup. 7. Loose harness connections. 8. Discharged battery. 9. Coil polarity incorrect.	1. See *Weak or intermittent spark.* 2. Clean or replace plugs. 3. Adjust gaps to specifications. 4. Install proper heat range. 5. Replace plug or plugs. 6. Replace pickup unit. 7. Clean and tighten connections. 8. Charge or replace battery. 9. Reverse coil primary leads.
Missing during acceleration.	1. Weak spark. 2. Plugs damp. 3. Fouled plugs. 4. Plug gap too wide. 5. Damaged plug. 6. Incorrect trigger wheel-to-pickup air gap. 7. Defective vacuum advance. 8. Incorrect coil polarity. 9. Crossfiring. 10. Weak ignition coil.	1. See *Weak or intermittent spark.* 2. Dry plugs. 3. Clean or replace plugs. 4. Gap as specified. 5. Replace plug. 6. Set gap to specifications. 7. Repair or replace vacuum advance. 8. Reverse coil primary leads. 9. Rearrange ignition secondary wires. 10. Replace ignition coil.
Missing during cruising and high-speed operation.	1. Weak spark. 2. Improper heat range plug (too hot). 3. Crossfiring. 4. Fouled plugs. 5. Plug gap incorrect. 6. Damaged plug. 7. Ignition timing incorrect. 8. Defective distributor. 9. Loose or corroded wire connections. 10. Defective spark plug wires. 11. Weak ignition coil.	1. See *Weak or intermittent spark.* 2. Install proper heat range plug. 3. Arrange wires properly. If needed, install new wires. 4. Clean or replace plugs. 5. Gap to specifications. 6. Replace plug. 7. Reset timing. 8. Repair or replace distributor. 9. Clean and tighten connections. 10. Replace wires. 11. Replace ignition coil.
Missing at all speeds.	1. Weak spark. 2. Fouled spark plugs. 3. Damaged plug. 4. Crossfiring. 5. Plug gap too wide or too narrow. 6. Plugs and/or distributor damp. 7. Improper plug heat range. 8. Defective distributor. 9. Defective spark plug wires. 10. Distributor trigger wheel pin sheared or missing. 11. Burned or corroded breaker points. 12. Defective condenser.	1. See *Weak or intermittent spark.* 2. Clean or replace plugs. 3. Replace plug. 4. Arrange wiring correctly and if needed, install new wires. 5. Adjust gap as needed. 6. Dry distributor and plugs. 7. Change to correct heat range. 8. Repair or replace distributor. 9. Replace plug wires. 10. Install new pin. 11. Replace and gap points. 12. Replace condenser.

Continued

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Condition	Possible Causes	Correction
Coil failure.	1. Carbon tracking on tower. 2. Excessive system voltage. 3. Oil leak in coil. 4. Engine heat damage. 5. Physical damage.	1. Replace coil and wire nipple. 2. Adjust voltage regulator. 3. Replace coil. 4. Replace coil. Relocate or baffle against heat. 5. Replace coil.
Short spark plug life.	1. Incorrect plug heat range (too hot—burns). 2. Incorrect plug heat range (too cold—fouls). 3. Mechanical damage during installation. 4. Loose spark plug (overheats and burns). 5. Incorrect plug reach (too short—fouls). 6. Incorrect plug reach (too long—strikes piston). 7. Worn engine—oil fouling. 8. Bending center electrode. 9. Detonation. 10. Preignition. 11. Lean mixture.	1. Install correct (cooler) spark plug. 2. Install correct (hotter) spark plug. 3. Install correctly. 4. Tighten plugs to proper torque. 5. Install plugs with correct reach. 6. Install plugs with correct reach. 7. Switch to hotter plugs or overhaul engine. 8. Bend side electrode only. 9. Adjust timing. Change to higher octane gas and/or remove carbon buildup. 10. Remove carbon buildup, install valves with full margin, install cooler plugs. 11. Adjust air-fuel ratio.
Preignition.	1. Overheated engine. 2. Glowing pieces of carbon. 3. Spark plugs overheating. 4. Sharp valve edges. 5. Glowing exhaust valve.	1. Check cooling system. 2. Remove carbon. 3. Change to cooler plugs. 4. Install valves with full margin. 5. Check for proper tappet clearance, for sticking, and air leaks.
Detonation.	1. Ignition timing advanced. 2. Engine temperature too high. 3. Carbon buildup is raising compression ratio. 4. Low octane fuel. 5. Exhaust heat control valve stuck. 6. Excessive block or head metal removed to increase compression.	1. Retard timing. 2. Check cooling system. 3. Remove carbon. 4. Switch to high octane fuel. 5. Free valve. 6. Use thicker gasket, change head, or true warped head or block surface.

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The dashboard has been removed from this car, revealing the complex wiring for the vehicle's instrumentation and auxiliary systems.

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Chapter 36
Lights, Instrumentation, Wipers, and Horns—Operation and Service

After studying this chapter, you will be able to:

- Explain the operating principles of automotive light, wiper, and horn systems.
- Diagnose problems in light, wiper, and horn systems.
- Summarize automatic light and wiper systems.
- Replace burned-out bulbs.
- Explain how to aim headlights.
- Describe the safety practices to follow when working with light, wiper, and horn systems.
- Explain both analog and digital instrumentation.
- Summarize how to remove and service an instrument cluster.
- Correctly answer ASE certification test questions on light, instrumentation, wiper, and horn systems.

The lighting and instrumentation circuits on today's cars can be very complex. The dash instrument clusters can have their own ECM and power supply to operate the dash cluster and display screen in the center of the dash. The number of wires and electronic devices in and under the dash can be mind-boggling if you are not familiar with each individual circuit.

This chapter summarizes the typical lighting and instrumentation systems found on late-model vehicles, including exterior lighting, interior lighting, instrument cluster, and dash monitor displays. It will give you the background for using factory service manuals for specific makes and models of vehicles. See **Figure 36-1**.

Light

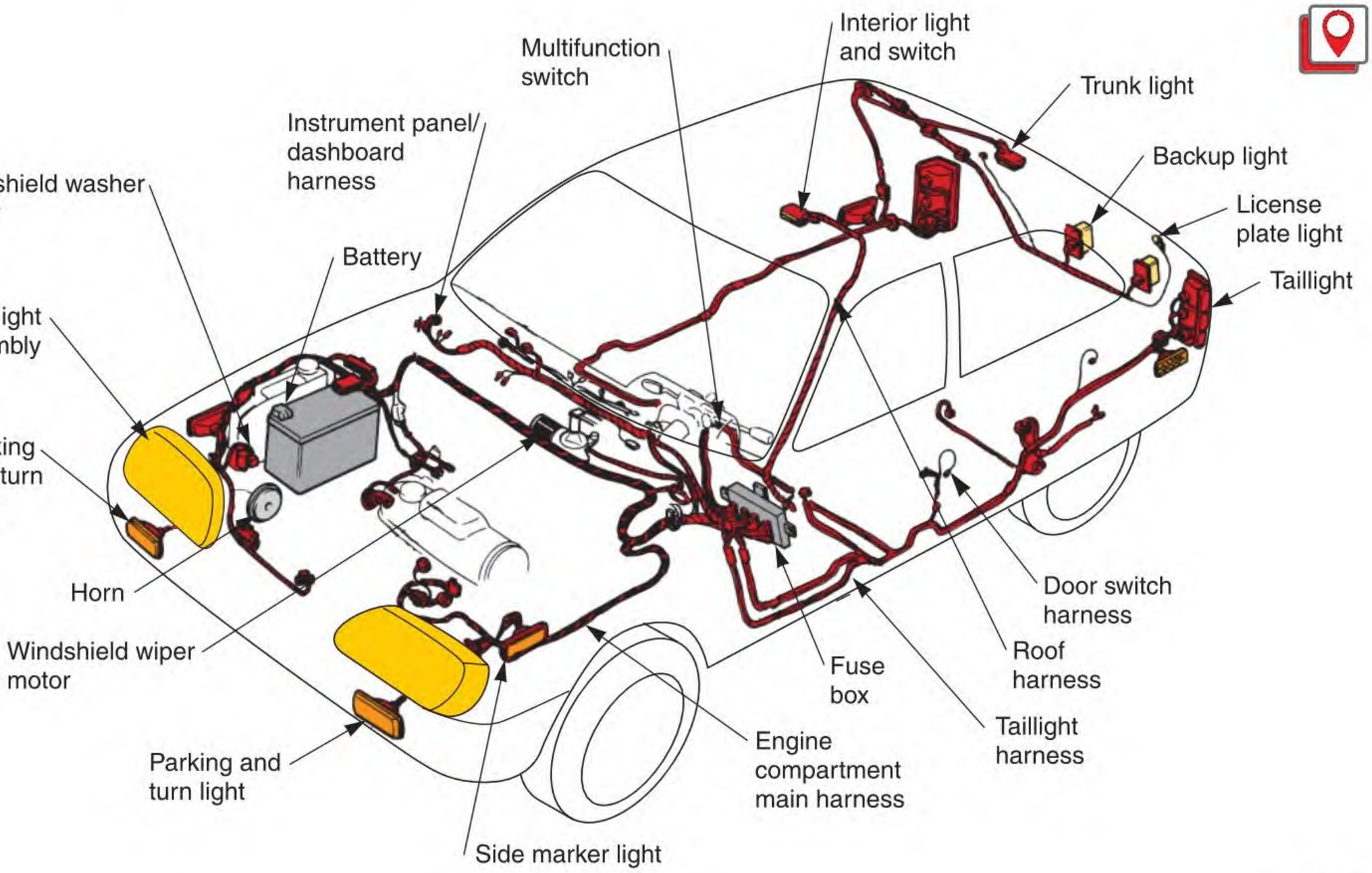
Light is energy from electromagnetic radiation within the frequency or spectrum of the human eye. Life would not exist on earth without light, and it would be dangerous to drive at night without some form of artificial light.

The speed of light is exactly 299,792,458 meters per second (186,282 miles per second). There are two scientific theories for light:

- Light is the movement of electromagnetic waves through space.
- Light is the movement of atomic particles (photons) through space.

Light energy can be used to illuminate objects or to send computer data or information in a digital circuit. In the automobile, lights are used to illuminate the road ahead of the vehicle, illuminate the dash displays, provide interior lights when you open the doors, and illuminate the rear of the vehicle. With the use of photonic devices, light energy can also represent data when transferring information in a digital circuit.

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Honda

Figure 36-1. Light, wiper, and other major electrical systems are simple when studied separately. Note the location of the major components.

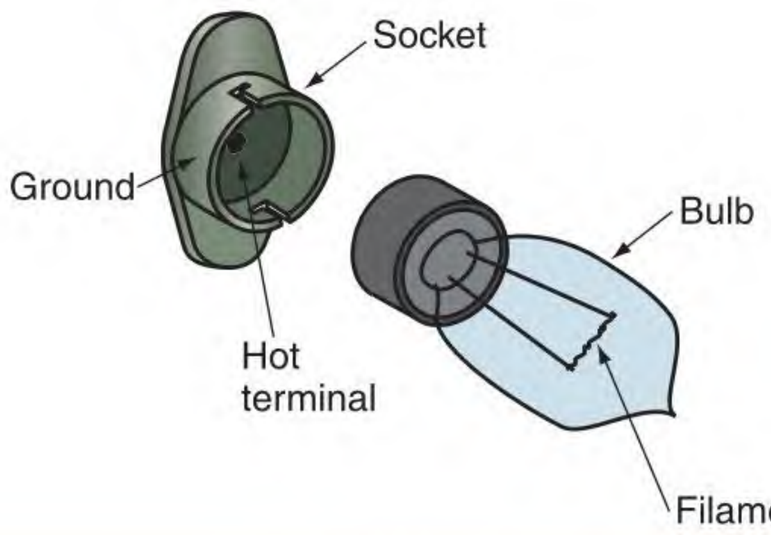
Lightbulbs

A lightbulb, **Figure 36-2**, is a resistance element surrounded by a vacuum or inert gas enclosed in a sealed glass housing. The resistance element, or ***filament***, is a hard metal that can withstand extreme heat. The bulb's glass housing is either air-free or filled with an inert gas to keep the filament from burning up.

Incandescent lightbulbs send current through a filament (usually tungsten resistance wire) inside a partial vacuum in an airtight glass enclosure, producing heat and the emission of light energy. The current makes the filament glow white-hot. Incandescent bulbs produce a white light, unless the glass is tinted.

Since the element of an incandescent bulb is not exposed to oxygen, it does not burn in half. A burned-out incandescent bulb has slowly vaporized its filament or resistance wire over an extended service time, or its airtight seal has been broken, causing the filament to burn in half.

Thumb-sized incandescent bulbs are used for running lights, turn lights, and backup lights. Turn signal lights, brake lights, and marker lights use one- or two-filament, low-current incandescent bulbs. Bulbs for turn signal lights and brake lights often have two separate filaments. Backup lights and marker lights normally have only one filament.



Lightbulb	
Symbol	Letter Designation
	LT

Fiat

Figure 36-2. Parts of a lightbulb and its socket.

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Halogen lightbulbs use tungsten and halogen gas to produce white light. This type of bulb is brighter than a conventional incandescent bulb because the halogen gas surrounding the filament glows more brightly. Halogen bulbs are commonly used for headlights, fog lights, and sometimes marker and signaling lights.

High-intensity discharge bulbs (HIDs) emit light energy by producing a small electric arc between two metal halide electrodes. HID bulbs are encased in glass and usually contain xenon gas that glows when exposed to an electric arc. Sometimes called a "burner lightbulb," an HID bulb can produce a light output three times brighter than a conventional filament bulb.

A ***ballast*** (transformer) and control circuit is needed to step up battery voltage and send high-voltage pulses to the HID electrodes to produce tiny, but blindingly bright, welding-type arcs. The high frequency of the voltage going to the bulb electrodes makes the flashing electric arc appear to glow constantly. HID bulbs are normally used for headlights and fog lights. They emit bluish light rather than white light.

Neon (Ne) lightbulbs use a ballast to send current though an inert or noble gas that glows when excited by electrical energy. Neon bulbs are seldom used as OEM equipment but are available in the aftermarket as add-on lighting.

Light-emitting diodes (LEDs) emit light energy when a tiny amount of current is sent through a semiconductor material. LEDs are very small and only draw a small amount of electrical energy. They are often used as tiny indicator lights in vehicle dashboards because of their long service life and small packaging. LEDs are also used in taillights, turn signals, and brake lights.

Lighting Systems

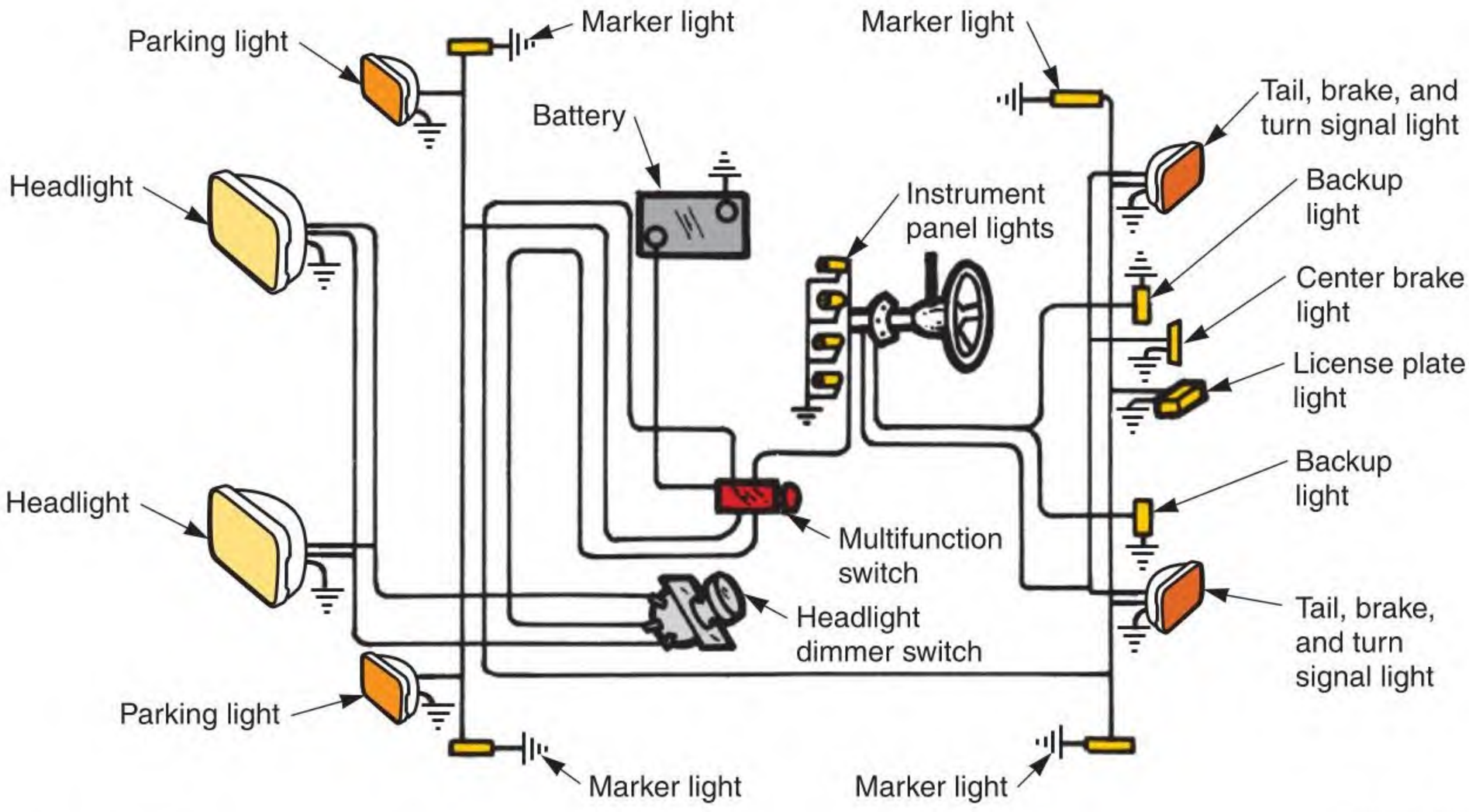
The lighting system consists of the components (fuses, wires, switches, and relays) that operate the interior and exterior lights on a vehicle. The exact circuit and part configurations vary with each make and model of vehicle. However, the systems operate similarly.

The exterior lights typically include the headlights, turn signal lights, stoplights, parking lights, backup lights, and side marker lights.

The interior lights normally include the dome light, instrument lights in the dash, trunk light, and other courtesy lights.

Headlamp System

The ***headlamp system*** includes the battery, headlamp wiring, fuse panel, light switch, dimmer switch, headlamps (headlights), taillights, marker lights, and instrument lights. See **Figure 36-3**. If the headlamps are concealed, the system also has either a vacuum



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Figure 36-3. The light switch is the heart of the lighting system. It feeds current to circuits.

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or electric motor mechanism to operate the doors (flaps) over the headlamps.

The headlamp switch is an on/off switch in the dash panel or on the steering column. It controls current flow to the bulbs in the headlamp system. It may also contain a ***rheostat*** (variable resistor) for adjusting the brightness of the instrument panel lights. The rheostat can also be mounted in the dash. A vacuum switch may be added to the headlamp switch or in the circuit when vacuum doors are used over the headlamps.

A ***multifunction switch*** is capable of controlling several circuits simultaneously—headlights (bright and dim circuits) and turn lights, for example. Most late-model vehicles use multifunction switches. Look at **Figure 36-4**.

Most multifunction switches have a ***flash-to-pass feature***, which energizes the high beams when the switch arm is pulled back. This lets the driver quickly warn traffic that he or she is going to increase speed and pass. As soon as the multifunction switch arm is released, the headlamps return to low beams.

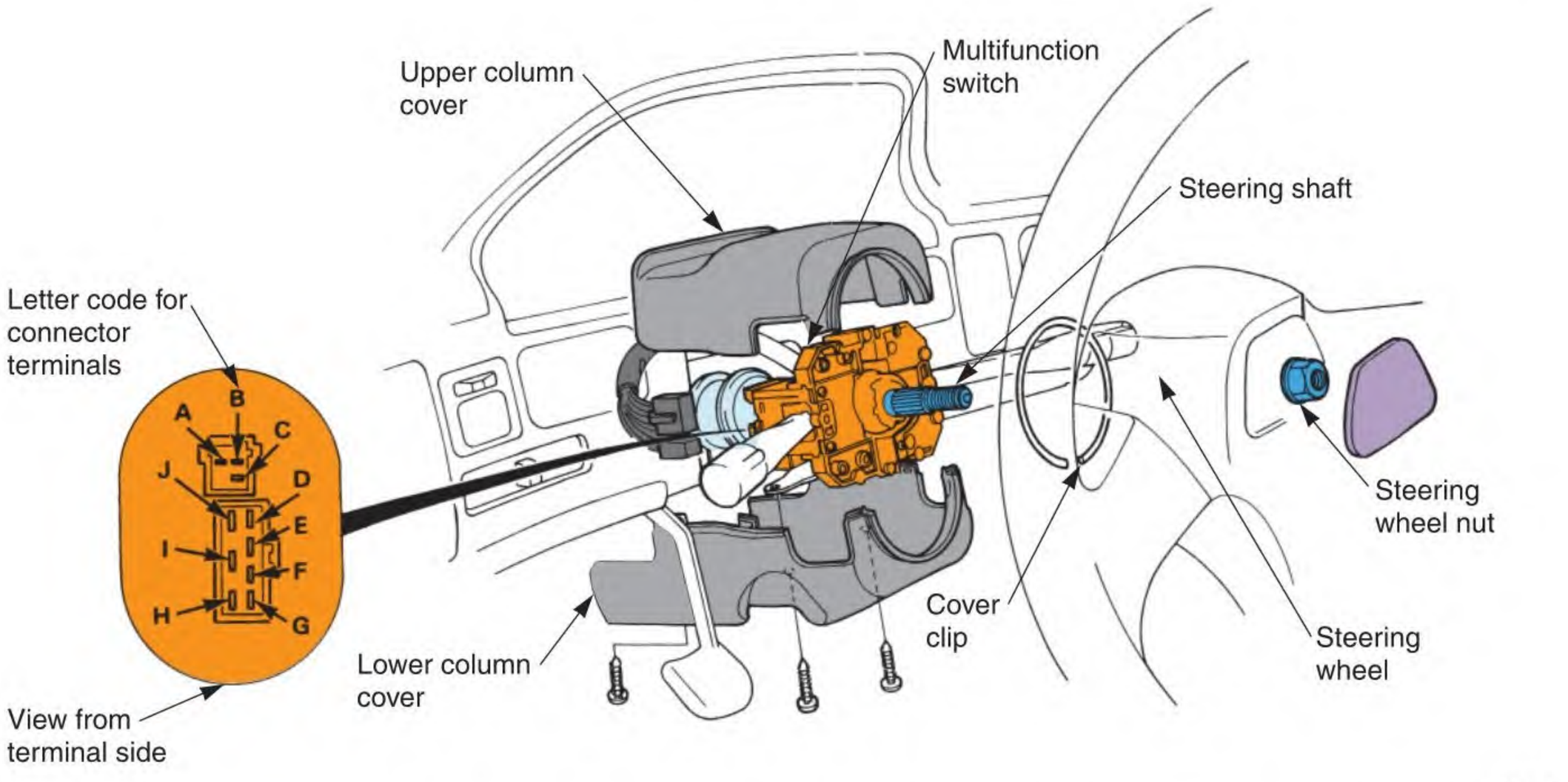
The headlamp bulbs illuminate the road during night driving or bad weather conditions. Headlight bulbs can have one or two elements. Two elements are needed to provide low and high beams. Low beams are used for driving in traffic and high beams for greater visibility when there is no oncoming traffic. When current flows through the bulb element or filament, it gets white-hot and glows to produce light energy.

Most late-model cars use halogen headlamp bulb inserts, which are small bulbs that fit into a larger plastic housing. A headlight lens disperses the light beam in front of the vehicle and protects the bulb. This lens can be made of glass or plastic. The bulb is made of heat-resistant quartz that is filled with halogen gas to protect the filament from damage. See **Figures 36-5** and **36-6**.

Halogen bulbs are rated in watts. A typical low-beam bulb is 45 watts, and a typical high-beam bulb is 65 watts. Federal regulations limit how bright low-beam headlamps can be on public roads. The maximum brightness for low beams is 20,000 candlepower. Brighter bulbs are available, but should not be installed for use on public roads.

Some late-model vehicles are equipped with high-intensity discharge bulbs (HIDs). This type of lamp does not use a filament. Instead, a high-voltage electric arc flows between two electrodes in the bulb. This arc excites the xenon vapor contained in the bulb, producing a bright blue-white light.

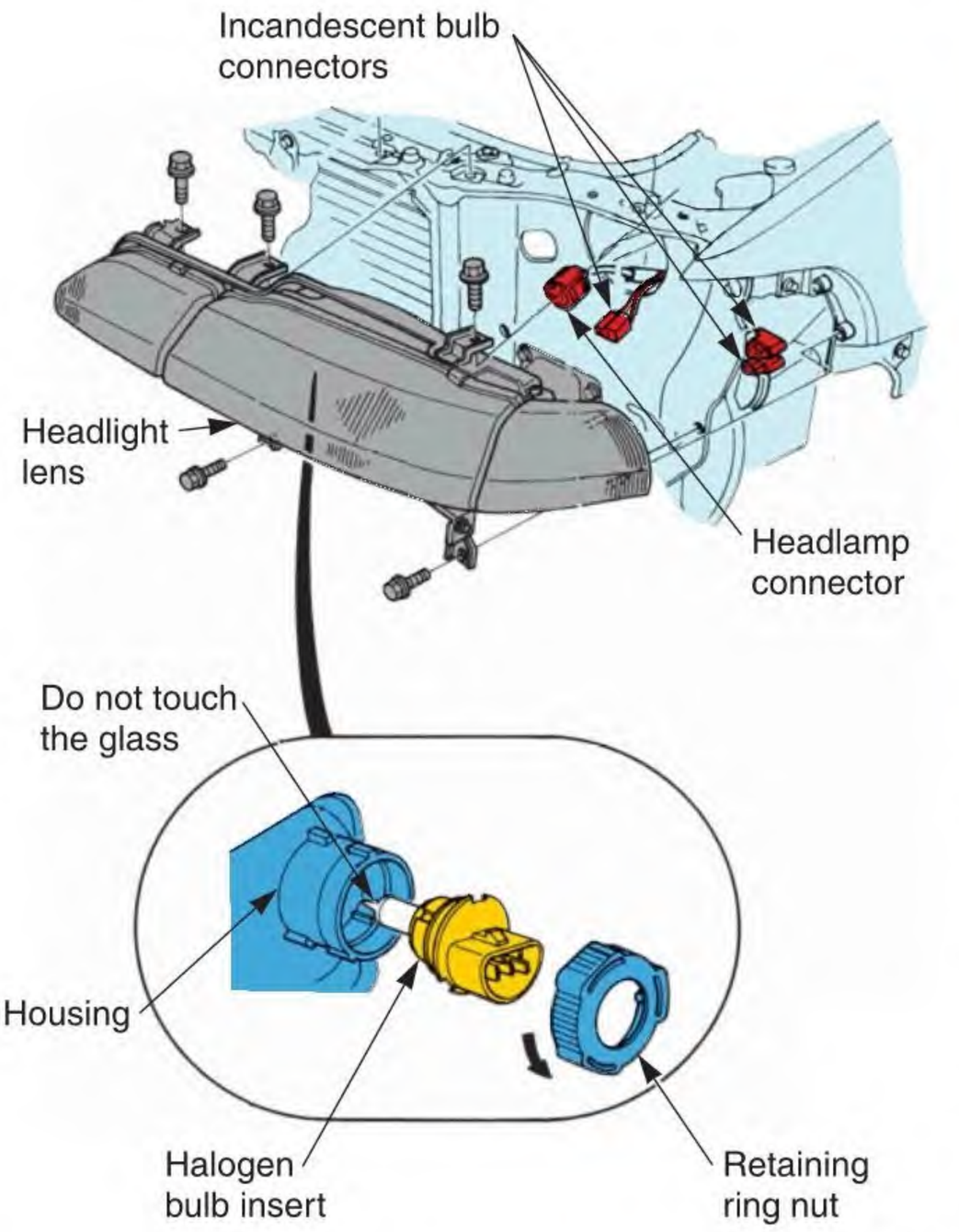
An external ballast is used to convert battery voltage into high-voltage ac to create and maintain the



Honda

Figure 36-4. A multifunction switch on the steering column is common. It can be tested after removing the covers around the steering column. Letters on the connector can be compared to service manual charts and diagrams for probing voltage in different switch positions.

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Honda

Figure 36-5. Late-model vehicles commonly have halogen headlamp bulb inserts. The bulb insert installs in a plastic housing behind the lens. The lens and housing are not vacuum sealed. Note how the retaining ring nut locks the insert bulb into the housing.



Fiat

Figure 36-6. An insert-type headlight bulb is shown. In the inset, you can see that the bulb has filaments for low and high headlight beams.

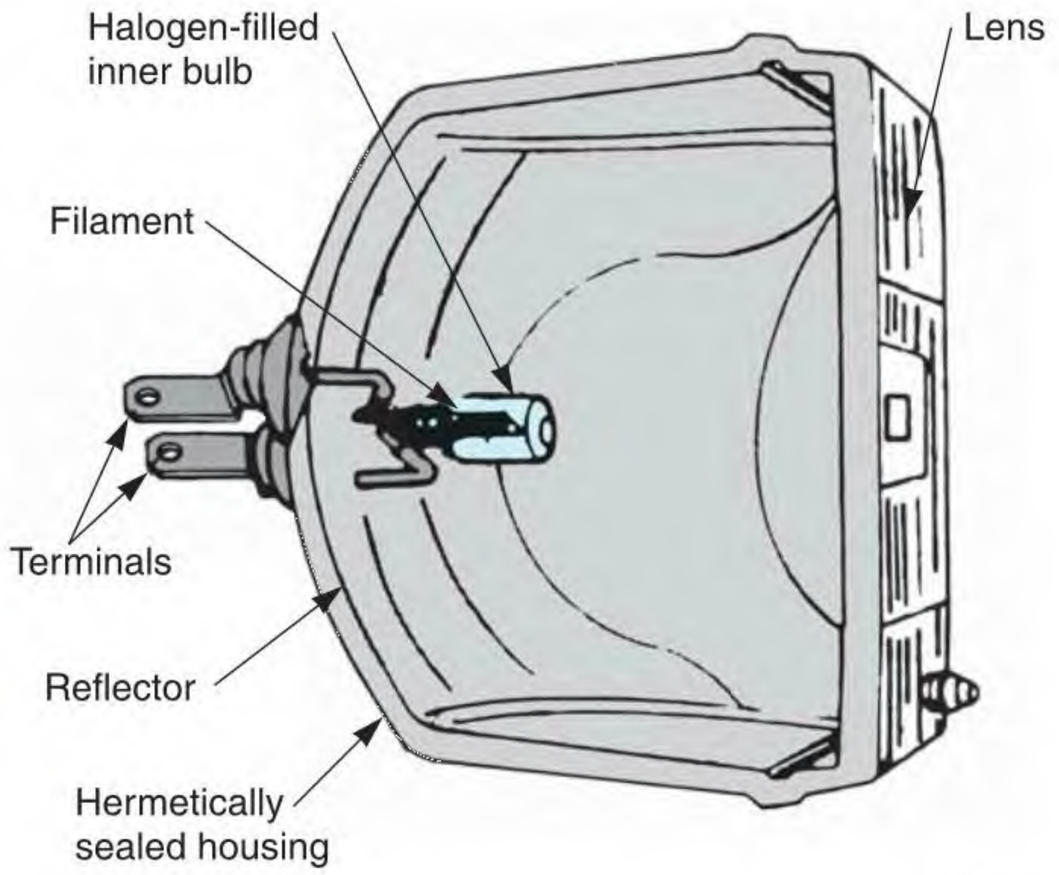
Older vehicles were equipped with ***sealed-beam headlamps***. These lamps have their filament(s) enclosed in a vacuum-sealed glass housing that has an integral headlight lens. See **Figure 36-7**. Sealed-beam headlamps have been phased out for smaller halogen headlamp bulb inserts.

arc. When an HID is first turned on, an igniter works with the ballast to provide several thousand volts to establish the arc. The ballast then provides as many as 450 volts to maintain the arc. As the bulb warms, the amount of voltage needed to maintain the arc drops to as little as 50 volts.

High-intensity discharge bulbs produce more light than standard halogen bulbs while consuming less power. Another advantage to HID lights is that they last longer than conventional bulbs.

Warning

Be aware of the startup voltage of HIDs and use basic safety measures to prevent electric shock. Also, HID bulbs are under high pressure when hot, creating an explosion hazard. Never operate an HID bulb that has been removed from the headlight assembly.



Chrysler

Figure 36-7. A sealed-beam lamp has an airtight glass housing around the filaments. This sealed-beam lamp has a small halogen inner bulb inside a glass lens.

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Tech Tip

Always make sure you have the correct replacement lamp. Normally, a lamp number is stamped on the housing. If needed, take the old lamp to the parts house so it can be matched up.

Headlamp Dimmer Switch

A ***dimmer switch*** controls the high and low headlamp beam function. This switch is commonly mounted on the steering column. It simply controls which bulb filaments receive power. Refer to **Figure 36-8**.

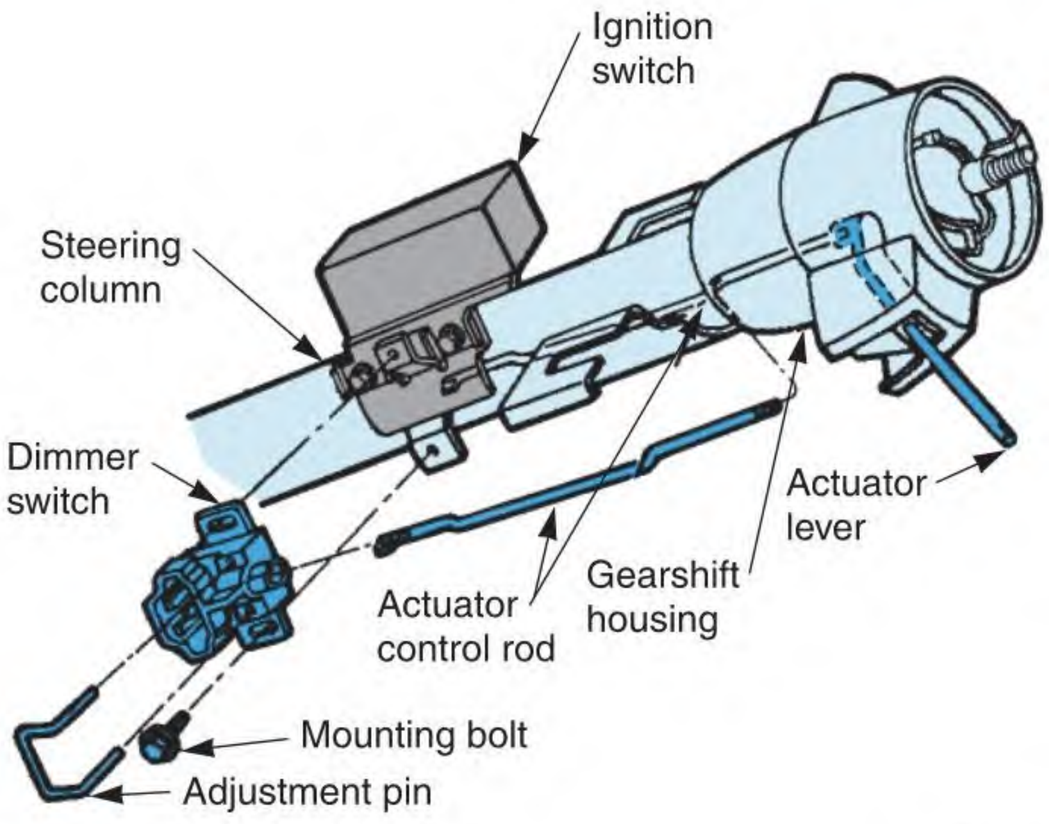
When the driver activates the dimmer switch, the electrical connection to the headlamps is changed. In one position, the headlamp high beams, or brights, are turned on. In the other position, the dimmer switch changes to low beam filaments for driving in traffic.

Automatic Headlamp Systems

An ***automatic headlight dimmer system*** uses a light sensor, amplifier, and relay to control the high and low beams. The system automatically dims the lights when detecting light from oncoming traffic. It switches to high beams when no oncoming light is detected.

The light sensor, or photosensor, may be mounted in the grille area or on the dash. The sensor produces a small amount of electric current when exposed to light. The amplifier uses this current to operate a dimmer relay. The relay changes the electrical connection from high beam to low beam automatically to keep the bright lights from blinding the occupants of oncoming vehicles.

Other variations of automatic control of the lighting system are available. Some turn the headlamps on when dark. Others (***auto-off headlamp system*** or delayed exit system) automatically turn the headlamps off after a short delay period. By remaining lit, the headlamps increase visibility and security when walking away from the vehicle.



Chrysler

Figure 36-8. The dimmer switch is mounted on the steering column in late-model vehicles.

Daylight Running Lights

With ***daylight running lights*** (DRL), the headlamps are lit anytime the engine is running. This is a safety feature that makes the vehicle more visible. **Figure 36-9** shows a lighting system circuit diagram that includes DRL.

Turn Signal, Emergency, and Brake Light Systems

The turn signal, emergency, and brake light systems are normally considered separate circuits. However, they commonly use some of the same wiring, electrical connections, and lightbulbs. This is illustrated in **Figure 36-10**.

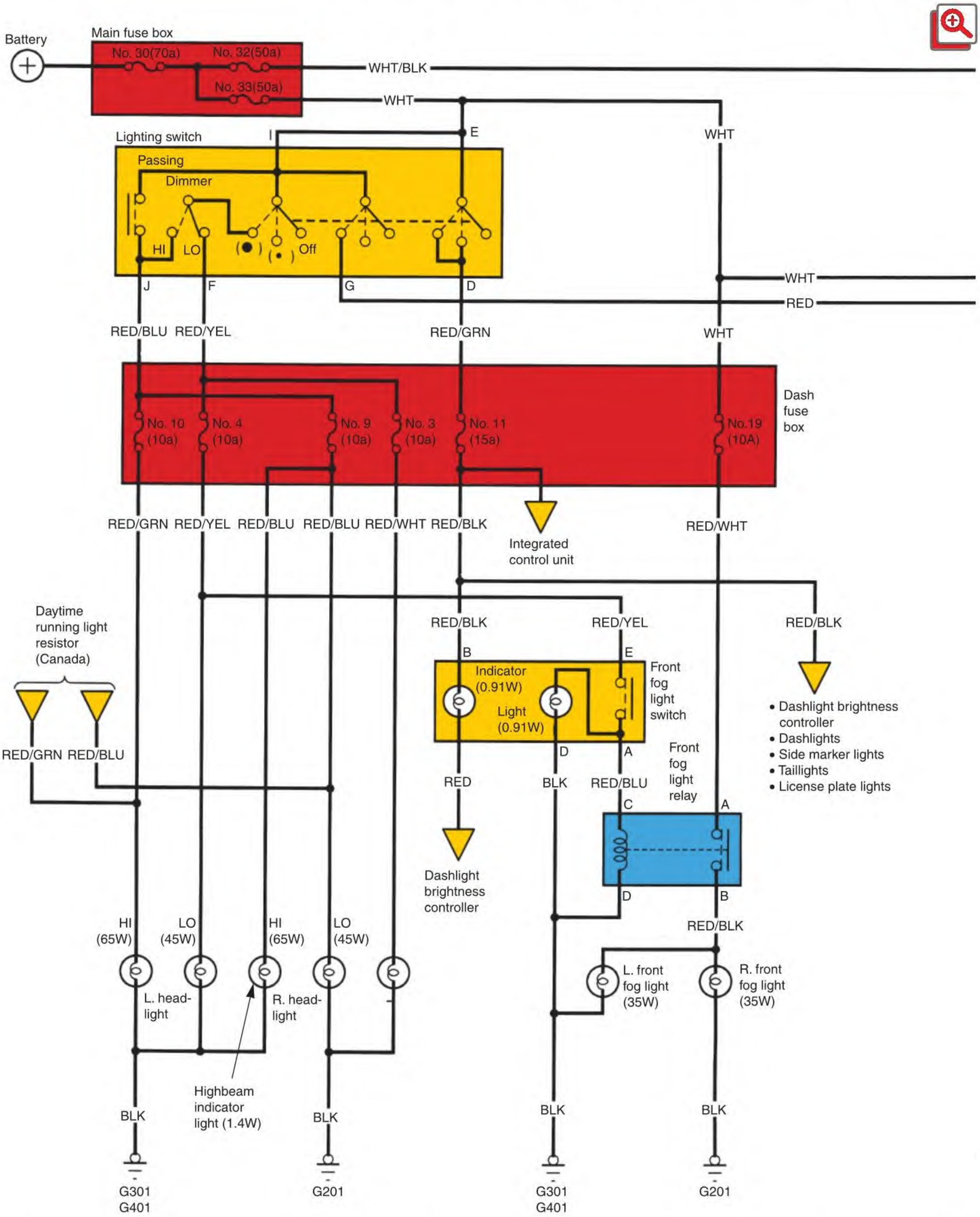
The lights in these systems are small incandescent bulbs. They can contain either one or two filaments. **Figure 36-11** shows two common types of bulbs for turn, emergency, stop, and backup lights.

Flashers

A ***flasher*** is used to operate the turn signals and emergency flasher lights on a vehicle. It is the component that makes and breaks the circuit to make the lightbulbs flash on and off. Usually, one flasher is used for the turn signals and another is used for the emergency flasher lights.

Flashers are similar to circuit breakers, but are designed to open and close the circuit at a constant rate. Flashers use a bimetal strip and a small heating element. Current flows through the heating element, warming and warping the bimetal strip. This turns off the lights. Then the strip cools and reconnects the circuit to flash the lights back on. This cycle is repeated to operate the turn signals or emergency flasher lights. A clicking sound can be heard from a flasher as its contact points open and close. See **Figure 36-12**.

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Figure 36-9. Typical wiring diagram for a lighting system. Trace electrical connections from the main fuse box (top left) to headlights (lower left) and daytime running lights (lower right). Color codes on wires are needed when testing for circuit problems.

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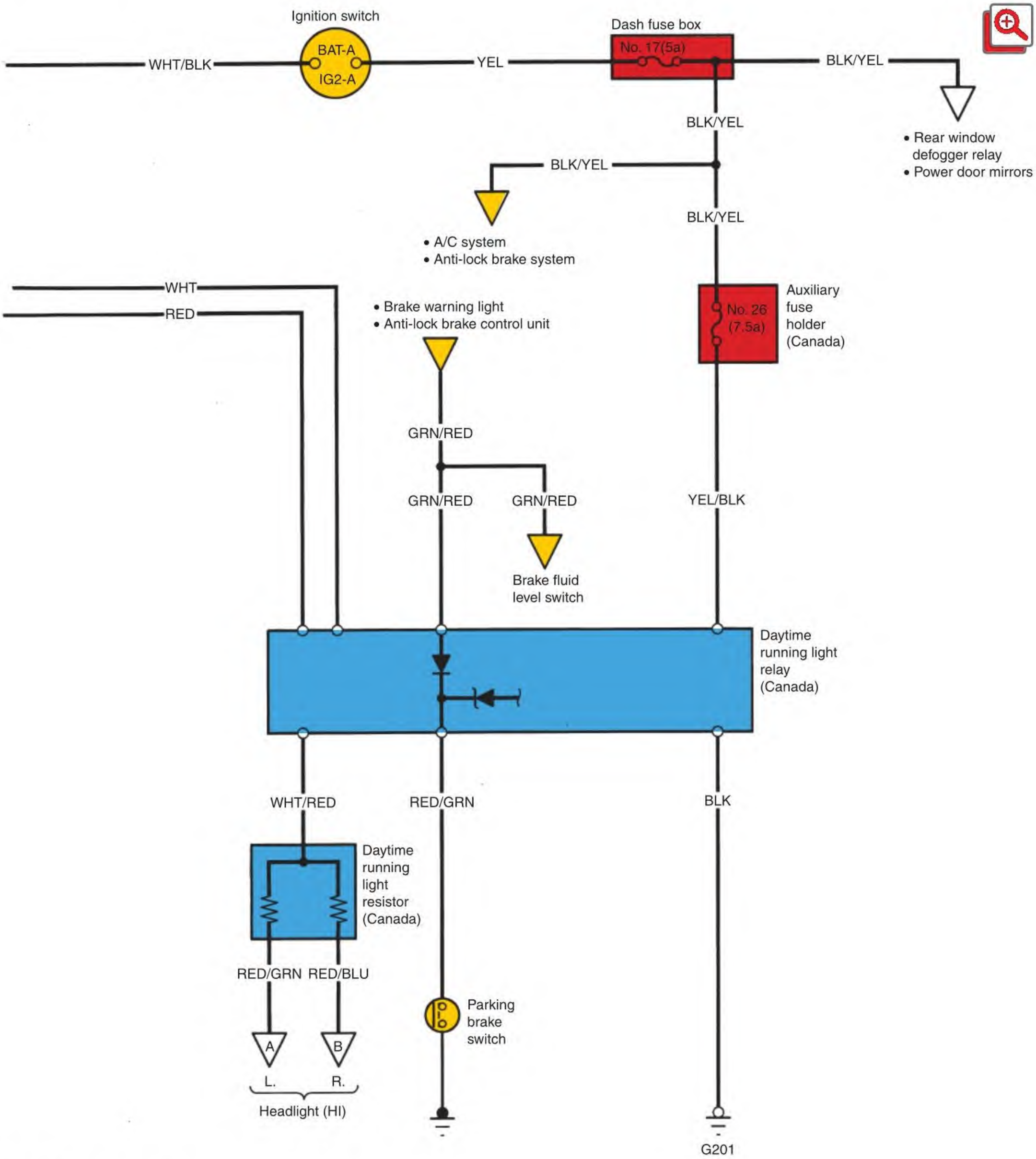
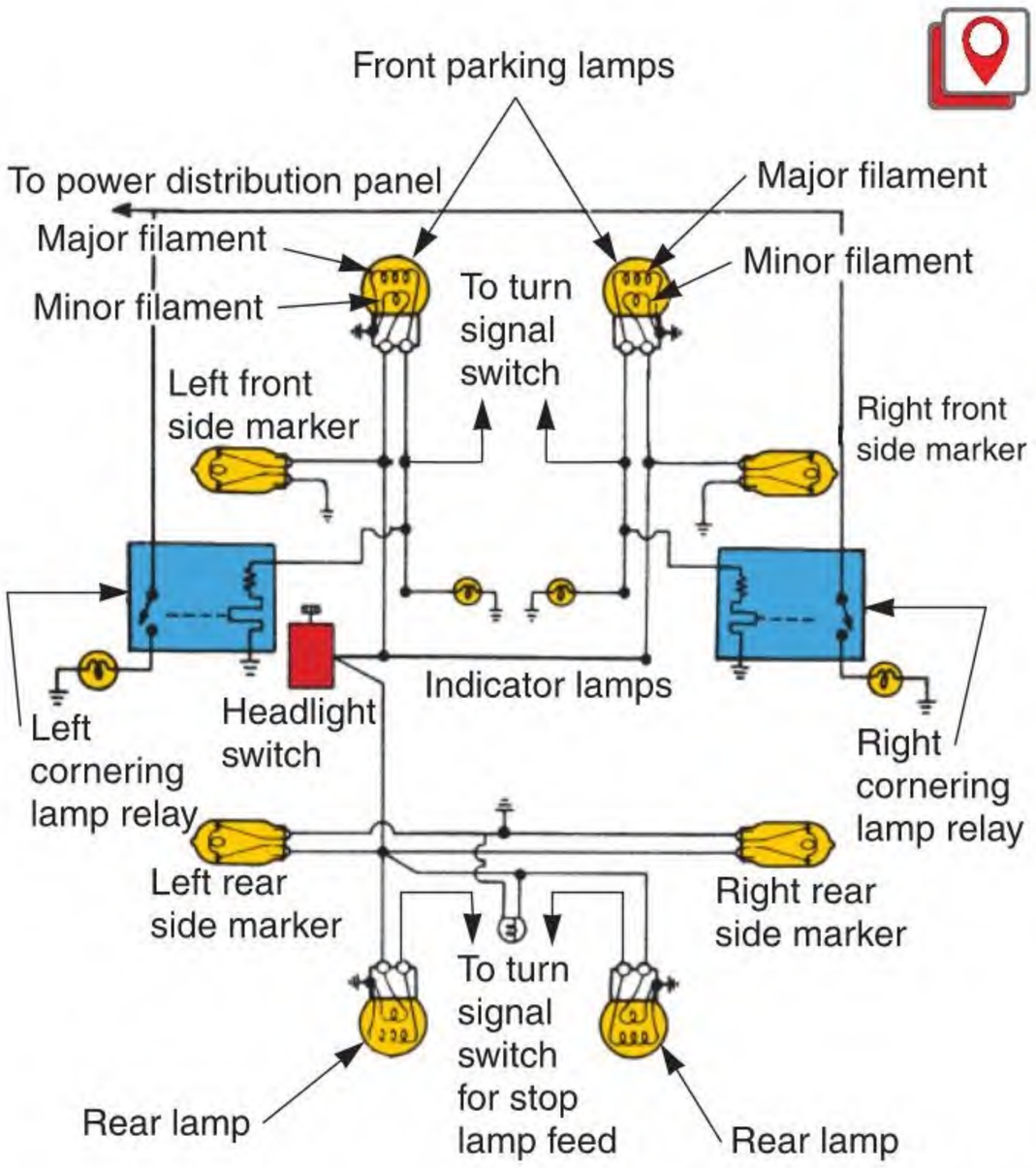


Figure 36-9. Continued

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Figure 36-10. Study the basic circuit for turn signals and marker lights.

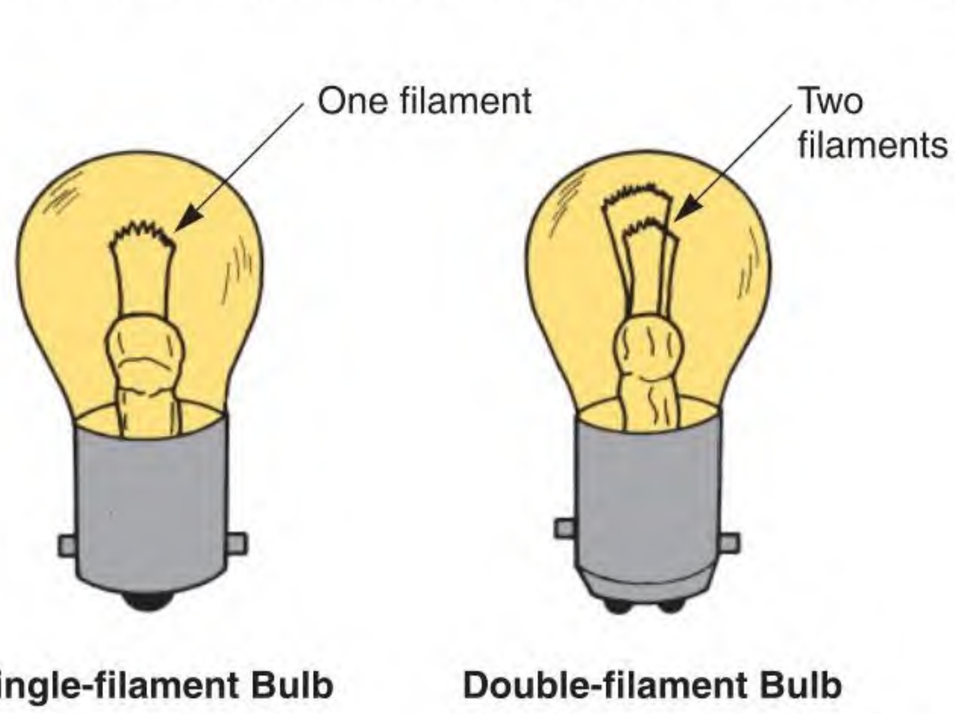
Flashers can be located on the fuse panel or wired in-line somewhere under the dash. Service manual diagrams show flasher locations.

Turn Signal System

The ***turn signal system*** consists of a fuse, turn signal switch, flasher unit, turn signal bulbs, indicator bulbs, and related wiring. When the steering column-mounted switch is activated, it causes the right or left side turn lamps to flash. Turn indicator lights in the instrument panel or on the fenders also flash.

The turn signal switch may be mounted in the center of the steering column, behind the steering wheel. A multifunction switch can also be used to control turn lights, horn, and dimmer switch. Look at **Figure 36-13**.

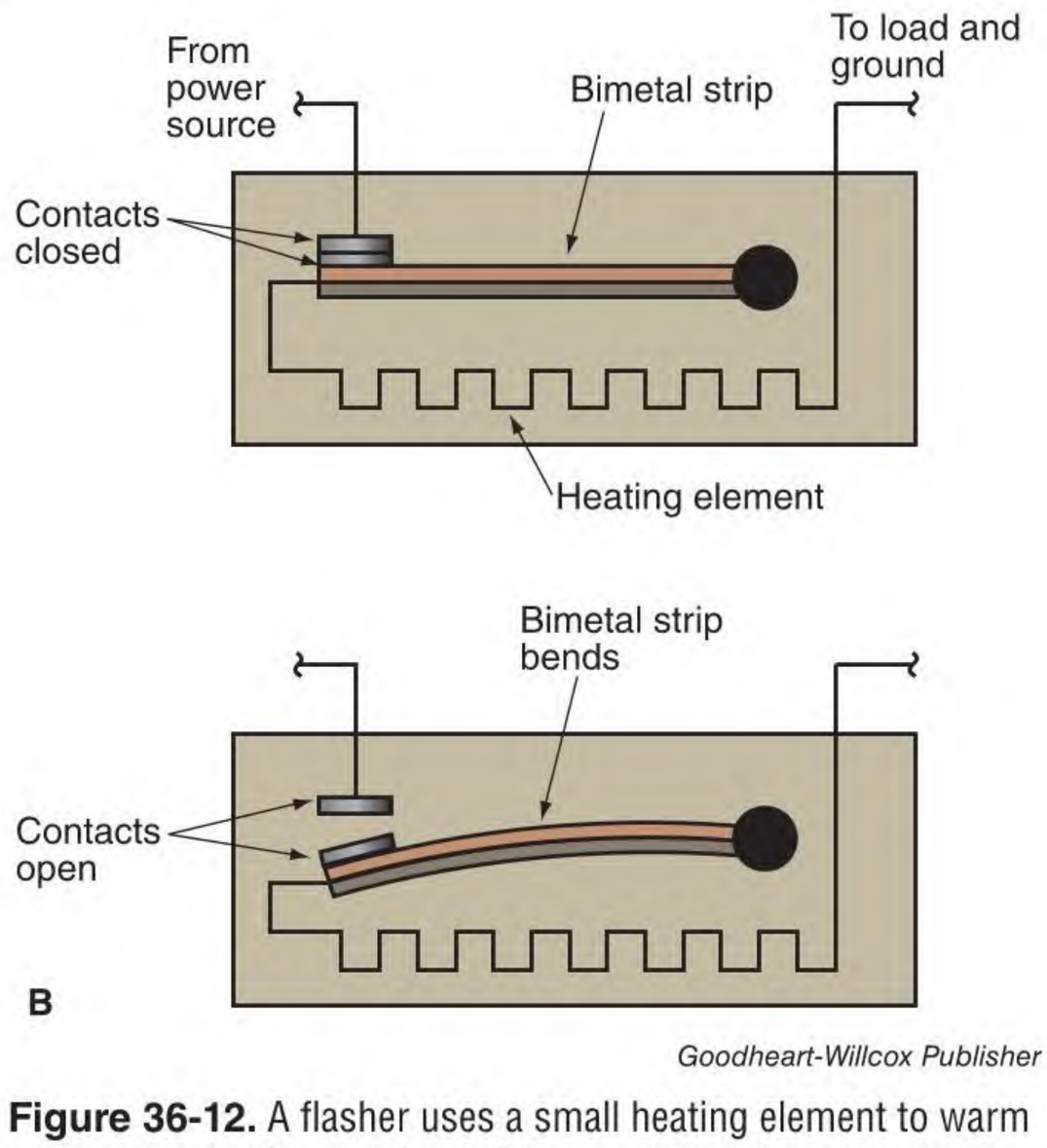
The turn signal flasher automatically opens and closes the turn signal circuit, causing the bulbs to flash. A bimetal strip is connected to a set of contact points and to the fuse panel. When current flows through the turn signal flasher, the bimetal strip is heated and



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Figure 36-11. Single-filament bulbs are commonly used as backup and marker lights. Double-filament bulbs serve as parking, turning, or braking lights.





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Figure 36-12. A flasher uses a small heating element to warm a bimetal strip. Current through the contact points operates the heating element. When the strip warms, it bends and opens the contacts. Then the strip cools and reconnects the heater and contacts. This action is repeated quickly and the contacts click open and closed to make lights flash on and off.

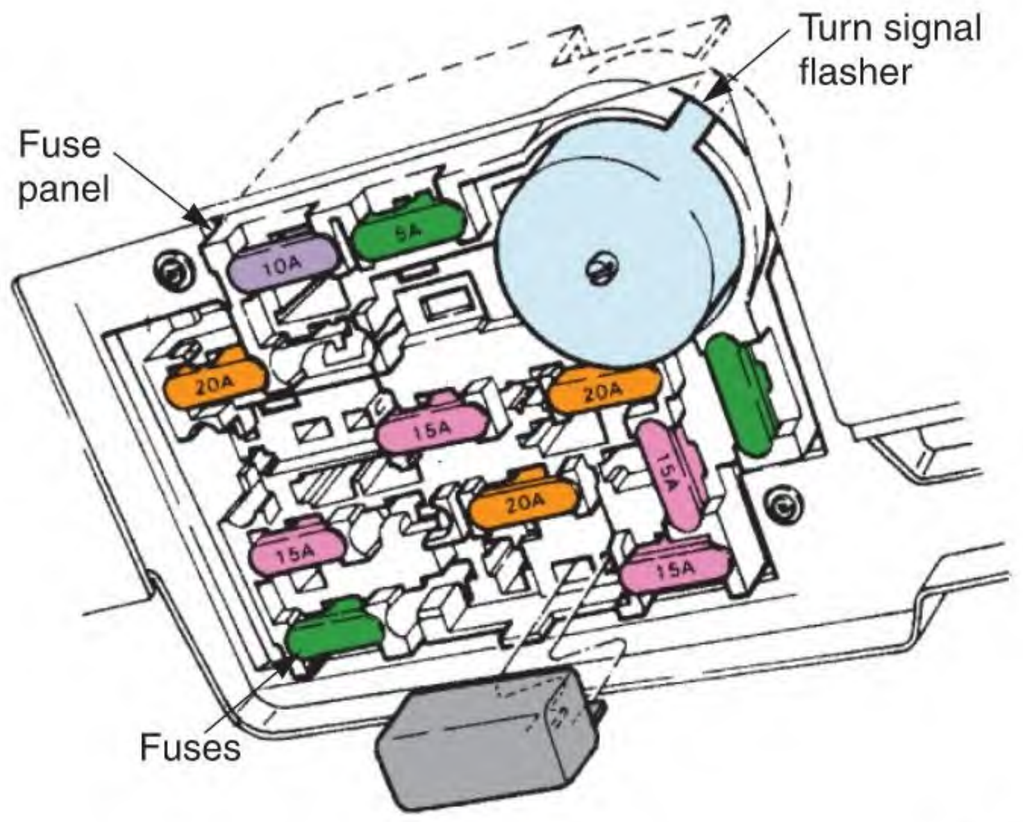
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Chrysler and Ford

Figure 36-13. The turn signal switch can be mounted around the steering shaft or on the side of the steering column.

bends. This opens the contact points and breaks the circuit. As the bimetal strip rapidly cools, it closes the points and again completes the circuit. This heating and cooling cycle takes place in about a second. The turn lights flash as the points open and close.

The turn signal flasher is frequently mounted on the fuse panel, **Figure 36-14**. However, it may be



Ford

Figure 36-14. The turn signal flasher is often located on the fuse panel or under the dash.

located somewhere else, such as under the dash. A shop manual will give the flasher location.

Tech Tip

A turn signal flasher is designed to operate with a specific current draw. Altering the load (adding trailer lights, for instance), can affect the operation of the flasher. Generally, if you increase current draw through the circuit, the flasher will blink more quickly. If you decrease current draw (one bulb burns out), it will slow or even stop the blinking action of the flasher.

Emergency Light System

The ***emergency light system***, also termed hazard warning system, consists of a switch, a flasher unit, turn signal lamps, and related wiring. The emergency light switch is normally mounted on the dashboard or the steering column. It is either a push-button switch or a push-pull switch.

When the switch is closed, current flows through the emergency flasher. Like a turn signal flasher, the emergency flasher opens and closes the circuit to the lights, causing the turn signals to flash. Oncoming traffic is warned of a possible emergency or hazard.

Brake Light System

The ***brake light system*** is commonly made up of a fuse, brake light switch, rear lamps, and related wiring.

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The brake light switch is normally mounted on the brake pedal, as in **Figure 36-15**. Battery power is fed to the brake light switch from the ignition switch. When the brake pedal is pressed, it closes the switch, and current flows through the wiring to the brake lights. This turns on the rear brake lights to warn traffic of the stop.

The brake light switch can also be located on the master cylinder. In these switches, hydraulic pressure from the brake system closes the switch to turn on the brake lights.

Backup Light System

A backup light system typically has a fuse, gear shift- or transmission-mounted switch, two backup lamps, and wiring to connect these components.

The backup lamp switch closes the light circuit when the transmission is shifted into reverse. This illuminates the area behind the car. See **Figure 36-16**.

Illuminated Entry System

The ***illuminated entry system*** turns on the interior lights when you move the door handle or open the door. It allows you to see the key cylinders and the interior of the passenger compartment at night. Illuminated entry systems vary from simple to complex. Look at **Figure 36-17**.

A simple illuminated entry system uses door-jam switches to turn on the interior lights. When a door is opened, it closes that switch to energize the lights.

More complex illuminated entry systems use an electronic control module, various switches, and several interior lights. Both door switches and a driver's door handle switch energize the system. When one of the switches is closed, it signals the ECM. The ECM can then turn on the lights and time when they go off. Note that this circuit also illuminates the key cylinders and footwell in the passenger compartment.

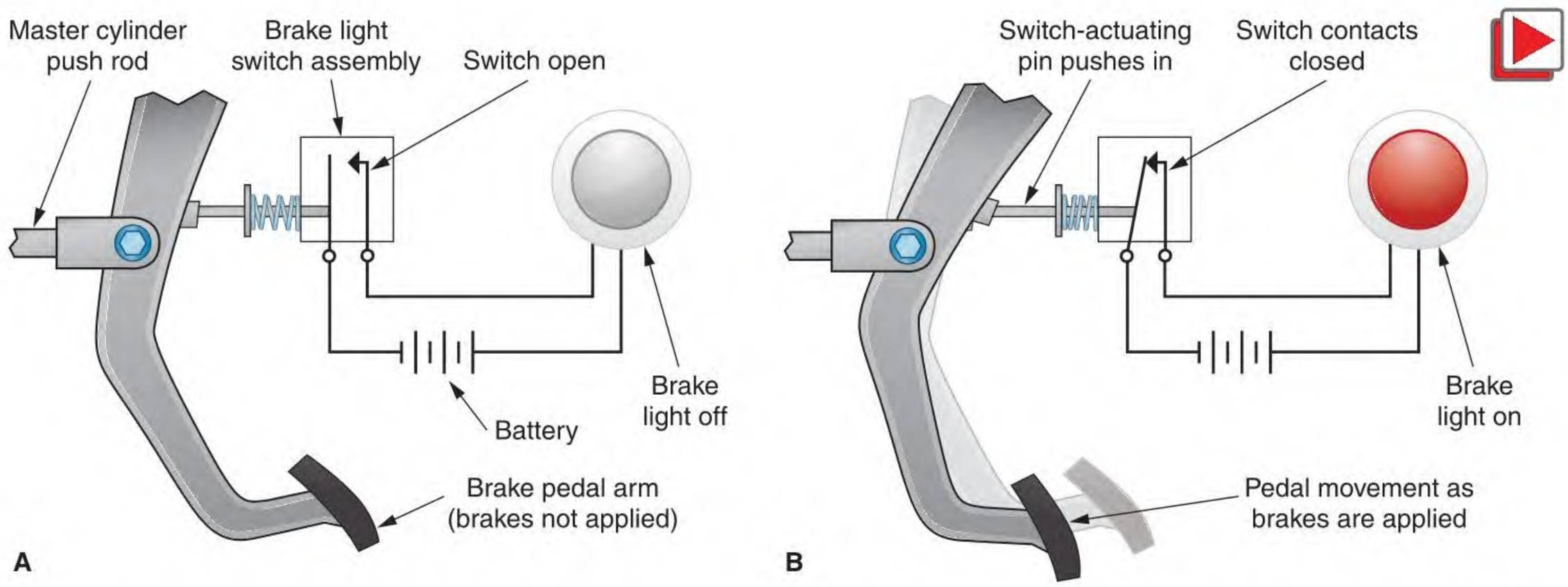
Light-Monitoring Systems

A ***light-monitoring system*** turns on a warning light in the instrument panel when a headlight, brake light, or other light burns out. This is a safety feature to help ensure that all the vehicle's lights are working properly.

In most systems, a control module monitors the amount of current flowing through each of the lighting circuits. If a bulb burns out, less current will flow through the related circuit. The control module detects this change in current flow and illuminates the warning light, alerting the vehicle's driver to the problem.

Light System Service

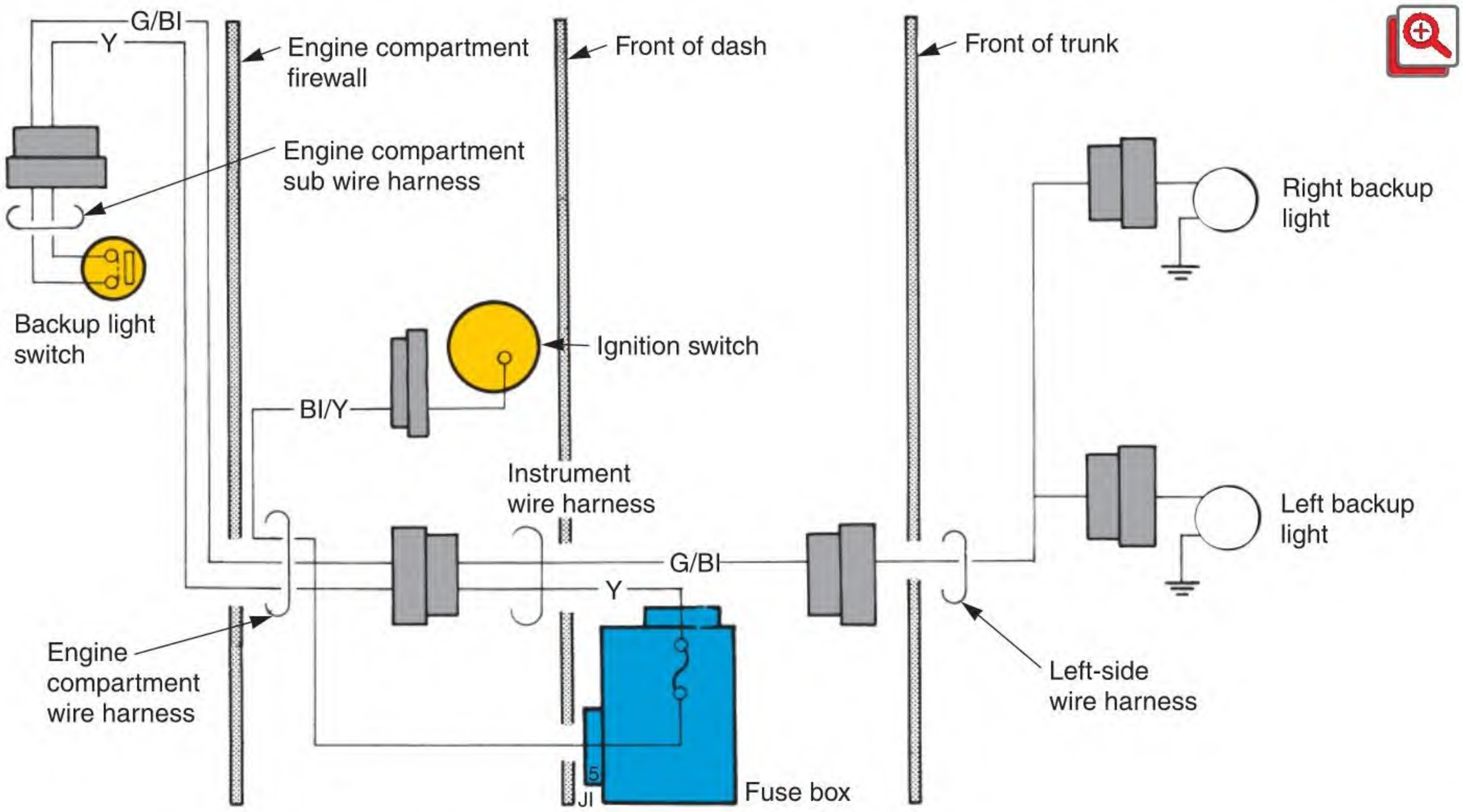
Light system service involves changing burned-out bulbs, testing bulb sockets, checking fuses, finding shorted and open circuits, aiming headlights, and similar tasks. This section of the chapter will summarize the most important types of electrical tests and repairs performed on a car's lighting system.



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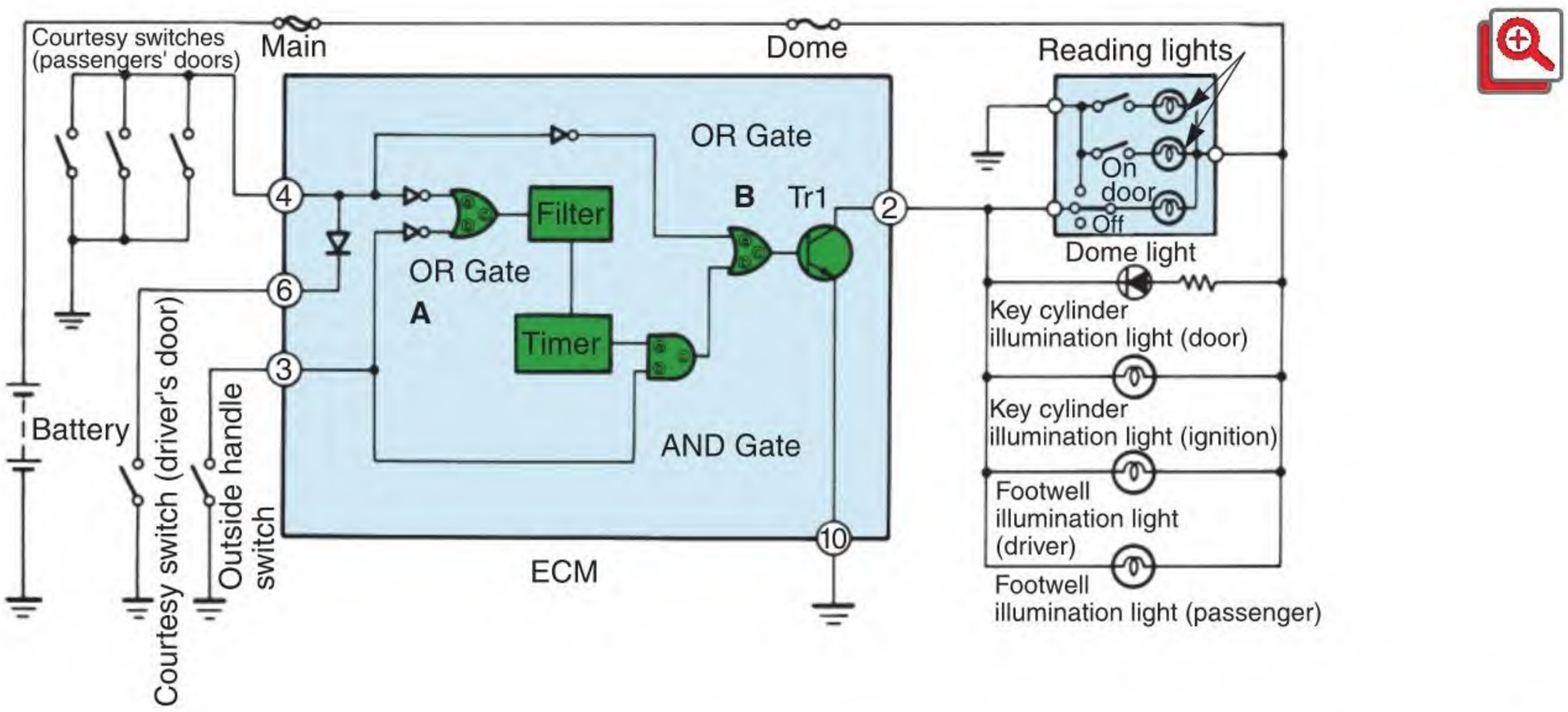
Figure 36-15. Study brake light switch action. A—Brake pedal released, contacts open, brake lights are off. B—Pedal depressed, contacts close, brake lights function. Note the part names.

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Honda

Figure 36-16. Note the basic configuration of the backup light circuit. Vertical lines represent the firewall, dash, and trunk divider.



Lexus

Figure 36-17. This illuminated entry system uses several switches (left) to signal the ECM (center), which operates the lights (right). When you pull up on the driver's door handle, it energizes the system. The lights fade in about ten seconds if no other switch is closed.

Lamp Replacement

A burned-out bulb has the filament melted in half. Sealed-beam headlamps are usually held in place with small screws and a retaining ring. Halogen insert bulbs normally fit into the rear of the bulb housing. You must push and twist to install some headlamp bulb inserts. Sometimes a small ring screws over and secures the halogen insert. Spring clips can secure halogen fog lamp bulbs.

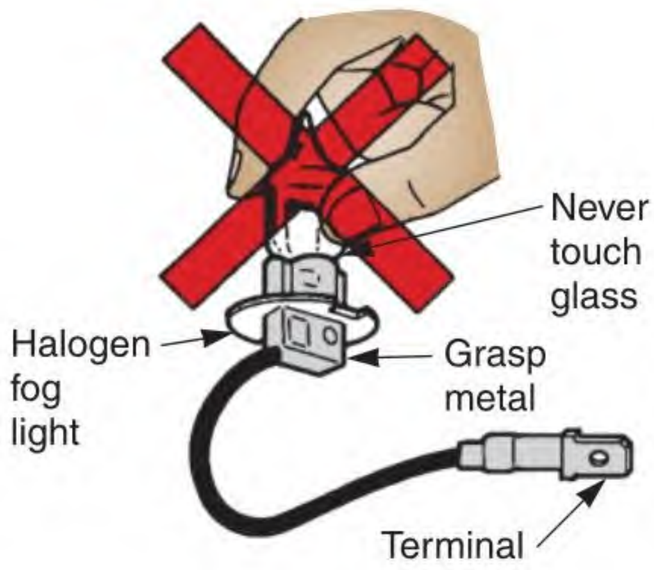
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Most incandescent bulbs are housed in a lens. They are normally held in the socket by a spring and small dowels or a press fit. You may have to remove the lens or reach behind the housing to access the bulb. This is illustrated in **Figure 36-18**.

Always make sure you have the correct replacement bulb.

Caution

Never touch the glass surface of a halogen or high-intensity discharge bulb. The oil from your skin and the high operating temperature can make the glass shatter or shorten the bulb's service life. See **Figure 36-19**.



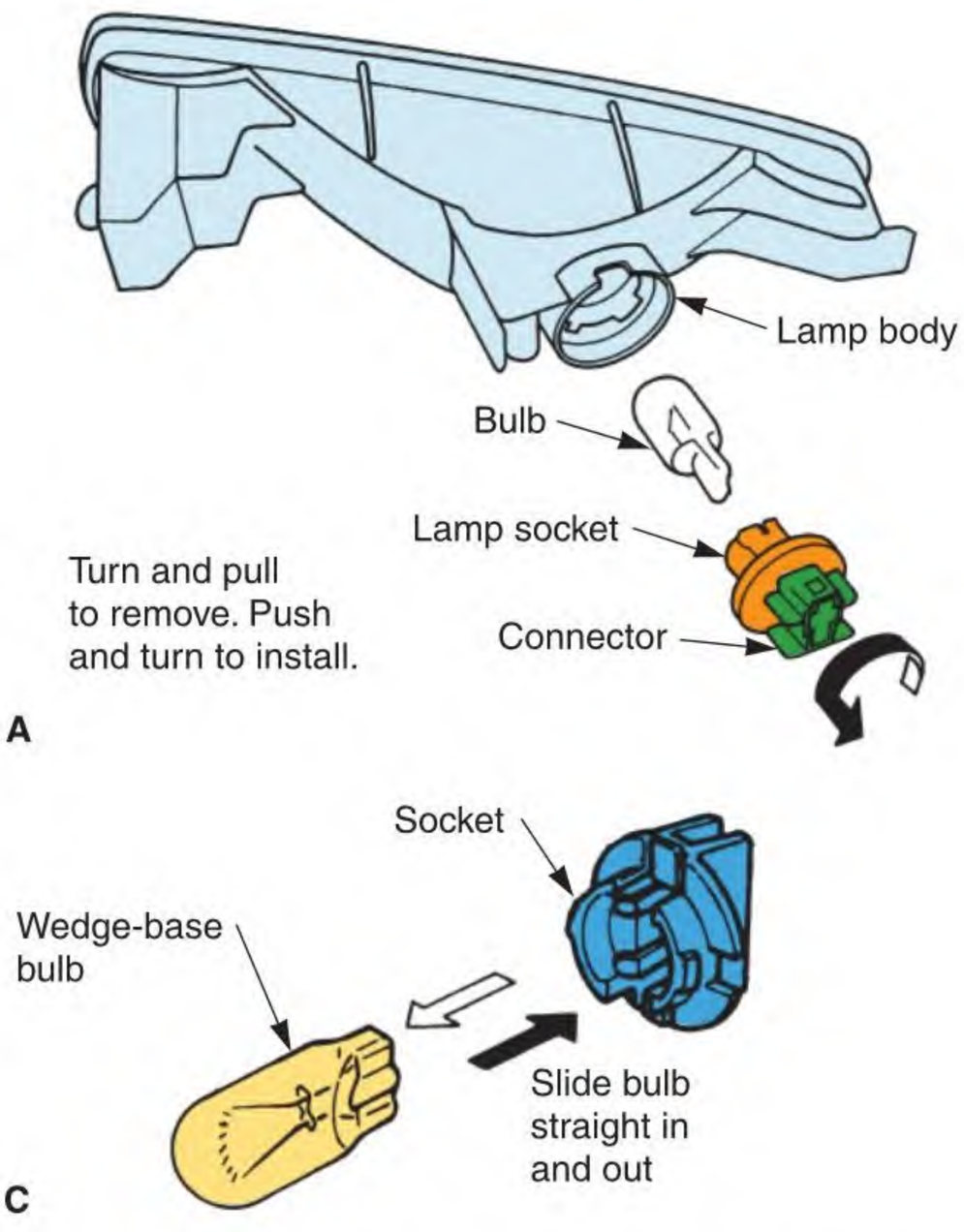
Mazda

Figure 36-19. Never touch the glass on a high-intensity halogen headlamp or fog lamp bulb. Oil from your skin can make the glass shatter and ruin the new bulb.

No-Light Problems

A no-light problem is a total failure of the light circuit or bulb. First, check to see if the bulb is burned out. Close inspection of the filament will show whether it has burned. If the bulb is good, check for power to the bulb socket.

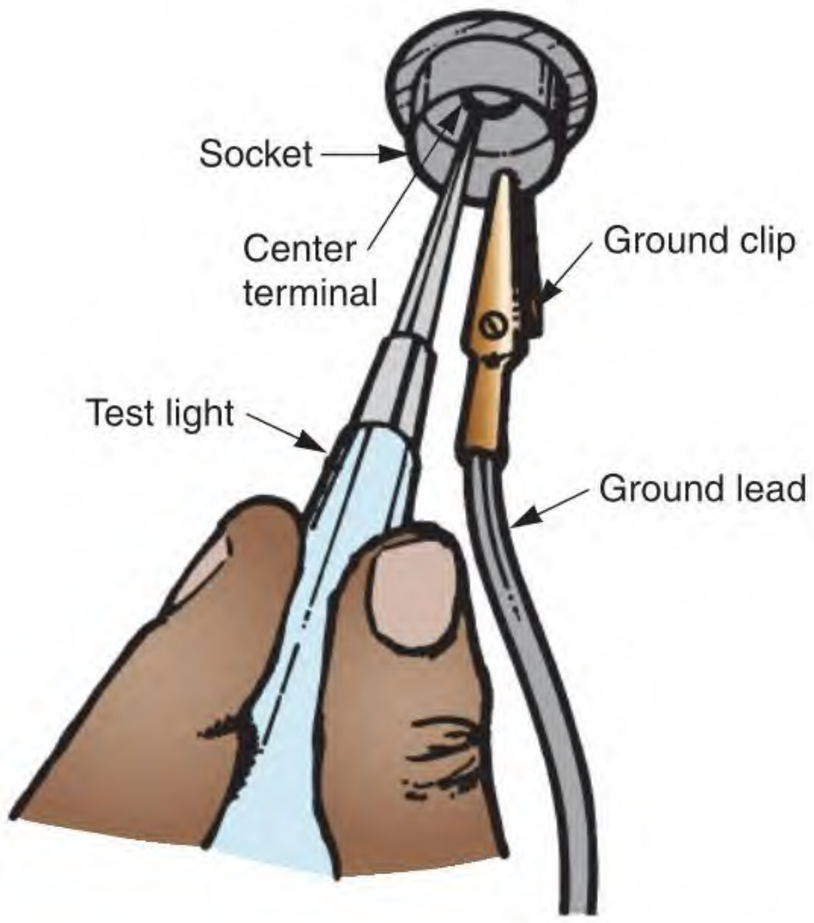
Figure 36-20 shows how to check for voltage in a bulb socket. With the light turned on, there is a socket or circuit problem if the test light does not glow. If you



Honda and Nissan

Figure 36-18. Study bulb configurations. A—The socket has lugs that lock into the lamp body. Partial turn will free or install the bulb socket. B—Push in and turn to install or remove a bulb with prongs. Socket has spring-loaded terminals. C—Just pull in or out on wedge-base bulb. Be careful not to break the bulb and cut your fingers. D—Double-end bulbs are snapped in and out as shown.

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Figure 36-20. If the new bulb does not work, check for voltage to the socket with a test light. You may need to clean rust and corrosion out of the socket.

do not have power to the socket, trace back through the circuit to find the open preventing current flow.

Flickering Light Problems

Flickering lights (lights go on and off) point to a loose electrical connection or a circuit breaker that is kicking out because of a short.

If all or several of the lights flicker, the problem is in a section of the circuit common to those lights. Check to see if the lights flicker only with the light switch in one position. For example, if the lights flicker only when the headlights are on high beam, you should check the components and wiring in the high beam section of the circuit.

If only one light flickers, the problem is in that section of the circuit. Check the bulb socket for corrosion. Clean the socket. Also, make sure the bulb terminals are not worn. Worn bulb terminals can upset the electrical connection. If needed, replace the bulb socket and bulb.

Light Switch Problems

Light switch problems occur when a switch shorts closed or becomes open all the time. If shorted closed, the lights will always glow. If always open, the lights will not come on.

Figure 36-21 shows several types of switches used to operate lights and instrumentation systems.

To test a switch, use a test light or voltmeter to check for power going to and from the switch in the closed, or on, position. You can also disconnect the switch and test it with an ohmmeter, **Figure 36-22**.

Turn Signal Problems

If the turn signals do not flash, check for a burned-out bulb. Even one burned bulb will reduce current and prevent the flasher unit from functioning. A burned-out bulb is the most common cause of turn signal problems.

If both right and left turn signals do not work, check the fuse and flasher unit. The problem may also be in the turn signal, or multifunction, switch. This switch is prone to wear and failure after prolonged service. Something common to both sides of the circuit may be at fault if no bulb is coming on.

The basic steps for removing a multifunction switch are demonstrated in **Figure 36-23**.

Brake Light Problem

If none of the brake lights are working, something common to all the bulbs is at fault, such as the brake light switch or feed circuit. If only one bulb is not working, check the bulb and its section of the circuit.

Other Light Circuit Problems

With other light circuit problems, you may want to refer to the wiring diagram for the specific make and model of vehicle. It will give wire color codes, connector locations, and other useful troubleshooting information.

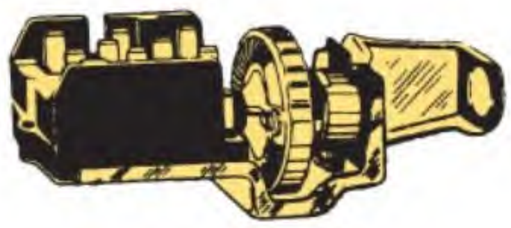
Aiming Headlights

Aiming headlights involves adjusting the beams so they are directed to light the area in front of the vehicle. Headlights can be aimed using headlight aimers, a wall screen, or leveling bubbles on the headlight housings. These methods ensure that the headlight beams point in the direction specified by the vehicle manufacturer.

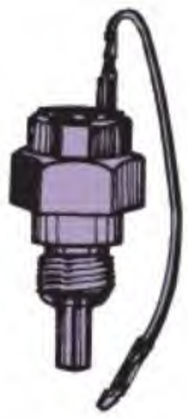
Headlights aimed too high could blind occupants in oncoming vehicles. Headlights aimed too low or to one side could reduce visibility for the driver.

Before attempting to aim a vehicle's headlights, make sure the vehicle has about a half tank of gas and the correct tire inflation pressure. Remove extra cargo that could lower rear curb height and upset your headlamp adjustments. Only the spare tire and jack

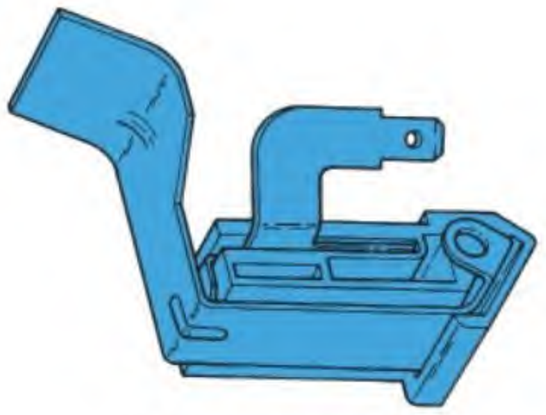
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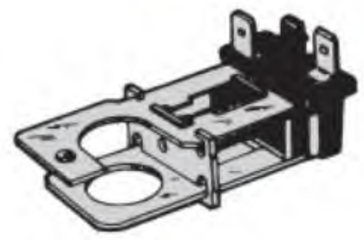
Light switch, in dash



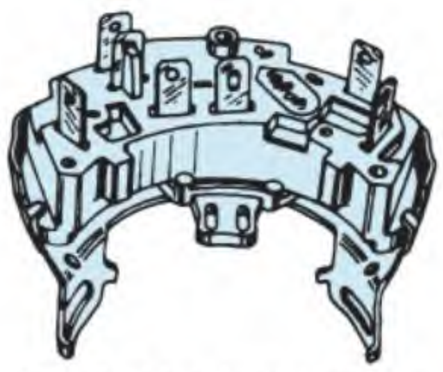
Temperature switch, in head or block



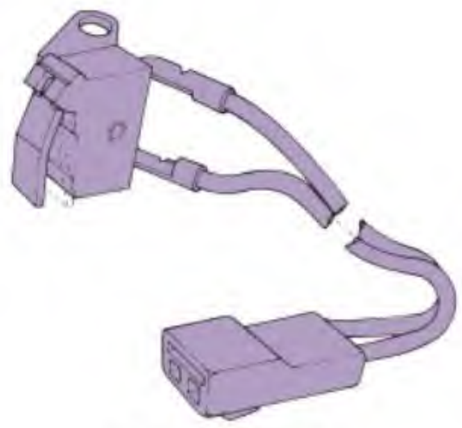
Tailgate ajar switch, in body at tailgate



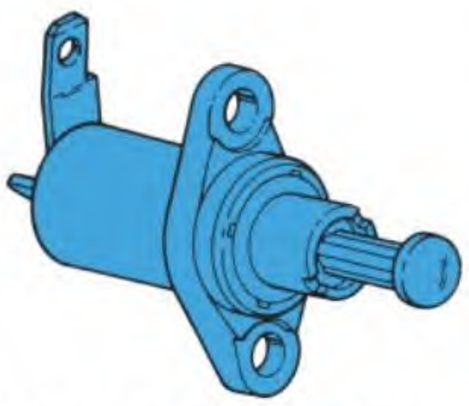
Brake light switch, on pedal assembly



Neutral-backup switch, on steering column or transmission/transaxle



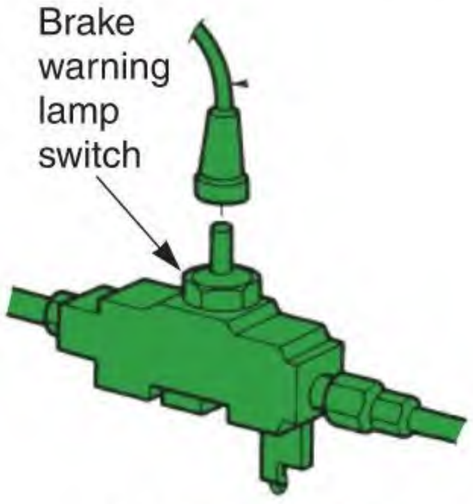
Key-in switch, in steering column



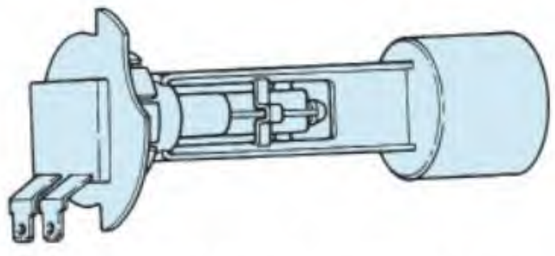
Door ajar switch, in body near front of door



Low fuel level switch, on fuel tank



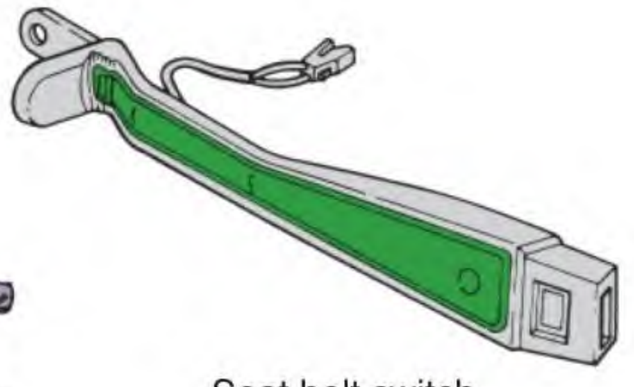
Brake light switch, in brake line



Low windshield washer fluid switch in fluid reservoir



Low oil pressure switch, in engine block



Seat belt switch, in buckle

GP Parts and Chrysler

Figure 36-21. Study the various switches used in light and instrumentation circuits.

should be in the trunk. Some manufacturers recommend that someone sit in the driver and passenger seats while the lights are being aimed.

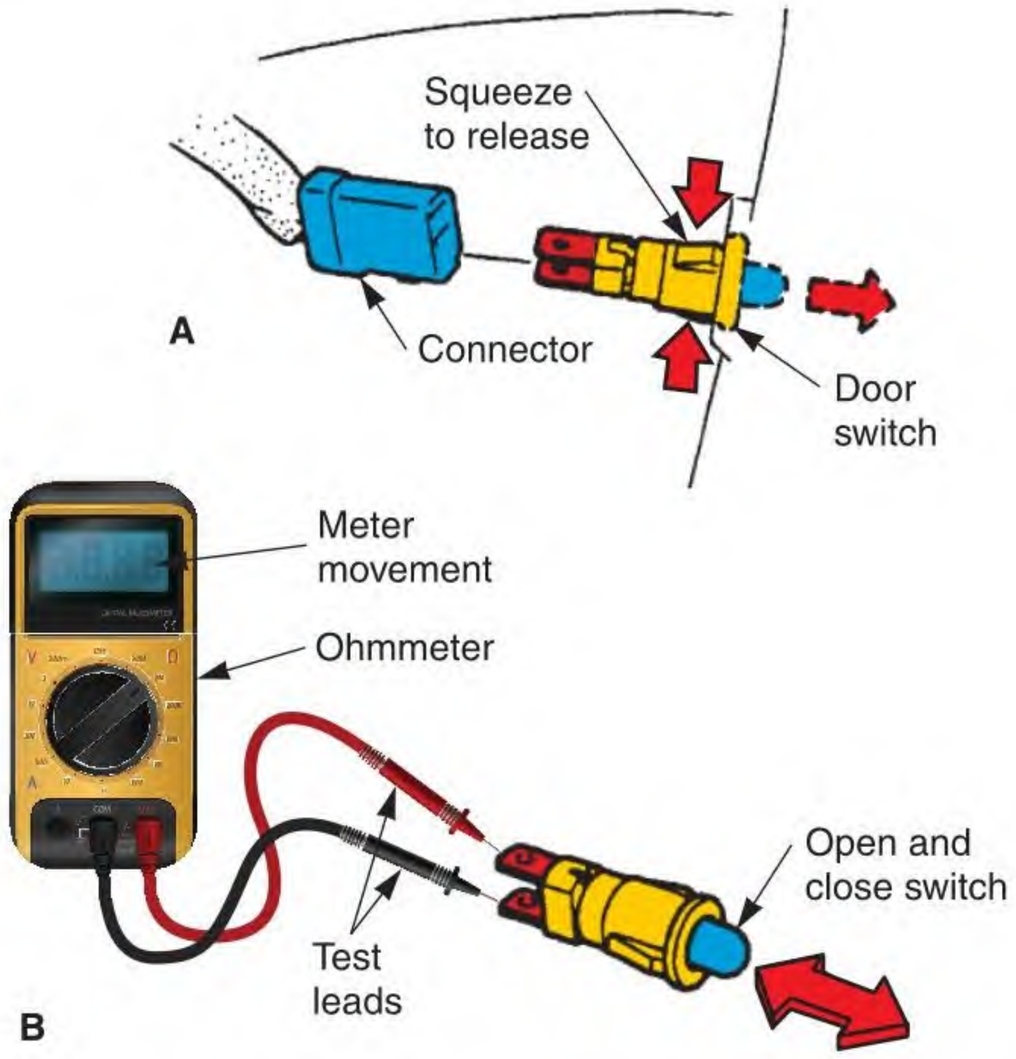
Headlight aimers are devices for pointing the car's headlamps in a specified position. To use aimers, follow the instructions for the specific type of equipment. Some require a level floor. Others have internal leveling mechanisms to allow for an uneven shop floor. A headlight aiming screen is a series of measured lines marked on a shop wall for aiming a car's headlamps. One is shown in **Figure 36-24**. Note that lines are drawn on the wall at specific horizontal and vertical locations depending upon vehicle dimensions.

The car is normally located 25″ (7.6 meters) from the screen on a level floor. When the headlights are turned on, the highest points of light intensity (brightness) should align with the marks on the wall or screen. Aiming the low beams also aims the high beams. Refer to a service manual for added details.

Headlight adjusting screws are provided to alter the direction of the headlamp beams. One screw provides vertical adjustment. Another screw provides horizontal adjustment. Turn the screws until the aimer or screen shows correct beam alignment. See **Figure 36-25**.

Headlight leveling bubbles are built into many late-model headlight assemblies to simplify headlight aiming, **Figure 36-26**. You simply adjust the housing screws until the leveling bubble is centered in its indicator.

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Mazda

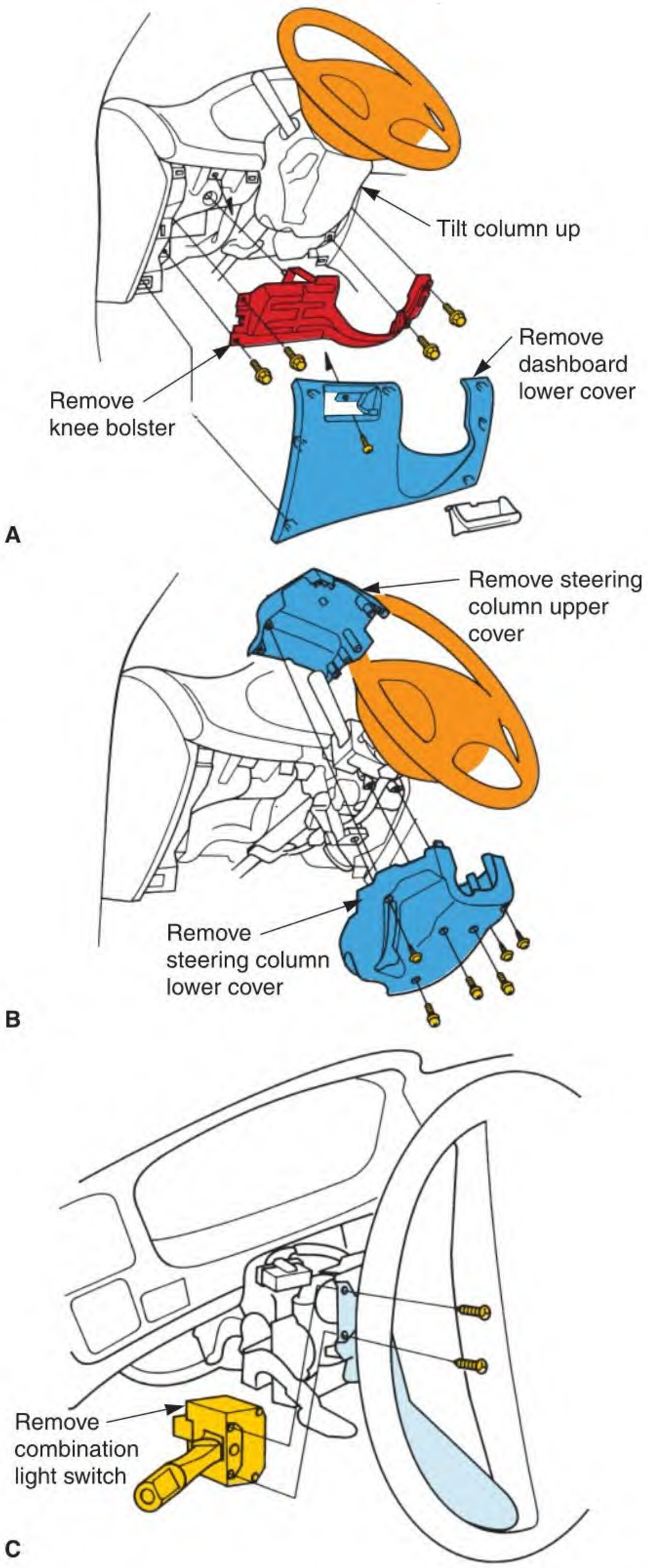
Figure 36-22. Switches, because of their moving parts, are a common source of trouble. They can short closed or become broken and remain opened. A—To test a switch, remove the wiring connector. This is a door switch that must be squeezed lightly for removal from the door pillar. B—Connect an ohmmeter across the switch terminals. Activate the switch and the meter reading should go from almost zero to infinity.

Dash Instrumentation

Instrumentation is used to inform the driver of various operating conditions—oil pressure, engine temperature, computer trouble codes, air bag system status, etc. Today's vehicles use a wide range of instruments, some simple and others complex. It is important that you understand the basics of instrumentation because it must be serviced in the field when problems develop.

Analog instruments use rotating needles or dials to indicate operating conditions. See **Figure 36-27A**. An analog speedometer, for example, uses a large needle that rotates around to show vehicle speed. An analog tachometer gives the same type of display for engine speed.

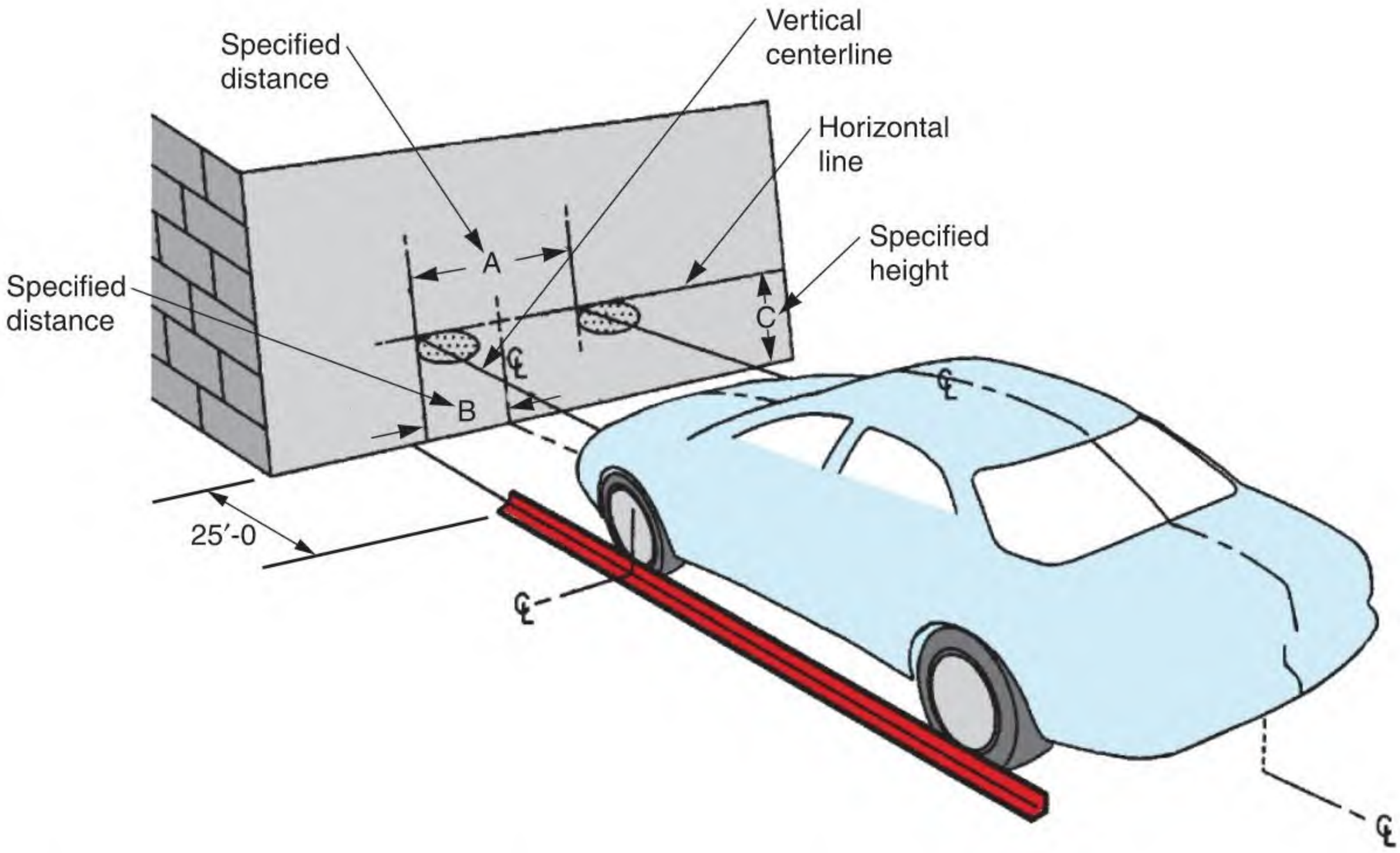
Digital instruments use various lights and electronic displays to show operating conditions. They do not have the mechanical parts, as with analog instruments. Digital displays are more complex than analog displays because an electronic control module is needed to act as an interface between the sensor



Honda

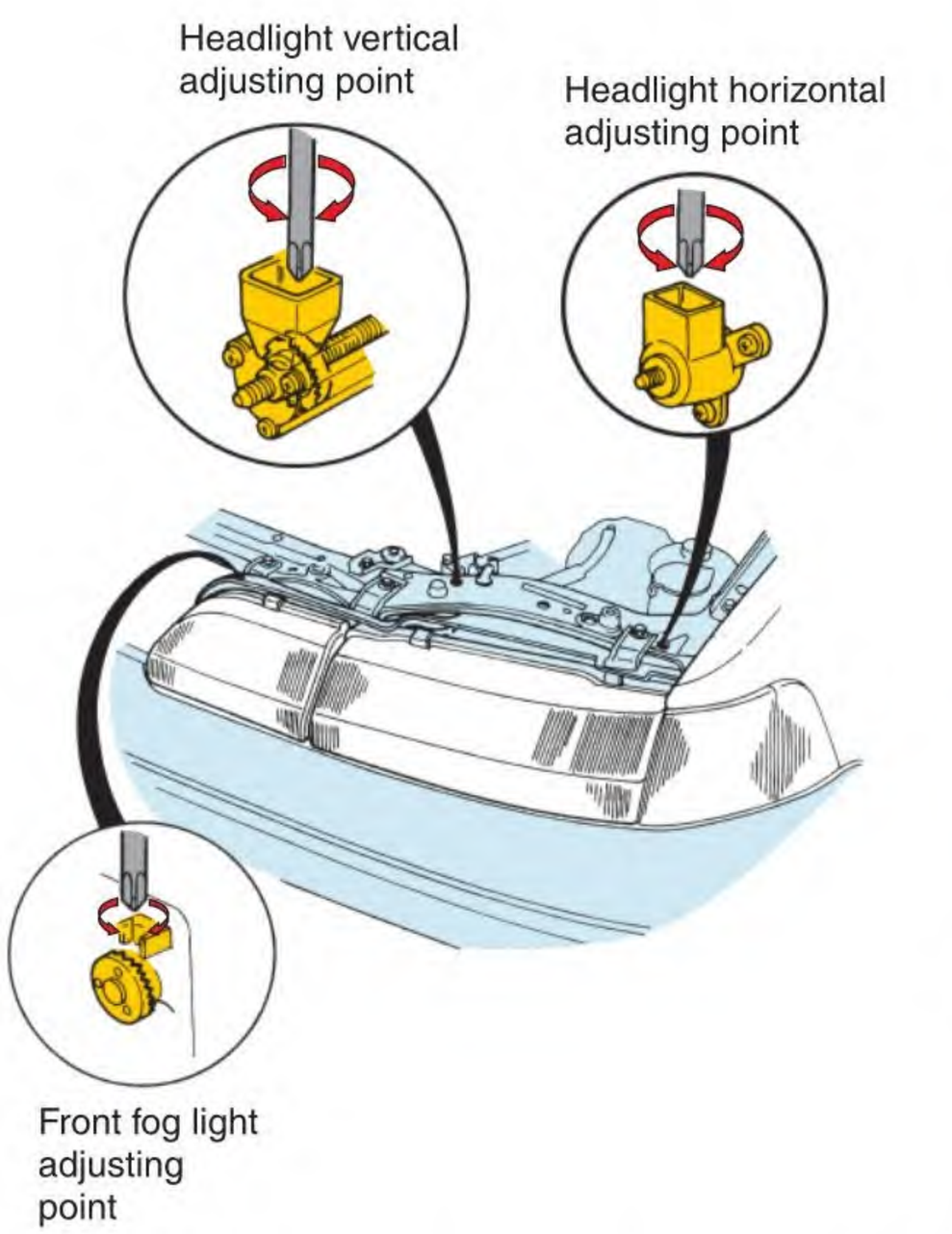
Figure 36-23. To service a bad multifunction switch, follow these basic steps and detailed instructions in service manual. A—Remove electrical connections or test the switch using service manual diagrams and instructions. B—If bad, replace the multifunction switch. The switch shown can be replaced without steering wheel removal. Others may require steering wheel removal.

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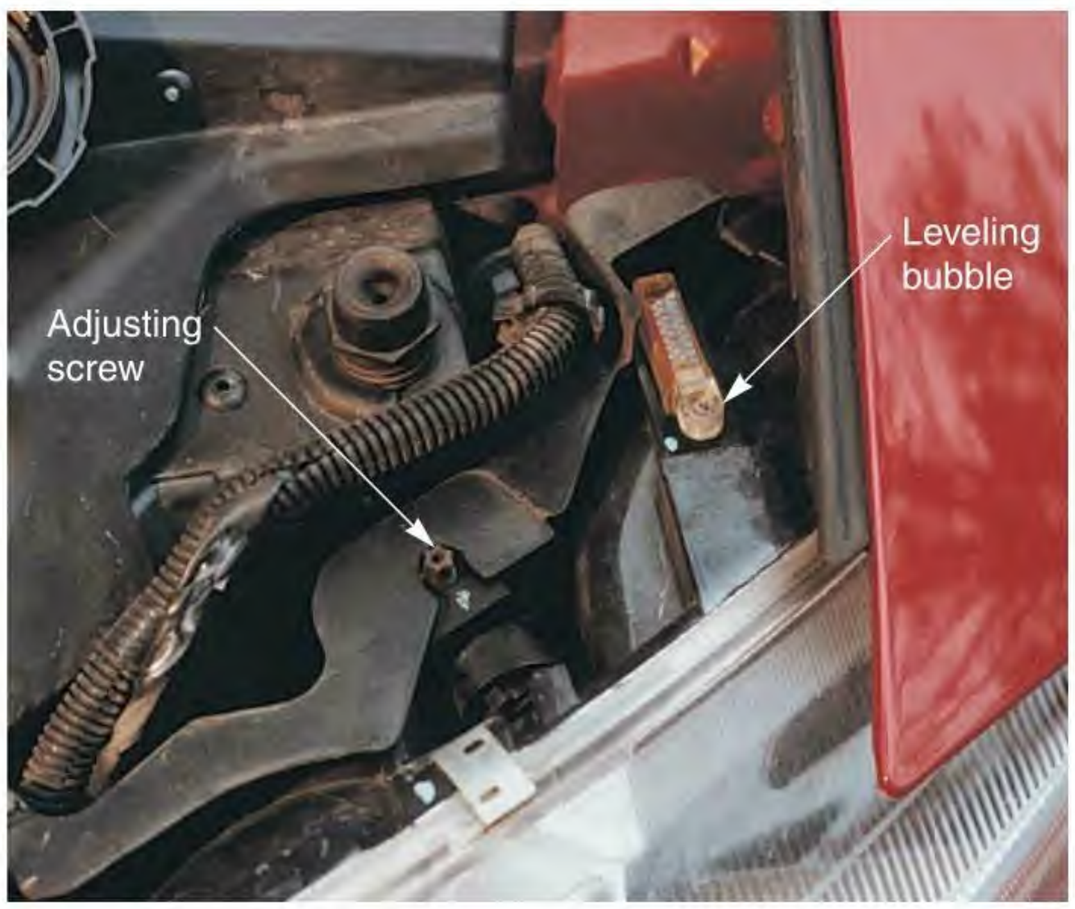
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Figure 36-24. Lines can be marked on the shop wall according to vehicle specifications for aiming headlights. The car must be located a prescribed distance from the wall. Adjust headlamp low beams until they shine in designated areas on the wall.



Honda

Figure 36-25. Note the location of headlight adjustment screws.



Honda

Figure 36-26. This car has a leveling bubble to aid in the adjustment of headlamps.

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and the digital readout panel. Digital instruments can use vacuum fluorescent or liquid crystal displays. Look at **Figure 36-27B**.

Vacuum fluorescent displays are small glass tubes filled with neon or argon gas. They glow when electrically energized, making them very visible and easy to read.

Liquid crystal displays (LCDs) are semiconductor panels that pass light when electrically energized and block light when not energized. An LCD display is often backlighted to make it easier to read.

Instrument Cluster

The instrument panel is the general area of the dash behind the steering wheel that holds most displays. It is usually a removable assembly that includes the dash pad and the plastic covers over the front of the instrument cluster. The ***instrument cluster*** is the housing and clear plastic cover that holds the gauges, indicator lights, speedometer head, and bulbs.

To service an instrument cluster, remove the small screws around the outside of instrument panel. Often, you must remove a cover before accessing the screws that hold the instrument cluster in place. See **Figure 36-28A**.

Before completely removing the instrument cluster, disconnect the wires and speedometer cable (if used). If you try to force the cluster out without disconnecting everything on the rear of the housing, the wiring and cluster could be damaged. Look at **Figure 36-28B**.

With the cluster out, it is easy to replace burned-out bulbs and inoperative gauges. Refer to **Figure 36-29**.

To replace gauges, you must open up the instrument cluster. Small screws hold the front lens to the housing. Remove these screws and remove the lens. The gauges may also be held in place by small screws through the rear of the cluster, **Figure 36-30**.

Tech Tip

The instrument cluster warning lights should glow when the ignition key is turned to the *On* position and go out when the engine is started. If a light does not glow, the bulb may be burned out or there may be a problem in the warning light circuit. If a light remains on after the engine is started, there is a problem in the corresponding system.

Dash Gauges

There are basically two types of gauges—balancing coil gauges and bimetal gauges. Both are commonly used. The two types are illustrated in **Figure 36-31**.

A ***balancing coil gauge***, **Figure 36-31A**, uses two electric coils to cause needle deflection. The sending unit changes the current flow through the coils to deflect the gauge needle right or left using the magnetic field generated by each coil.

A ***bimetal gauge***, **Figure 36-31B**, uses two dissimilar metals bonded together to cause gauge needle deflection. Generally, as current flow from the sending

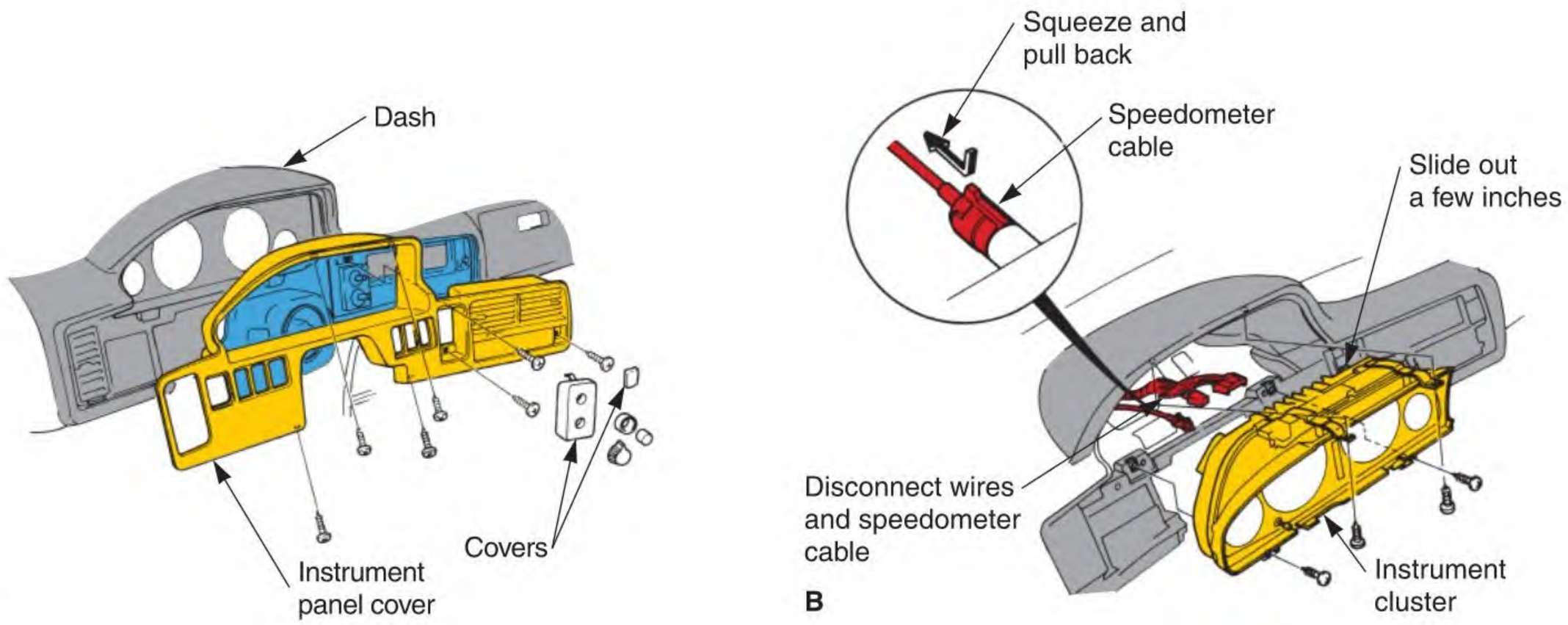


A B

Ford, Honda

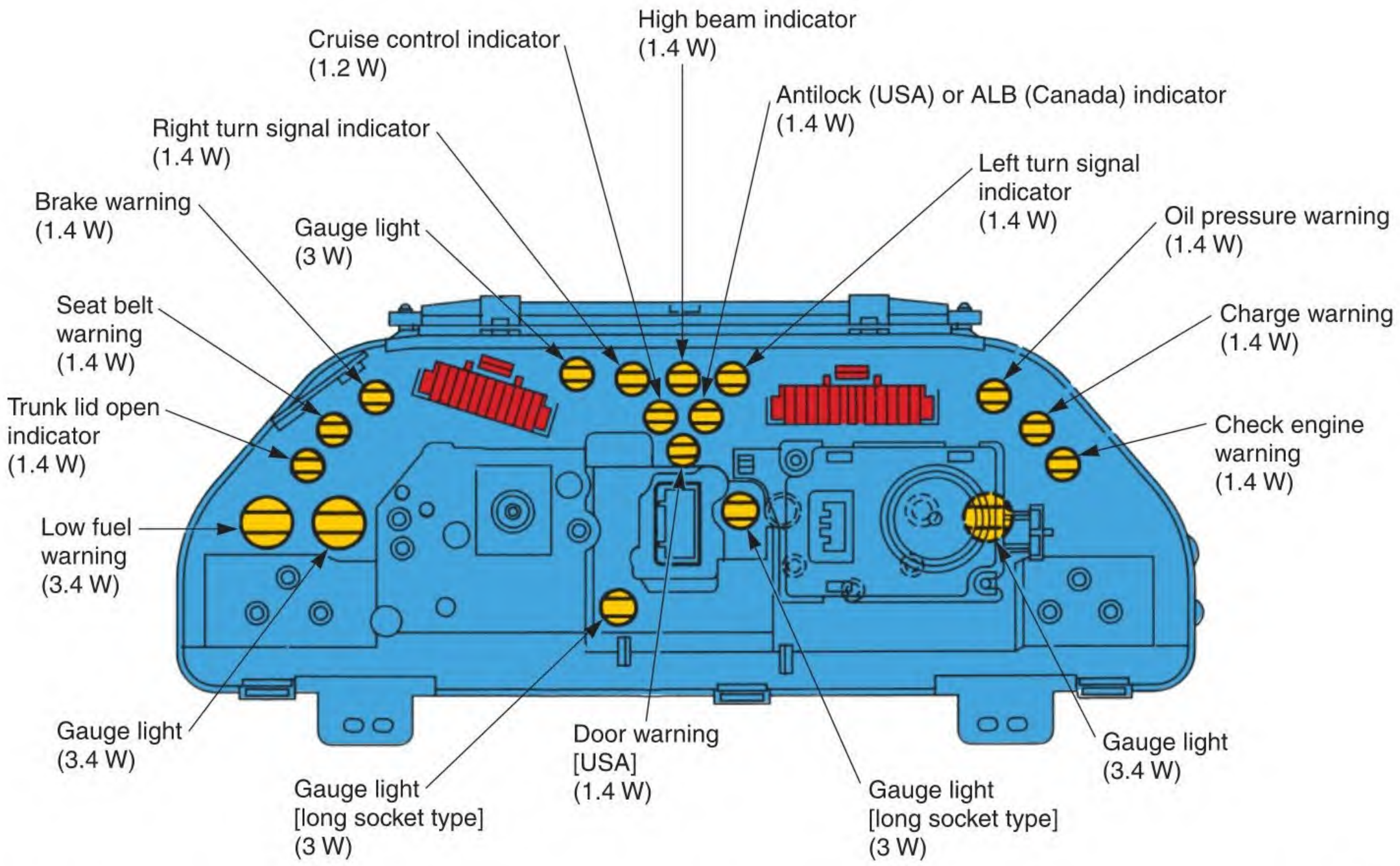
Figure 36-27. Compare analog and digital instrument clusters. Both can use conventional incandescent bulbs and light-emitting diodes. A—An analog instrument cluster uses needles that sweep around gauges. A speedometer can be mechanical or electronic. B—A digital cluster uses vacuum fluorescent or liquid crystal displays to show conditions.

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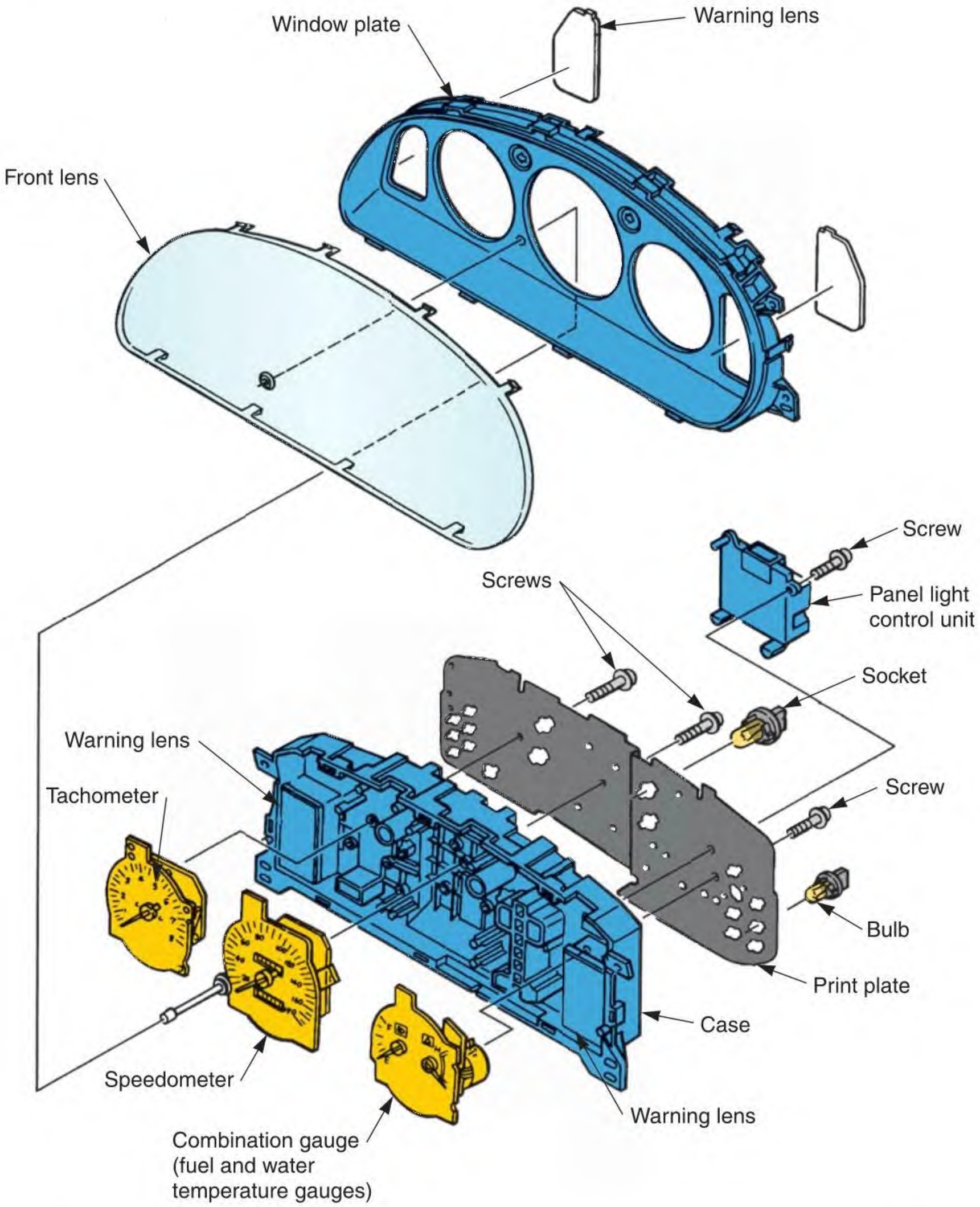
Figure 36-28. Study the basic steps for removal of the instrument cluster. A—First, remove the small screws that hold the covers over the cluster. B—Remove the screws that go through the edges of the cluster and pull the cluster out a little. You can then disconnect wires and the speedometer cable.



Honda

Figure 36-29. The rear view of one instrument cluster is shown. Note how the lamps are labeled for easy replacement.

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Mazda

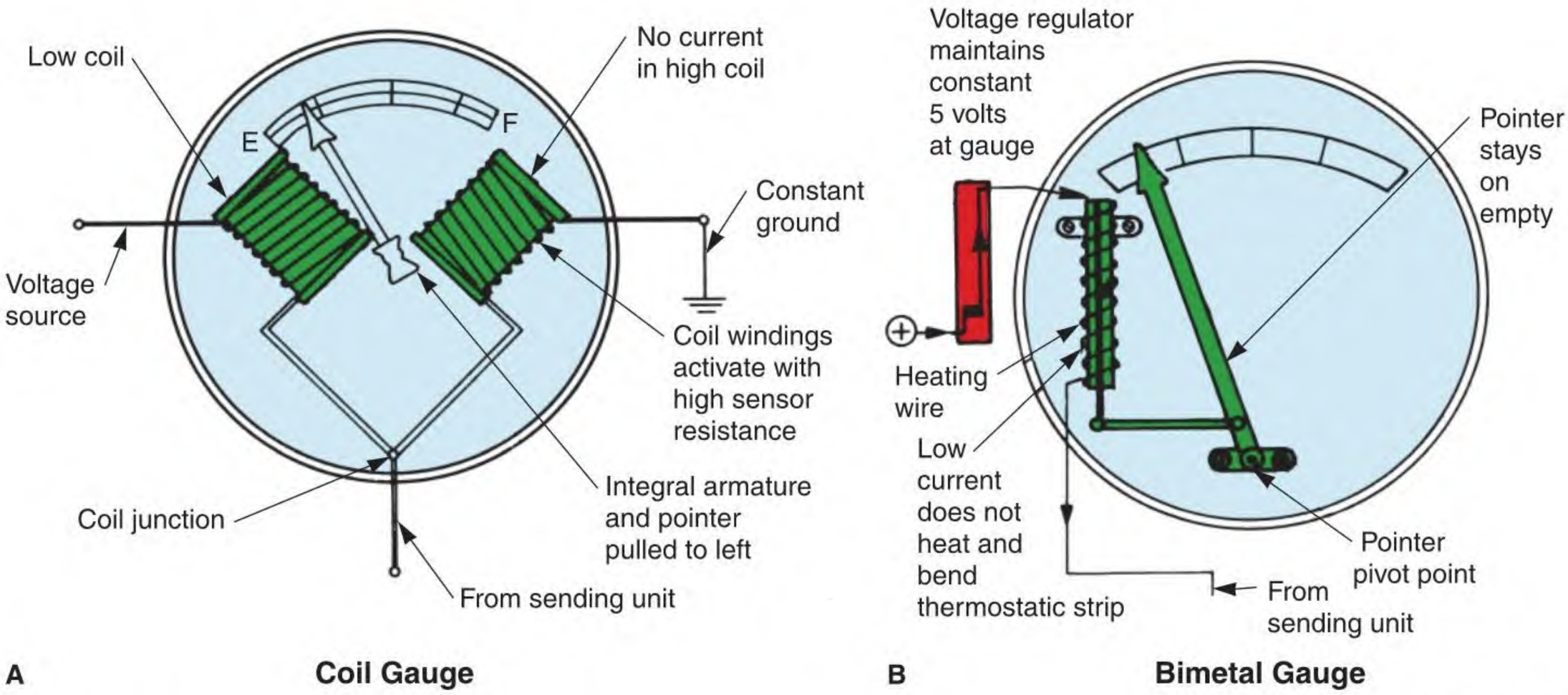
Figure 36-30. This exploded view shows the general method for disassembly of an instrument cluster. This is required when replacing gauges. Keep fingerprints off the front glass and gauge faces or dust will collect on them.

unit increases, the bimetal strip heats and deflects more. Less current flow causes less bimetal arm bending and less needle deflection.

Sending units are used to control current flow to gauges. Many sending units are simply variable resistors. For example, with an oil pressure gauge, the sending unit is mounted on the engine to sense oil pressure. If oil pressure is low, the sending unit's resistance may be high to limit current flow to the oil pressure gauge. The gauge does not deflect to the right and the driver knows there is low oil pressure. This same principle also applies to other gauges.

If a gauge is not working, check the sending unit first. The sending unit may not be working and may be preventing gauge operation. Special testers are available for checking the sending unit current going to the

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Figure 36-31. Compare the two types of gauges. Note the gauge voltage regulator in the circuit on the right. It maintains constant supply voltage to the gauge so it reads accurately. A—A coil gauge uses two coil windings to magnetically attract the indicating needle. With high current flow through the sending unit (low sending unit resistance), the left coil produces a stronger magnetic field, which moves the needle to the left. With low current through the sending unit (high sending unit resistance), more current flows through the coil on the right and the needle moves to the right. B—A bimetal gauge uses a thermostatic strip to move the indicator needle. With low current flow through the sending unit, the strip stays cool and does not bend, so the needle stays to the left. With higher current flow through the sending unit (low sending unit resistance), high current heats the bimetal strip and bends it. This bending action acts on the indicator needle to move it to the right.

gauge. For example, the sending unit wire may need to be grounded. This should make the gauge deflect completely to the right or left. If not, something other than the sending unit is at fault (wiring, fuse, gauge, connector).

Caution

Do not ground a sending unit wire unless told to do so in a service manual. Some digital display circuits can be damaged by grounding the sending unit wire.

Speedometers

There are two basic types of speedometers—mechanical and electronic. The electronic speedometer is becoming more common on late-model vehicles. **Figure 36-32** compares simplified mechanical and electronic speedometers.

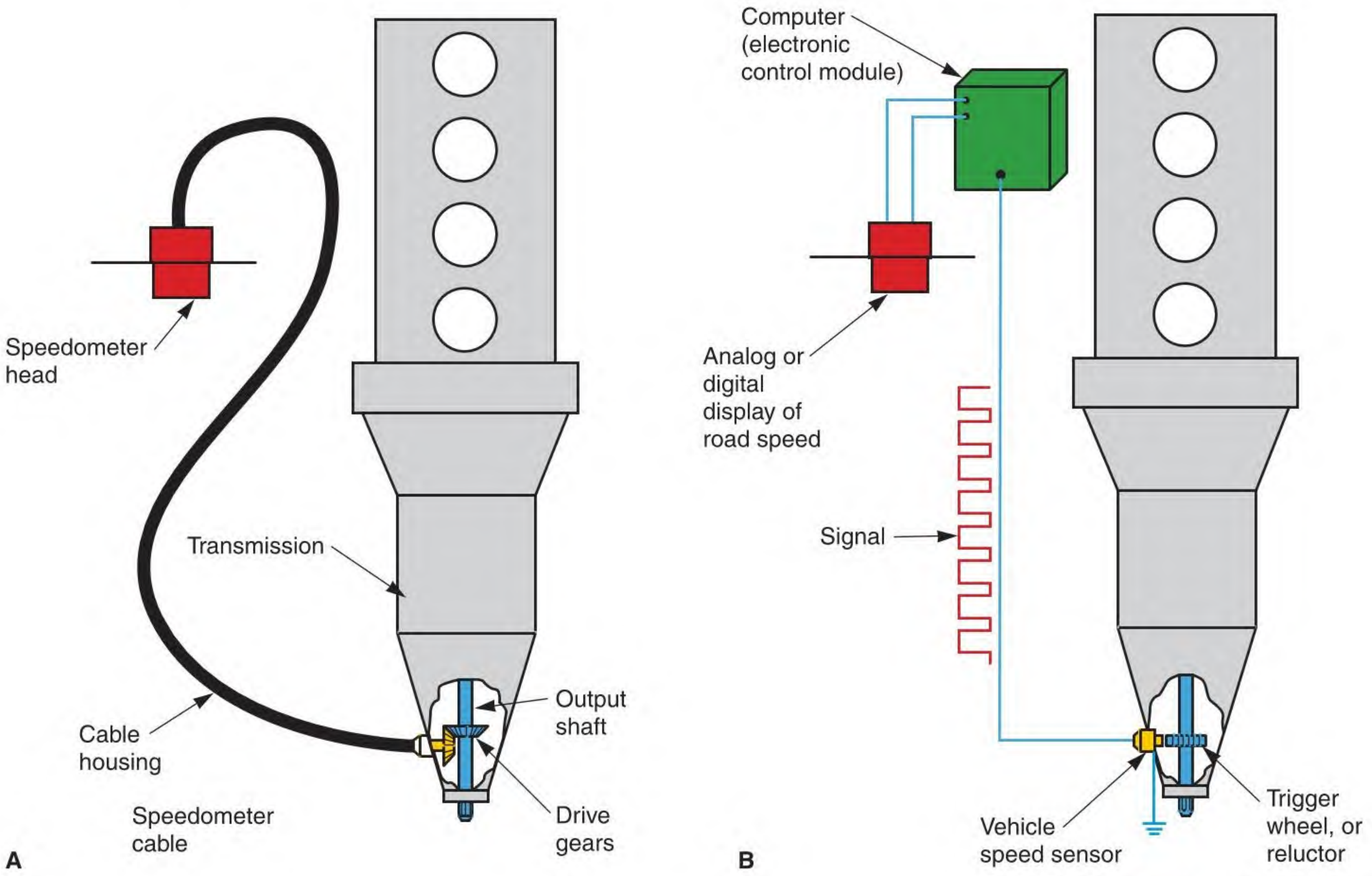
Mechanical Speedometers

Older vehicles are equipped with a ***mechanical speedometer*** that uses plastic transmission/transaxle drive gears, a metal speedometer cable, a cable housing, and a mechanical speedometer head. When the vehicle is moving, a drive gear on the transmission or transaxle output shaft turns a speedometer cable gear. This gear spins the metal speedometer cable in its housing. This rotating motion is transferred up to the dash to the speedometer head. Depending on rotating speed, the needle on the speedometer head is deflected to the right to indicate vehicle speed.

A dry speedometer cable will stick in its housing and cause the indicator needle to jump back and forth. The speedometer cable can also break, preventing speedometer operation. These are common problems with high-mileage vehicles.

To service a mechanical speedometer cable, disconnect the cable housing at the instrument cluster. You must normally depress a plastic latch that holds the cable housing to the cluster. Then, you can slide the speedometer cable out of the rear of the cluster.

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Figure 36-32. Compare mechanical and electronic speedometers. A—A mechanical speedometer is driven by small gears inside the transmission or transaxle. A gear on the output shaft spins another gear on the end of the speedometer cable. The cable spins inside the housing to transfer motion to the speedometer head to deflect the needle. B—An electronic speedometer commonly uses a vehicle speed sensor on the side of the transmission or transaxle. A trigger wheel or reluctor on the transmission output shaft sends a frequency signal into a sensor. The sensor signal is then used by the electronic control module to power the speedometer display.

To remove the speedometer cable, grasp and slide it out of its housing using a pair of pliers. If it is dry, wipe grease on the cable and slide it back into its housing. If it is broken, disconnect the cable housing at the transmission. You may need to use needle nose pliers to remove the small broken end from the transmission. Install a new speedometer cable of the original length.

If the speedometer needle does not return to zero when the vehicle is stopped, the speedometer head is usually bad. It should be replaced.

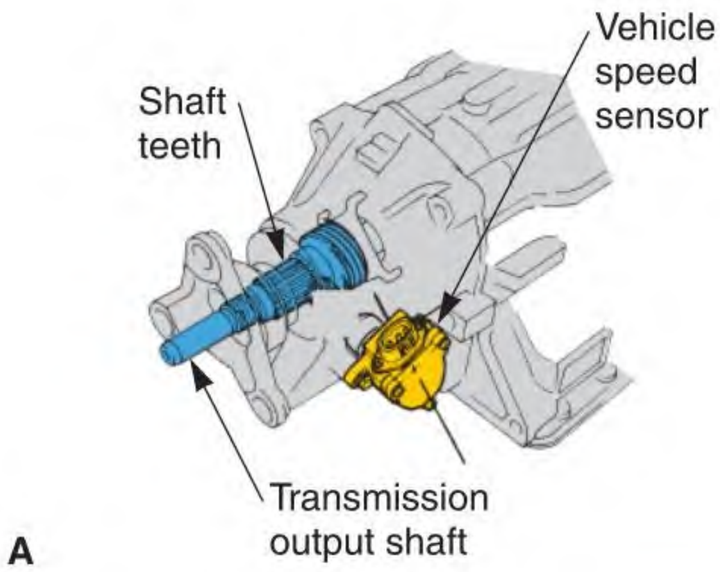
Electronic Speedometers

A modern ***electronic speedometer*** uses the vehicle speed sensor, an electronic control module, and an electronic or electric speedometer head or display. The vehicle speed sensor on the transmission or transaxle sends a signal representing road speed to the control module. The module can then produce an output signal to drive the digital display or servo motor in the speedometer head.

Electronic speedometers are now more common than mechanical speedometers. They are more dependable and consume less energy. Instead of spinning a heavy steel cable, the speed sensor electrical signal is used to drive the electronic speedometer more efficiently. Look at **Figure 36-33**.

Many electronic speedometers will only read up to a certain speed (85 mph or 145 km/h). Even though the vehicle can be driven faster, the ECM will not display a higher speed. This is normal on most vehicles.

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Lexus

Figure 36-33. Study the parts of an electronic speedometer-odometer system. A—The speed sensor is mounted on the side of the automatic transmission. It feeds signals to the ECM. Note the teeth on the output shaft. B—A pulse motor is used to drive a mechanical odometer, which shows vehicle mileage. The pulse motor is also driven by the ECM.

Tech Tip

When servicing an electronic speedometer, never change the odometer (mileage) reading. You must often reuse the old ***odometer chip*** (miniaturized circuit that stores mileage of the vehicle). If it is not reprogrammable, the chip must be removed from the old cluster and installed in the new one. For more information on odometer chip replacement and reprogramming, refer to the text index.

If an electronic speedometer fails to work properly, first check for stored trouble codes. Then, check for a good signal from the vehicle speed sensor. If the signal is reaching the ECM, check for a control signal going to the digital display. If only part of the display is working, you probably have a bad segment (part of display number or letter), and the display should be replaced.

Driver Information Center

The driver information center is a dash-mounted keyboard-display for inputting and reading data about the vehicle. It allows you to send data to the instrumentation computer to find miles-to-empty, average fuel consumption, estimated time of arrival, and other information. The information center uses signals from many sensors to calculate this information. **Figure 36-34** shows how a digital display operates for several types of vehicle conditions.

Driver information centers are very complex and vary with make and model. Always refer to the service manual for testing and repair directions.

Digital Instrument Clusters

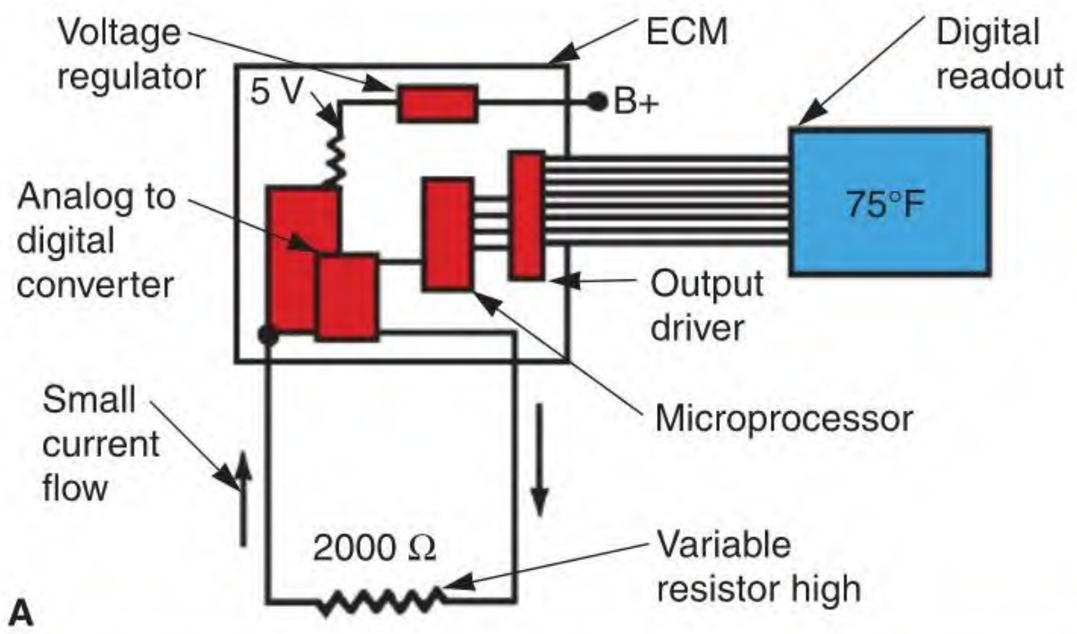
A digital instrument cluster does not use analog or needle gauges; it uses computer-driven numbers or graphic displays. The trend is to use digital displays in new cars. They are easy to read, lightweight, and dependable.

Instrumentation ECM

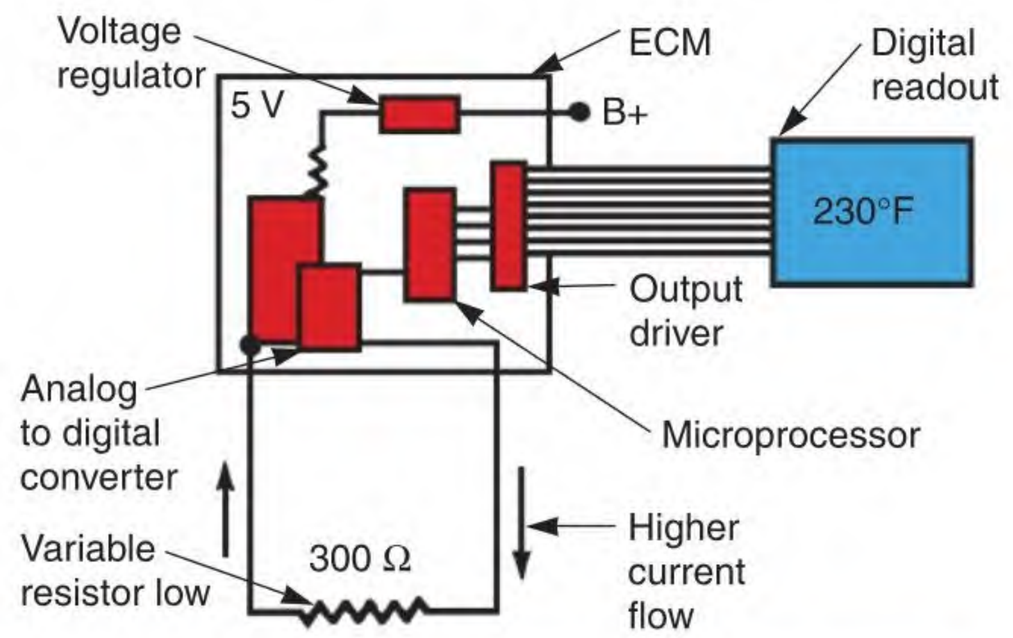
The ***instrumentation electronic control module*** reacts to signals from vehicle sensors, dash switches, and other ECMs to operate the digital or digital-analog displays in the dash. Its construction and design is similar to the computers or ECMs discussed in previous chapters.

An instrumentation ECM has integrated circuits and a powerful processor that can handle a large quantity of input data and then rapidly send out control

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A



B

Sensor	Condition	Value	Readout
Engine temperature	Cold Normal	2000 Ω 200 Ω	75°F 230°F
Oil pressure	High Low	100 Ω 5 Ω	65 psi 15 psi
Fuel level	Full Half Empty	100 Ω 50 Ω 10 Ω	Full 1/2 E

Sensor	Condition	Value	Readout
Engine speed	Idle Cruising	5000 cycles/sec. 50,000 cycles/sec.	1000 rpm 5000 rpm
Oil level	Normal Low	Infinite Ω Zero Ω	Bulb out Bulb on
Vehicle speed	High Low	High frequency Low frequency	10 mph 55 mph

C

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Figure 36-34. This simplified illustration shows how different types of sensors can be used to indicate different conditions. The ECM converts sensor signals into output signals for displays. A—The engine is cold and sending unit internal resistance is high. The ECM shows a cold temperature readout. B—The engine is warmer and the sending unit resistance drops. The ECM uses a different amount of current flow to show the warmer engine temperature.

signals for the instrument displays and, sometimes, other devices.

A ***multiplex integrated control (MIC) system*** allows several ECMs to communicate with each other by exchanging digital signals over a single wire or conductor. New vehicles have MIC systems that electronically connect or integrate all or most of the ECMs or computers in the vehicle. This allows for more precise control of every computer-controlled system. An MIC allows different ECMs to communicate with each other digitally.

A ***body control area network (B-CAN)*** operates relay modules, such as:

- Entry lights.
- Exterior lights.
- Horns.
- Interlocking system.
- Key-in reminders.
- Keyless entry.
- Power door locks.
- Seat belt reminders.
- Security alarm.
- Turn and hazard signals.
- Wiper-washer system.

A B-CAN communicates at a data rate of about 33 kbps (kilobits per second).

A ***fast control area network (F-CAN)*** is a computer interface used to control the engine, transmission, air bags, and other more critical systems. F-CAN communicates at 500 kbps. To allow both computer data rate systems to communicate, the gauge control module can convert from F-CAN to B-CAN and B-CAN to F-CAN.

Instrumentation Power Supply

An instrumentation power supply can be used to provide a constant voltage for the digital displays, ICs, and other related devices. An instrumentation power supply can provide up to 60 volts of power needed to drive and illuminate the displays.

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Instrumentation Switches

Instrumentation switches trigger the ECM to output another signal. For example, dash switches normally use dropping resistors to send a unique current level back to the ECM. Each switch is fed a constant reference voltage. However, each switch has a different ohms value-dropping resistor. As a result, each switch produces its own voltage output signal for the ECU. The ECU will know which switch has been activated and output a correct response, such as changing a radio station or turning on a blower.

Dash Monitors

A ***monitor***, or display screen, provides graphic information for the driver and passengers. It can give the driver information from the global positioning or mapping system, in-car telephone, climate control system, sound system, and other systems. The monitor is usually mounted in the center of the dash, although it is sometimes placed in the instrument cluster.

A liquid crystal display (LCD) polarizes light into an image when energized by an electrical signal. LCDs can be very thin and light. They consume very little electrical energy and are commonly used in passenger vehicle dashboards.

An LCD is often used as an information screen for voice command, a navigation map, roadside assistance, a stereo, a calendar, and other display functions.

A plasma screen contains a layer of hundreds of thousands of phosphor cells between two panels of glass. The phosphor cells emit visible light (red, green, and blue) when excited. Plasma screens are sometimes used as aftermarket, rear-seat-mounted video displays for DVD players in four-door trucks, SUVs, and vans.

A monitor ECM is used as an interface between the main body ECM and the LCD display. It processes the data from the body computer, other ECMs, and control switches to drive the LCD screen. The monitor controller mounts under the dash. It is similar in construction to other electronic control circuits.

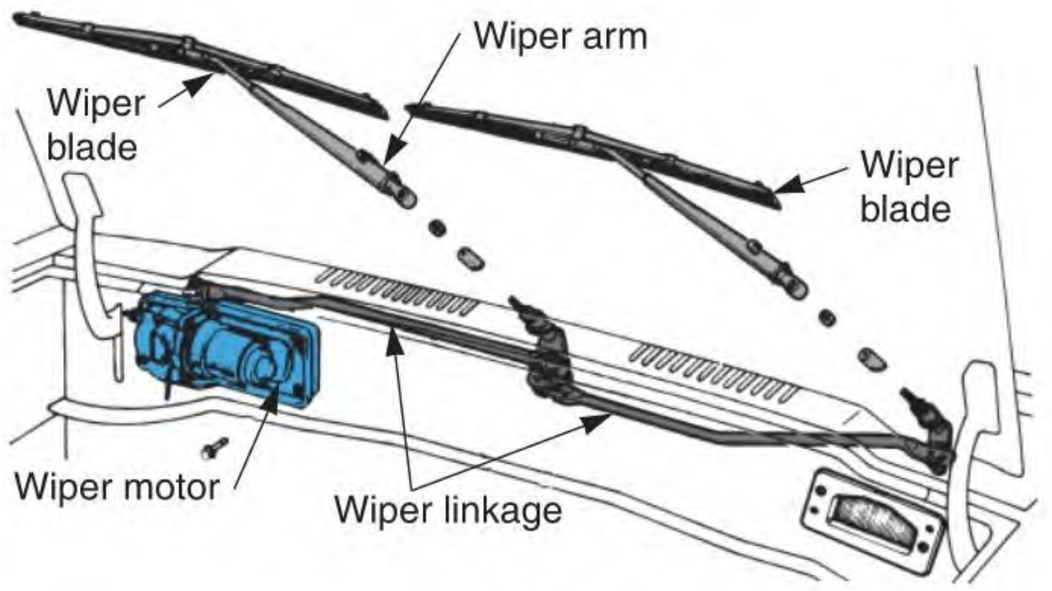
Heads-Up Display

A ***heads-up display (HUD)*** reflects display information onto the windshield or a plastic dash panel for easier viewing. It complements the conventional displays in the instrument cluster. The driver does not have to take his or her eyes off the road to view the HUD, **Figure 36-35**.



Siemens

Figure 36-35. This heads-up display reflects images onto the windshield so readings are easy to see while driving.



Toyota

Figure 36-36. Study the basic parts of a typical windshield wiper system.

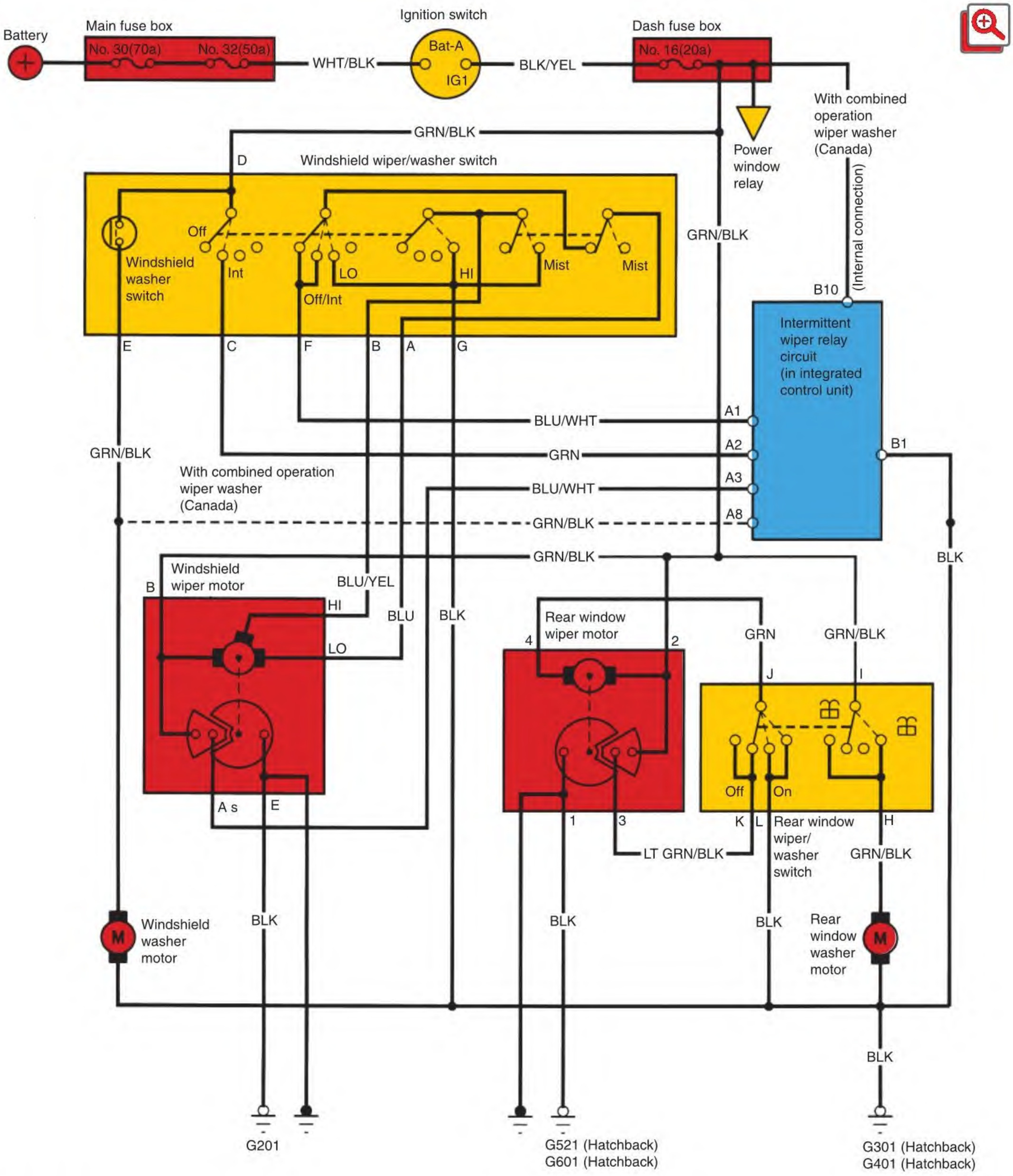
Windshield Wipers

A typical ***windshield wiper system*** is made up of a switch, wiper motor assembly, wiper linkage, wiper arms, wiper blades, and usually a windshield washer system. Either a fuse or circuit breaker protects the system. See **Figure 36-36**.

The windshield wiper switch is a multiposition switch that sometimes contains a rheostat. Each switch position provides a different wiping speed. The rheostat operates the delay mode for slow wiping action. A relay is frequently used to complete the circuit between the battery and the wiper motor. A typical windshield wiper-washer circuit diagram is shown in **Figure 36-37**.

The wiper motor assembly consists of a permanent-magnet motor and a transmission. See

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Honda

Figure 36-37. Study the wiring diagram of a wiper-washer system. Trace through and find all major parts.

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Figure 36-38. The wiper motor transmission changes rotary motion into a back-and-forth wiping motion. The transmission is normally a set of plastic gears, an end housing, and a crank.

The ***wiper linkage*** is a set of arms that transfers motion from the wiper motor transmission to the wiper arms. The rubber wiper blades fit on the wiper arms.

Tech Tip

If a vehicle's windshield wipers fail to return to the park position at the bottom, check for a bad ground in the wiper motor circuit. A separate ground circuit may be opened and ungrounded if the wiper arms stop in the middle of the windshield. Fixing the wiper motor ground will often repair this common windshield wiper problem.

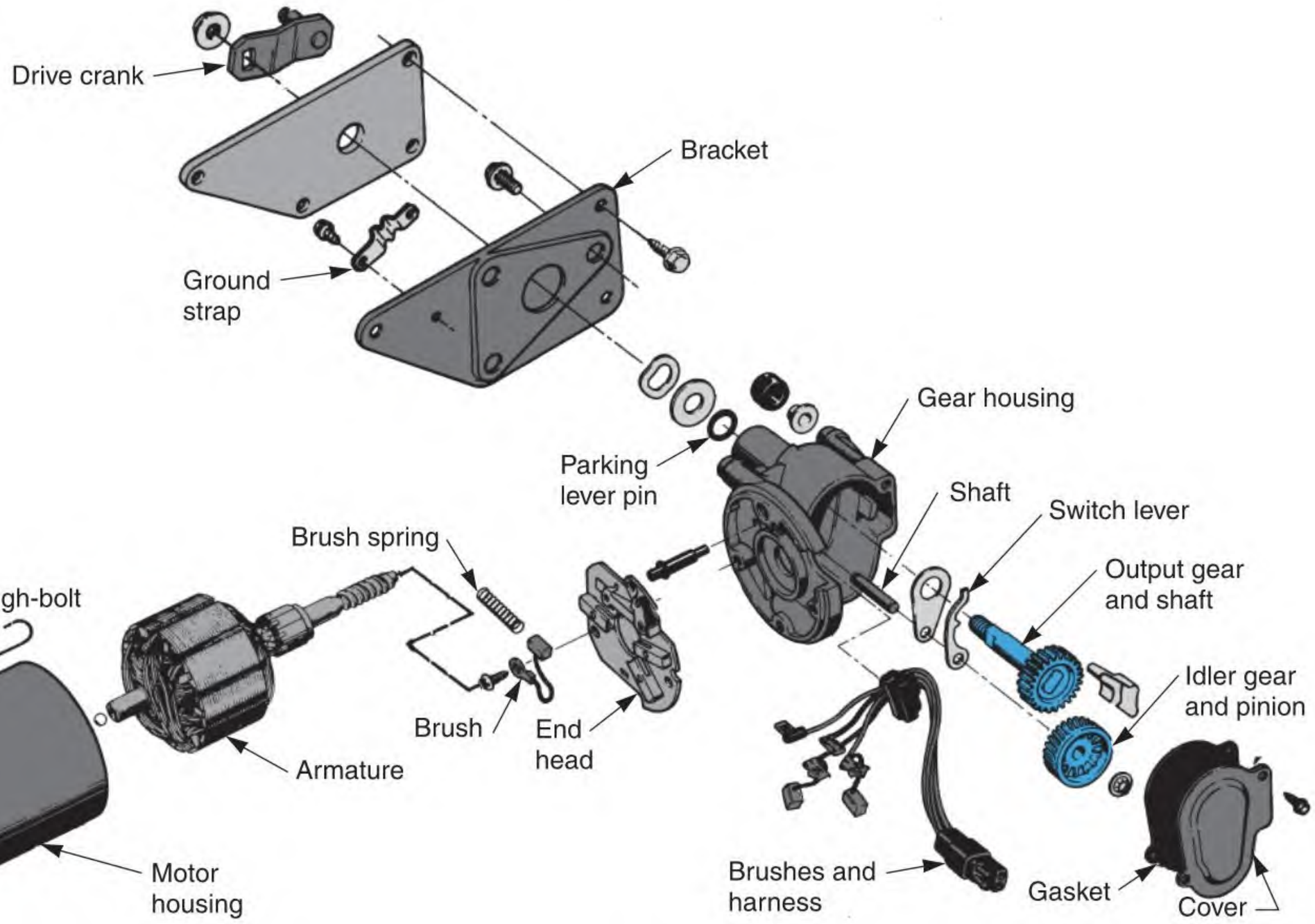
Windshield Washers

A ***windshield washer*** consists of a reservoir, pump, rubber hoses, connections, and washer nozzles. See **Figure 36-39**. The reservoir is located in the engine compartment and holds a supply of windshield washer solution. When the washer switch or button is activated, the wiper motor and the washer pump turn on. The washer solution is forced out of the reservoir and onto the windshield.

There are two types of pumps used with windshield washer systems: a rotary pump and a bellows (diaphragm) pump. Most new cars use a rotary pump mounted in the solvent reservoir. A tiny electric motor spins an impeller, which forces the washer solution onto the windshield. A bellows pump is normally mounted on and powered by the wiper motor.

Rain-Sensing Wiper System

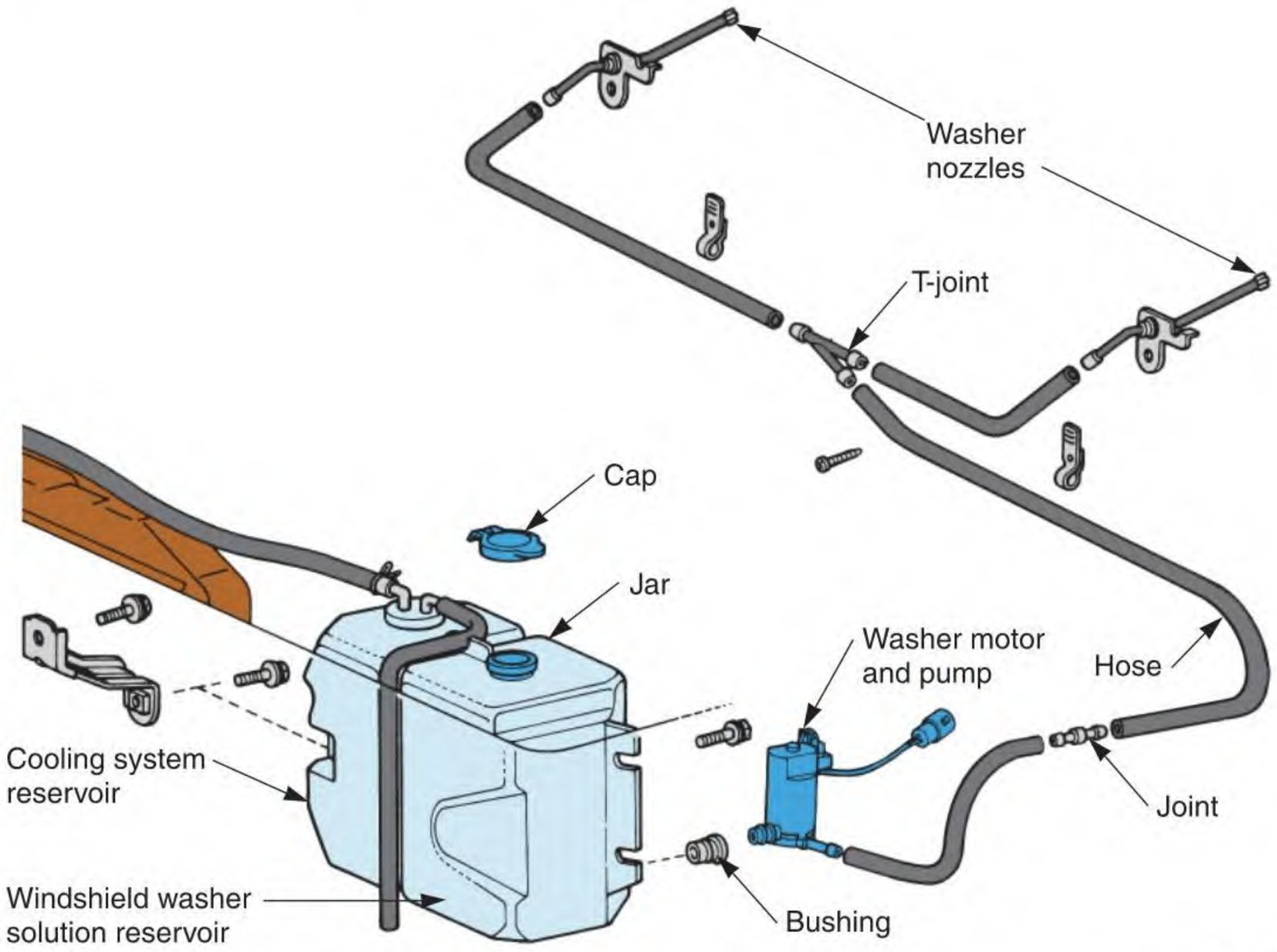
A ***rain-sensing wiper system*** automatically turns the windshield wipers on when water is detected on the windshield. The system uses light-emitting diodes



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Figure 36-38. An exploded view of a wiper motor assembly is shown. The two plastic gears are the most common problem. They are replaced when stripped or broken.

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Figure 36-39. Study this windshield washer system. A small electric motor and pump force the solution out of the reservoir, through the hoses, and out of the nozzles. Check for debris in reservoir strainer, hoses, and nozzles when the system is not working. Then, check pump operation.

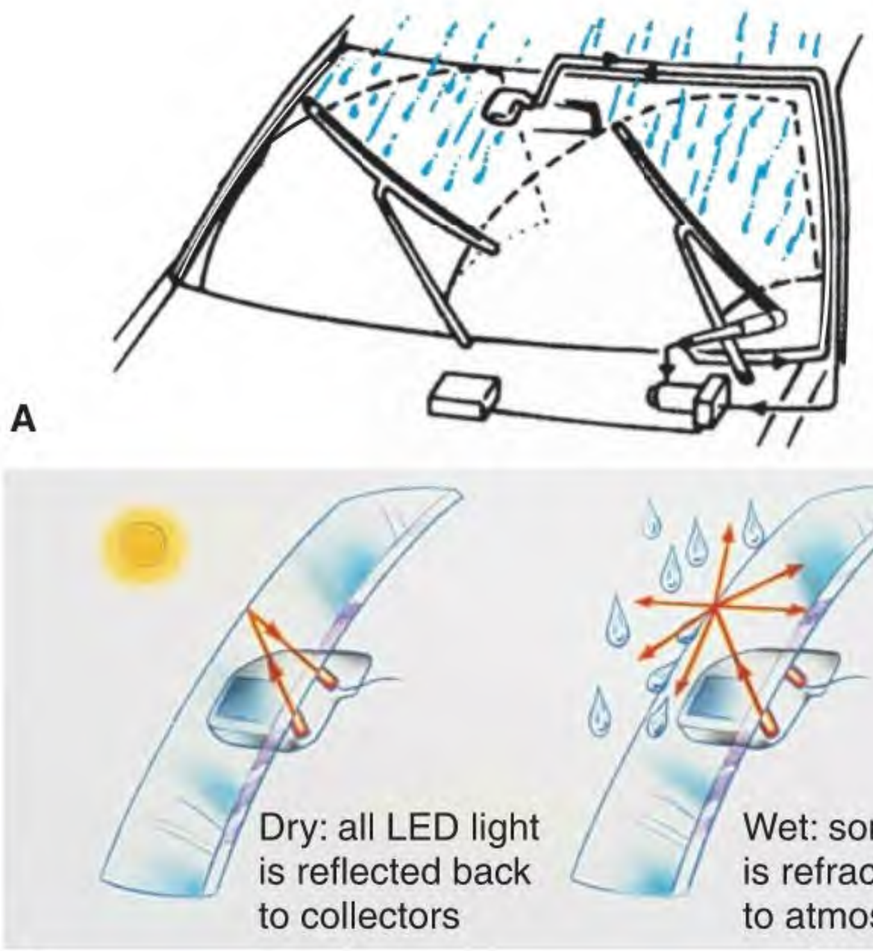
and a light sensor or an infrared system to detect water. When water is on the windshield, less light is refracted back from the windshield to the light sensor. This allows an electronic control module to turn the wipers on to remove rain or snow. In heavy rain, the wipers wipe across the windshield more quickly. Manual override is also possible. **Figure 36-40** shows the basic operation of a rain-sensing wiper system.

Windshield Wiper Service

Windshield wiper blades should be inspected periodically. If they are hardened, cut, or split, replace them. **Figure 36-41** shows common wiper blade service methods.

For electrical problems in a wiper system, use a service manual and its wiring diagram of the circuit. First, check the fuses and electrical connections. If they are good, use a test light to check for power to the wiper motor.

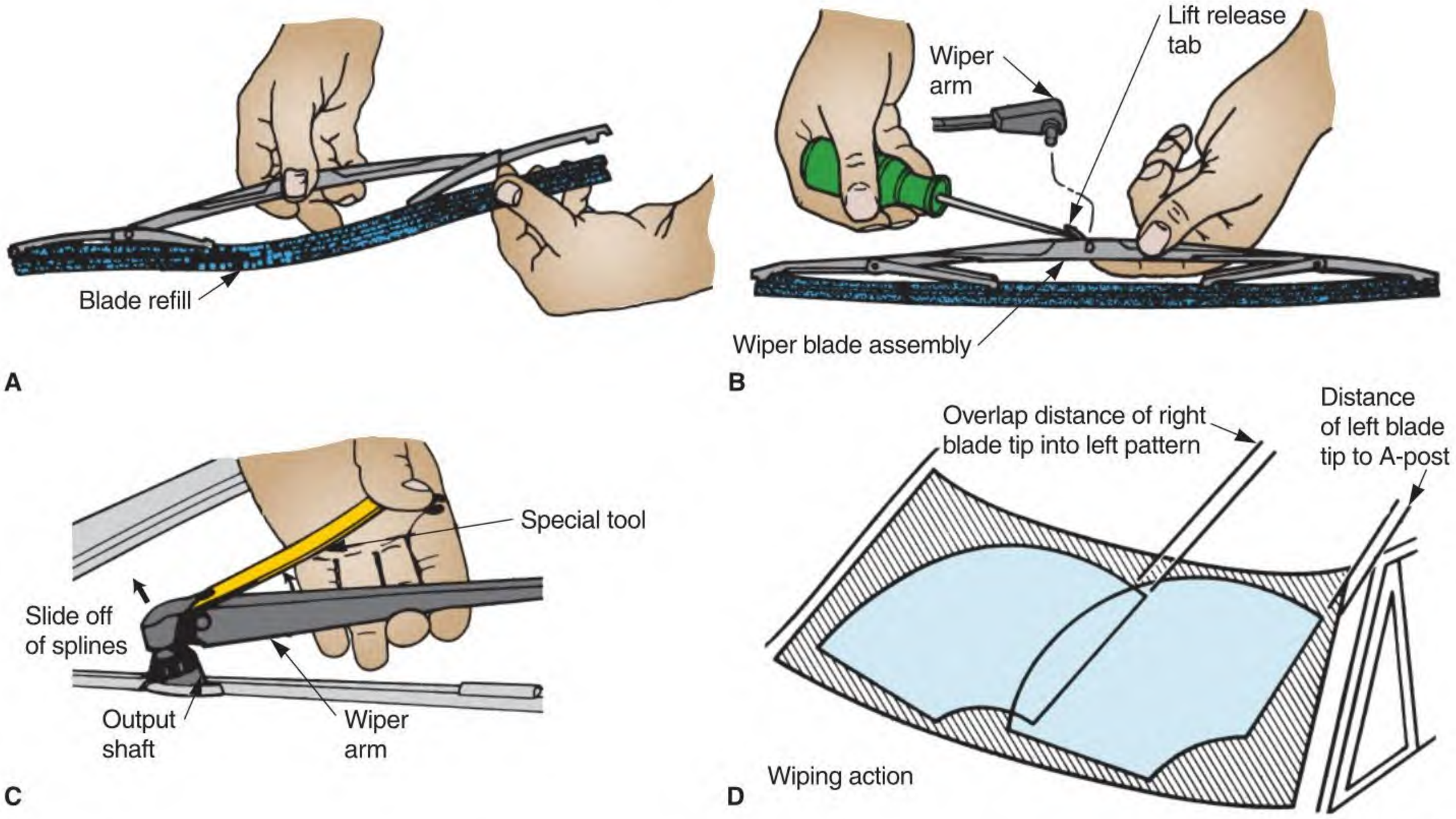
If power is being fed to the wiper motor, either the motor or transmission may be at fault. Before replacing the motor or transmission gears, make sure the motor is properly grounded. If power is not reaching



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Figure 36-40. Basic operation of a rain-sensing wiper system is shown here. A—A sensor on the back of the windshield and the ECM operate the wiper motor. B—When the windshield is clear, LED light is reflected back to a photo sensor and the wipers stay off. When the windshield has water or snow on it, some light is reflected away from the sensor. The sensor signal tells the ECM to turn on the wipers.

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Chrysler

Figure 36-41. Study basic wiper service. A—A new rubber wiper refill is slid into place. B—To replace the complete wiper blade assembly, free it from the wiper arm. C—The arm can sometimes be removed by prying up as shown. D—Typical pattern for positioning arms on output shafts. Refer to a service manual for exact procedures.

the wiper motor, check the wiper switch and circuit connections for openings.

If the windshield washer does not work, check the fuse and connections. Use a test light to check for power going to the motor. If the test light does not glow (washer on), the wiper switch may be bad.

When working on a windshield wiper or washer system, always follow the exact recommendations given by the manufacturer. Systems and procedures vary from car to car.

Normally, the wiper motor must be replaced as a unit. The transmission gears are usually the only serviceable part in the assembly. An electric washer motor is also replaced when defective. It cannot be disassembled and repaired.

Horns

Today's ***horn systems*** typically include a fuse, horn button switch, relay, horn assembly, and related wiring. When the driver presses the horn button, it closes the horn switch and activates the horn relay. This completes the circuit. Current then flows through the relay circuit and to the horn.

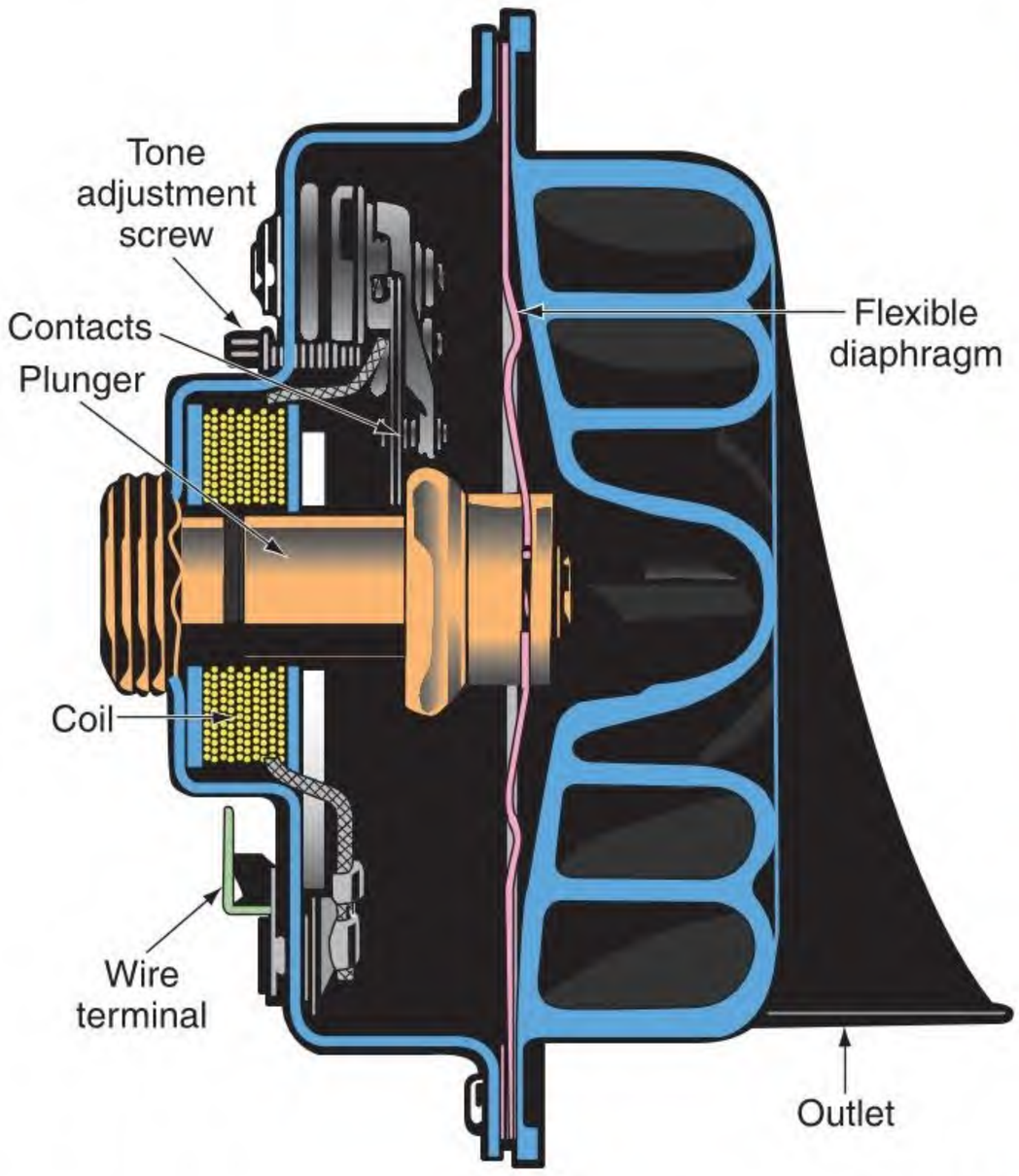
Most horns have a diaphragm that vibrates by means of an electromagnet. When energized, the electromagnet pulls on the horn diaphragm. This movement opens a set of contact points inside the horn. This allows the diaphragm to flex back toward its normal position. Again, the points close and the diaphragm is pulled into the electromagnet. As a result, a rapid vibrating action is produced. A honking sound is transmitted out of the horn, **Figure 36-42**.

Horn Service

When a horn will not sound, check the fuse and connections, and test for voltage at the horn terminal. If a horn blows continuously, the horn switch may be bad. A relay is another cause of horn problems. The contacts in the relay could be burned, or they may stick together.

Refer to a shop manual when diagnosing and repairing a horn system. Use your knowledge of the system and basic testing methods to locate troubles.

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Deere & Co.

Figure 36-42. A horn contains a coil, points, and a flexible diaphragm. Coil and point action makes the plunger slide in and out of the coil. The plunger moves the diaphragm to produce horn sound.

The technician uses the test light to check for power at the low-beam terminal of the light switch. Power is going to the switch, but it is not flowing through the switch to the low-beam circuit.

Correction: The technician replaces the multifunction switch on the steering column. He then checks to make sure all the vehicle's lights are working properly. He describes the problem and explains the repair to Mrs. Jones. He also shows her the old part.

Summary

- The lighting system consists of the components (fuses, wires, switches, and relays) that operate the interior and exterior lights on a vehicle.
- The headlamp system generally includes the battery, headlamp-related wiring, fuse panel, light switch, dimmer switch, headlamps, taillights, marker lights, and instrument lights.
- A multifunction switch is capable of controlling several circuits—headlights (bright and dim circuits) and turn lights, for example—simultaneously.
- Most late-model cars use halogen headlamp bulb inserts, which are small bulbs that fit into a larger plastic housing.
- A dimmer switch controls the high and low headlamp beam function.
- An automatic headlight dimmer system uses a light sensor, amplifier, and relay to control the high and low beams.
- The turn signal system consists of a fuse, turn light switch, flasher unit, turn lightbulbs, indicator bulbs, and related wiring.
- Light system service involves changing burned-out bulbs, testing bulb sockets, checking fuses, finding shorted and open circuits, aiming headlights, and other similar types of tasks.
- Aiming headlights involves adjusting the beams so they shine in the proper direction.
- Instrumentation is used to inform the driver of various operating conditions—oil pressure, engine temperature, computer trouble codes, air bag system armed, etc.
- Analog instruments use rotating needles on dials to indicate operating conditions.



Diagnostic Case Study

Concern: Mrs. Jones walks into the office and says, "My headlights don't work. They work on high beams, but when I switch to low beams they go dead."

Cause: Duff verifies the problem and turns the repair over to the shop's electrical technician. The technician removes the halogen bulbs and inspects the elements. Both bulbs are in good condition. He then uses a test light to check for voltage at the wire terminals in the bulb sockets. With the light switch in the high-beam position, voltage is present at the high-beam terminals of the sockets. However, when the switch is moved to the low-beam position, there is no voltage at the low-beam terminals. This narrows down the possible problem sources to the headlight switch or the wiring harness.

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- Digital instruments use various types of lights or electronic displays to show operating conditions.
- The instrument cluster is the housing and clear plastic cover that holds the gauges, indicator lights, speedometer head, and bulbs.
- A balancing coil gauge uses two electric coils to cause needle deflection.
- A bimetal gauge uses two dissimilar metals bonded together to cause gauge needle deflection.
- A sending unit or sensor is used to control current flow to the gauge.
- A mechanical speedometer uses plastic transmission/transaxle drive gears, a metal speedometer cable, a cable housing, and a mechanical speedometer head.
- An electronic speedometer uses the vehicle speed sensor, an electronic control module, and an electronic or electric speedometer head or display.
- A typical windshield wiper system comprises a switch, wiper motor assembly, wiper linkage, wiper arms, wiper blades, and usually a windshield washer system.
- Horn systems typically include a fuse, horn button switch, relay, horn assembly, and related wiring.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

analog instruments
automatic headlight dimmer system
auto-off headlamp system
balancing coil gauge
ballast
bimetal gauge
body control area network (B-CAN)
brake light system
daylight running lights
digital instruments
dimmer switch
electronic speedometer
emergency light system
fast control area network (F-CAN)
filament
flasher
flash-to-pass feature
halogen lightbulbs
headlamp system
headlight aimers
heads-up display (HUD)
high-intensity discharge bulbs (HIDs)
horn systems
illuminated entry system
incandescent lightbulbs
instrument cluster
instrumentation electronic control module
light
light-monitoring system
mechanical speedometer
monitor
multifunction switch
multiplex integrated control (MIC) system
odometer chip
rain-sensing wiper system
rheostat
sealed-beam headlamps
sending units
turn signal system
windshield washer
windshield wiper system
wiper linkage

Activities

1. Select a specific vehicle make and model that is at least two years old. Go to the automotive department of a discount or department store. Find the store's replacement lamp identifier system, which may be a book, large card, or computer screen. Use it to identify the proper replacements for headlights, taillights, turn signals, brake lights, backup lights, and side marker lights (if used). List all the part numbers.
2. Demonstrate the proper procedure for checking headlight aiming using marks on a wall. Show how to correct the aim of the lights, if necessary.
3. Find a wiring diagram for a car or truck, and make a photocopy. Use a brightly colored pencil or marker to trace the wiring that makes up the windshield wiper and washer circuit.

Review Questions

Answer the following questions using the information provided in this chapter.

1. Incandescent lightbulbs send current through a _____ located inside a partial vacuum in an airtight glass enclosure.
2. List three advantages of high-intensity discharge bulbs.
3. An automatic headlight dimmer system consists of a(n) _____ sensor, _____, and _____ to control the high and low beams.
4. Explain the construction and operation of a flasher unit.

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5. A vehicle has a problem causing the left headlight to flicker on and off. The right headlight works properly. The light seems to flicker when the car strikes bumps in the road. Technician A says that the light system relay may be bad. Vibration could be opening the points in the relay. The relay should be tested and replaced if needed. Technician B says that the problem involves just the left headlight section of the circuit. This technician suggests checking the headlamp socket and electrical connections to that bulb. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. One burned-out bulb cannot keep the turn signals from flashing on and off. True or False?
7. Describe the operation of both mechanical and electronic speedometers.
8. List and explain the major parts of a windshield wiper system.
9. How does a rain-sensing wiper system work?
10. Explain the operation of a horn circuit.

ASE-Type Questions

1. Headlight systems are being discussed. Technician A says that most late-model cars use halogen headlamp bulb inserts. Technician B says HID bulbs produce more light than standard halogen bulbs while consuming less energy. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Which of the following is often used by automatic headlight dimmers to control beams?
   (A) Relay.
   (B) Amplifier.
   (C) Light sensor.
   (D) All of the above.
3. Each of the following is part of the brake light system *except:*
   (A) brake light switch.
   (B) fuse.
   (C) rear lamps.
   (D) flasher unit.
4. A halogen headlight bulb must be replaced. Technician A says these bulbs are generally held in place with a retaining ring secured with small screws. Technician B says you should never touch the glass surface of the bulb. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. The right turn signals work but the left ones do not. Technician A says to check the flasher unit. Technician B says the turn signal switch could be bad. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Each of these conditions should exist during a headlight aiming test *except:*
   (A) panel lights dimmed.
   (B) tires inflated correctly.
   (C) car has half a tank of gas.
   (D) spare tire and jack in trunk.
7. A headlight aiming screen is a:
   (A) veil covering headlights.
   (B) series of lines on shop wall.
   (C) transparent paper partition.
   (D) None of the above.
8. Which of the following is *not* a type of pump used with windshield washer systems?
   (A) Rotary.
   (B) Bellows.
   (C) Rheostat.
   (D) Diaphragm.
9. Generally, the *only* serviceable part of a windshield wiper motor assembly is the:
   (A) wiper motor.
   (B) wiper blades.
   (C) wiper switch.
   (D) transmission gears.
10. When correcting a horn system problem, Technician A says horns are not serviceable and can only be adjusted. Technician B says horns are serviceable but cannot be adjusted. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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Headlamp Diagnosis

Condition	Possible Causes	Correction
Headlamps are dim with the engine off or idling.	1. Loose or corroded battery cables. 2. Loose or worn alternator drive belt. 3. Charging system output too low. 4. Battery has insufficient charge. 5. Battery is sulfated or shorted. 6. Faulty lighting circuit. 7. Both headlamp bulbs defective.	1. Clean and tighten battery cable clamps and posts. 2. Adjust or replace alternator drive belt. 3. Test and repair charging system. 4. Test battery state-of-charge. Recharge or replace battery. 5. Perform load test. Recharge or replace battery. 6. Test and repair circuit. 7. Replace both bulbs.
Headlamp bulbs burn out frequently.	1. Charging system output too high. 2. Loose or corroded terminals or splices in circuit.	1. Test and repair charging system. 2. Inspect and repair all connectors and splices.
Headlamps are dim with engine running above idle.	1. Charging system output too low. 2. Faulty headlamp circuit. 3. High resistance in headlamp circuit. 4. Both headlamp bulbs defective.	1. Test and repair charging system. 2. Test and repair circuit as necessary. 3. Test amperage draw of headlamp circuit. 4. Replace both bulbs.
Headlamps flash randomly.	1. Poor headlamp circuit ground. 2. High resistance in headlamp circuit. 3. Faulty headlamp switch. 4. Loose or corroded terminals or splices in circuit.	1. Repair circuit ground. 2. Test amperage draw of headlamp circuit. 3. Replace headlamp switch. 4. Repair terminals or splices.
Headlamps do not illuminate.	1. No voltage to headlamps. 2. No ground at headlamps. 3. Faulty headlamp switch. 4. Faulty headlamp dimmer switch. 5. Faulty headlamp circuit.	1. Replace fuse. 2. Repair circuit ground. 3. Replace headlamp switch. 4. Replace headlamp dimmer switch. 5. Repair circuit.

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Turn Signal Diagnosis

Condition	Possible Causes	Correction
Turn signal flashes at twice the normal rate.	1. Faulty external lamp. 2. Poor ground at lamp. 3. Open circuit in wiring to external lamp. 4. Faulty contact in turn signal switch.	1. Replace lamp. 2. Check and repair wiring. 3. Repair wiring harness. Check connectors. 4. Replace switch.
Dash indicator lamp illuminated brightly; external lamp glows dimly and flashes at a rapid rate.	1. Loose or corroded external lamp connection. 2. Poor ground circuit at external lamp.	1. Tighten or replace connection. 2. Check and repair wiring.
Hazard warning system does not flash.	1. Faulty fuse. 2. Faulty flasher. 3. Open circuit in wiring to turn signal switch. 4. Faulty contact in turn signal switch. 5. Open or grounded circuit in wiring to external lamps.	1. Replace fuse. 2. Replace flasher. 3. Repair wiring. 4. Replace switch. 5. Repair wiring.
Indicator lamp illuminates brightly, but external lamp does not light.	1. Open circuit in wire to external lamp. 2. Burned out lamp.	1. Repair wiring. 2. Replace lamp.
System does not flash on either side.	1. Faulty fuse. 2. Faulty flasher unit. 3. Loose bulkhead connector. 4. Loose or faulty rear wiring harness or terminals. 5. Open circuit to flasher unit. 6. Open circuit in feed wire to turn signal switch. 7. Faulty switch connection in turn signal switch. 8. Open or grounded circuit in wiring to external lamps.	1. Replace fuse. 2. Replace flasher. 3. Tighten connector. 4. Repair wiring harness. 5. Check repair wiring harness. 6. Check and repair wiring harness. 7. Test and replace switch. 8. Check and repair wiring harness.
System does not cancel after completion of the turn.	1. Broken canceling finger on turn signal switch. 2. Broken or missing canceling cam on clockspring.	1. Replace switch. 2. Replace clockspring.
External lamps operate properly; no indicator lamp operation.	1. Faulty indicator lamp in instrument cluster.	1. Replace lamp.

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Chapter 37
Sound Systems and Power Accessories

After studying this chapter, you will be able to:

- Describe the operating principles of a radio.
- Explain the basic difference between AM, FM, digital, and satellite radios.
- Diagnose basic sound system problems.
- Explain the operation and service of power windows.
- Describe and repair a power door lock system.
- Sketch a rear window defogger circuit.
- Summarize the operation and testing of a cruise control system.
- Correctly answer ASE certification test questions on the service of sound systems and power accessories.

Today, cars are often equipped with a wide array of options. These include power seats, power windows, power rearview mirrors, power antennas, memory functions, satellite radio, and exotic sound systems. To be a competent technician, you must be able to understand how these systems are constructed and operate. This chapter covers the principles of these systems. It will prepare you for later chapters that cover diagnosis and repair.

After studying this chapter, you will be well-prepared to diagnose and repair optional power accessories. Remember that power accessory designs and circuits vary. Therefore, you must refer to factory service information to get specific diagrams and specifications for the exact car being repaired.

Radio

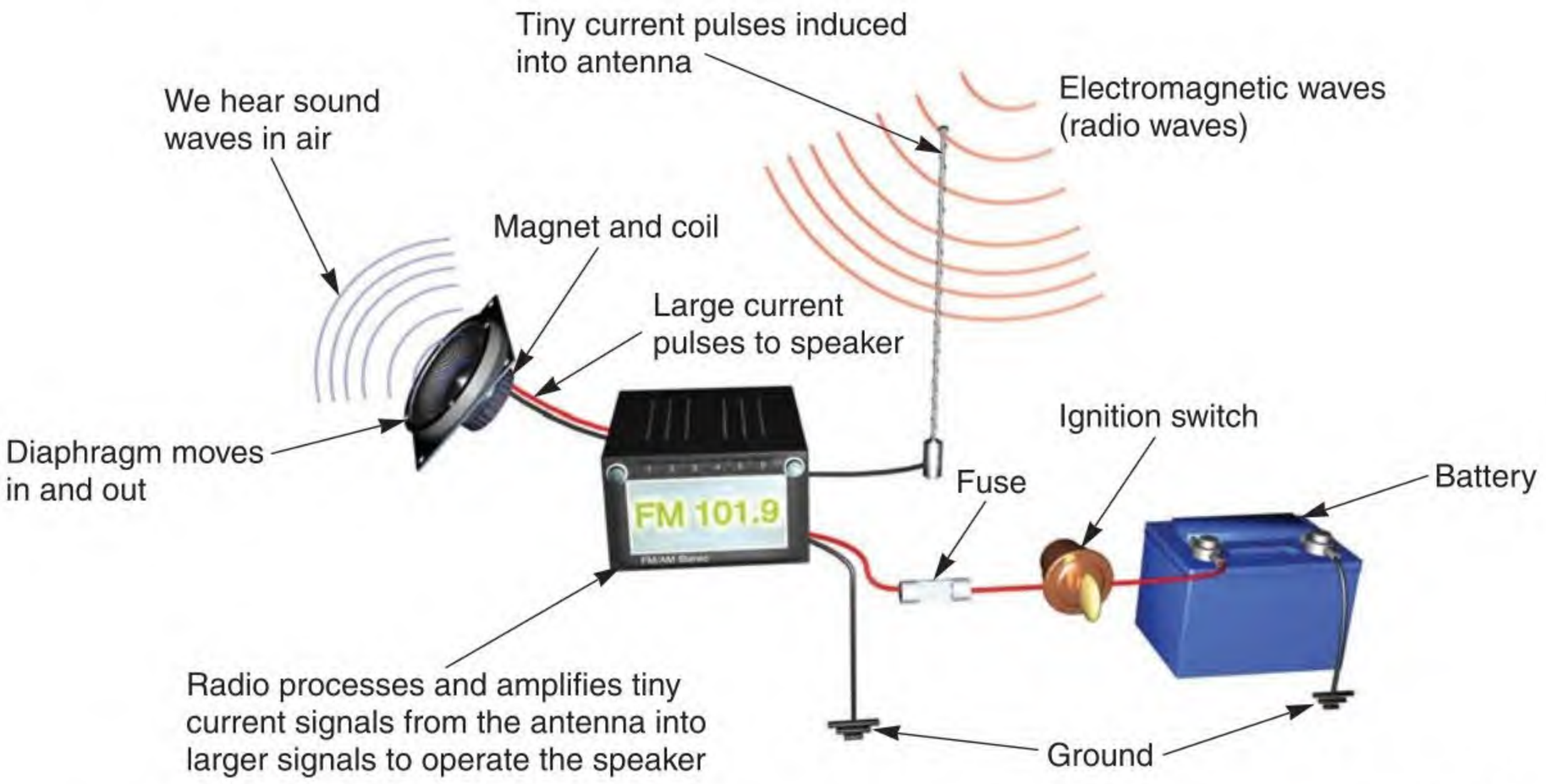
The term ***radio*** refers to the transmission of information through space using electromagnetic waves with frequencies below visible light. By modulating, or changing, the amplitude (voltage), frequency (speed), phase (spacing between separate codes waves), and/or pulse width (digital signal) of the electromagnetic waves, the radio transmitter can send information such as music, speech, and display data (such as channel, song, artist, and track) through space.

A basic ***radio system*** consists of the antenna, radio (receiver-amplifier), power supply circuits, and speakers.

The basic operation of a radio is illustrated in **Figure 37-1**. The ***radio station*** sends out an electromagnetic signal from a large broadcasting tower. When this signal moves past the vehicle's antenna, tiny electrical signals are induced in the antenna.

The radio amplifies and alters these "weak" radio signals into stronger current pulses that operate the

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Figure 37-1. Study the basic principle of a car radio. Radio waves are tiny electromagnetic pulses picked up by the antenna. The radio alters and amplifies these waves into strong current signals for speakers. The physical movement of each speaker diaphragm causes air pressure pulses, which we hear as sound.

speakers. Each speaker diaphragm moves back and forth, producing air pressure waves. We hear these air pressure waves as sounds (voices or music).

A ***sound system*** is more elaborate than the basic radio system just described and often includes an AM/FM digital stereo radio, a CD player, and sometimes a power booster, a subwoofer speaker, and a power antenna. These parts are shown in **Figure 37-2**.

Radio System

The following are fundamental parts of a radio system:

- Antenna—An antenna is a metal shaft or wire in the window glass that picks up electromagnetic waves sent from a radio station.
- Antenna cable—The antenna cable is a coaxial cable that protects weak electrical signals induced into the system by electromagnetic radio waves.
- Radio—The radio contains a receiver-amplifier that strengthens weak radio wave signals and electronically processes them to drive the speakers. It also contains a ***tuner***, which allows the driver to select different ***radio frequencies*** (stations).
- Speaker wires—Speaker wires are small-gauge wires that carry pulsing current signals to the speaker coils.
- Speakers—Speakers are coil-operated diaphragms that move back and forth, causing vibrations in air to produce sound.
- Power supply circuit—The power supply circuit includes the wiring, fuses, and other parts that feed direct current to the radio.

An antenna picks up the broadcast signal and feeds it through the antenna lead to the radio. Some antennas are a very fine piece of wire in the windshield glass. Other antennas are a metal mast (rod) mounted in the car body. A power antenna uses a small electric motor and gear mechanism to raise and lower the antenna mast.

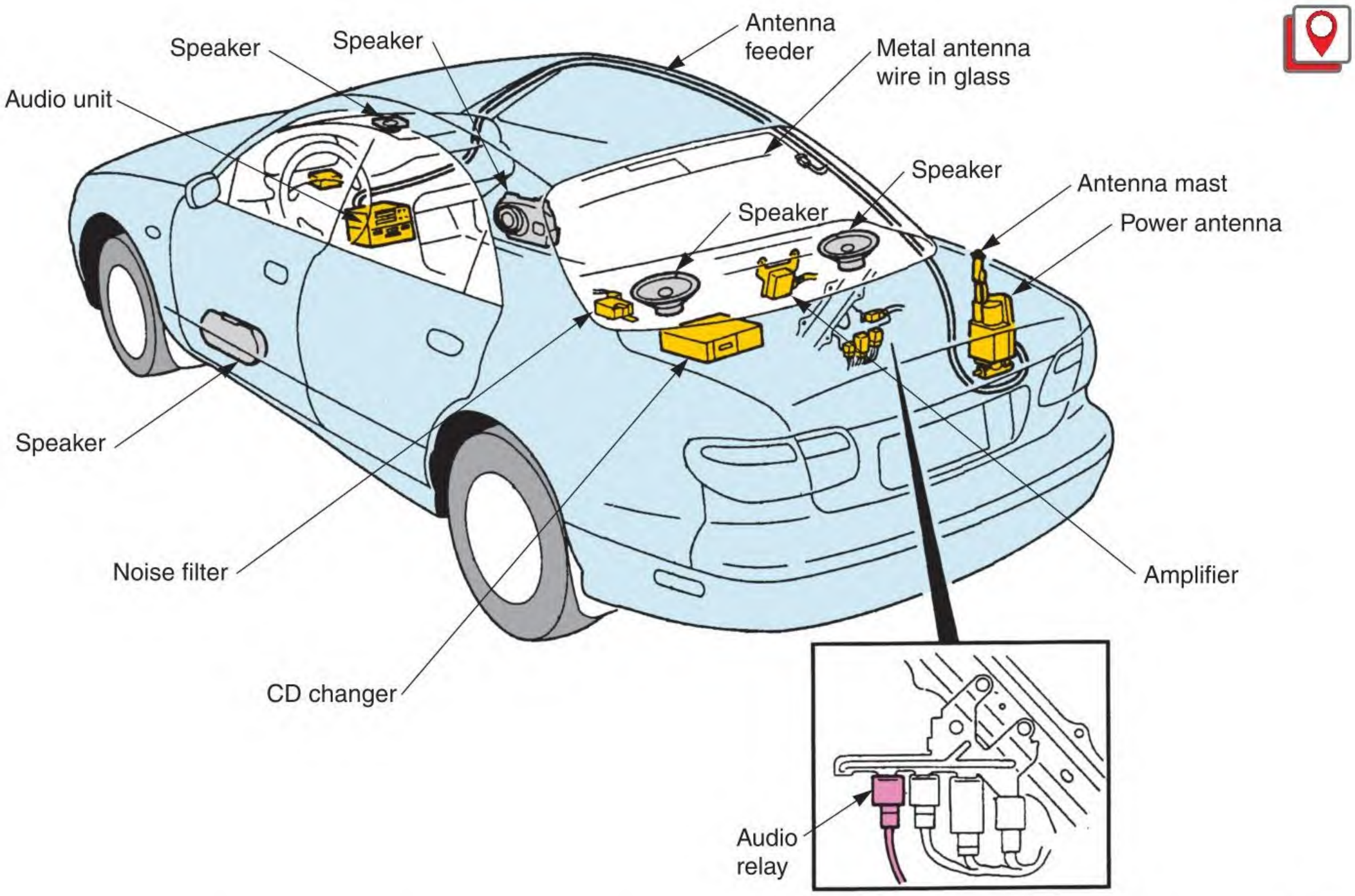
AM, FM, Digital Radio Systems

There are three types of radio signals generated by broadcast towers: AM (amplitude modulating), FM (frequency modulating), and digital, **Figure 37-3**.

An ***AM radio*** is designed to pick up a radio signal that varies in amplitude (strength). It operates on a frequency of 530–1,610 kilohertz (kHz), which gives it a longer broadcasting range than FM.

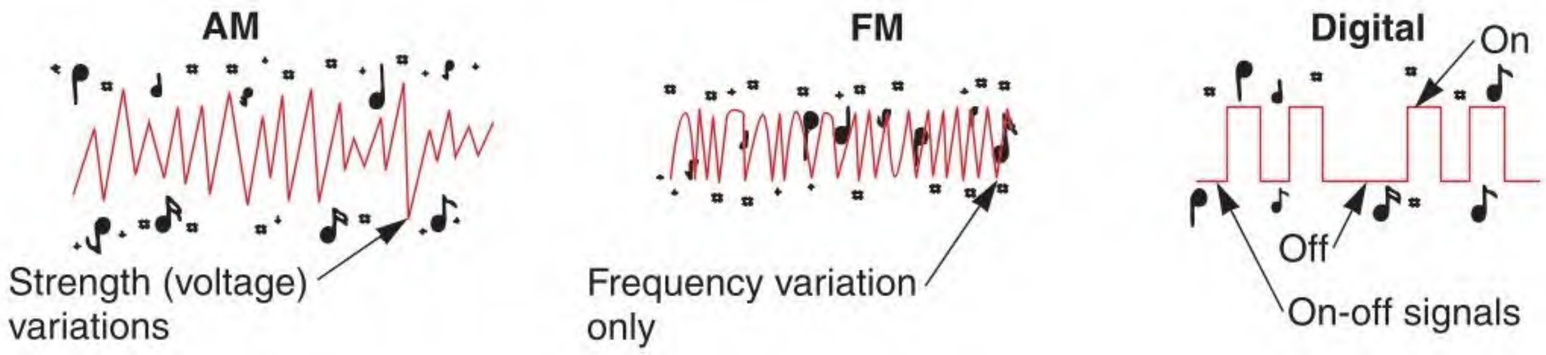
An ***FM radio*** is designed to receive a radio signal that varies in frequency (fluctuating speed). The FM band is a higher frequency, from 88–108 megahertz (MHz). Since the FM radio wave is not reflected off the ionosphere (upper atmosphere), it has a relatively short broadcasting range (approximately 35 miles

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Mazda

Figure 37-2. Late-model vehicles normally come equipped with elaborate sound systems. Multiple speakers, an amplifier or power booster, a CD player, and a power antenna add to service complexity.



Chrysler

Figure 37-3. Note the difference between AM, FM, and digital signals. Radios must have circuitry that can "read" these different radio signals.

or 56 kilometers). FM radio is capable of producing stereo (stereophonic or multidimensional) sound. A stereo uses at least two speakers and has different sounds coming from each speaker.

Digital radio uses analog signals that are compressed and digitized (converted to on-off signals) so more programming can be broadcast in a given spectrum. The digital signal is similar to the one produced by a digital compact disc. HD programming is found between analog FM stations.

Satellite Radio

Satellite radio operates off a radio (electromagnetic) transmitter that orbits about 22,000 miles (35,000 km) above Earth. The satellite broadcasts use an FCC-allocated broadcast frequency in the S-band (2.3 GHz) for sending digital data. One satellite can send out the same radio signal for hundreds of miles. While AM and FM signals are good only within a certain radius, satellite radio systems employ multiple

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satellites so listeners can hear the same stations without losing reception when traveling across the country.

Satellite radio uses a special chip set inside the radio. This chip accepts and translates the digital satellite signals to a lower frequency for operating the amplifier circuits and speakers of the system. Consumers must pay the service provider a fee for their radios to translate and play a satellite radio signal.

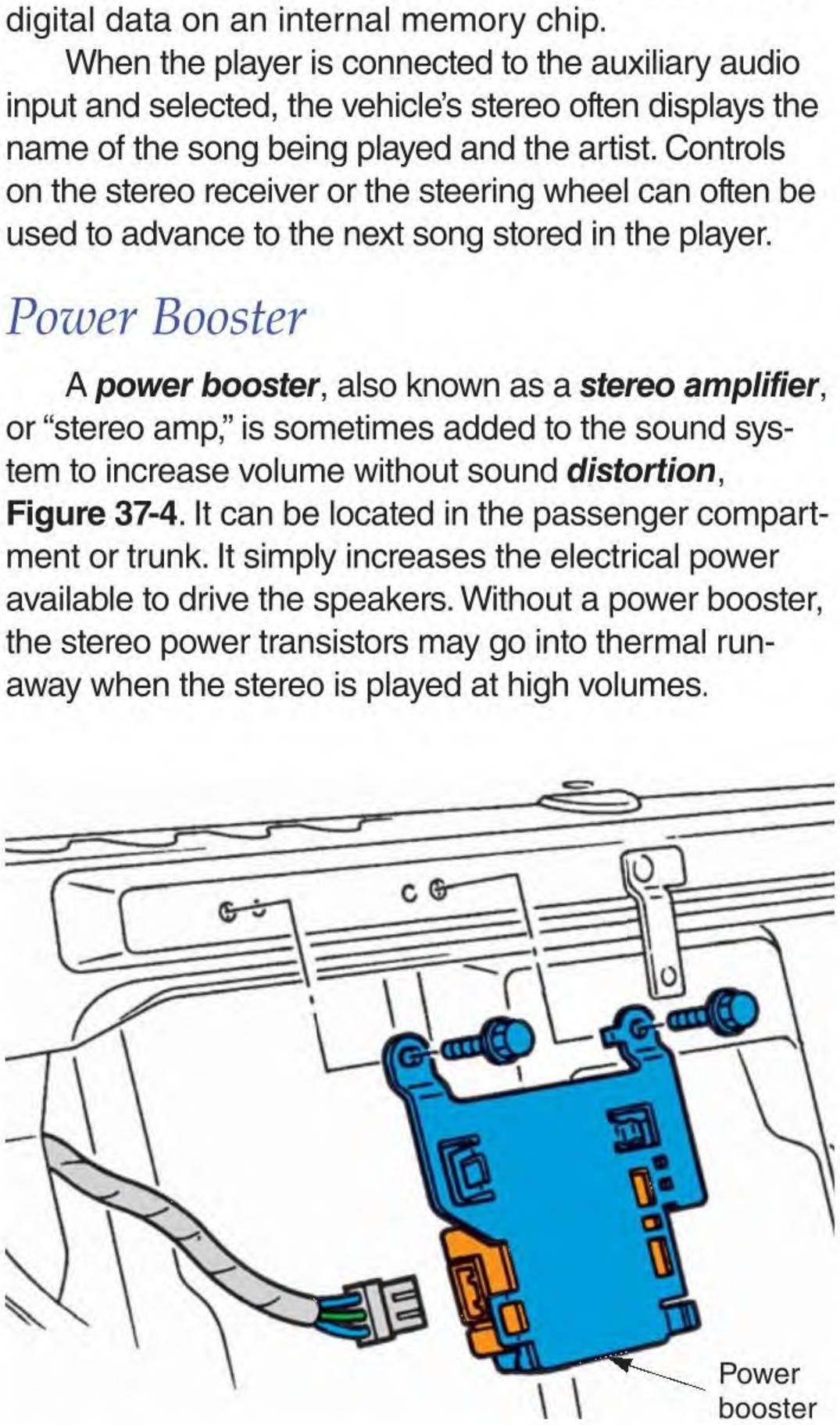
Auxiliary Audio Input

Many new vehicles have a built-in ***auxiliary audio input*** that allows a digital audio player to be connected to the vehicle's stereo system. A ***digital audio player***, such as an iPod or an MP3 player, is a compact music player that stores large amounts of digital data on an internal memory chip.

When the player is connected to the auxiliary audio input and selected, the vehicle's stereo often displays the name of the song being played and the artist. Controls on the stereo receiver or the steering wheel can often be used to advance to the next song stored in the player.

Power Booster

A ***power booster***, also known as a ***stereo amplifier***, or "stereo amp," is sometimes added to the sound system to increase volume without sound ***distortion***, **Figure 37-4**. It can be located in the passenger compartment or trunk. It simply increases the electrical power available to drive the speakers. Without a power booster, the stereo power transistors may go into thermal runaway when the stereo is played at high volumes.



Mazda

Figure 37-4. A power booster may be located in the trunk or under a seat.

Thermal runaway occurs when a transistor is driven too hard (too much output current is controlled by the transistor). The output of the transistor will fluctuate as the transistor's thermal capacity is exceeded, and severe distortion will be heard from the speakers. With enough thermal runaway, the transistor will fail.

When troubleshooting a sound system, determine which sections of the system are working and which are not. For example, if the radio and tape player work but the CD player does not, check the part of the circuit related only to the CD player. If tests find something wrong with the CD player, send it to a specialized shop for repairs.

Radio Service

If a radio fails to work, check its fuse. You may have external problems: a blown fuse, an open antenna or power supply lead, or bad speakers. Do not condemn the radio until all other problem sources have been eliminated. If only one speaker is not working, the coil in that speaker coil could be faulty. If two or more speakers are not working, the problem is probably inside the radio circuits.

Tech Tip

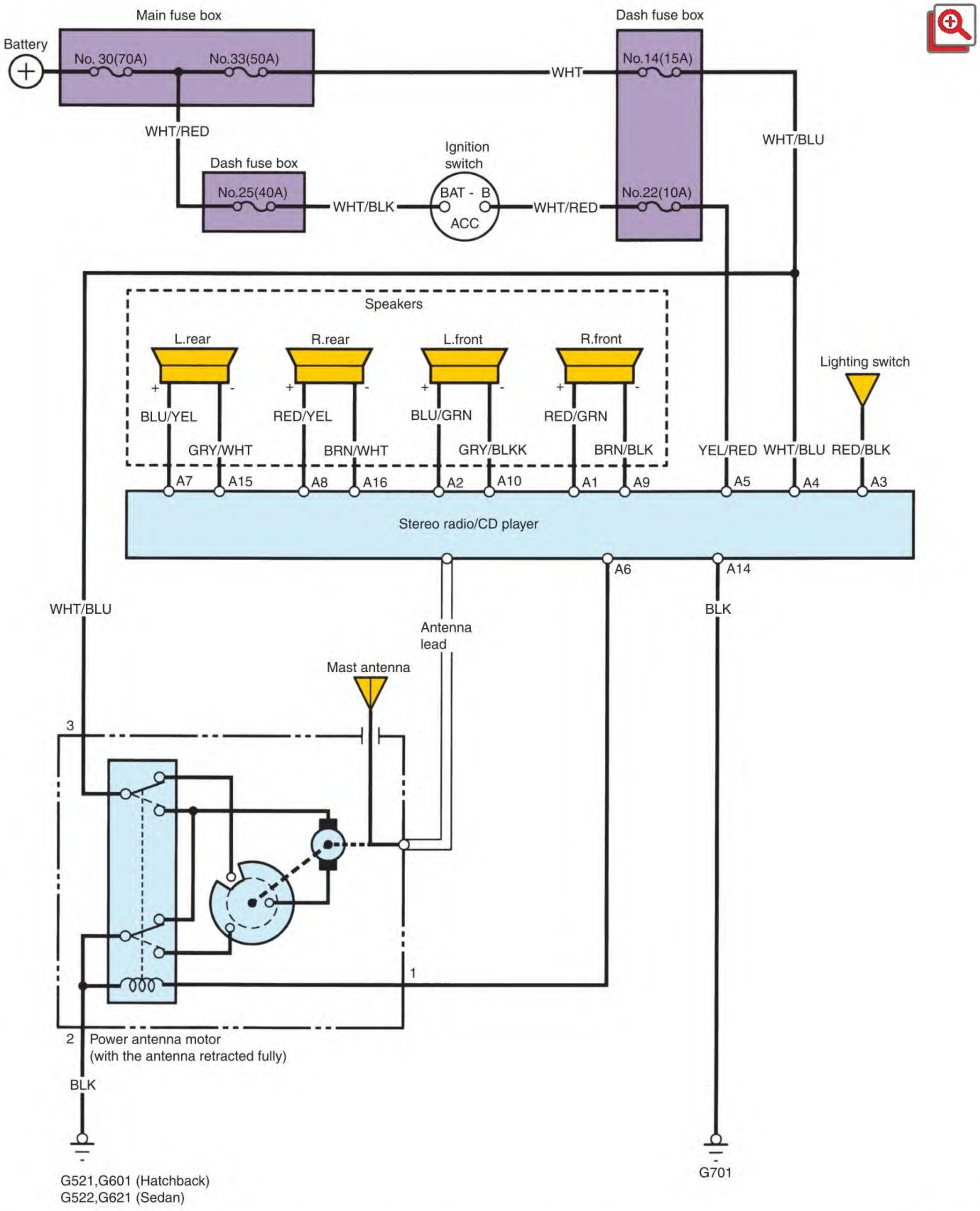
Just because the lights in a radio are working does not mean the radio circuitry is getting power. Quite often, two power leads feed the radio. One lead is for the memory circuitry and the other is for the face lights. Make sure both leads are providing electrical power to the radio, as show in **Figure 37-5**.

When the radio is found to be faulty, it should be removed and sent to an authorized repair technician. Various methods are used to secure radios. Some radios can be removed by simply removing the screws on the faceplate. You can then pull the radio out far enough to disconnect the speaker wires, power connectors, and antenna lead. Others require partial dash disassembly for removal. In some cases, you may need to lie on the floor to remove a rear support bracket and the wiring. Other stereo heads require small metal tools to reach in and release hidden clips securing the unit in the dash. Refer to factory literature if in doubt.

Antennas

An ***antenna*** picks up the broadcast signal and feeds it through the antenna lead to the radio. A very fine piece of wire mounted in the windshield glass can

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Honda

Figure 37-5. Study connections and components in this stereo system wiring diagram.

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serve as the antenna. Other antennas are a metal ***mast*** (rod) mounted on the body. Look at **Figure 37-6**.

A ***power antenna*** is a telescoping antenna that is extended and retracted by an electric motor. The electric motor turns a gear. The gear then operates a cable or slide mechanism on the antenna mast. Most power antennas go up and down automatically when the stereo is turned on or off. In some cases, however, a dash-mounted switch actuates the electric motor to move the antenna up or down.

Antenna Service

If you suspect a bad antenna (no signal coming from antenna lead), connect a known good antenna to the radio. If the new antenna causes the stereo to work, replace the old antenna.

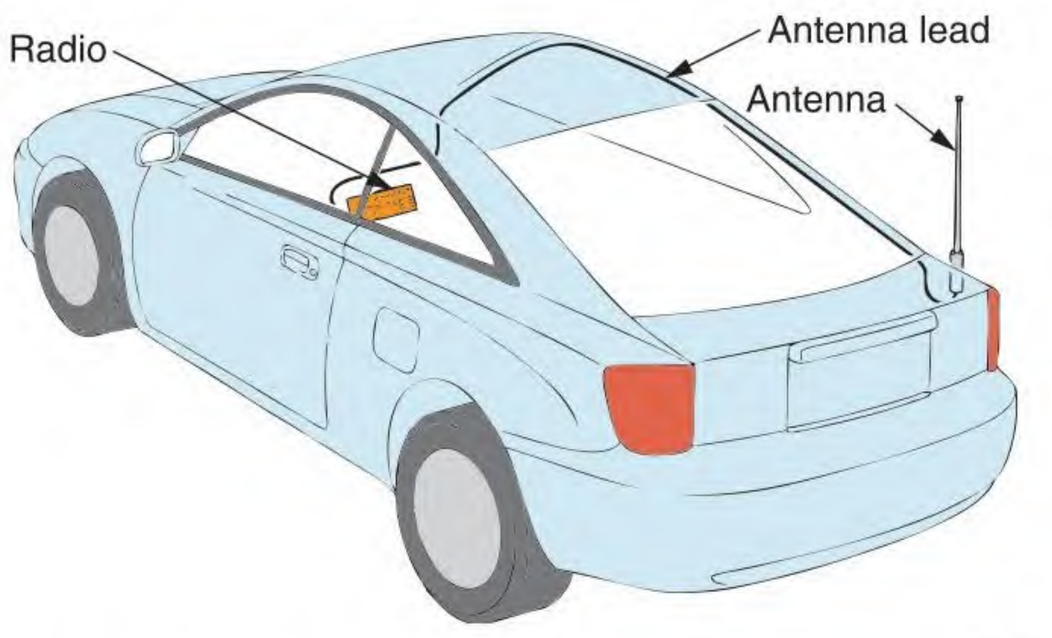
If a power antenna does not go up or down, check for power going to the motor. Use a test light or voltmeter. If power is reaching the antenna motor, the motor is probably bad. If you are not getting power, trace back through the circuit to find the problem.

Speakers

A ***speaker*** uses a permanent magnet and a coil of wire mounted on a flexible diaphragm to convert electricity into motion and sound. When current passes through the coil of wire, the resulting magnetic field pulls the coil and diaphragm toward the permanent magnet. Rapid movement of the speaker diaphragm causes pressure waves in the air. We hear these pressure waves as sound.

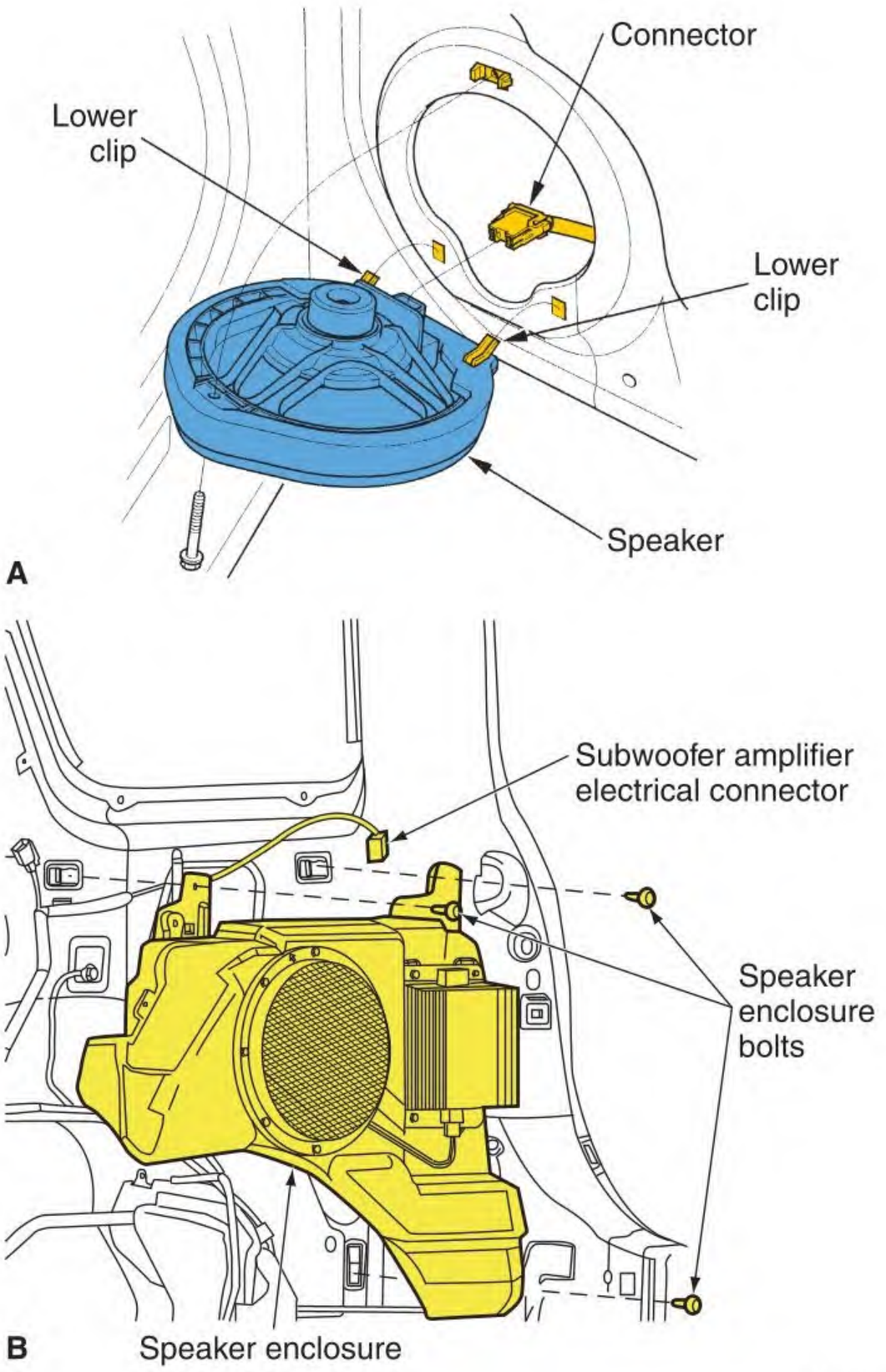
Different types of speakers are used to reproduce different sound frequencies. A tweeter is a small-diameter speaker cone that is able to reproduce the highest frequencies detectable by the human ear. A midrange speaker is a medium-size speaker that is ideal for reproducing sounds in the middle of the ear's frequency range. A subwoofer is a medium-size speaker mounted in a large enclosure to reproduce low and midrange sound waves.

The speakers may be mounted in the doors, dash, or behind the rear seat. Look at **Figure 37-7**. FM and digital stereo radios have two or four speakers.



Toyota

Figure 37-6. This vehicle has a mast-type antenna. The antenna picks up the broadcast signal. The signal then travels through the antenna lead to the radio.



Honda

Figure 37-7. Speakers can be mounted in doors, in the upper dash, in interior side panels, or behind the rear seat. A—This speaker has a conventional mount in the door frame. Remove the screws after carefully popping of the grille. You may have to remove the inner door trim panel. The rattle of loose mounting screws will sound like a blown speaker diaphragm or separated coil windings, which require speaker replacement. B—Many of today's automotive speakers are mounted in an acoustic chamber that benefits sound quality. This one has a small amplifier mount on it next to the speaker. Always test the amplifier with a scope if the speaker looks and tests good as described earlier.

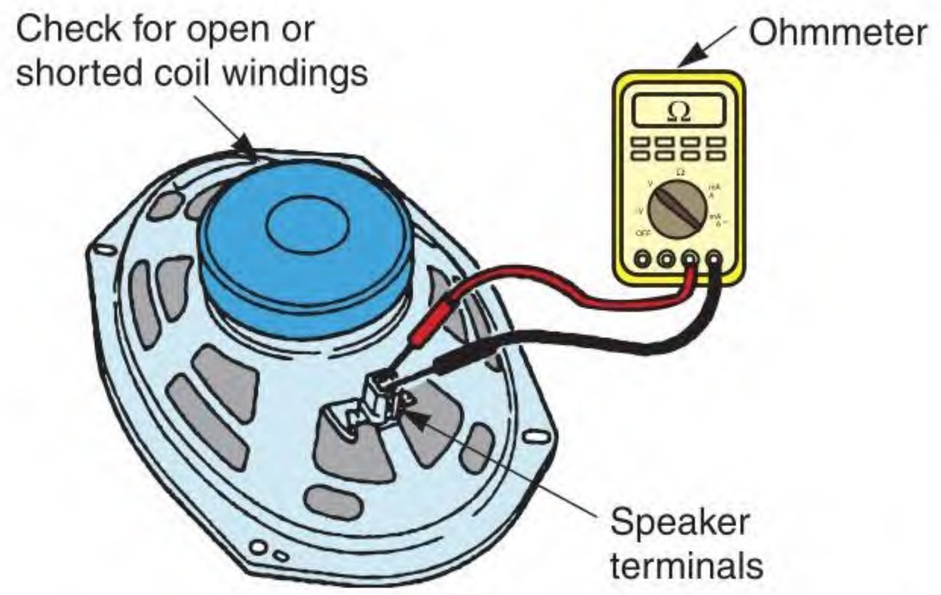
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Speaker Service

A faulty speaker will usually distort the sound of the radio. The speaker may rattle, especially when the volume is adjusted to a higher output level. A broken coil winding or terminal-to-coil wire can render the speaker inoperable.

Speakers are not usually repairable and should be replaced when defective. However, terminal-to-coil wires can sometimes be soldered when broken. The speaker mounting screws can also vibrate loose, creating a sound similar to a blown speaker. Tighten the speaker mounting screws and recheck audio quality.

Figure 37-8 shows how to check for shorted or open speaker coil windings. Most auto speakers should have an impedance of either 4 or 8 ohms.



Mazda

Figure 37-8. To verify an internal problem with a speaker coil, check it with an ohmmeter. If shorted, resistance will be almost zero. If the windings are open, the ohmmeter reading will be very high.

CD Players

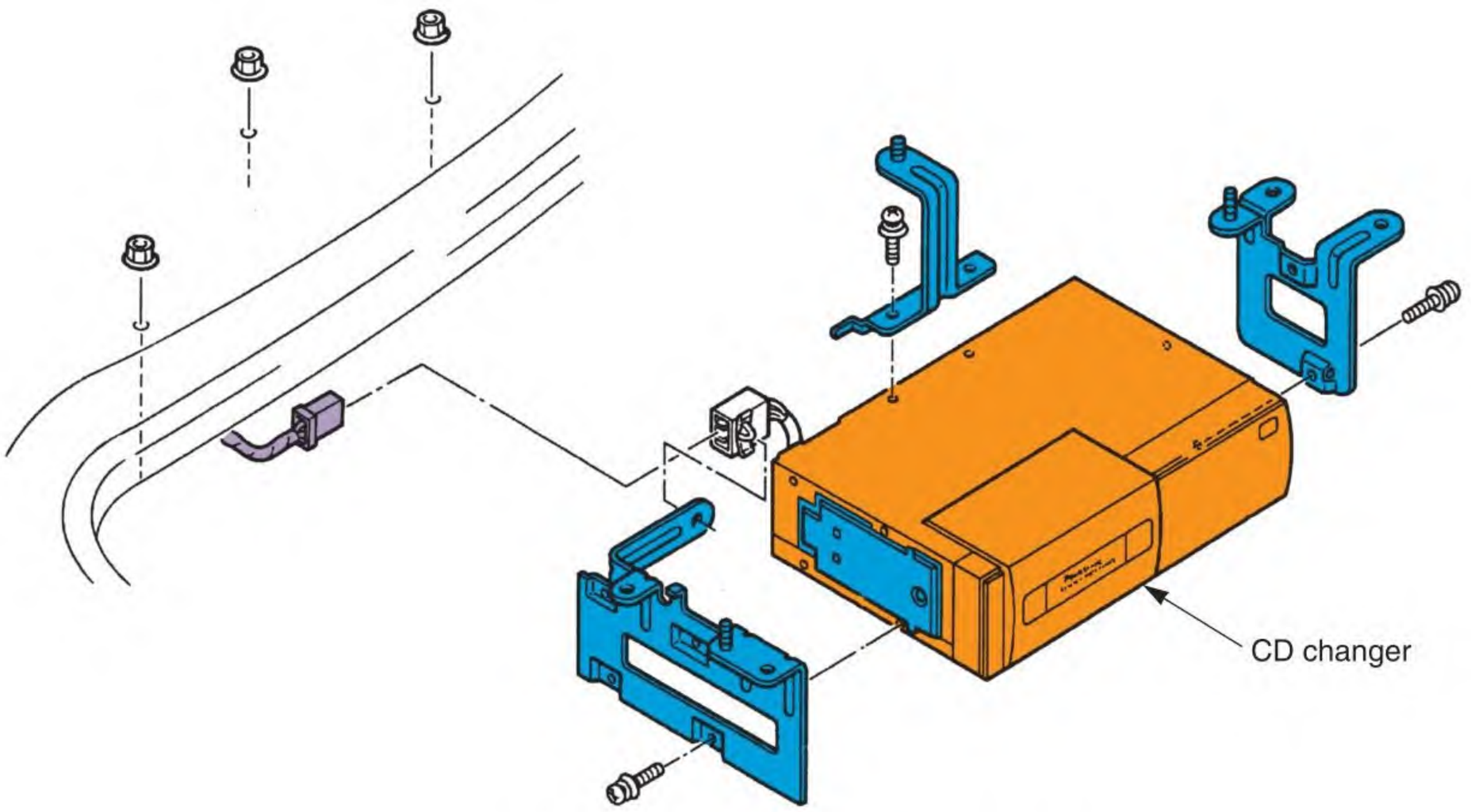
CD players, also termed ***compact disc players***, play music that is stored digitally on a plastic disc. They are common on today's vehicles. The CD player can be made as part of the stereo in the dash, or a remote unit located in the trunk, **Figure 37-9**.

DVD Player

An automotive ***digital video disc (DVD) player*** with a display screen is usually mounted in the rear seatbacks. This allows backseat passengers to watch a DVD while the vehicle is in operation.

Tech Tip

Steering wheel touch controls (switches mounted on steering wheel) are sometimes provided for the stereo, air conditioning, speed control, and other systems. Keep the steering wheel controls in mind when troubleshooting problems with these systems.



Mazda

Figure 37-9. A CD changer normally mounts in the trunk. Check for stuck CDs, dirty heads, and power feed problems caused by bad wiring before sending the unit out for repairs.

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Radio Noise

Radio noise is undesired interference or static (popping, clicking, or crackling) obstructing the normal sound of the radio station. Radio noise is commonly caused by a bad antenna, an open or shorted noise suppressor (capacitor), a bad secondary wire, a faulty radio, or other problems. If the stations are too far away, noise will also interfere with the signal.

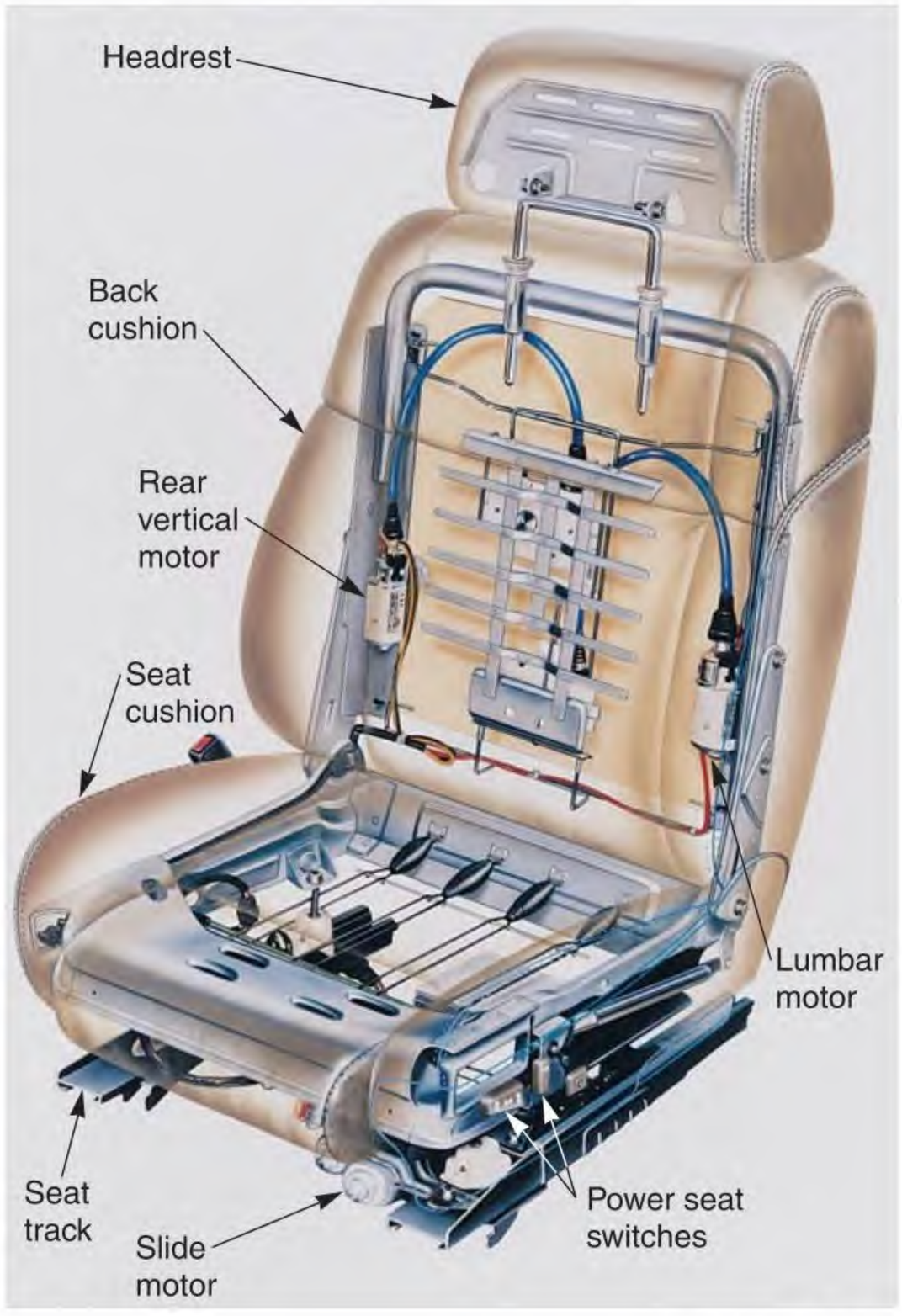
Study the sound of the radio noise to determine its source. For example, a low-pitched clicking that changes with engine speed may be caused by the ignition system (open secondary wire). A high-pitched whirring sound that also changes with engine speed could be from the electrical system (bad capacitor or alternator diode).

One of the first parts to check when radio noise is present is the antenna. Plug a known good antenna into the radio. Ground the antenna base and note any changes in radio output. If the noise is eliminated, the old antenna is faulty. If the noise remains the same, check the noise suppressors.

Noise suppressors are capacitors that absorb voltage fluctuations in the car's electrical system. They result in smoother dc current entering the radio, which reduces radio noise.

Noise suppressors can be located at the alternator, ignition coil, heater blower motors, servo motors, and ac hybrid drive motors. All these components can produce voltage fluctuations and noise. Refer to a service manual for exact suppressor locations.

A clip-on test capacitor can be used to check noise suppressors. Connect the test capacitor across or in place of the suppressor. If the radio static is reduced, the old noise suppressor may be bad.



General Motors

Figure 37-10. Cutaway view of a power seat shows the seat motors, transmission cables, tracks, and other parts. Seat removal may be needed to service seat motors.

Power Seats

Power seats use several switches, electric motors, and drive assemblies to change the seat positions. The power seat switches can be on the inner door panels or on the sides of the seats. The power seat motors and drive assemblies can be under or in the seats, **Figure 37-10**.

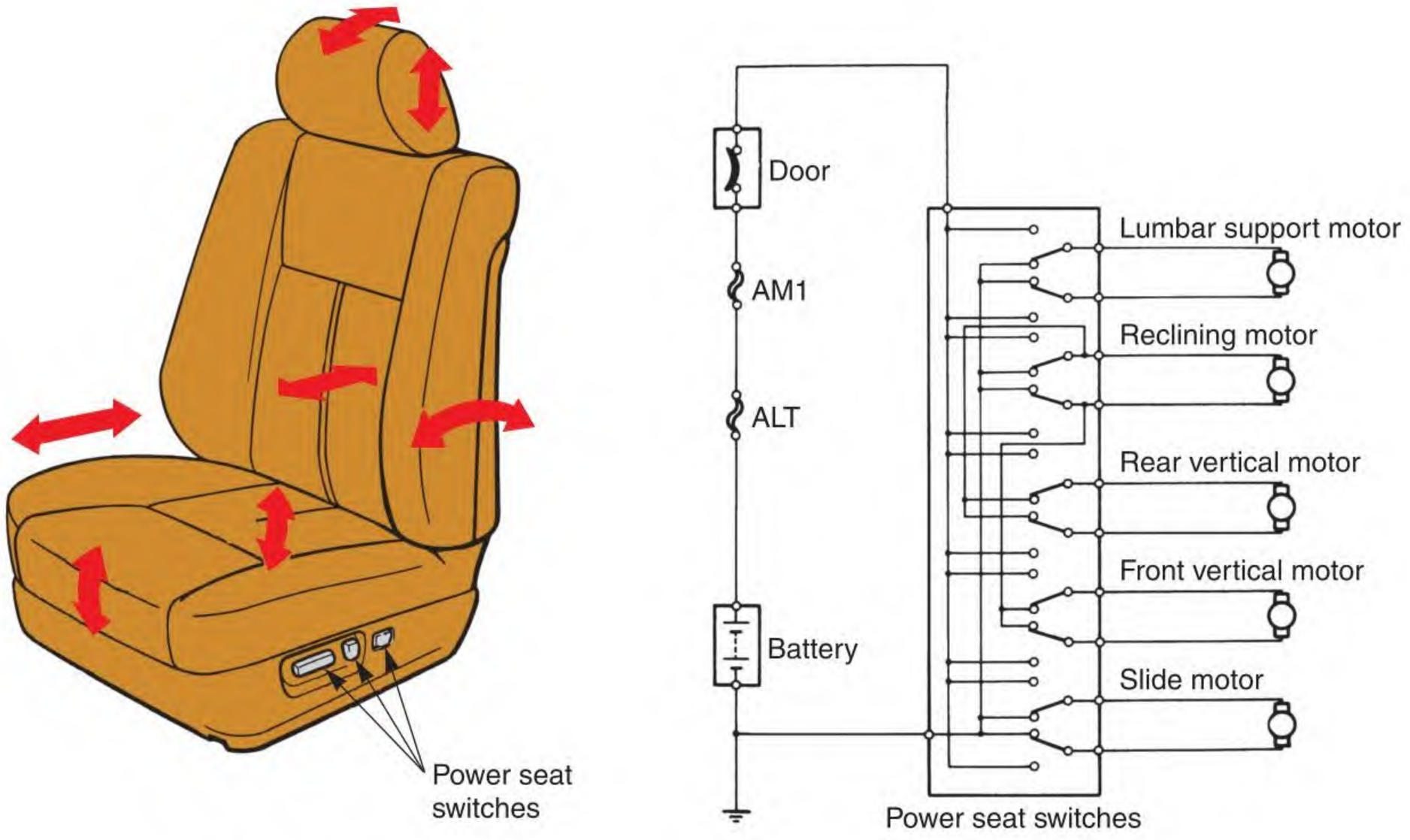
When activated by a switch, the reversible dc motors operate a gear mechanism. The gear mechanism changes the rotating motion of the motor armature into a linear motion that positions the seat. Most power seats have more than one seat motor. Power is sometimes transmitted from the power seat motors to the tracks or adjustment mechanisms by steel cables inside metal housings. **Figure 37-11** shows how a simple power seat circuit can create several seat positions.

Memory seats use a small computer, or module, to "remember" seat positions for several people. Some computer memory systems are networked and will remember not only seat positions but also steering wheel tilt positions, rearview mirror settings, and even electronic suspension settings for each driver.

Tech Tip

As a safety feature, many power seat memory systems will only work with the transmission shift lever in park or neutral. They are wired to the neutral safety switch or the electronic control module. Make sure the transmission is in park (automatic transmission or transaxle) when checking memory seat operation.

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Driver's Seat **Electrical Circuit (driver's seat-standard type)**

Lexus

Figure 37-11. Note that the wiring diagram shows which switches and motors operate the various seat adjustments.

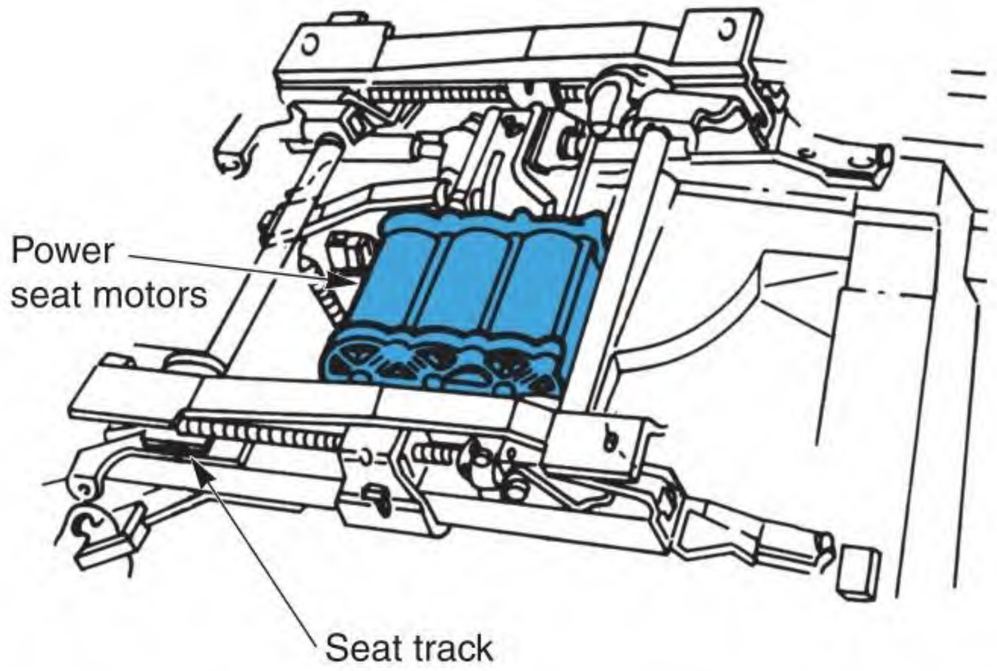
A ***power seat module*** can be programmed to return the seat to a desired position for different drivers. The seat is placed in the desired position and then one of two memory buttons is held down so the module can "remember" the seat location. The next time the memory button is pushed, the module can use the seat sensors and power motors to return the seat to the same location.

Power Seat Service

When diagnosing power seat problems, try to isolate the problem source to a specific area of the circuit. If only one seat fails to work, check parts that affect only that seat. Test its control switch and the wiring between the switch and motors. When the seat only fails in one mode (up and down, for example), check the motor and transmission (gear-cable mechanism) providing that action.

If both front power seats fail to function, check the common section of the circuit. Inspect the fuse, circuit breakers, wire connections, and any other components affecting both seats.

The most common reasons for power seat problems are the switches and drive motors. Remove and replace any switch or motor that does not work properly. See **Figure 37-12**. If you have difficulty repairing a power seat, read the information in a service manual. It will give directions for servicing the particular unit.



Ford

Figure 37-12. This seat has been removed to service a power seat motor. If the seat works in all but one position, only service the motor that operates that seat adjustment.

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Heated Seats

Heated seats use a heating element (or multiple heating elements), switch, relay, and related wiring to warm the seat cushions in cold weather. Most systems have two large-resistance wires or heating elements routed through the seat cushions. See **Figure 37-13**.

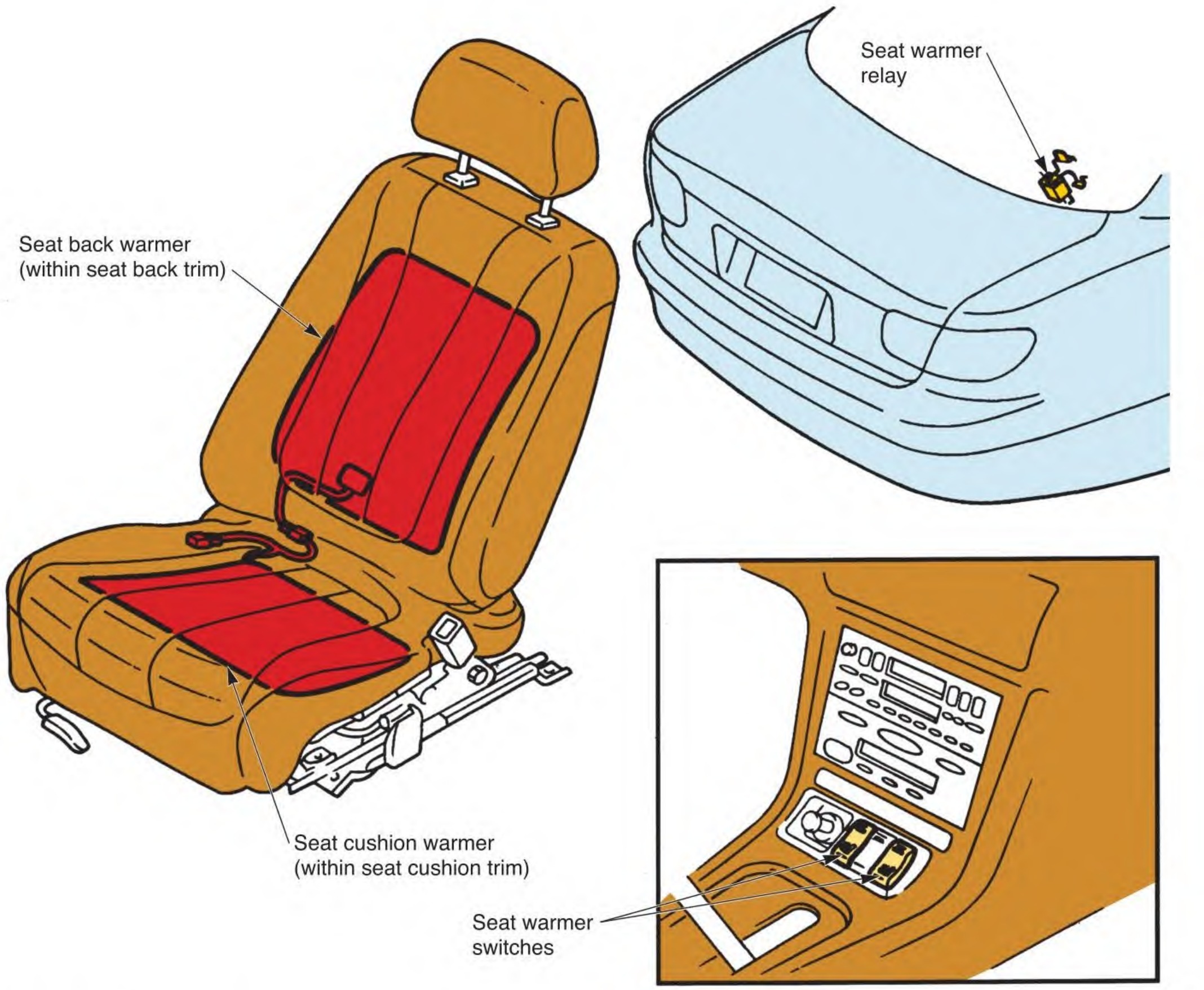
When you press the seat warmer button or switch, it energizes the warmer relay. The relay is a holding relay that stays on once energized. The relay then sends high current through the heating elements, which makes them get warm. The seat warmers stay on until you press an off button or until you shut the ignition switch off.

To service heated seats, check the fuse first. Next, test the warmer switch and then the relay. If you are getting power to the heating element but it does not get hot, the element is probably open and must be replaced.

Power Windows

A ***power window*** uses a control switch, reversible electric motor, circuit breaker, fuse, and related wiring to operate the door windows, **Figure 37-14**.

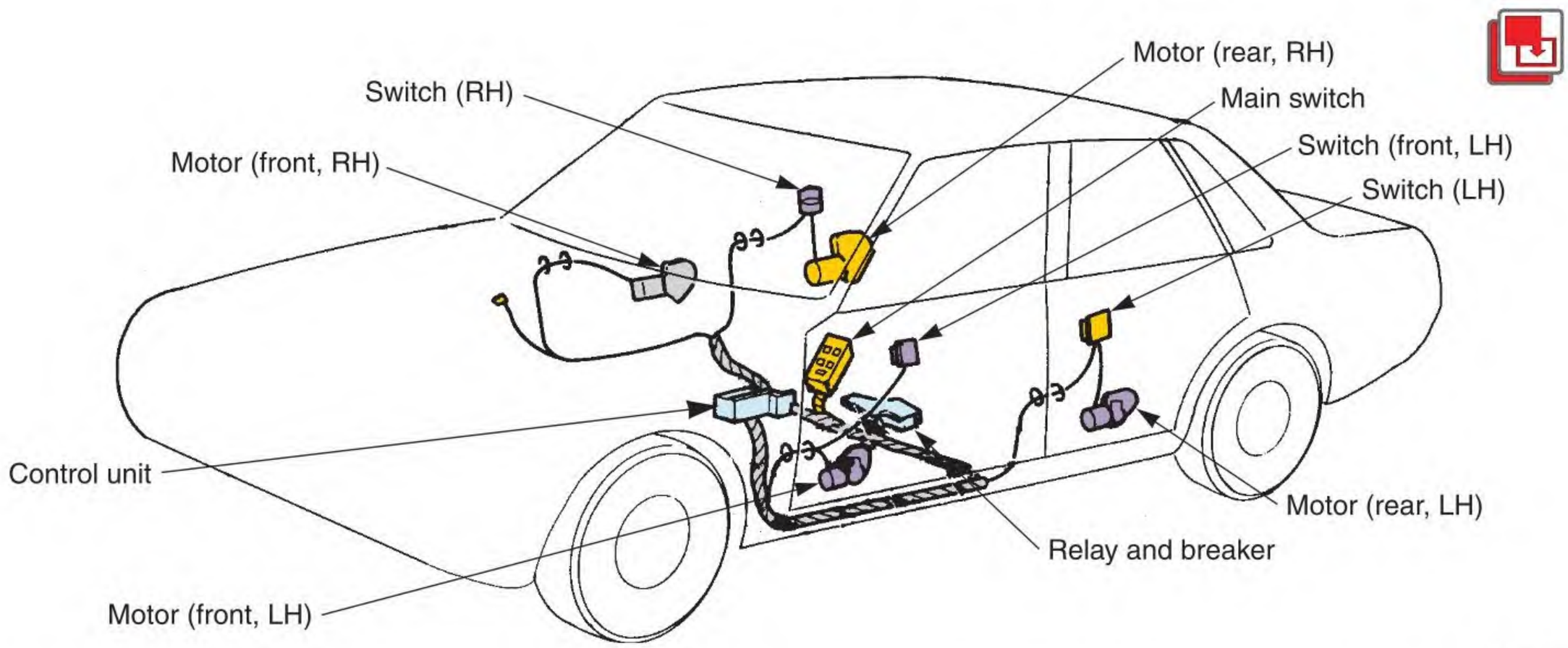
A small electric ***power window motor*** is located inside each door to operate the ***window regulator*** (up-down mechanism for the glass). The motors have a ***gearbox***, or ***transmission*** (usually worm and



Mazda

Figure 37-13. A heated seat simply uses two wires threaded inside seat cushions. First check for power to the resistance wires from the switch and relay. Then verify problem with resistance wire by testing it with ohmmeter.

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Subaru

Figure 37-14. Study the basic layout of a complete power window system. Switches operate electric motors inside each door. With inoperative power windows, check fuses and switches first. Then, remove door panels to test and service window motors.

ring gear), that changes the rotating motion of the motor armature into a partial rotation of a larger gear. This action pushes the window open or closed. See **Figure 37-15**.

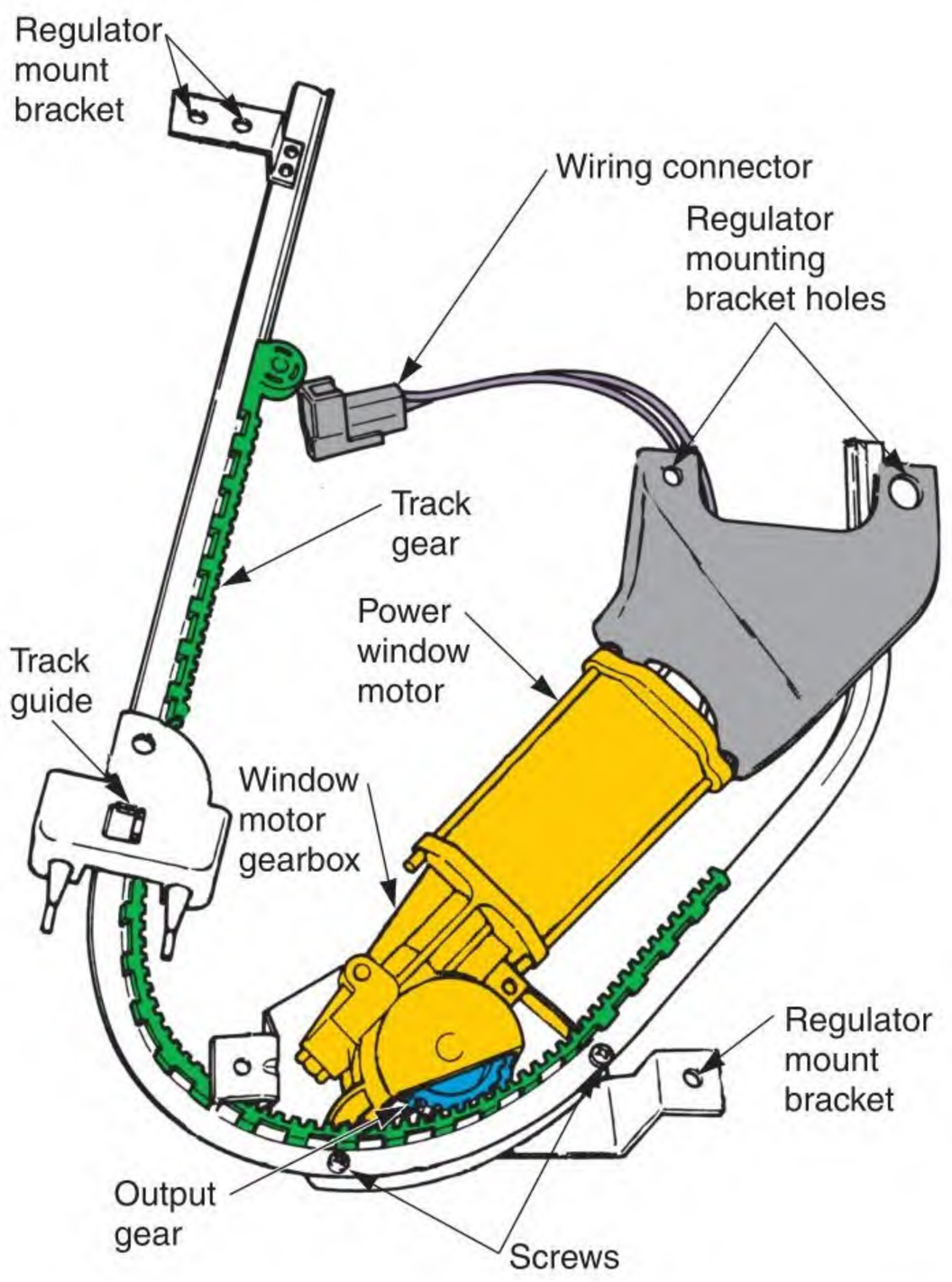
A circuit breaker protects the window motor from overheating damage. The breaker can open if the switch is held in one position too long. The circuit breaker can be located inside the motor or elsewhere in the circuit. A basic power window circuit is shown in **Figure 37-16**.

Some power windows will stop or reverse direction if an obstruction resists window closing. In some of these systems, a magnetic trigger wheel is mounted on the motor's armature shaft. As the trigger wheel turns, it creates a signal in a magnetic or Hall-effect sensor in the motor assembly. If the sensor outputs a slower-than-normal signal, the power window ECM will cut voltage or reverse the polarity of the voltage going to the window motor. This stops the window or lowers it to prevent damage to objects or injury to people who accidentally put parts of their bodies (hands, head, and arms) into the path of the window as it closes.

Power Window Service

When none of the power windows work, first check the fuse or circuit breaker for the whole system. If only one of the windows is inoperative, use a test light to check for power to its switches and motor.

If you hear a humming sound when a window switch is pressed, the motor gearbox may have



Chrysler

Figure 37-15. Check for a good electrical connection at the power window motor first. Also check for worn drive gear, track damage, and bad motor. Loose mounting bolts will cause a clunking sound when window changes direction.

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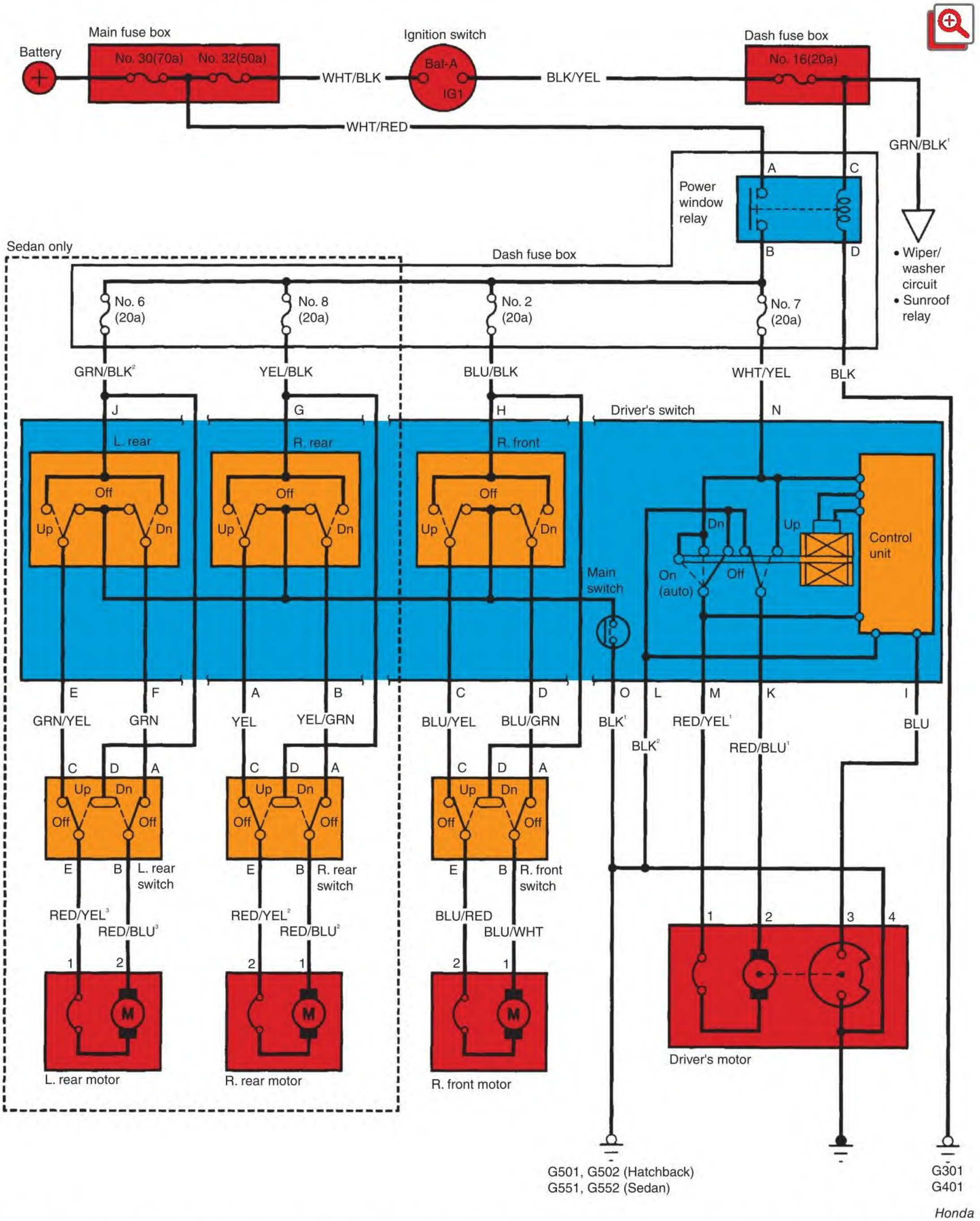


Figure 37-16. Study this wiring diagram for a typical power window circuit. Note how the electronic control unit operates the driver's window. It causes the window to go all the way down when the button is briefly pushed. The driver can release the switch right away to again grasp the steering wheel. This feature is handy at tollbooths.

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stripped gear teeth. The plastic gears in the window motor gearbox can strip after prolonged service. The motor will spin, but movement will not be transferred to the window. If the motor or the switches are found to be bad, they should be replaced.

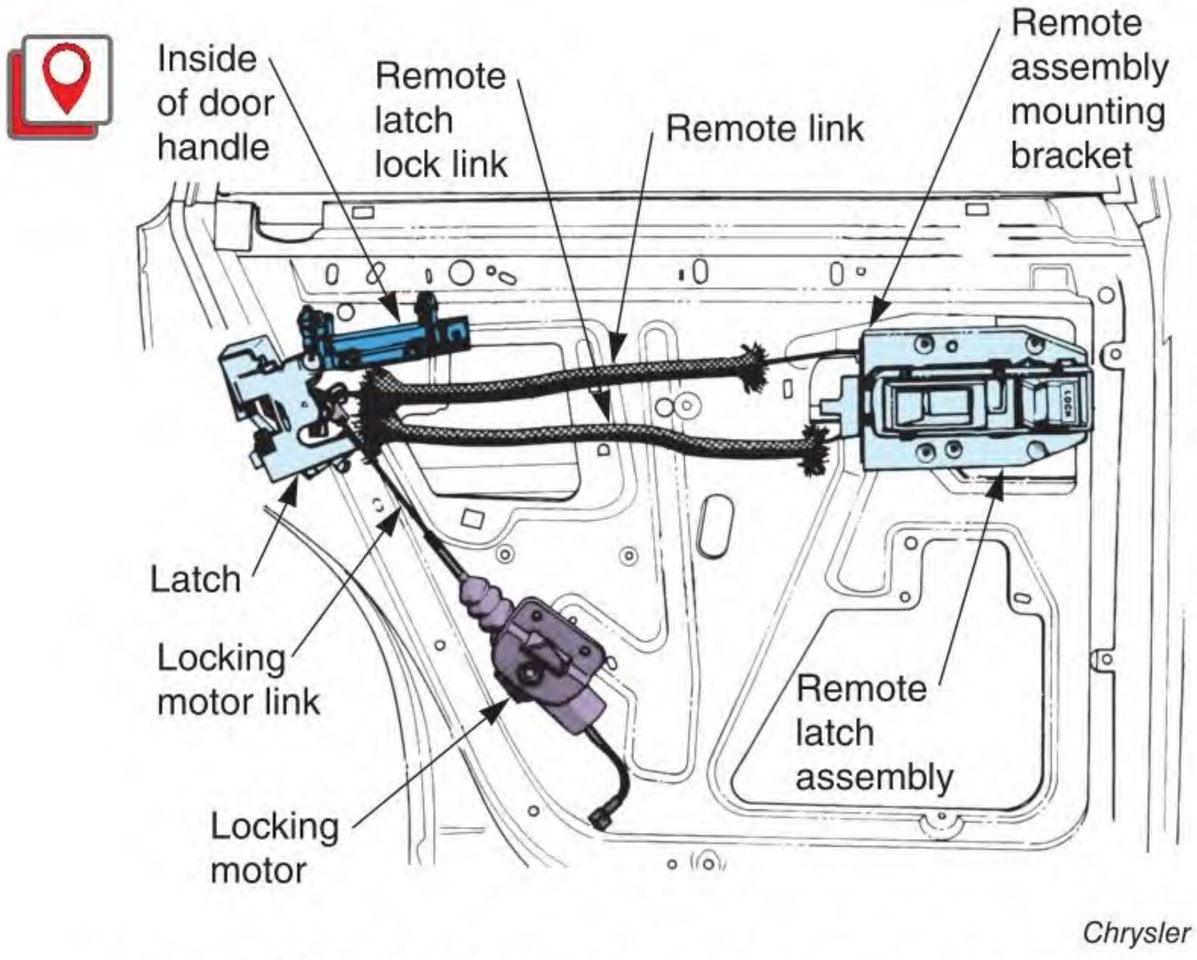
With hard-to-find problems, refer to the service manual wiring diagram for the power windows. The diagram will show all the components that could affect power window operation and help with troubleshooting.

Warning

Be careful because the sheet metal edges on and in doors can cause serious cuts or lacerations. Also, never wear a wristwatch or rings when servicing inside a door. The metal could short across wires or get caught, causing injury or part damage.

Power Door Locks

Power door locks typically use electric switches and solenoids or motors to operate the door lock mechanisms, **Figure 37-17**. When the door key is turned, it closes a switch. A motor or solenoid then moves an arm on the door latch to lock or unlock the door. An additional switch is normally provided on the driver's door panel.



Chrysler

Figure 37-17. Most power door lock systems use a large solenoid to activate the latch. Study construction of this system.

If all the power door locks fail to function, check the main fuse, electrical connections, and other components common to the whole circuit. If only one door lock is bad, check its switch and solenoid or motor. The door lock switches and solenoids are the most common causes of trouble.

Figure 37-18 is a typical power door lock circuit. Study its connections and components.

Door Panel Removal

Door panel removal may be needed to service power windows, seat control switches, door latches, or radio speakers.

Service Procedure

The basic procedure for removing a door panel is as follows:

1. Remove all screws that hold the door panel to the door frame. Some are visible; others may be covered with small plastic buttons or covers.
2. Unscrew and remove the door lock button.
3. Remove the inner door handle and window crank, if used.
4. Once all major parts have been removed, you often have to pop out spring clips around the outside of the door panel. Be careful not to bend or tear the panel. Refer to a manual if you have difficulty.

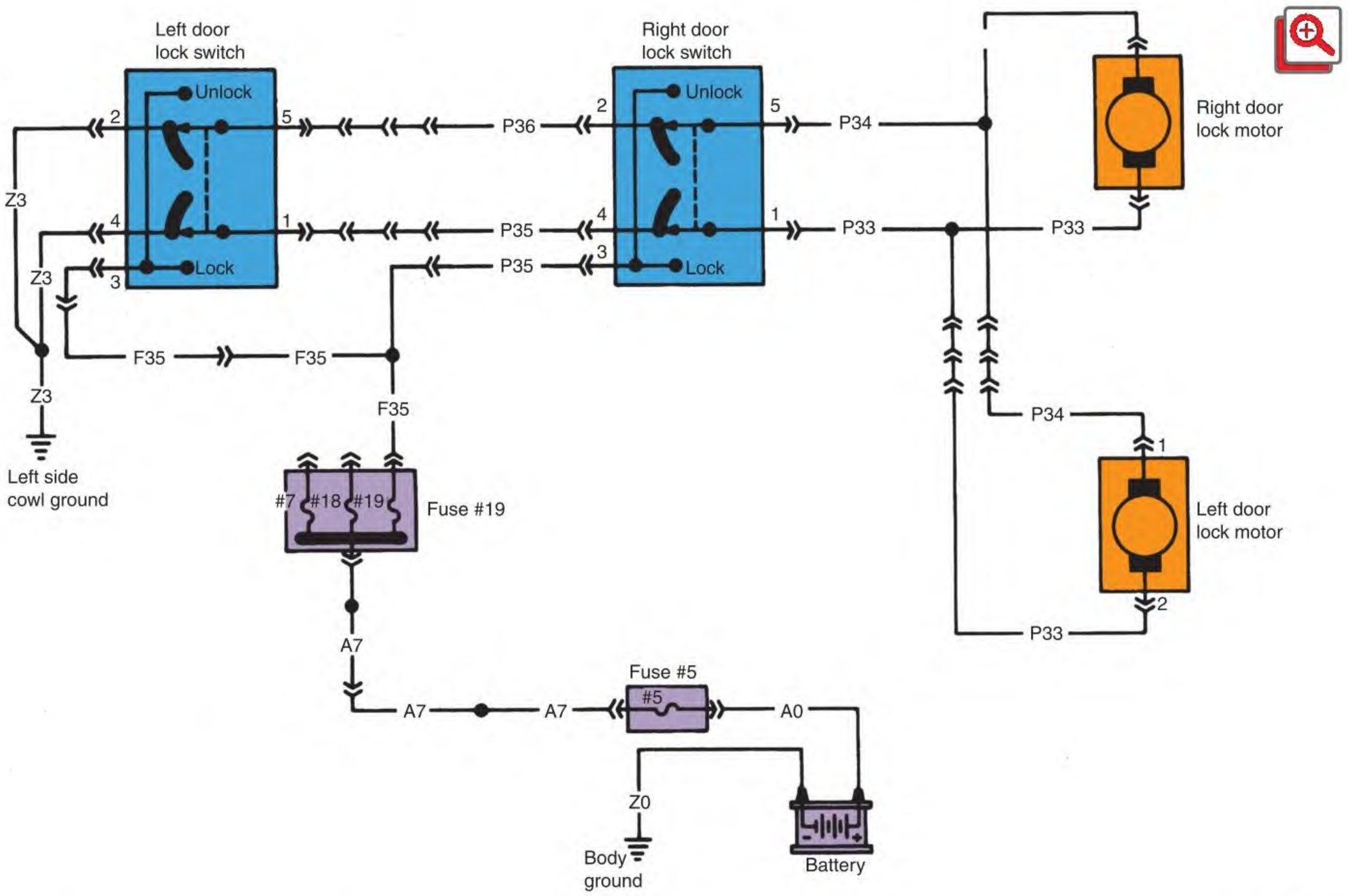
Tech Tip

The wiring going through the body and into the door can break internally after the door has been opened and closed thousands of times. Keep this in mind when troubleshooting any power device inside or on the door.

Power Trunk Release

A ***power trunk release*** is comprised of a solenoid mounted on the trunk latch, a fuse, a switch, and related wiring. When you close the trunk release switch, it sends power to the solenoid. The solenoid plunger then acts on the trunk latch and the trunk pops open.

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Chrysler

Figure 37-18. Basic door lock circuit connections and components.

Service of this circuit is fairly simple. Most problems are in the switch or solenoid. Use basic testing methods to isolate the problem.

Power Steering Wheel

A ***power steering wheel*** uses a computer and various switches, sensors, and motors to automatically tilt and telescope (extend or retract) the steering wheel. Like memory seats, most systems can be programmed to position themselves automatically. Some are tied to the memory seat circuit and use the same computer.

Figure 37-19 shows a power steering wheel circuit. Study its parts and electrical connections.

Rear Window Defogger

A ***rear window defogger***, also called a ***rear window defroster***, commonly uses a switch, a relay, an indicating light, and a window heating grid. See **Figure 37-20**.

When the switch is turned on, it allows current to flow to the indicator light and to the heating grid. The heating grid is resistance wire, usually mounted on or in the window glass. Current flowing through the grid causes the wire to heat up and defog or deice the vehicle's window.

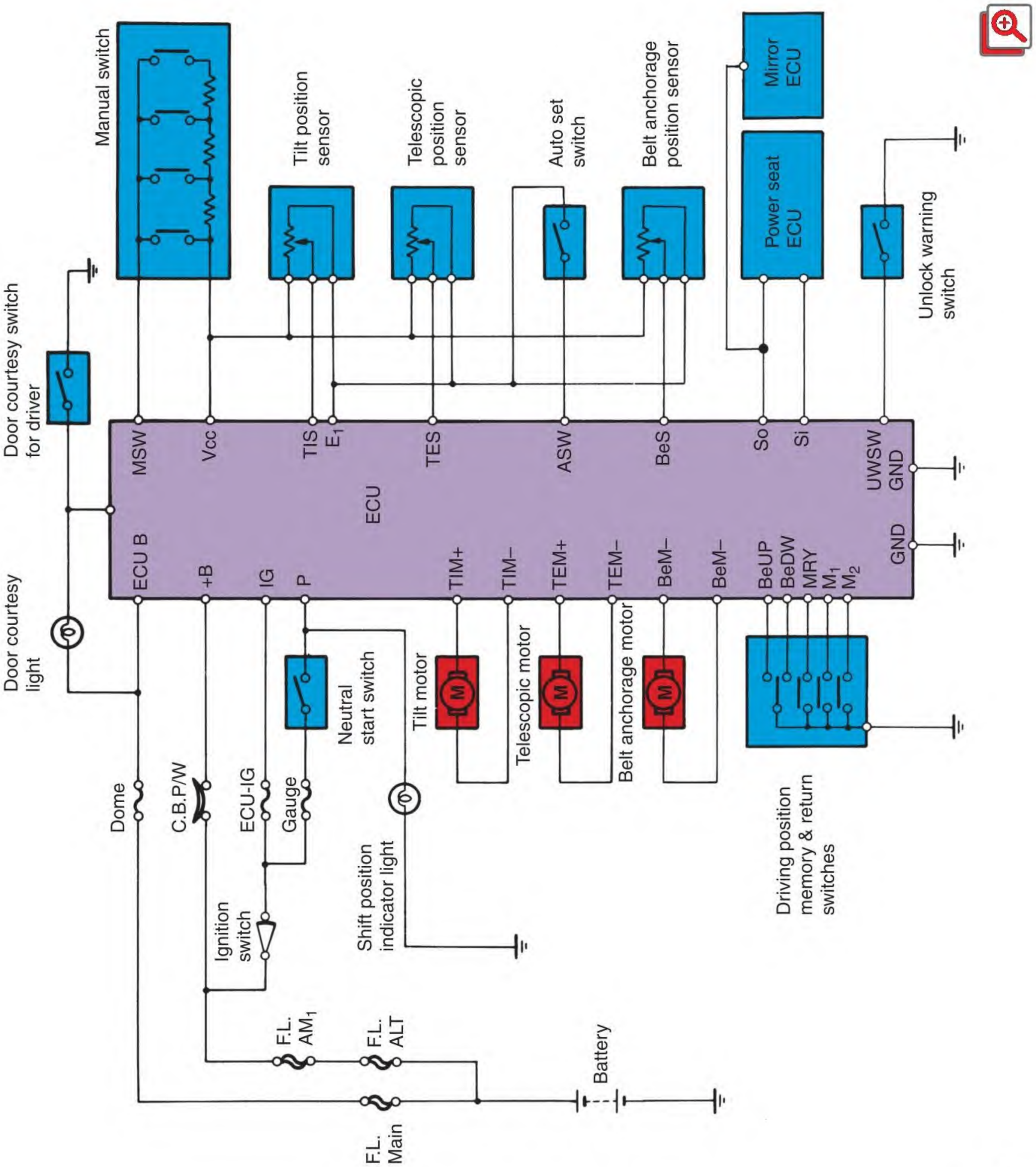
Some rear windows have ***zone clearing defoggers***, which heat and clear one area before another. Most have higher-resistance wire in the middle to heat and clear the center area of the glass first. They provide for more rapid rearview mirror use. Then, the rest of the window heats and clears.

A few vehicles use a blower or fan to defog and deice the rear window. Its operation is similar to a heater blower.

Window Defogger Service

When the grid-type rear window defogger does not work, check the fuse first. Then, check for adequate voltage going to the grid with the power switch closed.

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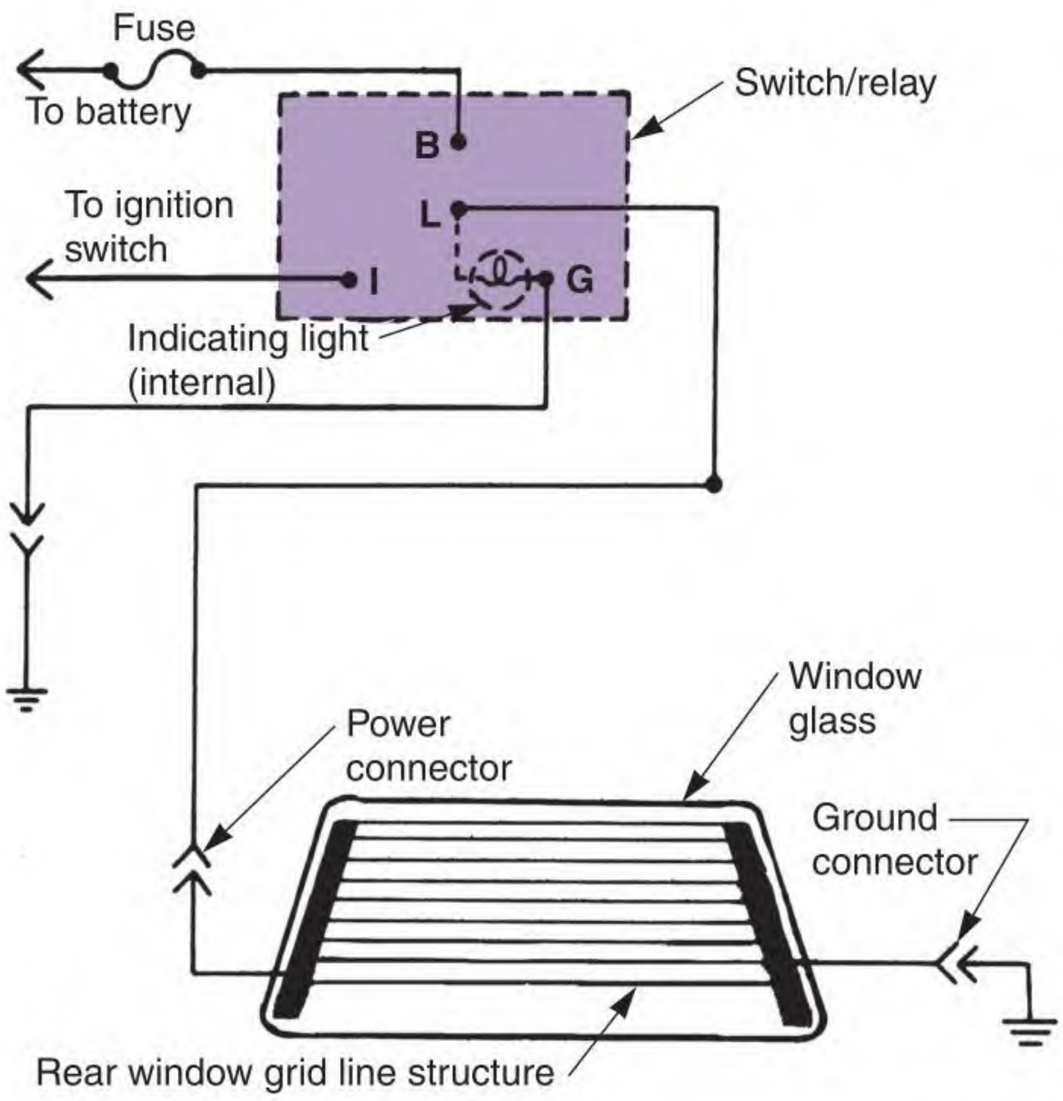


Subaru
Lexus

Figure 37-19. This wiring diagram shows how the ECU can control steering wheel tilt, telescoping action, and the seat belt anchoring motor. Note sensors and switches that feed data to the ECU. Also note the power seat ECU is also networked to this ECU.

If voltage is low at the grid input, test the circuit for opens. If power is being fed to the grid, the grid may be bad. Test the grid as described by the manufacturer. Some allow the repair of a broken heating grid using a special ***grid repair agent***, which conducts electricity.

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Chrysler

Figure 37-20. This is a circuit for a rear window defogger. When fed current through a switch and relay, the resistance wire on the glass heats up.

Heated Windshield

A ***heated windshield system*** uses a special conductive film sandwiched inside the windshield glass. The transparent film in the windshield glass is usually a zinc and tin oxide material. When high voltage (typically 70–90 volts) is passed through this clear conductive film, the glass heats up and melts ice or snow.

Most systems use a control module to full-field the alternator and bypass the rest of the electrical system so that enough energy is available to rapidly warm the windshield glass. The other electrical systems operate off of battery voltage when the windshield deicing system is turned on. If the system senses a low battery charge (below 11 volts), the system automatically shuts off to prevent excessive battery discharge.

Warning

Use caution when working on heated windshield systems. When turned on, there is enough voltage and current to cause a serious electrical shock. Electrocution could result from being shocked by this system's high power output!

Reminder System

A ***reminder system*** (warning system or chime system) makes an audible signal (buzz, chime, or audible warning) if:

- Seat belts are not fastened when the engine is started.
- Keys are left in the ignition with the engine off.
- The headlamps are left on with the engine off and a door is open.

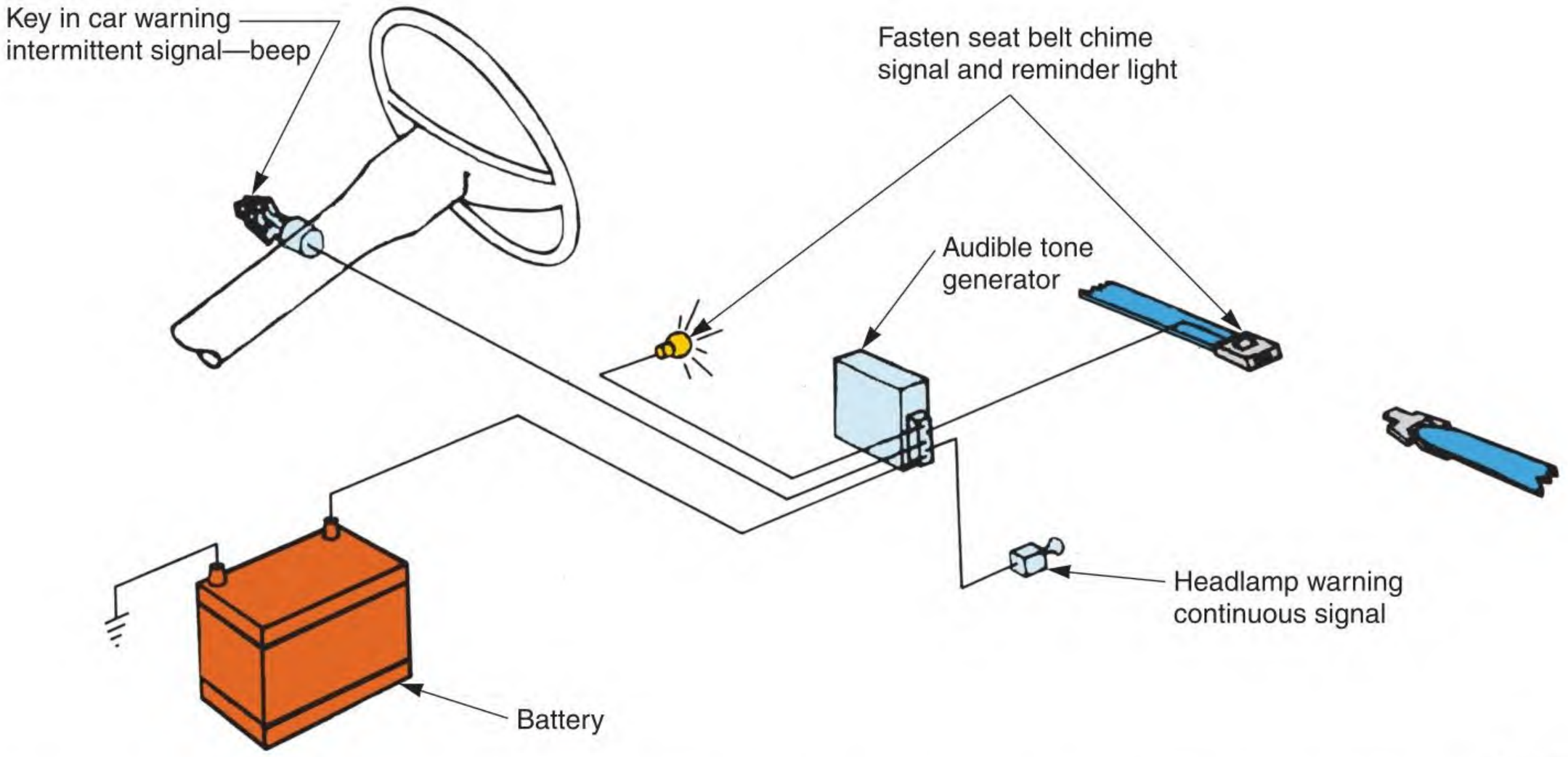
Refer to a service manual when troubleshooting and repairing a reminder system. Numerous design variations are used by different vehicle makers. An illustration of a basic reminder system is shown in **Figure 37-21**.

Cruise Control Systems

An electronic ***cruise control system*** uses a computer, sensors, and a throttle actuator to maintain vehicle speed for highway driving. See **Figure 37-22**.The major parts of a modern cruise control system include:

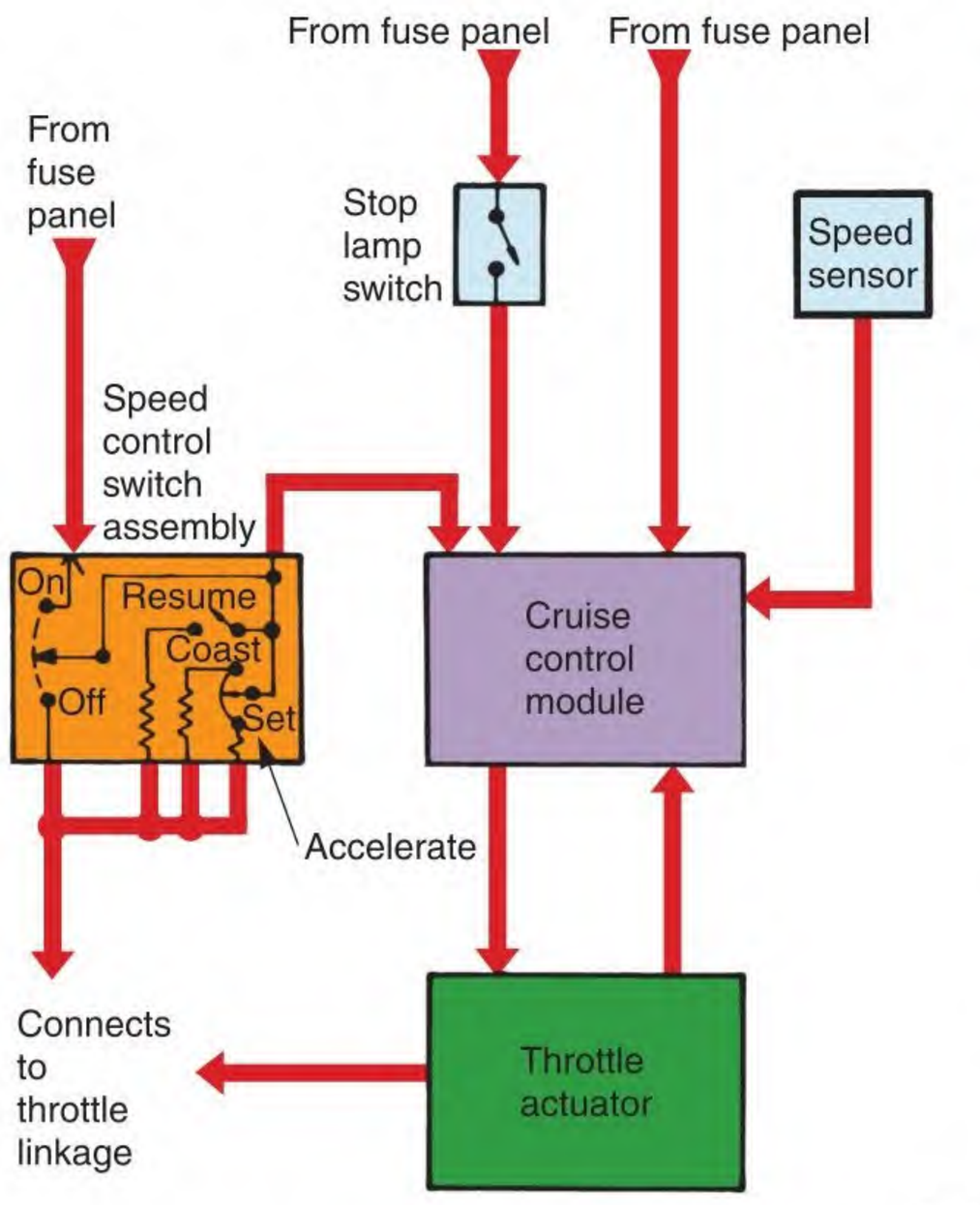
- ***Power switches***—Power switches feed current to computer to activate and ready the system for operation.
- ***Control switch***—The control switch signals the computer to maintain present vehicle speed.
- ***Vehicle speed sensor***—The vehicle speed sensor feeds a pulsing signal that represents velocity of the vehicle into the computer.
- ***Cruise control module***—The cruise control module uses input signals to control outputs to throttle actuator.
- ***Throttle actuator***—The throttle actuator physically moves the engine throttle lever to control engine power and resulting vehicle speed.
- ***Brake light switch***—The brake light switch signals the control module to shut off the cruise control when the brakes are applied.
- ***Clutch switch***—The clutch switch signals the control module to deactivate the cruise control when the clutch pedal is depressed.
- ***Neutral safety switch***—The neutral safety switch signals the control module to shut off the cruise when the shift lever is moved out of drive.
- ***Engine control module***—The engine control module analyzes switch and sensor signals to control the operation of the cruise control system.

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Chrysler

Figure 37-21. A warning or reminder system makes a sound when the key is left in the ignition, when seat belts are not fastened, and when lights are left on. Circuit in tone generator is the "heart" and "brain" of the system.



Ford

Figure 37-22. Layout of an electronic cruise control system. Speed sensors send electrical information to control module. The module can then operate the throttle actuator, which connects to the throttle linkage on the engine. Also note the circuit in the speed control switch.

Tech Tip

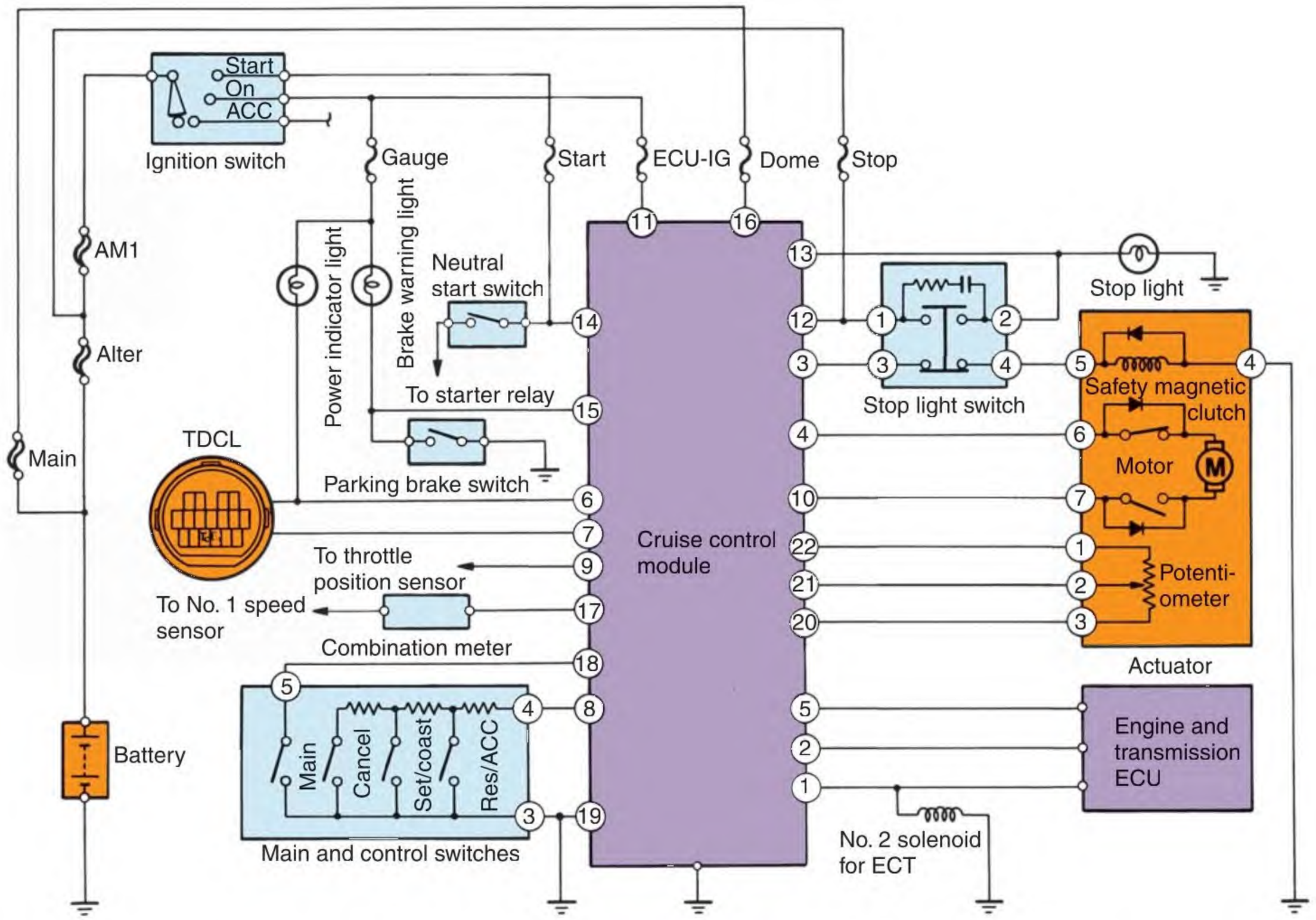
The industry trend is to combine the cruise control module circuitry into the engine control module. This allows the "drive-by-wire" accelerator pedal circuit to work in conjunction with the engine ECM to control engine speed and power output to maintain a preset highway cruising speed.

When cruise control system is activated using the power and control switches, the vehicle speed sensor feeds an ac signal to the cruise control module. The module's circuits use this signal to move the throttle actuator back and forth to maintain the same speed or vehicle sensor frequency, **Figure 37-23**.

The cruise control senses engine speed and controls the throttle valve opening on the engine. In this way, the driver can set the road speed of the vehicle and the cruise control system will maintain that speed.

For example, if the car starts to go up a hill, the vehicle speed will start to drop. The cruise control module will detect a slower frequency signal from the speed sensor. It can then move the throttle actuator for more engine power to keep the car traveling at the preset speed. The opposite occurs if the car starts down a hill.

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Lexus

Figure 37-23. Study the operation of a typical electric cruise control system. Note the various inputs (on left) to the cruise control module and how the module can then operate the actuator (on right), which acts on the engine throttle to control vehicle speed. The vehicle speed sensor signal allows the cruise control module to maintain required road speed.

When the driver presses on the brakes, the ***brake switch*** deactivates the system. The ***resume switch*** allows the driver to reset the same cruising speed when desired.

Cruise Control System Service

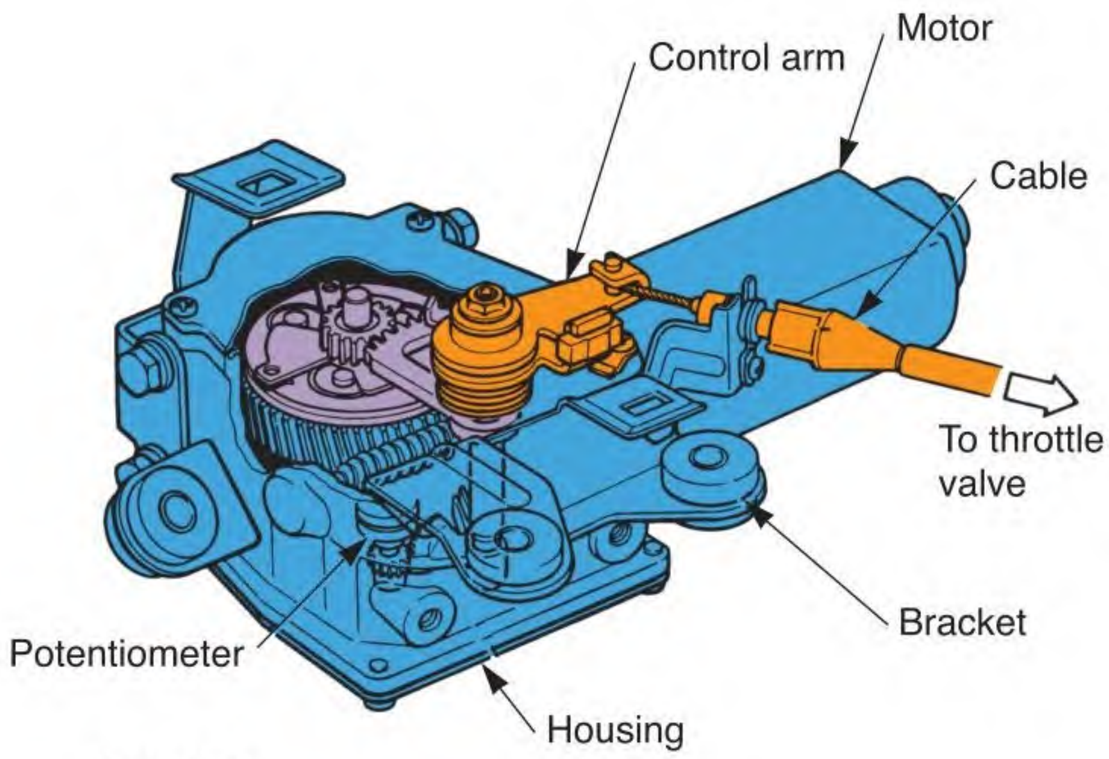
Since cruise control system designs vary so much, only general service methods can be given. Refer to a service manual for details.

If the cruise control will not work at all, check the fuse and power feed wires to the system. Do not forget the simple things. For example, if a brake light switch is shorted on all the time, the cruise control will not engage. The on and resume switches can also wear and fail. Test all simple things before suspecting the control module or actuator.

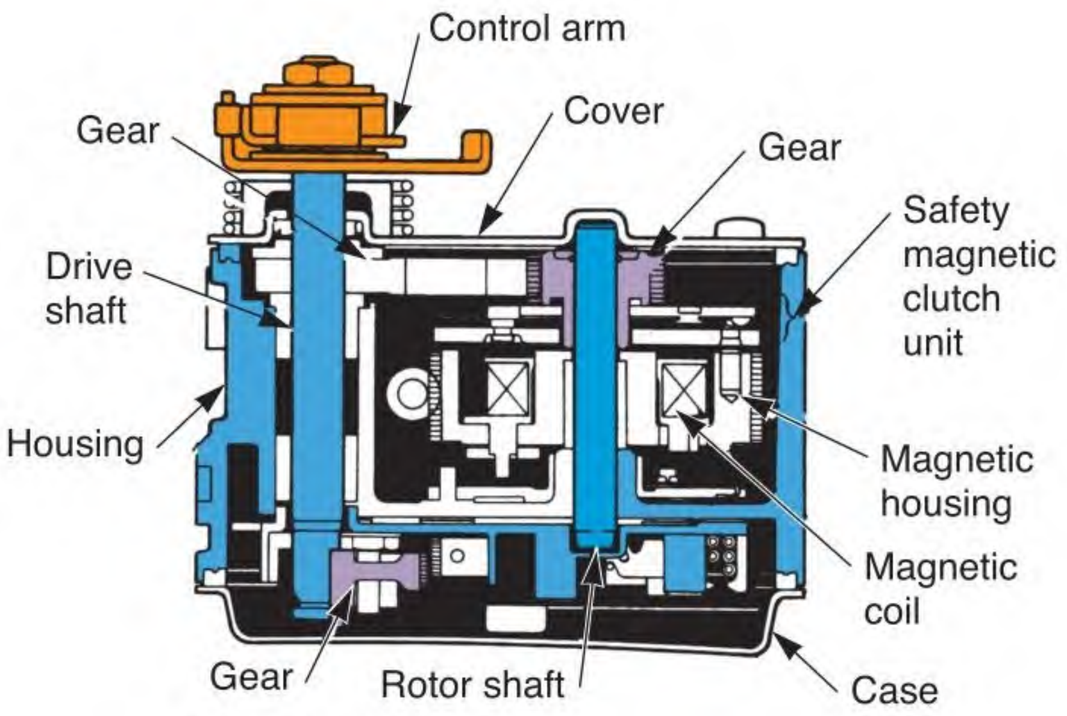
Figure 37-24 shows a cutaway of a motor-type throttle actuator. It uses a small dc motor and gearbox to move the throttle linkage. Check the motor for normal operation by connecting power to its windings. On older vehicles, the gears may be worn or stripped.

Some systems use a vacuum-type throttle actuator. If the system has a vacuum actuator, check all vacuum lines for leaks. Use a piece of vacuum hose to listen for the "hissing sound" of a vacuum leak. To check actuator operation, use a hand pump to apply vacuum to the actuator diaphragm assembly. The diaphragm may rupture and leak after prolonged use. Any solenoid valves that control vacuum can also be tested using basic methods.

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Actuator



Cross Section

Lexus

Figure 37-24. Cutaway view shows an electric motor-operated cruise control actuator. A reversible dc motor turns the worm gear. The larger driven gear has a lever that can pull or release a cable going to the engine throttle valve. The ECU can then spin the motor in the needed direction to maintain the desired road speed.

Warning

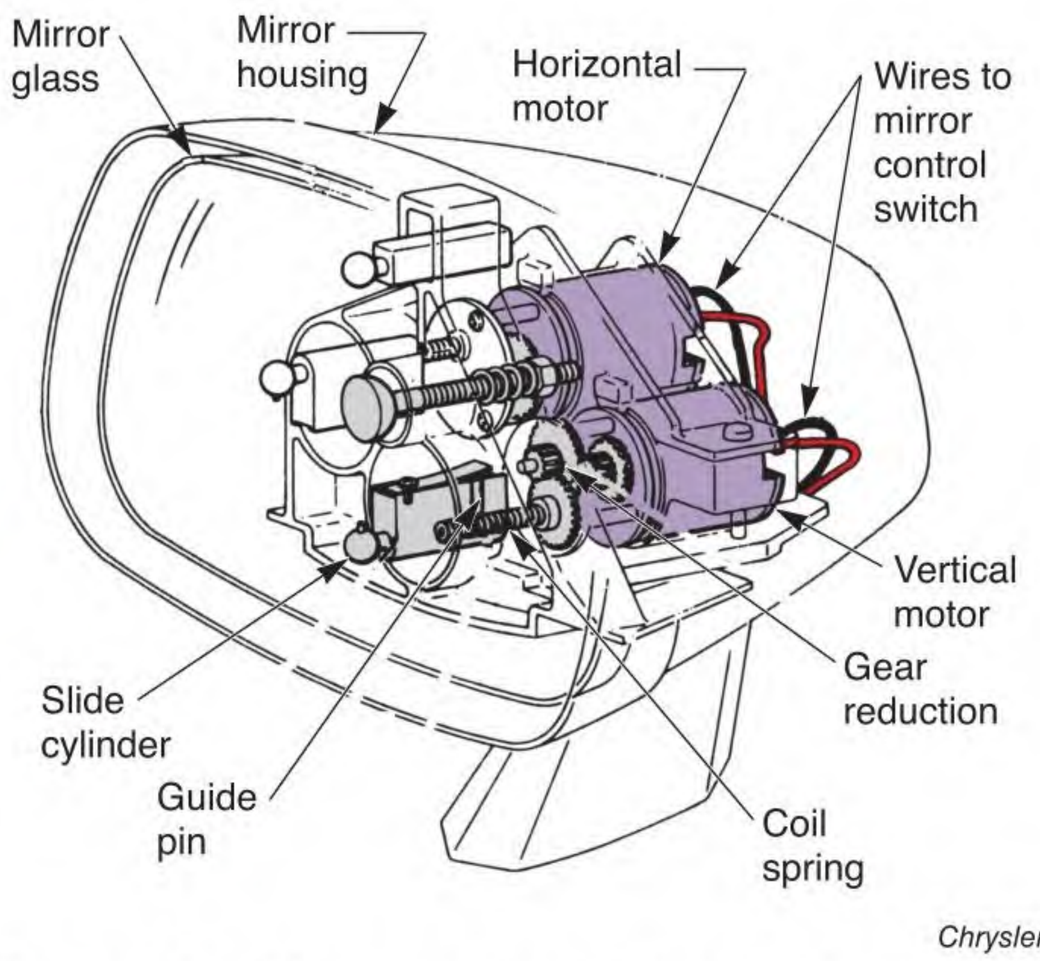
Use only recommended high-impedance testing instruments and factory-recommended procedures when servicing a cruise control system. If you do something wrong and the cruise control will not disengage or not hold the correct speed, it could cause an accident. People could be killed by your mistake!

Power Mirrors

Power mirrors commonly use tiny reversible electric motors to tilt the sideview mirror glass into different positions. A multiposition "joy switch" is normally used to energize each mirror motor. The mirror motors often operate a screw mechanism that can push or pull on the backside of the mirror glass, **Figure 37-25**.

Basic testing methods can be used to troubleshoot a power mirror system. If neither mirror works, check the fuse and power supply circuit. If only one mirror fails to adjust, check its switch and motors. Usually, you will have to remove the door panel to test the switch, wiring, and motors.

A heat gun is often used to warm and remove the rearview mirror glass if cracked or if the motors can be replaced. Many manufacturers recommend replacement of the whole power mirror assembly if anything is wrong with it.



Chrysler

Figure 37-25. This power mirror uses tiny dc motors that drive screw mechanisms to adjust the rearview mirror angle. It is often serviced as a complete assembly and internal repairs are not done.

Driver Information Center

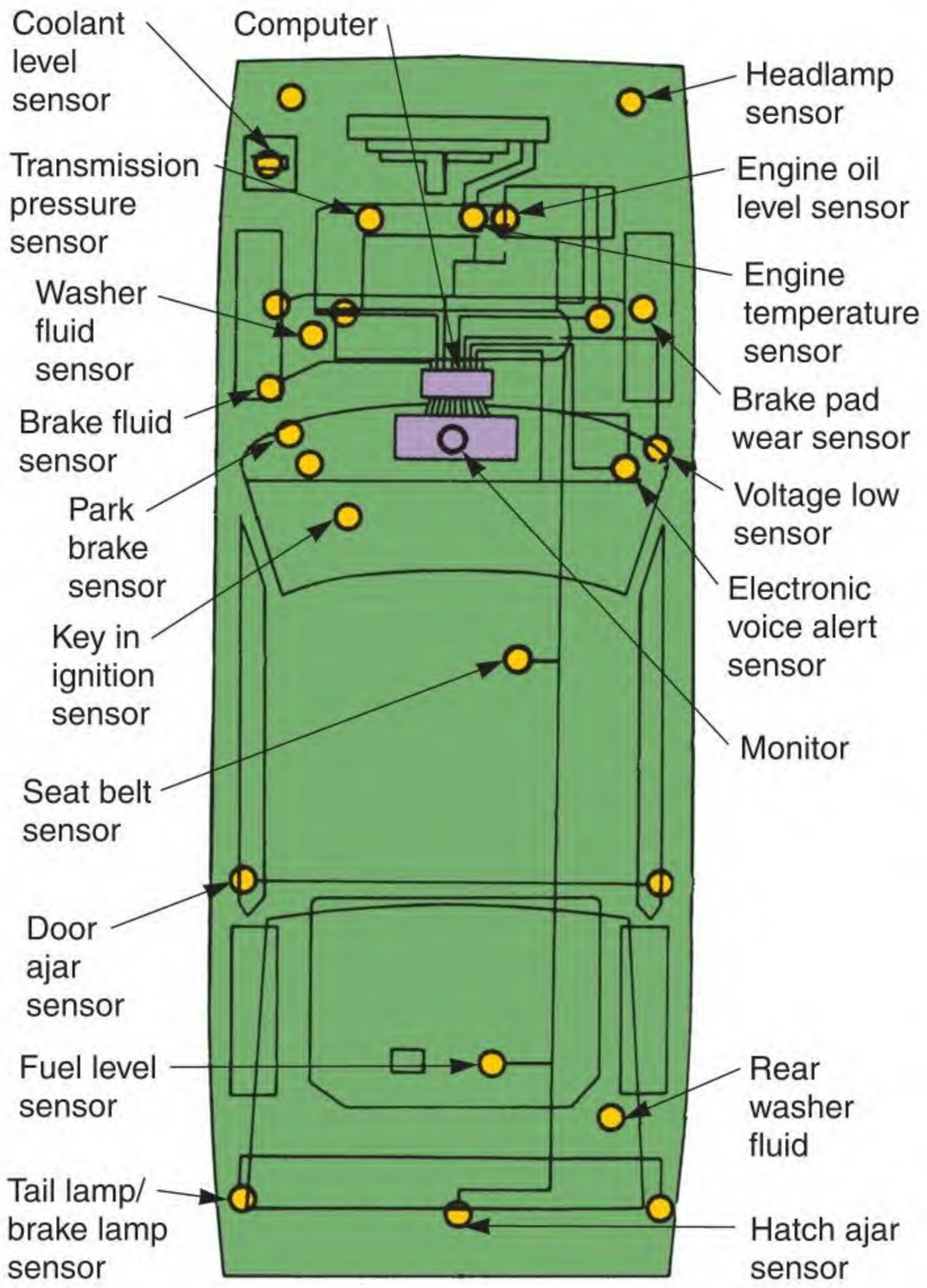
A ***driver information center*** uses a computer, a small speaker or digital display, and numerous sensors and switches to inform the driver of various conditions. The computer is programmed to output a visual display or an audible warning when a specific sensor detects a

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bad condition. This might include displaying—or even saying—your washer fluid is low, check your brake fluid, your door is ajar, and similar messages.

Figure 37-26 shows the major parts of a driver information center. Note the numerous sensors that monitor vehicle conditions so the computer can display information.

Figure 37-27 is a basic wiring diagram for a vehicle monitoring system. It is also capable of relaying audio messages stored in computer memory.



Goodheart-Willcox Publisher

Figure 37-26. Top view of car shows general locations of components in this driver information center. A keyboard is often provided so driver can request information. An on-board computer can then use sensor data to calculate answer to be displayed on the monitor or display window.

Vehicle Degaussing

Magnetic fields sometimes build up around a vehicle's body structure. This can be caused by magnetic antenna mounts, large aftermarket amplifiers, repeatedly driving next to high-voltage power lines, hybrid voltage levels, and parking a car under power lines or large transformers. If the vehicle's steel body becomes highly magnetized, problems can occur with the electronic compass and other devices that are sensitive to magnetic fields.

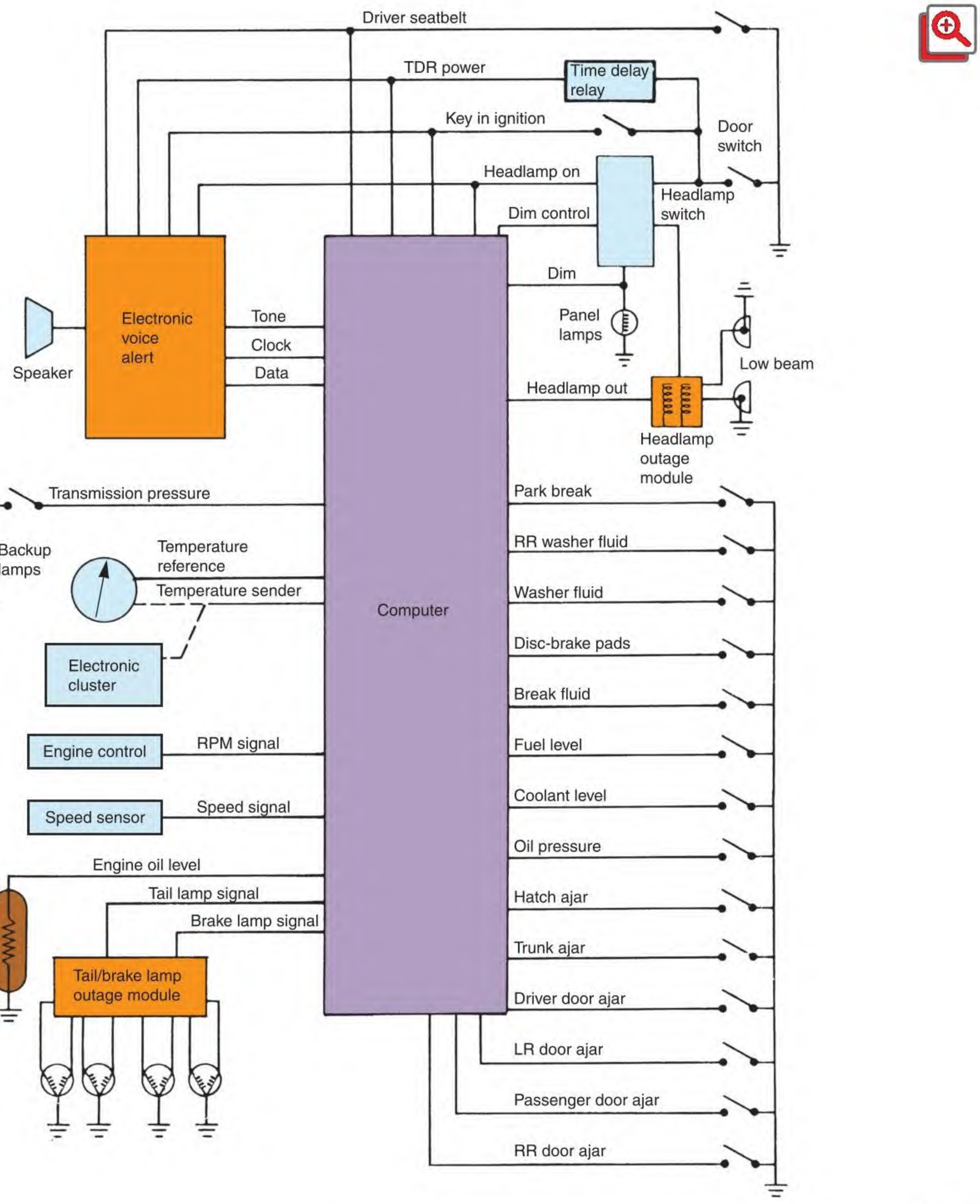
Vehicle degaussing, or ***vehicle demagnetizing***, involves using a demagnetizing tool to remove a magnetic field built up around a vehicle's body. During use, the demagnetizing tool can be pulled toward the steel body with considerable force. If the demagnetizer snaps down against the body, it may scratch the paint or dent the body panel. Before using the demagnetizing tool, place a shop cloth or a large fender cover on the roof or body panels to protect them from damage.

Caution

Never activate a demagnetizing tool near any type of magnetic media, such as computer hard drives, video tapes, audio tapes, digital music devices, or memory chips. A demagnetizing tool will instantly erase all stored information from these devices.

To use the demagnetizing tool, stand several feet from the vehicle and turn on the tool's magnetic coil. Walk toward the vehicle and hold the tool about 1″ (25.4 mm) from the roof panel. Move the demagnetizer in a circular pattern over the roof panel several times. When you have finished, lift the tool straight up from the roof panel and move several feet away from the vehicle before turning off the tool. If needed, the hood and trunk areas can also be demagnetized using the same pattern as the roof panel. After demagnetizing the vehicle, recalibrate the compass if needed and reinstall any devices removed from the vehicle.

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Chrysler

Figure 37-27. This simplified wiring diagram shows how the ECU processes inputs and produces outputs for driver information system. Note the speaker at upper left. With this system, your car will actually talk to you to inform you of many operating conditions or possible problems, such as low fluid levels, fluid change needed, parking brake on, door ajar, and low oil pressure.

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Diagnostic Case Study

Concern: Mr. Davis brings in his 2012 Lexus because his passenger-side power window has stopped working.

Cause: Duff asks if the other windows in the vehicle work properly. Mr. Davis says that all the other windows work. Since only one power window does not work, Duff knows that the main fuse is not blown. Duff assigns the task to one of the shop's general repair technicians.

The technician removes the necessary interior trim to expose the switch terminals. He touches a test light to the switch terminals for the passenger-side window. The test light illuminates at both output terminals when the switch is moved to the appropriate position. This indicates that current is flowing through the switch and into the wires going to the window motor.

The technician then removes the door panel and touches the test light on the feed wires at motor. Again, the test light illuminates when the switch is moved to the proper positions. Current is getting to the motor, but the motor is still not working. The technician attaches a jumper wire from the motor's ground wire to another ground. With power applied, the motor still does not work. This is an indication that the motor itself is faulty.

Correction: The technician removes the old power window motor from the door. He obtains a used motor from a salvage yard and bench-tests it. The new motor tests good, and the technician installs it in the car. He makes sure the window is operating properly and then replaces the door panel and interior trim pieces. Finally, he releases the car to the customer.

Summary

- A basic radio system consists of an antenna, radio (receiver-amplifier), speaker(s), and power supply circuit.
- An AM radio is designed to pick up a radio signal that varies in amplitude (strength).
- An FM radio is designed to receive a radio signal that varies in frequency (fluctuating speed).
- A digital radio uses analog signals that are compressed and digitized so more programming can be broadcast in a given spectrum.
- Satellite radio operates off a radio (electromagnetic) transmitter that orbits about 22,000 miles (35,000 km) above Earth.
- Just because the lights in the stereo are working does not mean the radio circuitry is getting power.
- If you suspect a bad antenna (no signal coming from antenna lead), connect a known good antenna to the radio.
- A faulty speaker will usually distort the sound of the radio. Sometimes, a power booster is added to the sound system to increase volume without sound distortion.
- Radio noise is undesired interference or static (popping, clicking, or crackling) obstructing the normal sound of the radio station.
- Power seats use several switches, electric motors, and drive assemblies to change the front seat positions.
- Memory seats use a small computer, or ECU, which can be programmed to remember seat positions for several people.
- A power window basically uses a control switch, reversible electric motor, circuit breaker, fuse, and related wiring to operate the door windows.
- Power door locks typically use an electric switch and a solenoid or motor to operate the door lock mechanisms.
- A power steering wheel uses an ECU, various switches, sensors, and motors to automatically tilt and telescope (extend or retract) the steering wheel.
- A rear window defogger, also called a rear window defroster, commonly uses a switch, relay, indicating light, and window heating grid.
- A heated windshield system uses a special conductive film sandwiched inside the windshield glass.
- An electronic cruise control system uses a computer, sensors, and a throttle actuator to maintain vehicle speed when highway driving.
- Power mirrors commonly use tiny reversible electric motors to tilt the side view mirror glass into different positions.

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- A driver information center uses computer, a small speaker or digital display, and numerous sensors and switches to inform the driver of various conditions.
- Vehicle degaussing, or vehicle demagnetizing, involves using a demagnetizing tool to remove a magnetic field built up around a vehicle's body.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

AM radio
antenna
auxiliary audio input
brake light switch
brake switch
CD players
clutch switch
compact disc players
control switch
cruise control module
cruise control system
digital audio player
digital radio
digital video disc (DVD) player
distortion
driver information center
engine control module
FM radio
gearbox
grid repair agent
heated seats
heated windshield system
mast
memory seats
neutral safety switch
noise suppressors
power antenna
power booster
power door locks
power mirrors
power seat module
power seats
power steering wheel
power switches
power trunk release
power window
power window motor
radio
radio frequencies
radio noise
radio station
radio system
rear window defogger
rear window defroster
reminder system
resume switch
satellite radio
sound system
speaker
steering wheel touch controls
stereo amplifier
thermal runaway
throttle actuator
transmission
tuner
vehicle degaussing
vehicle demagnetizing
vehicle speed sensor
window regulator
zone clearing defoggers

Activities

1. Use a car radio to "hunt" for radio stations broadcasting from other communities, on both the AM and FM bands. Note the call letters and towns, and then mark them on a map. Check the distance the farthest signal traveled. Was it AM or FM?
2. Take a survey among students at your school to determine which vehicle music system options are most popular. Determine how many student cars have just radios, satellite radios, radios with CD changer/players, etc. Make a bar graph to show your results.

Review Questions

Answer the following questions using the information provided in this chapter.

1. What are the parts of a basic radio system?
2. Explain the difference between AM and FM signals.
3. A customer complains that one of the speakers in his vehicle's sound system is not working. Technician A says that the radio is faulty and must be replaced. Technician B says that the inoperative speaker should be checked before condemning the radio. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. A(n) _____ uses a permanent magnet and coil of wire mounted on a flexible diaphragm.
5. What are some of the symptoms of a faulty speaker?
6. Why are noise suppressors used?
7. If one power window fails to go up and down, check the circuit fuse first. True or False?

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8. When a power window switch is pressed, a whirring sound can be heard from inside the door. Technician A says that the motor windings are open and the motor is bad. Technician B states that the power window gearbox might have stripped plastic gear teeth. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. How does a heated windshield system work?
10. Explain the operation of a cruise control system.

ASE-Type Questions

1. Technician A says an AM radio is designed to pick up a radio signal that varies in amplitude. Technician B says an AM radio is designed to pick up a radio signal that varies in frequency. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Technician A says an FM radio has a longer broadcasting range than an AM radio. Technician B says an AM radio has a longer broadcasting range than an FM radio. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. Technician A says an AM radio is designed to pick a signal that varies in frequency. Technician B says an FM radio is capable of producing stereophonic sound. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. Technician A says that the circuits feeding power should be considered when troubleshooting an automotive radio system. Technician B says a receiver-amplifier is a basic circuit inside a radio. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. Satellite radio is being discussed. Technician A says that a satellite radio system allows a vehicle's occupants to listen to the same station when traveling across the country without losing reception. Technician B says satellite programming is found between analog FM stations. Technician B says an AM car radio normally has one speaker mounted in the top of the dash. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Technician A says a power booster is added to some sound systems to increase volume without sound distortion. Technician B says that systems without a power booster may go into thermal runaway when the stereo is played at high volumes. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. A car's power antenna is inoperative. Technician A checks for vacuum leaks, which may affect the antenna's operation. Technician B checks the antenna's motor and electrical circuit. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. Which of the following can cause radio noise?
   (A) Bad alternator diodes.
   (B) Open spark plug wire.
   (C) Bad noise suppressor.
   (D) All of the above.
9. An automobile's radio is producing "radio noise." Technician A checks the radio's antenna. Technician B looks for a bad spark plug wire. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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10. Technician A says an automotive "noise suppressor" can be mounted inside the car's alternator. Technician B says an automotive "noise suppressor" can be mounted on the car's ignition coil. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
11. One of the power seats in an automobile is not operating. Technician A tests the seat's electrical switch. Technician B checks the operation of the seat's electrical motor. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
12. One of an automobile's power windows is not working. Technician A checks the operation of the window's electric motor. Technician B checks for a blown fuse at the car's fuse box. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
13. All of an automobile's power door locks are inoperative. Technician A looks for a blown fuse at the fuse box. Technician B checks for a faulty solenoid in the left-rear door panel. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
14. One of a car's door panels must be removed. Technician A removes the window crank handle. Technician B removes the armrest screws. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
15. A car's rear window defogger is malfunctioning. Technician A tests the operation of the defogger's "heating grid." Technician B checks the defogger's electrical switch. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Sound System Diagnosis		
Condition	**Possible Causes**	**Correction**
Nothing works.	1. Blown fuse. 2. Bad switch. 3. Broken feed wire. 4. Broken ground wire. 5. Bad radio.	1. Replace fuse. 2. Replace switch. 3. Repair wire. 4. Repair wire. 5. Send out for service.
Radio powers up, static or no sound.	1. Poor antenna connection. 2. Misadjusted trim screw. 3. Disconnected speakers. 4. Bad radio.	1. Repair antenna. 2. Adjust antenna trim screw. 3. Fix wiring. 4. Send out for service.
Distorted sound from speakers.	1. Blown speakers. 2. Loose speaker mounting. 3. Speaker polarity reversed. 4. Incorrect speaker ohms. 5. Bad radio.	1. Replace speakers. 2. Tighten fasteners. 3. Reverse wires to speaker. 4. Match speaker resistance to radio. 5. Send out for service.
Poor reception.	1. Poor antenna connection. 2. Misadjusted trim screw. 3. Bad radio.	1. Repair antenna. 2. Adjust trim screw. 3. Send out for service.
Popping or clicking noise in speakers.	1. Radio interference. 2. Bad antenna. 3. Bad spark plug wires. 4. Missing ground straps.	1. Replace noise suppressors. 2. Replace antenna. 3. Replace spark plug wires. 4. Install ground straps.

Power Accessory Diagnosis		
Condition	**Possible Causes**	**Correction**
Nothing works.	1. Blown fuse. 2. Open switch. 3. No power to circuit.	1. Replace fuse. 2. Replace switch. 3. Repair feed wire.
Intermittent problem.	1. Loose wires. 2. Bad switch.	1. Repair wiring. 2. Replace switch.

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Chapter 38
Security and Navigation Systems

After studying this chapter, you will be able to:

- Explain the operation of vehicle security systems.
- Explain the operation of vehicle navigation systems.
- Compare security system design variations.
- Service vehicle security and navigation systems.

This chapter will introduce the major components and circuits of typical security and navigation systems. Many systems are now networked. They possess video and audio capabilities that display and speak street names and directions on the way to the destination. This allows the driver to better navigate streets and highways. Some will even help the police track and find the exact location of stolen or missing vehicles using global positioning and satellite technology. Refer to **Figure 38-1**.

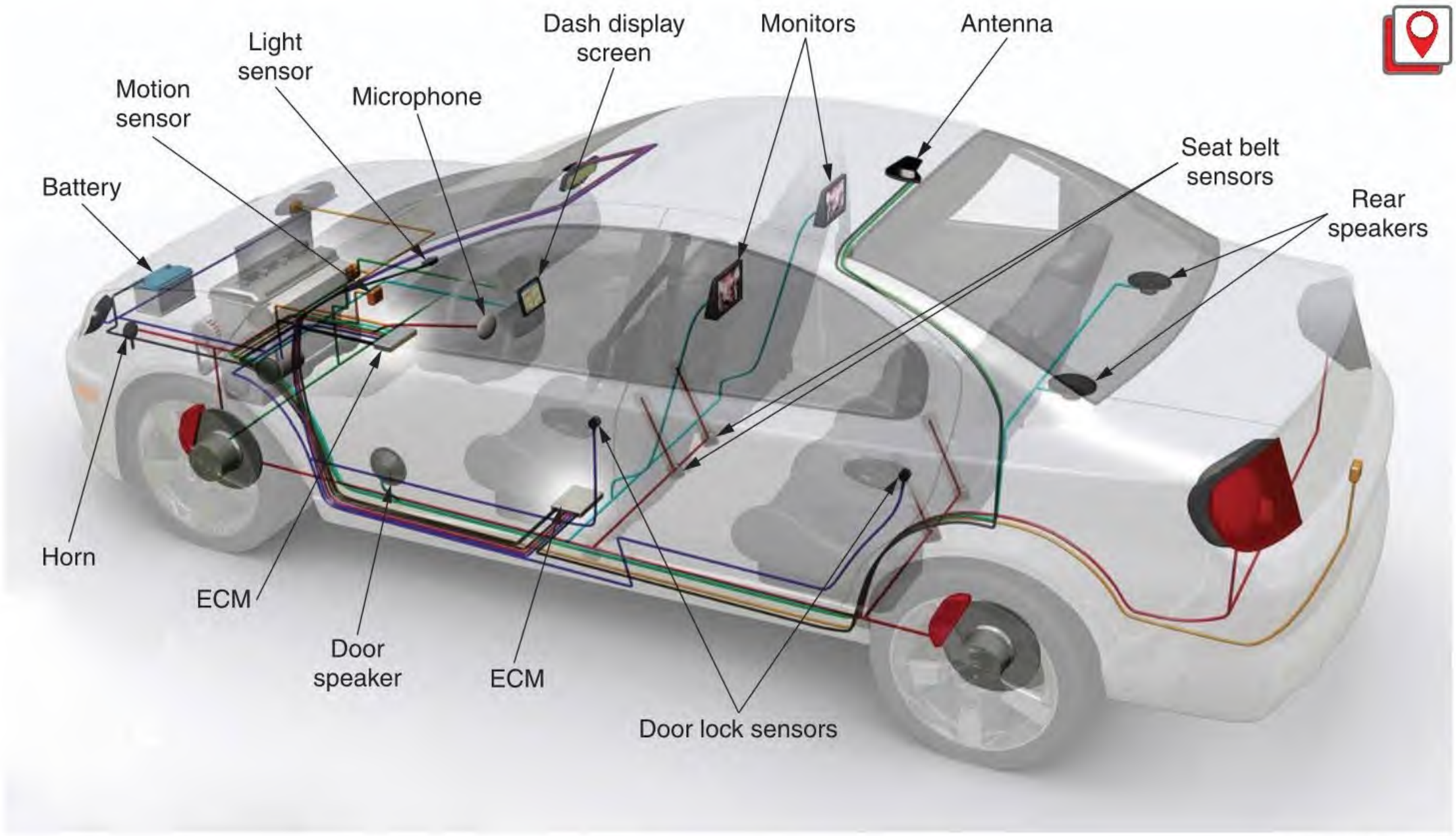
Security Systems

A ***security system*** is designed to help prevent the theft of a vehicle and its contents. A security system basically uses motion sensors and switches to feed signals to an electronic control module. The control unit can then lock the vehicle and operate a warning siren or horn if someone tampers with the vehicle. Some systems also disable the starting system and engine to prevent the vehicle from being started.

A remote transmitter or a dash-mounted keyboard is used to activate and deactivate the system. Much like a garage door opener, the transmitter produces a radio signal of a specific frequency. A receiver circuit responds to this signal and triggers the control module to perform various tasks, such as turning the system on or off, unlocking the doors, sounding the siren, etc.

Security system designs vary tremendously. This is done so thieves are not able to learn about the operation of any one system too well. For this reason, you should refer to the schematic and technical literature from the manufacturer of the security system. It will give the details for doing competent service and repair work.

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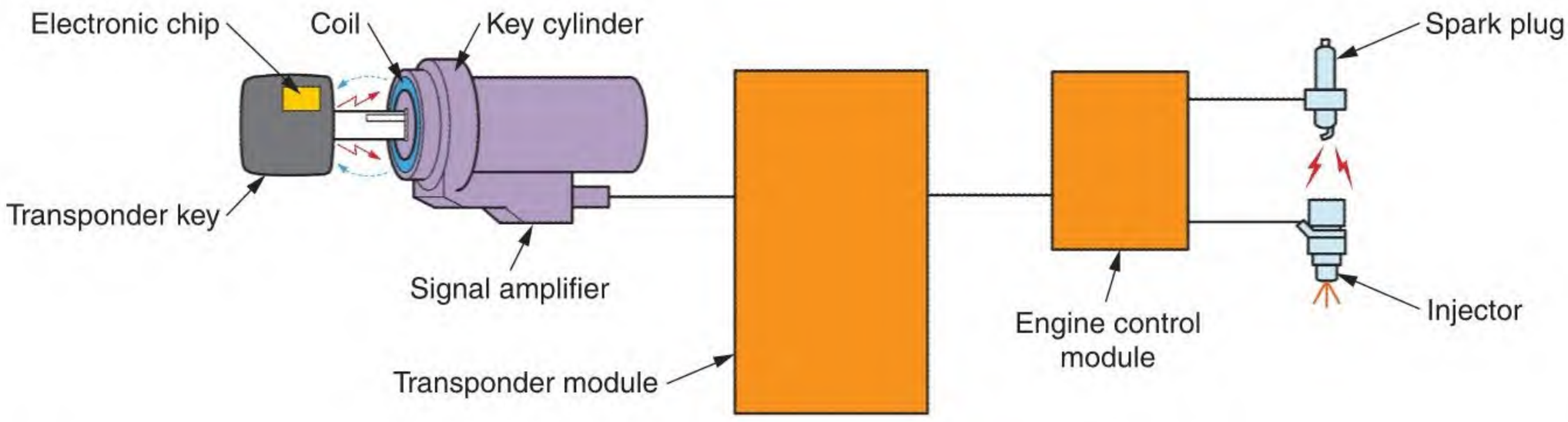
Figure 38-1. Many new cars come equipped with security and navigation systems. To service these systems, you must know how they work.

Transponder Key

Many late-model anti-theft systems use a ***transponder key*** that contains an electronic chip. This type of key is designed to prevent thieves with a knowledge of electronics from overriding the security system. Look at **Figure 38-2**.

Each time the transponder key is inserted into the key cylinder, a coil in the cylinder produces an electromagnetic field that excites the transponder chip. This causes the chip to generate a coded signal, which is amplified and sent to the transponder module.

If the transponder module recognizes the signal produced by the chip, it will allow the engine to be started. If the module does not recognize the chip's signal, it disables the starting and engine support systems so the vehicle cannot be driven.



Toyota

Figure 38-2. A transponder key contains a small electronic chip that produces a coded signal. The signal is amplified and sent to the transponder module. The module then determines if the correct key is being used to start the vehicle.

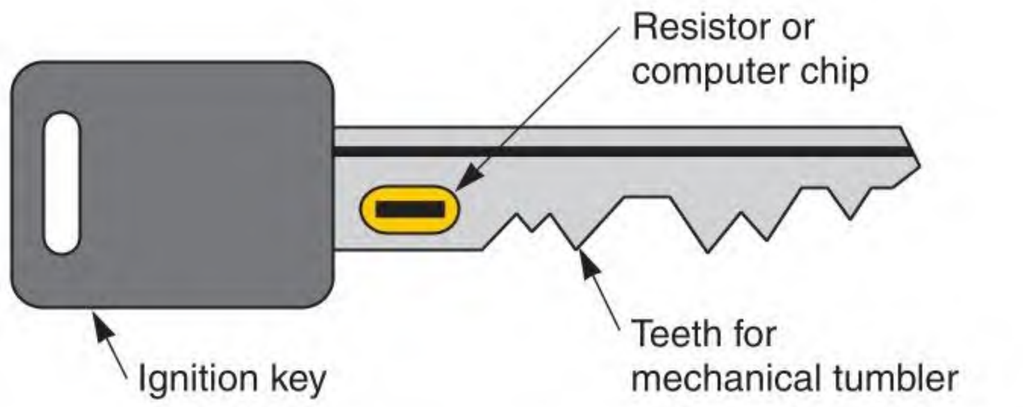
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Resistance Key

Some theft deterrent systems use a ***resistance key***, which is an ignition key with a small electrical resistor mounted on its side. Several key resistance values are available. The resistor has small electrical connections on the sides, **Figure 38-3**. The key's metal teeth and the built-in resistor must match the vehicle to break security.

The ECM reads the resistance of the key to make sure it is not an unauthorized duplicate of only the metal teeth of the key. If the key resistance matches the one programmed into the control module, the vehicle starts normally.

However, if the key's resistance is not correct, the control module opens the starter relay circuit so the engine will not crank. The control module may also disable the engine support systems.



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Figure 38-3. A resistance key has a small electrical resistance element built into a hole in the key. It engages contacts in the tumbler when inserted. This allows the vehicle computer to determine whether the correct key has been inserted.

Tech Tip

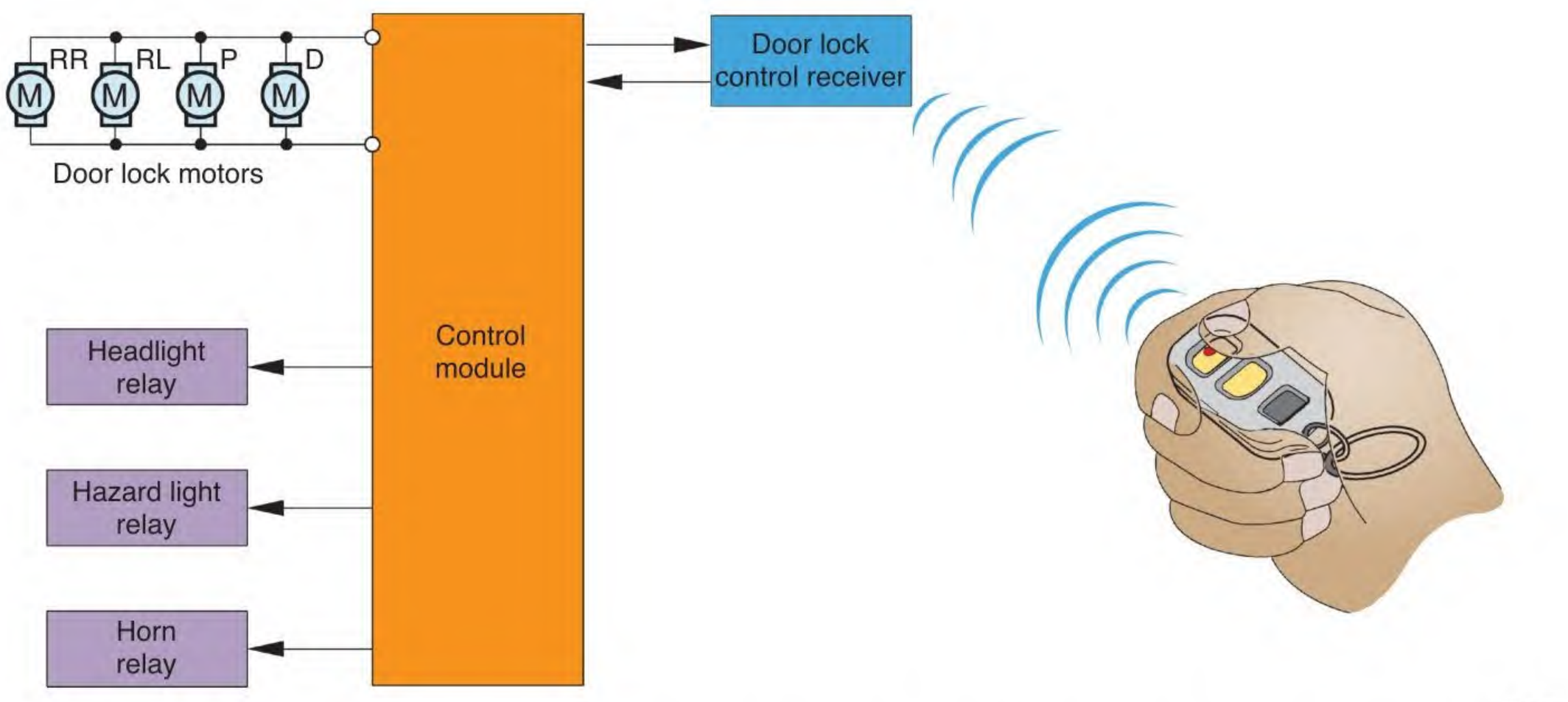
Resistance and transponder keys cannot be duplicated at your average hardware store or locksmith. You must usually contact the manufacturer to get service parts and codes.

Keyless Entry Systems

A ***keyless entry system*** allows the driver to unlock a vehicle's doors without using a key. There are two basic types of keyless entry systems: remote keyless entry systems and keypad-type keyless entry systems.

A remote keyless entry system uses a key fob that contains a small transmitter. When the driver pushes the button on the key fob to lock or unlock the doors, a corresponding signal is sent to a receiver located in the vehicle, **Figure 38-4.** The receiver then signals the lock module to activate the door lock motors, locking or unlocking the doors. Many keyless entry systems can also be used to unlock the trunk or power lift gate.

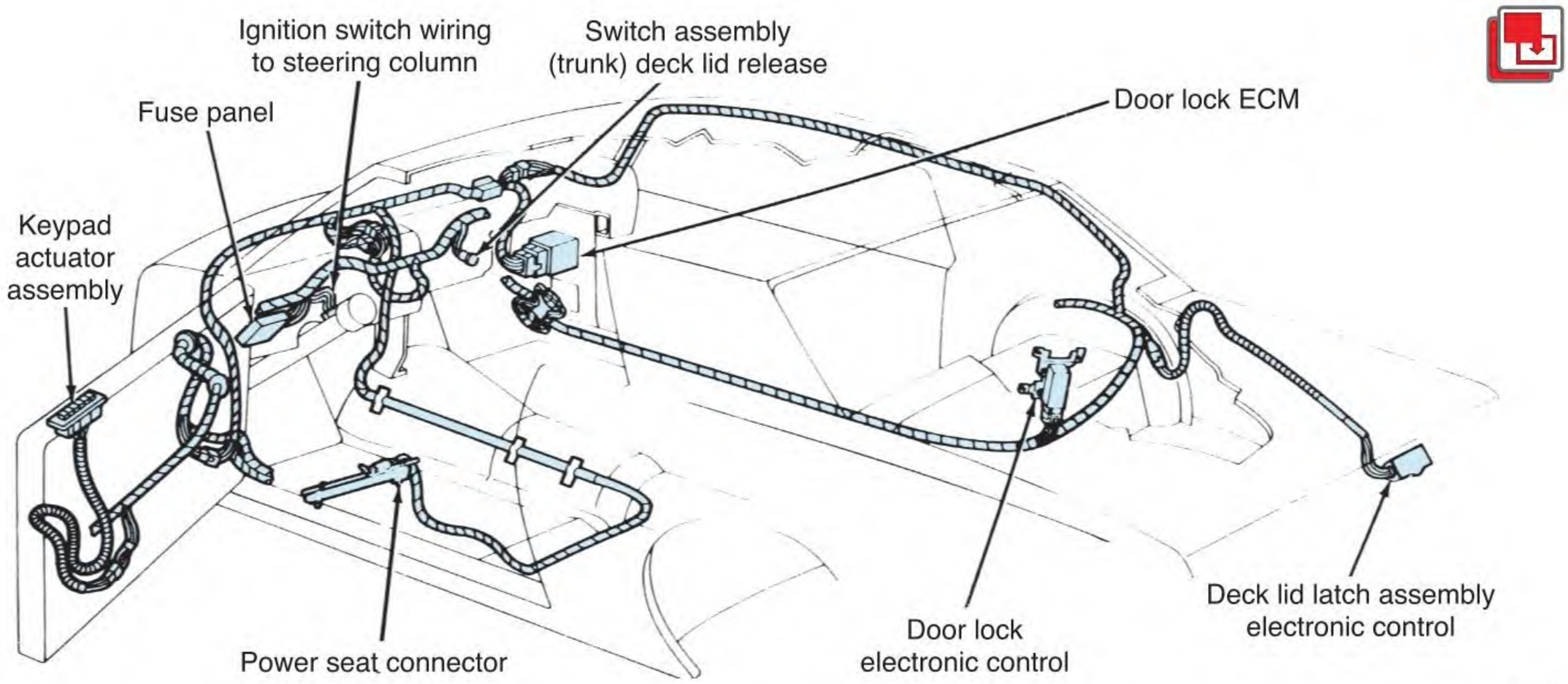
In keypad-type keyless entry systems, **Figure 38-5**, the keypad is mounted in the door and usually has five numbers. Pressing the numbers in the correct sequence will send a valid code to the module to unlock the doors. If the wrong number sequence is used, the module will ignore the electrical signals from



Toyota

Figure 38-4. A remote keyless entry system allows the driver to lock and unlock the vehicle's doors by simply pressing a button on a key fob.

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Ford

Figure 38-5. A keyless entry system has a keypad on the outside of the door. When the number buttons are pressed, electrical signals are sent to the processor. If a correct number sequence is pressed, the processor will send current to the door solenoids to unlock the doors. A keypad and processor can also be used to unlock the trunk and other doors.

the keypad and keep the doors locked. The module sends current to the door solenoids only when the keypad is pressed in the right sequence.

Smart Key Systems

Some late-model vehicles are equipped with ***smart key systems***. These systems allow the driver to lock and unlock doors, open the trunk, and start the engine without inserting a key or pushing buttons on a key fob. The smart key system uses proximity sensors that send signals to a control module whenever the key fob is nearby. Some systems automatically unlock the doors when the proximity sensors detect the key fob within a few feet of the vehicle and lock them again when the key fob is moved away from the vehicle. In other systems, the driver must touch one of the front door handles to unlock or lock the doors.

Most smart key systems use a push-button ignition switch rather than a keyed ignition switch. When the proximity sensors determine that the key fob is *inside* the passenger compartment, they prompt the module to allow the vehicle to be started. The driver can then start the vehicle's engine by simply pressing the start button.

Navigation Systems

Navigation systems use our nation's satellite global positioning system to display the geographic location of the vehicle. A dash display shows a road map with the position of the vehicle on it. Advanced systems can give other useful information: traffic information, roadwork, parking lot openings, miles to destination, turnoffs, etc. See **Figure 38-6**.

Basically, the navigation system communicates with the satellite system to determine vehicle direction and speed. The vehicle's on-board computer compares this data with a large database of roads and highways, usually from a compact disc. Look at **Figure 38-7**.

A road map of the area with a representation of the vehicle's location can then be shown on the dash display. This helps the driver navigate highways and roads more efficiently. Besides visually helping the driver navigate, some systems also use verbal output to help the driver. Refer to **Figure 38-8**.

Global Positioning System (GPS)

A ***global positioning system (GPS)*** uses a series of earth-orbiting satellites to communicate through a vehicle's antenna. Also called a ***global navigation satellite system***, or GNSS, it can provide location and time information anywhere near the earth's surface.

Using a GPS, a vehicle receives electromagnetic signals from orbiting satellites through its GPS antenna. This allows the vehicle's navigation systems to pull up maps showing vehicle location (street

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A



B

Siemens and Acura

Figure 38-6. Study the location and information displayed on display screens. A—Display screens are often mounted in the center of the dash or in the instrument cluster of modern vehicles. B—A display screen, like a monitor, can show various images for using various vehicle systems.

map) and direction of movement (compass). See **Figure 38-9**.

Vehicle Tracking Systems

A ***vehicle tracking system*** is a security system that can track the location of a car or truck if it is stolen. One system uses an on-board security control module, a miniature transmitter and receiver, the global positioning satellite (GPS) system, and a 24-hour monitoring/response center, **Figure 38-10**.

If a vehicle with this type of system is stolen, a signal is transmitted by the monitoring center to activate the tracking system. Once activated, the control module uses information received from the GPS system to pinpoint the vehicle's location. The system then transmits the location of the vehicle to the monitoring center.



A



B

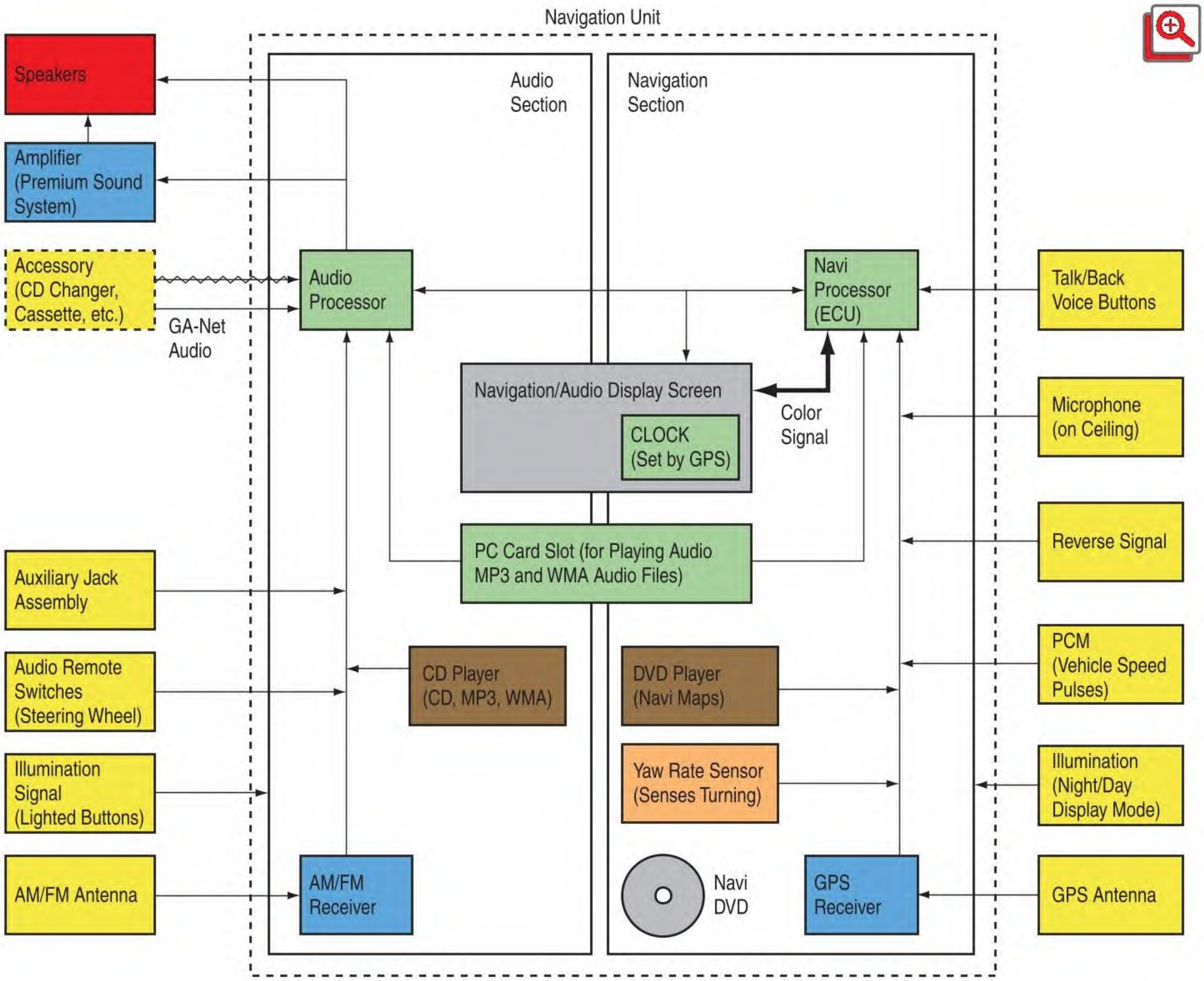


C

Lexus

Figure 38-7. A navigation system improves convenience and safety. The system helps you find your destination with minimal confusion. The navigation system provides voice directions to the driver. A—The driver selects the region of interest. B—The driver selects points of interest. C—Routes are calculated to the destination.

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Honda

Figure 38-8. This block diagram shows how the major components connect in a navigation system.

This type of vehicle tracking system is usually small and self-contained, allowing it to be easily hidden on the vehicle. Such a system usually incorporates a backup battery. This allows the system to continue receiving and transmitting even after the vehicle's battery has been removed.

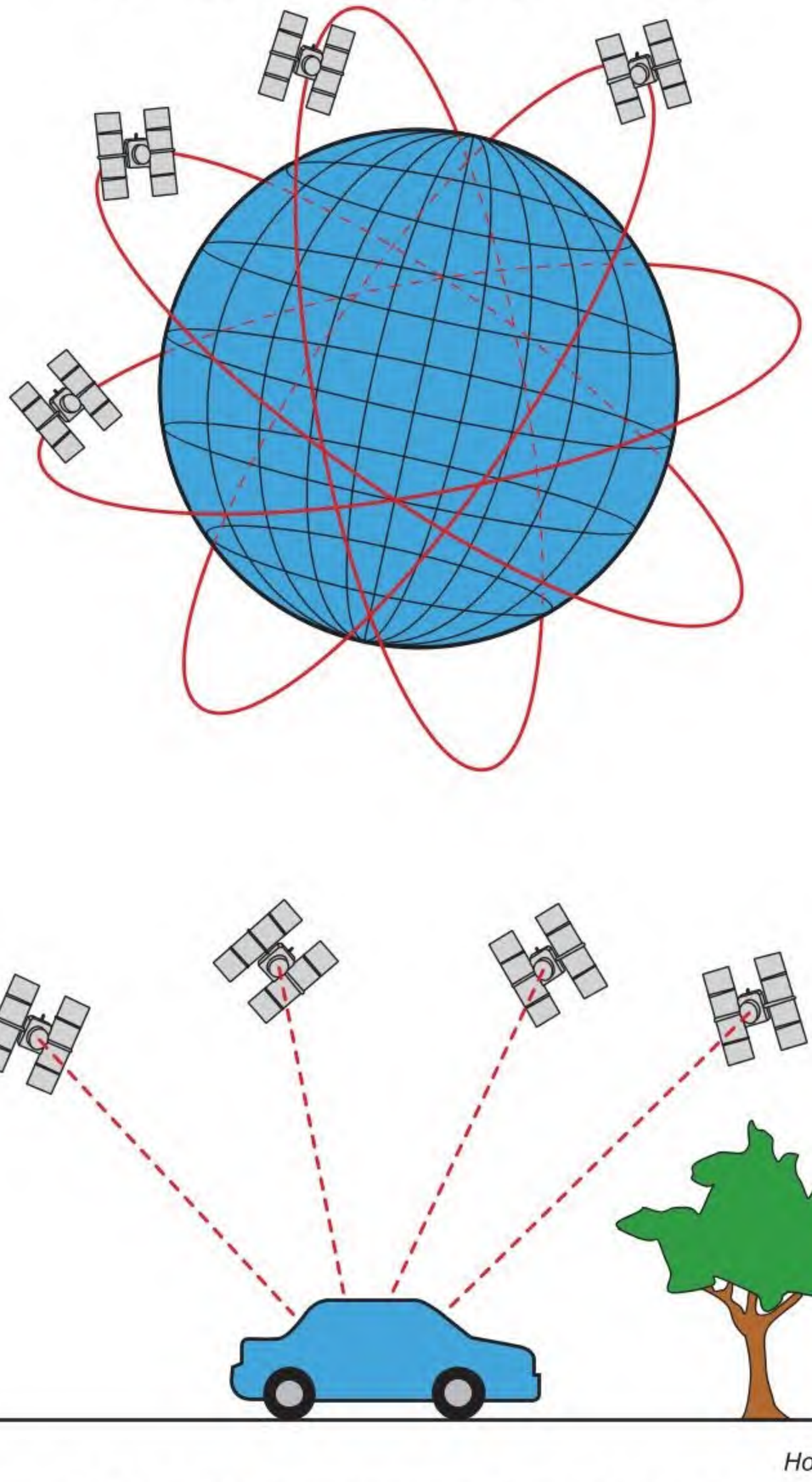
Some tracking systems also provide added security for the driver during a carjacking or kidnapping. The driver can press an emergency call button on his or her key ring. This allows the people at the response center to listen to conversation in the vehicle and to take action as needed. They can call the police and tell them the exact location and description of the vehicle. Other systems enable the vehicle to be remotely disabled.

Driver Information Center

The ***driver information center*** is a dash-mounted keyboard display for inputting and reading data about the vehicle. It allows you to send data to the instrumentation computer to find miles-to-empty, average fuel consumption, estimated time of arrival, and other information. The information center uses signals from many sensors to calculate this information. See **Figure 38-11**.

Driver information centers are very complex and vary with the vehicle's make and model. Always refer to the service manual for testing and repair directions.

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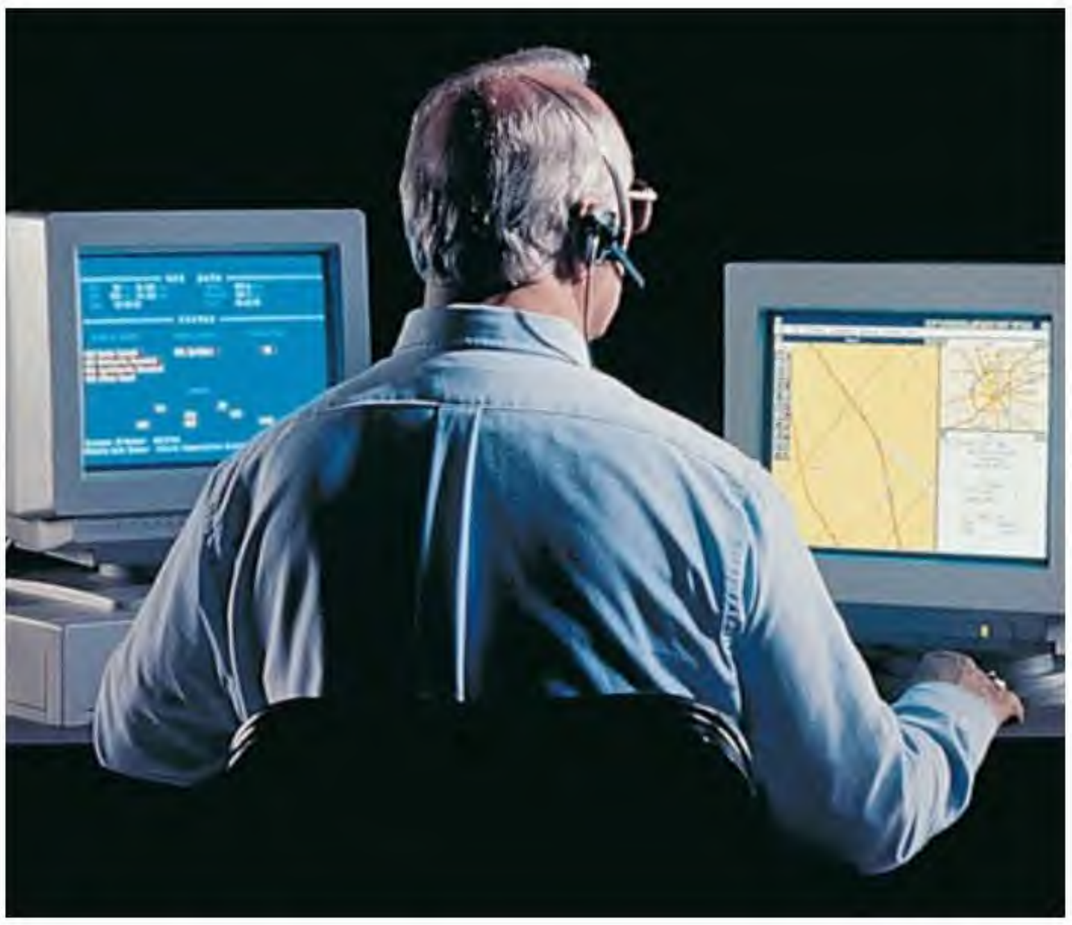


Honda

Figure 38-9. A global positioning system, or GPS, allows the navigation system to track a vehicle's location and show the location on a map on the display screen. Satellites orbiting above the earth send signals to the vehicle's GPS antenna so the on-board computer can calculate the vehicle's direction and location on surface of the earth.

Night Vision Systems

A ***night vision system*** uses an infrared camera and monitor system to help the driver view through fog, snow, rain, and other vision-impairing atmospheric conditions. The camera could be mounted in the front grille. When activated in bad weather or at night, the camera could produce an image on the dash-mounted monitor or on a heads-up display on the windshield. This would let the driver see longer distances through fog to detect oncoming vehicles,



ATX Research

Figure 38-10. A vehicle tracking system has trained operators at computer workstations 24 hours a day. If a vehicle is stolen or hijacked, an operator can phone police and give the exact location of the vehicle.

people, curves in the road, or other dangers. See **Figure 38-12**.

Video Camera Display

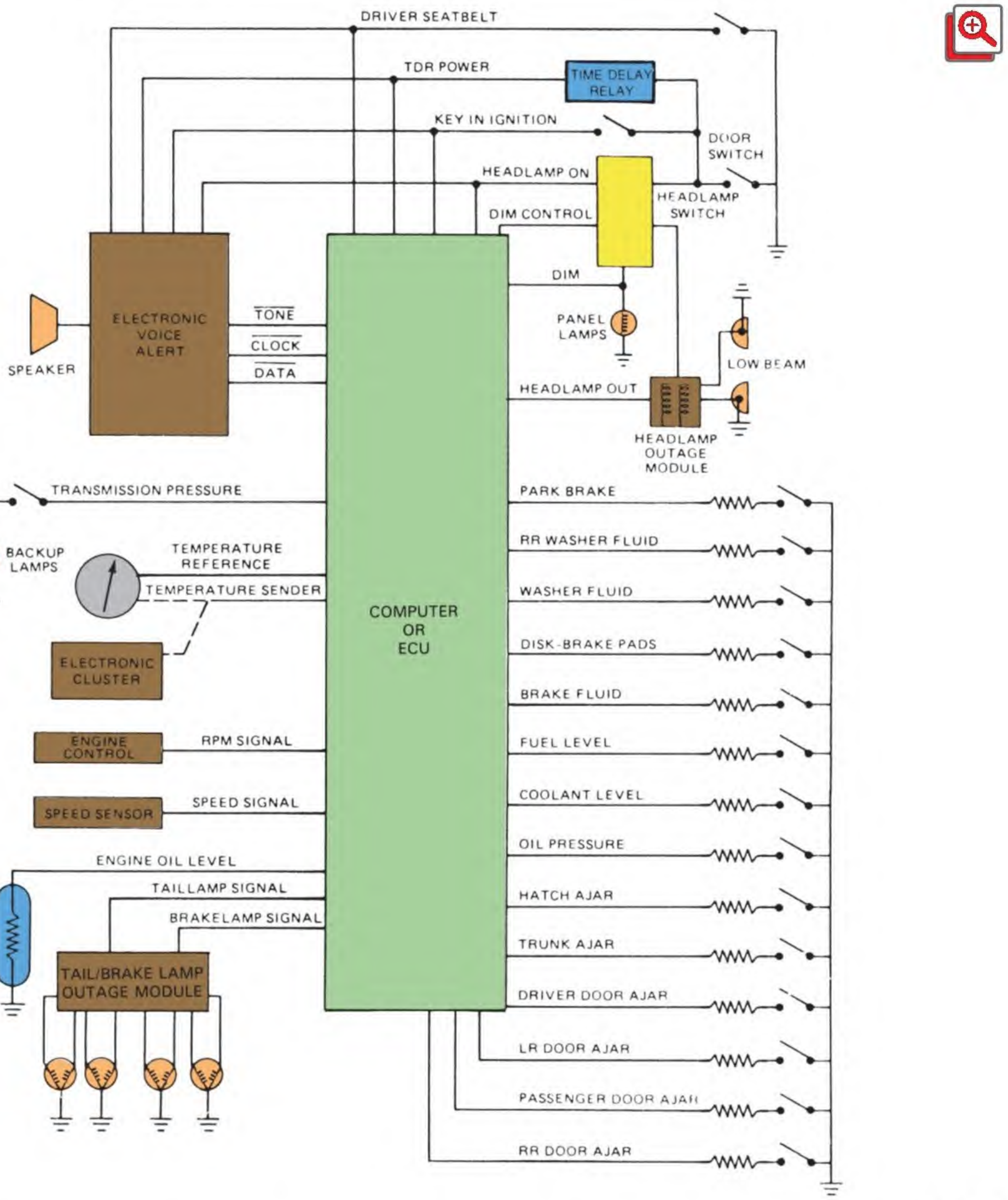
A ***video camera display*** is often used to show the view from the rear of the vehicle when the vehicle is in reverse. A tiny, low-resolution camera is mounted inside the rear body or bumper. The camera aims straight behind the rear center to show the road or driveway right behind the vehicle. The display screen gives a better view of what is behind the car than the side-view mirror and the windshield-mounted rear-view mirror, whose views are blocked by the rear body structure. Look at **Figure 38-13**.

Voice-Activated Systems

A voice-activated system uses a microphone and computer data to perform functions by reacting to spoken words. This is an optional feature on many modern phone and navigation systems. For example, if the driver says "call home," the recognition system will output a signal to the car phone to dial the home phone number. Other voice commands might include "change the radio station, mute the radio, and lock the doors."

A voice-activated system can be programmed to react to words such as "dial," followed by a phone

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Chrysler

Figure 38-11. Circuit diagram shows the major parts of a typical voice alert system. On the right, various switches feed data into the ECU. On the left, various sensors and a lamp outage module feed signals into the ECU. If a condition is not satisfied, the ECU outputs a signal to the voice alert circuit. It can then generate a simulated voice signal for operating a speaker so the car can "talk" to the driver.

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A



B

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Figure 38-12. Night vision greatly improves the view of the road, especially with oncoming traffic on a dark road. A—Note the poor view of the road behind oncoming car. Eyesight is blinded by headlights. B—The heads-up display clearly shows people walking on the edge of the road in front of the driver.

number or by the name of the person or place to call. The driver can also program new word commands into the voice-activated system. See **Figure 38-14**.

Collision Avoidance System

A ***collision avoidance system*** measures the distance between the front of a vehicle and any object in its path and automatically controls the braking and engine speed control systems to prevent an accident. Refer to **Figure 38-15**.

Most collision avoidance systems will first make an audible warning so the driver can slow down on his or her own. If the driver fails to take corrective action, the collision avoidance system might reduce engine (and vehicle) speed or even apply the brakes if a collision is probable.

There are two common types of distance sensors used in collision avoidance systems: radar sensors and infrared sensors. ***Radar sensors*** transmit electromagnetic energy waves from the front of the vehicle. These energy waves bounce off any objects in front of the vehicle and then return to the sensor. The system's computer monitors the amount of time it takes for the waves to return to the sensor and then uses this information, as well as data from the vehicle speed sensor, to calculate the distance between the object and the vehicle.

An ***infrared sensor*** sends out an invisible light beam from the front of the vehicle. This light beam bounces off objects in front of the vehicle and returns to the sensor. The amount of time it takes for the light beam to return to the sensor is monitored by the computer system and used to determine a safe driving distance for the exact road speed.

Adaptive Cruise Control

An ***adaptive cruise control system*** can alter vehicle speed automatically when coming up on another vehicle too quickly. Front-mounted radar works with the vehicle's on-board computer to reduce cruising speeds to prevent following too closely behind another vehicle.

Automatic Parking System

An ***automatic parking system*** uses computer control to back up, steer, and brake a car into a parking space. The driver simply pulls up next to a parking space, activates auto park, and the car drives itself into the parking space between two cars. See **Figure 38-16**.

Proximity sensors (usually sonar or sound sensors) around the perimeter of the vehicle measure the distance from the auto body to anything around the car. Some sonar sensors make a faint clicking sound. This allows a built-in sensor microphone to measure the amount of time it takes for the sound wave to return to the sensor. The proximity sensor can take very accurate assessment of distances of any object around the car to avoid a collision.

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Bosch and Subaru

Figure 38-13. Various types of cameras and even radar can be OEM equipment on today's vehicles. A—Radar is for long-range sensing of objects in front of the vehicle. Infrared cameras can provide night vision in front of the vehicle. Video cameras can be used in the front and rear of the vehicle for operating the video screen in the passenger compartment. Rear camera is convenient to avoid hitting objects when backing up. B—A video image from a rear-mounted camera aids in backing up the vehicle. C—A vehicle-mounted video camera is very small. The stepped shroud prevents lens glare for clearer image.



Siemens

Figure 38-14. A voice recognition system can react to the spoken word. The driver speaks commands into a microphone in the dash. The microphone signal is processed by the instrumentation computer to perform the desired function given audibly by the driver.

Connectivity

Many new cars come equipped with advanced connectivity for the ability to communicate with other electronic products (laptop computers, smart phones, tablets, memory chips, etc.). Since vehicle wiring and components vary, you must refer to the factory service literature to understand these new and ever-changing local area networks. Refer to **Figure 38-17**.

Security and Navigation System Service

Servicing vehicle security and navigation systems usually involves part replacement. However, sometimes the problem can be a bad antenna or power feed problem to the unit.

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A



B

Siemens

Figure 38-15. Devices using infrared radiation are used to avoid collisions. A—Collision avoidance sensors use either radar or infrared light to bounce a signal off any object in front of the vehicle. B—The computer calculates the time it takes the signal to bounce off the object and warns the driver or applies the brakes to avoid a collision.



Siemens

Figure 38-16. This auto-park system measures distance to objects all around the vehicle. It can then operate the engine throttle, brakes, and steering to park the car with minimum human intervention. Let go of the steering wheel and remove your feet from the brake and gas pedals. Activate automatic parking and the vehicle will back into its parking place by itself.



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Figure 38-17. Many new vehicles come with complete connectivity to many external sources of data. Devices can communicate wirelessly.

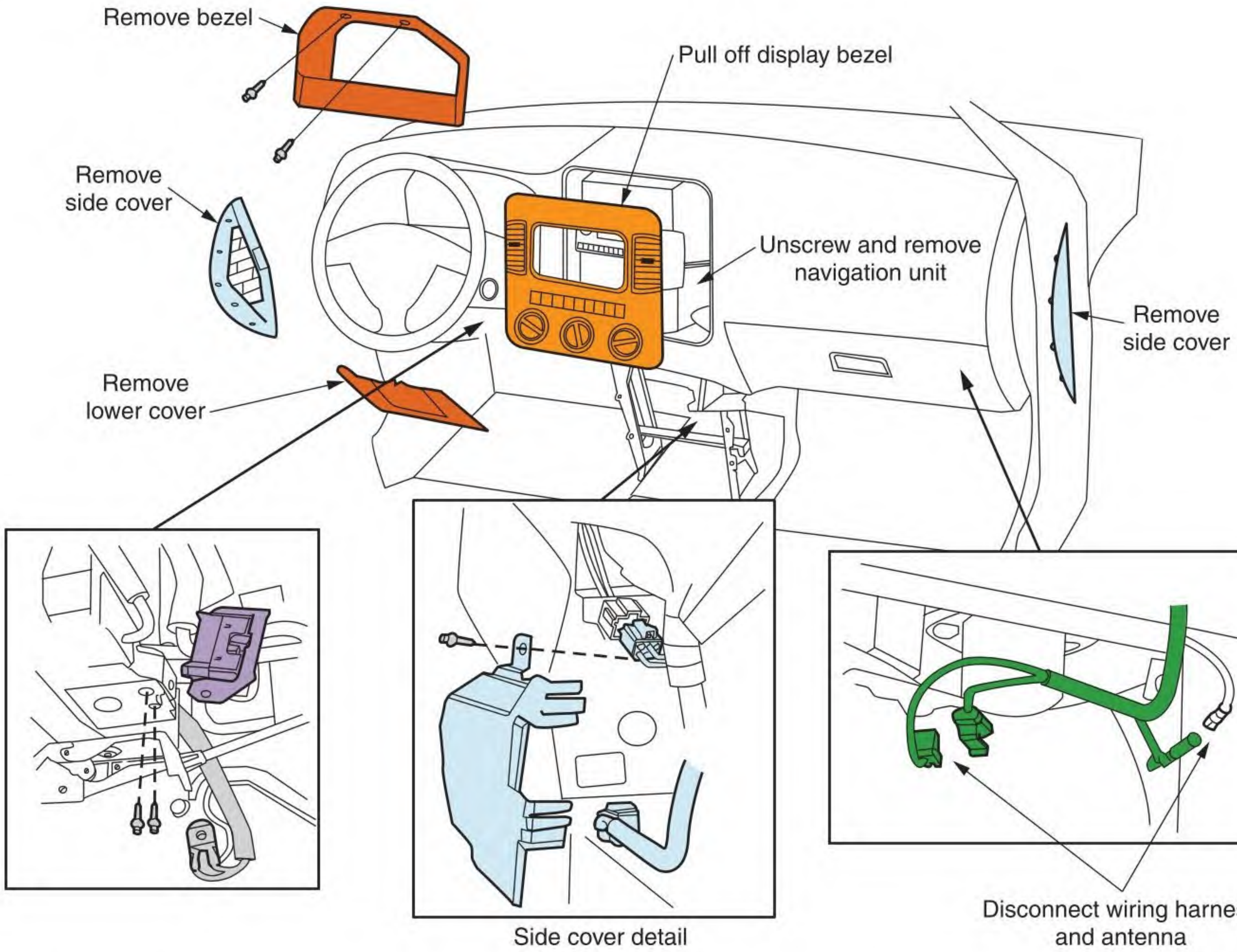
Service Procedure

To find the source of the problem:

1. Try to operate the failed system to verify the customer complaint.
2. Try to pinpoint any external problem that could keep the unit from operating (bad antenna, dead ECM, no display, etc.).
3. Check for blown fuses and for power going to the unit if the unit does not turn on.
4. If the power supply circuit has a relay in it, make sure the relay is working. Plug-in relay testers are available.
5. Make sure the unit has a good ground wire attached properly.
6. Review stored trouble codes, which may indicate the source of the problem.

Normally, if a unit is getting power and is grounded but fails to work normally, the unit must be removed for replacement or repair. Look at **Figure 38-18**.

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Figure 38-18. Note how front bezels come out of this vehicle dash. You must remove a few screws and then pull lightly on the part to free it from rubber mounted clips and dash.

Dropping Resistor Signals

Did you ever wonder what really happens when you press a button on a car's dash to change volume or look at a new display screen?

Dropping resistor signals are used to provide input signals to the body or instrumentation ECM as varying dc voltage and current signals. For example, by pressing a button on the vehicle dash, you are connecting a circuit with a specific amount of resistance to the ECM. The analog-to-digital converter chip in the ECM will output preprogrammed functions for each voltage and current level. Each switch and knob in the vehicle dash places a unique set of resistors in series to produce its own voltage/current signal. This allows many control buttons and knobs to be wired together in a circuit to one wire returning to the ECM. Study **Figure 38-19**.

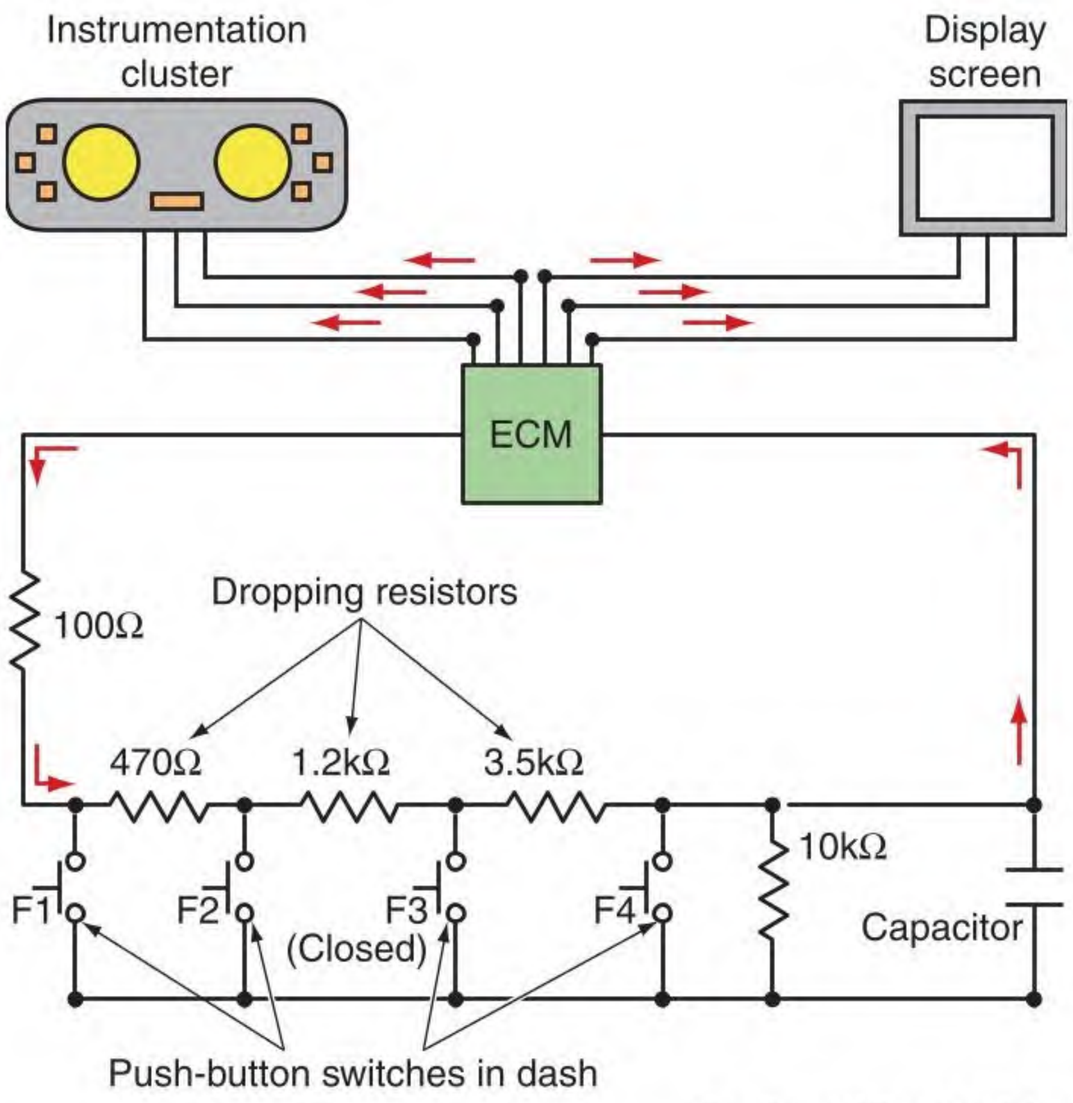


Green Tech

Mercury Pollution

The mercury contained in fluorescent lights is considered to be toxic. Because of this, fluorescent lights should not be discarded as regular waste. Instead, they should be collected and recycled. It is important that fluorescent lights are not broken. Broken fluorescent lights can leak mercury, creating a hazardous area.

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Figure 38-19. Note how dash buttons or switches are often wired to an ECM. Dropping resistors allow each button switch to send a unique voltage/current signal back to the ECM. Different size resistors are placed across each switch to provide a unique signal from each switch. ECM can use these signals to operate a digital gauge cluster or LCD display screen.

Summary

- A security system is designed to help prevent theft of the vehicle and its contents.
- Security systems designs vary tremendously so thieves are not able to learn about the operation of any one system too well.
- A transponder key contains an electronic chip that sends a coded signal to a module. If the module recognizes the signal, it allows the engine to be started.
- Some theft deterrent systems use a resistance key which places a small electrical resistor in the side of the ignition key.
- Navigation systems use our nation's satellite global positioning system to display the geographic location of the vehicle.
- A vehicle tracking system is a security system that can track, or follow, the location of a car or truck if it is stolen.
- A night vision system uses an infrared camera and monitor system to help the driver view through vision-impairing atmospheric conditions.
- A voice-activated system uses a microphone and computer data to perform functions by reacting to spoken words.
- A collision avoidance system uses radar to detect a vehicle or other object in front of the vehicle.
- An automatic parking system uses computer control to back up, steer, and brake a car into a parking space.
- Servicing vehicle security and navigation systems usually involves part replacement; however, the trouble may be a bad antenna or power feed problem to the unit.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

adaptive cruise control system
automatic parking system
collision avoidance system
driver information center
dropping resistor signals
global navigation satellite system
global positioning system (GPS)
infrared sensor
keyless entry system
navigation systems
night vision system
proximity sensors
radar sensors
resistance key
security system
smart key system
transponder key
vehicle tracking system
video camera display

Activities

1. Pick any make and model car with a navigation system. Look up how to troubleshoot the vehicle's navigation system in factory service information. Write a short report of anything you learned about testing vehicle navigation systems.
2. Write another report on how to remove the navigation system for service.

Review Questions

Answer the following questions using the information provided in this chapter.

1. Describe the basic operation of a typical security system.
2. How is a security system activated or deactivated?

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3. Why are security system designs so varied?
4. What is a transponder key?
5. How does a resistance key work in a security system?
6. What is the benefit of a smart key system?
7. What type of information can a navigation system provide?
8. Explain the operation of GPS.
9. A video camera display is often used to show the view from the rear of the vehicle when the vehicle is in _____.
10. How does a collision avoidance system operate?

ASE-Type Questions

1. Technician A says a security system uses motion sensors and switches to send signals to an electronic control module. Technician B says security systems are identical in all cars. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. When a resistance key's _____ is not correct, the control module opens the starter relay circuit so the engine will not crank.
   (A) current
   (B) voltage
   (C) resistance
   (D) All of the above.
3. Keypad-type keyless entry systems are being discussed. Technician A says these systems use a key fob that contains a small transmitter to lock and unlock the vehicle's doors. Technician B says the five numbers on the keypad must be pressed in the correct sequence for the doors to unlock. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. Technician A says navigation systems use a satellite global positioning system to display the geographic location of the vehicle. Technician B says the vehicle's on-board computer compares satellite data with a large database of roads and highways. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. Technician A says the driver information center is usually mounted on the vehicle dashboard. Technician B says the driver information center uses an infrared camera to help the driver see through fog, snow, and rain. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Technician A says a vehicle's video camera display gives drivers an obstructed view of objects located behind the vehicle. Technician B says a voice-activated system can be programmed to react to certain words. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. Technician A says most collision avoidance systems use radar to measure the distance and speed of objects in front of the vehicle. Technician B says the ECM may also use signals from the vehicle speed sensor to detect a possible collision. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. Technician A says many automatic parking systems use sonic proximity sensors. Technician B says that no one makes a car with an automatic parking feature. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. When you press a button on the dash, what happens?
   (A) The voltage to the ECM is changed.
   (B) The circuit resistance is changed.
   (C) The current to the ECM is changed.
   (D) All of the above.
10. Technician A says that dropping resistors are used to allow many dash buttons to be wired together into a control circuit. Technician B says that pushing each dash button produces a unique voltage/current signal that can be read and understood by ECM. Who is correct?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Security System Diagnosis

Condition	Possible Causes	Correction
Alarm will not shut off.	1. Failed motion sensor. 2. Failed switch. 3. Circuit short or open. 4. Bad control module.	1. Replace sensor. 2. Replace switch. 3. Repair wiring. 4. Replace control module.
Alarm will not turn on.	1. Blown fuse. 2. Circuit short or open. 3. Bad control module. 4. Failed motion sensor. 5. Failed switch. 6. Bad siren or horn.	1. Replace fuse. 2. Repair wiring. 3. Replace control module. 4. Replace sensor. 5. Replace switch. 6. Replace parts.
Intermittent operation.	1. Loose connection. 2. Switch not adjusted properly. 3. Cracked circuit board.	1. Test and repair circuit. 2. Adjust switch to close fully. 3. Replace control module.

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Section 6

Fuel, Exhaust, and Induction System Technology

Chapter 39
Automotive Fuels, Combustion Efficiency

Chapter 40
Fuel Tanks, Pumps, Lines, and Filters

Chapter 41
Gasoline Injection Fundamentals

Chapter 42
Gasoline Injection Diagnosis and Repair

Chapter 43
Diesel Injection Fundamentals

Chapter 44
Diesel Injection Diagnosis, Service, and Repair

Chapter 45
Exhaust System Technology and Repair

Chapter 46
Turbochargers and Superchargers—Construction, Operation, and Repair

Today's fuel systems must meter a precise amount of fuel into the engine under a wide range of constantly changing operating conditions. The fuel system has the important job of optimizing engine performance while keeping fuel consumption and emissions to a minimum. This is no easy task!

This section will explain modern fuel systems in detail. Chapter 39 describes the properties of various fuels and discusses normal and abnormal combustion. Chapter 40 covers fuel tanks, fuel pumps, and fuel filters. Chapters 41 and 42 describe the operation and service of electronic fuel injection, the most common type of fuel system. Chapters 43–46 explain the operation and repair of diesel injection, exhaust systems, turbochargers, and superchargers.

The information in this section will help you pass ASE Test A6, Electrical/Electronic Systems; Test A8, Engine Performance; and Test A9, Light Vehicle Diesel Engines.



Chapter 39
Automotive Fuels, Combustion Efficiency

After studying this chapter, you will be able to:

- Summarize how crude oil is converted into gasoline, diesel fuel, liquefied petroleum gas, and other products.
- Describe properties of gasoline and diesel fuel.
- Explain octane and octane ratings.
- Describe normal and abnormal combustion of gasoline and diesel fuel.
- Summarize the properties of alternative fuels.
- Correctly answer ASE certification test questions on automotive fuels and combustion.

An automotive ***fuel*** is any substance (liquid, gas, or solid) that can be easily burned to produce heat. Most passenger vehicle engines burn liquid gasoline, while a few consume diesel fuel, gasohol, alcohol, and alternative fuels.

Combustion is the chemical reaction that occurs when a fuel is burned with an oxidant (oxygen). ***Normal combustion*** is a primary factor controlling good fuel economy, maximum engine power, low exhaust emissions, and long engine service life. ***Abnormal combustion*** occurs when combustion happens too quickly (explosion) or too slowly (incomplete burn). ***Combustion efficiency*** is a measure of how well combustion consumes all the fuel's heat energy for maximum cylinder pressure (propulsion) and minimum exhaust by-products (pollution).

To quickly isolate numerous vehicle problems, you must understand the factors that affect proper fuel combustion. This knowledge will help you diagnose engine performance and mechanical problems more quickly.

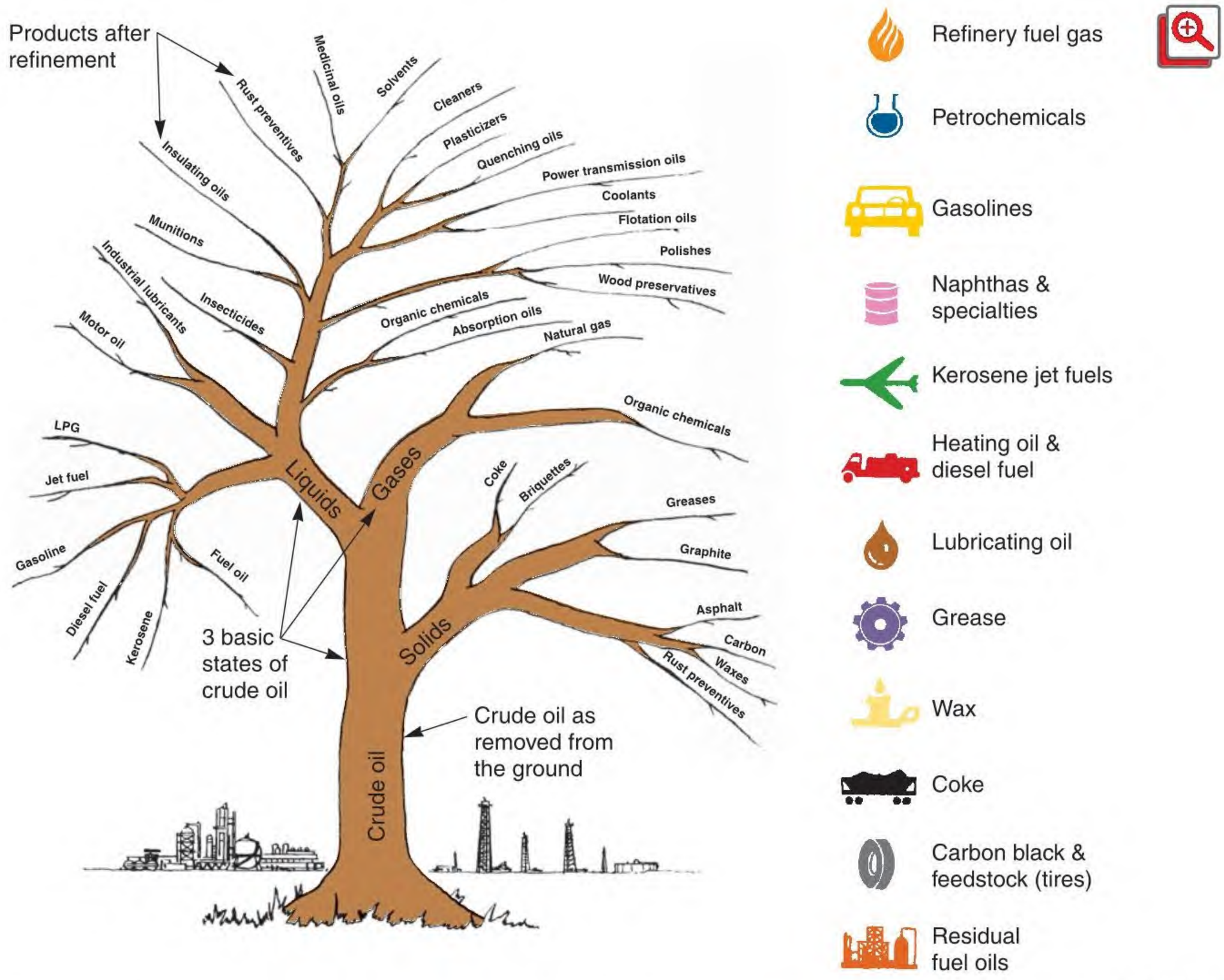
Petroleum (Crude Oil)

Crude oil, or ***petroleum***, is oil taken directly out of the ground. It is used to make gasoline, diesel fuel, liquefied petroleum gas, and many nonfuel materials (asphalt, motor oil, etc.). **Figure 39-1** shows some of the products made from crude oil.

Natural crude oil is a mixture of semisolids (neither solid nor liquid), liquids, and gases. Chemically, crude oil consists of highly flammable hydrocarbons.

Hydrocarbons are chemical mixtures of about 12% hydrogen (flammable gas vapor) and 82% carbon (heavy, black solid). Crude oil also contains sulfur, nitrogen, metals, and saltwater. These elements must be removed.

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Gulf Oil Corp.

Figure 39-1. Crude oil is used to make many products besides gasoline and diesel fuel.

Processing Crude Oil

Crude oil deposits are contained inside the earth. Oil companies perform ***exploration tests*** (seismic studies, surface mapping, and test drilling) to find oil. After determining where oil might be located, a drill crew bores a hole thousands of feet into the ground. A huge steel derrick is used for the deep earth drilling operation. The derrick has a cutting bit capable of passing through dirt, sand, and rock.

Once the oil deposit has been reached, the oil is pumped to the surface and sent to a refinery. The ***refinery*** converts the crude oil into more useful substances, such as motor oil, gasoline, and diesel fuel. See **Figure 39-2**.

Distillation is the first conversion process. During distillation, a ***fractionating tower*** breaks the crude oil down into different parts, or fractions (LPG, gasoline, kerosene, fuel oil, and lubricating oils). Refer to **Figure 39-3**. After distillation, other processes purify and alter the content of each crude oil fraction.

Gasoline

Gasoline is the most common type of automotive fuel. It is an abundant and highly flammable part of crude oil. Extra chemicals, called additives (detergents, antioxidants, etc.), are mixed into gasoline to improve its operating characteristics.

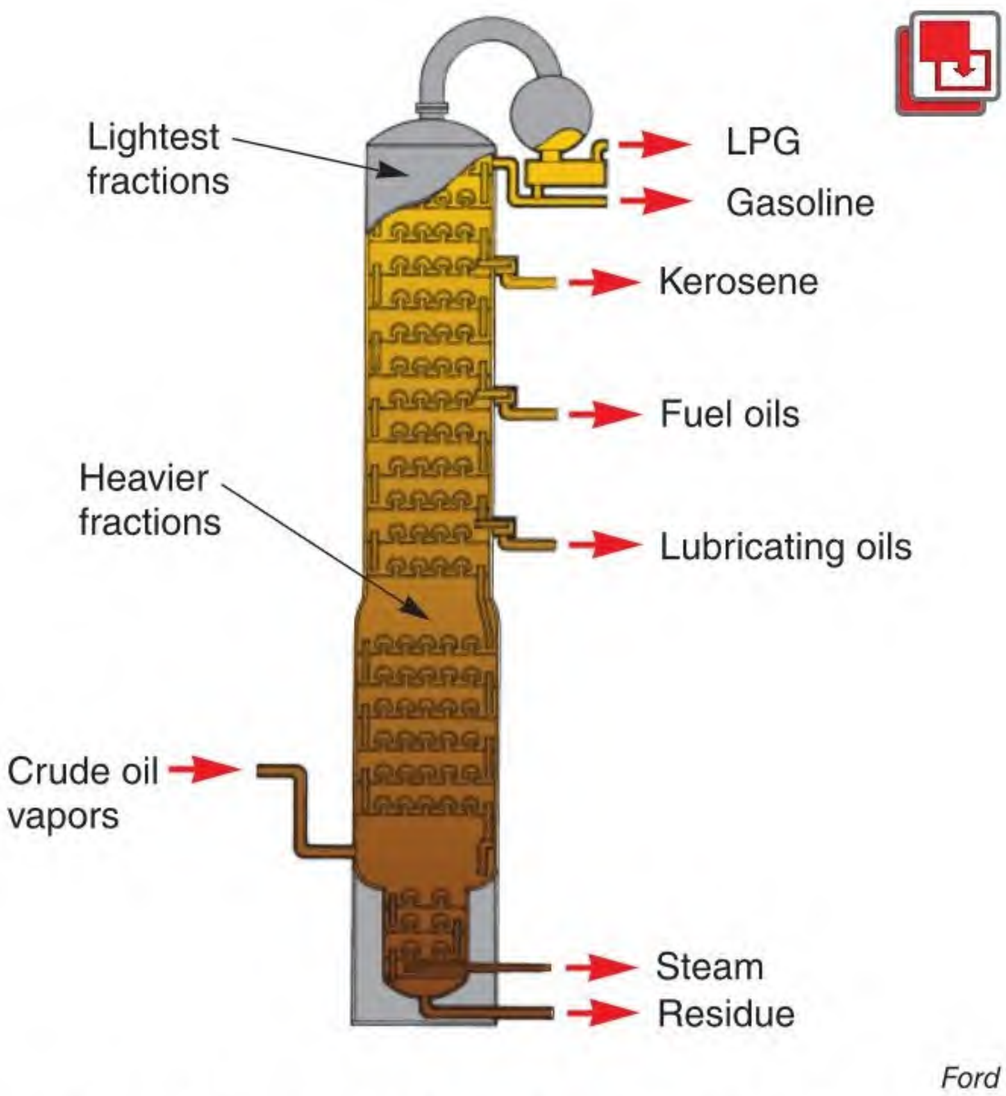
Antiknock additives slow down the burning of gasoline. This helps prevent engine ping, or knock (knocking sound produced by abnormal, rapid combustion).

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Mercedes Benz

Figure 39-2. During the refining process, oil companies use large fractionating towers to separate the crude oil vapors into useful parts or fractions.



Ford

Figure 39-3. A fractionating tower allows crude oil vapors to condense and separate into trays. Each weight of vapor flows off its tray and into storage containers.

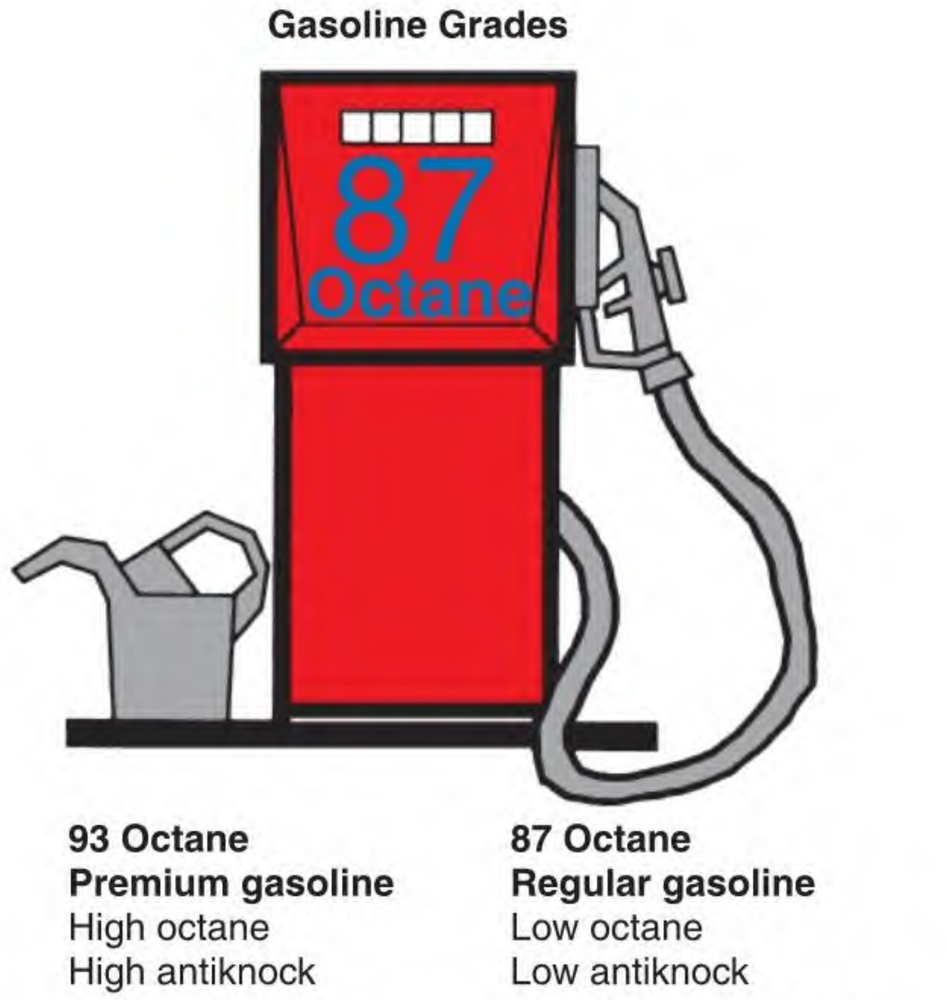
Tech Tip

Tetraethyl lead, or lead, is a naturally occurring heavy metal. For many years, lead was added to gasoline as an octane booster to prevent detonation and engine wear. After scientists learned that lead was a common cause of birth defects and other serious illness, all fuel and oil additives containing lead were banned from the market.

Gasoline Octane Ratings

The ***octane rating*** of gasoline is a measurement of the fuel's ability to resist knock or ping. Gasoline with a high octane number (91, for example) will resist knock and ping better than gasoline with a low octane number (87, for example). High-octane gasoline should be used in high-compression or turbocharged/supercharged engines. Low-octane gasoline is more suitable for normal compression, high efficiency engines.

Octane ratings are given as numbers on the gas station pump, **Figure 39-4**. Automakers recommend octane ratings of fuel for their engines. The owner's manual



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Figure 39-4. The gasoline grade indicates the antiknock value of gasoline blend.

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will give the octane rating recommended for the car's engine. Use a fuel with an octane rating as high as the automaker's recommendations. **Figure 39-5** summarizes several factors that control engine octane requirements.

Octane enhancers, or ***oxygenates***, are now used as blending components in gasoline to increase octane levels and reduce engine knock. Octane enhancers are alcohols made up of hydrogen, carbon, and oxygen. Examples of octane enhancers include toluene, ethanol, and MTBE.

Tech Tip

Avoid using high octane fuel in an engine designed to burn low octane fuel. There is no benefit to engine power or fuel economy by purchasing the higher priced fuel. Contrary to what many people believe, a high octane fuel actually is less volatile and burns more slowly than low grade fuel. High octane fuel may not burn properly in a low compression, naturally-aspirated engine. Its improper use can actually decrease engine power and gas mileage. Use the cheaper, low octane fuel in engines with lower compression ratios.

Gasoline Combustion

For gasoline (or any other fuel) to burn properly, it must be mixed with the right amount of air. The volatile (flammable) air-fuel mixture must then be compressed, pressurized, and ignited. The resulting combustion, or rapid oxidation, produces heat, expansion of gases, and engine cylinder pressure. The cylinder and combustion chamber pressure pushes down on the pistons to rotate the crankshaft. Refer to **Figure 39-6**.

Normal Gasoline Combustion

Normal gasoline combustion occurs when the spark plug ignites the fuel and burning progresses quickly and smoothly through the air-fuel mixture. Maximum cylinder pressure should be produced a few degrees of crank rotation after piston TDC on the power stroke. Normal gasoline combustion is illustrated in **Figure 39-7**.

Normal combustion takes only about 3/1000 of a second. This is much slower than an explosion. Dynamite explodes in about 1/50,000 of a second. Under some undesirable conditions, however, gasoline can burn too quickly, making part of combustion like an explosion. This is detailed later.

Air-Fuel Mixture

For proper combustion and engine performance, the correct amounts of air and fuel must be mixed. If too much fuel or too much air is used, engine power, fuel economy, and efficiency will suffer.

A ***stoichiometric fuel mixture*** is a chemically correct air-fuel mixture. For gasoline, it is a mixture ratio of 14.7:1 (14.7 parts air to 1 part fuel, by weight).

Octane Requirement Factors

Octane number requirement tends to go *up* when:

1. Ignition timing is advanced.
2. Air density rises due to supercharging, a larger throttle opening, or higher barometric pressures.
3. Humidity or moisture content of air decreases.
4. Inlet air temperature goes up.
5. Lean fuel-air ratios.
6. Compression ratio is increased.
7. Coolant temperature is raised.
8. Antifreeze (glycol) engine coolant is used.
9. Combustion chamber design provides little or no quench area.
10. Vehicle weight is increased.
11. Engine loading is increased, such as when climbing a grade, pulling a trailer, or increasing wind grade, or increasing wind resistance with a car-top carrier.

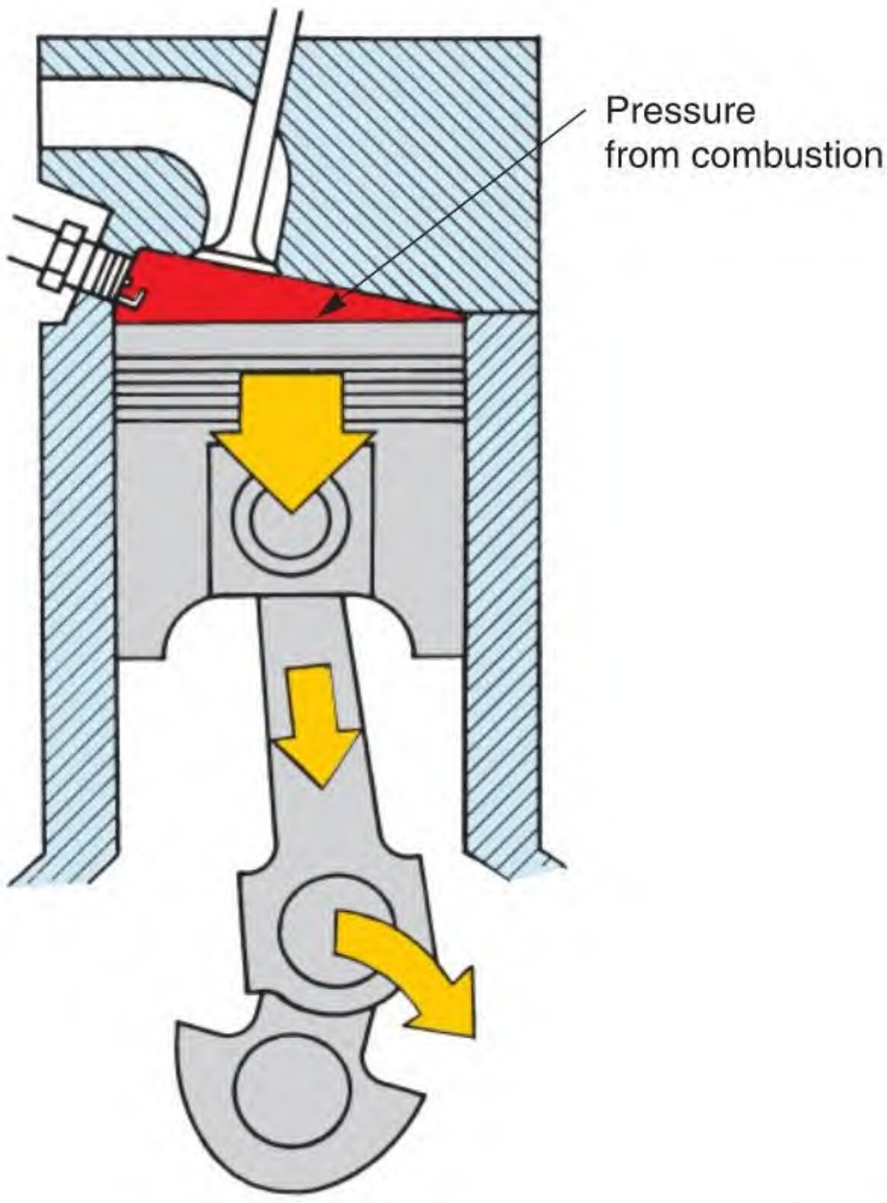
Octane number requirement tends to go *down* when:

1. Car is operated at higher altitudes (lower barometric pressure).
2. Fuel-air ratio is richer or leaner than that producing maximum knock.
3. Spark plug location in combustion chamber provides shortest path of flame travel.
4. Combustion chamber design gives maximum turbulence of fuel-air charge.
5. Compression ratio is lowered.
6. Exhaust gas recycle system operates at part-throttle.
7. Ignition timing retard devices are used.
8. Humidity of the air increases.
9. Ignition timing is retarded.
10. Inlet air temperature is decreased.
11. Reduced engine loads are employed.

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Figure 39-5. Various factors that control octane requirements.

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Ford

Figure 39-6. Combustion flame produces heat. Heat causes gases to expand. Expansion causes pressure. Pressure pushes the piston down on power stroke.

Under constant engine conditions, this ratio helps ensure that all the fuel is burned as efficiently as possible during combustion.

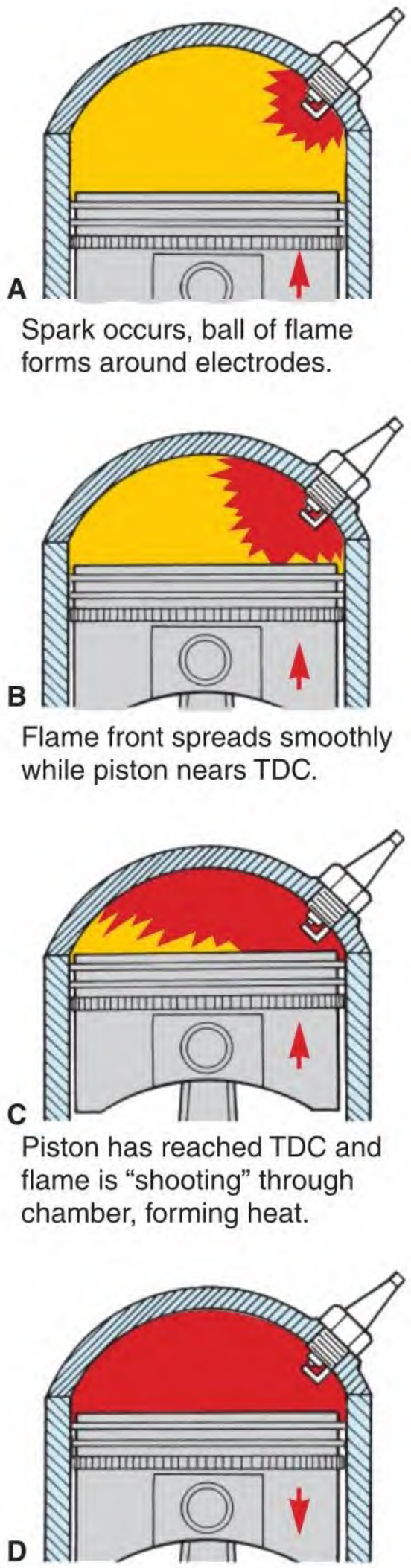
Lean and Rich Air-Fuel Mixture

A ***lean air-fuel mixture*** contains a large amount of air compared to fuel. Look at **Figure 39-8A**. For gasoline, 20:1 is a very lean mixture.

A ***rich air-fuel mixture*** is the opposite of a lean mixture; more fuel is mixed with a smaller portion of air. For gasoline, 8:1 (8 parts air to one part fuel) is a very rich fuel mixture. Refer to **Figure 39-8B**.

A slightly lean mixture is desirable for high gas mileage and low exhaust emissions. Extra air in the cylinder ensures that all the fuel is burned. Too lean a mixture, however, can cause poor engine performance (lack of power, missing, and even engine damage).

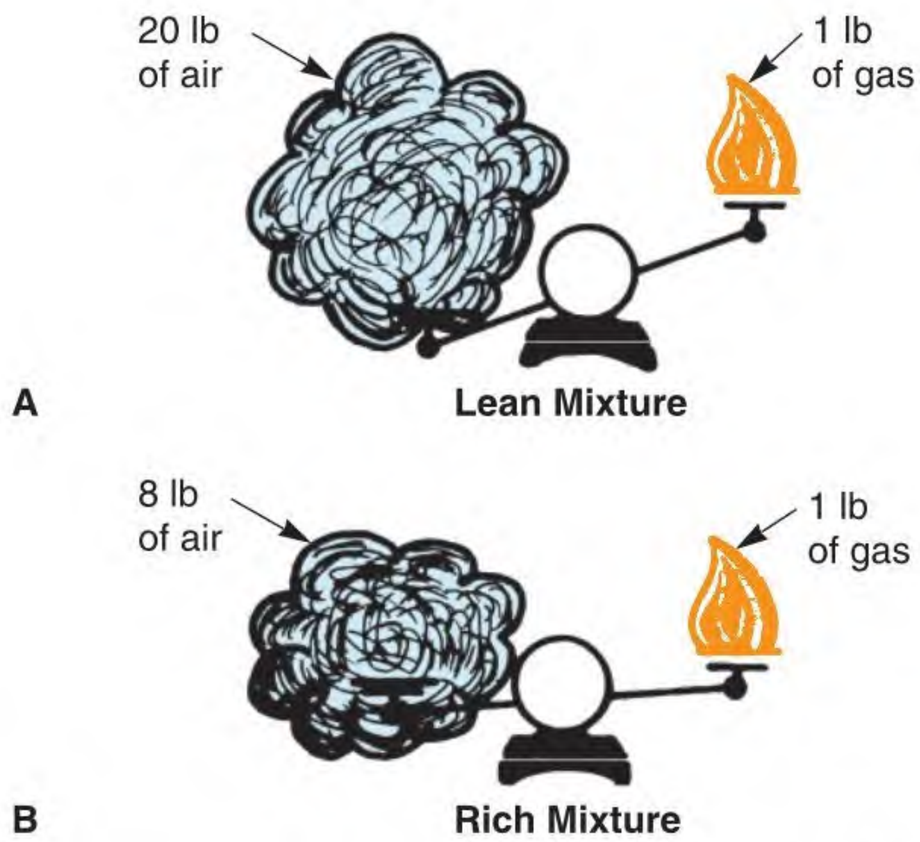
A slightly rich mixture tends to increase engine power. However, it also increases fuel consumption and exhaust emissions. An over-rich mixture will reduce engine power, foul spark plugs, and cause incomplete burning (black smoke at engine exhaust).



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Figure 39-7. The following is the process for normal gasoline combustion. A—A spark at the spark plug starts the fuel burning. A small ball of flame forms around the tip of the plug. The piston is moving up in the cylinder, compressing the fuel mixture. B—The flame spreads faster and moves about halfway through the mixture. Generally, the flame is moving evenly through the fuel mixture. The piston is nearing TDC, causing increased pressure. C—The piston reaches TDC. The flame picks up more speed. D—The flame shoots out to consume the rest of the fuel in the chamber. Combustion is complete with the piston only a short distance down in the cylinder.

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Figure 39-8. A—Lean fuel mixture has less fuel mixed with the air. B—Rich fuel mixture has more fuel mixed into the air.

Abnormal Combustion

Abnormal combustion occurs when the flame does not spread evenly and smoothly through the combustion chamber. The lean air-fuel mixtures, high operating temperatures, and low-octane fuels of today make abnormal combustion problems more common.

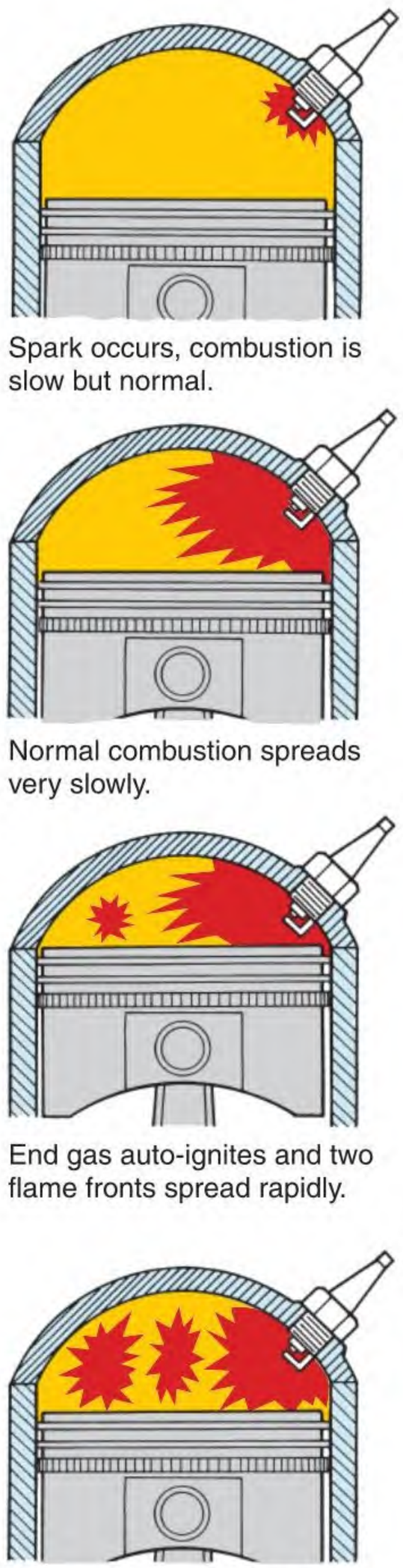
Detonation

Detonation results when part of the unburned air-fuel mixture explodes violently. This is the most severe and engine-damaging type of abnormal combustion.

Engine knock is a symptom of detonation. The combustion chamber pressure rises so quickly that parts of the engine vibrate. Detonation sounds like a hammer hitting the side of the engine. **Figure 39-9** shows the four phases of detonation.

As you can see, the ***end gas*** (unburned portion of mixture) is heated and pressurized for an extended period. Combustion is too slow because of an incorrect air-fuel mixture, a lack of turbulence, or a fuel distribution problem. This causes the end gas to explode with a "bang" (knock). Refer to **Figure 39-10**.

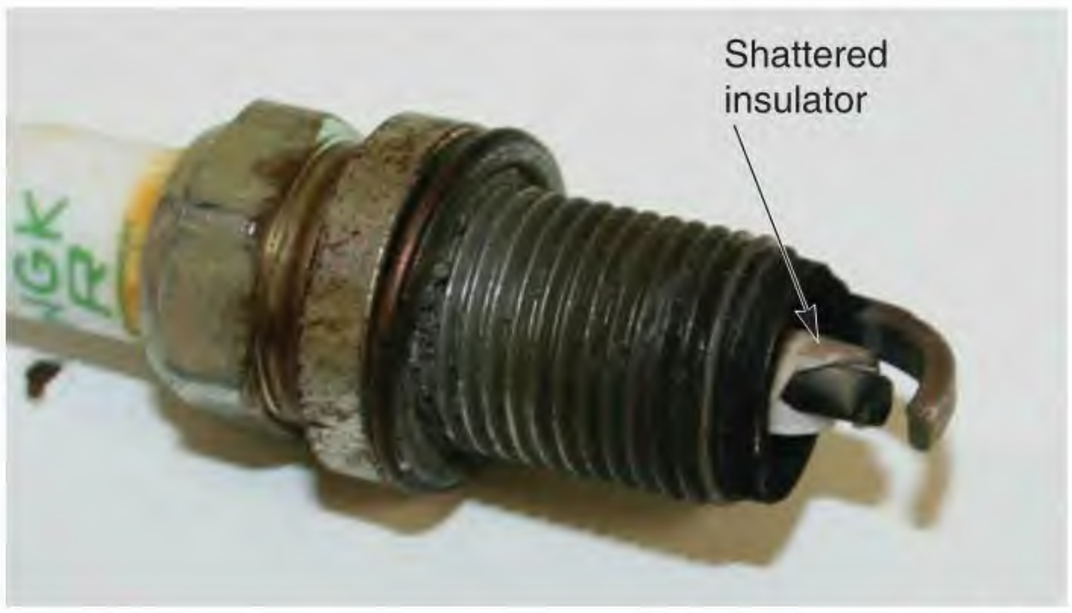
Detonation can greatly increase the pressure and heat in the engine combustion chamber. Detonation damage includes cracked cylinder heads, blown head gaskets, burned pistons, and shattered spark plugs. See **Figure 39-11**.



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Figure 39-9. Detonation is caused by combustion being too slow. End gas, or unburned air-fuel mixture, ignites and two flame fronts collide with a loud knock.

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Figure 39-10. Detonation can shatter the insulator on a spark plug.



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Figure 39-11. This piston was damaged from prolonged detonation. Heat melted the piston and pressure blew a hole along the side of the piston head.

Tech Tip

Racing fuels have additives to greatly increase their resistance to preignition and detonation. Racing fuels come in many blends, with ratings from 100 to 120 octane and higher. For example, if a small-displacement turbocharged engine is developing over 1000 horsepower at 50 pounds of boost pressure, the car better be running 118 octane or higher racing fuel. If a lower octane rating fuel is used, a split second of detonation will usually result in instant engine destruction. At these boost levels, even a split second of detonation can cause burned pistons, broken piston rings, badly bent connecting rods, and engine block damage.

Never recommend a racing fuel to customers driving their vehicles on city streets! This is against federal law and can result in expensive fines to you or your repair facility. Improper fuel can also void a vehicle's warranty and result in catalytic converter and engine damage. Always recommend fuel with an octane rating specified by the vehicle manufacturer. A fuel sticker displaying recommended octane rating for a specific engine is installed on the car. This sticker is usually located over the fuel filler opening. Recommended octane ratings will also be listed in the owner's manual.

Preignition

Preignition, or ***surface ignition***, results when an overheated surface in the combustion chamber ignites the air-fuel mixture. A "hot spot" (overheated bit of carbon, sharp metal edge, hot exhaust valve) causes the mixture to burn prematurely.

A ***ping***, or a mild knock, is a light tapping noise that can be heard during preignition. It is not as loud or as harmful as a detonation knock. Study **Figure 39-12**.

Preignition is similar to detonation, but the actions are reversed. Detonation begins after the start of normal combustion. Preignition begins before the start of normal combustion.

Caution

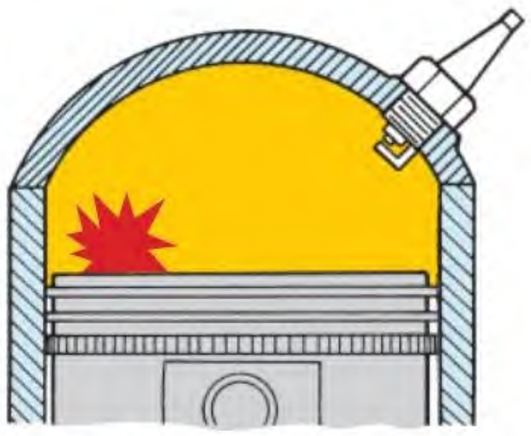
Prolonged preignition can produce harmful detonation. If an engine pings or knocks excessively, serious engine damage can result. Correct the problem right away.

Dieseling

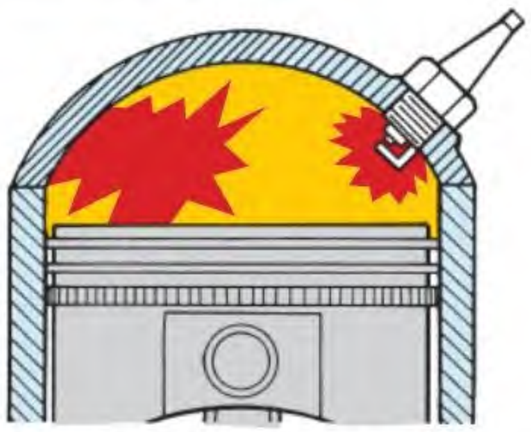
Dieseling, also called ***after-running*** or ***run-on***, is a problem in which the engine keeps running after the key is turned off. A knocking, coughing, or fluttering noise is heard as the fuel ignites and the crankshaft spins uncontrollably. When dieseling, the gasoline engine ignites the fuel from heat and pressure, somewhat like a diesel engine. With the ignition key off, the engine runs without voltage to the spark plugs.

The most common causes of dieseling are a high idle speed, leaking injectors, carbon deposits in the combustion chambers, low-octane fuel, an overheated engine, or spark plugs that have too high a heat range. This problem will be discussed later in the text.

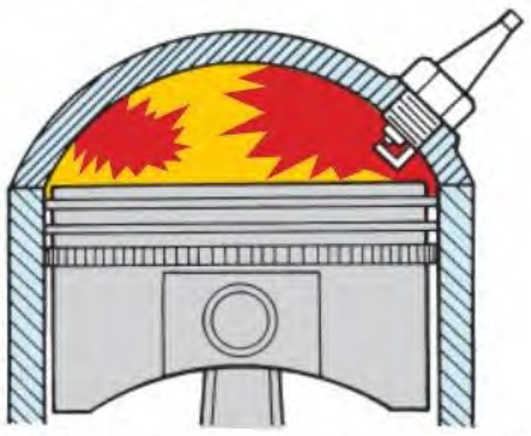
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Hot carbon deposit ignites fuel mixture.



Spark plug "fires" and two flame fronts form.



Both flame fronts shoot toward each other at high speed.



Two flames collide causing pressure "spike" and a knock.

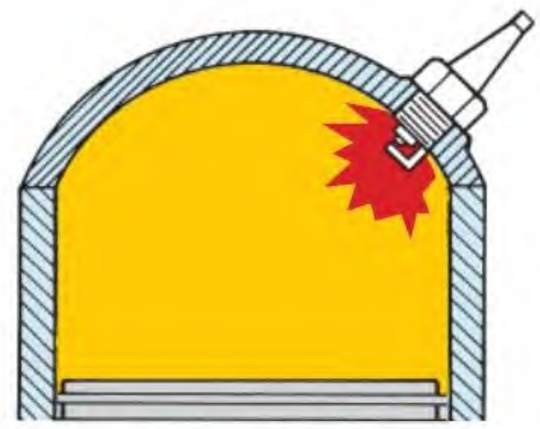
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Figure 39-12. Preignition is caused by early ignition of the fuel mixture. Abnormal and normal flames collide, producing a pinging noise.

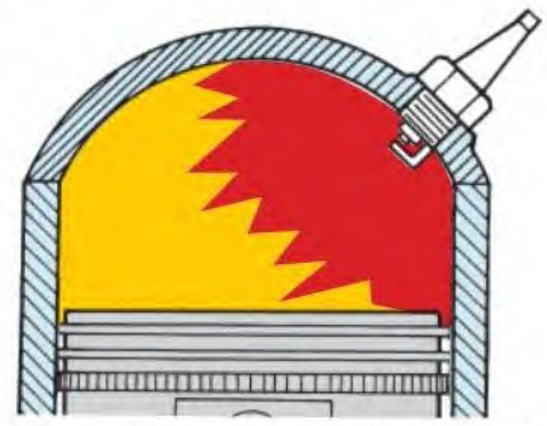
Spark Knock

Spark knock is an engine combustion problem caused by the spark plug firing too soon in relation to the position of the piston. Spark timing that is advanced too far causes combustion pressure to slam into the upward-moving piston. This causes maximum cylinder pressure before TDC, not just after TDC as it should. See **Figure 39-13**.

Spark knock and preignition produce about the same symptoms—pinging under load. To find the cause of pinging, first check the ignition timing. If timing is correct, check other possible causes.

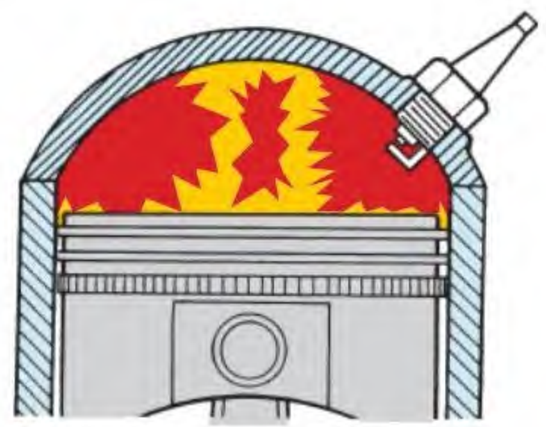


Spark plug "fires" too soon.



Piston moves toward flame front.

Pressure builds as piston slams into combustion flame.



Spark knock occurs because of excessive pressure in cylinder.

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Figure 39-13. Spark knock is a ping or knock caused by an ignition timing problem.

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Diesel Fuel

Diesel fuel is the second most popular type of automotive fuel. A gallon of diesel fuel contains more heat energy than a gallon of gasoline. It is a thicker fraction (part) of crude oil. Diesel fuel can produce more cylinder pressure and vehicle movement than an equal amount of gasoline.

Since diesel fuel is thicker and has different burning characteristics than gasoline, a high-pressure injection system must be used to spray the fuel directly into the combustion chambers. A low-pressure injection system or carburetor would not meter the thick diesel fuel properly. Look at **Figure 39-14**.

Diesel fuel will not ***vaporize*** (change from a liquid to a gas) as easily as gasoline. If diesel fuel were to enter the intake manifold of an engine, it would collect on the inner walls of the manifold. This would upset engine operation.

Combustion requires fuel to be in a vapor state. Diesel engines inject the diesel fuel directly into the combustion chamber. The compressed, hot air vaporizes and burns the fuel.

Diesel Fuel Grades

Diesel fuel grades ensure that diesel fuel sold all over the country has uniform standards. Diesel engine makers are then able to select a diesel fuel grade that meets the needs of their engines. There are three diesel fuel grades: No. 1 diesel, No. 2 diesel, and No. 4 diesel.

No. 2 diesel is normally recommended for use in diesel automotive engines. It is also the only grade of fuel available at many service stations. No. 2 diesel has a medium ***viscosity*** (thickness or weight), which provides proper operating traits for the widest range of conditions.

No. 1 diesel is thinner than No. 2 diesel and is sometimes recommended as a winter fuel. Low temperatures tend to thicken diesel fuel, causing performance problems (hard starting, poor fuel delivery).

Some auto manufacturers allow the use of only No. 2 diesel fuel, with special cold weather additives being used in the winter. In some engines, the thin No. 1 diesel fuel will not provide adequate lubrication. Metal-to-metal contact may occur, causing serious engine damage. When in doubt, refer to the vehicle's service manual.



Jaguar

Figure 39-14. A diesel engine is a compression-ignition engine. High pressure heats air in the cylinder. When fuel is sprayed into the hot air, combustion begins.

Caution

Diesel fuel should not be confused with fuel oil or home heating oil. Diesel fuel contains fewer impurities than fuel oil. Fuel oil should never be used in a diesel engine or damage will result.

Diesel Fuel Cloud Point

One of the substances in diesel fuel is ***paraffin*** (wax). At very cold temperatures, this wax can separate from the other parts of the diesel fuel. When this happens, the fuel will turn cloudy or milky. ***Cloud point*** is the temperature at which paraffin separates out of the fuel. At cloud point, the paraffin can clog the fuel filters and prevent diesel engine operation.

Diesel Fuel Water Contamination

Water contamination is a common problem with diesel engines. When mixed with diesel fuel, water can clog filters and corrode components. The parts in diesel injection pumps and nozzles are very precise. They can be easily damaged by water.

Many late-model diesel injection systems have ***water separators*** to prevent water damage. These will be covered in later chapters.

Diesel Fuel Cetane Rating

A ***cetane rating*** indicates the cold starting ability of diesel fuel. The higher the cetane number, the easier

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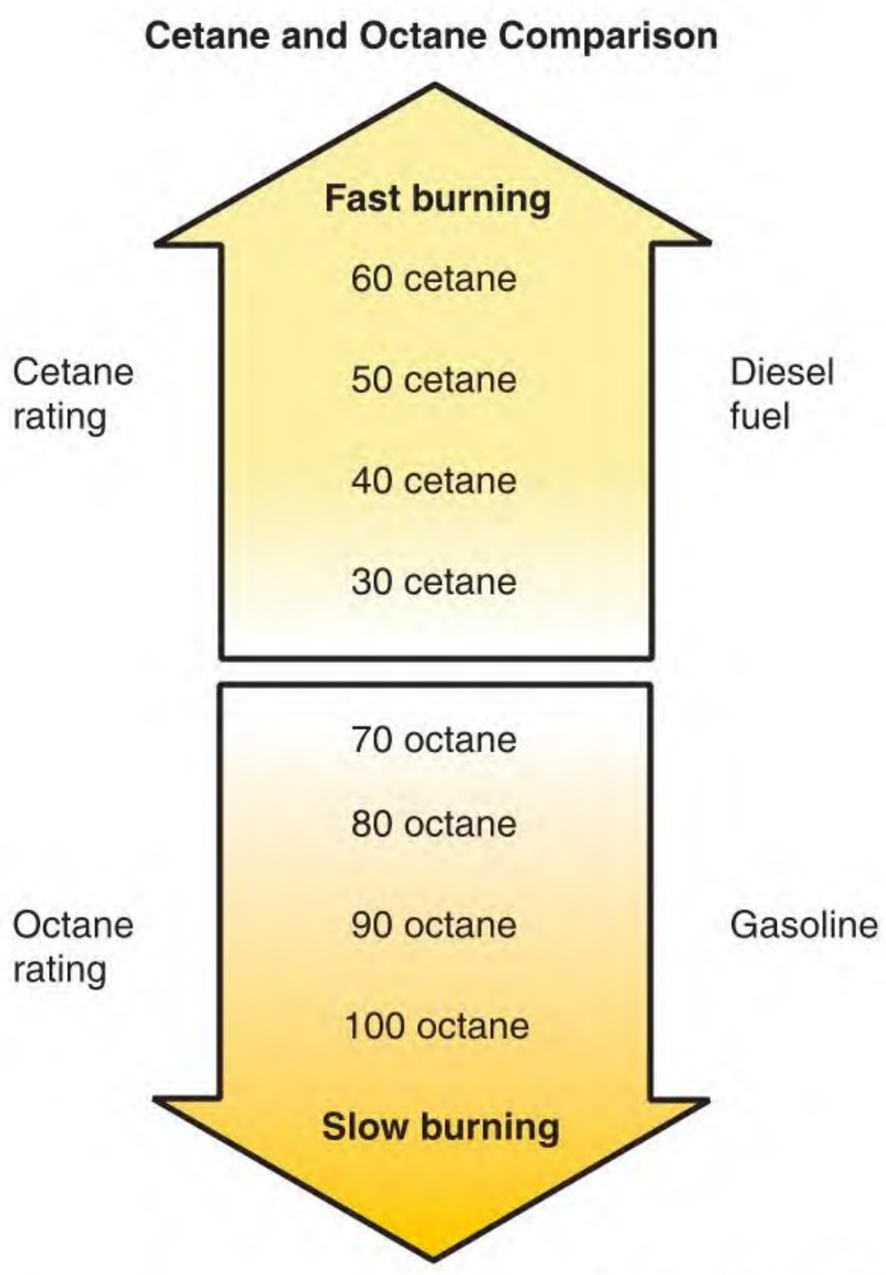
the engine will start and run in cold weather. Most automakers recommend a cetane rating of about 45. This is the average cetane value of No. 2 diesel fuel.

A cetane number, in some ways, is the opposite of a gasoline octane number. This is shown in **Figure 39-15**. A high cetane number means the fuel will ignite easily from heat and pressure. In a diesel, the fuel must ignite and burn as soon as it touches the hot air in the combustion chamber.

Diesel Combustion

A diesel engine is a ***compression-ignition engine***. This engine compresses air until it is hot enough to ignite the fuel. A spark plug would not ignite diesel fuel properly. If gasoline were used in a diesel engine, it would detonate on the compression stroke and not produce useful energy.

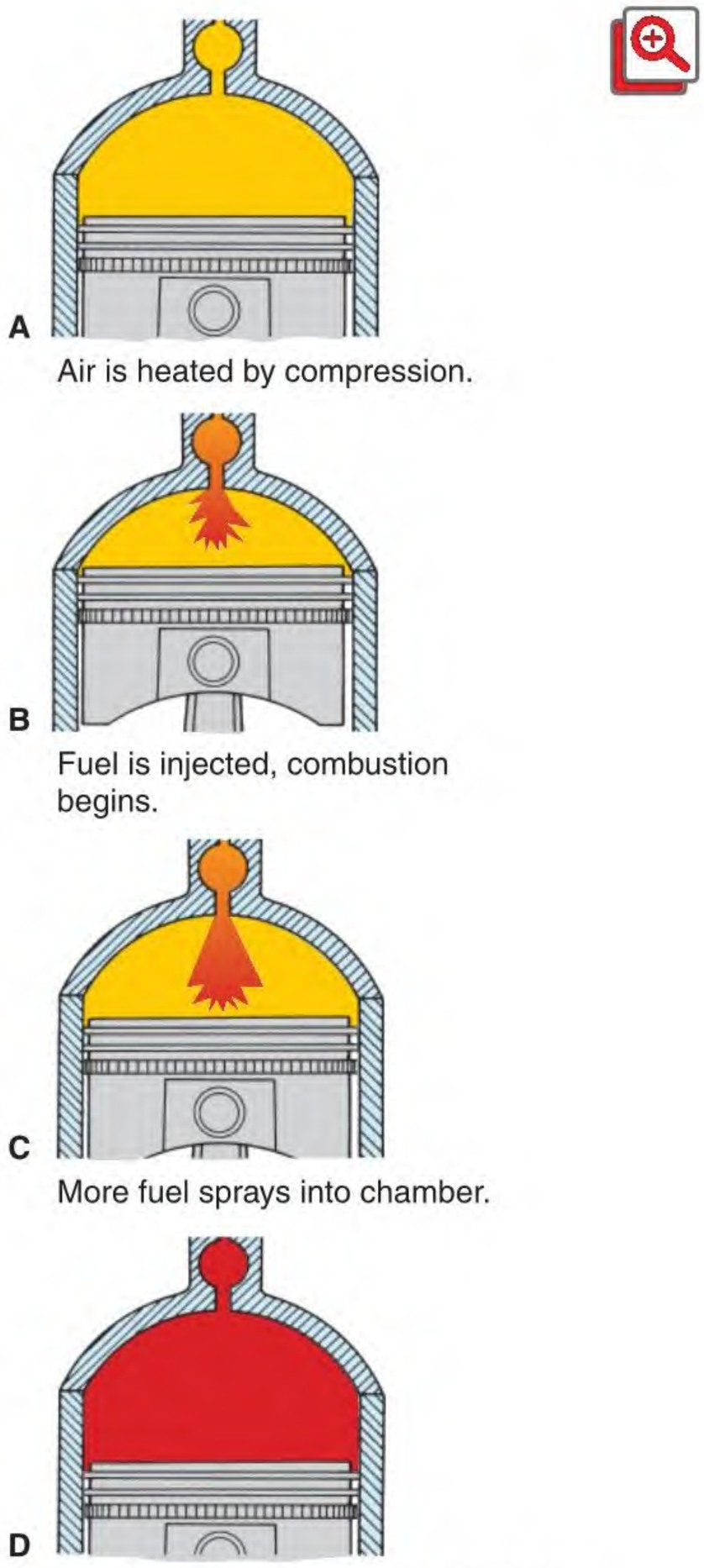
Diesel fuel is thick and hard to ignite. A high-pressure mechanical pump and nozzle force the fuel into the engine combustion chamber. An extremely high compression ratio heats the air in the cylinder. When fuel is sprayed into the hot air, it begins to burn. Normal diesel combustion is illustrated in **Figure 39-16**.



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Figure 39-15. Diesel fuel cetane rating is the opposite of gasoline octane rating.

Note that fuel is injected into the engine for several degrees of crankshaft rotation. This causes a smooth, steady buildup of pressure for quiet diesel engine operation.



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Figure 39-16. Displayed here is normal diesel combustion. A—The piston moves up to compress and heat the air in the cylinder. Note that this is different than a gasoline engine, which compresses both fuel and air. B—Diesel fuel is injected directly into the combustion chamber. The hot air makes the fuel begin to burn and expand. C—More fuel is sprayed into the chamber. More pressure is developed and the piston begins to move down in the cylinder. D—The rest of the fuel is injected into the chamber. Pressure continues to form, pushing the piston down on the power stroke.

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Selective Catalytic Reduction Systems

Selective Catalytic Reduction (SCR) systems can be found on some late-model diesel-powered vehicles. These systems automatically spray diesel exhaust fluid (DEF) into the vehicle's exhaust stream. A catalytic converter located downstream of the DEF spray nozzle breaks down toxic NO_x emissions into harmless water and nitrogen.

DEF is mixture of urea and de-ionized water. It is stored in a separate tank that typically has a blue filler cap and is located near the fuel tank. See **Figure 39-17**.

The rate of diesel exhaust fluid (DEF) consumption is termed the "dosing rate." Most diesel vehicles that use DEF have a dosing rate of 2% per gallon of diesel fuel burned. For every 100 gallons of fuel burned, 2 gallons of DEF would be injected into the exhaust system in front of the catalytic converter.

The EPA requires vehicle manufacturers to install safeguards that help prevent diesel engines from being operated without DEF. When DEF is low, a warning indicator on the instrument panel will illuminate. If the driver ignores the warning indicator and operates the diesel engine without DEF, the engine's ECU will greatly reduce engine power and limit driving speeds until the DEF container is refilled.

Alternative Fuels

Alternative fuels include any fuel other than gasoline and diesel fuel. Liquefied petroleum gas, alcohol, methane gas, and hydrogen are examples of alternative fuels.



Baloncici/Shutterstock

Figure 39-17. The DEF tank generally has a blue cap for easy identification.

Liquefied Petroleum Gas

Liquefied petroleum gas (LPG) is sometimes used as a fuel for automobiles and trucks. It is one of the lightest fractions of crude oil. Chemically, LPG is similar to gasoline. However, at room temperature and pressure, LPG is a vapor, not a liquid. Refer again to **Figure 39-3**.

A special fuel system is needed to meter the gaseous LPG into the engine. One is shown in **Figure 39-18**. Note the names and construction of the basic parts.

LPG is commonly used in industrial equipment, such as forklifts. It is also used in some fleet vehicles that always refuel at the same location. Being a gas, LPG burns cleanly, producing few exhaust emissions.

Alcohol

Alcohol has the potential to be an excellent alternative fuel for automotive engines. The two types of alcohol used in automobiles are ethyl alcohol and methyl alcohol.

Ethyl alcohol, also called ***grain alcohol*** or ***ethanol***, is made from farm crops. Grain, wheat, sugarcane, potatoes, fruit, oats, soy beans, and other crops rich in carbohydrates can be made into ethyl alcohol. This type alcohol is a colorless, harsh tasting, toxic, and highly flammable liquid.

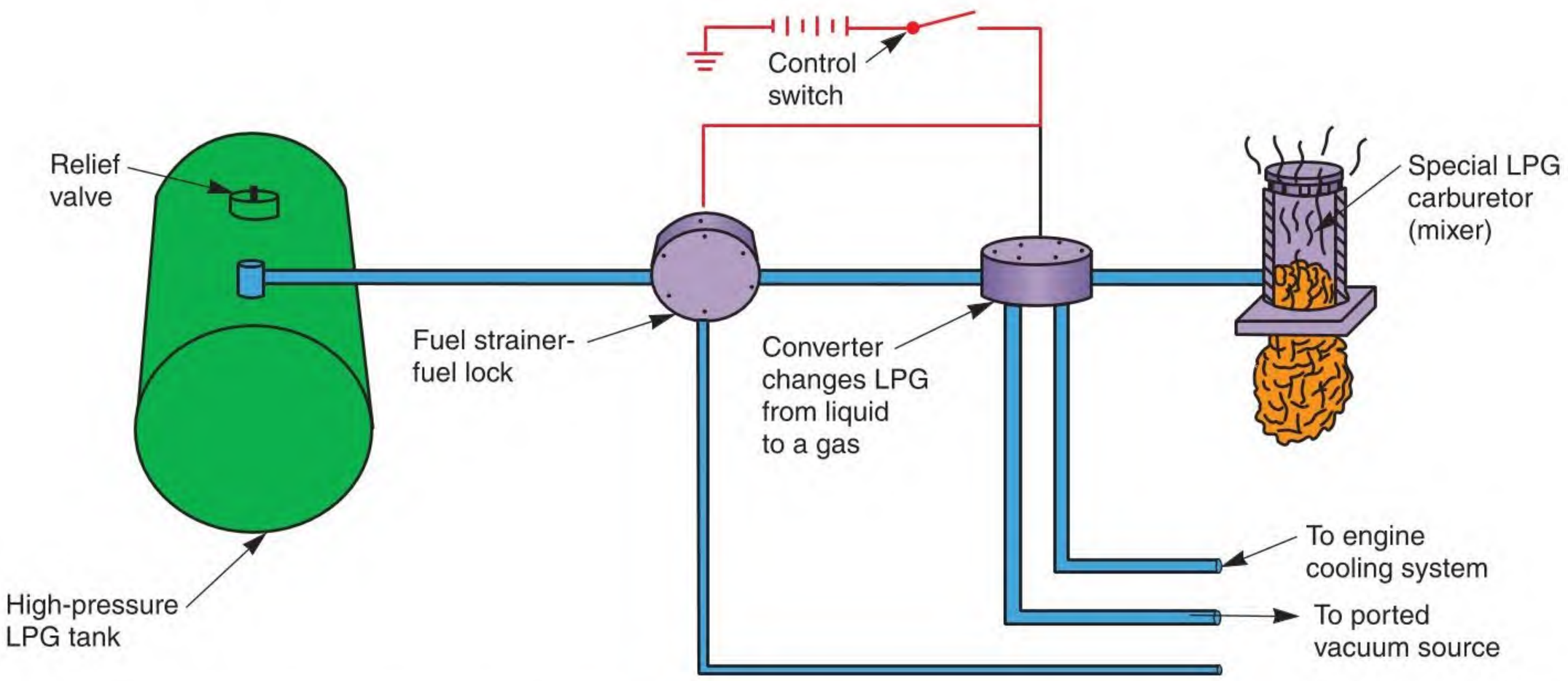
Methyl alcohol, also termed "***wood alcohol***" or ***methanol***, can be made out of wood chips, petroleum, garbage, and animal manure. It has a strong odor, is colorless, poisonous, and very flammable.

Alcohol is a clean-burning fuel for automobiles. It is not commonly used because it is expensive to use and produce. Also, the vehicle's fuel system requires modification before it can burn straight alcohol. Almost twice as much alcohol must be burned, compared to gasoline. This reduces fuel economy by 50%.

Tech Tip

Methanol is commonly used as a racing fuel. It burns cooler than gasoline and does not produce a visible flame. This can be very dangerous because you cannot see the flames if there is a fire. For increased safety, racing organizations have required the use of additives in methanol racing fuel to make its flame more visible.

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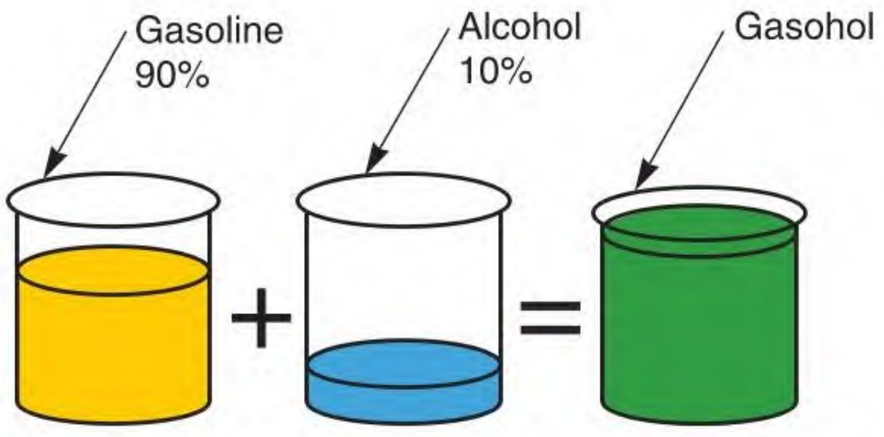
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Figure 39-18. An LPG fuel system uses a high-pressure storage tank. A fuel strainer-fuel lock cleans fuel and prevents leakage when the engine is not running. A converter uses heat from the engine coolant to change the liquid LPG into a gas. A special carburetor meters LPG into the engine.

Gasohol

Gasohol, as the name implies, is a mixture of gasoline (usually 87 octane gasoline) and alcohol (usually grain alcohol). The mixture can range from 2–20% alcohol. In most cases, gasohol is a blend of 10% alcohol and 90% gasoline. See **Figure 39-19**.

Gasohol is commonly used as an alternative fuel in motor vehicles because fuel system and engine modifications are not needed. Many gas stations sell gasohol as a high-octane fuel. The alcohol tends to reduce the knocking tendencies of the gasoline. It acts like an antiknock additive. For example, 10% alcohol can increase 87 octane gasoline to 91 octane. Gasohol can be burned in a high-compression, high-horsepower engine without detonating and knocking.



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Figure 39-19. Gasohol is usually a mixture of 10% alcohol and 90% gasoline.

Tech Tip

Flex fuel vehicles are designed to operate on a mix of up to 85% ethanol (alcohol) and only 15% gasoline. Their fuel system can sense the alcohol/gasoline percentages and adjust fuel injection as needed to maintain the correct air-fuel ratio.

Synthetic Fuels

Synthetic fuels are fuels made from coal, shale oil rock (rock filled with petroleum), and tar sand (sand filled with petroleum). See **Figure 39-20**.

Synthetic fuels are synthesized (changed) from a solid hydrocarbon state to a liquid or gaseous state. Synthetic fuels are being experimented with as a means of supplementing crude oil. As crude oil–based fuels become more expensive, synthetic fuels will become more practical.

Hydrogen

Hydrogen is a highly flammable gas that is a promising alternative fuel of the future. Hydrogen is one of the most abundant elements on our planet. It can be produced through the electrolysis of water (sending electric current through saltwater). This is illustrated in **Figure 39-21**.

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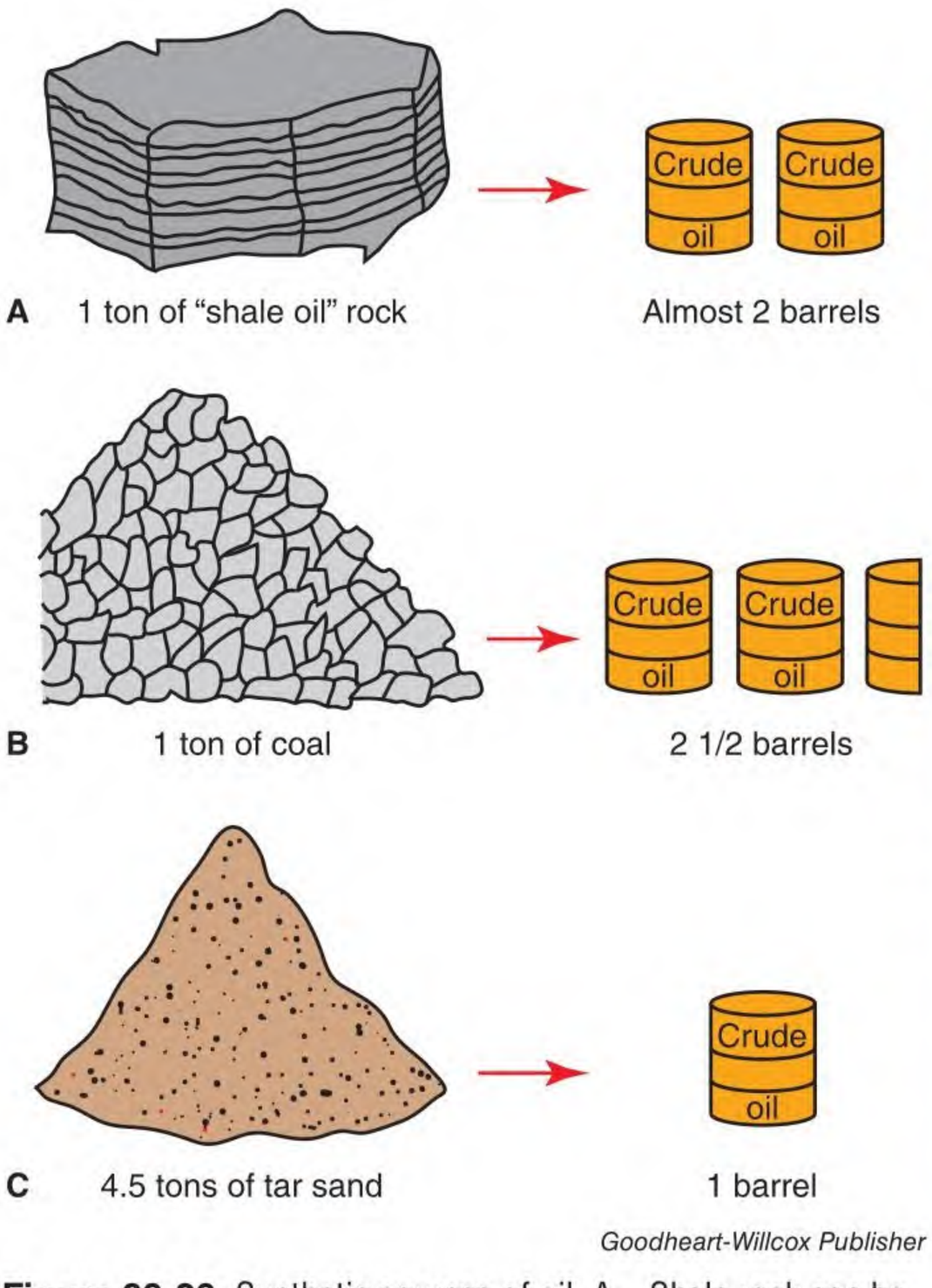


Figure 39-20. Synthetic sources of oil. A—Shale rock can be converted into oil. B—Coal can produce about two and one-half barrels of oil per ton. C—Four and one-half tons of tar can be changed into about one barrel of oil.

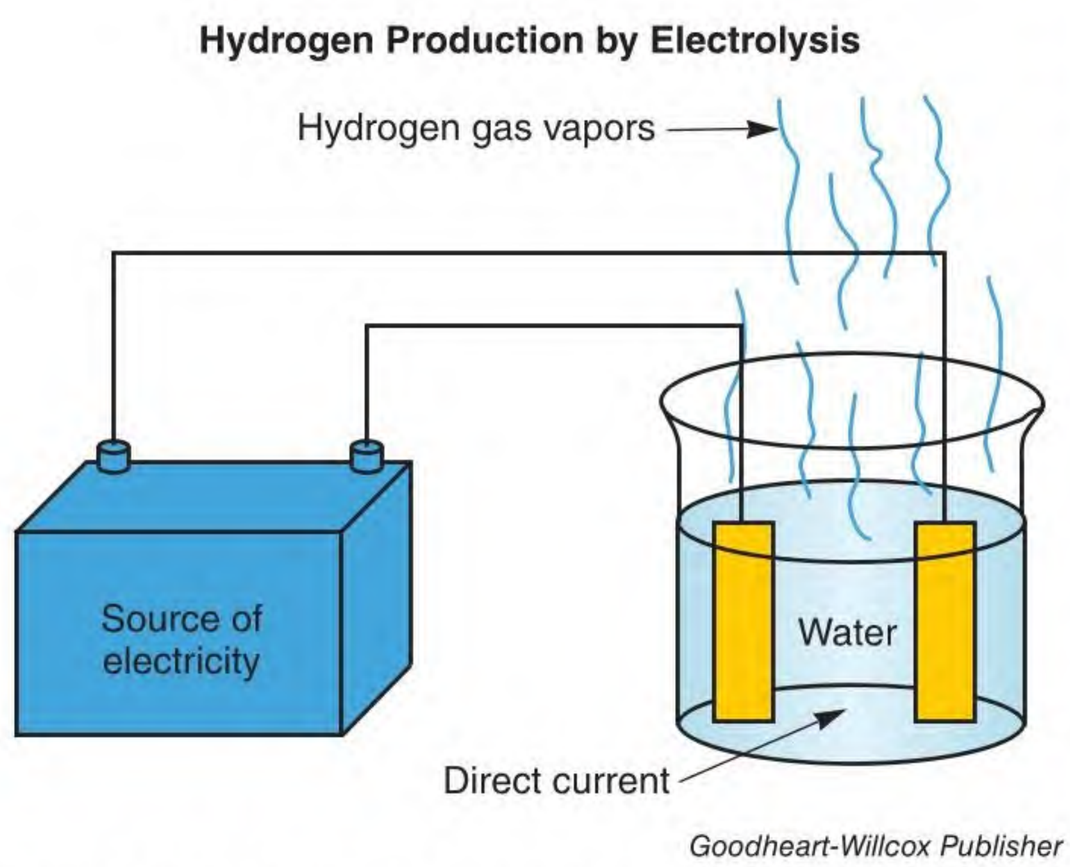


Figure 39-21. Hydrogen gas can be made through the electrolysis of water. Solar cells, wind energy, or ocean thermal energy may make production feasible someday.

Hydrogen is an ideal fuel. Hydrogen burns almost perfectly, leaving only water and harmless carbon dioxide as by-products.

Many manufacturers are now working to develop hydrogen-powered vehicles. Presently, hydrogen is expensive to make and store. However, as we use up our supply of crude oil, we may someday make hydrogen a major source of automotive fuel.

Diagnostic Case Study

Concern: Mrs. Shy drives her 2010 Cadillac into the shop for service. She says the car seems to be running fine, but it is making a noise that sounds like there is a woodpecker under the hood. A dash light is also glowing.

Cause: Duff drives the vehicle to verify the problem. He notices a light, erratic pinging sound coming from the engine compartment during acceleration. Duff suspects the sound is the result of using low-octane fuel in a high-compression engine. A scan tool reading also shows a trouble code for the knock sensor.

Duff questions Mrs. Shy about the type of gasoline she uses in the vehicle. She informs him that she uses regular gasoline because it is cheaper than the premium grades. She adds that she spent so much for the car that she has been trying to save a little money on gasoline. Duff checks the owner's manual, which specifies that fuel with an octane rating of 91 or higher should be used in the vehicle. Duff knows that prolonged engine ping can trip a code for the knock sensor circuit, which is hearing the pinging and reporting a problem to its ECM.

Correction: Duff assigns the repair to one of his apprentice technicians. He instructs the technician to drain the fuel tank and then refill it with "premium" gasoline.

The apprentice does as he is instructed. He then starts the car and allows it to run for a few minutes before performing a test drive. During the test drive, no pinging or knocking sounds are heard, and no further trouble codes are set. When the apprentice returns the car to Mrs. Shy, he shows her the fuel octane rating information in the owner's manual and explains the importance of using the correct grade of gasoline.

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Summary

- Petroleum, also called crude oil, is oil taken directly out of the ground.
- Gasoline is the most common type of automotive fuel.
- The octane rating of gasoline is a measurement of the fuel's ability to resist knocking or pinging.
- Normal gasoline combustion occurs when the spark plug ignites the fuel and burning progresses smoothly through the air-fuel mixture.
- A stoichiometric fuel mixture is a chemically correct, or perfect, air-fuel mixture.
- Detonation results when part of the unburned air-fuel mixture explodes violently.
- Preignition results when an overheated surface in the combustion chamber ignites the fuel mixture prematurely.
- Dieseling, also called after-running or run-on, occurs when the engine keeps running after the key is turned off.
- Diesel fuel is the second most popular type of automotive fuel.
- No. 2 diesel fuel is normally recommended for use in car and truck diesel engines.
- A cetane rating indicates the cold starting ability of diesel fuel.
- Alternative fuels include any fuel other than gasoline and diesel fuel. LPG, alcohol, and hydrogen are examples of alternative fuels.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

abnormal combustion
after-running
alcohol
alternative fuels
antiknock additives
cetane rating
cloud point
combustion
combustion efficiency
compression-ignition engine
crude oil
detonation
diesel fuel
diesel fuel grades
dieseling
distillation
end gas
engine knock
ethanol
ethyl alcohol
exploration tests
flex fuel vehicles
fractionating tower
fuel
gasohol
gasoline
grain alcohol
hydrocarbons
hydrogen
lean air-fuel mixture
liquefied petroleum gas (LPG)
methanol
methyl alcohol
normal combustion
octane enhancers
octane rating
oxygenates
paraffin
petroleum
ping
preignition
refinery
rich air-fuel mixture
run-on
spark knock
stoichiometric fuel mixture
surface ignition
vaporize
viscosity
water contamination
water separators
wood alcohol

Activities

1. Research automotive fuels on the Internet and prepare a written report on additives and their properties.
2. Research magazines and newspapers for information about the manufacture of alcohol for use as an automotive fuel.
3. Research and discuss modifications of engines for use of LPG as a fuel.

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Review Questions

Answer the following questions using the information provided in this chapter.

1. _____, also called _____, is oil taken directly out of the ground.
2. What are hydrocarbons?
3. Crude oil is converted into more useful substances at a(n) _____.
4. _____ are extra chemicals added to gasoline to improve its operating characteristics.
5. The _____ of gasoline is a measurement of the fuel's ability to resist knock or ping.
6. If an automaker recommends gasoline with an octane number of 91, 87 octane gasoline is also acceptable. True or False?
7. Which of the following is *not* needed for proper combustion?
   (A) Air.
   (B) Compression.
   (C) Condensation.
   (D) Ignition.
8. Describe normal gasoline combustion.
9. Define the term *stoichiometric fuel mixture*.
10. A(n) _____ air-fuel mixture ratio contains a large amount of air.
11. A(n) _____ air-fuel mixture ratio contains a large amount of fuel.
12. What are the results of lean and rich air-fuel mixtures?
13. Explain detonation, preignition, spark knock, and dieseling in a gasoline engine.
14. How does diesel fuel differ from gasoline?
15. What does diesel fuel cetane rating indicate?
16. _____ is made from farm crops and _____ can be made out of wood chips, petroleum, garbage, and animal manure.
17. What is gasohol?
18. Gasohol can normally be used without major engine or fuel system modifications. True or False?
19. A certain gasohol mixture contains 5% alcohol. What is the approximate percentage of gasoline in this mixture?
    (A) 85%.
    (B) 92%.
    (C) 90%.
    (D) 95%.
20. Which of the following does *not* pertain to hydrogen as an alternative fuel?
    (A) Made from most abundant element.
    (B) Produced through electrolysis.
    (C) Burns without toxic emissions.
    (D) Economical or inexpensive to make.

ASE-Type Questions

1. Crude oil is used to make each of these *except:*
   (A) LPG.
   (B) gasoline.
   (C) hydrocarbons.
   (D) hydrogen.
2. Crude oil is a mixture of:
   (A) liquids.
   (B) semisolids.
   (C) hydrocarbons.
   (D) All of the above.
3. Which of these is a commonly used antiknock additive?
   (A) Naphthas.
   (B) Oxygenates.
   (C) Petrochemicals.
   (D) None of the above.
4. Which of the following is the measurement of a fuel's ability to resist knock?
   (A) Octane rating.
   (B) Cetane rating.
   (C) Cloud point.
   (D) All of the above.
5. Normal combustion takes about:
   (A) 1/100 of a second.
   (B) 3/1000 of a second.
   (C) 3/10,000 of a second.
   (D) 1/50,000 of a second.
6. A chemically correct air-fuel ratio is called a:
   (A) rich air-fuel mixture.
   (B) lean air-fuel mixture.
   (C) combustible fuel mixture.
   (D) stoichiometric fuel mixture.

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7. Each of these is a form or result of abnormal combustion *except*:
   (A) detonation.
   (B) ignition lag.
   (C) engine knock.
   (D) after-running.
8. A diesel fuel substance that can separate from other fuel parts and clog fuel filters is:
   (A) lead.
   (B) water.
   (C) carbon.
   (D) paraffin.
9. Automakers recommend a cetane rating of about:
   (A) 45.
   (B) 50.
   (C) 55.
   (D) 60.
10. When looking at cetane ratings, Technician A says that the higher a cetane number is, the easier an engine starts and runs in cold weather. Technician B says that the higher a cetane number is, the easier a fuel ignites from heat and pressure. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Chapter 40
Fuel Tanks, Pumps, Lines, and Filters

After studying this chapter, you will be able to:

- Define the major parts of a fuel supply system.
- Describe the operation of mechanical and electric fuel pumps.
- Explain the tests used to diagnose problems with fuel pumps, fuel filters, and fuel lines.
- Repair a fuel line or replace a fuel hose.
- Locate and replace fuel filters in both gasoline and diesel fuel systems.
- State safety rules for working on fuel supply systems.
- Describe the construction and action of air filters.
- Correctly answer ASE certification test questions on fuel tanks, fuel pumps, fuel lines, fuel filters, and air filters.

A ***fuel system*** must provide a combustible air-fuel mixture to power the engine. See **Figure 40-1**. Today's cars commonly use gasoline injection and sometimes diesel injection systems. Older vehicles use carburetors.

This chapter explains the construction, operation, and service of fuel tanks, fuel lines, fuel filters, air filters, and fuel pumps. These parts make up the fuel and air supply systems. The information in this chapter will prepare you for later chapters on fuel metering systems. Study carefully!

The type of fuel system found on a passenger vehicle depends primarily on the vehicle's date of manufacture or model year. See **Figure 40-2**.

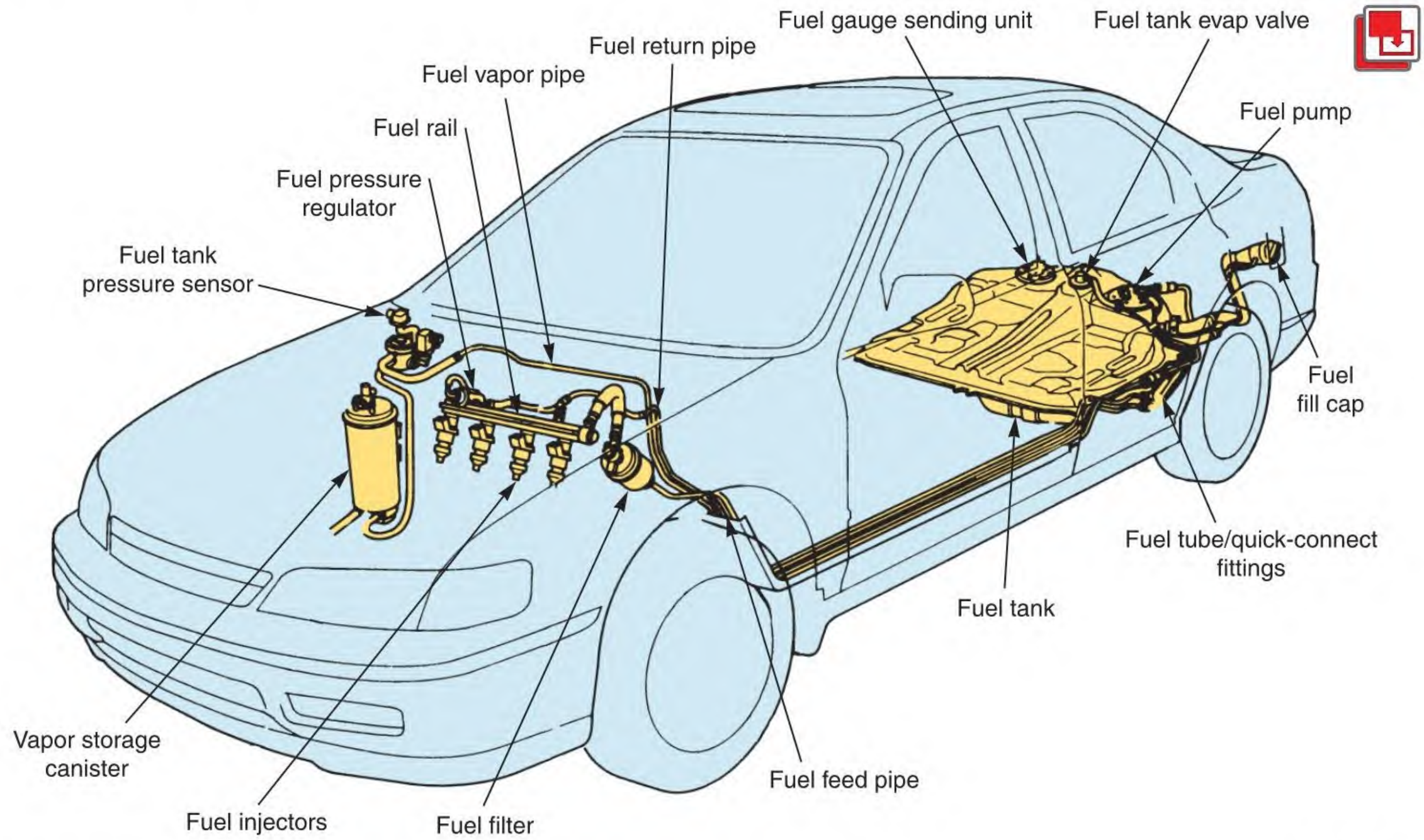
From the early 1900s to the late 1970s, passenger vehicles used carburetors and engine vacuum to meter fuel into the engine. A single, low-pressure, mechanical fuel pump was mounted on the engine to pull fuel from the tank and force it to the carburetor. Vacuum, or suction, pulled the fuel out of the carburetor and into the airstream entering the engine's intake manifold.

In the 1980s, cars and light trucks were equipped with throttle body fuel injection (single-point injection) and electronically-controlled carburetors. These early engineering attempts at electronic fuel control were not very dependable or efficient.

Most vehicles built since the 1990s use multiport, or multi-point, fuel injection to better meter gasoline into each engine cylinder. In a multiport injection system, each cylinder's fuel injector nozzle aims right at its intake valves. When the intake valves are pushed open, the air and fuel charge are pulled into the cylinder.

Many late-model gasoline engines are equipped with direct injection systems (DIS) to improve engine power and efficiency. In these systems, gasoline is sprayed into the air already inside the engine's combustion chambers for more complete burning of the fuel.

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Honda

Figure 40-1. Note the location of typical fuel supply system components.

Direct fuel injection has always been used on diesel engines. Early-model diesels used a mechanical injection pump and mechanically actuated fuel injectors. Late-model diesels still use a mechanical fuel pump, but they use electronic fuel injectors instead of cam-operated mechanical injectors.

Tech Tip

A few late-model engines are equipped with both direct and port fuel injection systems to improve throttle response for higher performance.

Fuel System Technology

A modern fuel system has three subsystems:

- Fuel supply system—A ***fuel supply system*** provides clean, filtered gasoline, diesel oil, or alternate fuel to the fuel injectors.
- Air supply system—An ***air supply system*** allows clean, filtered, air to flow into the engine's combustion chambers.
- Fuel metering system—A ***fuel metering system*** meters the correct amount of fuel into the engine cylinders depending on engine speed, temperature, load, throttle position, and other factors.

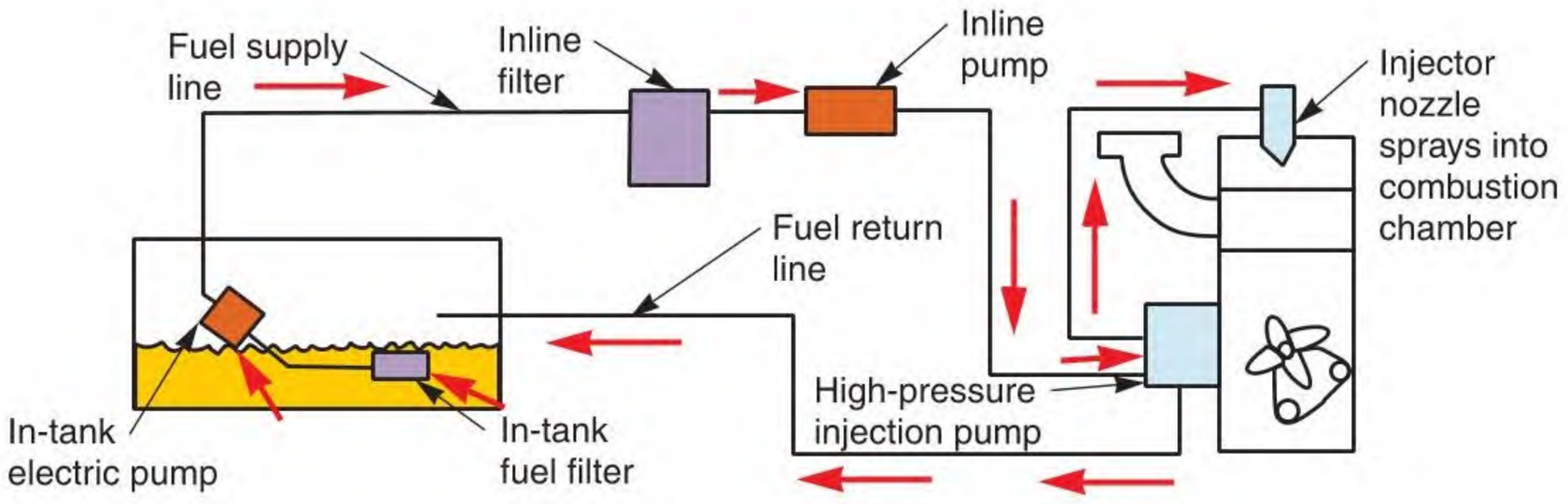
Fuel Supply System

A fuel supply system draws fuel from the fuel tank and forces it into the fuel metering device (usually gasoline injectors). Modern vehicles use mechanical and electric fuel pumps in tandem.

A fuel supply system includes the following basic parts:

- Fuel tank—A ***fuel tank*** stores gasoline, diesel fuel, gasohol, alcohol, LPG, or other combustible material safely.
- Fuel lines—***Fuel lines*** safely carry fuel between the fuel tank, fuel pumps, fuel hoses, fuel filters, pressure regulator, and other parts of the system.

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Figure 40-2. Study the basic types of fuel supply systems. Note the differences between direct gas or diesel injection; port fuel injection; throttle body injection; and old carburetor systems.

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- Fuel pumps—***Fuel pumps*** draw fuel from the tank and force it to the engine and fuel-injectors.
- Fuel filters—***Fuel filters*** remove contaminants such as water, rust, and other debris in the fuel.

Fuel Tanks

An automotive fuel tank must safely hold an adequate supply of fuel so the vehicle can be driven a reasonable distance without refueling. With front-engine vehicles, it is mounted in the rear of the car, under the trunk or the rear seat.

The size of a fuel tank determines, in part, a car's ***driving range*** (distance a vehicle can be driven without stopping for fuel). ***Fuel tank capacity*** is the volume of fuel (in gallons or liters) a fuel tank can hold. Average fuel tank capacity is 12–25 gallons (45–95 liters).

Fuel Tank Construction

Fuel tanks can be made of sheet steel, aluminum, or injection molded plastic, with adhesive bonding forming a chemical weld between mating surfaces. Sheet metal stampings may also be welded together robotically to form a leakproof seam all the way around the mating surfaces. Other parts (filler neck, baffles, vent tubes, expansion chamber) are added to form the complete fuel tank assembly, **Figure 40-3**. A zinc alloy is normally plated to the sheet metal to keep the tank from rusting.

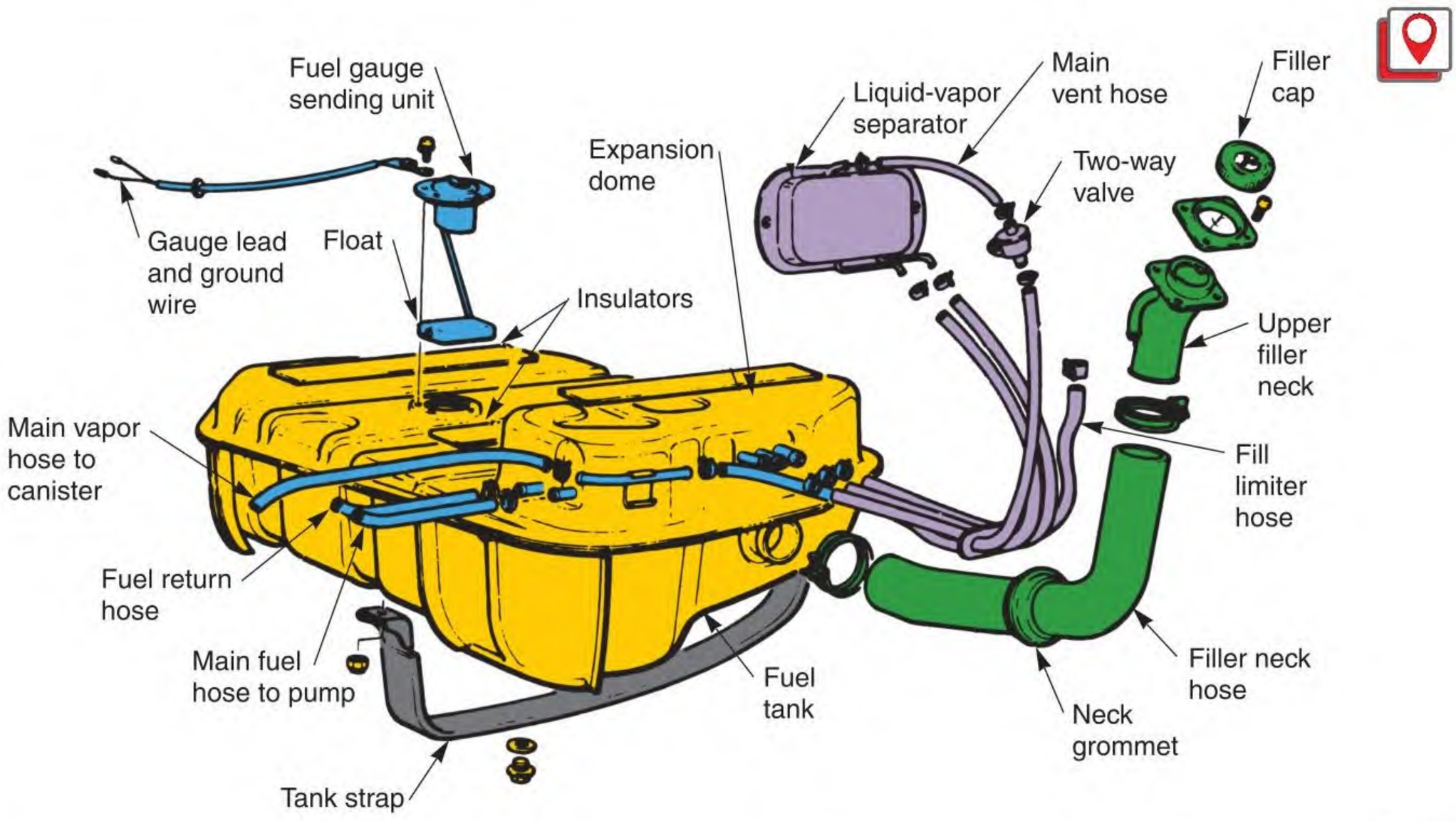
The ***filler neck*** is the extension tube that allows the gas pump nozzle to be used to fill the tank with fuel. The ***filler cap*** fits on the end of the filler neck. The neck extends from the tank through the body of the car. A flexible hose is normally used as part of the filler neck. It allows tank vibration without part breakage.

A ***spillback ball*** is a large "ping pong–type" ball in the filler neck to prevent fuel from leaking out of the vehicle during fill-ups.

Modern filler caps are sealed to prevent the escape of fuel and fuel vapors (emissions) from the tank. Normally, fuel vapors are not vented to the atmosphere.

Fuel tank baffles are located inside the fuel tank to keep fuel from sloshing, or splashing, around in the tank. The baffles are metal plates that restrict fuel movement when the car accelerates, decelerates, or turns.

Fuel tank straps are used to secure the tank to the vehicle. They are thick steel bands that bolt around the fuel tank to hold it in place. Some tanks are held in place with bolts that pass through the tank's flanges. A fuel tank cover is sometimes used to prevent damage from road debris.



Chrysler

Figure 40-3. The basic external parts of a typical fuel tank assembly are shown.

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Fuel Tank Pickup-Sending Unit

A ***pickup-sending unit*** extends down into the tank to draw out fuel and operate the fuel gauge. A coarse filter is usually placed on the end of the pickup tube to strain out larger debris in the fuel tank.

The sending unit is a variable resistor. Its resistance changes with changes in the fuel level. See **Figure 40-4**. This allows the sending unit to control the amount of current reaching the fuel gauge in the instrument panel.

When the fuel level in the tank is low (float down), the sending unit has a high resistance. Only a small amount of current flows to the gauge. The gauge shows a low fuel level.

When the tank is full (float up), the sending unit has a low resistance. More current flows to the gauge, and the gauge needle moves to the full position.

Fuel Tank Pressure Sensors

A ***fuel tank pressure sensor*** is used to monitor the buildup of fuel tank pressure in late-model vehicles equipped with OBD II systems. The sensor aids in the operation of the evaporative emissions and fuel return control circuits.

Fuel Lines and Hoses

Fuel lines and ***fuel hoses*** carry fuel from the tank to the engine. Refer to **Figure 40-5**. Fuel lines are normally made of strong, double-wall steel tubing. For fire safety reasons, a fuel line must be able to withstand the constant and severe vibration produced by the engine and road surface.

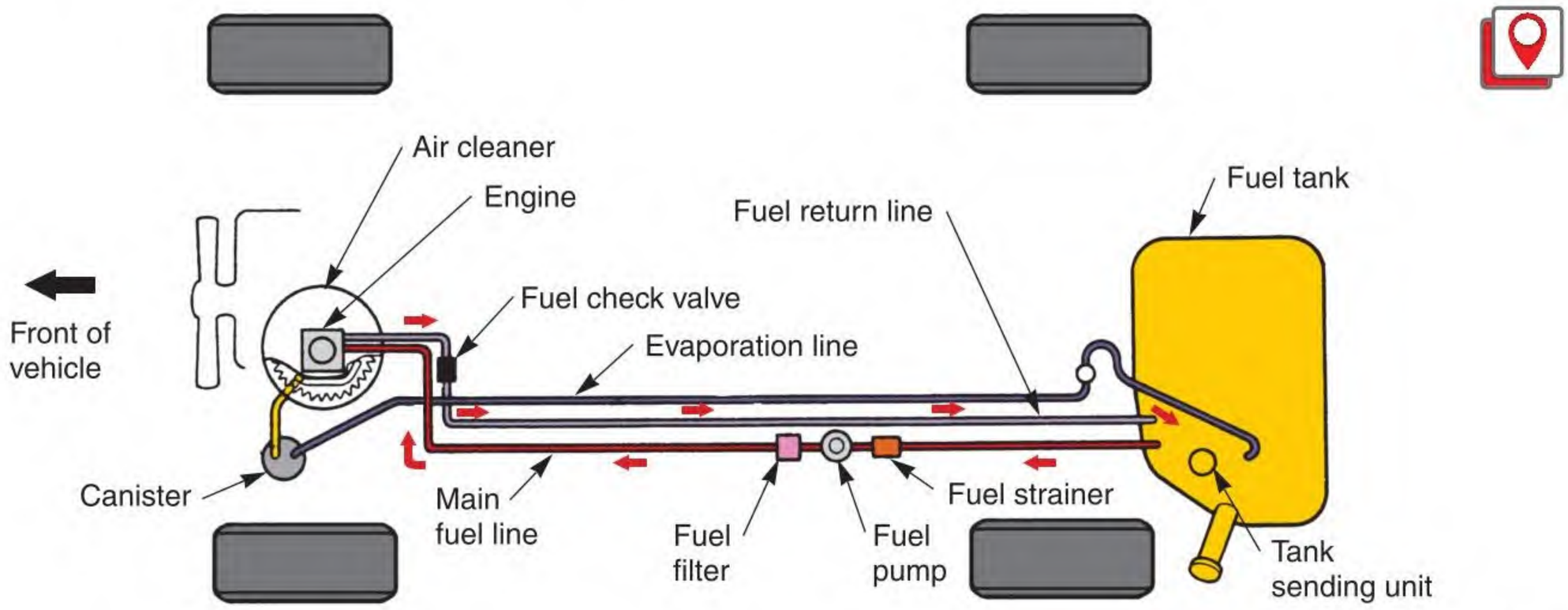
A ***fuel rail*** is a large-diameter fuel line that feeds fuel to the inlet openings of the fuel injectors. It serves the same purpose as the fuel line but provides a greater volume of fuel right before the injectors. The fuel rail prevents any injector from starving for fuel under high-demand conditions.

Fuel hoses, made of reinforced synthetic rubber, are needed where severe movement occurs between fuel system parts. For example, a fuel hose is used between the main fuel line and the engine. The engine

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Figure 40-4. Study fuel tank sending unit and fuel gauge operation.

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Mazda

Figure 40-5. Study fuel and emission control lines. Note the location of the fuel pump, filters, and other devices.

is mounted on rubber motor mounts. The soft mounts allow the engine some movement in the unibody or frame. A flexible hose can absorb this movement without breaking. ***Hose clamps*** secure fuel hoses to the fuel lines or metal fittings.

Plastic Fuel Lines

Plastic fuel lines, also called *fuel pipes*, are made of high-strength nylon tubing, which can withstand the chemical action, pressure, and heat encountered in fuel system applications. They can be used instead of metal lines in some low-pressure installations. Plastic lines are light and flexible, but they are not as strong as double-wall steel tubing.

Fuel feed, fuel return, and even injector feed lines can be made of plastic. The inside diameter of the plastic line determines its size when ordering. Rubber hose or heavy corrugated plastic conduit is often placed over the plastic line to protect it from chafing, vibration, and heat.

Quick-disconnect fittings are often used with plastic fuel lines. One end of the fitting is male, and the other end is female. An O-ring seal is compressed inside the fitting to prevent leaks.

Fuel Return System

Most vehicles use a ***fuel return system*** to cool the gasoline and prevent vapor lock (bubbles form in overheated fuel and stop fuel flow). In these systems, a fuel return line carries excess fuel back to the tank. This keeps engine heat from overheating the gasoline by constantly circulating unused fuel back to the fuel tank.

Returnless Fuel Injection Systems

Some late-model vehicles are equipped with ***returnless fuel injection systems***. As their name implies, these systems do not have fuel return lines. This design helps reduce evaporative emissions by minimizing fuel vaporization. In a conventional fuel return system, the fuel that returns to the tank is hot. The hot fuel warms the rest of the fuel in the tank. Warming the fuel in the tank causes it to vaporize more readily. Because hot fuel is not returned to the tank in a returnless system, the fuel in the tank remains relatively cool and fuel vaporization is minimized.

Returnless fuel injection systems control fuel system pressure by varying fuel pump output. When pressure in the fuel rail changes, this sensor signals the computer or ECM to increase or decrease current sent to the electric fuel pump motor, varying the output of the pump. The engine ECM can also vary the amount of time the fuel injectors are "on" to compensate for changes in system pressure.

Fuel Filters

Fuel filters stop contaminants (rust, water, corrosion, sand, dirt) from entering the fuel pump, fuel lines, pressure regulator, fuel rail, and injectors. A fuel filter inlet screen is normally located on the fuel tank pickup inside the fuel tank. A second fuel filter (main fuel filter) is commonly located in the main fuel line.

Fuel Filter Construction

A ***pleated fuel filter*** made of coated paper or plastic is the most common fuel filter element found in

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gasoline fuel systems. Some fuel systems use a sintered bronze (porous metal) element or similar design. All types are capable of stopping very small particles that can easily damage precision fuel injectors and mechanical fuel pumps.

A ***bowl fuel filter*** can be found on modern diesel engines. These filters can easily trap water since water is heavier than fuel. The water settles to the bottom of the bowl while the light fraction gasoline floats on top of the water. When the element inside the bowl becomes dirty, the technician can remove the bowl for water removal, cleaning, and filter replacement.

A ***canister fuel filter*** is housed inside a metal container mounted in a fuel line. When the filter requires replacement, a new element can be installed inside its steel container.

A ***fuel strainer***, often called a *soft metal sock*, on the inlet of the in-tank fuel pump keeps debris from entering the system.

Fuel Filter Locations

Fuel filters may be found in the following locations:

- In the fuel tank on the end of the fuel pickup tube.
- In the fuel line before the fuel rail, fuel injectors, diesel injection pump, or carburetor.
- Inside the fuel pump.
- In the fuel line right after the electric fuel pump.
- Under the fuel line fitting in antique carburetors.

When in doubt about fuel filter locations, refer to a service manual. It will give information about service intervals, cleaning, and replacement of all system filters.

Tech Tip

If a fitting must be loosened when changing a fuel filter, use a flare nut wrench. Do not overtighten and strip the fitting when replacing the filter. Double-check that the fuel hose, if used, is fully installed over the fitting barbs.

Fuel Pumps

A fuel pump draws fuel out of the fuel tank and forces it to the engine under pressure. Many modern engines use two fuel pumps to push liquid gasoline or other fuel out of its storage tank, through the fuel lines, fuel filters, and pressure regulator, and to the electronic fuel injectors.

There are two basic types of automotive fuel pumps: electric and mechanical. The electric fuel pump is a low-pressure feed pump inside the fuel tank or in series with a fuel line. The mechanical fuel pump is a high-pressure fuel pump mounted on the engine. See **Figure 40-6**.

Most multiport injection systems use a single electric fuel pump. Some engines with multiport fuel injection often have two electric fuel pumps: one in the tank and one in a fuel line before the engine. The two fuel pumps are connected in series using fuel hoses and metal fuel lines.

Tech Tip

A spark or electric short will not ignite gasoline or diesel oil in its liquid state. In-tank fuel pumps are submerged in liquid fuel inside the fuel tank while being electrically energized. It is safe to send current through wires and fuel in the fuel tank. Only if the tank was empty and full of fumes could an in-tank fuel spark or pump short cause the tank to explode.

Never try to weld and repair a leaking gas tank! The heat can dissolve fuel varnish in the tank, generating flammable, explosive fumes.



Bosch

Figure 40-6. Study the parts of a high-pressure mechanical fuel pump.

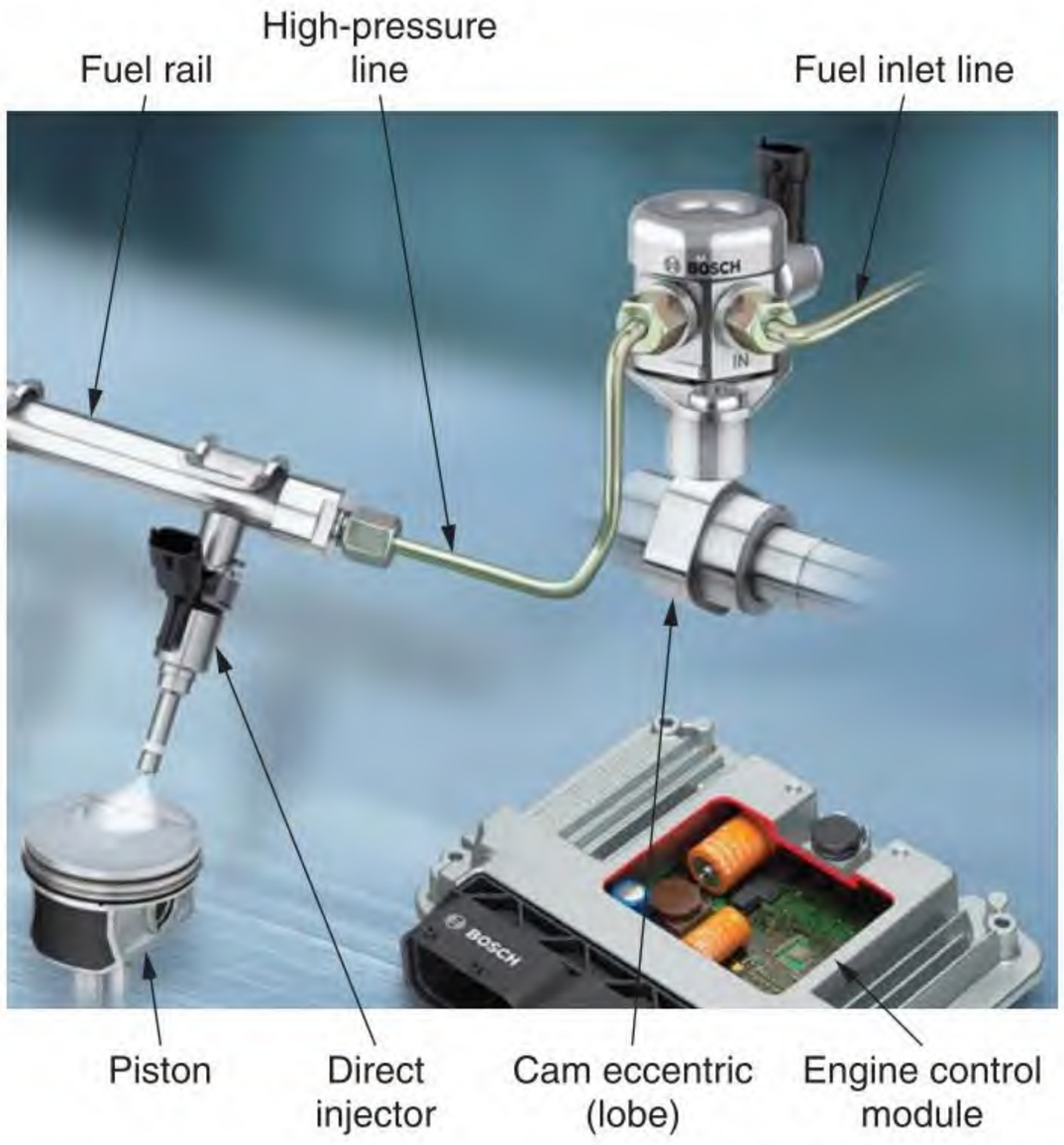
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A direct fuel injection system has an electric feed pump and a mechanical high-pressure fuel pump in series to multiply pressure. The feed pump primes the high-pressure fuel pump with gasoline. The mechanical pump multiplies this fuel pressure to fill the fuel rail and injectors with gasoline or diesel oil.

Mechanical Fuel Pumps

A ***mechanical fuel pump*** is usually powered by an engine camshaft ***eccentric*** (egg-shaped lobe) to produce a reciprocating motion on a piston or plunger. The fuel pump eccentric can be inside the fuel pump or machined on the engine's OHC camshaft. As the eccentric rotates, its lobes push the pumping plunger into the pump to build pressure. Then, when the lobe rotates away from the fuel pump rod, spring tension pushes on the pump piston or plunger back down to fill the pressure chamber with another charge of fuel.

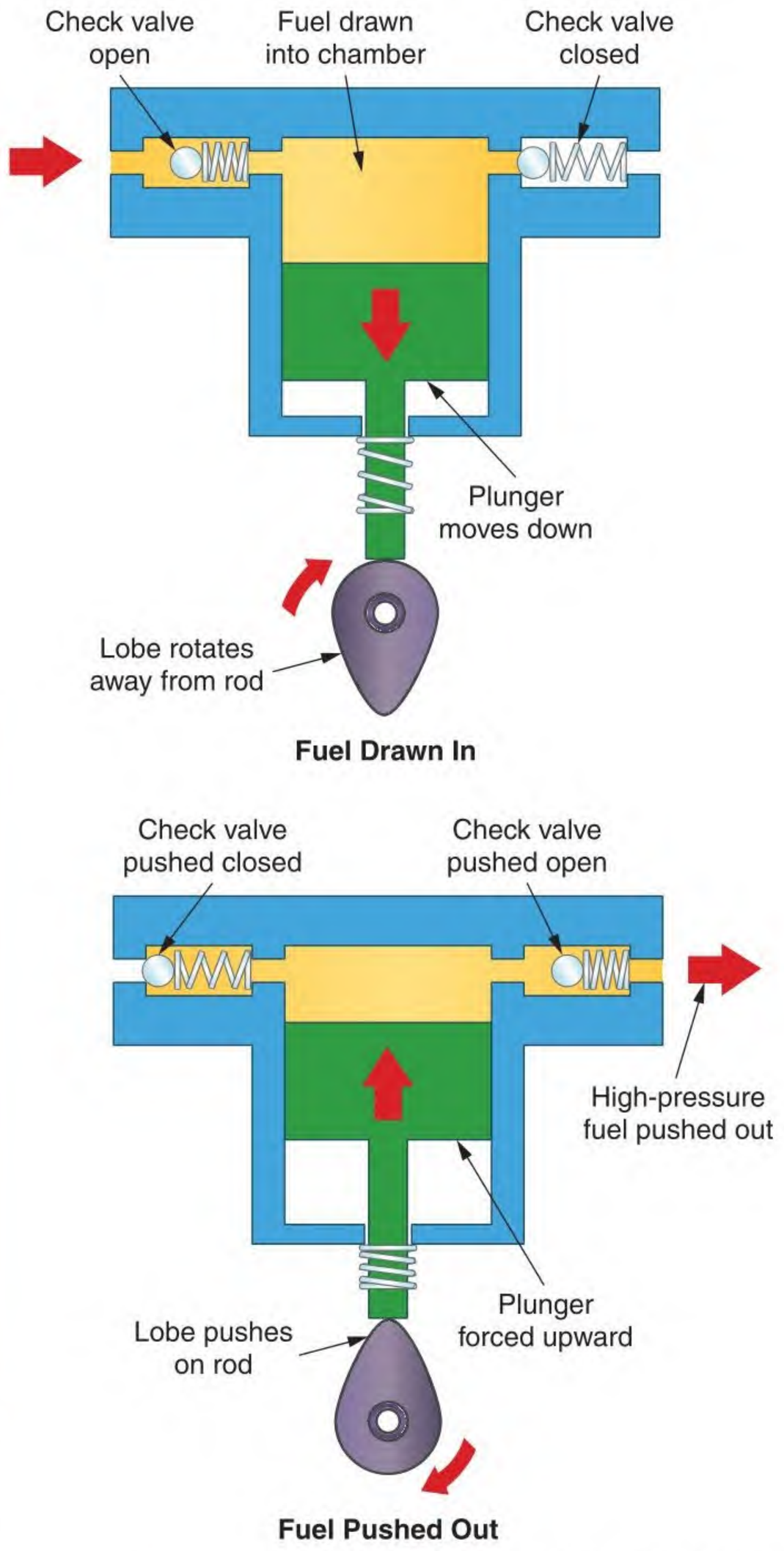
Mechanical fuel pumps are used on all engines with direct fuel injection and on older carburetor fuel systems. Since the mechanical pump uses a back-and-forth motion to create pressure, it is classified as a ***reciprocating*** pump. See **Figure 40-7**.



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Figure 40-7. The mechanical fuel pumps used in late-model direct ignition systems are often driven by a multi-lobe eccentric machined on the engine camshaft. This type of mechanical fuel pump can force 2000 psi of pressure into the injector body.

Two ***check valves*** are used in a mechanical fuel pump: the inlet check valve and the outlet check valve. Fuel flows easily through the valves in one direction but cannot flow through in the other direction. The two check valves are reversed to allow pump flow in only one direction. This causes the fuel to enter through one valve and exit through the other. Refer to **Figure 40-8**.



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Figure 40-8. Notice the direction of fuel flow through these check valves.

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High-Pressure Mechanical Fuel Pump Operation

The operation of a high-pressure mechanical fuel pump used in DEFI systems is relatively simple. During the ***fuel pump pressure stroke***, the eccentric lobe pushes on the mechanical fuel pump rod and plunger. This compresses the fuel pump spring and pushes the plunger into the pumping chamber. The area in the pumping chamber is decreased. Since a liquid cannot be compressed, the resulting pressure pushes fuel past the outlet check valve. This forces fuel past the pressure regulator and into the fuel rail.

On the ***fuel pump charging stroke***, the eccentric lobe rotates away from the fuel pump. This releases the fuel pump spring so it can pull the pumping plunger and rod in the other direction. This snaps the outlet valve closed and pushes the inlet valve open so the pumping chamber can be refilled with fuel from the tank.

A fuel pump gasket prevents oil leakage between the mechanical fuel pump and the engine. Some late-model, high-pressure fuel pumps contain their own eccentric and are driven by the engine timing chain.

Fuel Pump Pressures

Pressures produced by the mechanical fuel pumps used in direct injection systems can range from 1500–2000 psi (10–14 MPa). A fuel leak at these pressures can be very dangerous. This is enough fuel pressure to cause serious injury even if the fuel does not ignite and burn. A high-pressure fuel leak can puncture your skin and inject gasoline into your bloodstream, which could be fatal.

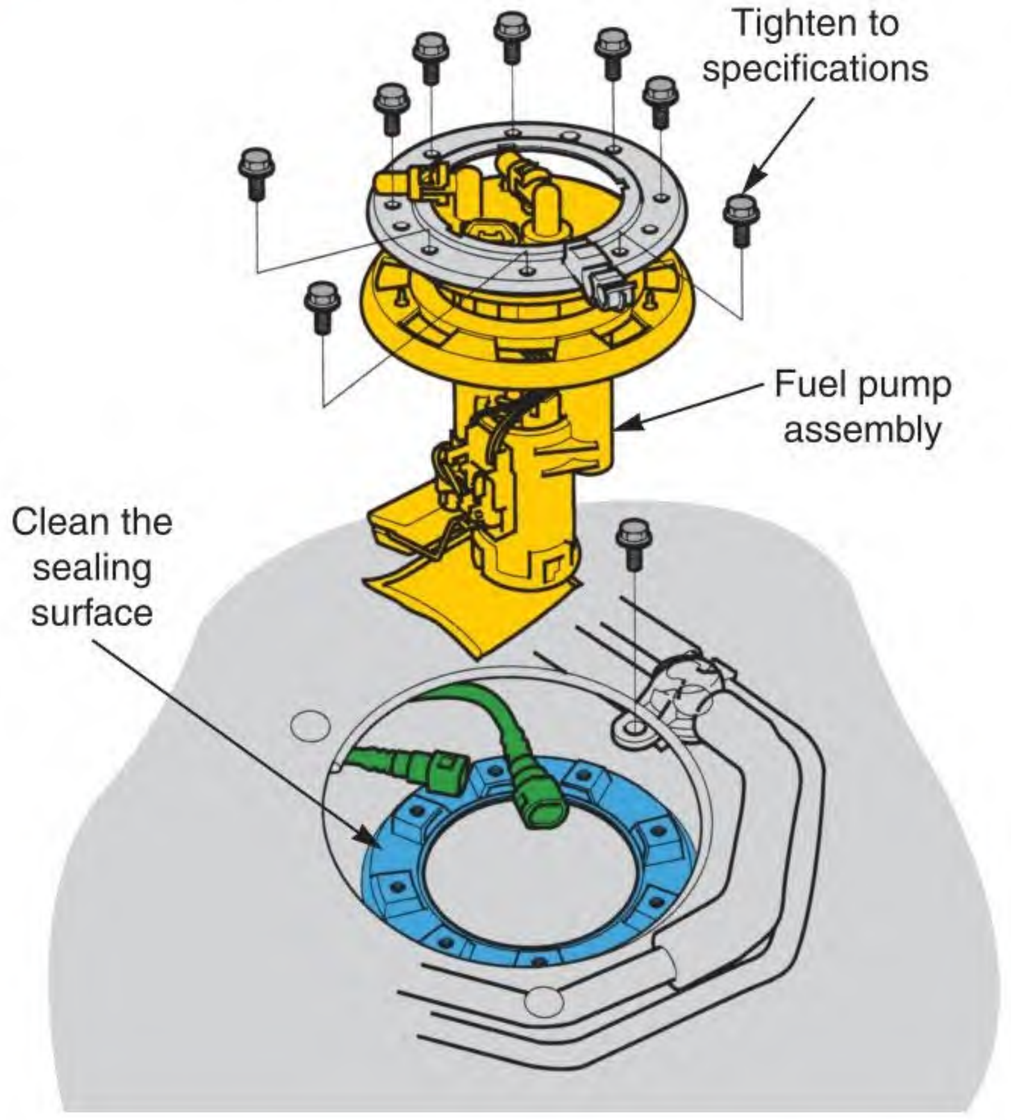
If a high-pressure fuel leak ignites, the fuel spraying out of the leak will look like a large blowtorch as hot flames shoot out of the engine compartment. High fuel pressures are only present after the engine-driven mechanical pump and inside the thick steel fuel line and fuel rail going to the fuel injectors.

Electric Fuel Pumps

An ***electric fuel pump***, like a mechanical pump, produces fuel pressure and flow for the fuel metering section of a fuel system. Electric fuel pumps are commonly used on all types of modern vehicles. They are usually located in the fuel tank or in series with a fuel line. Refer to **Figure 40-9**.

A few vehicles have one pump in the fuel tank and a second pump in the fuel line. In many late-model vehicles, the tank sending unit is an integral part of the in-tank fuel pump assembly. See **Figure 40-10**.

An electric fuel pump has advantages over a mechanical fuel pump. An electric pump can produce almost instant fuel pressure. A mechanical pump slowly builds pressure as the engine is cranked for starting. Also, most electric fuel pumps are rotary-type pumps. They produce a smoother flow of fuel (fewer pressure pulsations) than reciprocating, mechanical pumps.



Honda

Figure 40-9. When replacing an in-tank electric fuel pump, clean the sealing surface on the tank, install a new rubber seal (if needed), and torque the fasteners to specifications. Also, check that electrical connections and hoses are secure.

Electric fuel pump pressure ranges from 10–50 psi (68–344 kPa). All of the fuel supply system (hose, lines, filters and other parts) contains low fuel pressure to prime and pre-pressurize the engine-drive pump.

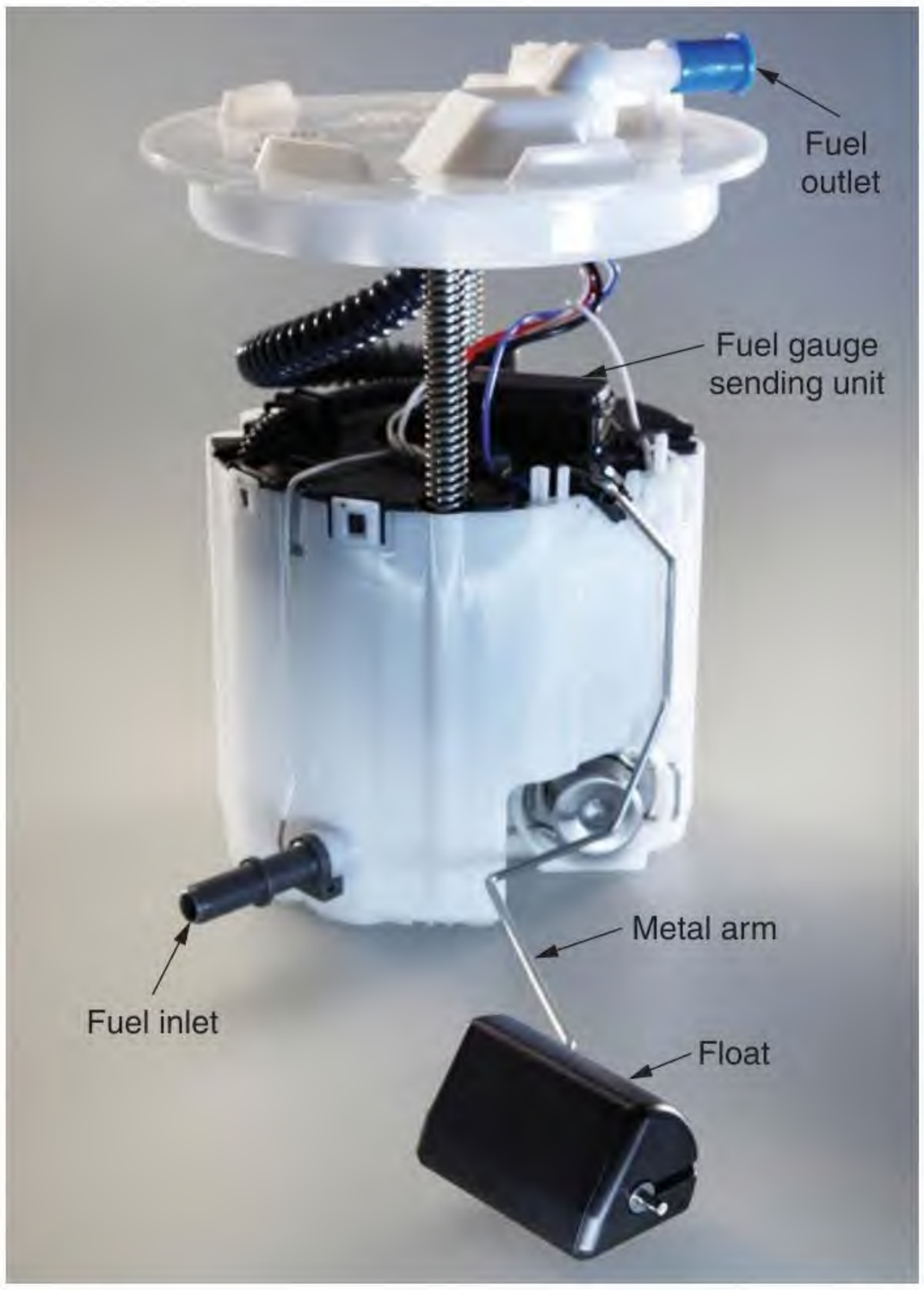
Rotary Fuel Pumps

Rotary fuel pumps include the impeller type, the roller vane type, and the sliding vane type. They all use a circular, or spinning, motion to produce pressure.

An ***impeller electric fuel pump*** is a centrifugal pump. Normally, it is located inside the fuel tank. This pump uses a small dc motor to spin the impeller (fan blade). The impeller blades cause the fuel to move outward due to centrifugal force (spinning matter is propelled outward). This produces enough pressure to move the fuel through the fuel lines. See **Figure 40-11**.

A ***roller vane electric fuel pump*** is a positive-displacement pump (each pump rotation moves a specific amount of fuel). It is normally located in the main fuel line. Small rollers and an offset-mounted rotor disc produce fuel pressure.

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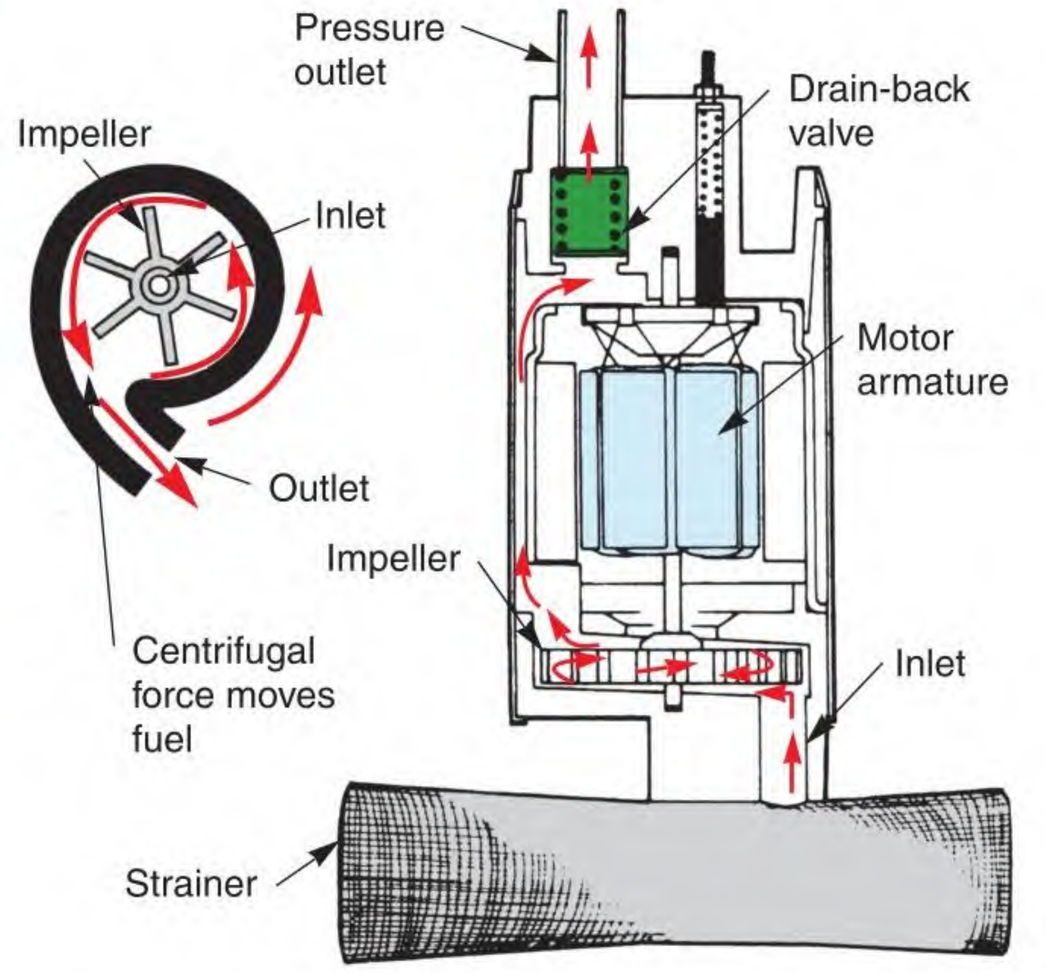
Figure 40-10. Study this in-tank fuel pump assembly. Note the location of the sending unit, which operates the instrument panel fuel gauge.

When the rotor disc and rollers spin, they pull fuel in on one side of the pump. Then, the fuel is trapped and pushed to a smaller area on the opposite side of the pump housing. This squeezes the fuel between the rollers, and the fuel flows out under pressure.

A ***sliding vane electric fuel pump*** is similar to a roller vane pump. However, it uses square vanes instead of round rollers.

Most rotary electric fuel pumps have check valves and relief valves. The check valves keep fuel from draining out of the fuel line when the pump is not running. A ***relief valve*** limits the maximum output pressure of the pump.

A ***reciprocating electric fuel pump*** has the same basic action as a mechanical fuel pump. However, it uses a solenoid instead of a ***rocker arm*** to produce a pumping motion. This is not a common type of original equipment pump.



Volvo, Ford

Figure 40-11. An in-tank, impeller-type electric fuel pump is shown. The impeller produces a very smooth flow of fuel through the system. A check valve prevents fuel from draining out of lines and back into the tank when the pump is not running.

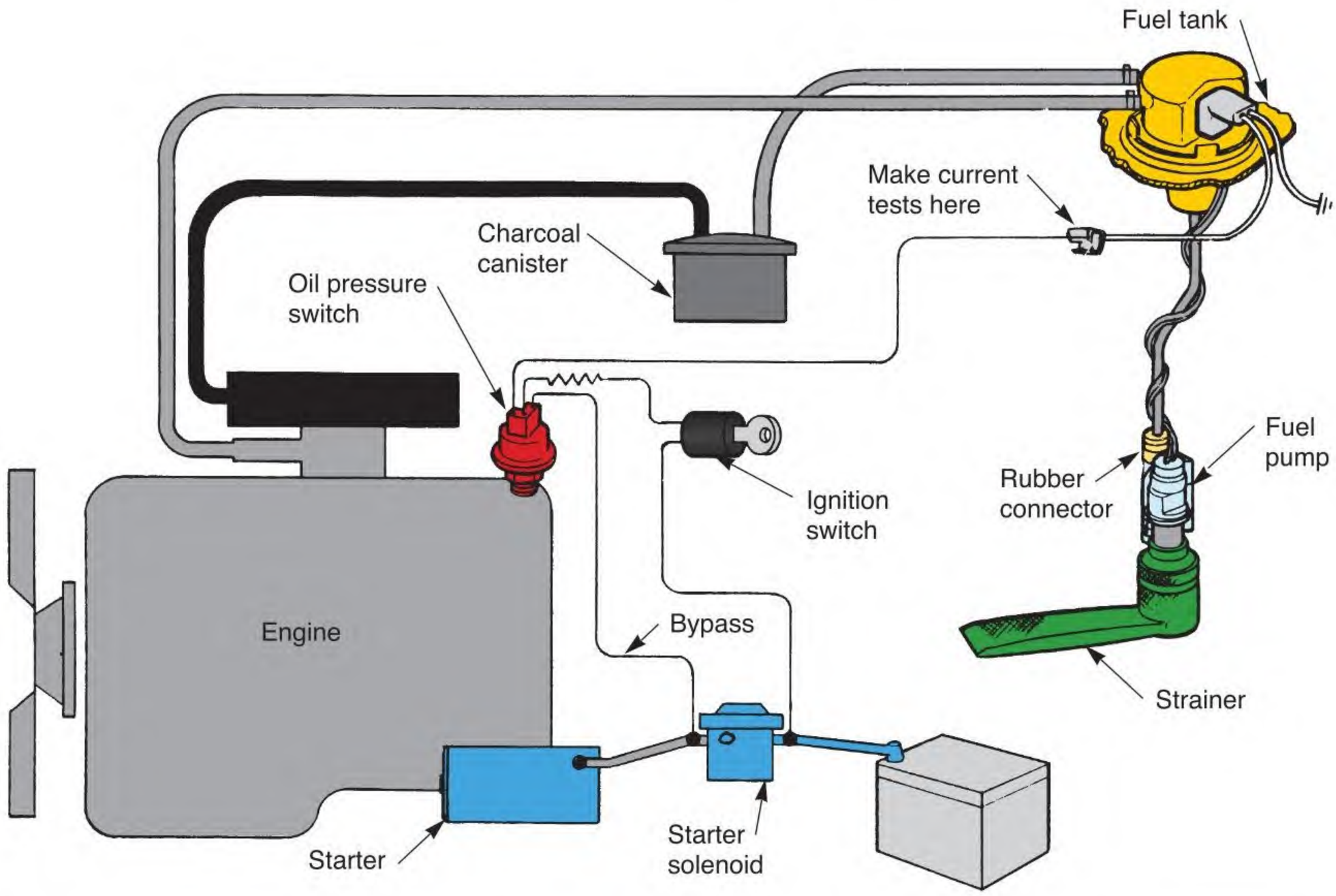
Electric Fuel Pump Circuits

An electric fuel pump circuit must send a controlled amount of current to the pump motor. The engine ECM normally sends current through the fuel pump circuit when the engine is started or is running. The circuit must be fused so that excess current flow is prevented. A circuit for an electric fuel pump is shown in **Figure 40-12**.

An ***inertia switch circuit*** cuts electric fuel pump power in the event of a serious auto collision or accident. It is a normally closed switch that opens after an impact or sudden change in inertia. Since the switch is wired into the fuel pump circuit, it can prevent the fuel pump from running after an accident. The inertia switch is wired between the fuel pump relay or ECU and the fuel pump. This is a safety feature that can prevent a fire. If a vehicle will not start after it is involved in an accident, check the inertia switch. See **Figure 40-13**.

The ***oil pressure switch*** is a safety feature that protects the engine from damage by shutting off the fuel pump if the oil pressure is low. The engine will stop running a few seconds after the fuel pump is shut off. The oil pressure switch also acts as a bypass to the fuel pump relay, allowing the vehicle to start when the relay is faulty. This normally results in an extended crank time.

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Ford

Figure 40-12. A typical electric fuel pump circuit with an oil pressure switch. If the engine oil pressure drops too low, the switch shuts off the fuel pump. Note other connections and parts of the circuit.

Fuel Supply System Service

Now that you have a basic understanding of how a fuel supply system functions, you are ready to learn about problems, tests, and repairs common to the system.

Warning

Always keep a fire extinguisher handy when working on a vehicle's fuel system. During a fire, a few seconds wasted looking for an extinguisher can be a lifetime!

Never weld or solder a fuel tank. A leaking tank should be sent to a well-trained specialist. Even an empty tank can explode. The heat produced during soldering or welding operations can cause fuel gum to melt, vaporize, and ignite.

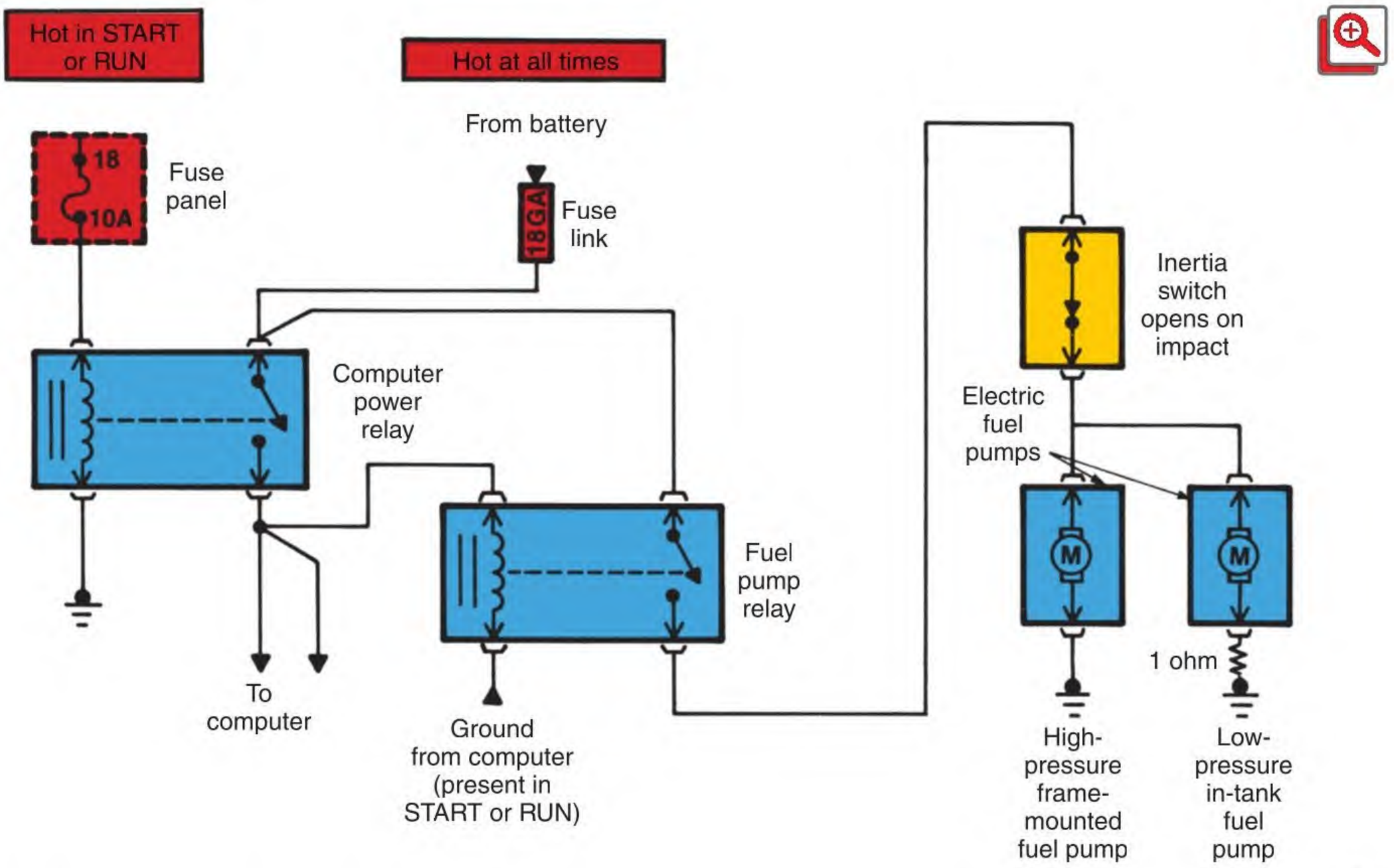
Fuel Supply System Scanning

Depending on the symptoms, you will often want to scan for diagnostic trouble codes before starting fuel supply system repairs. Vehicles equipped with OBD II systems may monitor fuel tank pressure, fuel line pressure, fuel level, and other conditions. A scan tool will quickly let you find any stored codes. Modern scanners also display operating values (voltage, current, resistance) for the electrical circuit, which can speed troubleshooting.

Vapor Lock

Vapor lock is a problem created when bubbles in overheated fuel reduce or stop fuel flow. During vapor lock, engine heat transfers through the metal parts of the pump and into the fuel. The fuel "boils," forming bubbles that displace fuel. This can reduce fuel pump output and cause engine performance problems. In very hot weather, a clogged fuel filter, a fuel pump problem, or restricted fuel return system can cause fuel overheating and vapor lock.

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Ford

Figure 40-13. Circuit shows how the inertia switch can be used to shut off electric fuel pumps after an auto accident or severe impact.

Fuel Tank Service

Typical fuel tank problems include fuel leakage, physical damage (dents, holes, etc.), and contamination (rust, dirt, and water). Vibration or rusting can cause a fuel tank to develop pinhole leaks. Rocks can puncture the tank. Internal deterioration of the tank or foreign matter in the fuel can cause contamination problems.

Fuel Tank Removal and Replacement

A fuel tank can be located under the trunk floor, in a body panel, or under the rear seat. It can be held in the vehicle by large metal straps or by bolts passing through the tank flange. With rear-engine vehicles, the fuel tank can be located in the front.

Before servicing a fuel tank, make sure you empty the tank. A full tank is very heavy and can rupture if dropped.

To remove fuel from the tank, unscrew the tank's drain plug and allow the fuel to flow into an approved safety can. If necessary, use a funnel to direct the fuel into the safety can without spillage. If a drain is not provided, use an approved pumping method to draw the fuel out of the tank.

With modern vehicles, you can normally use the in-tank or inline electric fuel pump to empty the tank. Disconnect the fuel hose at the main fuel line and route it into an approved gas can. Turn the ignition key on and allow the fuel pump to force the fuel from the tank into the can. Refer to **Figure 40-14**.

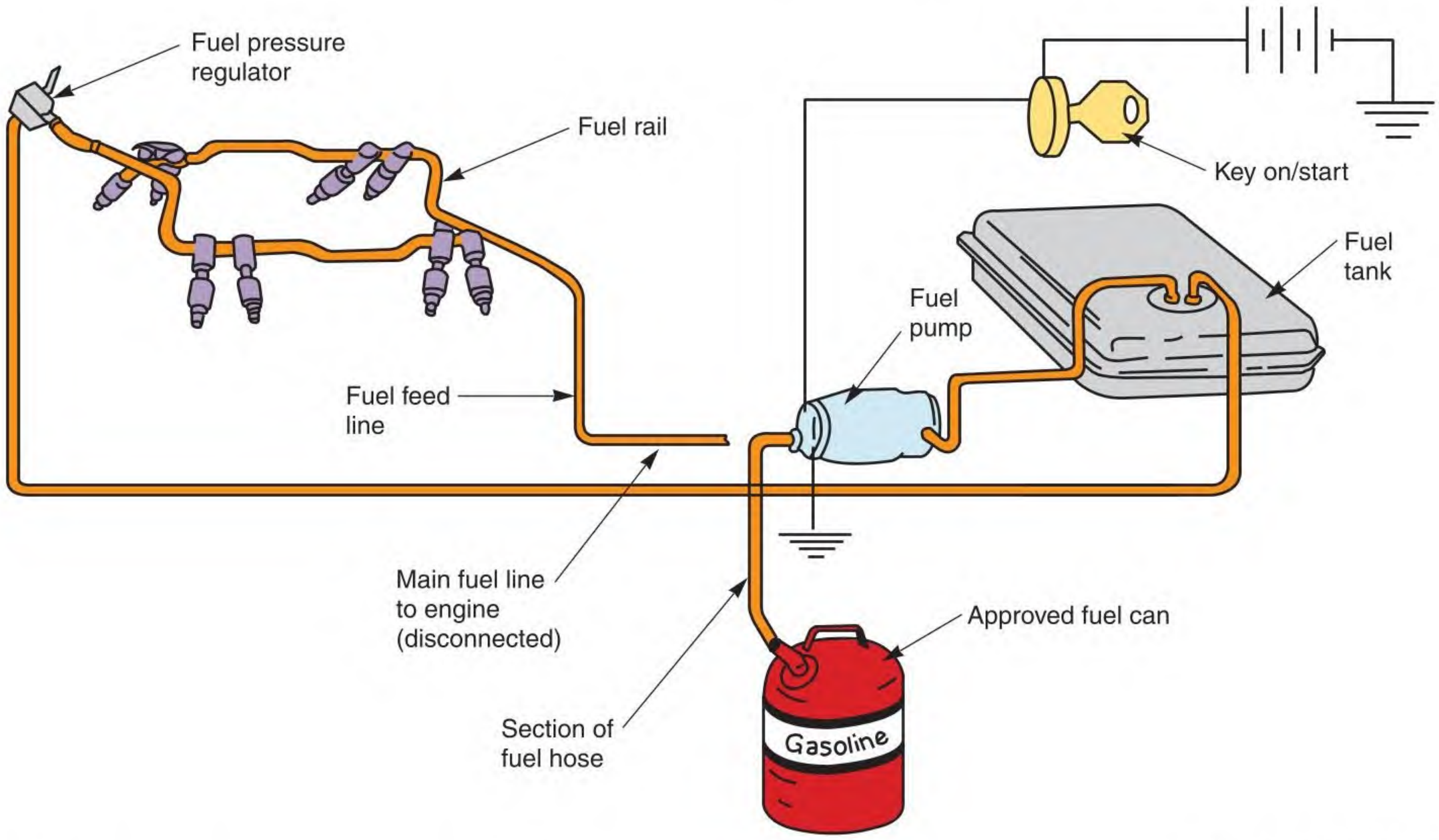
Warning

When working on vehicles with direct injection systems, never attempt to use the high-pressure mechanical pump to drain the fuel tank.

Tech Tip

If the control module shuts the pump off after a few seconds, use a jumper wire to connect voltage directly to the pump terminal to allow for complete draining.

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Figure 40-14. With electric fuel pumps, you can use the in-tank or inline pump to drain gasoline from the tank. Connect a long hose from the pump outlet to an approved fuel can. Energize the pump and make sure fuel does not spill out.

After draining the tank, disconnect the wires and fuel lines going to the fuel tank sending/pickup unit. Then disconnect and pull off the filler neck on the side of the tank. Support the tank with a floor jack, remove the metal straps or fasteners that secure the tank to the vehicle, and slowly lower the tank to the ground.

Remove the old electric fuel pump and sending unit assembly from the bad fuel tank. Install the fuel pump into the new tank. Use a rubber O-ring to make sure the new fuel tank does not leak.

If you are working alone, secure the fuel tank on a transmission jack and raise it up under the vehicle. Make sure you replace the rubber insulators. Check that all fuel lines are properly secured. Replace the fuel in the tank and check for leaks. If needed, a service manual for the vehicle will detail tank installation procedures.

Warning

Wipe up fuel spills immediately with a shop rag. Do not spread oil absorbent on fuel spills, because the oil absorbent will become extremely flammable. Oil absorbent can burst into flames if saturated with gasoline.

Fuel Tank Sending Unit Service

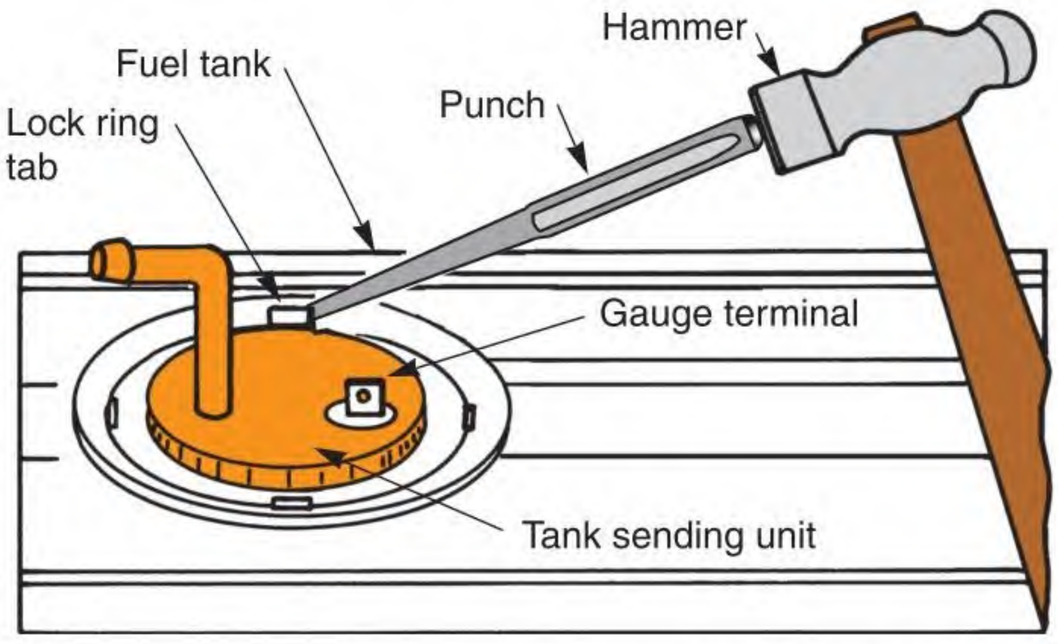
A faulty fuel tank sending unit can make the fuel gauge reading inaccurate. Usually, the variable resistor in the sending unit fails. However, you should remember that the fuel gauge or the gauge circuit may be at fault.

First, test the fuel gauge. Connect a factory fuel gauge tester to the fuel gauge feed wire. When the tester is set on *full*, for example, the fuel gauge should read *full*.

If the gauge does not function, either the gauge or the gauge circuit is faulty. If the fuel gauge begins to work with the tester in place, the fuel tank sending unit is bad.

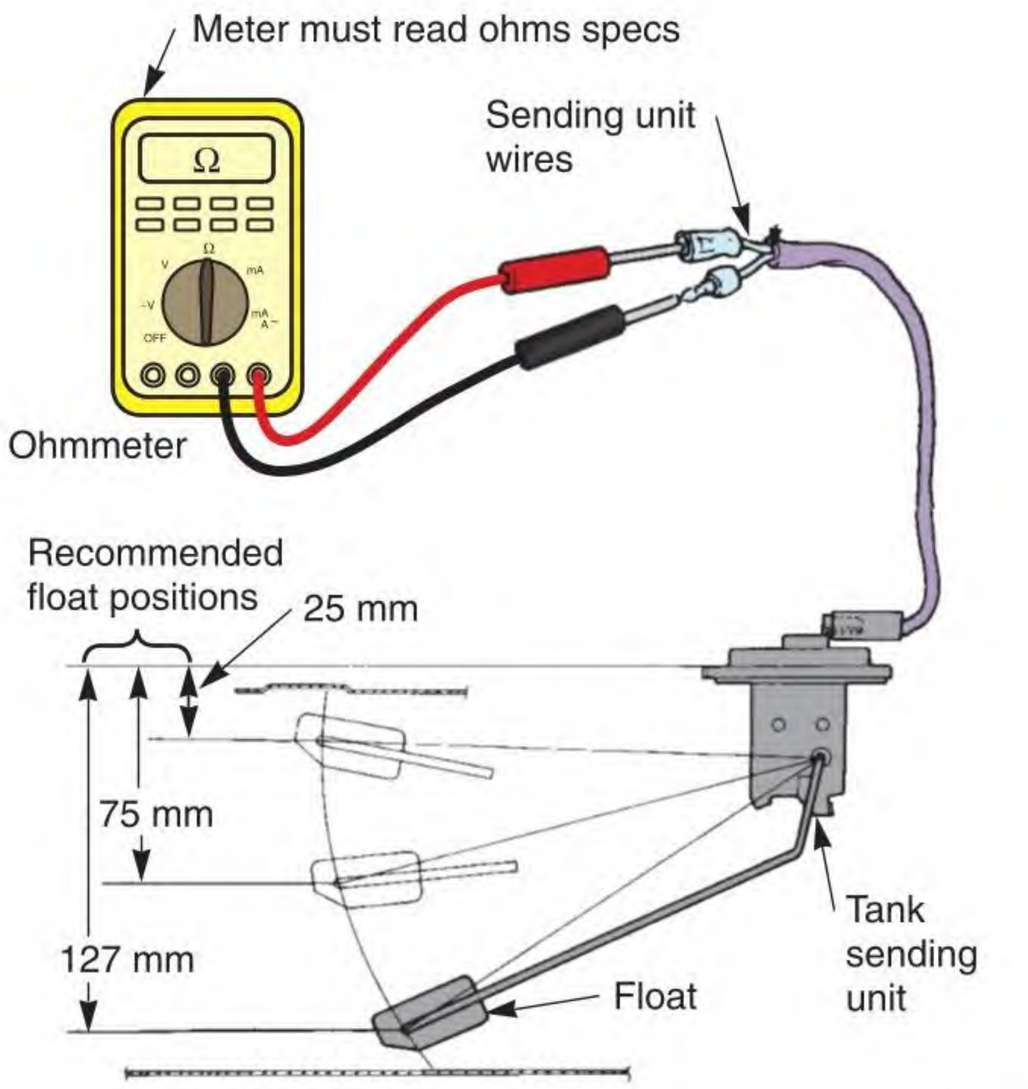
If your tests indicate an inoperative fuel tank sending unit, remove the unit after draining the tank. Unscrew the cam lock or screws holding the sending unit in the fuel tank. If you do not have a special cam tool, use a drift punch and light hammer blows to rotate the lock tabs. Lift the unit out of the tank, **Figure 40-15**.

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Figure 40-15. A long drift punch and light hammer blows will rotate and free the lock ring on a sending unit or fuel pump.



Honda

Figure 40-16. An ohmmeter can be used to check the condition of the tank sending unit. The reading should be within specifications with the float in prescribed positions.

Tech Tip

Some vehicles have a fuel pump access door in the trunk, so you do not have to remove the fuel tank to service the pump. By removing the small screws that hold the access door in place, you can service the in-tank pump more easily.

With the sending unit removed, measure its resistance with an ohmmeter, **Figure 40-16**. If the resistance is not within the factory specifications, or does not change when you move the float arm up and down, install a new sending unit.

Also, check the float for leakage. Shake the float next to your ear. If you can hear liquid splashing, replace the float. If the tank unit resistance is correct, check the tank ground. A poor ground could prevent gauge operation.

Fuel Line and Hose Service

Faulty fuel lines and hoses are common sources of fuel leaks. Fuel hoses can become hard and brittle after being exposed to engine heat and the environment. Engine oil softens and swells hoses. Always inspect fuel lines and hoses closely and replace any that are in poor condition. See **Figure 40-17**.

Caution

Some late-model fuel lines have snap-type fittings. Do not try to pry the fittings apart or they will be damaged. Use a fuel line fitting tool to release the fittings for service. This tool can be purchased at most auto part stores.

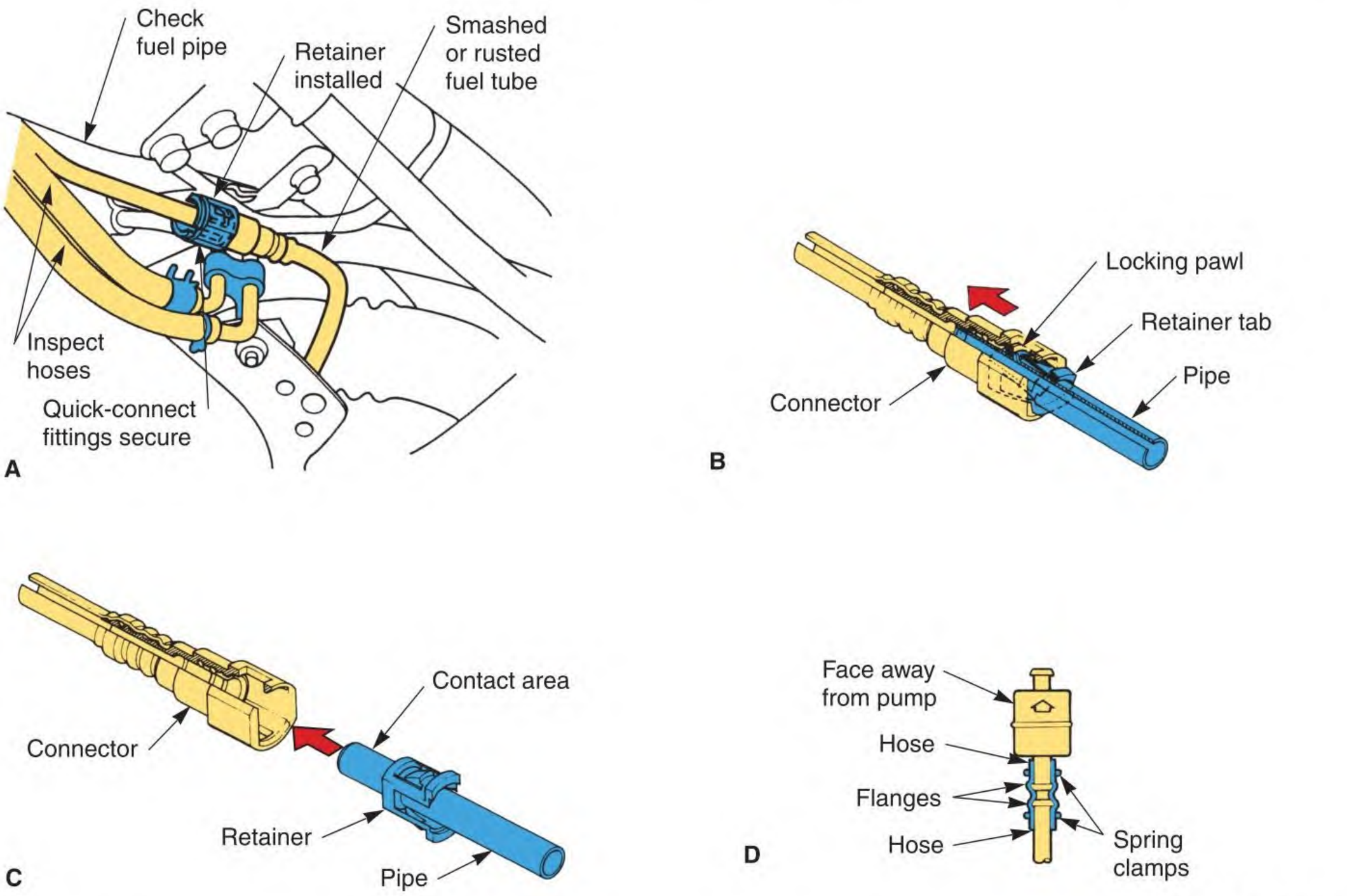
Metal fuel lines seldom cause problems. However, they should be replaced when smashed, kinked, rusted, or leaking. If available, install a new factory fuel line section to ease installation. Most metal fuel lines are bent and curved to fit the installation. Only if a replacement factory fuel line is not available should you make a fuel line using bending and flaring tools, **Figure 40-18**.

Fuel Line and Hose Service Rules

Remember these rules when working with fuel lines and hoses:

- Wear proper apparel, including work gloves and eye protection.
- Release any residual fuel pressure before working on fuel lines and hoses.
- Place a shop rag around the fuel line fitting during removal. This will keep fuel from spraying on you or on the hot engine. Use a flare nut or tubing wrench on fuel system fittings.
- Only use approved double-wall steel tubing for fuel lines. Never use copper or plastic tubing unless it is OEM equipment.
- Make smooth bends when forming a new fuel line. Use a bending spring or bending tool.

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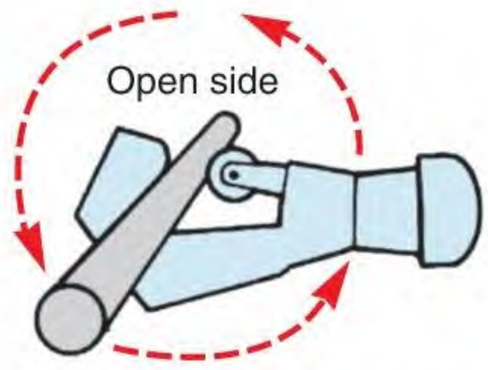


Honda and Chrysler

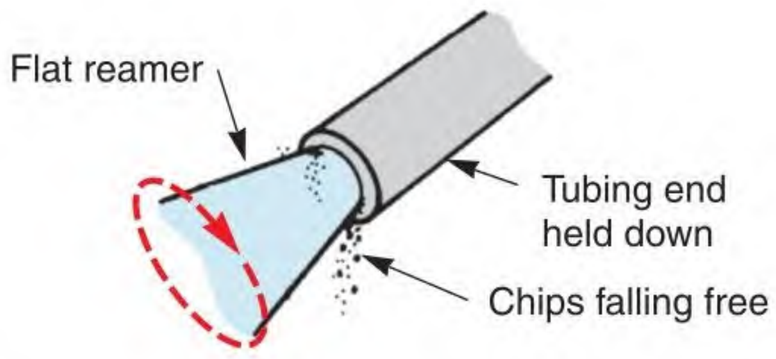
Figure 40-17. A—Always inspect fuel lines, hoses, and fittings for leakage and damage. Pay special attention to plastic lines. B—To disconnect this fuel line fitting, press down on the locking tab while pulling apart. C—To reconnect the fitting, simply push the two halves of the fitting together. D—When installing fuel hoses, make sure they are completely over raised areas on the fuel line. Clamps should be on the pressure side of flanges.

- Form double-lap flares on the ends of the fuel line. A single-lap flare is not approved for fuel lines.
- Reinstall fuel line hold-down clamps and brackets. If not properly supported, the fuel line can vibrate and fail.
- Route all fuel lines and hoses away from hot or moving parts. Double-check clearance after installation.
- Route plastic fuel lines in their original locations. They are more prone to damage from engine heat and abrasion than metal lines.
- A plastic line will kink if bent too sharply. This will restrict fuel flow and may cause the line to fail in service.
- Use a factory-recommended tool to release snap-type fittings used to secure plastic fuel lines.
- If a plastic line or fitting is damaged, replace it with a new one. Do not attempt repairs, such as inline splices.
- Do not use non-OEM plastic tubing to repair fuel systems. The line pressure rating and the composition of the plastic may be different. The incorrect plastic line can rupture.
- Plastic lines tend to stiffen in service. Avoid bending or rerouting used plastic lines.
- Always cover plastic fuel lines with a wet towel when welding, torch cutting, or grinding near them. A hot piece of metal can melt a plastic line.
- Never allow battery acid to contact a metal or plastic fuel line. Lines can be weakened or eaten away by acid.
- Use only approved synthetic rubber hoses in a fuel system. If vacuum-type rubber hose is accidentally used, the fuel can chemically attack and rapidly ruin the hose. A dangerous leak could result.

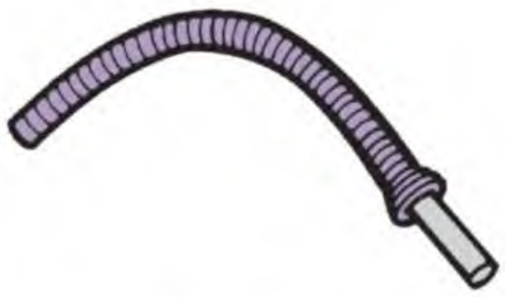
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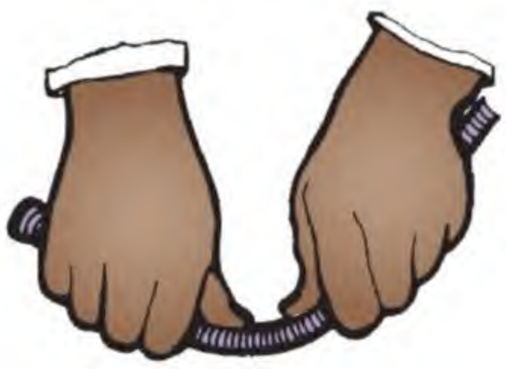
Step 1. Cut tubing with tube cutter.



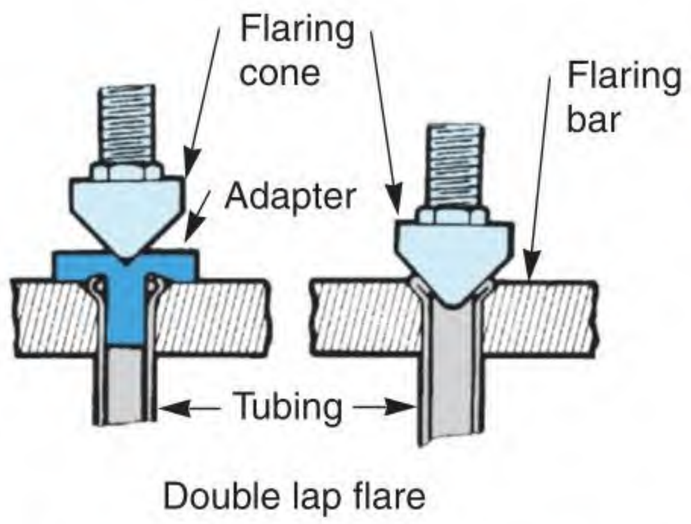
Step 2. Remove burrs.



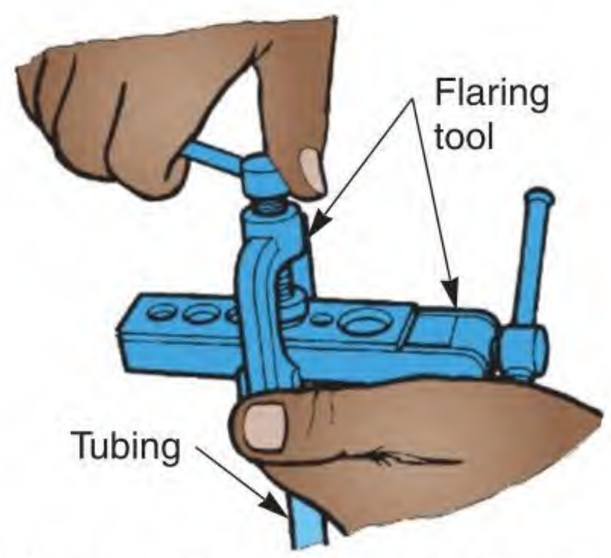
Step 3. Slip bender over tubing.



Step 4. Bend tubing to shape of old fuel line.



Step 5. Use a flaring tool adapter to fold the tube end inward.



Step 6. Tighten flaring tool into tubing.

Florida Dept. of Voc. Ed. and Chrysler

Figure 40-18. Fuel lines need double-lap flares. Study the basic steps for making a new fuel line. This procedure also applies to other lines (brake lines, steel vacuum lines, etc.).

- Make sure a fuel hose fully covers its fitting or line before installing the clamps. Pressure in the fuel system could force the hose off the fitting if it is not installed properly.
- When servicing press-fit fuel line fittings, you may need to replace the O-ring seal to prevent fuel leakage. Make sure you purchase the correct seal.
- Double-check all fittings for leaks. Start the engine and inspect the connections closely.

Warning

Direct fuel injection systems produce very high fuel pressure, above 2000 psi for late-model vehicles. Many systems maintain this pressure even after the engine is shut off. Follow recommended procedures for releasing pressure before disconnecting a fuel line or fitting. This will prevent fuel from spraying from the line or fitting and possibly causing injury or a fire!

Fuel Filter Service

Fuel filter service involves periodic replacement or cleaning of system filters. It may also include locating clogged fuel filters that are upsetting fuel system operation.

A clogged fuel filter can restrict the flow of fuel to the pressure regulator, gasoline injectors, diesel injection pump, or carburetor. Engine performance problems will usually show up at higher speeds.

A partially clogged fuel filter may cause the engine to temporarily lose power or stall when a specific engine speed is reached. This is due to the flow restriction caused by a partially clogged filter. A partially clogged filter may pass enough fuel at low engine speeds. However, when engine speed and fuel requirements increase, the engine may "starve" for fuel.

On modern vehicles, a clogged in-tank strainer is a common and difficult-to-diagnose problem. When clogged, the in-tank filter can collapse and stop all fuel flow. Then, after the engine stalls, the strainer can open again, leaving no trace of a restriction.

Some fuel filters have a check valve that opens when the filter becomes clogged. This allows unfiltered fuel, which may contain contaminants, to flow into

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the system. If a filter is clogged and contaminants are found in the fuel system, the tank, pump, and lines should be flushed with clean fuel.

Fuel Pump Service

Fuel pump problems include low fuel pressure, inadequate fuel flow, abnormal pump noise, or fuel leakage from the pump.

Low fuel pump pressure can be caused by worn pump bearings, high resistance in electric pump circuit, leaking check valves, or physical wear of moving parts. Low fuel pump pressure can make the engine starve for fuel at high engine speeds.

High fuel pump pressure is commonly caused by an inoperative pressure relief valve. If the pressure relief valve fails to open, both pressure and volume can be above normal. A faulty fuel pressure regulator can also cause high fuel pressure. This can produce a rich fuel mixture or even flood the engine, and will trip several trouble codes. On vehicles with fuel pressure sensors, a signal from the fuel pressure sensor may cause the ECM to shut down the engine.

Mechanical fuel pump noise (clacking sound from inside pump) is commonly caused by a weak or broken return spring or other part failure in the pump. Mechanical fuel pump noise can be easily confused with valve or tappet clatter. They sound very similar. To verify mechanical fuel pump noise, place a stethoscope on the pump body. The point of the loudest noise is the source of the problem.

Most electric fuel pumps make some noise (buzz or whirl sound) when running. Only when the pump noise is abnormally loud should an electric fuel pump be considered faulty. A clogged tank strainer can also cause excessive pump noise. Pump speed can increase because fuel is not entering the pump properly.

Fuel pump leaks are caused by physical damage to the pump body or deterioration of the gaskets. Inline electric pump leaks are usually from the inlet and outlet hoses.

Some mechanical fuel pumps have a small vent hole in the pump body. When the seal is ruptured, fuel will leak out of this vent hole.

It is possible for mechanical fuel pump with an internal leak to contaminate the engine oil with gasoline. Fuel can leak through the pump, into the cylinder head, and down into the oil pan. When a gasoline smell is noticed in the oil, replace the high-pressure pump. Then change the engine's motor oil and oil filter.

Fuel Pump Tests

Fuel pump testing commonly involves measuring fuel pump pressure and volume. Exact procedures vary, depending on fuel system type. Refer to a manual for exact testing methods. Sometimes, fuel pump vacuum is measured as another means of finding air leaks in fuel supply lines.

Always remember there are several other problems that can produce symptoms like those caused by a faulty fuel pump. Before testing a fuel pump, use a scan tool to check for:

- Restricted fuel filters (low fuel pressure live reading).
- Smashed or kinked fuel lines or hoses (low fuel pressure or lean codes).
- Air leak into vacuum side of pump or line (low fuel pressure code).
- Injection system troubles (injector codes, oxygen sensor codes, or engine misfire codes).
- Ignition system problems (engine misfire or other ignition related codes).
- Low engine compression (misfire code).

Tech Tip

Use a stethoscope to listen and learn the sound of normally operating high-pressure mechanical pumps. They will make a distinctive light churning sound as the pump rod rides up and down on its cam lobe and fuel moves through the system.

A bad mechanical fuel pump will usually be worn and make a louder, metal-on-metal tapping sound. A failed fuel pump may have a broken return spring, a worn or damaged pump plunger, leaking check valves, or a bad pressure regulating valve.

A faulty fuel pressure regulator could also decrease or increase fuel pressure and cause engine performance problems. Again, make sure the fuel pressure regulator is working normally before condemning a fuel pump.

Tech Tip

If you must test a high-pressure fuel pump, use a high-pressure gauge set designed for the exact make and model system.

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Measuring Fuel Pump Pressure

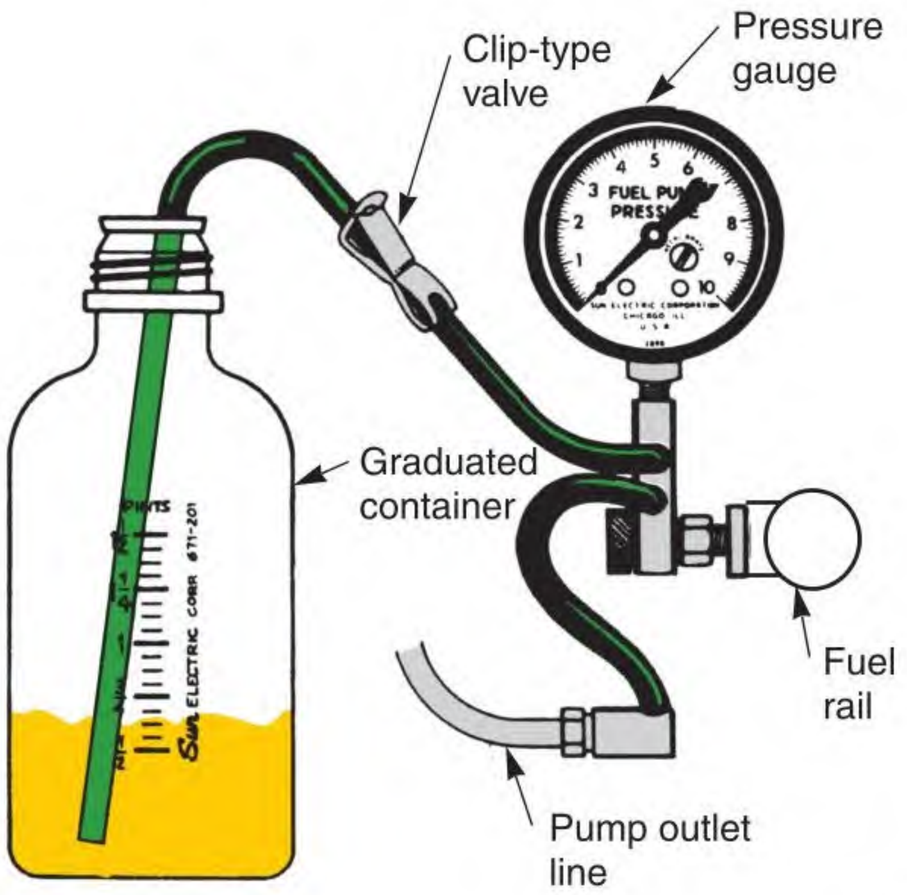
While wearing eye protection and work gloves, relieve any residual pressure in the system. Connect an appropriate pressure gauge to the output line of the fuel pump or to the appropriate test fitting on the engine fuel rail. Most fuel-injected engines normally have a test fitting on the engine fuel rail. You may have to install a test fitting (t-fitting) in a fuel line.

Tech Tip

Make sure you tighten all high-pressure fuel line fittings and test fittings with a torque wrench. Install a crowfoot or open-end wrench on a short extension and an inch/pound torque wrench. High-pressure fuel line fitting torque values vary, so refer to the vehicle manufacturer's specifications.

If it is a mechanical fuel pump, start the engine. Inspect all test fittings for leakage. Correct any leaks before proceeding. Compare your mechanical pump pressure readings with specifications.

To test an electric fuel pump, you need to activate (supply voltage to) the electric pump motor, press the hybrid start button, or start the engine. Compare your pressure readings to specifications. See **Figure 40-19**.



Chrysler

Figure 40-19. To test fuel pump pressure and volume, connect test equipment as shown. Connect a gauge to the fuel line before the fuel manifold, throttle body, or carburetor. Close the clip and start the engine to measure pressure. Open the clip to measure volume over a prescribed time span.

Warning

Never attempt to measure DIS engine fuel pressure on the output side of the mechanical fuel pump. Two thousand pounds per square inch (14 MPa) of pressure leaking out of a test fitting could cause serious injury.

A much safer way to check fuel pressures with today's DIS engines is with your scan tool. Compare live readings of fuel pressure on your tool display screen to factory specifications. If fuel pressure is too low or high, use a multimeter to test the fuel pressure sensors. A failing fuel pressure senor could be giving false readings to the system and scan tool.

Fuel pressure for a gasoline injection system can vary from 50–2000 psi (344–13,790 kPa), depending on the make and model of the vehicle. A diesel supply pump should produce around 10–15 psi (69–103 kPa) since it feeds higher viscosity diesel fuel to a high-pressure mechanical injection pump. Fuel pressure for old carburetor-type fuel systems should be very low, about 4–6 psi (28–41 kPa). Older fuel-injected vehicles may run 30–50 psi (207–344 kPa).

Remember to use factory values when determining fuel pump condition. Pressures vary considerably with makes and models.

If fuel pump pressure is not within specifications, check pump volume and the lines and filters before replacing the fuel pump.

If needed, connect the pressure gauge directly to the output of the low-pressure electric fuel pump. This will take the pressure regulator, feed lines, and other parts out of the system for isolating any problem. With fuel injection, remember that you may also be testing the fuel pressure regulator and not just the fuel pump.

Measuring Fuel Pump Volume

Fuel pump volume, also called ***fuel pump capacity***, is the amount of fuel the pump can deliver in a specific amount of time. It is measured by allowing fuel to pour into a graduated (marked) container for a certain time period.

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Tech Tip

Never attempt to measure high-pressure, mechanical fuel pump volume. The high-pressure pump is actually a low-volume pump by design. If it produces specified pressure, the fuel pump should provide adequate fuel volume even at the highest engine speeds. Make sure you have checked for clogged fuel filters, damaged fuel feed lines, and clogged in-tank strainers before condemning any fuel pump.

Service Procedure

To check fuel pump volume:

1. Route the output line from the fuel pump into a graduated container. For safety, a valve or clip should be used to control fuel flow into the container.
2. With the engine idling at the specified speed, allow fuel to pour into the container for the prescribed amount of time (normally 30 seconds).
3. Close off the clip or valve, and shut off the engine.
4. Compare volume output (amount of fuel in the container) to specifications.

Fuel pump volume output should be a minimum of one pint (0.47 liters) in 30 seconds for small automobile engines. Larger engines will require a slightly higher fuel volume output since fuel consumption will be higher. Refer to factory service manual values for the particular fuel pump and automobile.

Measuring Fuel Pump Vacuum

Fuel pump vacuum should be checked when a fuel pump fails pressure and volume tests. A vacuum test will rule out possible problems in the fuel lines, hoses, filters, and pickup screen.

For example, a clogged fuel pickup screen could make the fuel pump fail its pressure and volume tests. If the same fuel pump passes a vacuum test, you may need to remove the fuel tank and in-tank filter. If the filter is clogged with fuel gum, fuel flow to the engine could be stopped.

Service Procedure

To measure fuel pump vacuum:

1. Connect a vacuum gauge to the inlet side of the pump.
2. Leave the fuel hose in your graduated container from the volume test.
3. Open the valve and activate the pump (start engine and allow to run or connect voltage to electric pump).
4. Compare your vacuum reading to specifications.

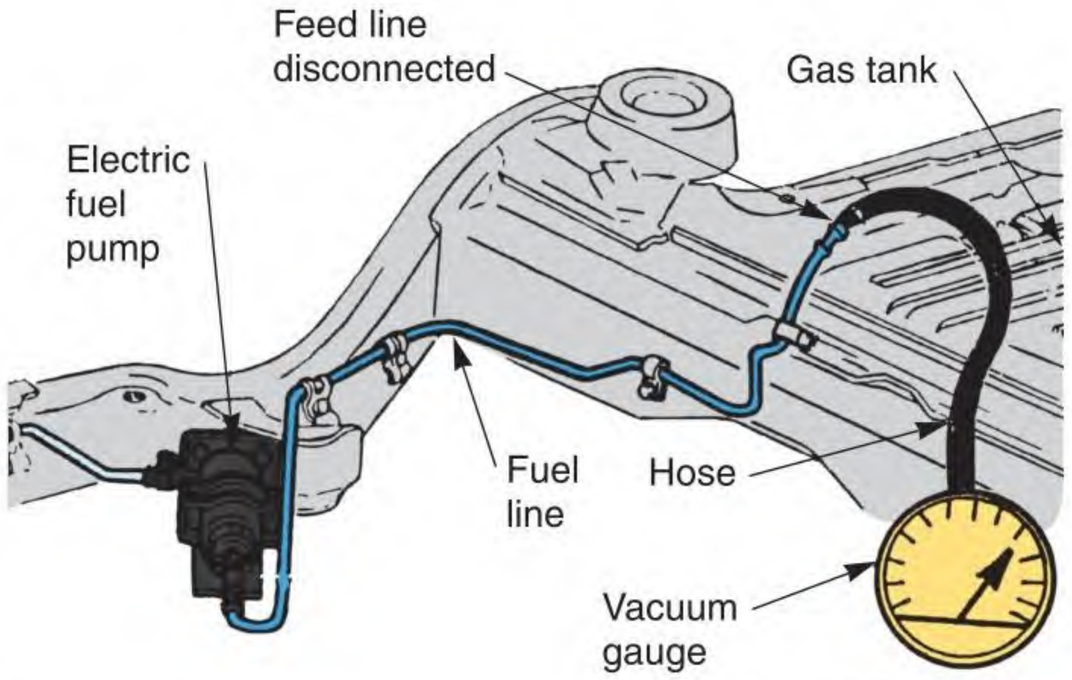
Typically, fuel pump vacuum should be about 7–10″ Hg. A good vacuum reading indicates a good fuel pump. Refer to **Figure 40-20**. If the pump failed the pressure or volume test but passed the vacuum test, the fuel supply lines or filters may be at fault.

Electric Fuel Pump Circuit Tests

Many electric fuel pump problems are caused by electrical circuit problems, **Figure 40-21**. Broken wires, bad relays, shorts, blown fuses, computer malfunctions, and other troubles can affect electric fuel pump operation.

If an electric fuel pump does not pass its pressure or volume tests, measure the supply voltage being fed to the pump motor. Look at **Figure 40-22**. If the voltage is low, there is a problem in the electrical circuit to the pump.

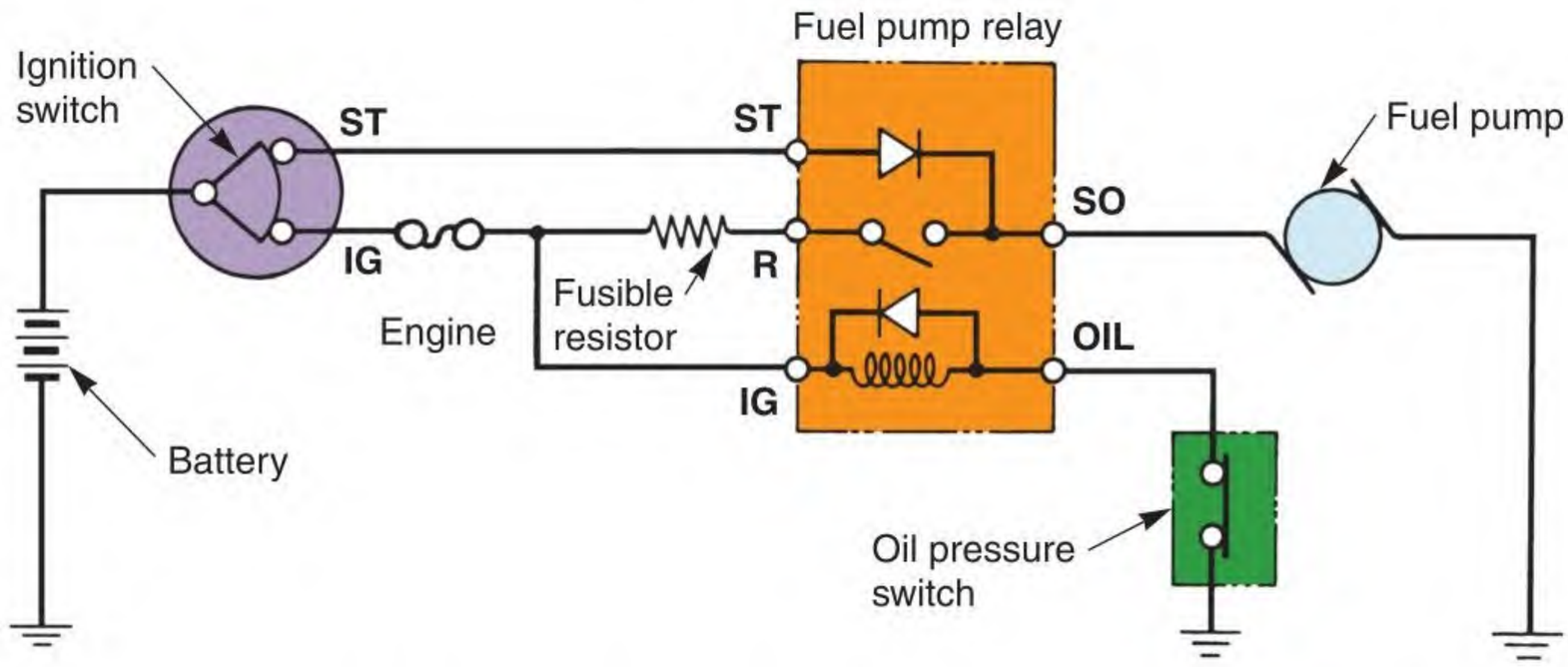
When circuit problems must be found, use the service manual and your knowledge of basic electrical testing procedures. Generally, test the circuit at various



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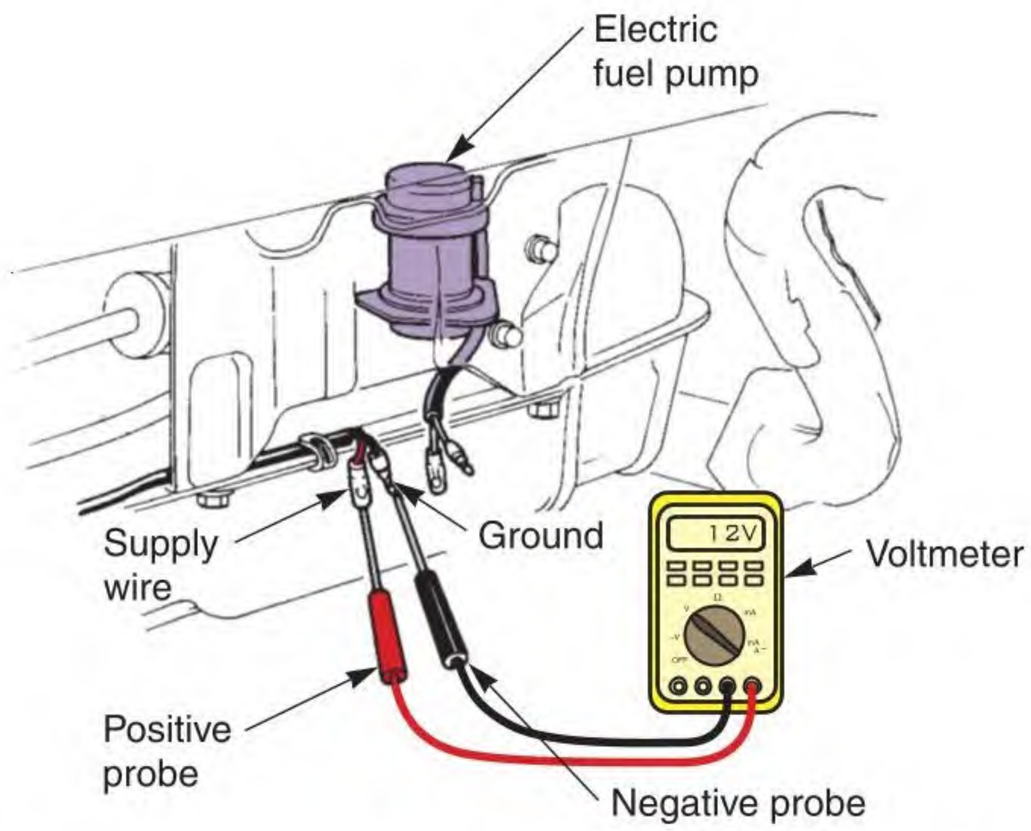
Figure 40-20. Fuel pump vacuum specifications are sometimes given. Connect vacuum gauge to inlet of inline pump and compare to specifications.

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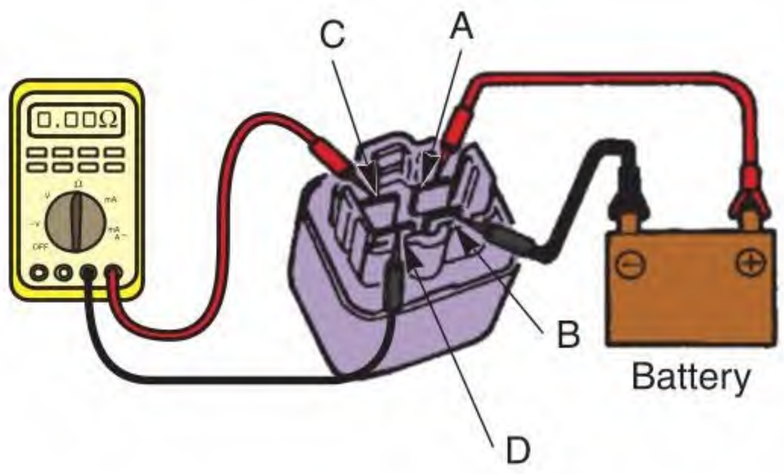
Toyota

Figure 40-21. A fuel pump control circuit. Note fusible resistor, relay, oil pressure switch, and pump. Any defective part could upset the pump operation.



Honda

Figure 40-22. Before condemning an electric fuel pump, make sure the circuit is in good condition. Measure the amount of voltage being supplied to the pump and compare to specifications. If voltage is low, repair the circuit.



Specification B+: Battery positive voltage

Terminal A — B	Terminal C — D
B+ applied	Continuity
B+ not applied	No continuity

Mazda

Figure 40-23. The fuel pump relay can fail and prevent pump operation. Note that you can energize the relay with battery power and then check point closing with an ohmmeter. Refer to the manufacturer's service manual for specific test instructions.

points until the source of the trouble is found. Make sure to check the electric fuel pump relay if power is not reaching the pump motor. Refer to **Figure 40-23**.

Fuel Pump Shutoff Circuits

An ***inertia switch*** can be used to block current flow to the electric fuel pump after a severe impact or collision. It is a safety device that can prevent a serious fire after an auto accident. The inertia switch is usually located in the trunk or near the electric fuel pump. After a collision, you must press a button on the inertia switch before the electric pump will function again.

The ***low oil pressure safety circuit*** is designed to protect the engine from major mechanical damage if the engine is operating on low oil or the oil pump fails. An oil pressure switch in the circuit signals the ECM to shut off the electric fuel pump if engine oil pressure drops too low.

A bad fuel pressure sensor circuit can result in an incorrect fuel pressure reading and a false pressure reading on your scan tool. If the pressure sensor's internal resistance has changed over time, the ECM may not be getting an accurate fuel pressure reading.

If your scan tool shows an abnormal pressure reading or a trouble code for high- or low-pressure sensor output, use a multimeter to verify that the sensor is bad.

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Measure sensor resistance at atmospheric pressure and compare it to specifications.

Mechanical Fuel Pump Replacement

When a fuel pump does not pass its performance tests, it must be removed and replaced or rebuilt.

Service Procedure

To remove a high-pressure mechanical fuel pump:

1. Disconnect the battery to avoid electric sparks that could start a fuel fire. On a hybrid, also disable the HV battery.
2. Following factory service manual procedures, relieve any residual fuel pressure.
3. Use tubing wrenches to disconnect the fuel lines going to the fuel pump.
4. Unbolt the pump from the engine. If needed, lightly tap the side of the pump with a plastic hammer to free the gasket.
5. Compare the old mechanical pump with the new one to make sure they are identical.
6. If required, scrape off any remaining gasket material on the engine cylinder head or engine front cover.
7. If used, install a new gasket or seal on the new fuel pump.
8. Fit the fuel pump onto its mount and hand start the fuel pump bolts or nuts.
9. Torque the fuel pump bolts to exact specifications. Because of the tight tolerances in the fuel pump, overtightening the fuel pump mounting bolts can lead to pump wear and failure.

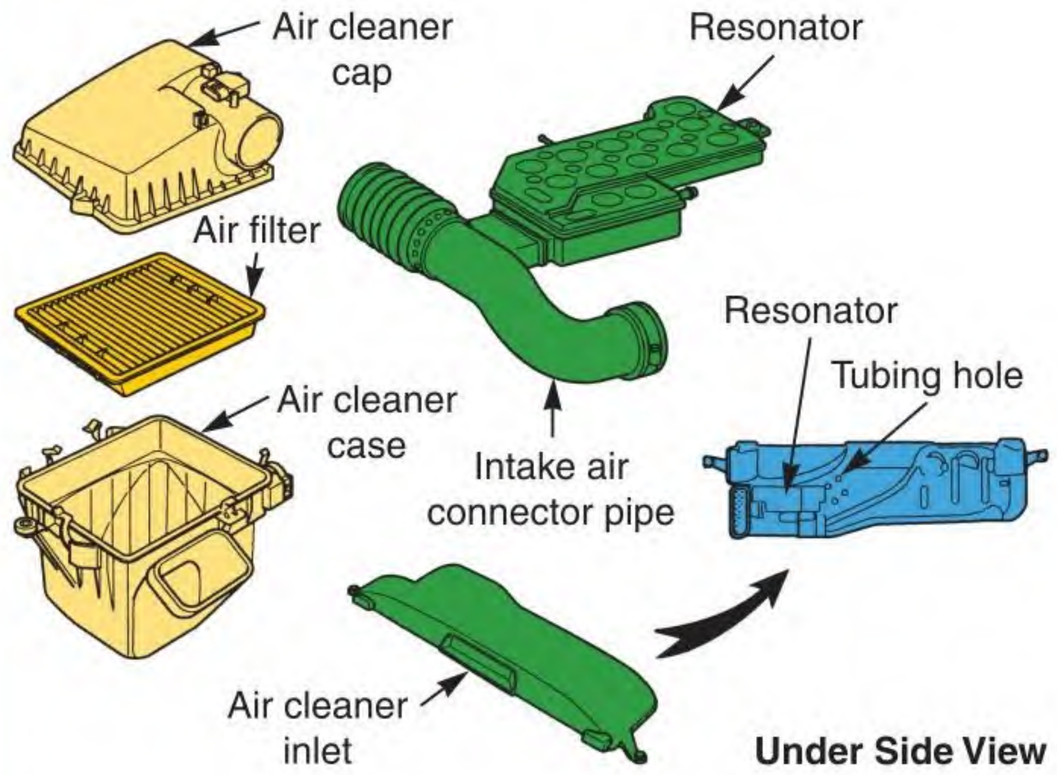
Electric Fuel Pump Replacement

An electric fuel pump may be located in the main fuel line or in the fuel tank. With an inline pump, simply disconnect the fuel fittings and remove the pump. An in-tank pump must usually be removed as part of the tank pickup-sending unit. This procedure was described earlier in the chapter.

Air Filter Service

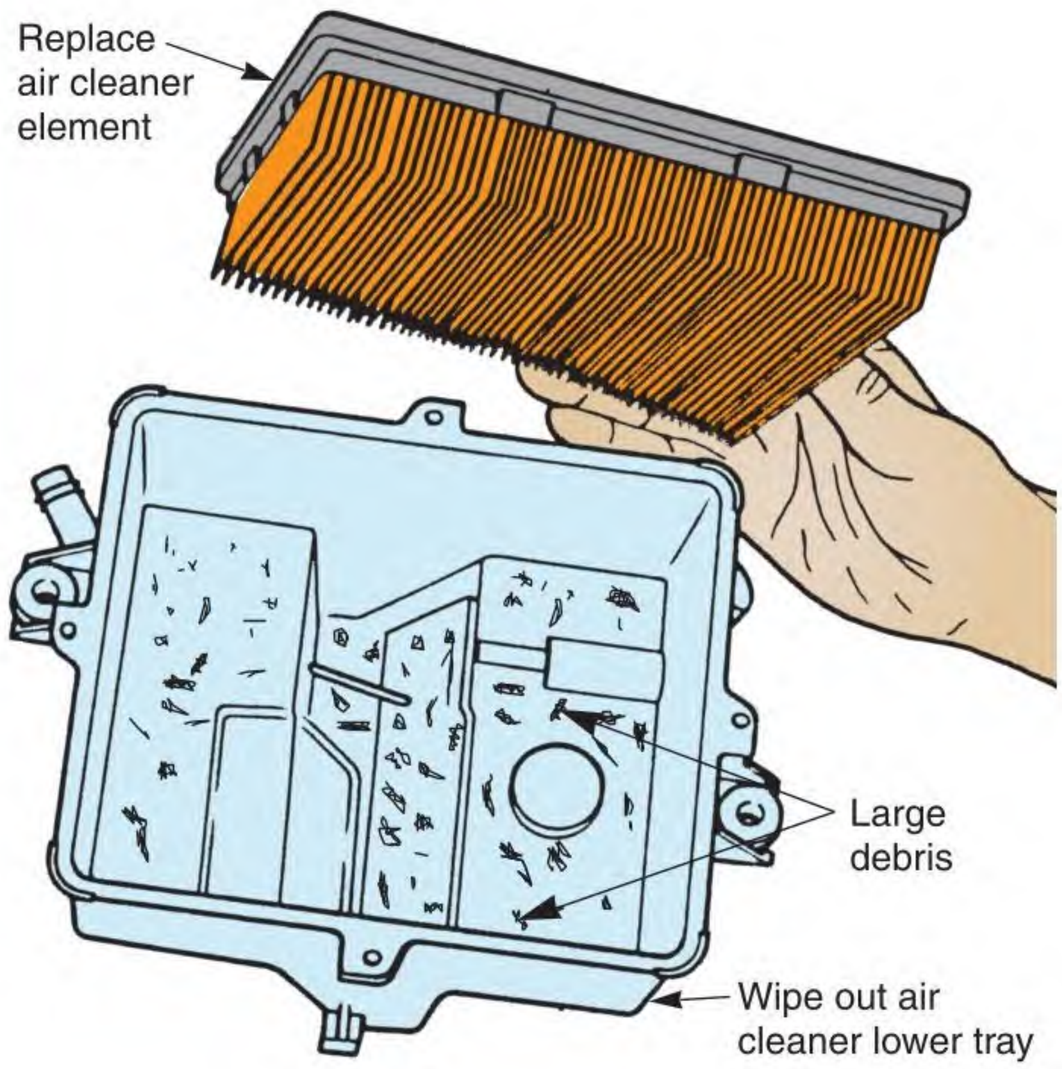
An ***air filter***, or ***air cleaner***, removes foreign matter (dirt and dust) from the air entering the engine intake manifold. Most air filters use a paper filter ***element*** (filter material). The filter element fits inside a metal or plastic housing. See **Figure 40-24**.

Air filter service usually involves replacing or cleaning the filter element. A paper filter element is usually replaced with a new unit. When replacing a filter element, you should also clean out the filter housing. Dirt can collect in the bottom of the housing. Look at **Figure 40-25**.



Honda

Figure 40-24. The air filter mounts inside a metal or plastic housing.



Ford

Figure 40-25. Paper filter elements are normally replaced when dirty. Make sure the housing is clean, secure, and not leaking.

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Be careful not to drop anything into the air inlet opening in the intake manifold engine. As a precaution, place a clean shop rag over the engine's air inlet.

Diagnostic Case Study

Concern: Mr. Boyd tells the service writer that his car stops running after about 10 miles of driving. If the car sits for about 15 minutes, it will start up again and he can usually get it to run OK until he gets home. The service writer says that he has no idea what the cause might be but that he will have a technician look at it.

Cause: Jim, the technician assigned to the job, first connects a scan tool to check for any stored trouble codes. The MIL light in the dash is not glowing but the indicator bulb could be burned out. The scan tool shows no stored or present codes. Jim takes the car for a test drive and after about ten miles of driving, the engine stalls and will not fire back up. Live readings on the scan tool show almost no fuel pressure right before the engine stops running. The car is towed back to the shop. Jim asks Duff for help finding the problem.

Duff says the problem has to be something that cannot set a trouble code. Duff remembers a past repair where the inlet screen on the end of the pickup tube in the gas tank was clogged with sticky fuel gum. The screen would allow fuel flow until a vacuum formed in the tank and the flexible screen would then fully collapse, stopping all flow. Duff tells Jim to drop the fuel tank and check the inlet screen.

Correction: Jim removed the fuel tank and found a gum-clogged inlet screen, which was stopping all fuel flow out of the tank. Since a new inlet screen is available, a new in-tank fuel pump with a new inlet filter had to be installed. The cost for the new pump was $150 and the labor time was three hours at $90 per hour.

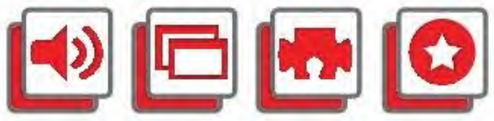
Summary

- A fuel supply system draws fuel from the fuel tank and forces it into the fuel metering device.
- Fuel tank capacity is the volume of fuel a fuel tank can hold. An average fuel tank capacity is 12–25 gallons (45–95 liters).
- A tank pickup-sending unit extends down into the tank to draw out fuel and to operate the fuel gauge.
- A fuel return system helps cool the fuel to prevent vapor lock (bubbles form in overheated fuel and stop fuel flow).
- An electric fuel pump, like a mechanical pump, produces fuel pressure and flow for the fuel metering section of a fuel system.
- The oil pressure switch is a safety feature that protects the engine from damage by shutting off the fuel pump when oil pressure is dangerously low.
- Typical fuel tank problems include fuel leakage, physical damage and contamination by foreign matter.
- To remove fuel from the tank, unscrew the drain plug and drain the fuel into an approved safety can. If a drain is not provided, use an approved pumping method to draw the fuel out of the tank.
- A faulty fuel tank sending unit can make the fuel gauge reading inaccurate.
- With a clogged fuel filter, the engine may temporarily lose power or stall when a specific engine speed is reached.
- Low fuel pump pressure can be caused by worn, dragging pump bearings, high resistance in electric pump circuit, leaking check valves, or physical wear of moving parts.
- Fuel pressure in a gasoline injection system can run from 50–2000 psi (344–13,790 kPa). A diesel supply pump should produce around 10–15 psi (69–103 kPa). Fuel pressure in a carburetor-type fuel system should be about 4–6 psi (28–41 kPa).
- Fuel pump volume, also called *capacity*, is the amount of fuel the pump can deliver in a specific amount of time.
- An inertia switch blocks current flow to the electrical fuel pump after a severe impact or collision.

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- Some vehicles provide a fuel pump access door in the trunk so you do not have to remove the fuel tank to service the pump.
- When replacing a filter element, you should also clean out the filter housing.

Technical Terms



Write the definitions for the following terms on a separate sheet of paper.

air cleaner
air filter
air supply system
bowl fuel filter
canister fuel filter
check valves
driving range
eccentric
electric fuel pump
element
filler cap
filler neck
fuel filters
fuel hoses
fuel lines
fuel metering system
fuel pumps
fuel pump capacity
fuel pump charging stroke
fuel pump pressure stroke
fuel pump testing
fuel pump vacuum
fuel pump volume
fuel rail
fuel return system
fuel strainer
fuel supply system
fuel system
fuel tank
fuel tank baffles
fuel tank capacity
fuel tank pressure sensor
fuel tank straps
hose clamps
impeller electric fuel pump
inertia switch
inertia switch circuit
low oil pressure safety circuit
mechanical fuel pump
oil pressure switch
pickup-sending unit
pleated fuel filter
reciprocating
reciprocating electric fuel pump
relief valve
returnless fuel injection systems
rocker arm
roller vane electric fuel pump
rotary fuel pumps
sliding vane electric fuel pump
spillback ball

Activities

1. Prepare a "tree diagnosis chart" for a fuel pump problem assigned by your instructor. Your resources will be a shop manual for the specific vehicle and your instructor. If your instructor requests it, present the procedure to the class using an overhead projector and sketches.
2. Review electrical principles of resistance in a circuit and explain with sketches how a thermostatic fuel gauge works.

Review Questions



Answer the following questions using the information provided in this chapter.

1. List and describe the three subsystems of a modern fuel system.
2. A(n) _____ system draws fuel from the fuel tank and forces it to the fuel metering device.
3. An average fuel tank capacity is around 12–25 gallons (45–95 liters). True or False?
4. What is the purpose of the spillback ball in a fuel tank filler neck?
5. Which of the following is *not* part of a fuel tank pickup-sending unit?
   (A) Vapor separator.
   (B) Filter.
   (C) Variable resistor.
   (D) Pickup.
6. Fuel lines are normally made of single-wall steel tubing. True or False?
7. When are fuel hoses needed?
8. Explain the operation of a fuel return system.
9. Which of the following is *not* used as a fuel filter element?
   (A) Coated paper.
   (B) Plastic.
   (C) Sintered bronze.
   (D) Foam.
10. The two basic types of fuel pumps are the _____ and _____ types.
11. Summarize how a high-pressure mechanical fuel pump operates.
12. Define the term *vapor lock*.

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13. Where can electric fuel pumps be located?
14. Which of the following is an advantage of an electric fuel pump?
    (A) Instant fuel pressure.
    (B) Fewer pressure pulsations.
    (C) Helps prevent vapor lock.
    (D) All of the above.
15. Rotary-type electric fuel pumps include the _____, _____, and _____ types.
16. A(n) _____ limits the maximum output pressure of an electric fuel pump.
17. Why is an oil pressure switch sometimes used in an electric fuel pump circuit?
18. List nine service rules for fuel lines and hoses.
19. Name five typical fuel filter locations.
20. During an electric fuel pump test, where can you connect your pressure gauge to eliminate the pressure regulator from the circuit?
    (A) Pump inlet.
    (B) Pump outlet.
    (C) Fuel rail.
    (D) None of the above.

ASE-Type Questions

1. Which of the following is *not* one of the three fuel system subsystems?
   (A) Cooling system.
   (B) Air supply system.
   (C) Fuel supply system.
   (D) Fuel metering system.
2. Which of the following are placed inside fuel tanks to prevent fuel splashing?
   (A) Caps.
   (B) Filters.
   (C) Baffles.
   (D) Restrictors.
3. When bubbles form in overheated fuel and prevent fuel flow, it is called:
   (A) blowby.
   (B) vapor lock.
   (C) fuel blocking.
   (D) condensation.
4. Which of the following are used to stop contaminants from entering parts that could be damaged by foreign matter?
   (A) Fuel filters.
   (B) Pleated paper elements.
   (C) Sintered bronze elements.
   (D) All of the above.
5. A mechanical fuel pump is powered by a(n):
   (A) pull rod.
   (B) eccentric.
   (C) rocker arm.
   (D) outlet valve.
6. Each of these is an electric rotary fuel pump *except:*
   (A) vacuum.
   (B) impeller.
   (C) roller vane.
   (D) sliding vane.
7. When performing fuel tank repairs, Technician A believes, for safety reasons, leaks should never be mended by welding or soldering. Technician B agrees, but says any fuel tank leak repair should be handled strictly by a specialist. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. Fuel filters are located:
   (A) in the fuel line.
   (B) in the fuel pump.
   (C) under the fuel line.
   (D) All of the above.
9. An electric fuel pump will usually produce:
   (A) 4–6 psi.
   (B) 6–10 psi.
   (C) 10–50 psi.
   (D) 28–41 psi.
10. Which of the following can be used to block current flow to an electric fuel pump after a severe collision?
    (A) Hose clamp.
    (B) Inertia switch.
    (C) Fusible resistor.
    (D) Fuel pump relay.

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Fuel Delivery System Diagnosis

Condition	Possible Causes	Correction
No fuel delivery.	1. No fuel. 2. Tank filter clogged. 3. Fuel lines kinked or clogged. 4. Vapor lock. 5. Fuel pump inoperative. 6. Fuel filter or filters clogged. 7. Frozen fuel line. 8. Air leak between fuel pump and tank. 9. Clogged injectors. 10. Inoperative injection pump (diesel).	1. Add fuel to the tank. 2. Replace tank filter. 3. Straighten or clean fuel lines. 4. Cool fuel lines. Change to less volatile fuel. Protect fuel lines from heat. 5. Replace pump. 6. Replace filters. 7. Thaw and remove water from the fuel system. 8. Repair leak. 9. Clean or replace injectors, locate source of deposits. 10. Repair or replace pump.
Insufficient fuel delivery.	1. Tank filter partially clogged. 2. Gas lines kinked or clogged. 3. Vapor lock. 4. Air leak between fuel pump and tank. 5. Fuel filter partially clogged. 6. Defective fuel pump. 7. Insufficient voltage reaching fuel pump. 8. Wrong pump. 9. Clogged injection pipes. 10. Defective injectors. 11. Faulty injection pump (diesel). 12. Fuel injection pulse width incorrect. 13. Mass airflow sensor malfunction. 14. Defective oxygen sensor.	1. Replace filter. 2. Straighten or clean fuel lines. 3. Cool fuel lines. Change to less volatile fuel. Protect fuel lines from heat. 4. Repair air leak. 5. Replace filter. 6. Replace pump. 7. Repair fuel pump circuit. 8. Install correct pump. 9. Clean or replace pipes. 10. Clean or replace injectors. 11. Rebuild or replace pump. 12. Check control module and sensors. Replace as needed. 13. Replace mass airflow sensor. 14. Replace oxygen sensor.
Excessive fuel delivery or pressure.	1. Defective fuel pump. 2. Incorrect pump. 3. Fuel injection pulse width excessive. 4. Fuel injection pressure regulator malfunctioning. 5. Engine control module defective. 6. Mass airflow sensor malfunction. 7. Defective oxygen sensor.	1. Replace pump. 2. Replace pump. 3. Check control module and sensors. Replace as needed. 4. Adjust or replace pressure regulator. 5. Replace control module. 6. Replace mass airflow sensor. 7. Replace oxygen sensor.

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In a port fuel injection system, the fuel rail delivers pressurized fuel to the fuel injectors.

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Chapter 41
Gasoline Injection Fundamentals

After studying this chapter, you will be able to:

- List some of the advantages of direct fuel injection systems.
- Describe the major assemblies of a modern gasoline injection system.
- Compare the operation of indirect gasoline injection to direct electronic gasoline injection.
- Summarize the operating voltages, current levels, and other values of sensors and injectors that are important to technicians.
- Summarize the operation of oxygen sensors to control an engine air-fuel ratio.
- Correctly answer ASE certification test questions on gasoline injection systems.

A typical ***gasoline injection system*** uses pressure from an electric or mechanical fuel pump to spray fuel into the engine's intake manifold (multiport or manifold injection) or its combustion chambers (direct injection). A gasoline injection system must provide the engine with the correct air-fuel mixture for specific engine operating conditions. Unlike a carburetor, the injection system uses pressure, not engine vacuum, to feed fuel into the engine. This makes a gasoline injection system very efficient.

All late-model vehicles use electric fuel pumps and electric solenoid-operated fuel injectors to spray gasoline into the intake manifold, intake valve port, or combustion chamber. In addition, direct electronic fuel injection systems use a supplemental mechanical fuel pump to increase system pressure.

Gasoline Injection Fundamentals

All electronic fuel injection systems can be divided into five subsystems:

- Fuel delivery system—The ***fuel delivery system*** feeds clean, liquid gas from the storage tank to the engine.
- Air induction system—The ***air induction system*** filters, routes, and controls outside air flowing into the cylinders.
- Sensor system—The ***sensor system*** measures pressure, temperature, engine speed, and exhaust cleanliness for the engine control module (ECM).
- Computer control system—In the ***computer control system***, the ECM responds to sensor signals to control the operation of the fuel injector and properly meter the precise amount of fuel into the engine.

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- Fuel metering system—The ***fuel metering system*** controls the amount of fuel injected into the engine. The ECM opens the injectors to meter fuel through the injectors and into the engine for burning.

The fuel delivery system of a modern direct electronic fuel injection (DEFI) system includes an ***electric fuel pump***, a mechanical fuel pump, a fuel filter, a pressure regulator solenoid, electronic fuel injectors (fuel flow control valves), and connecting fuel lines. Study **Figure 41-1**.

Atmospheric Pressure

Atmospheric pressure is the pressure formed by the air surrounding the earth. At sea level, the atmosphere exerts 14.7 psi (103 kPa) of pressure on everything. In higher altitudes, air pressure and air density drop, which lowers the amount of fuel that must be injected into the engine. Atmospheric pressure is caused by the weight of the air, as shown in **Figure 41-2**. Specific gauges and scan tools are used to measure atmospheric pressure in units of positive pounds per square inch (psi), Pascals, bars, or atmospheres.

Vacuum

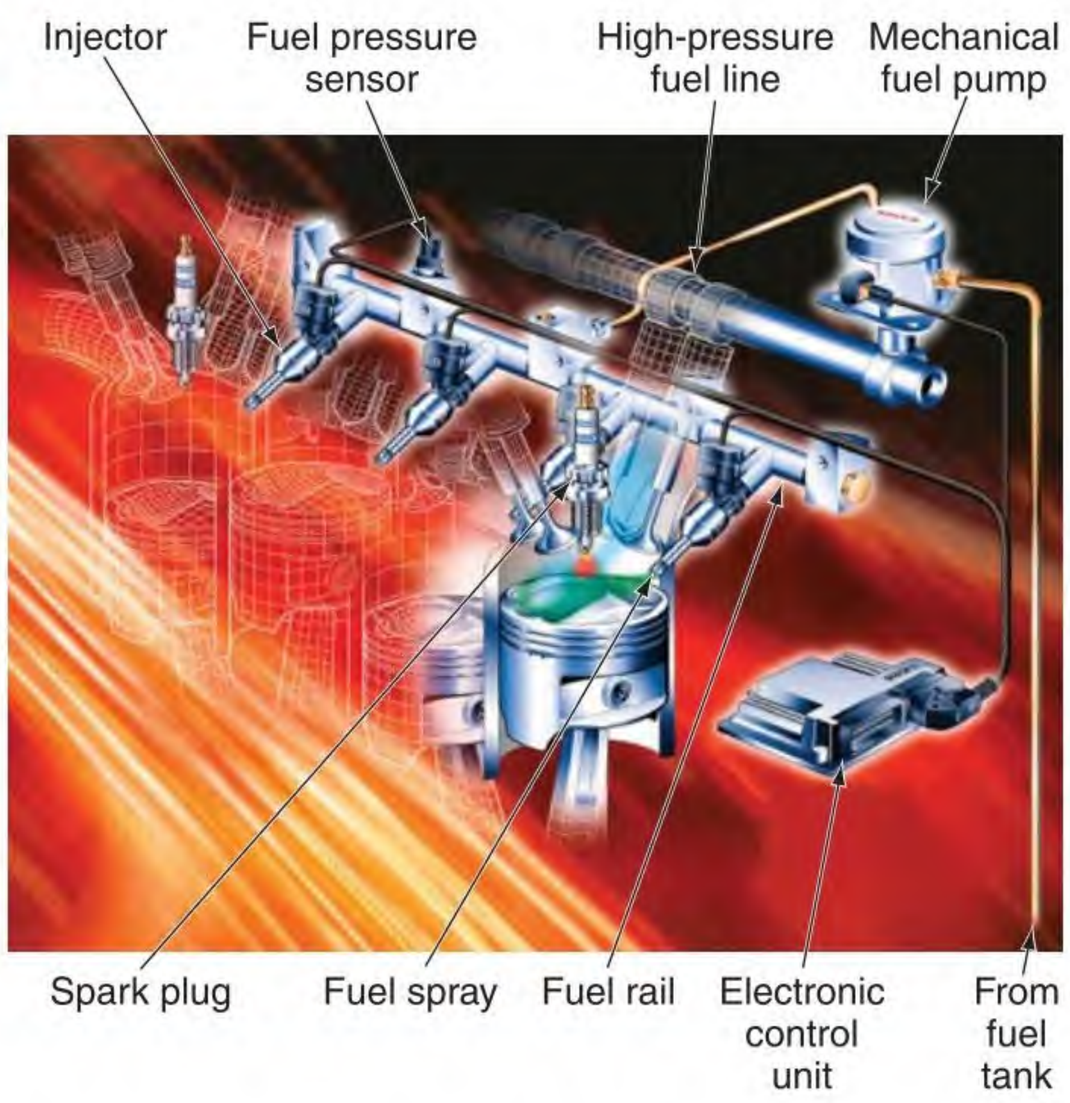
A ***vacuum*** is a pressure lower than atmospheric pressure that is formed in an enclosed area. "Suction" is another word for vacuum. Many sealed parts in and on an engine (vacuum diaphragms, solenoid air valves, and all vacuum hoses) contain vacuum pressure. Vacuum is measured in units of negative psi, inches of mercury, Pascals, or bars compared to outside atmospheric pressure.

Differences in Pressure Cause Flow

A difference in pressure between two areas can be used to cause flow. For instance, when you suck on a straw, atmospheric pressure pushes down on the liquid in the glass. This causes the liquid to flow through the straw and into the vacuum in your mouth. An engine uses differences in pressure to force fuel and air into its cylinders. The engine acts as a vacuum pump, producing a low-pressure area (or vacuum) in the intake manifold and cylinders. This pulls air into the engine to support combustion.

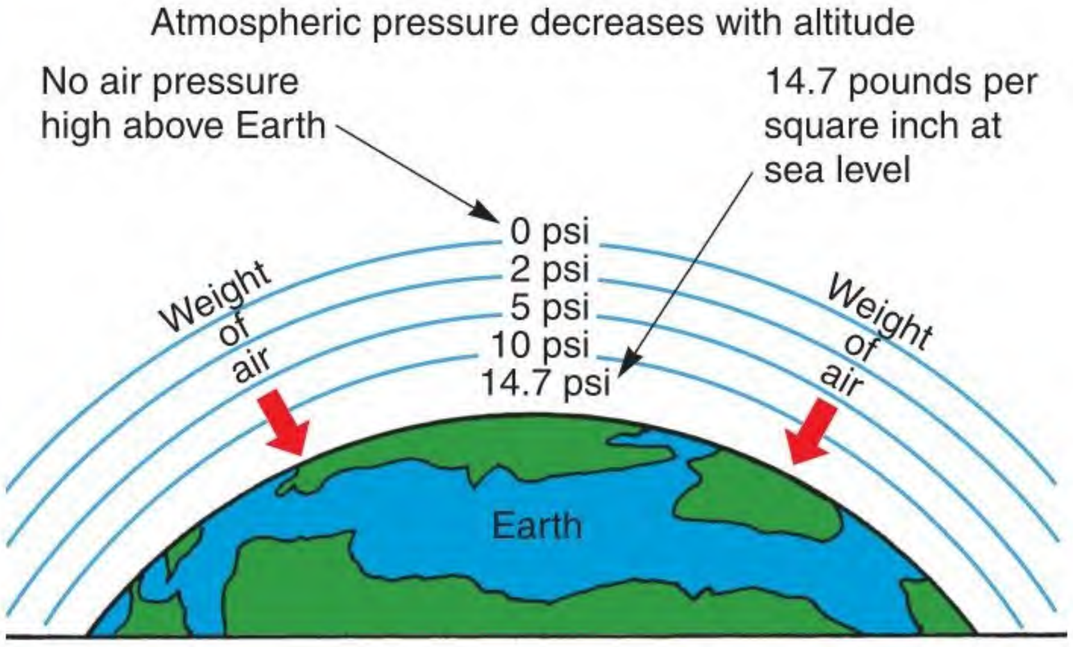
Engine Throttle Valve

The ***engine throttle valve*** is a "butterfly" or flap-type valve in the throttle body assembly that controls airflow and engine power output. See **Figure 41-3**. When closed, the throttle valve restricts the flow of air and the resulting flow of fuel into the engine. This keeps engine speed and power low for ***idling*** at low rpms. When the driver presses the accelerator to increase engine speed, the throttle cable slides inside its housing and swings the throttle valve open. Atmospheric pressure then pushes more air into the engine intake manifold. ***Engine sensors*** detect the resulting changes and increase fuel flow through the injectors.



Bosch

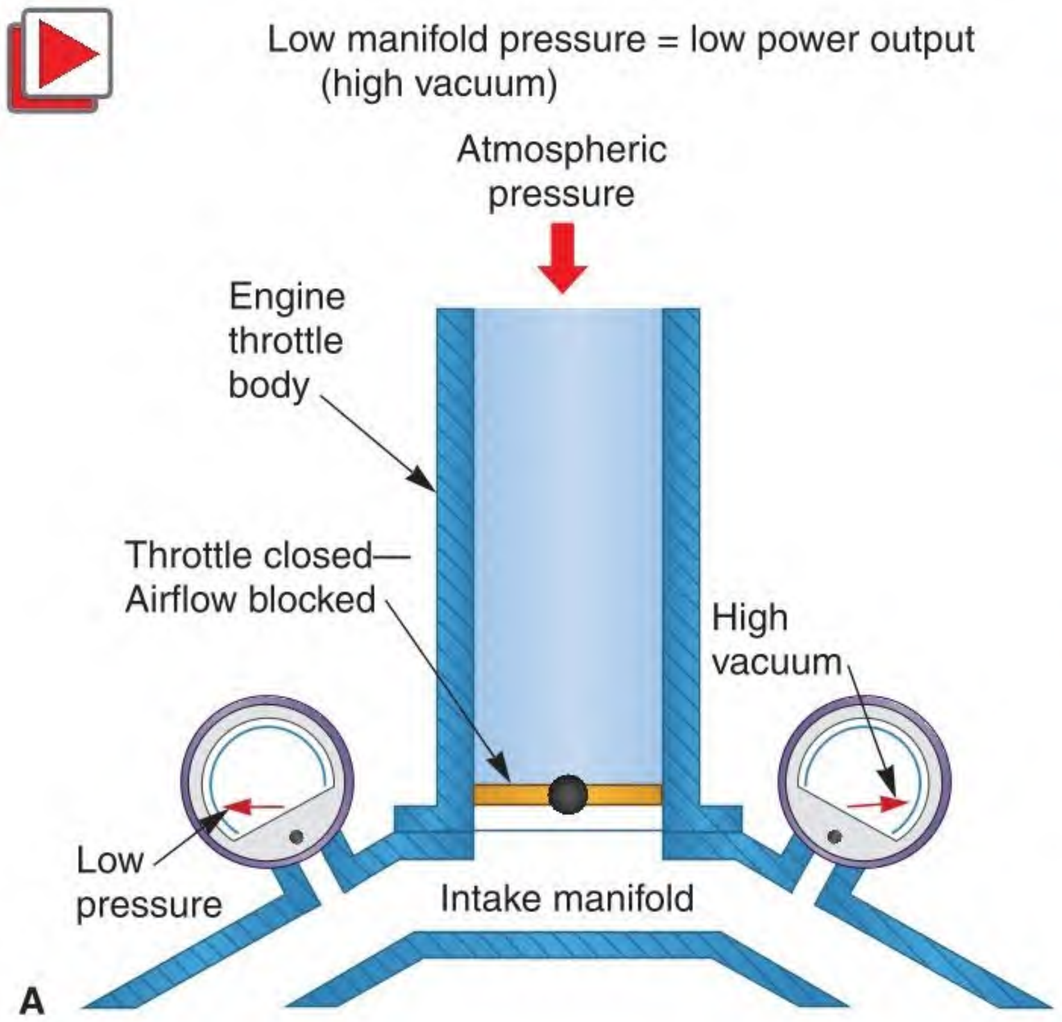
Figure 41-1. The components of a direct electronic fuel injection system develop high fuel pressure so that fuel can be injected directly into the combustion chambers.

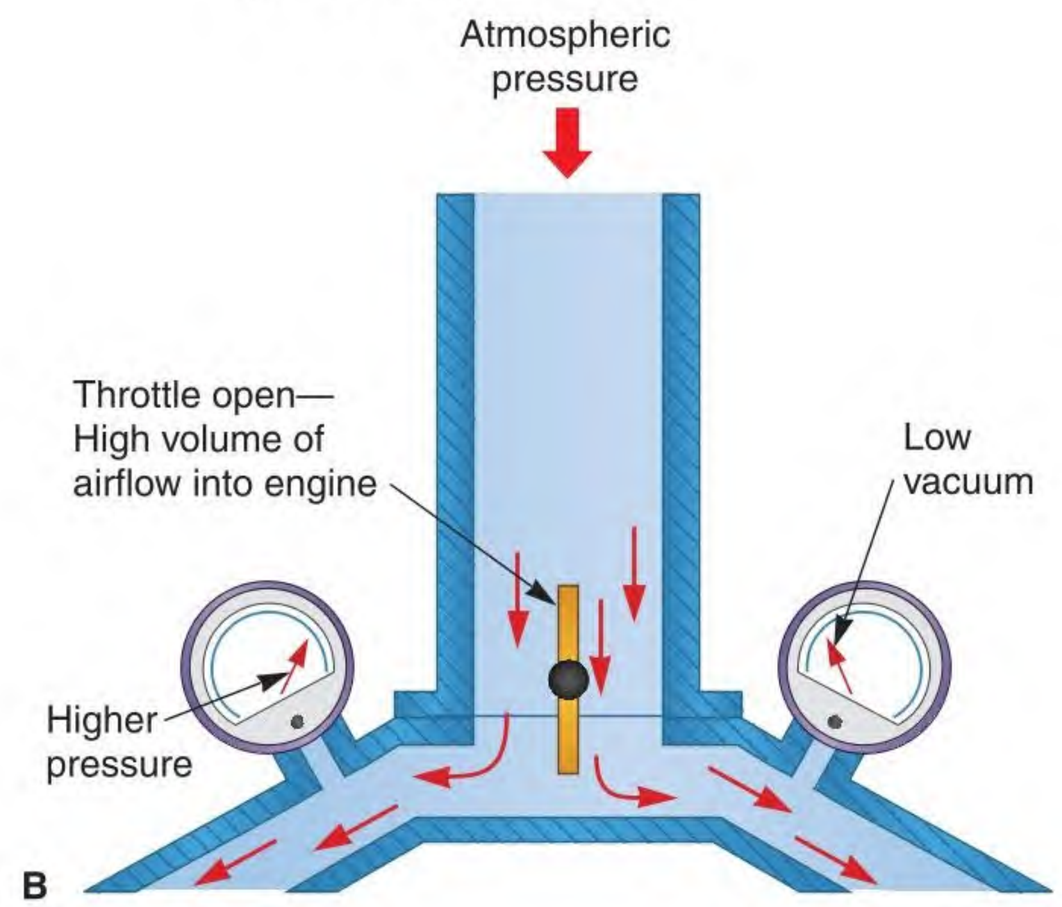


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Figure 41-2. Air pressure changes with altitude. Atmospheric pressure is what moves the air and fuel mixture into engine cylinders on intake strokes.

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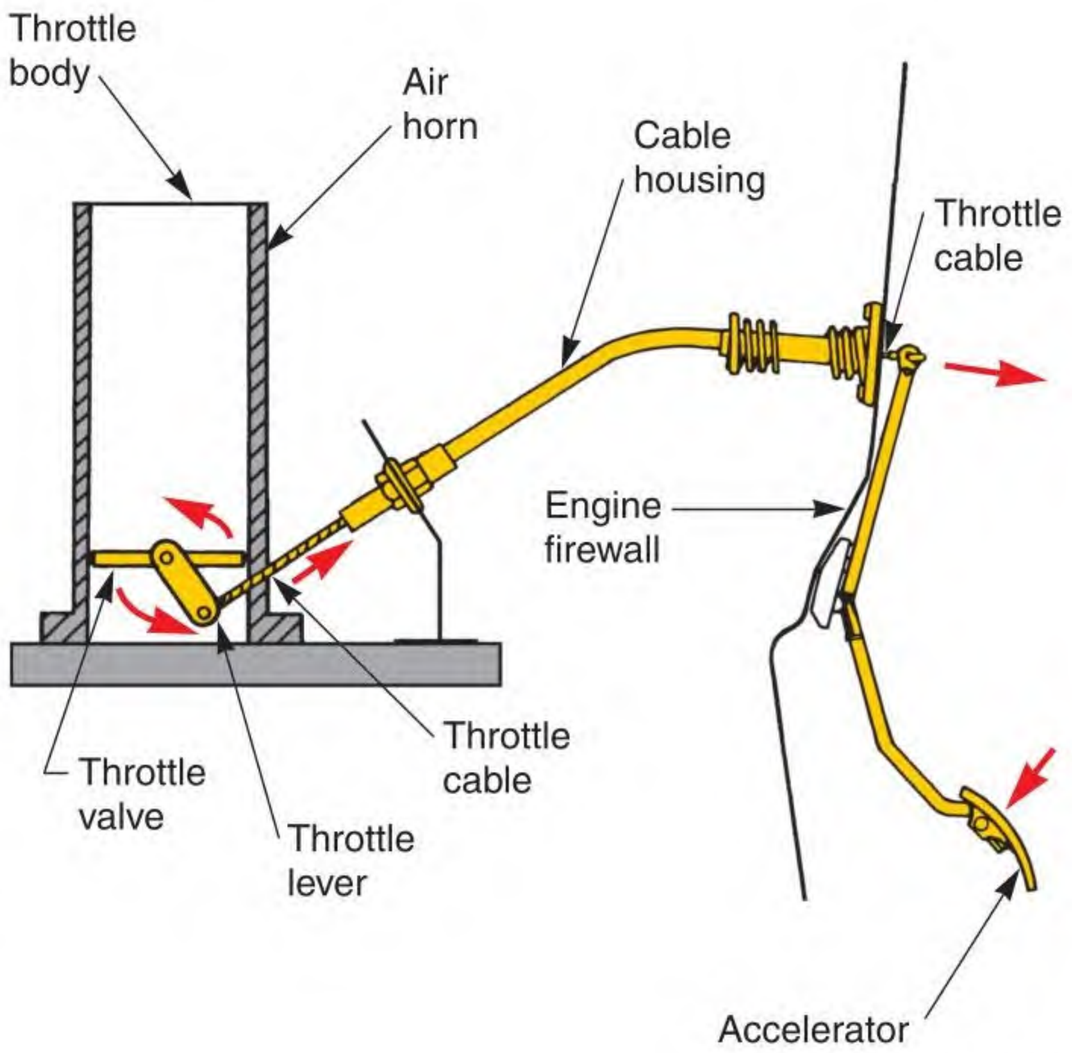
Figure 41-3. Throttle valve position controls airflow and the amount of vacuum in the intake manifold. A—A closed throttle valve produces high vacuum in the manifold. The engine tries to draw air through the throttle body, but cannot. B—An open throttle allows airflow, reducing the vacuum in the intake manifold.

With more air and fuel entering the cylinders, the pressure produced on the power strokes is increased. Engine speed and horsepower output then increase to accelerate the vehicle.

Tech Tip

In modern gasoline direct injection systems, it is possible to control engine speed without a throttle valve in the intake tract. Fuel injection quantity and timing can make the engine idle without the aid of a throttle valve. However, for safety purposes, manufacturers still use a throttle valve to protect against engine runaway (engine speed keeps increasing until engine fails) if an injector starts leaking fuel or the ECM fails to close the injectors.

When the accelerator is released, a throttle return spring pulls the throttle valve closed. Refer to **Figure 41-4**. This returns the engine to idle speed. ***Engine idle speed*** is the operating speed (in rpms) of an engine when the vehicle is in *Park* or *Neutral*. Idle speed is usually around 750 rpms. It can be controlled by the idle air control valve, idle speed solenoid, idle speed motor, or by the direct fuel injection system.



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Figure 41-4. The accelerator is connected to the throttle valve in the throttle body. This valve controls airflow and engine power output. Accelerator movement slides the cable inside the housing to transfer motion to the valve on the engine.

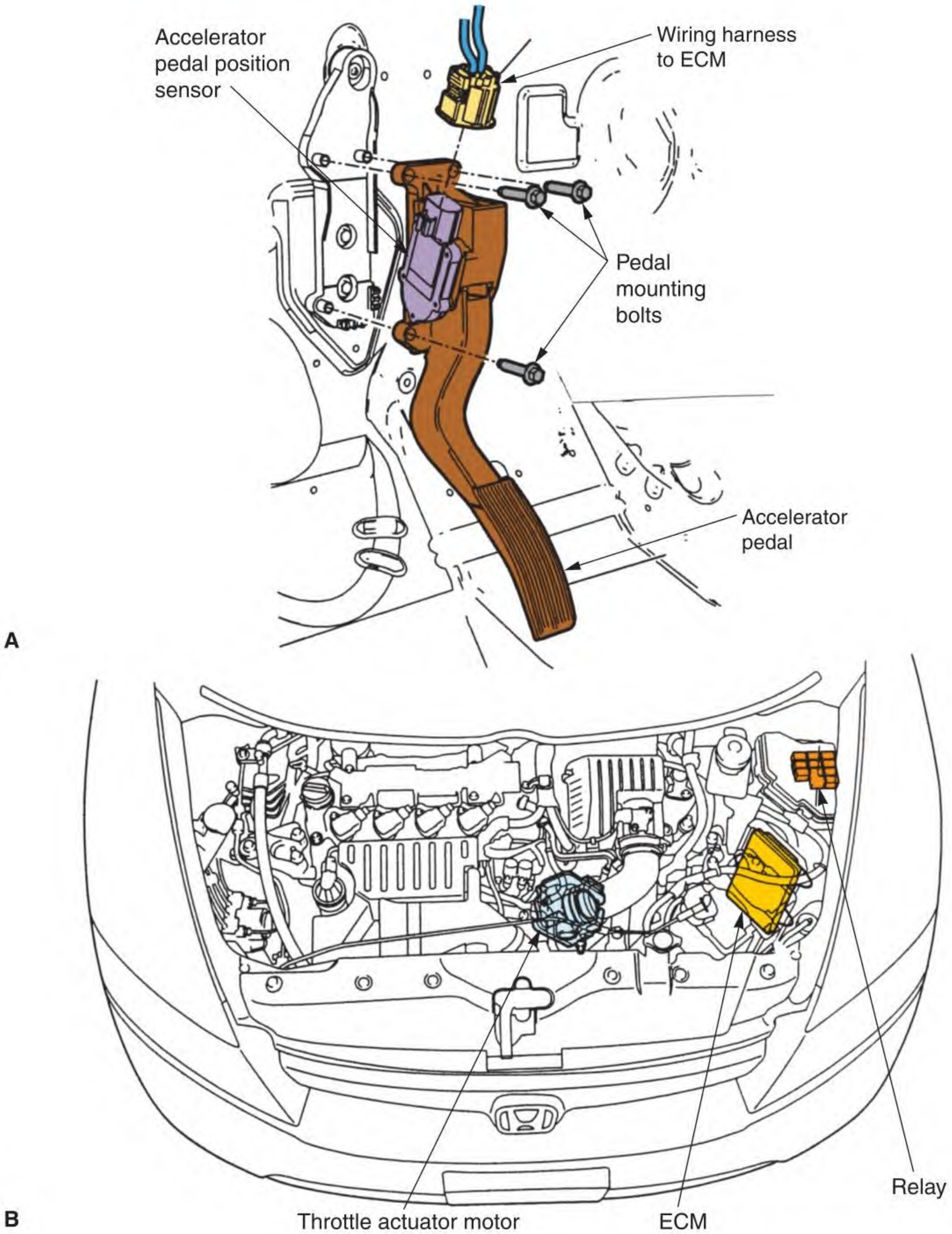
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Tech Tip

Throttle valves are not used on diesel engines. Removing the throttle valve and throttle body from the intake tract of an engine reduces pumping losses and improves diesel engine efficiency.

Throttle-by-Wire Systems

Throttle-by-wire systems, also termed ***drive-by-wire systems***, move the engine throttle valves electronically instead of using conventional mechanical linkage from the accelerator pedal. See **Figure 41-5**.



Honda

Figure 41-5. Throttle-by-wire systems control the throttle valve electronically. A—The accelerator pedal position sensor monitors the pedal position and sends a corresponding signal to the ECM. B—The ECM signals the throttle actuator to open or close the throttle valves based on signals from the pedal position sensor.

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An ***accelerator pedal sensor*** feeds an electric signal to the ECM that corresponds to pedal position. Refer to **Figure 41-6**. The accelerator pedal sensor usually has a multi-wire sensor with redundant variable resistors or hall chips that send opposing signals. One accelerator pedal signal might increase current flow to the ECM, and the other sensor decreases current flow back to the ECM. By operating in this way, the circuit becomes more dependable since one signal must change in opposite proportion to the other. If the ECM detects any variation in circuit voltages from normal, the ECM stores a trouble code and may even disable the engine until repairs are made.

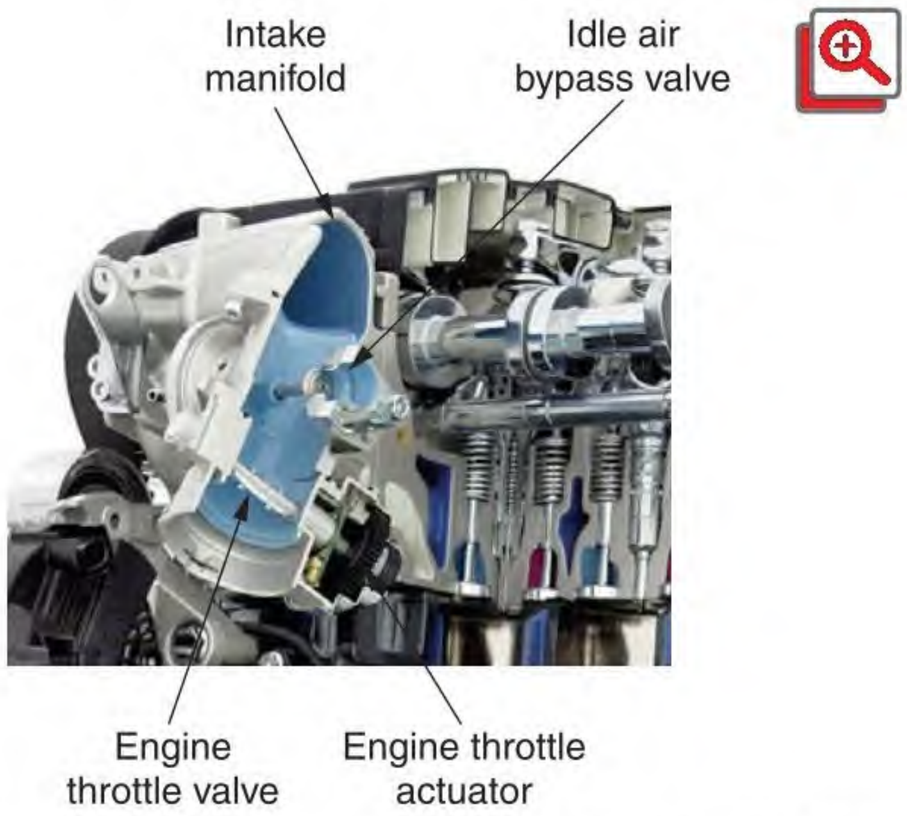
The ECM then sends an amplified control current to a servo motor ***actuator*** that opens and closes the engine throttle valve. The ECM can regulate acceleration, cruise consistency, and deceleration to improve fuel economy, reduce exhaust emissions, and prevent abrupt speed changes that could affect drive train service life. The ECM can also control engine speed by responding to the vehicle's gear shift sensor, traction control system, ABS, stability control, air conditioning, and other system inputs.

The ***engine throttle actuator*** is usually a small, reversible servo motor with an emergency release. Look at **Figure 41-7**. When the ECM sends current through the engine throttle actuator in one direction, the throttle can be swung open. If the ECM reverses dc motor polarity, the throttle is pulled closed. With an electronically-controlled engine throttle, the engine does not accelerate or rev as quickly when the accelerator is pushed down abruptly. If the transmission



Siemens

Figure 41-6. Accelerator pedal in a drive-by-wire system does not operate a steel cable going to the engine throttle valve. It operates a motion sensor that signals the computer to open or close the throttle.



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Figure 41-7. The engine throttle actuator has a tiny electric clutch to engage and disengage the motor from the throttle shaft.

shift lever is in *Neutral* or *Park*, the ECM may keep the engine at idle even when the gas pedal is pressed. Throttle-by-wire systems are found on both gasoline- and diesel-powered vehicles.

A ***throttle safety release*** is used in many throttle body assemblies to return the engine to idle even if the engine throttle actuator fails. It has an electric clutch release mechanism that disengages the engine throttle actuator if the ECM detects any problem. If power is lost to the engine throttle actuator, the motor drive clutch is disengaged, causing a spring to pull the throttle closed to slow the engine.

Gasoline Injection Timing

Older fuel injection systems use either ***continuous fuel injection*** (injectors spray fuel whenever engine was running) or ***intermittent fuel injection*** (injectors open and close regardless of intake valve positions). Modern direct and multiport injection systems are timed with the intake valves for improved efficiency.

A ***timed injection system*** sprays fuel into the engine during the intake or compression strokes, in relation to piston and valve action. The best example of timed injection is a diesel injection system that sprays fuel into its cylinders only on the compression strokes (hence, compression ignition engine without spark plugs). Combustion completely burns all of the injected fuel in about 5 milliseconds (0.005 seconds), at an engine speed of 4000 rpms. The whole combustion process forces the piston down to rotate

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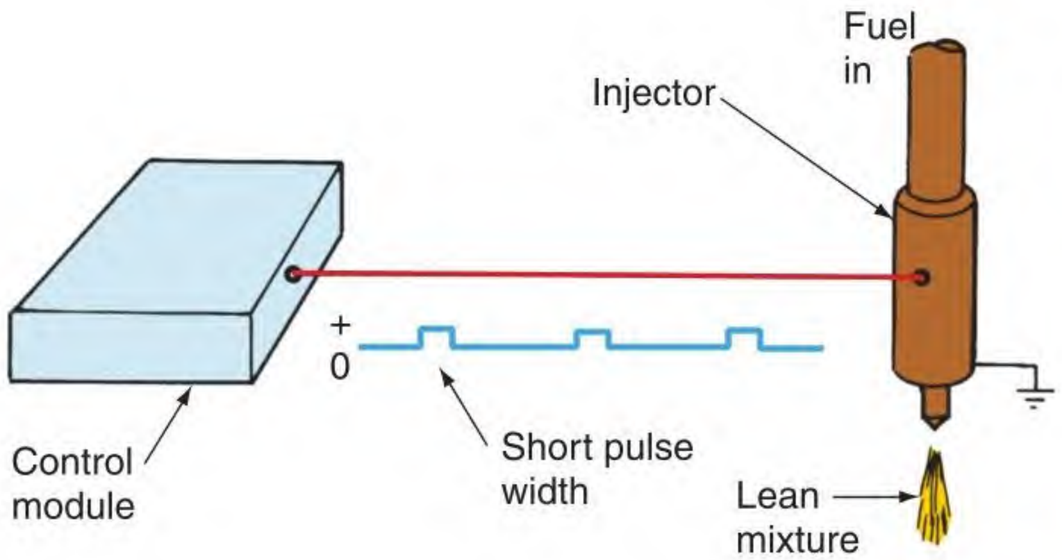
the crankshaft. Since passenger engines are multi-cylinder, at least one cylinder is always producing pressure and power to spin the crankshaft smoothly.

Injector Pulse Width

The ***injector pulse width*** indicates the amount of time each injector is energized and kept open. The ECM controls the injector pulse width and the amount of fuel sprayed into the engine. Study **Figure 41-8**. The ECM takes sensor readings for all critical engine operating conditions (air temperature, fuel pressure, crankshaft speed, camshaft position, transmission gear, etc.) using all power train sensors.

If the engine is accelerated for passing speeds, the ECM will lengthen the injector pulse width to richen the air-fuel mixture for more power. Under low load and engine power operating conditions, the ECM shortens the injector pulse width. With the injectors closed a larger percentage of time, the air-fuel mixture is leaner, producing better fuel economy, but less power.

If the engine temperature sensor signals the ECM that the engine is very cold, injector pulse width will be increased to spray more fuel to help start the cold engine. The ECM uses electrical data from the sensors to control the operation of the fuel injectors and other engine performance-related devices. A wiring harness connects the sensors to the input of the ECM. Another wiring harness connects the output of the ECM to the fuel injectors.



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Figure 41-8. Computer pulse width is used to control how much fuel is injected into the engine. A longer pulse width or duty cycle richens the fuel mixture. A shorter pulse width or duty cycle leans the mixture because the injectors are not opened as long on each pulse.

Direct and Indirect Injection

There are many types of gasoline ***fuel injection systems***. A gasoline injection system is often classified by where it injects fuel into the engine. An ***indirect injection system*** sprays fuel into the engine intake manifold. A ***direct injection system*** sprays high-pressure fuel into the engine's combustion chambers. Refer to **Figure 41-9**.

Indirect Injection Systems

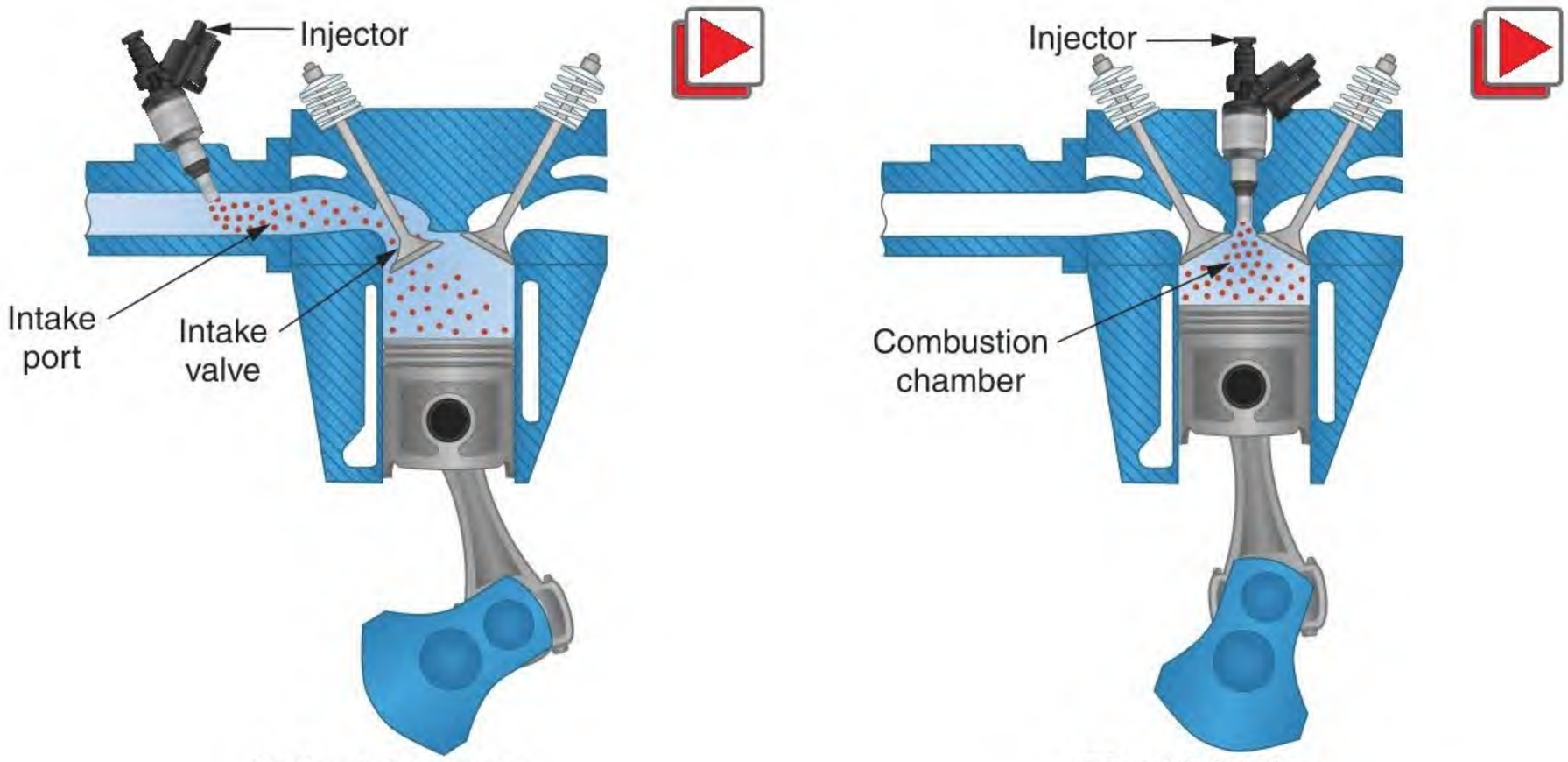
The two common types of indirect injection systems are throttle body injection systems and multiport injection systems, **Figure 41-10**. In a ***throttle body injection system (TBI)***, or single point injection, the injector nozzles are mounted in a throttle body assembly located on top of the engine. See **Figure 41-10A**. TBI was the first electronic fuel injection system used on passenger cars. Although a little more efficient than carburetors, they added little to engine power and efficiency.

Throttle body injection was replaced by multiport injection. A ***multiport injection system***, **Figure 41-10B**, has ***fuel injectors*** in the ***intake ports*** (air-fuel runners, or passages, going to each cylinder). Gasoline is sprayed into each intake port, toward each intake valve. One injector is provided for each engine cylinder. Some early designs also had a ***cold-start fuel injector*** to richen the fuel mixture in the engine manifold for cold engine startup.

Direct Fuel Injection

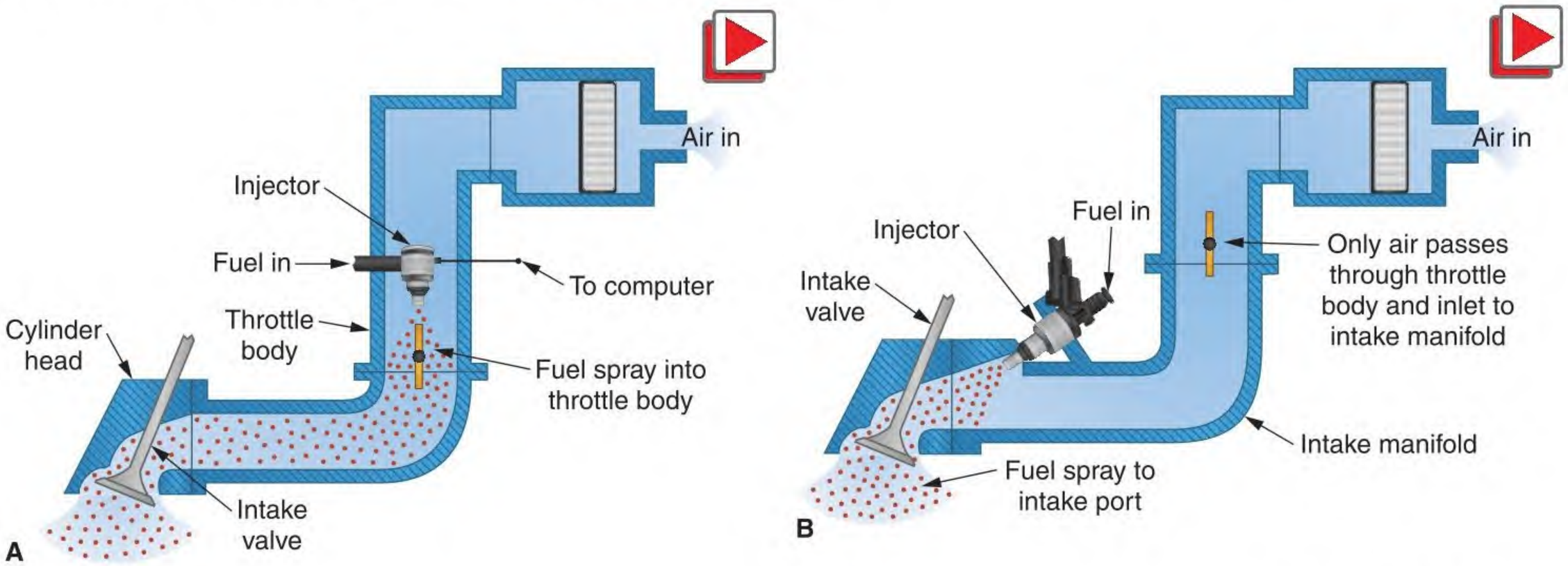
Direct fuel injection (DFI) systems inject fuel directly into the engine combustion chambers. Older direct fuel injection systems were all-mechanical diesel injection systems. New direct fuel injection systems are both mechanical and electronic. These systems are commonly referred to as ***direct electronic fuel injection (DEFI)***. In addition

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Figure 41-9. Study the differences between indirect and direct injection systems. In an indirect injection system, fuel is sprayed into the intake manifold. In a direct injection system, fuel is sprayed into the combustion chamber. Today's gasoline and diesel engines both use electronically-controlled direct injection systems.



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Figure 41-10. Indirect injection systems. A—In a throttle body injection system, the fuel injector is located in the throttle body. B—In a multiport injection system, an injector is located right before each intake valve. This improves efficiency and fuel distribution.

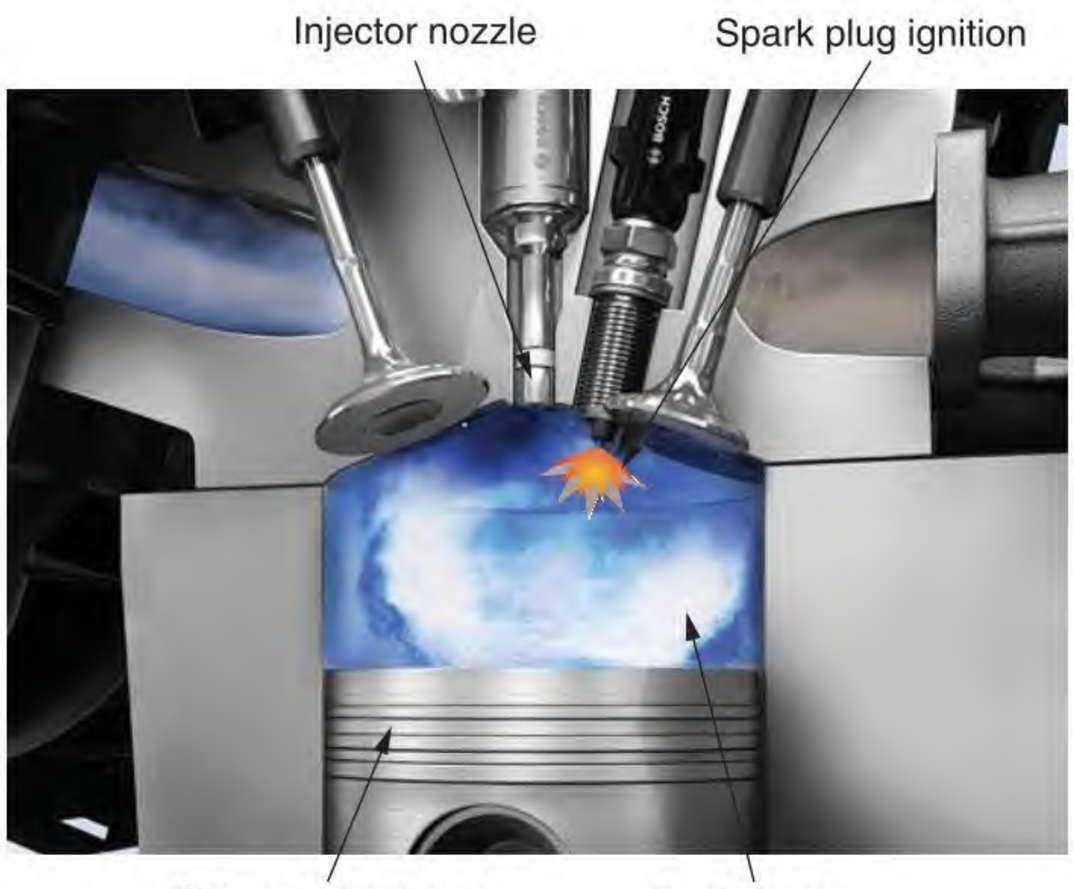
to an electric fuel pump, a DEFI system uses a mechanical fuel pump and high-pressure injectors to spray fuel straight into the engine's combustion chambers. This is the most common design found on late-model engines. Refer to **Figure 41-11**.

DEFI systems control the air-fuel mixture more precisely than other designs, lowering emissions and fuel consumption while increasing engine power output. Therefore, DEFI has replaced multiport injection in most late-model vehicles.

A DEFI system has three injection modes that affect combustion efficiency and engine horsepower: stratified charge mode, stoichiometric mode, and full power mode.

The ***stratified charge mode*** is an ultra-lean burn mode in which a small charge of fuel is injected into the combustion chambers during the end of the compression stroke. Lean burn is for light engine loads (low torque output) at lower engine speeds (1000 to 2000 rpms). During stratified charge combustion, the

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Bosch

Figure 41-11. A DEFI system can spray fuel into the engine during the intake stroke and the compression stroke. It can also control the shape and dispersion of the fuel charge injected into the combustion chamber.

engine piston is sliding up, compressing, and pushing the fuel spray charge up to the spark plug. When the spark plug fires, the large amount of oxygen with the small amount of gasified fuel explodes almost as quickly as it burns.

The ultra-lean mode air-fuel mixture is as high as 65:1 (65 parts air to one part fuel) and can be used for short periods of time without detonation. DEFI mixtures are much leaner than in a conventional engine with multiport fuel injection.

Although a stratified charge results in higher NO_x emissions due to higher combustion temperatures, the catalytic converter can treat and remove this toxin from the engine exhaust.

The ***stoichiometric mode*** produces a theoretically homogenous (equally mixed and dispersed) mixture of fuel and air. It provides good power and produces the lowest emissions of all DEFI modes of operation.

The stoichiometric mode tries to attain a mixture of 14.7:1 by weight. To achieve this theoretically perfect air-fuel charge in the cylinders, the injector sprays fuel during the intake stroke as air is rushing through the intake port and into the area above the engine piston.

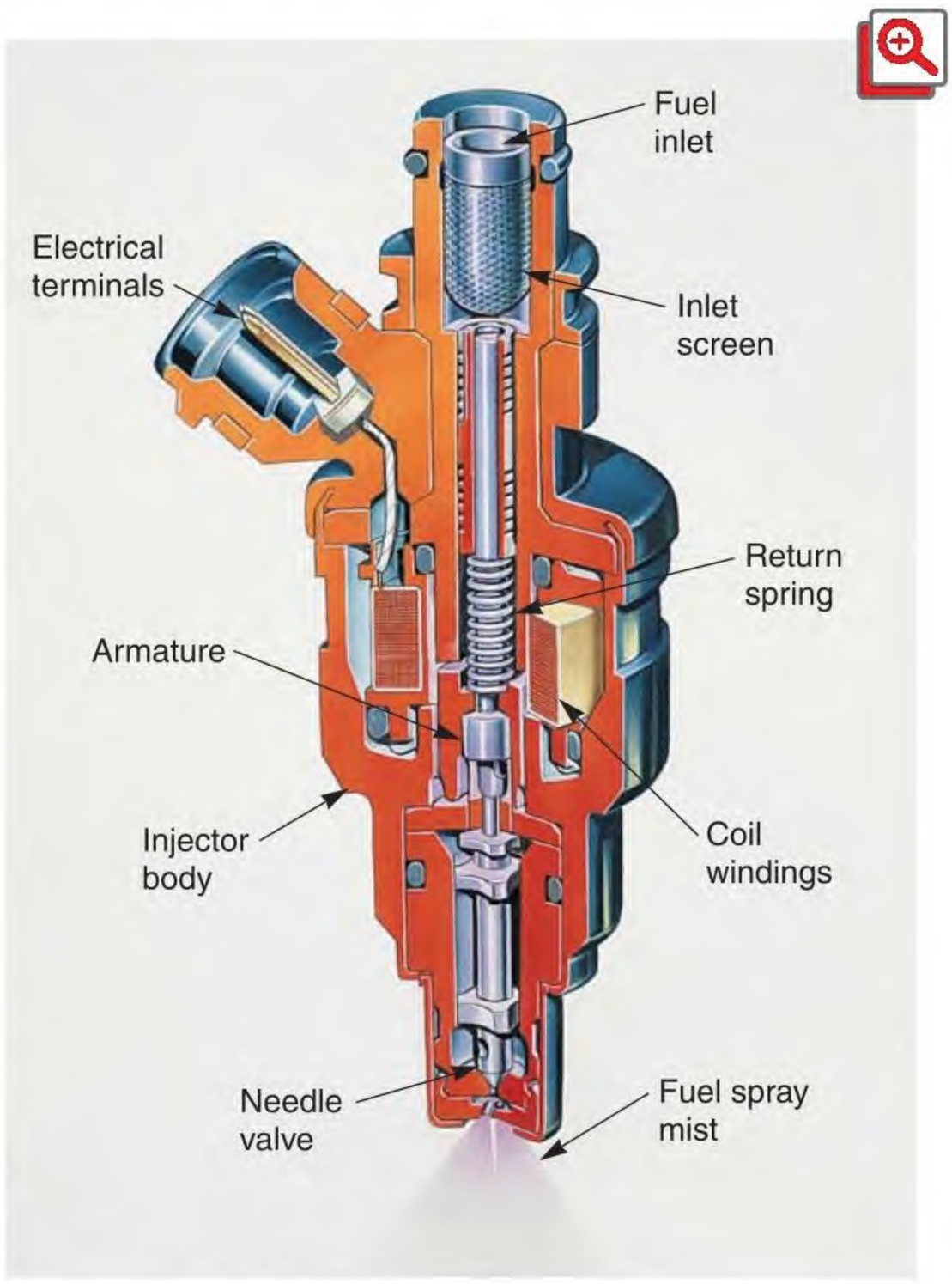
The ***full power charge mode*** produces a homogeneous, rich mixture (more fuel) that generates more combustion pressure and power. This is needed when the engine is accelerated quickly to produce more power and torque. Full power mode might use a slightly richer air-fuel mixture of about 13:1.

Electronic Fuel Injector Types

There are now two common types of electronic fuel injectors on the market: solenoid fuel injectors (electric current energized electromagnet pulls fuel valve open) and piezo fuel injectors (electric current energized crystal expands to push fuel valve open).

Solenoid Fuel Injectors

A ***solenoid fuel injector*** uses a small set of coil winding to produce an electromagnet inside the injector housing. See **Figure 41-12**. A solenoid fuel injector used in a multiport system typically consists of the following components:



Lexus

Figure 41-12. This cutaway view shows the major parts of a solenoid fuel injector.

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- Electric terminals—Electric terminals are electrical connections that complete the circuit between the injector coil and electronic control module.
- Injector solenoid—The injector solenoid is an armature and coil assembly that opens and closes the needle valve.
- Inlet screen—The inlet screen filters and traps debris before it can enter the injector nozzle.
- Needle valve—The needle valve is located on the end of the armature and seals against the needle seat.
- Needle seat—The needle seat is a round hole in the end of the injector that seals against the needle valve tip.
- Return spring—The return spring returns the needle valve to the closed position.
- O-ring seal—The O-ring seal fits around the outside of the injector body and seals in the intake manifold.
- Injector nozzle—The injector nozzle is an opening in the injector tip that produces the fuel spray pattern.

When the ECM grounds the injector circuit, a magnetic field expands around the injector windings to magnetically attract a spring-loaded iron or steel armature. The magnetic field overcomes spring tension and pulls the injector valve open to spray fuel into the engine's intake ports or combustion chamber. See **Figure 41-13**. When the windings are not energized, spring pressure holds the injector closed, keeping fuel from entering the engine.

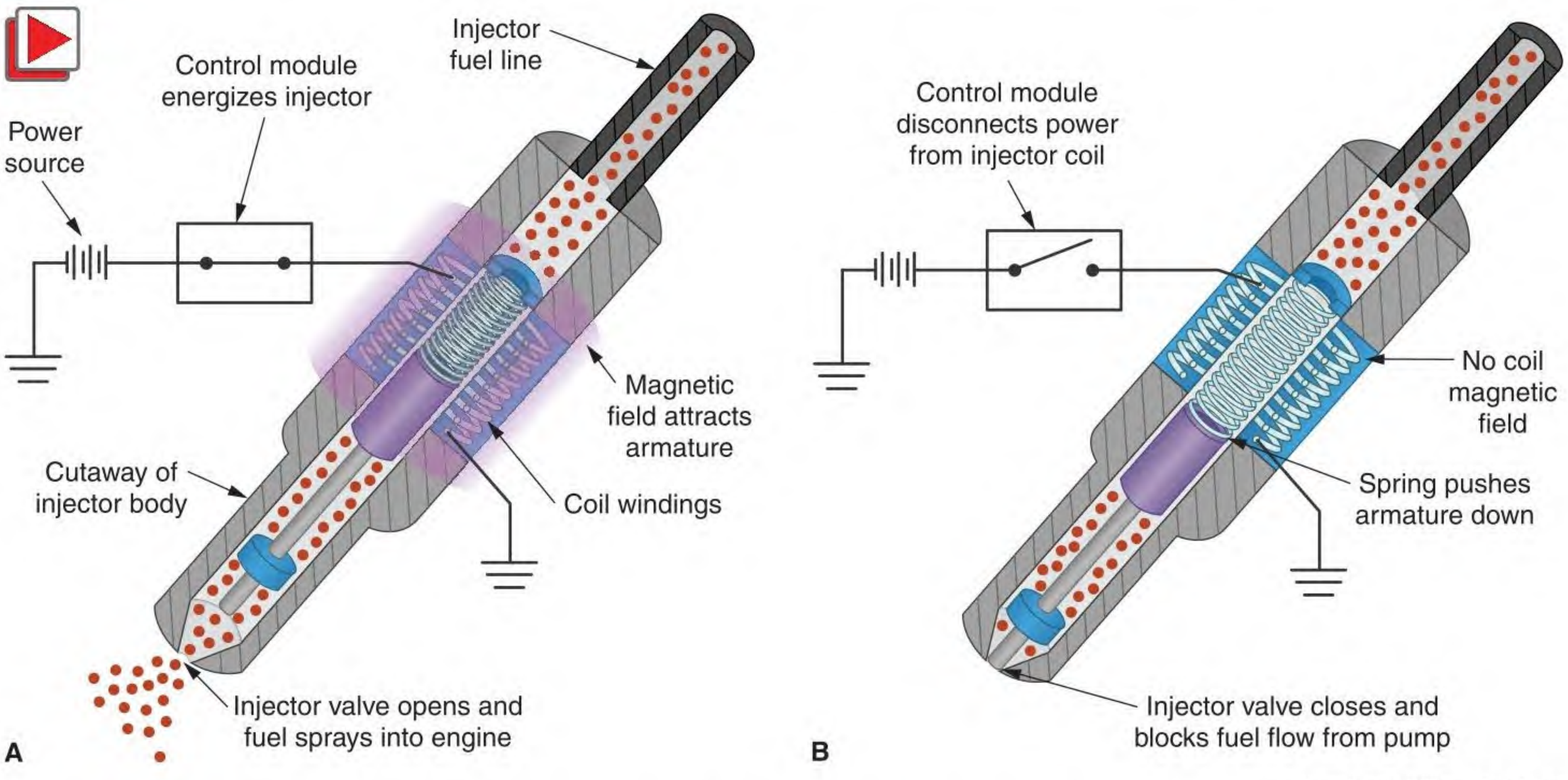
A solenoid fuel injector used in a multiport system is usually press-fit into the runner (port) in the intake manifold. Each injector is aimed to spray fuel toward an engine intake valve.

There are several variations of electronic multiport injection. It is important that you understand the primary differences between each type system.

Piezo Fuel Injectors

A ***piezo fuel injector*** uses a crystalline ceramic material instead of an electromagnet to open the injector valve. Refer to **Figure 41-14**. The piezo crystal converts electrical energy directly into motion. Piezo fuel injectors are used in the direct injection systems found on modern gas and diesel engines.

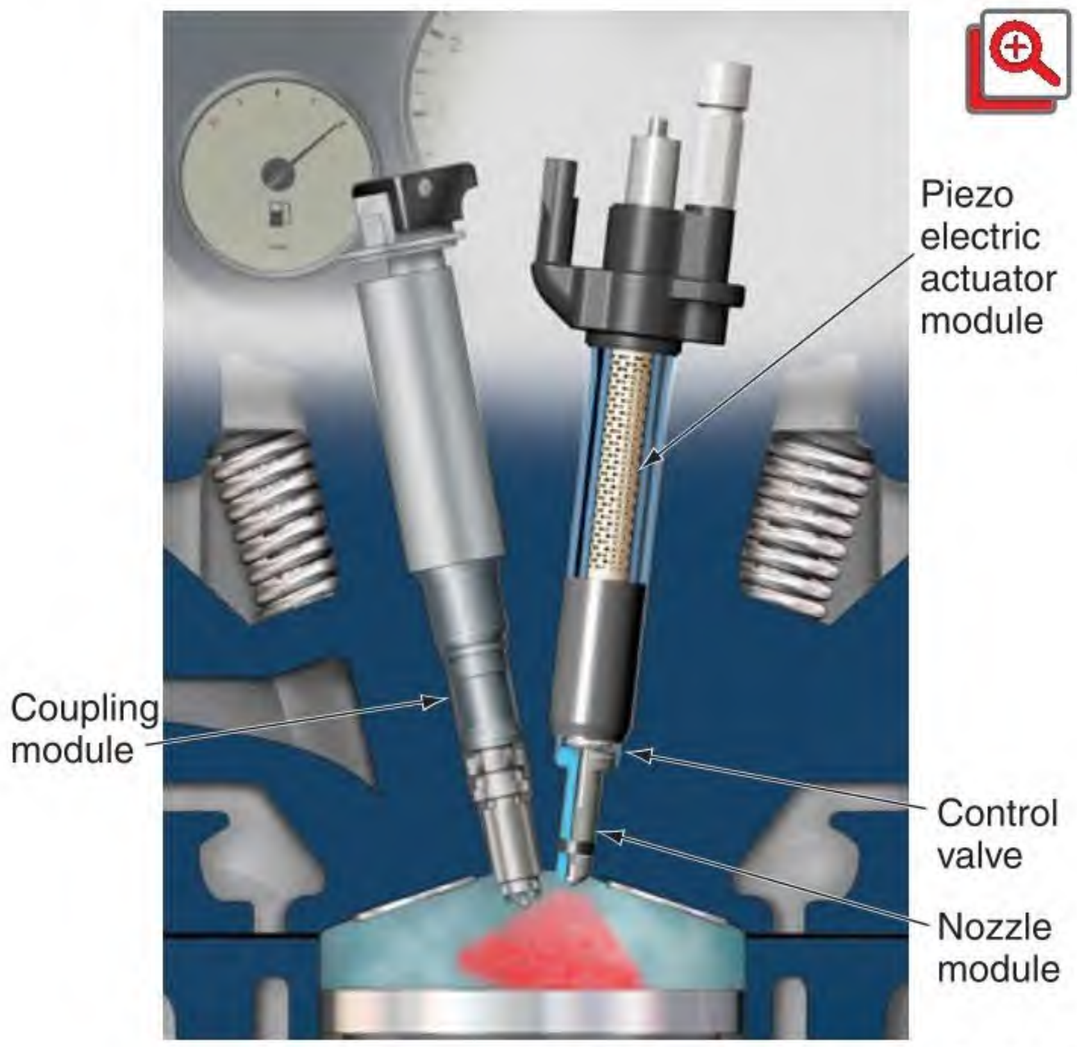
Current flow through the piezo crystal in one direction causes the atoms in the crystal to repel each other, physically expanding the crystal. This action pushes the injector valve open very quickly. When current flow is reversed, the piezo crystal is reduced in size, which closes the fuel injector.



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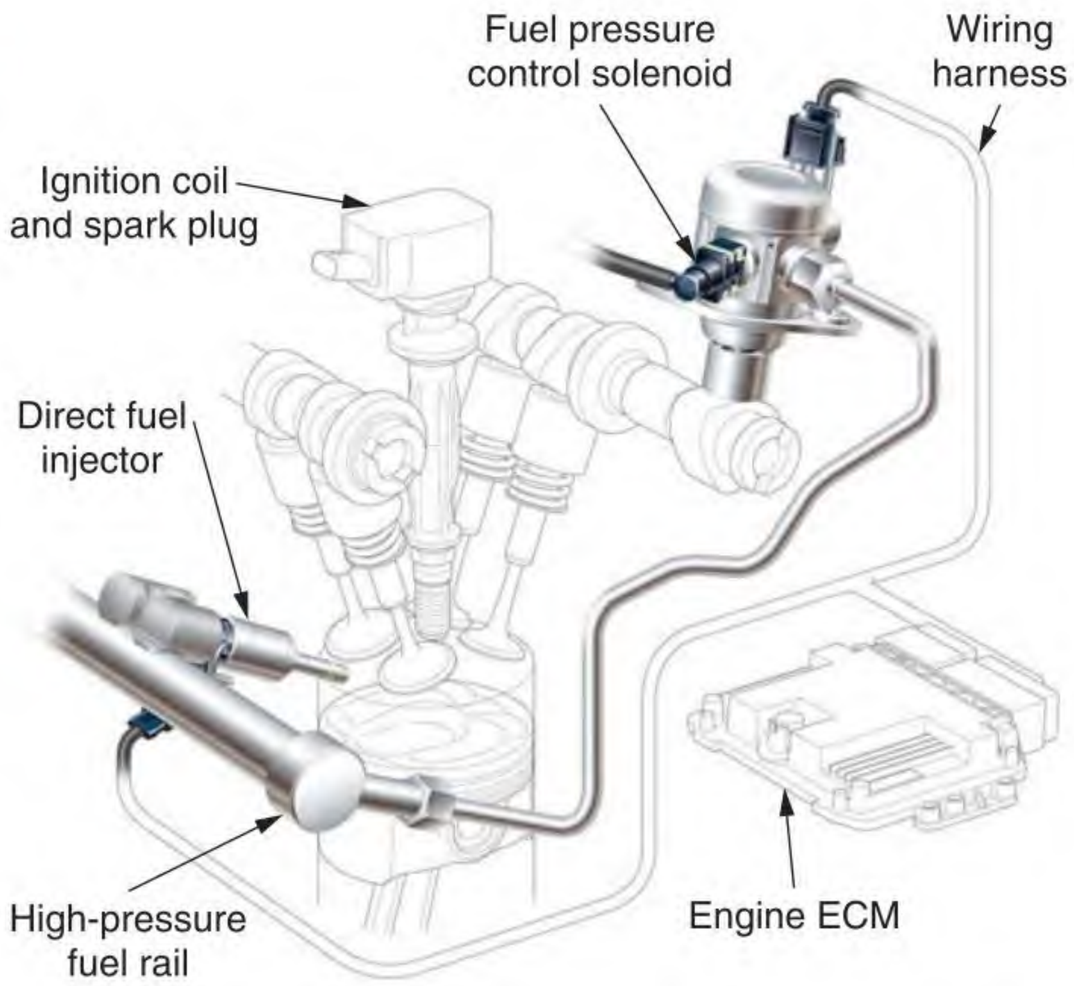
Figure 41-13. Solenoid fuel injector operation. A—Current through the injector coil builds a magnetic field. The field attracts and pulls on the armature to open the injector. Fuel then sprays out of the injector. B—When the control module breaks the circuit, the spring pushes the injector valve closed to stop fuel spray.

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Figure 41-14. Piezo gasoline injectors use a solid-state actuator to open the injector nozzle and spray fuel into the combustion chamber.



Volvo

Figure 41-15. Most DEFI fuel pressure regulators and fuel pressure sensors are built into high-pressure mechanical fuel pumps. The ECM can open or close a high-pressure bypass to maintain constant fuel pressure to injectors.

Because the needle valve, armature, and return spring in a piezo fuel injector are smaller and lighter than those used in solenoid-operated injectors, these components can be snapped open and closed more quickly. Consequently, a piezo injector can more precisely control fuel metering, leading to better fuel economy and reduced exhaust emissions.

Fuel Pressure Regulator

A ***fuel pressure regulator*** controls the amount of fuel pressure in the fuel rail. Both low- and high-pressure fuel injection systems require a fuel pressure regulator.

A ***DEFI fuel pressure regulator*** uses an electric solenoid to bypass excess fuel pressure back to the low pressure side of the system. The ECM controls the fuel pressure solenoid by rapidly snapping it open and closed. A solenoid-type pressure regulator is often mounted on the mechanical fuel pump or sometimes on the fuel rail. See **Figure 41-15**.

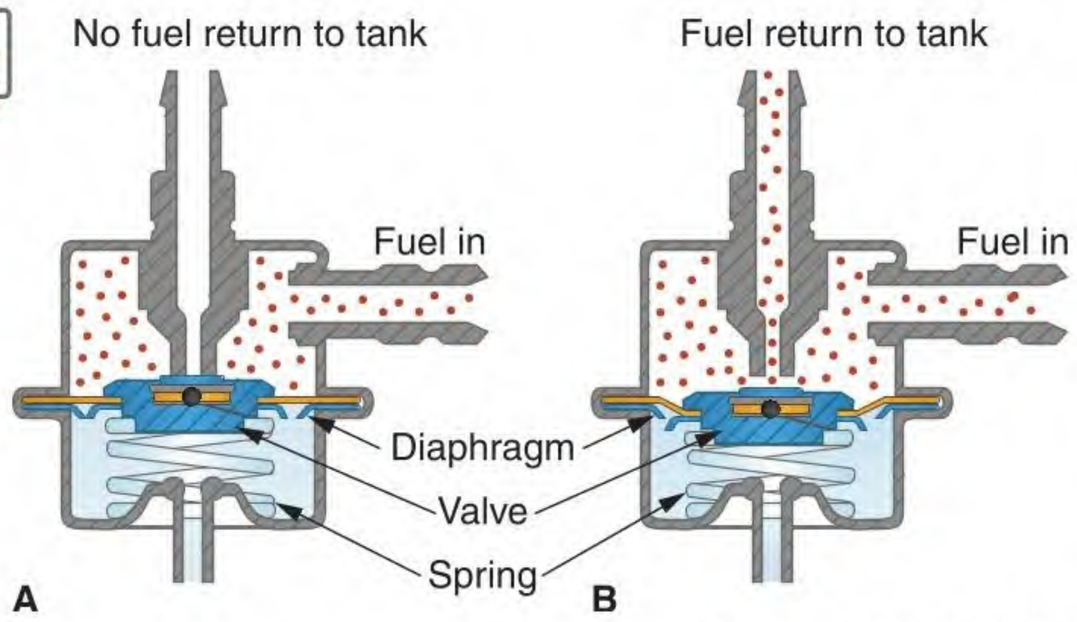
To increase fuel pressure, the ECM sends a longer duty cycle and more current to the electromagnet to force a small relief valve closed. To decrease fuel pressure, the ECM opens the ground circuit. This allows spring pressure to open the bypass valve to reduce fuel pressure.

Tech Tip

Since a DEFI fuel pressure regulator is normally open, any loss of electric power to or from the ECM or injector amplifier will open the fuel pressure relief valve to reduce fuel pressure. This prevents a failed computer circuit or relief valve from fuel pressure that exceeds specifications. Most DEFI systems will stop all mechanical fuel pump pressure by blocking the fuel inlet to the pump if the OBD software in the ECM detects any problem.

An ***EFI fuel pressure regulator*** uses engine vacuum, not the ECM, to control fuel pressure in multiport fuel injection systems. Changes in engine vacuum and load are used to control fuel pressure. Refer to **Figure 41-16**. When engine vacuum is low (during rapid acceleration, for example), low air pressure in the engine intake manifold cannot overcome spring tension. The EFI fuel pressure regulator would increase fuel pressure, so more fuel is injected into the engine. The opposite is true when engine vacuum is high—when engine load and power requirements are low.

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Figure 41-16. Fuel pressure regulator operation. A—Low engine vacuum indicates high engine load. The spring holds the regulator return closed to increase fuel pressure for more power. B—High engine vacuum indicates low load. Vacuum acts on the diaphragm, opening the regulator return to the tank, which reduces or limits fuel pressure.

Fuel Rail

The ***fuel rail***, also called a ***fuel log***, is a large diameter steel tube that feeds gasoline to the inlet fittings of the fuel injectors. Both indirect injection systems and direct injection systems require a fuel rail to all injectors to obtain the same amount of fuel pressure and flow. A large fuel rail is important, especially in DEFI systems, since the large volume or area inside the rail reduces pressure pulses that can affect fuel flow in these high-pressure systems.

A ***fuel system service fitting*** is often provided on low-pressure EFI systems for releasing and measuring fuel pressure. Most high-pressure DEFI systems do not provide a service fitting in the fuel rail for obvious safety reasons. Low-pressure EFI systems operate on less than 15 psi (103 kPa). A high-pressure fuel injection system with an engine-driven fuel pump can produce over 2000 psi (13,789.5 kPa).

DEFI Amplifier Module

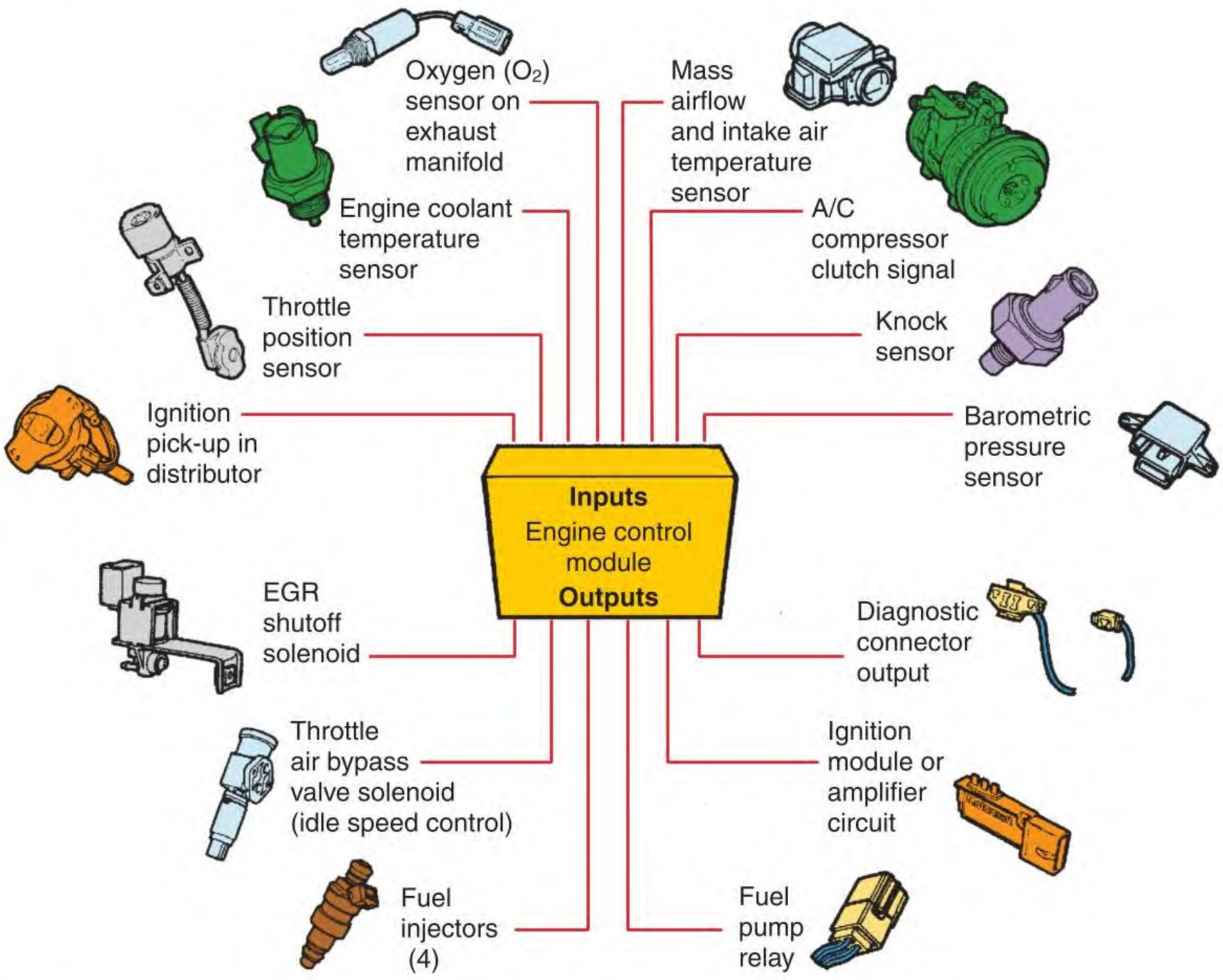
A ***DEFI amplifier*** is needed to increase the voltage and current signal sent from the ECM to operate the high-pressure direct injectors. High-pressure injectors used in DEFI systems often require up to 100 volts dc for proper solenoid operation. Large capacitors in the DEFI amplifier can be used to boost voltage and current to pulse the high-pressure injectors open. Check the operating voltages for injectors in service literature before connecting test instruments to the wiring harness connectors.

Fuel Control Sensors

Fuel control sensors monitor various operating conditions and send information about these conditions to the engine control module. See **Figure 41-17**. The most common sensors used to help control the operation of a gasoline injection system include:

- Oxygen sensors—Oxygen sensors measure the amount of unburned fuel in engine exhaust.
- Manifold absolute pressure (MAP) sensors—MAP sensors measure engine vacuum. The ECM uses the MAP sensor signal as a means of monitoring engine load or power output.
- Throttle position sensors—Throttle position sensors detect the angle of the throttle valve opening in the throttle body.
- Accelerator pedal sensors—Accelerator pedal sensors detect if the driver wants to increase or decrease engine speed.
- Engine coolant temperature sensors—Engine coolant temperature sensors measure the engine operating temperature.
- Airflow sensors—Airflow sensors measure the quantity of air entering the engine.
- Intake air temperature sensor—The ECM uses signals from the intake air temperature sensors to calculate air density.
- Crankshaft position sensors—Crankshaft position sensors produce a signal representing engine speed (rpms).
- Camshaft position sensors—Camshaft position sensors detect the position and speed of the camshaft.
- High fuel-pressure sensors—High fuel-pressure sensors measure the amount of fuel injected into the engine.
- Low fuel-pressure sensors—Low fuel-pressure sensors monitor the operation of the in-tank pump.
- Fuel tank temperature sensors—Fuel tank temperature sensors monitor the air pressure for fuel vapor emissions control.
- Fuel temperature sensors—Fuel temperature sensors closely control the amount of fuel injected. Cold fuel is denser than hot fuel and carries more heat energy per pound.
- Vehicle speed sensors—Vehicle speed sensors are used by the ECM to determine vehicle road speed and transmission gear ratio.

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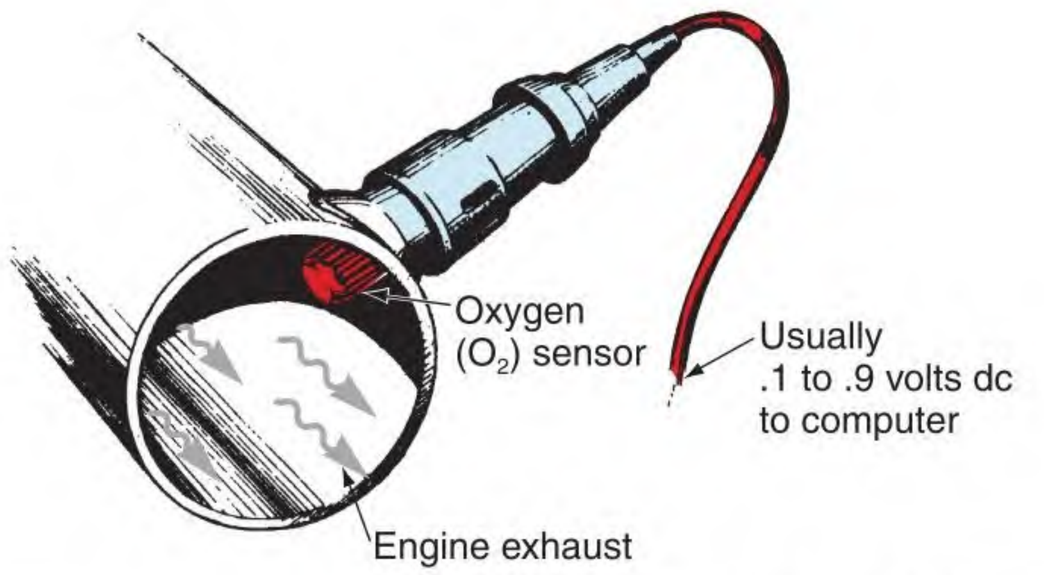
Ford

Figure 41-17. Various sensors feed information to the engine control module. The ECM uses this data to operate other system components.

- Brake pedal switch sensors—Brake pedal switch sensors signal the ECM to shut off the fuel injector when the brake pedal is depressed to conserve fuel.
- Hybrid control module sensors—Hybrid control module sensors tell the engine control module when the gas engine should be started to recharge the HV battery.
- Traction control module sensors—Traction control module sensors tell the engine control module to reduce fuel injector pulse width and engine power output in order to prevent tire skid on acceleration or when speed in corners is too high.

Oxygen Sensor

An ***oxygen sensor***, also called an ***exhaust gas sensor*** or ***O_2 sensor***, measures the oxygen content in the engine's exhaust gases as a means of checking combustion efficiency. Look at **Figure 41-18**. It is the primary sensor that contributes to electronic fuel injection efficiency and engine tuning.



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Figure 41-18. The oxygen sensor mounts in the exhaust system pipe so it can electronically monitor the amount of oxygen and unburned fuel contained in the gases coming out of the engine. Contents of the engine exhaust affect the oxygen sensor voltage output.

If the amount of unburned oxygen leaving the engine is too low, the engine is running too lean. If the oxygen content of the exhaust is too high, the engine

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is running too rich. A properly tuned fuel system should have just a little extra unconsumed oxygen in the exhaust to show all the fuel has been consumed during combustion.

OBD I (and older) vehicles use one O_2 sensor located in the exhaust manifold or exhaust pipe before the catalytic converter. Vehicles with OBD II use at least two oxygen sensors: one O_2 sensor before the catalytic converter and one after the catalytic converter. Refer to **Figure 41-19**. Using two oxygen sensors allows more precise control of fuel metering and the resulting emissions. V-12, V-10, V-8, and some high performance V-6 engines have four oxygen sensors, if equipped with dual exhaust pipes.

The ***primary oxygen sensor***, also termed ***front O_2 sensor***, is used to monitor the oxygen in the exhaust gases as it leaves the engine. This indicates whether the engine's air-fuel mixture is too lean or too rich. It is located before, or in front of, the catalytic converter, usually as close to the engine as possible.

The ***secondary oxygen sensor***, also termed ***rear O_2 sensor***, is mounted downstream in the exhaust system. See **Figure 41-20**. The rear oxygen sensor primarily monitors the catalytic converter for proper operation. Any O_2 sensor mounted after the catalytic converter is referred to as a ***catalyst monitor***.

Oxygen Sensor Positions

The ***oxygen sensor position*** in a vehicle is assigned a number by its location and order in relation to the engine's banks. Oxygen sensor position is given on your scan tool readout.

The sensor closest to the number one cylinder is denoted as Oxygen Sensor, Bank 1, Sensor 1. If the engine is a V-type, sensors located in the other bank are considered to be located in Bank 2. Sensors further down the exhaust stream from the engine are consecutively numbered as Sensor 2, Sensor 3, and so on. In almost all cases, the sensor with the highest number is the catalyst monitor.

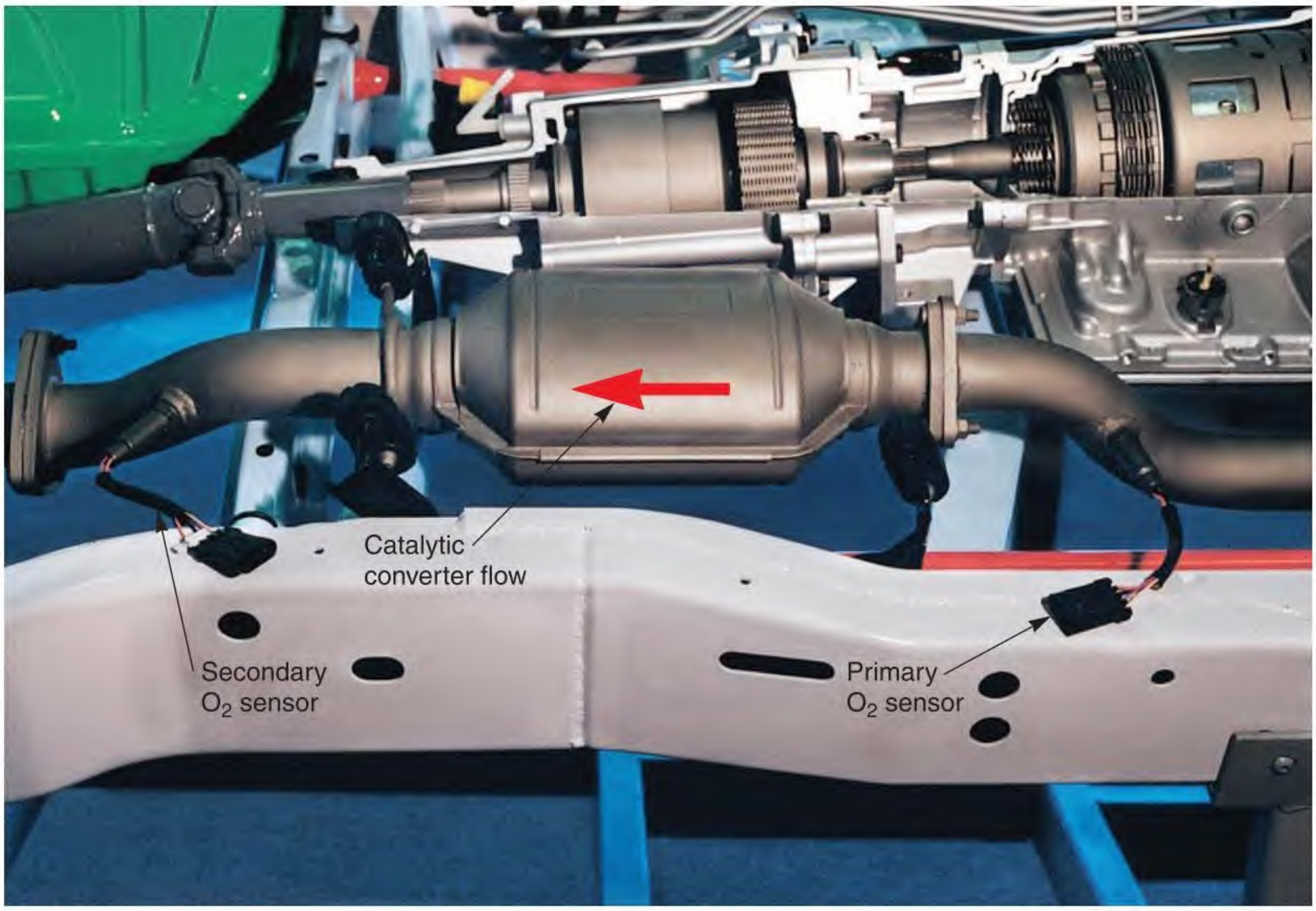
Open Loop and Closed Loop

When in ***open loop***, the electronic fuel injection system does not use engine exhaust gas content as a main indicator of the air-fuel mixture. Instead, the system operates on preprogrammed information stored in the computer. For example, right after cold engine starting, the computer operates in open loop. See **Figure 41-21A**. Several sensors, especially the oxygen sensor, cannot provide accurate information before the engine reaches normal operating temperature. Therefore, the computer is set to ignore these sensor inputs when the engine is cold.

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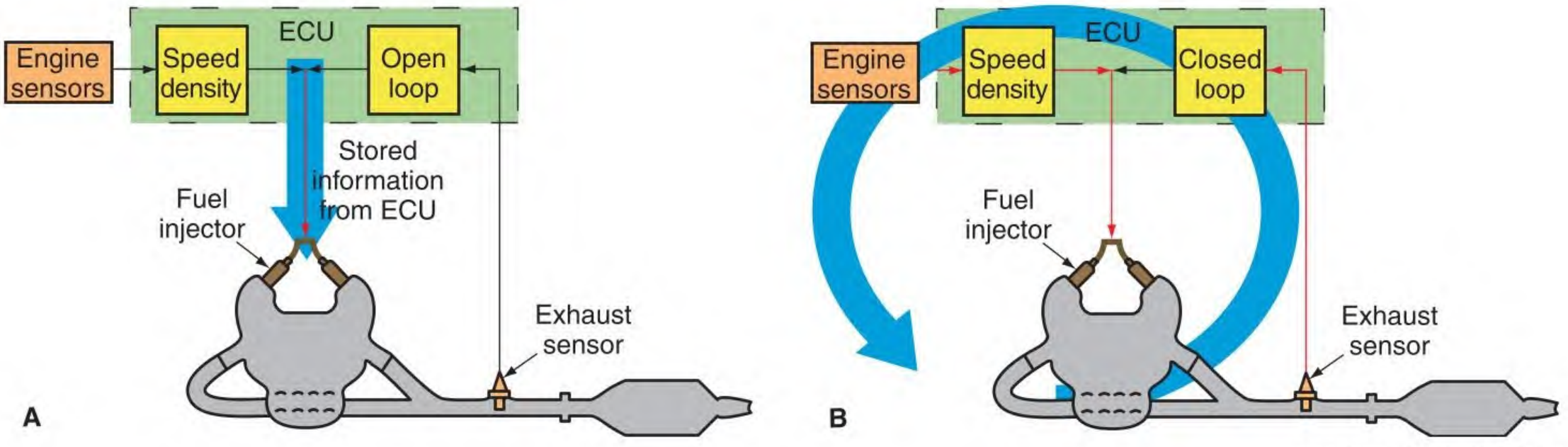
Figure 41-19. The primary oxygen sensor measures the air-fuel ratio coming directly out of the engine. The rear oxygen sensor checks catalytic converter efficiency. A—If either the front or rear oxygen sensors detect too much unburned fuel in the exhaust, the malfunction indicator light in the dash is turned on. If only the front sensor detects excessive exhaust pollution, it signals the computer to store a trouble code for misfire or engine problem. B—If the rear oxygen sensor signal is almost the same as the signal from the front oxygen sensor, the catalytic converter has failed and is no longer burning hydrocarbons. A trouble code for the converter would be stored in computer memory.

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Figure 41-20. The secondary oxygen sensor is positioned after the catalytic converter where it can monitor the performance of the catalytic converter.



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Figure 41-21. The exhaust or oxygen sensor "sniffs" exhaust gases to check whether the air-fuel ratio is too lean or too rich. A—In open loop, the ECU uses stored information to control the air-fuel ratio. B—In closed loop, an imaginary loop is produced as data flows through the system.

Closed loop means that the computer is using information from the oxygen sensor and the other sensors. This information forms an imaginary loop, or circle, from the ECM, through the fuel system, into the exhaust system, and back to the ECM, **Figure 41-21B**.

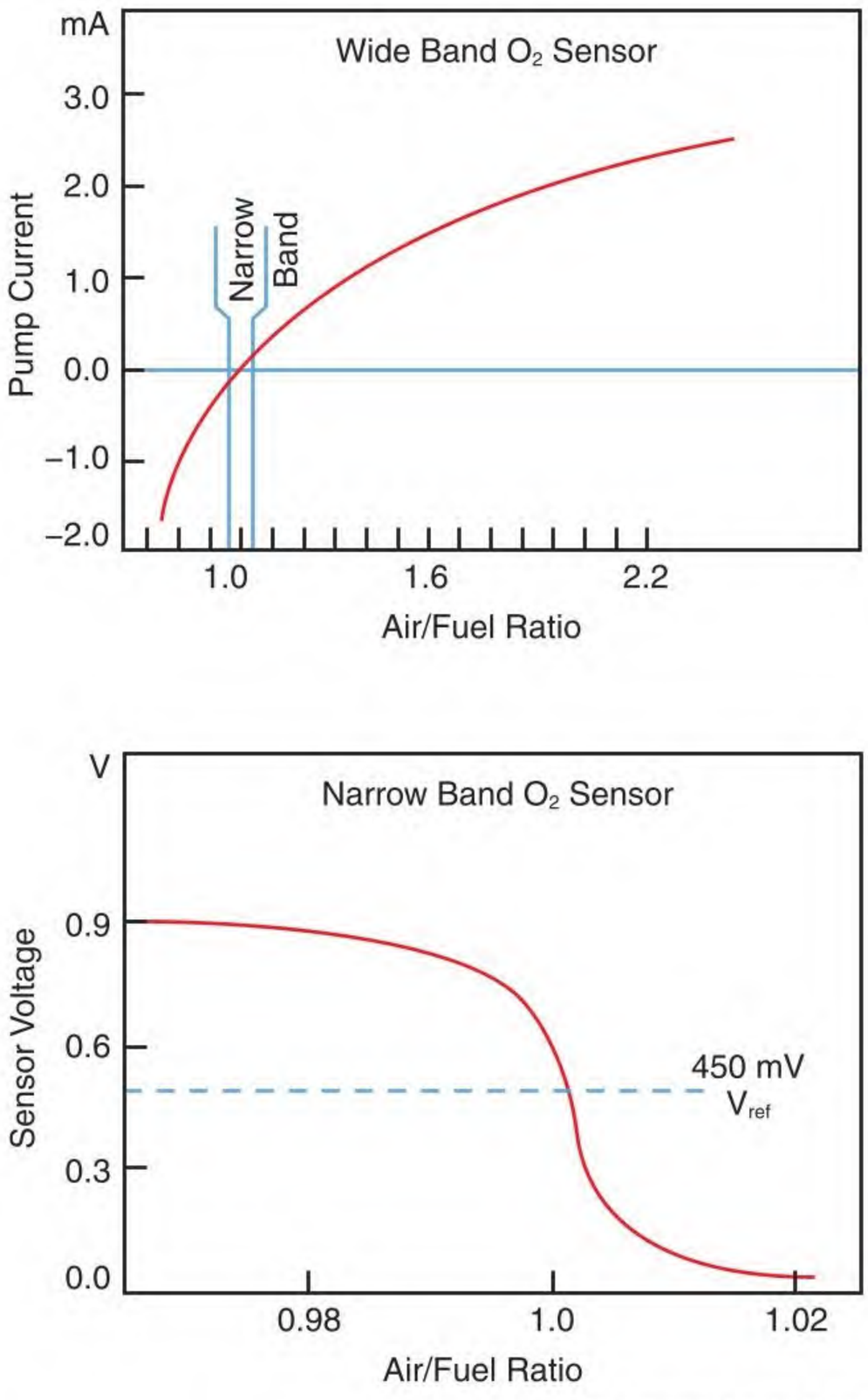
After the catalytic converter and oxygen sensor(s) heat up, an electronic gasoline injection system functions in closed loop. This lets the computer double-check the fuel mixture it is providing to the engine.

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Narrow Band Oxygen Sensors

Since automakers use various oxygen sensor designs and circuits, you should be familiar with the most common types found on today's vehicles. Zirconia, titania, and planar sensors are considered narrow band sensors. ***Narrow band oxygen sensors*** can only measure combustion efficiency near stoichiometric (chemically correct). These sensors do not allow for extremely lean or rich fuel mixture settings by the vehicle manufacturer. Look at **Figure 41-22**.

Zirconia oxygen sensors use zirconia and platinum to produce the voltage output that represents oxygen in the exhaust gases. The surface of the sensor is coated with platinum, which helps the sensor maintain a high operating temperature. At an operating temperature of about 600°F (315°C), the oxygen sensor's element becomes a semiconductor and generates a small voltage.



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Figure 41-22. Note how the wide band oxygen sensor produces pump current as an output signal, whereas the narrow band produces voltage as an output signal. Also note how a wide band oxygen sensor can measure air-fuel ratios over a wider operating range.

The ECM compares the voltage produced by the zirconia oxygen sensor to a reference voltage of approximately 450 mV (0.45 volts). If the engine's air-fuel mixture is too rich, there will be almost no oxygen in the exhaust gases. This creates a large difference in oxygen content between the sensor's inner and outer surfaces, and causes the sensor to generate a voltage of about 600 mV (0.6 volts). The voltage generated informs the ECM that a leaner mixture is required to reduce emissions.

If the engine's air-fuel mixture is too lean, there will be a smaller difference in oxygen content between the sensor's surfaces. As a result, the sensor will generate a weaker voltage signal of about 300 mV (0.3 volts). The ECM will then enrich the fuel mixture and try to maintain a stoichiometric air-fuel mixture.

Planar zirconia oxygen sensors are similar to conventional zirconia sensors, but the zirconia element, electrodes, and heater are combined in a flat, laminated strip. This type of sensor is more resistant to contamination and vibration than a conventional zirconia sensor. Planar sensors also reach operating temperature much faster than a conventional zirconia sensor. This allows the computer system to enter closed loop sooner, significantly reducing cold-start hydrocarbon emissions.

A ***lean burn oxygen sensor*** measures the oxygen content in the exhaust of lean-burn engines. This type of sensor can measure ratios as lean as 23:1. It has four wires and a modified zirconium dioxide element with either a thimble or planar design. The heater resistance of a lean burn oxygen sensor is 12–15 ohms. It produces discrete output voltages ranging from 0–5 volts.

Some vehicles are equipped with titania oxygen sensors. A ***titania oxygen sensor*** uses a thick film of titania to detect the amount of oxygen present in the exhaust gases. It has three or four wires and 12–18 mm threads. The heater resistance of a titania oxygen sensors is 4–7 ohms.

Instead of producing voltage like a zirconia oxygen sensor, the titania oxygen sensor varies its internal resistance to signal the ECM. The titania sensor is smaller than a zirconia oxygen sensor. It is manufactured as a sealed unit, which makes it less susceptible to outside contamination (engine oil leak dripping on the outside of sensor, for example). Titania oxygen sensors also have the advantage of an almost instant oxygen content signal on cold startup. There is no

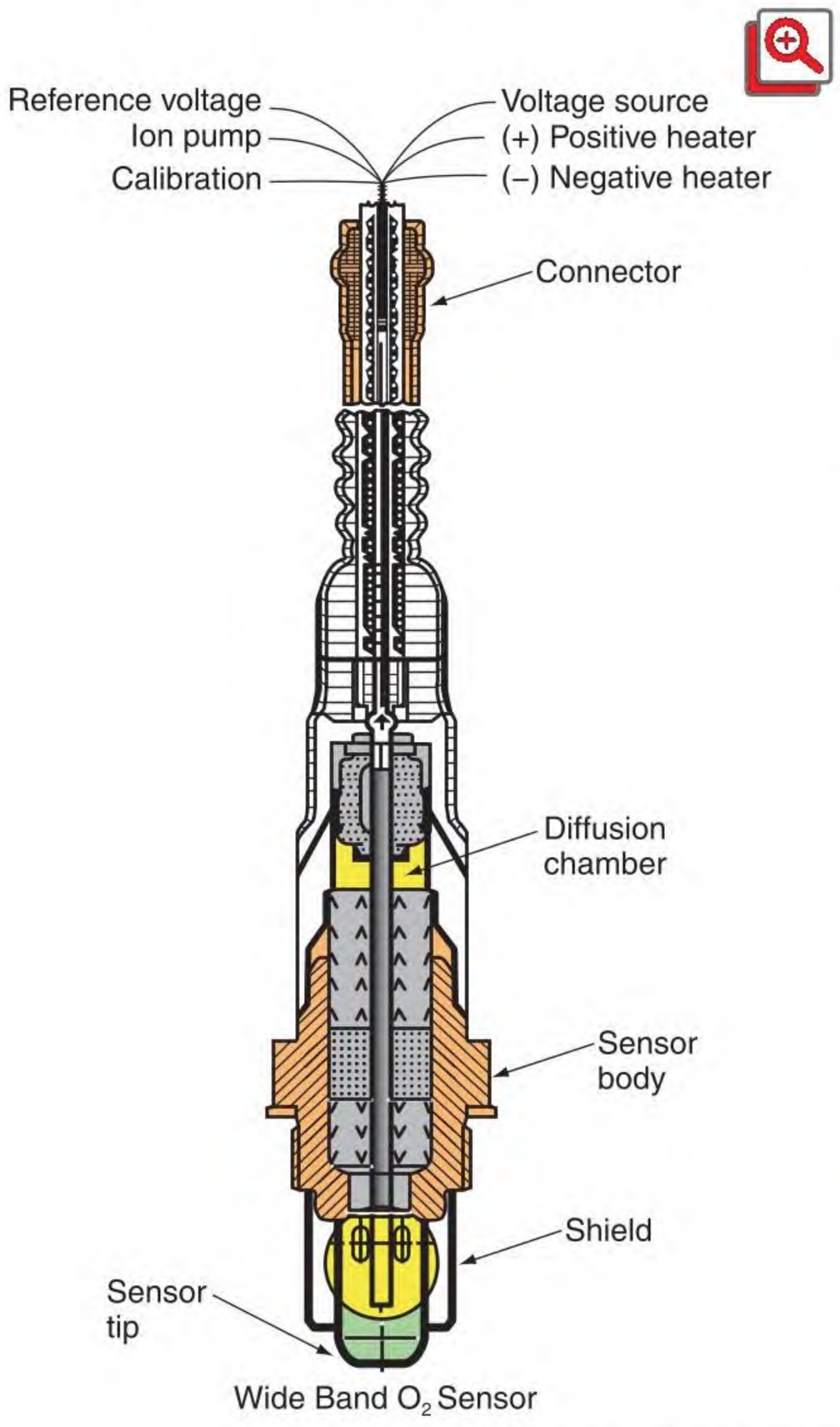
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need to use a heating element to warm a titania sensor to get it to operating temperature.

A constant reference voltage is fed from the ECM to the titania oxygen sensor's positive terminal. As the oxygen content in the exhaust gas changes, the titania sensor's resistance also changes. This causes the voltage drop across the sensor to change. The control module monitors changes in voltage drop and adjusts fuel injector pulse width accordingly.

Wide Band Oxygen Sensors

Narrow band oxygen sensors simply toggle their output voltage to indicate either a rich or lean condition. A ***wide band oxygen sensor***, on the other hand, can change its output gradually and in direct proportion to the oxygen content of the exhaust gases. Refer to **Figure 41-23**. Additionally, a wide band oxygen sensor can monitor air-fuel ratio over a much broader range above and below stoichiometric than a narrow band oxygen sensor. A wide band sensor can sense air-fuel mixture ratios between 0.9 and 2.2. It is more complex than conventional oxygen sensors.



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Figure 41-23. Study the basic construction of a wide band oxygen sensor.

A wide band oxygen sensor does not produce voltage output to indicate the engine air-fuel ratio. Instead, it uses internal voltage signals to produce a small ***O_2 sensor pump current*** that represents oxygen content. The O_2 sensor pump cell can consume either oxygen or unburned fuel (hydrocarbons), depending on the direction of the pump current fed into the sensor from the ECM. Look at **Figure 41-24**.

During normal operation, a small sample of exhaust gases passes through the diffusion gap into the pump cell. Depending on whether the exhaust gases are rich or lean, the reference cell produces a source voltage (V_s) above or below the reference voltage (V_{ref}). A rich mixture will produce high voltage and a lean mixture will produce low voltage. This source voltage is sent to the control circuit. If a rich mixture is indicated, the control circuit sends a negative pump current to pump cell. This causes the pump cell to consume hydrocarbons in the measuring chamber. If a lean mixture is indicated, the control circuit sends a positive pump current to the pump cell, causing the cell to consume excess oxygen.

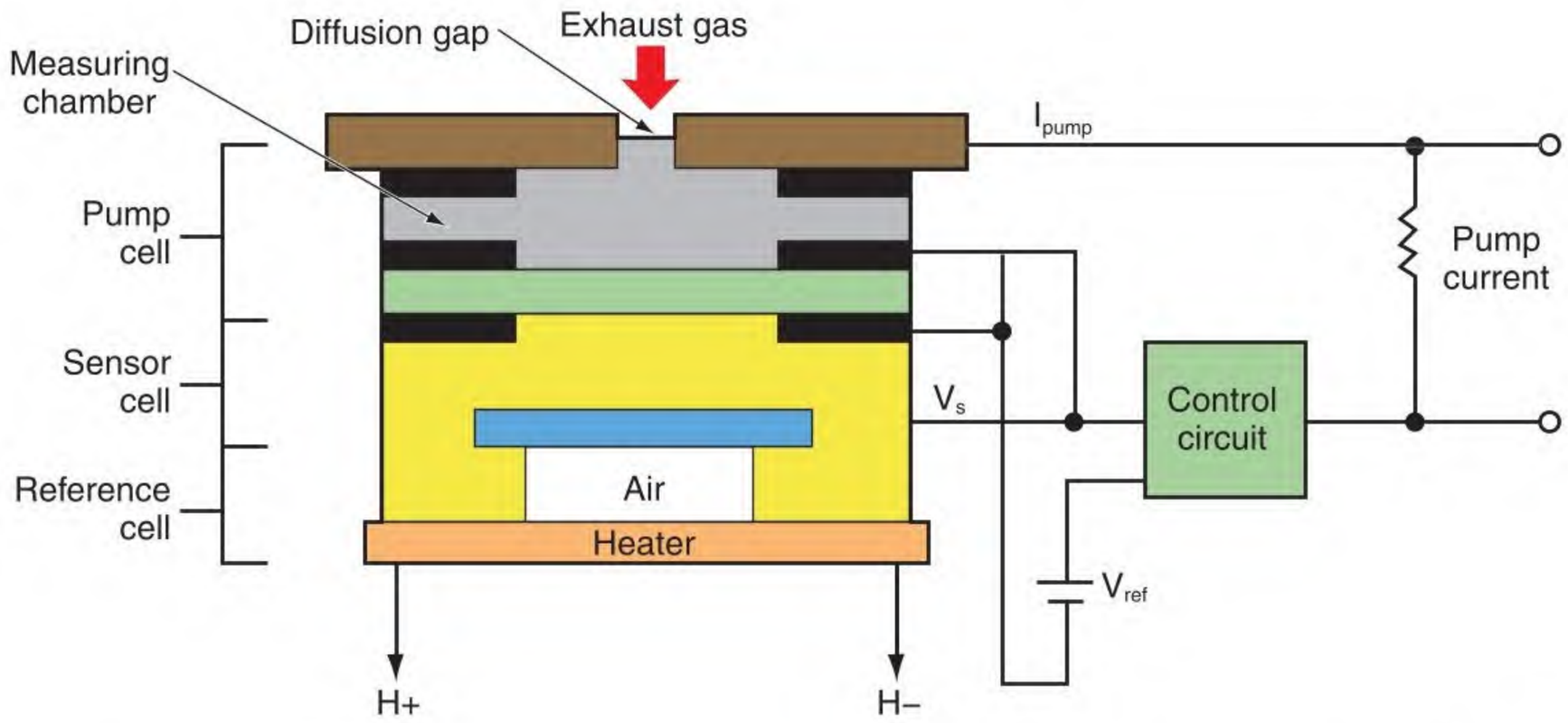
When the free oxygen or free fuel has been neutralized, the voltage feedback signal drops to about 450 mV (same as V_{ref}) and no pump current is supplied to the pump cell. The pump current (from the control circuit) required to find equilibrium is an indication of the engine air-fuel ratio (lambda). The pump current is very low (0.02 amps or less). The ECM converts this low current signal to a voltage signal that can be read by a scan tool.

Many factory engines and fuel systems now use a wide band O_2 sensor to improve fuel metering. Off-road race cars are often retrofitted with one or two wide band oxygen sensors to better tune the race engines for high horsepower. Wide band sensors normally have five or six wires coming out of them.

Manifold Absolute Pressure Sensor

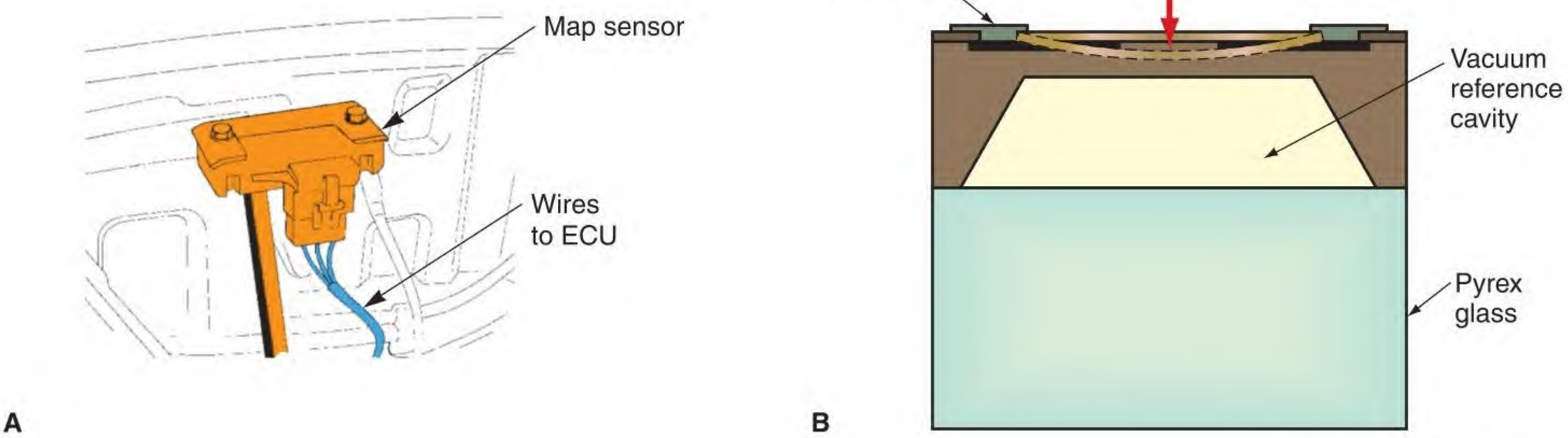
A ***manifold absolute pressure (MAP) sensor*** measures the pressure, or vacuum, inside the engine intake manifold, **Figure 41-25**. Manifold pressure is an excellent indicator of engine load. High manifold pressure (low intake vacuum) indicates a high load, requiring a rich mixture. Low manifold pressure (high intake vacuum) indicates very little load, requiring a

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Figure 41-24. Note that three different cells are used in this wide band sensor: pump cell, sensor cell, and reference cell. They work together to produce a computer return signal that is more accurate than a conventional oxygen sensor.



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Figure 41-25. The engine manifold absolute pressure (MAP) sensor changes resistance with changes in vacuum (pressure). A—A MAP sensor often mounts on top of the engine or in the engine compartment. B—This MAP sensor uses a piezo-resistor chip that converts a change in pressure into a change in resistance. Manifold pressure acts on the top of the sensor chip to flex it up and down.

leaner mixture. The manifold absolute pressure sensor varies resistance with changes in engine load. This data is used by the computer to alter the fuel mixture.

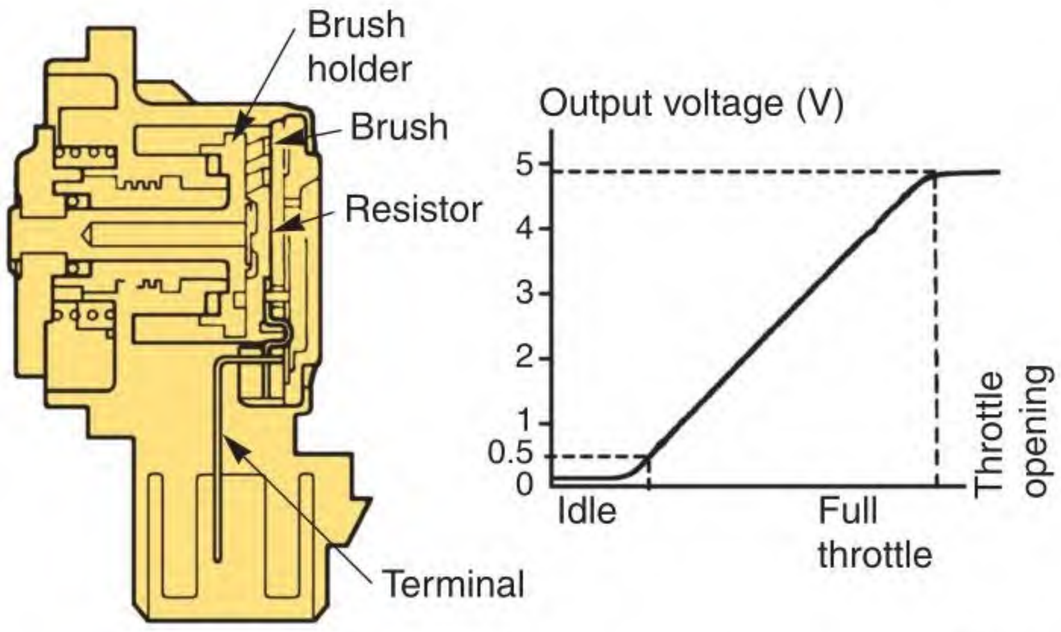
Throttle Position Sensor

A ***throttle position sensor*** is a variable resistor connected to the throttle plate shaft, **Figure 41-26**. Throttle shaft rotation causes the arm contact to slide on the resistor. In this way, different current levels are produced for different throttle positions. When the throttle opens or closes, the sensor changes resistance and signals the ECM. The computer then richens or leans the mixture, as needed.

Engine Coolant Temperature Sensor

An ***engine coolant temperature sensor*** monitors the operating temperature of the engine. It is mounted so that it is exposed to the engine coolant. When the engine is cold, the sensor might provide a low resistance (high current flow). The ECM would then richen the air-fuel mixture for

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Honda

Figure 41-26. The throttle position sensor uses a variable resistor to report the amount of throttle opening to the ECM. The ECM can then alter the fuel mixture for idle and wide open throttle positions.

cold engine operation. When the engine warms, the coolant temperature sensor resistance changes so the ECM knows to make the mixture leaner.

Airflow Sensor

An ***airflow sensor*** is used in many EFI systems to measure the amount of outside air entering the engine. This helps the ECM determine how much fuel is needed. Information is then sent to the ECM indicating air inlet volume.

Intake Air Temperature Sensor

An ***intake air temperature sensor*** measures the temperature of the air entering the engine. Cold air is more dense than warm air, requiring more fuel for the proper air-fuel ratio. The intake air temperature sensor helps the computer compensate for changes in outside air temperature and maintain an almost perfect air-fuel mixture ratio.

Crankshaft Position Sensor

A ***crankshaft position sensor*** is used to detect engine speed. It allows the ECM to change injector timing and duration with changes in engine rpms. Higher engine speeds generally require more fuel.

Fuel Pressure Sensor

The ***fuel pressure sensor*** mounts on the fuel rail and sends an electronic signal, proportional to the pressure inside the rail, to the ECM. The ECM can then control fuel pump speed and/or fuel injector pulse width to compensate for variations in fuel system pressure. A fuel pressure sensor is often used in returnless fuel injection systems.

Fuel Temperature Sensor

A ***fuel temperature sensor*** monitors the temperature of the fuel in the fuel rail. Fuel temperature has a slight effect on a fuel density and how much air and fuel must be atomized together to achieve a stoichiometric mixture and efficient combustion. Based on the signal from the fuel temperature sensor, the ECM can fine-tune fuel metering, ignition timing, boost pressure, and other engine operating parameters. In some vehicles, a fuel pressure sensor and a fuel temperature sensor are housed in a single unit. Refer to **Figure 41-27**.

Other Sensors

There are several other sensors that can be used to affect the operation of a fuel injection system. These include an A/C compressor sensor, transmission sensors, EGR sensor, and engine knock sensor. These sensors provide additional data about operating conditions affecting engine fuel needs.

Engine Idle Speed Control

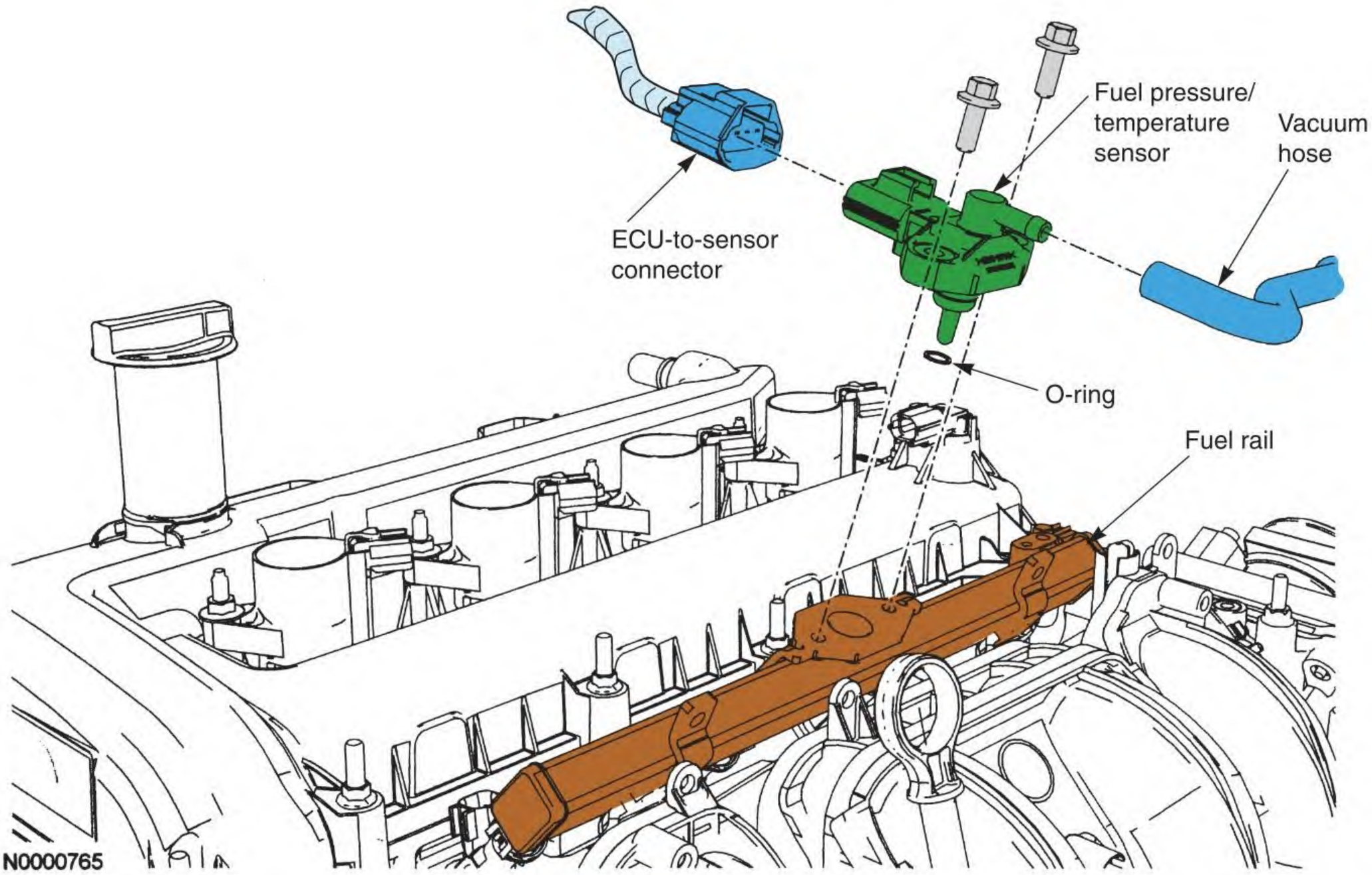
An ***idle air control motor*** may also be used to help control engine idle speed. It is a solenoid- or servo motor-operated air bypass valve. It works something like a thermo or temperature-sensitive mechanical valve, but it is ECM controlled.

The system's ECM opens the idle air control valve when temperature sensors signal a cold engine. This allows more air to enter the intake manifold, increasing idle speed to keep the engine from stalling. As the engine warms, the ECM gradually closes the valve, decreasing the amount of air that bypasses the throttle valve and reducing engine speed to curb idle (normal idle rpms). See **Figure 41-28**.

Industry Trend

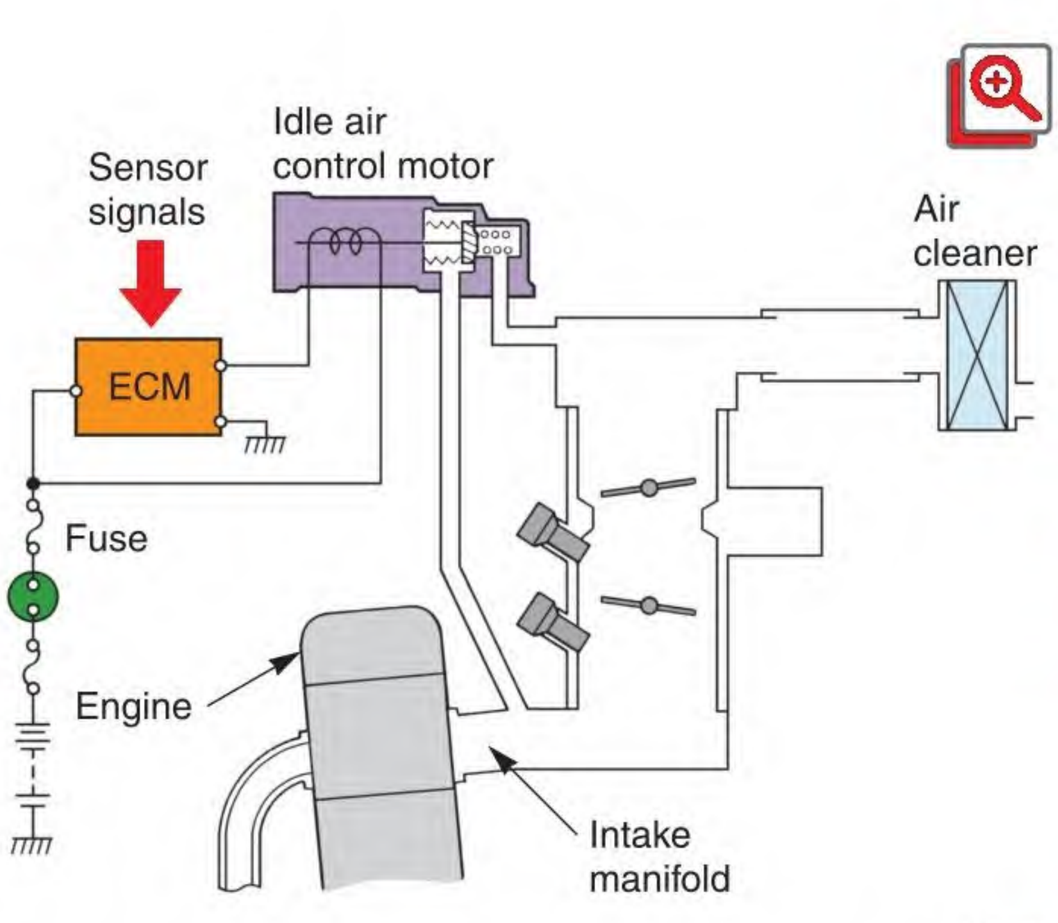
Today's small cars have greatly improved fuel efficiency. Small but powerful engines squeeze more energy out of every drop of fuel. Electronic engine controls, lighter body/frame structures, and sleeker body shapes have all helped reduce fuel consumption, conserving our natural resources.

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Ford

Figure 41-27. Some manufacturers combine fuel pressure and fuel temperature sensors in a single housing.



Honda

Figure 41-28. This diagram shows how the control module can open or close the idle air motor to affect engine idle speed. As more air bypasses the throttle valve, engine speed increases. This keeps the engine from stalling when cold.

Summary

- All electronic fuel injection systems can be divided into five subsystems: fuel delivery system, air induction system, sensor system, computer control system, and fuel metering system.
- Atmospheric pressure (14.7 psi at sea level) affects the amount of fuel that must be injected into the engine.
- Many sealed parts in and on an engine contain vacuum pressure.
- The engine throttle valve controls airflow and engine power output.
- An indirect injection system sprays fuel into the engine intake manifold. A direct injection system sprays high-pressure fuel into the engine's combustion chambers.
- A DEFI system has three injection modes: stratified charge mode, stoichiometric mode, and full power mode.
- Two common types of electronic fuel injectors are solenoid fuel injectors and piezo fuel injectors.

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- Both low- and high-pressure fuel injection systems require a fuel pressure regulator.
- Both indirect injection systems and direct injection systems require a fuel rail to all injectors to obtain the same amount of fuel pressure and flow.
- Fuel control sensors monitor various operating conditions and send information about these conditions to the engine control module.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

accelerator pedal sensor
actuator
air induction system
airflow sensor
atmospheric pressure
catalyst monitor
closed loop
cold-start fuel injector
computer control system
continuous fuel injection
crankshaft position sensor
DEFI amplifier
DEFI fuel pressure regulator
direct electronic fuel injection system (DEFI)
direct injection system
drive-by-wire system
EFI fuel pressure regulator
electric fuel pump
engine coolant temperature sensor
engine idle speed
engine sensors
engine throttle actuator
engine throttle valve
exhaust gas sensor
front O_2 sensor
fuel delivery system
fuel injection system
fuel injectors
fuel log
fuel metering system
fuel pressure regulator
fuel pressure sensor
fuel rail
fuel system service fitting
fuel temperature sensor
full power charge mode
gasoline injection system
idle air control motor
idling
indirect injection system
injector pulse width
intake air temperature sensor
intake ports
intermittent fuel injection
lean burn oxygen sensor
manifold absolute pressure (MAP) sensor
multiport injection system
narrow band oxygen sensors
O_2 sensor
O_2 sensor pump current
open loop
oxygen sensor
oxygen sensor position
piezo fuel injector
planar zirconia oxygen sensor
primary oxygen sensor
rear O_2 sensor
secondary oxygen sensor
sensor system
solenoid fuel injector
stoichiometric mode
stratified charge mode
throttle body injection system (TBI)
throttle position sensor
throttle safety release
throttle-by-wire systems
timed injection system
titania oxygen sensor
vacuum
wide band oxygen sensor
zirconia oxygen sensors

Activities

1. Using a service manual for a fuel-injected vehicle, study the section on fuel injector operation. Demonstrate your understanding of how the injectors are controlled to your instructor.
2. Develop a drawing of the fuel injection system for a gasoline engine and produce a multimedia presentation from it. Using the presentation, explain to the class how the system works.
3. Without starting any engines, inspect several vehicles to locate the major parts of the fuel injection system. Find the fuel injectors, pressure regulators, and fuel rail. Write a short report describing the differences in the fuel systems of each vehicle.

Review Questions

Please do not write in this text. Place your answers on a separate sheet of paper.

1. What is the difference in operation between a multiport fuel injection system and a direct fuel injection system?
2. List the five subsystems common to all electronic fuel injection systems.
3. At sea level, the atmosphere exerts _____ psi of pressure on everything.
4. Engine idle speed is usually around 750 rpms. True or False?

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5. This type of gasoline injection system sprays fuel into the engine in relation to piston and valve action:
   (A) Bank injection.
   (B) Continuous injection.
   (C) Intermittent injection.
   (D) Timed injection.
6. Define the term *injector pulse width*.
7. An indirect injection system sprays fuel into the engine's combustion chambers. True or False?
8. A(n) _____ injection system has fuel injectors in the intake ports.
9. What is an advantage of DEFI systems over other designs?
10. Identify and describe the three injection modes of a DEFI system.
11. A(n) _____ fuel injector uses a crystalline ceramic material instead of an electromagnet to open fuel injector valves.
12. Explain the operation of a DEFI fuel pressure regulator.
13. What is a DEFI amplifier?
14. List six common fuel control sensors. Briefly describe the function of each.
15. Any O_2 sensor mounted after the catalytic converter is referred to as a(n) _____.
16. What is the difference in electronic fuel injection system operation when in open loop versus closed loop?
17. Zirconia, titania, and planar sensors are examples of wide band oxygen sensors. True or False?
18. A(n) _____ oxygen sensor can change its output gradually, in direct proportion to the oxygen content of the exhaust gases.
19. When the MAP sensor indicates a high load (high manifold pressure/low intake vacuum), a _____ air-fuel mixture is required.
20. How does a crankshaft position sensor contribute to fuel control?

ASE-Type Questions

1. Gasoline injection systems feed fuel into an engine using:
   (A) suction.
   (B) vacuum.
   (C) pressure.
   (D) All of the above.
2. Direct electronic fuel injection systems are being discussed. Technician A says that these systems control the air-fuel mixture more precisely than indirect systems. Technician B says that these systems have been replaced by multiport systems in most late-model vehicles. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. In which fuel injection system is gasoline sprayed into the top center of an intake manifold?
   (A) Port fuel injection.
   (B) Electronic fuel injection.
   (C) Multiport fuel injection.
   (D) Throttle body fuel injection.
4. The sensor used to detect engine speed is the:
   (A) throttle position sensor.
   (B) manifold pressure sensor.
   (C) crankshaft position sensor.
   (D) idle valve actuator.
5. Which of the following is *not* a solenoid injector part?
   (A) Piezo crystal.
   (B) Return spring.
   (C) Needle valve.
   (D) Injector nozzle.
6. While discussing electronic gasoline injection systems, Technician A states that multiport EFI systems are classified as direct injection systems. Technician B says that multiport EFI systems use one injector per engine cylinder. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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7. Which of the following is a normal fuel pressure inside the fuel rail of today's DEFI systems?
   (A) 10 psi (68.9 kPa).
   (B) 100 psi (689.5 kPa).
   (C) 1000 psi (6894.7 kPa).
   (D) 2000 psi (13,789.5 kPa).
8. High-pressure injectors used in DEFI systems often require up to how many volts dc for proper solenoid operation?
   (A) 10 volts dc.
   (B) 50 volts dc.
   (C) 100 volts dc.
   (D) 200 volts dc.

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Chapter 42
Gasoline Injection Diagnosis and Repair

After studying this chapter, you will be able to:

- Inspect a fuel injection system to identify fuel leaks, vacuum leaks, and disconnected wires.
- Explain OBD II typical live sensor and injector readings for late-model fuel injection systems.
- Diagnose problems in a gasoline injection system using a scan tool, multimeter, and scope.
- Compare the scope waveforms for common injector circuits.
- Use a scan tool to relieve fuel pressure and to test fuel pumps, fuel pressure regulators, and high-pressure fuel injectors.
- Perform a fuel injector balance test.
- Perform on-car injector flow tests.
- Use a noid light and handheld scope to analyze fuel injector operation.
- Replace multiport and direct fuel injectors.
- Check EFI engine sensors with a scan tool.
- Correctly answer ASE certification test questions about fuel injection system diagnosis, service, and repair.

As you have learned, direct gasoline injection systems are quickly replacing conventional port fuel injection systems. Direct EFI provides better fuel economy and higher engine power output, while producing fewer emissions than other injection system designs. Direct and port EFI systems have similar parts (solenoid injectors, a similar ECM, and same engine sensors). Primarily, direct fuel injection into the combustion chambers requires high injector operating voltages and electric solenoids to control fuel pressure from a high-pressure mechanical fuel pump.

This chapter describes the most common problems, tests, and repair procedures for low- and high-pressure gasoline injection system configurations. The explanations and procedures stress the use of advanced scan tools and specialized testers to safely measure fuel pressure, test the fuel injectors and pressure regulator, and relieve high fuel pressure before making repairs.

Gasoline Injection Problem Diagnosis

To diagnose problems in a gasoline injection system, you must use the following:

- Your knowledge of EFI systems (location and normal operation of parts).
- Basic troubleshooting skills, such as reading scan tool trouble codes, measuring circuit electrical values with a meter, and interpreting scope waveforms from fuel injectors.
- Factory service information.
- A scan tool, **Figure 42-1**.

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Figure 42-1. A scan tool is usually one of the first tools used to diagnose fuel system malfunctions. A scan tool can indicate the source of most problems in late-model OBD II vehicles.

As you try to locate problems, visualize the operation of the four subsystems: air, fuel, sensor, and control. Relate the function of each subsystem component to the trouble code or performance problem. This allows you to eliminate several possible problem sources and concentrate on others. For example, if the engine is missing at idle and your scan tool indicates a problem with injector number 4, you know to start your tests at that injector circuit in cylinder number 4 at the rear of an inline, 4-cylinder engine.

On-Board Diagnostics

Modern EFI systems have extensive on-board diagnostic abilities. The engine ECM can detect an out-of-spec circuit (wrong voltage, current, or resistance) and produce a trouble code pinpointing the problem location. Remember, a trouble code indicates a circuit problem. However, since circuit wiring and the ECM seldom fail, the sensor or actuator in that circuit is usually to blame.

If your scan tool indicates a bad oxygen sensor circuit, for example, the sensor itself most likely has failed and needs replacement. Since an oxygen sensor "sniffs" the engine exhaust gases, it is exposed to extreme combustion heat, carbon, soot, nitrogen oxides, carbon monoxide, carbon dioxide, and other acidic chemicals. Prolonged engine exhaust gas flow over these sensors can contaminate and damage them.

Failed or lazy O_2 sensors cause more fuel consumption and exhaust emissions than any other part on a car. When an O_2 sensor fails, the fuel injection system can no longer calculate exactly how much fuel the engine needs for maximum combustion efficiency. You can observe live O_2 sensor voltage readings on your scan tool.

For another example, if a high-pressure, higher voltage fuel injector coil winding burns open and fails (improper internal resistance), the ECM will tell you which injector circuit (cylinder number) has failed. It cannot, however, tell you whether the wiring to the injector is causing the problem. Further tests would be needed to isolate the problem to the fuel injector, its control circuit, fuel injection amplifier, or engine control module.

A glowing malfunction indicator light (MIL) in the dashboard tells the driver and the technician that something is wrong. The technician can connect a scan tool to the vehicle to check for stored trouble codes. The scan tool can also indicate live circuit readings of fuel pressure, engine manifold air pressure, engine temperature, air inlet temperature, and exhaust gas sensor readings.

Fuel injection systems monitor the following engine operating conditions:

- Engine manifold pressure.
- Engine airflow into intake manifold.
- Intake air temperature.
- Engine coolant temperature.
- Exhaust gas oxygen content (both before and after the catalytic converter).
- Engine throttle position.
- Reference voltage sent to the sensors by the ECM.
- Electric, in-tank fuel pump pressure.
- Engine driven, mechanical fuel pump pressure.
- Fuel tank pressure (low air pressure in fuel storage tank to prevent venting of fumes into atmosphere).
- Injector pulse width (live reading of injector on time given in milliseconds, or thousandths of a second).
- Fuel trim (short- and long- term adjustment of fuel-air mixture).

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Idle live readings are typical circuit values with the engine running at curb idle speed and full operating temperature. You can compare scan tool readings to known normal or specification readings to help find fuel injection problems. See **Figure 42-2**.

The following are some examples of readings indicating trouble in a fuel injection system:

- A prolonged engine vacuum leak might set a long-term fuel trim trouble code because the ECM has been trying to adjust the fuel mixture for the air leak around the throttle valves.
- A low oxygen reading for the rear O_2 sensor might indicate the catalytic converter has failed and cannot treat the unburned fuel properly.
- If the engine is at room temperature, the IAT (air temperature) and ECT (engine temperature) readings should be about the same. If one sensor shows a wrong temperature reading, that circuit is at fault.

You can use trouble codes and live readings to find almost any fuel system trouble.

Live Scan Tool Readings (Engine Idle Speed)	
Engine RPM	780 rpm
MAP	13 inch/hg
MAF	.59 lb/minute
IAT	90°F (32°C)
ECT	105°F (40°C)
O_2 B1–S1	842 mV
O_2 B1–S2	773 mV
TPS	
Ref Voltage	5 volts DC
Fuel Pressure	500 psi (3447 kPa)
Fuel Tank Pressure	5 psi (34 kPa)
DEFI Pressure	2000 psi (13 MPa)
Inj Pulse Width	15.9 milliseconds
Fuel Temperature	90° F (32° C)

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Figure 42-2. Typical electrical values are shown for a fuel injection system with the engine running at idle.

Inspecting the Fuel Injection System

Service Procedure

If your scan tool or work order shows something is wrong with the fuel injection system, use the following inspection procedure:

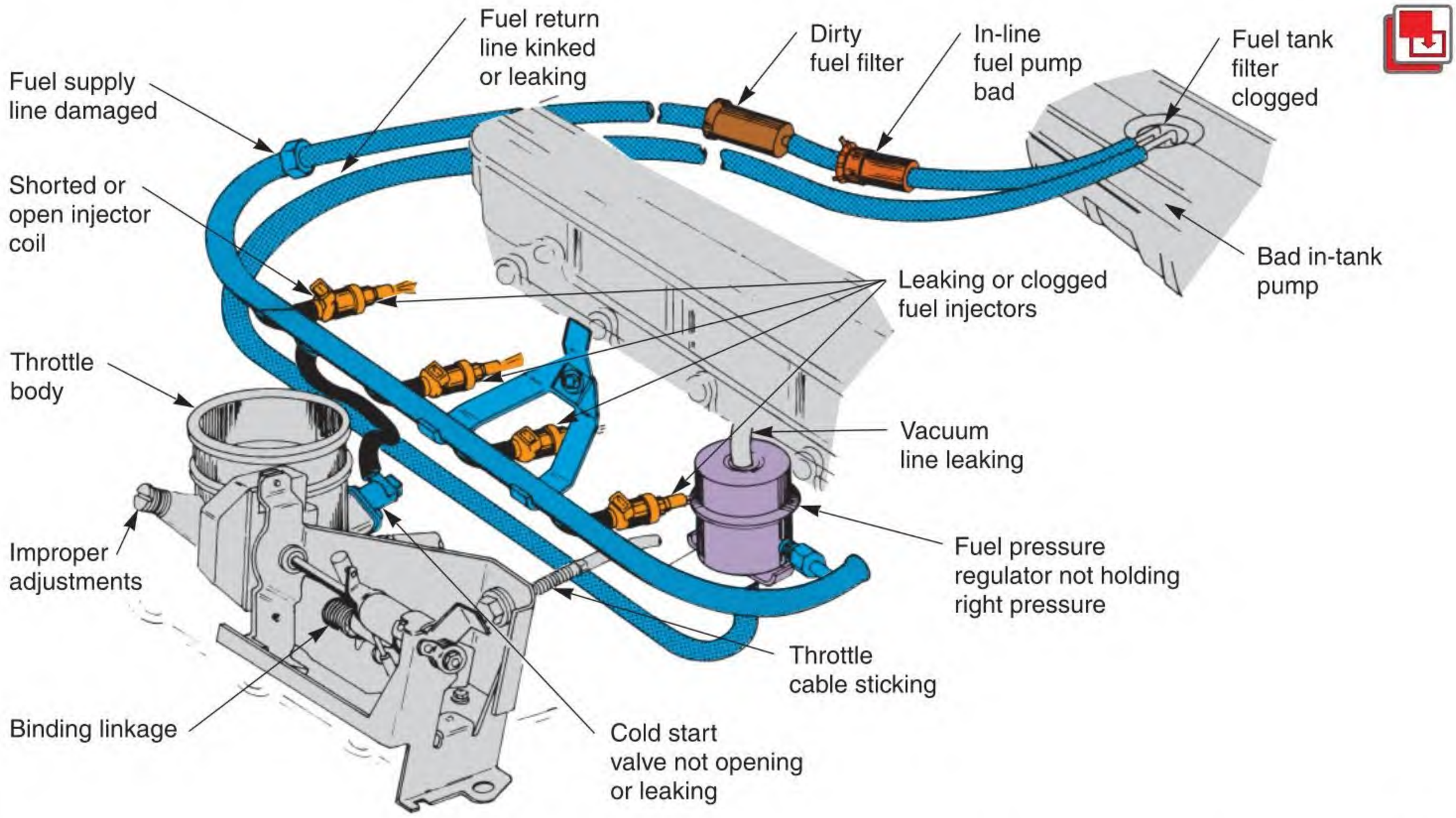
1. Inspect the engine compartment for fuel leaks, air leaks, dirty air filter, and other obvious troubles. See **Figure 42-3**.
2. Without starting the engine, raise the hood and inspect all fuel lines to and on the engine.
3. While wearing full face protection, long sleeves, and work gloves, check around the mechanical fuel pump and fuel rail to find the smell and wetness of liquid gasoline. Also have a fire extinguisher handy.
4. Check the condition of all vacuum hoses and wiring running from the ECM to the injectors, fuel pressure sensor, and fuel pump.
5. Look for vacuum leaks, kinked or rusted metal gas lines, loose electrical connections, and other problems.
6. In particular, check the vacuum hose connection to the MAP sensor.
7. With your scan tool connected, start the engine and review live data readings for fuel pressures, injector pulse width, and other electrical values relating to fuel injection.
8. If the engine has a miss, use a stethoscope to listen for a dead fuel injector. Touch the tip of the stethoscope on each injector to listen for the click of its pintle valve snapping shut.

If you know which injector might be at fault from the trouble code, inspect that circuit's metal terminals for rust, corrosion, and signs of overheating or burning (gray or black terminals). High resistance at the terminal connections can cause injector problems and engine misfiring.

Fuel Injector Sounds

If your scan tool indicates a problem with a specific injector, listen to its operation with a stethoscope. Start and idle the engine. Touch the probe on the top of the fuel injector body. If the injector is operating, you should hear a distinct clicking sound as the pintle snaps up and down on its seat.

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Fiat

Figure 42-3. After evaluating symptoms, try to narrow the list of components that could be at fault. Visualize the operation of each part. Do not overlook common problems, such as a clogged fuel filter.

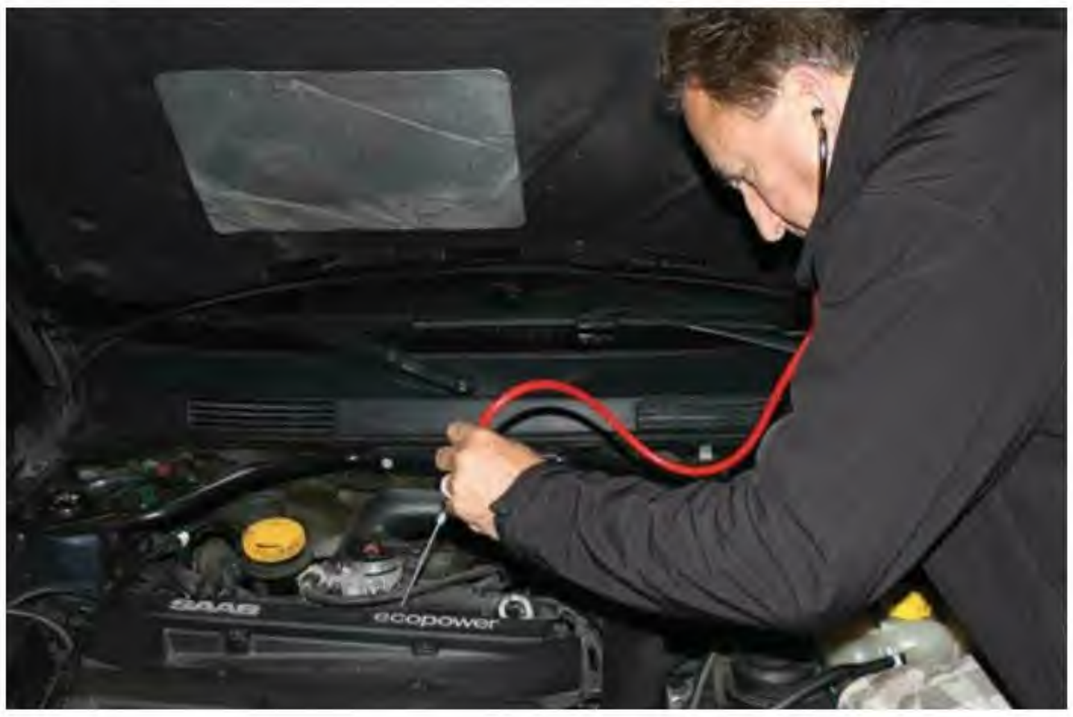
A direct gasoline injector clicks much louder than a conventional lower pressure fuel injector. Both make a rapid double-clicking sound when they open and close. However, direct injectors use a higher voltage to control 10 times as much fuel pressure. With the hood open and the engine idling, you can hear all of the direct injectors and mechanical fuel pump clicking as they operate.

If the injector rattles or is quiet, it may be sticking, have a broken spring, or not be opening at all. You could have a bad ECM power transistor, a break in the wiring to the injector, or the injector itself may be bad. See **Figure 42-4**.

Warning

Modern DEFI or direct gasoline injection systems operate at dangerous fuel pressure levels. Many systems can pressurize the gasoline to over 500 psi (3.44 MPa) at idle and over 2000 psi (13.78 MPa) during acceleration or high rpms. Most DEFI systems retain high pressure even when the engine is shut off. A fuel leak at these pressures can puncture human skin and inject gasoline directly into the bloodstream. This could be deadly even if the fuel spray does not ignite.

Always use extreme caution and wear appropriate safety gear when working on a high-pressure fuel system. Wear a full face shield, long sleeves, and work gloves when servicing a running direct injection engine.



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Figure 42-4. A stethoscope can be used to verify the operation of a fuel injector. You should hear a distinct clicking sound when the injector opens and closes.

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OBD II Fuel System Monitoring

With late-model on-board diagnostic (OBD II) systems, the vehicle's computer or ECM will record potential problems in its memory. A scan tool can read this data and convert it into a brief description of the problem. The scan tool will tell you which sensors, injectors, and other monitored components are not operating normally. The scan tool may also indicate what might be wrong with the component. This will save considerable time when troubleshooting.

Vehicles equipped with OBD II systems can set trouble codes that pinpoint injector problems. For example, if the scan tool readout shows a problem with the number three injector, you know to test this injector and its supply circuit for problems.

The scan tool and system knowledge will help you find failed fuel system sensors, actuators, circuits, or engine ECM. ***Fuel system monitoring*** involves checking whether a stoichiometric, or theoretically perfect, fuel mixture is being fed to the engine. Primarily, the feedback from the upstream oxygen sensor (located before catalytic converter) is used to determine fuel mixture content. If the oxygen sensor detects abnormal combustion resulting from a poor fuel mixture or other trouble, it trips a trouble code.

Before a trouble code is tripped, however, the ECM will try to adjust the fuel mixture as needed. It will alter the temporary fuel trim or injector pulse width to compensate for abnormal combustion by-products.

Fuel trim values indicate whether the ECM has had to lean or richen the air-fuel mixture to maintain a perfect stoichiometric mixture. ***Short-term fuel trim*** refers to the temporary adjustment of injector pulse width to correct the fuel mixture. ***Long-term fuel trim*** is a permanent adjustment of injector pulse width to compensate for altered operating parameters. The ECM uses this data to determine if the vehicle will pass an emissions test.

Minor fuel trim adjustments are normal with part wear. However, if the ECM determines the vehicle might flunk an emission test from long-term fuel trim data, it will trip a trouble code to warn the driver and technician.

A normal range for both short and long fuel trim is typically plus or minus 8. If the numbers are 10 or higher, the engine is running lean (not enough fuel). If the values for both short and long fuel trim are both minus 10 or more, the engine is running rich (too much fuel). This general information will help you diagnose the cause of the fuel injection system problem.



Tech Tip

Engine vacuum leaks often cause a lean air-fuel mixture. This causes the ECM to incorrectly inject extra fuel to try to richen the fuel mixture. Your scan tool short fuel trim will read lean (SFT above 10). To check for an engine vacuum leak, increase engine speed to 1500 to 2000 rpms and hold it for a full minute. If the scan tool short fuel trim drops back down to normal (about 8), it confirms that you have a vacuum leak at idle. If the short fuel trim value does not change much, the lean fuel condition is caused by a fuel delivery problem (worn fuel pump, clogged fuel filter, gummed, dirty fuel injectors or a fuel pressure regulator problem).

OBD II Oxygen Sensor Monitoring

Oxygen sensor monitoring is done to keep the normally closed loop mode of operation efficient. The ECM usually checks the upstream oxygen sensor for abnormal voltage, slow response times, and similar problems. It also checks the downstream oxygen sensor for normal voltage output. If abnormal voltages are detected, a trouble code is produced.

Note that many oxygen sensors in OBD II systems are heated to speed warm-up. Quicker oxygen sensor warm-up allows the computer system to go from open loop (startup or cold mode) to closed loop (full operating temperature mode) in less time. In closed loop, the ECM can quickly make its own adjustments of fuel mixture based on feedback information from the sensors.

The oxygen sensor ***heater monitor*** checks the action of the heating element in the sensor. It does this by rapidly turning the heating element on and off while checking its response. If the control module detects an abnormal heater response, it trips a trouble code.

Scan Tool Fuel Trim Data

A ***fuel trim malfunction trouble code*** will be set if the ECM is having difficulty maintaining the engine air-fuel ratio.

A ***lean trouble code*** will be set if an O_2 sensor detects high amounts of oxygen in the engine exhaust. Something is reducing the amount of fuel that should be injected into the engine. A common reason for a lean code is a large vacuum leak in the engine. A leaking intake manifold gasket or leaking vacuum

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hose can bypass air around the airflow sensor. The air leak will also lower vacuum to the MAP so that both sensors will send inaccurate signals back to the ECM.

A ***rich trouble code*** means just the opposite. Instead of too much oxygen, too much fuel is being injected into the cylinder for engine speed and load. A leaking injector can cause a rich code, as well as dirty engine oil. Since EGR crankcase fumes are burned in the engine, dirty oil fumes passing over the O_2 sensors will make the signal that the engine is running too rich.



Tech Tip

Defective aftermarket MAF sensors are now a common cause of fuel trim codes and fuel mixture problems. Factory MAF sensors and other complex digital sensors should always be purchased from the auto manufacturer. The extra money spent will result in fewer "comebacks" and unhappy customers.

Fuel System Tests

Fuel system tests are needed to verify scan tool trouble codes so you do not unnecessarily take hours to replace good components. Using a stethoscope, scan tool live readings, scope waveforms, and multimeter will help ensure that you replace only the fuel system part at fault.

OBD Fuel Injection System Tests

On late-model vehicles, an advanced scan tool/scope will perform many sensor and actuator tests. Most high-end scan tools with a scope function will serve the following functions:

- Measure ***injector pulse widths*** as numeric or scope readings in milliseconds. The scope in the tool will also let you view injector operating voltages over time.
- Perform an ***injector balance test*** to measure pressure drop and flow from fuel injectors. The scan tool will build a specific amount of fuel pressure in the system, and then fire each injector for the same amount of time. An injector with a low or high pressure drop is faulty.
- Perform fuel pump tests and measure low- and high-fuel pump pressures.
- Perform sensor tests (oxygen sensor, MAP sensor, etc.) to find problems with input devices that affect fuel injection.
- Perform actuator tests of the throttle control motor, accelerator pedal, and other circuits.

Before these topics are discussed in detail, you should understand how to do a thorough inspection of all fuel system parts to find obvious troubles.

Fuel Injector Problems

A bad injector can cause a wide range of problems including rough idle, hard starting, poor fuel economy, and engine miss. It is very important that each fuel injector provide the correct fuel spray pattern and an equal charge of fuel in each cylinder.

A leaking injector richens the fuel mixture by allowing extra fuel to drip from the closed injector valve. The injector valve may be worn or dirty, or the return spring may be weak or broken. When you try to start the engine, the leaking injector can flood the combustion chamber with fuel. Your primary oxygen sensor will show a very rich mixture upon initial engine starting and then will lean down as the engine runs and warms to operating temperature. You might also have an engine misfire code in the cylinder with the leaking injector.

A dirty injector can restrict fuel flow and make the mixture too lean. If foreign matter collects in the valve, a poor spray pattern and inadequate fuel delivery can result. Your scan tool will show a normal pulse width and pattern, but that cylinder will run lean and may not fire, possibly setting an engine misfire code.

An inoperative EFI injector normally has shorted or open coil windings. Current is reaching the injector, but since the coil is bad, a magnetic field cannot form and open the injector valve. When you touch a stethoscope on the dead fuel injector, you will not hear it clicking opened and closed. The voltage will not spike and then return to holding current through the injector windings, as it should. A handheld scope connecting across the injector wire terminals will show a low or nonexistent injector waveform.

A faulty DEFI injector can have a burned or damaged nozzle that can cause a poor fuel spray pattern in its combustion chamber. Since the nozzle is exposed to a combustion flame millions of times in the life of an engine, it can be burned and eroded after a prolonged service life. This can affect engine power and efficiency.

Fuel Injector Resistance

Before condemning a fuel injector because it tripped a trouble code or made an abnormal sound, measure the injector's internal resistance with an

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ohmmeter. Remove the electrical harness connector from the fuel injector. Touch your ohmmeter leads across the two pins or terminals inside the fuel injector as shown in **Figure 42-5**. Compare your ohms or resistance value to specifications. If the ohmmeter reading is higher or lower than normal, the injector windings have failed and the injector must be removed and replaced.

A failed injector coil winding will usually show up as either infinite resistance (maximum ohms) or no resistance (zero ohms). ***Low impedance fuel injectors*** should have an internal resistance of about 0.5 to 3 ohms. They require very little voltage for rapid operation. The ECM's current-limiting ability keeps them from overheating. If 12 volts are applied to a 0.5 ohm injector, the injector would pull six amps from the ECM ($12 \times 0.5 = 6$).

High impedance fuel injectors should have between 10 and 12 ohms to be within specifications. Higher voltages are required to operate fuel injectors with a higher internal resistance.

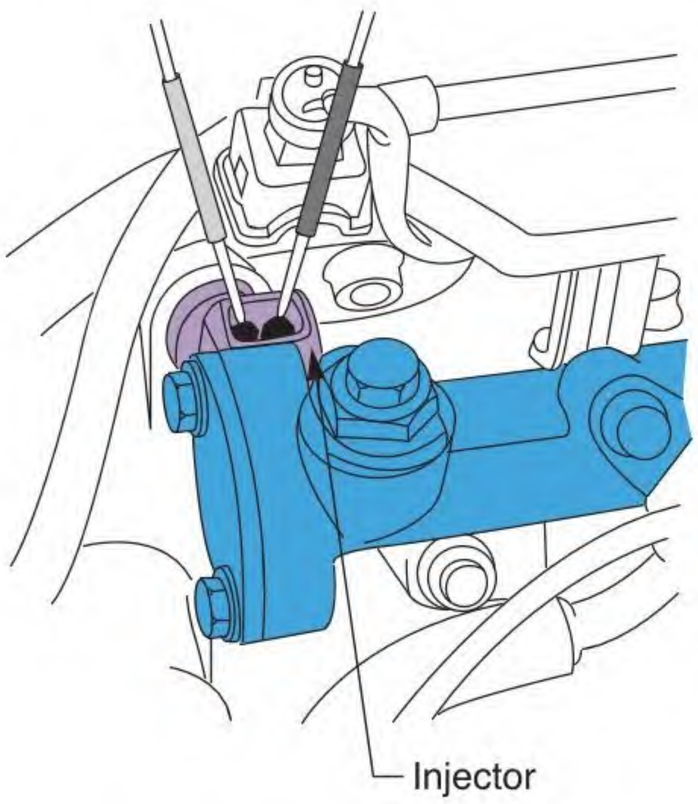
Piezo fuel injectors can have an ohms reading of 150,000 ohms to 200 kilohms. Piezo fuel injectors can pull up to 30 peak amps to initially open the nozzle and 10 amps to hold it open. This can require over 200 volts dc from the large capacitors and step-up transformers in the ECM.

Fuel Injector Operating Voltages

EFI injector operating voltage is usually 12.5–15 volts dc for non-direct or port injection systems. The ECM applies battery voltage to the injector windings all the time. Then, to fire a fuel injector, it grounds the other wire coming out of the injector coil. With a complete circuit, the injector fires until the ECM opens its ground circuit again.

DEFI injector operating voltage will usually be higher than battery voltage, from 50–100 volts dc. A high-injector operating voltage causes the injector to open and close more quickly for better fuel control in less time. Three or more injector pulses can be used during the intake and compression strokes to control combustion pressure and control detonation.

To measure fuel injector operating voltage, place a voltmeter across ground and the power side terminal with the injector still connected to the ECM. You can also measure injector voltages with a scope, advanced scan tool, or DEFI injector tester.



Honda

Figure 42-5. To check injector resistance, touch the meter probes to the injector terminals as illustrated here. Compare the resistance reading to the manufacturer's specifications.

Fuel Injector Scope Testing

A trouble code for a fuel injector circuit indicates the ECM is not sensing normal injector circuit voltages over time. When an electronic fuel injector fires, a specific waveform should be produced as the fuel nozzle snaps open and closed.

As the electromagnet strains to initially move the needle valve off its seat, the voltage and current spikes at about 50–100 volts dc. Once the injector needle valve opens and its metal plunger is pulled up into the injector solenoid, a lower battery voltage can be applied to keep the injector open.

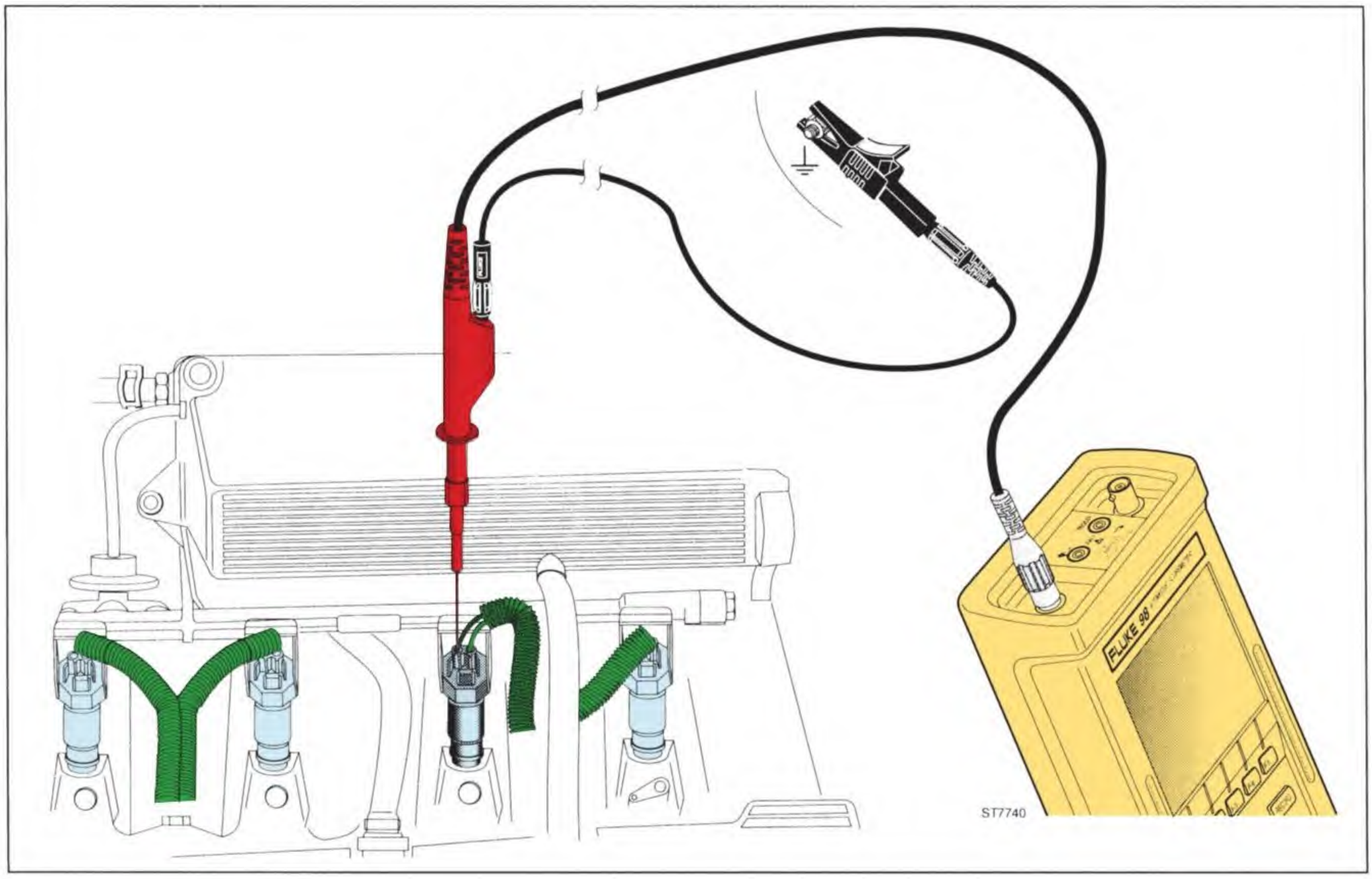
A fuel injector that opens and closes properly should produce a specific shape waveform on your scope. If voltage levels over time are not within specifications, the engine ECM will trip a code identifying the bad injector by cylinder number. You still do not know whether the injector, its wiring, or the ECM is bad.

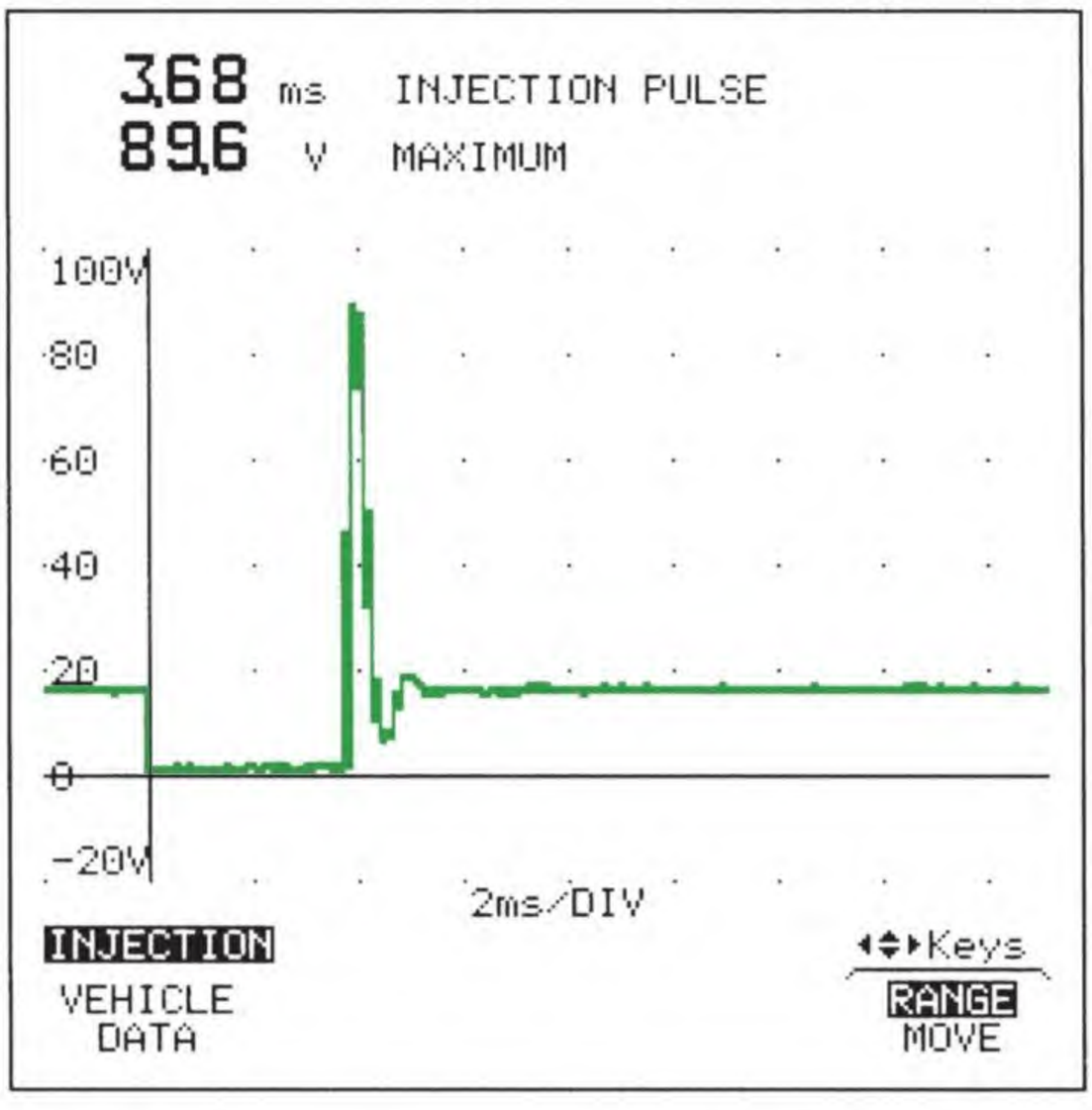
A ***fuel injector scope test*** involves measuring the maximum and minimum injector voltages and time of injection in milliseconds. This test can be done with some scan tools or a handheld scope. See **Figure 42-6**.

Fuel Injector Scope Waveforms

A properly functioning injector will produce a scope waveform or trace as the injector opens for a few milliseconds and then snaps closed. If one injector produces a rounded, malformed waveform without specific voltage variations over time, that injector is faulty (sticking, clogged, high internal resistance, shorted, or broken return spring). The power transistor control circuit inside the ECM or injector amplifier ECM either grounds or applies voltage to the injector to make it spray fuel into the engine.

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Figure 42-6. A handheld scope is handy when troubleshooting fuel injector or ECM problems. A—Use a needle test probe to reach into the plastic connector to touch the metal terminal for the injector coil windings. B—By setting the scope to correct voltage and sweep rate, you can view injector voltage as the coil windings are energized and the fuel valve opens and closes.

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Service Procedure

To complete a fuel injector scope test:

1. Wear safety glasses and work gloves, especially when servicing a high-pressure, direct fuel injection engine.
2. Connect the red scope lead to the positive wire coming from the injector amplifier or ECM. Refer to a factory wiring diagram for wire color codes if in doubt.
3. Connect the black scope lead to any good ground on the engine.
4. Set the scope to maximum injector circuit voltage. This is often above 100 volts for DEFI systems and 15 volts for port EFI systems.
5. Set scope frequency to milliseconds, or thousandths of a second.
6. Block the tires, shift gear to *Park*, and apply the emergency brake.
7. Start the engine.
8. Compare your injector scope waveform to a known good pattern for that make and model car.

If the scope waveforms are shaped differently than normal, something is usually wrong with the injector.

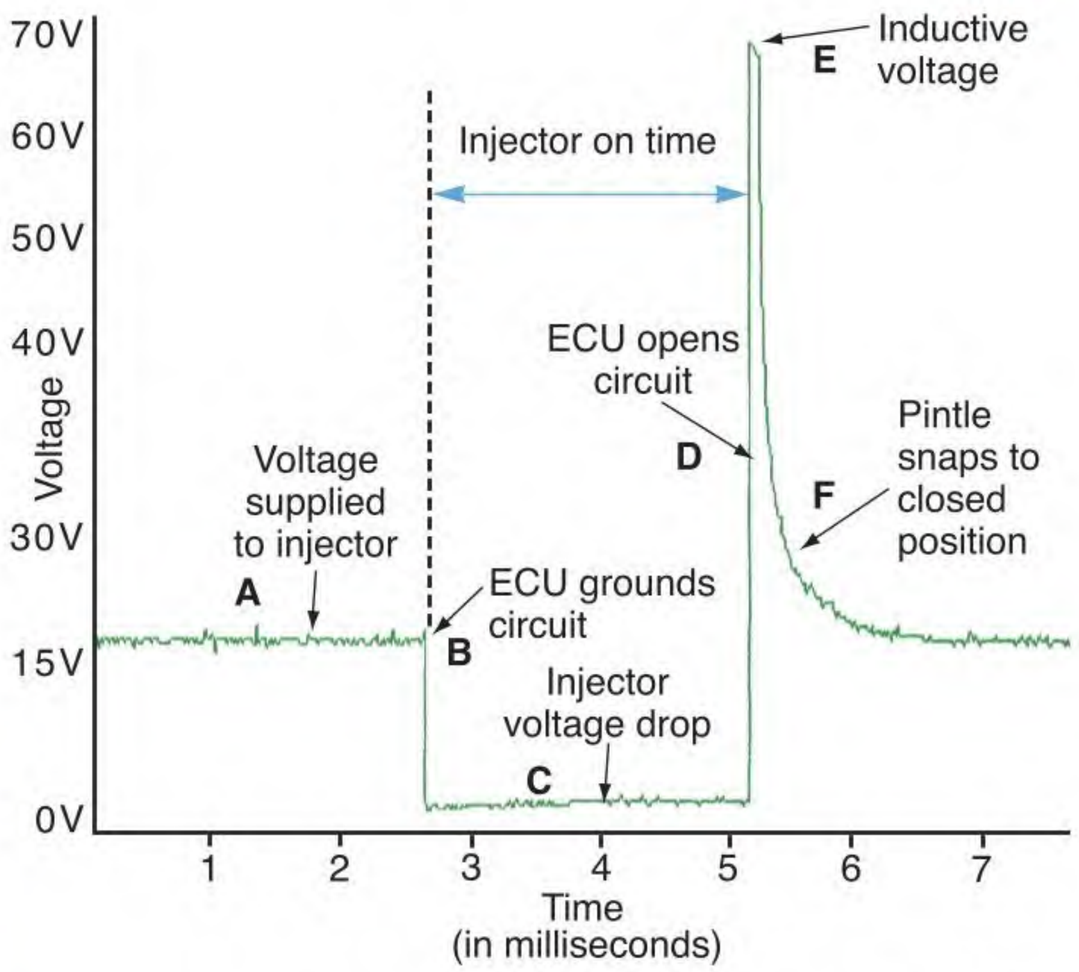
By comparing all injector waveforms, you can easily find abnormal waveforms (internal injector problems) and incorrect injector pulse widths (duration of current flow) sent from the ECM. When the ECM completes the injector circuit, current starts to flow through the small electromagnet inside the injector. The buildup of the magnetic field in the injector and the movement of the armature (metal core or needle) affects the shape of the injector waveform. The injector waveform can be very helpful in finding injector problems quickly when you carefully note when the injector gets electrical power, when the magnetic field builds, when the armature slides into the magnetic field, and when the injector opens and closes.

Caution

Never use jumpers to apply full battery voltage to an injector winding. Excess current flow will quickly overheat and ruin today's low-resistance fuel injectors. New fuel injectors may have only 0.5 ohms. If you apply 12 volts to 0.5 ohms, you will send 24 amps through the small injector coil windings. The injector solenoid windings will smoke and burn up almost instantly.

Saturated Switch Fuel Injector Waveform

A typical saturated switch fuel injector waveform is shown in **Figure 42-7**. Point A shows that voltage is applied to the injector, but the circuit is not grounded through its control circuit. At point B, the ECM grounds injector circuit and voltage drops to almost zero due to small resistance in the high performance fuel injector and its control circuit. Voltage remains low (point C) as current is fed through injector windings. At point D, the ECU opens the circuit to stop current flow to the injector windings. This causes the magnetic field across the injector coil windings to collapse, inducing an inductive voltage spike (point E). As the magnetic field continues to collapse, voltage drops to the level supplied to the injector (point A) and the pintle returns to closed position, stopping fuel flow. Injector on time is measured from point B where the ECM grounds circuit to point D where ECM opens circuit. Typical saturated switch injector circuit on times vary from about 2–9 milliseconds. At engine idle, when only a short burst of fuel spray into the cylinder is needed, the injector may be held open for only 2 milliseconds.



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Figure 42-7. Study an actual test waveform for good saturated switch injector.

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Compare actual fuel injector on times with specifications. You can also compare the questionable on time with that of other good injectors in the same engine. Advanced scan tools will be able to pull up images of good and bad injector waveforms for the make and model car being repaired. An injector scope waveform will also isolate the problem to the injector or ECM driver circuit.

Injector, circuit, and ECU problems will show up when the trace has major variations from normal. If a trace is supposed to be square at one point, it must be perfectly square. If a part of the trace is supposed to have a spike (injector closing inductive kick), it should have a spike of sufficient voltage.

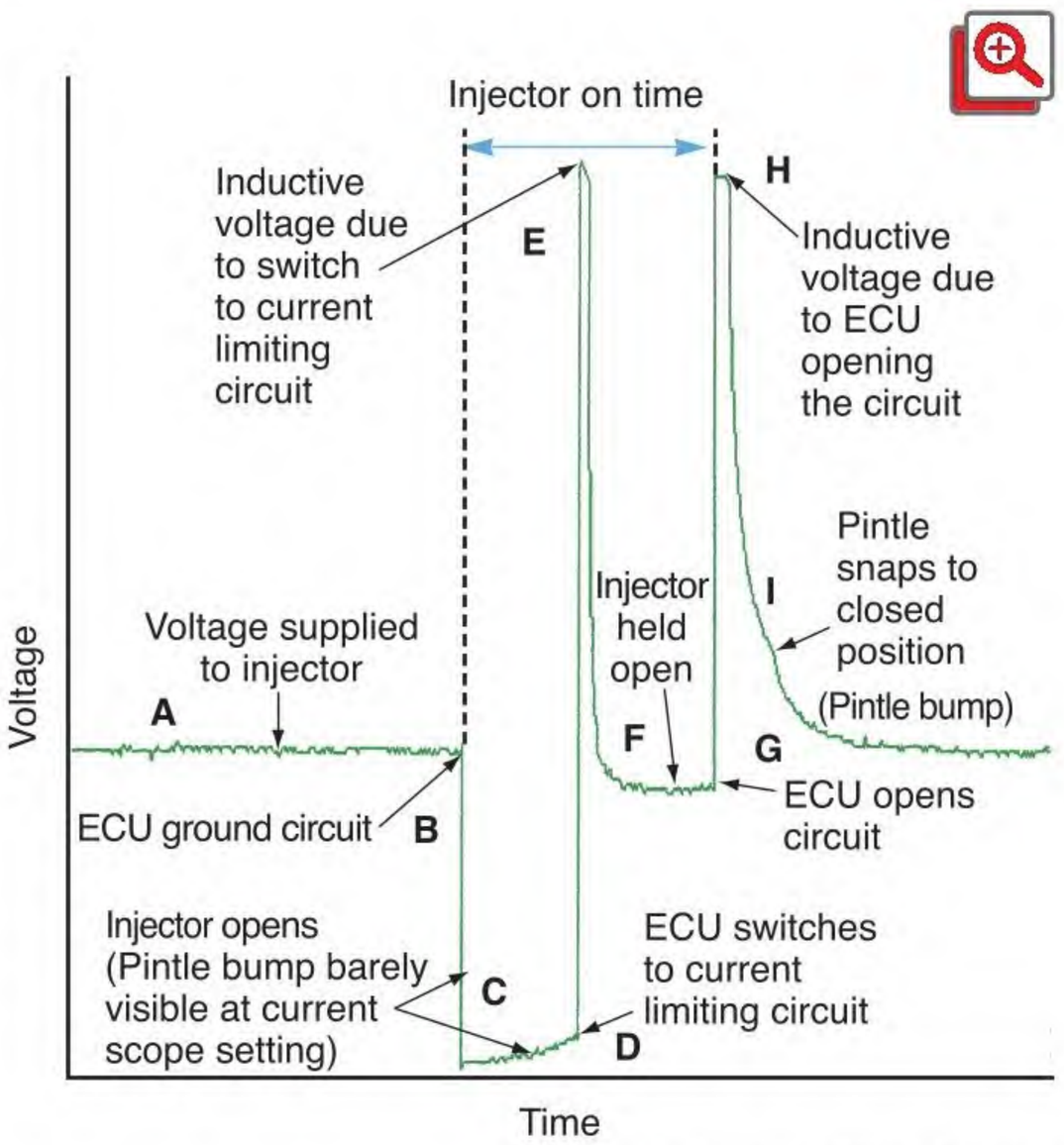
A PNP fuel injector waveform is similar to the saturated switch waveform, except that the waveform is inverted on the scope screen. This is because the ECU completes the injector circuit by making a connection to the positive side of the voltage source.

Peak-and-Hold Fuel Injector Waveform

A ***peak-and-hold fuel injector*** circuit uses a high amount of current to open the injector and a low amount of current (less than one amp) to hold the injector open. The injector coil circuit has less than 12 ohms of resistance to provide the high amount of current to pull the pintle off its seat to open the injector nozzle. The ECU provides the current limiting resistance needed to hold the injector open.

A peak-and-hold fuel injector waveform will have two induced voltage spikes: one when the ECU lowers current by switching to the limiting resistor circuit, and another when the ECU shuts off current flow to the injector.

Figure 42-8 shows a typical peak-and-hold fuel injector waveform. Voltage (about 13.5 volts) is applied to the injector and point A. The circuit is open (infinite resistance), so the fuel injector is off. This part of the trace should be fairly smooth. At Point B, the ECM grounds the injector circuit, allowing current to flow through injector coil windings. Note that voltage drops to almost zero (due to small resistance in the injector circuit) at B. The injector is *on* and the pintle is pulled up. If a sharp drop toward zero volts is not produced, the power transistors or drivers in the ECM are weak and failing or the injector is sticking or failing. Voltage drop across the injector windings and circuit is shown at point C. This part of the trace should be almost at zero volts. If your trace reaches zero volts or ground, the injector windings or wiring may be shorted to ground. If the trace is located several volts



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Figure 42-8. This is a normal scope waveform for a peak-and-hold fuel injector circuit.

above ground, the injector control circuit or scope test leads might have a bad ground. At point D, the ECM switches to a current limiting circuit to prevent the fine wire inside the injector windings from overheating and burning up. Magnetic field strength and coil impedance should respond to movement of the injector armature as the injector opens and closes. This is shown at point E. After the inductive voltage spike, the injector is held open (point F) at a lower voltage level with about 0.6 amps flowing through coil windings. As the injector is held open, fuel continues to spray out of the nozzle into the engine. At point G, the ECM opens the injector circuit, inducing another inductive voltage spike (point H). As the pintle and armature snap closed, a small ripple occurs in the waveform. This is visible at point I. Voltage returns to charging voltage.

A ***pintle bump*** is a slight variation in the injector waveform that occurs when the pintle opens or closes. As the pintle begins to open, its movement causes a slight current fluctuation. This causes a small pintle bump in the injector waveform. Similarly, a slight voltage is induced in the circuit when metal pintle snaps closed. This too causes a pintle bump in the waveform. Refer again to **Figure 42-8**. By observing the pintle bumps in the injector waveforms, a technician can see exactly when an injector opens and closes. If

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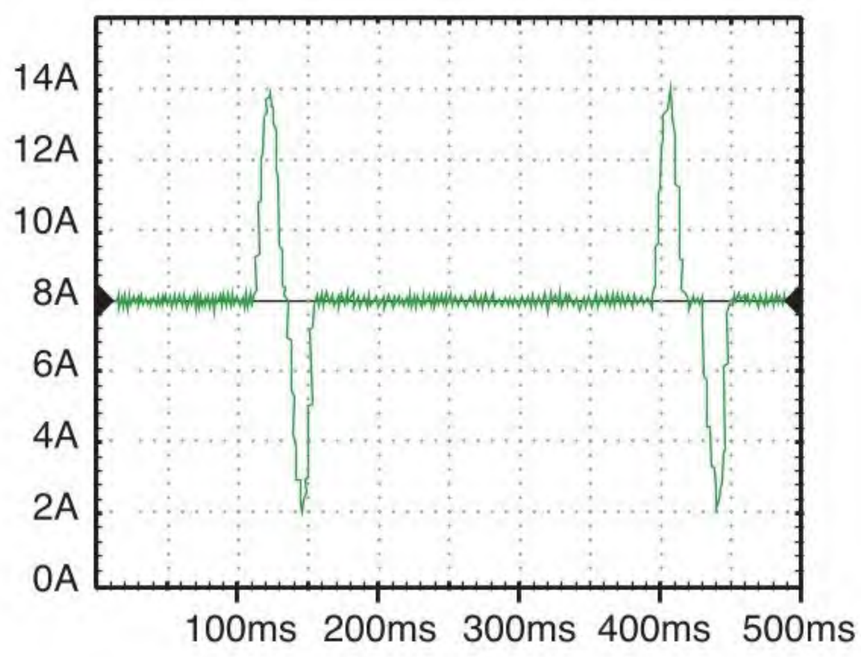
a pintle bump is missing, the injector may be sticking or not opening and closing normally.

Testing Piezo Fuel Injectors

Piezo injectors have both their voltage supply and ground switched *on* and *off* at the same time by the ECM. Compared to a conventional injection, a piezo injector generally requires higher applied voltage (90–175 volts) to hold the nozzle open. It also requires higher current levels (15–30 amps) to keep the piezo crystal expanded in size to hold the fuel needle open. A good piezo injector waveform is shown in **Figure 42-9**.

Tech Tip

Exact injector waveforms will vary slightly with vehicle manufacturer. Some injector testers and scopes will allow you to stack and align the injector waveforms, one above the other. On and off times from the stacked waveforms that do not line up perfectly may indicate a sluggish or sticking injector that needs cleaning. A sharp vertical rise in current with no lower holding current means the injector is shorted or stuck and must be replaced.



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Figure 42-9. This is a good scope or scan tool waveform for a piezo crystal type fuel injector. The scope is wired or connected to measure current and not voltage. Piezo injectors can pull over ten amps to open fuel injectors.

Fuel Injector Noid Light Test

A ***noid light*** is a special test light used for checking electronic fuel injector feed circuits for battery power. Different noid lights are made to fit wiring harnesses from each auto manufacturer. Usually, the specific makes of vehicles that the noid light will fit are printed on the tool. A noid light should be used if an injector is not clicking and opening. See **Figure 42-10**.



A



B

OTC/SPX Corp.

Figure 42-10. A—Noid lights are designed to check for normal current pulse being sent to each injector. B—To use a noid test light, disconnect the harness from the injector. To avoid damage, release the locking mechanism on the connector. Do not force the connector off.

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Service Procedure

To test a fuel injector with a noid light:

1. Disconnect the wiring harness from the fuel injector. Make sure to release the plastic connector properly to prevent damage. Most harness connectors use a flexible positive lock to keep the wiring from vibrating loose.
2. Fit the correct noid light with the matching connector configuration into the injector harness connector.
3. Start the engine and observe the small bulb inside the noid light.
4. If the noid light flashes, the ECM is sending voltage into the injector circuit. Power is reaching the injector from the electronic control unit. If the noid light does *not* flash on and off, something is keeping current from reaching the injector. There may be an open in the wiring, harness or pool electrical connection between the pins or terminals in the ECM connector. No current to an injector could also be caused by a burned current-limiting resistor, burned boost capacitor, or blown power transistor in the ECM or injector amplifier module.
5. Repeat the noid light test on any injector that is not clicking and operating properly.

Refer to a factory wiring diagram when solving complex fuel injection electrical/electronic problems. Fuel injection circuit diagrams will show all electrical connections and components to sensors, injectors, and throttle control motor.

Fuel Injector Balance Testing

An injector balance test involves the use of a scan tool, PC, or specialized fuel injector tester to measure the amount of fuel flowing through each injector. This test, commonly performed on modern direct and port fuel injection systems, will tell you if any injectors are clogged, cracked, shorted, or not opening fully. Instead of the engine ECM, the scan tool or ***EFI tester*** fires the fuel injectors while measuring pressure drop and implied fuel flow.

Relieving EFI System Pressure

Caution

Always relieve fuel pressure before disconnecting any EFI fuel line, even with low pressure (50 psi, or 345 kPa, at idle) port injection systems. All direct EFI systems now operate on high fuel pressures (above 2000 psi, or 14 MPa, at idle). Most direct gasoline injection systems will maintain some residual fuel pressure for several hours after the engine is shut off.

There are several ways to relieve fuel system pressure:

- Use your scan tool to operate the pressure relief valve in the high-pressure mechanical pump.
- Pull the fuse or relay for the electric fuel pump and run the engine until it stalls.
- For low-pressure fuel systems only, open a pressure relief valve on the fuel rail and allow it to spray into a shop towel.

In modern fuel systems, a scan tool or laptop computer can release fuel pressure by energizing the pressure relief valve mounted on the high-pressure, mechanical fuel pump. Your scan tool or laptop will require manufacturer-specific software in order to do live actuator or injector tests or to release fuel pressure electronically.

Most low-pressure EFI systems have a ***fuel pressure relief valve*** for "bleeding" any remaining gasoline pressure in the fuel rail and injectors. It is a small-threaded service valve on the engine fuel rail. A plastic cap covers this spring-loaded ***Schrader valve***. When the tip of the fuel pressure relief valve is depressed, fuel will spray out of the valve to release pressure.

When a relief valve or a pressure regulator relief is not provided, remove the fuse for the fuel pump or disconnect its wires. Start and idle the engine until it stalls. When the engine stops running from lack of fuel, residual pressure has been removed from the fuel lines and fuel rail. It is then safe to loosen fuel line fittings for repairs. Check scan tool and manufacturer service information to determine if you can relieve fuel pressure electronically.

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Caution

Even after you have released all fuel pressure from the system, wrap a shop rag or towel around any fuel fitting to be loosened and removed. This will contain and catch any gasoline that still leaks out of the gas line. Place the gasoline soaked towel in an approved, fire-resistant container. The container must have a closeable metal lid to contain and smother spontaneous combustion of gasoline vapors.

Pre-OBD II Injector Balance Test

Millions of older passenger vehicles do not have advanced diagnostics that allow a scan tool to take idle, fuel pressure, and other readings when servicing the fuel system. For this reason, you should know how to test the fuel system of any car or truck that enters your garage.

Service Procedure

To perform a manual fuel injector balance test on a pre-OBD II vehicle:

1. Connect a tachometer to the ignition system to read engine speed or rpms.
2. Unplug the idle speed motor or air bypass valve.
3. Disconnect the electrical connector for the suspected bad fuel injector. Engine speed should drop if the injector is working normally. If engine speed stays the same, the fuel injector or its supply circuit wiring is at fault.
4. Test for power to the injector using a noid light.
5. If the noid light fails to flash *on* and *off*, a power signal is not reaching the injector coil or crystal. Check for an open wire or electrical connection between the connector and ECM or amplifier circuit.
6. A clogged or dirty injector would not cause any change in engine rpms. Either that engine cylinder is not getting a proper charge of fuel, or it has a distorted spray pattern. If the noid flashes and rpms do not drop, resistance or scope test the fuel injector to verify its problem.
7. If needed, repeat this test (steps 3–6) on the other injectors. If all of the injectors are working normally, engine idle speed should drop equally when each fuel injector is disabled.
8. Reconnect all injector connectors and the connector on the throttle.

Service Procedure

To perform an injector balance test with an EFI tester and a pressure gauge:

1. Connect a pressure gauge to the test fitting on the fuel rail. Make sure all fittings are tight and not leaking.
2. Close off the valve for measuring fuel volume if provided on the fuel gauge assembly. See **Figure 42-11**.
3. Connect the tester wiring to the injector in question.
4. Turn the ignition key on to pressurize the system. Then, turn the ignition key off.
5. Press the injector balance tester button while watching the pressure gauge drop.
6. Record your pressure drop reading.
7. Repeat this test on the other fuel injectors. This will allow you to measure how much fuel each injector is feeding into the engine when energized. Study **Figure 42-12**.

If all injectors are working properly, there must be no more than 1.5 psi (10 kPa) difference in pressure drop per injector. If any injector has a lower than normal pressure drop, it is clogged or sticking closed and is reducing fuel flow. If any injector has a higher pressure drop than the others, it is leaking or sticking open to cause excess fuel flow.

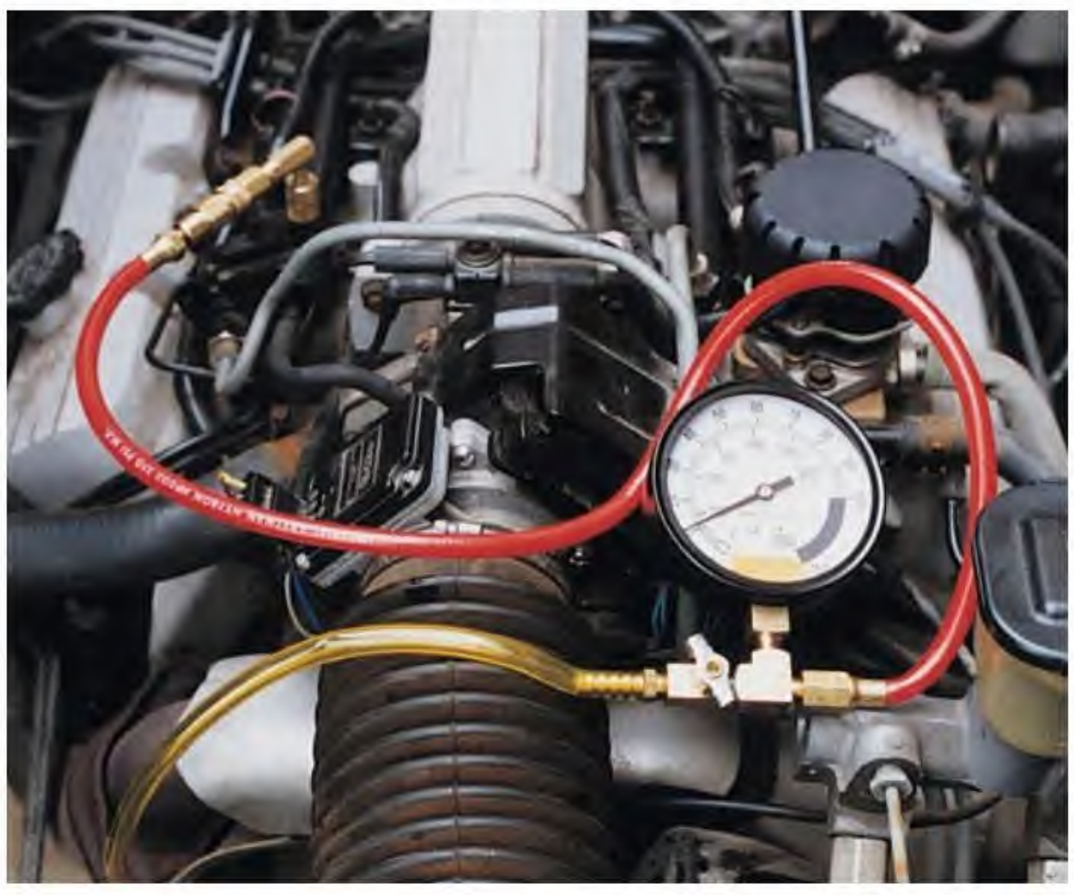
OBD II Injector Balance Test

Late-model engine ECMs have a built-in test for injector balance that can be run through a scan tool, PC, or injector tester. This allows the injectors to be shut off individually and the difference in their cylinders' power contribution to be recorded. Remember that a mechanical problem inside the engine (worn piston rings, damaged piston, or burned valve) could cause a cylinder to fail an injector test due to low compression stroke pressure.

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A



B

OTC/SPX Corp.

Figure 42-11. An injector balance test will find clogged or failing fuel injectors. A—An injector flow balance tester. B—Connect a pressure gauge to the fuel rail test fitting. If necessary, close the gauge valve for measuring fuel volume.

Service Procedure

To perform an injector balance test on OBD II–controlled injectors:

1. Connect a scan tool or injector tester to the vehicle and warm the engine to full operating temperature.
2. In the Scan Tool or Tester menu, go to Injector Tests and follow the directions on the menu screen.
3. Start and idle the engine to build fuel pressure.
4. Shut the engine off and immediately press *Yes* for injector balance tests.
5. The scan tool or tester will then fire each injector with the same injector pulse width while recording pressure drop for each fuel injector.

If fuel pressure drop is low for any injector, that fuel injector is not injecting the same amount of fuel as the others. The injector inlet screen could be partially clogged with gasoline gum or varnish, or its needle valve could be sticking.

If the pressure drop for all fuel injectors is the same, all of the fuel injectors should be metering the same amount of fuel into the engine. Therefore, something else is causing the combustion problem.

On-Car Injector Flow Tests

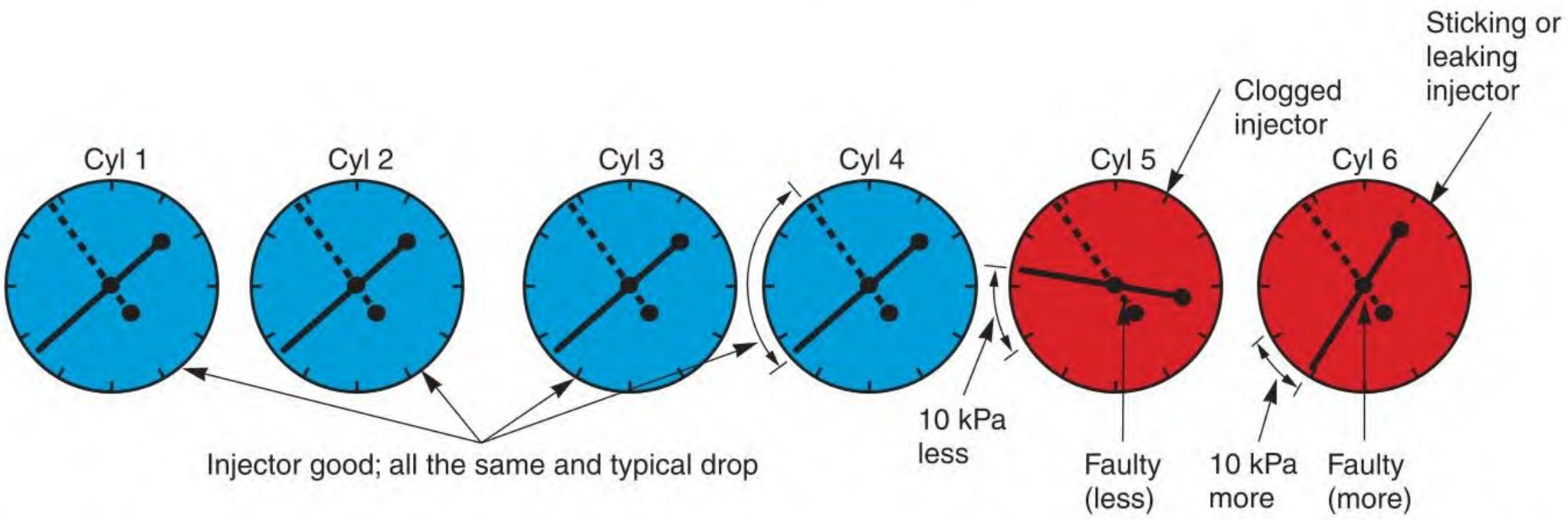
To properly test DEFI systems, you should use a dedicated digital fuel injection system tester. The tester will use data from the injector voltage waveforms, fuel pressure sensor signals, and other fuel control sensor signals to quickly analyze problems and calculate fuel flow through each injector. Study **Figure 42-13**.

Fuel Injector Maximum Flow Test

An ***injector maximum flow test*** fires each fuel injector for a predetermined amount of time while measuring flow through the injector. It measures steady or maximum fuel flow with the injector pintle and nozzle held fully open. It tests for injector balance by comparing flow and instantaneous fuel rail pressure drops as each fuel injector is opened.

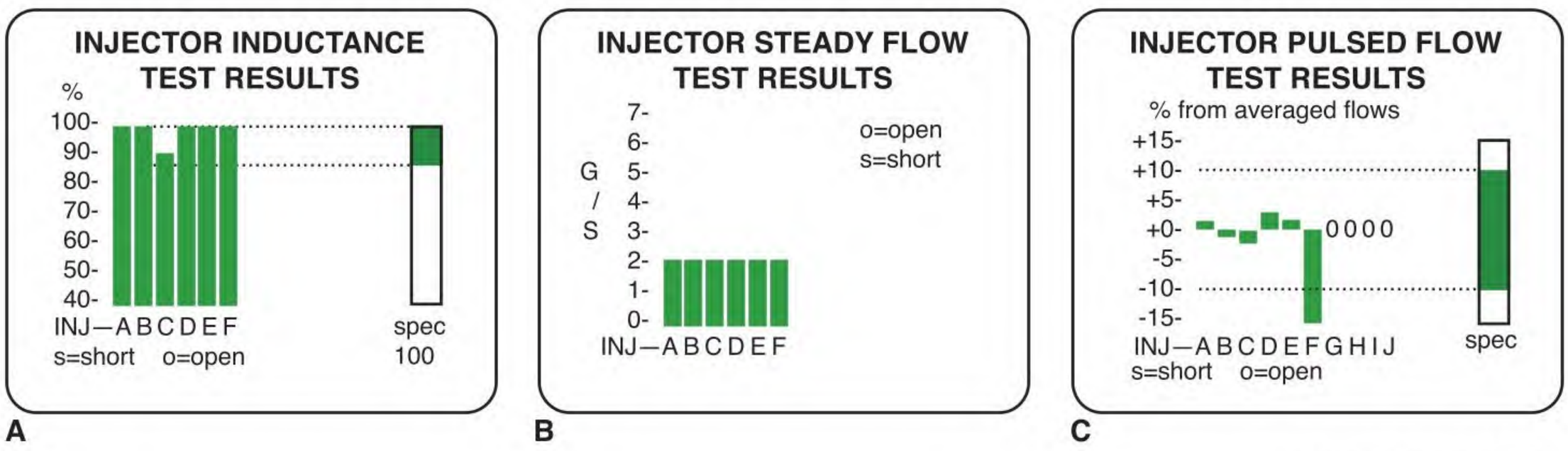
The injector maximum flow test will help find problems with clogged injector inlet screens (which can be flushed and cleaned without injector removal), problems with the injector nozzle or its pintle, coil

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Figure 42-12. Pressure drop at the gauge should be the same for each injector. Turn the key on or activate the fuel pump between each test so pressure is the same at each injector. If one injector has less pressure drop when fired, it might be clogged. If pressure drop is excessive, the injector might be worn or sticking. If pressure does not hold, the injector is leaking.



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Figure 42-13. These are typical screen displays from a digital injector tester. A—Inductance test shows one fuel injector winding that is lower than the others. B—A steady flow test shows equal flow through all injectors with the engine running. C—This injector pulsed flow test indicates that one injector may be sticking.

windings, or piezo element. Reduced fuel flow from any injector, no matter how small, indicates that the injector might have a poor fuel spray pattern, or it might be sticking or have another problem. Any fuel injector problem reduces combustion efficiency, engine power, and exhaust cleanliness.

Fuel Injector Pulsed Flow Test

A ***fuel injector pulsed flow test*** fires an injector several times with a normal pulse width to check pintle response. ***Pintle response*** is how quickly the pintle moves as the magnetic field in the injector coil builds. Most advanced scan tools and digital fuel injection testers can calculate pintle response from the injector waveforms (changes in voltage over time).

An injector pulsed flow test can find problems in a fuel injector, such as a weak return spring, sticking or gummed pintle, pintle wear, or injector body wear.

Fuel Injector Impedance Test

A ***fuel injector impedance test*** measures the internal resistance of the injector coil windings (not piezo injectors) while carrying a full amp load. The digital fuel injector tester electronically measures the magnetic field strength inside the injector electromagnet. Since impedance and field strength are related, an impedance test indicates how quickly the injector will open to spray fuel. It is much better than an injector ohmmeter resistance test because bad injector coil

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windings might not "act up" until higher current flow heats and expands the injector windings.

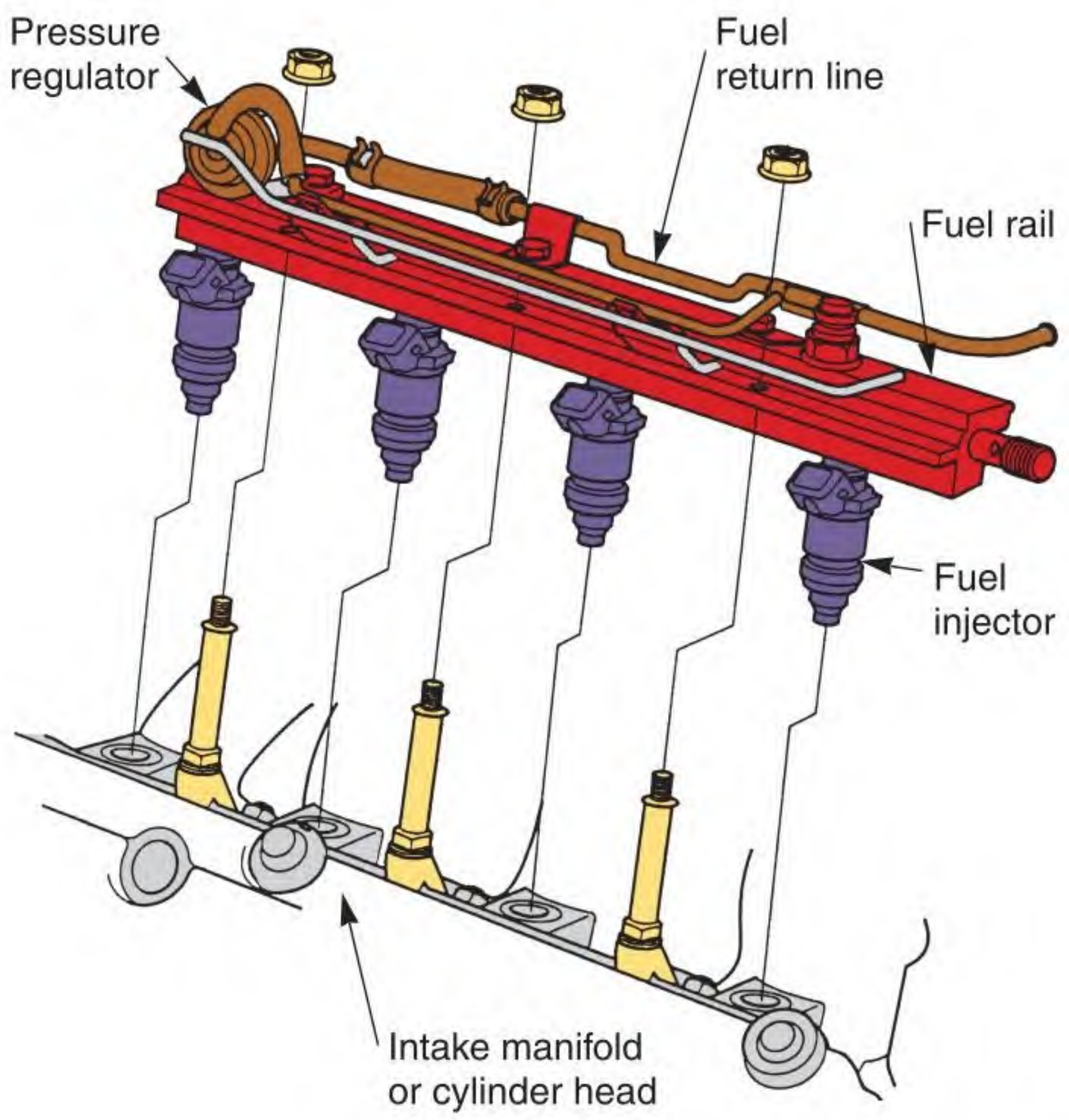
The fuel injector impedance test can find intermittent injector problems; weak, sticking injectors and shorted or fractured injector windings.

Replacing Multiport Fuel Injectors

An EFI multiport injector is easy to replace. After bleeding off fuel pressure, simply remove the hose from the injector and fuel rail. Unplug the electrical connection and remove any fasteners holding the injector. Pull the injector out of the engine. Study **Figure 42-14**.

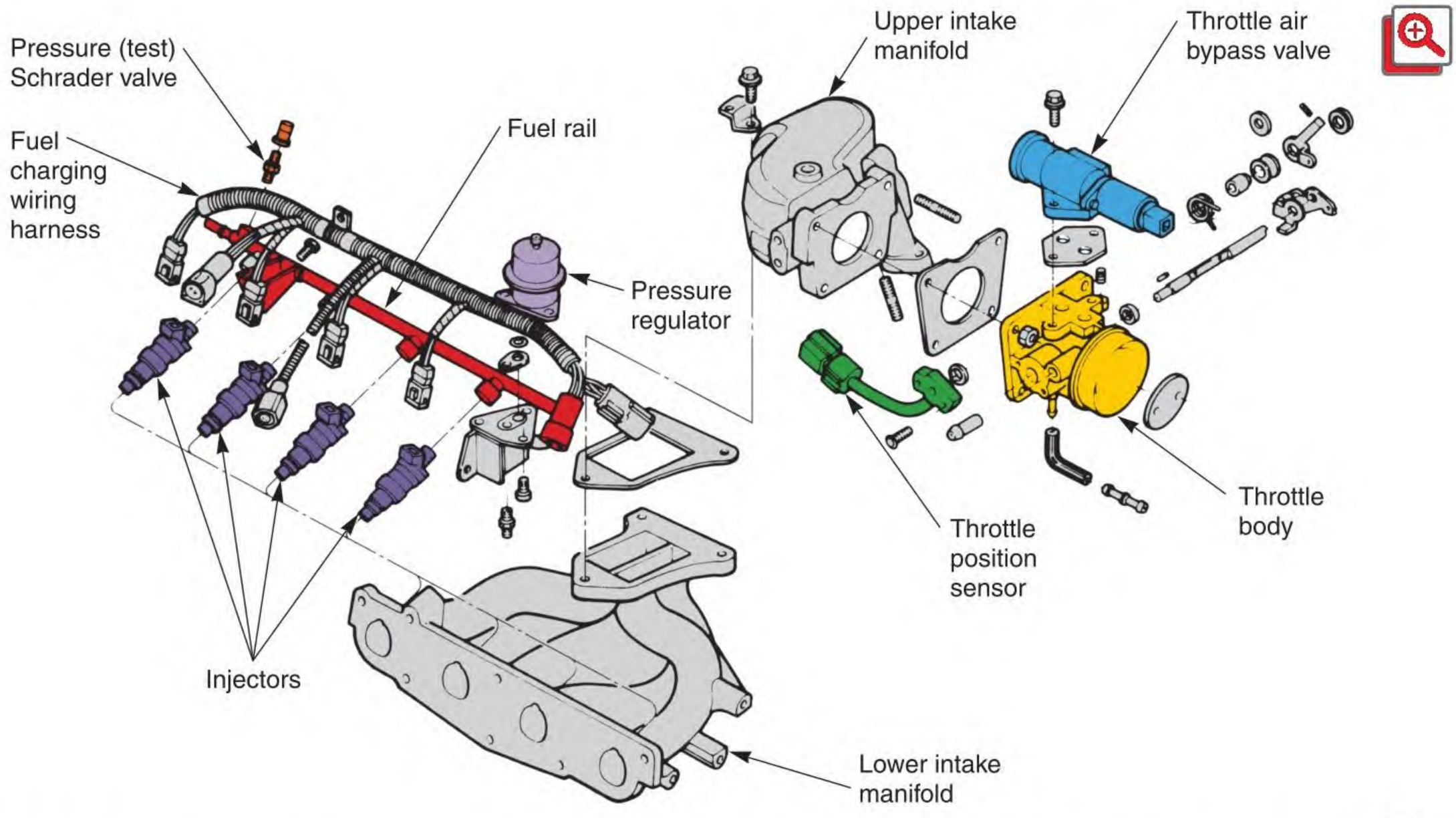
Sometimes, you must remove the fuel rail before you can service the injectors. All the injectors may have to be removed with the fuel rail. Then, each injector can be removed from the rail. Refer to **Figure 42-15**.

A ***fuel injector boot*** is a soft rubber grommet or O-ring that fits between the fuel injector and its opening in the engine. It must seal the opening to prevent engine vacuum leakage.



Honda

Figure 42-15. When servicing high-pressure fuel injectors, replace nylon seals, O-rings, and threaded fasteners. You may have to size the nylon seals for the engine. Use a torque wrench to tighten the injector hold-down nuts or bolts.



Ford

Figure 42-14. Exploded view of multiport injectors, fuel rail, pressure regulator, air bypass valve, throttle body, throttle position sensor, and intake manifold assembly. Study part locations.

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Inspect the boot and other rubber parts closely, **Figure 42-16**. Some manufacturers suggest that you replace the boot, seals, and hose if the injector is removed for service.

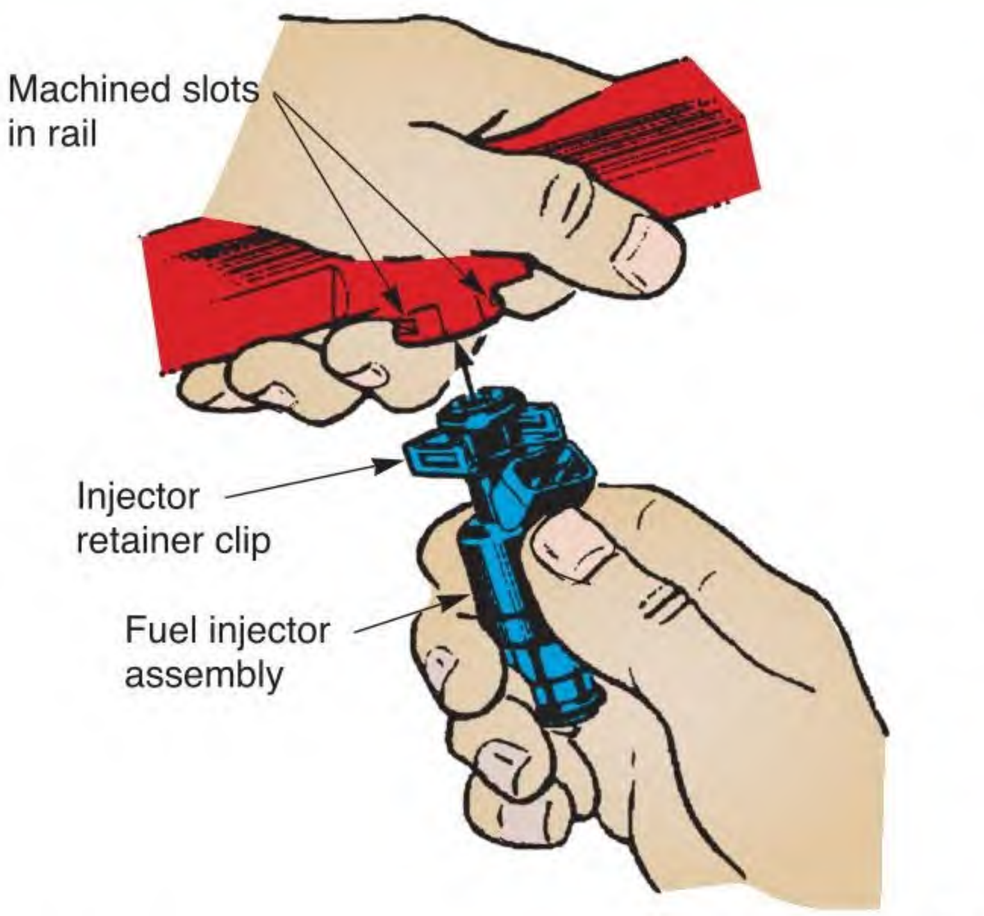
Install the new or serviced injector in reverse order of removal. Use the directions in the shop manual for details. Exact procedures can vary.

Replacing Direct Fuel Injectors

Service Procedure

To replace direct fuel injectors:

1. Release residual fuel pressure using your scan tool, laptop, or injector tester.
2. If you are servicing a hybrid vehicle, disable the HV battery by pulling its plug.
3. Disconnect the stainless steel fuel line between the mechanical fuel pump and the fuel rail. Wrap a shop rag around the fitting to catch fuel that leaks out.
4. Remove the bolts and hold-down plates that secure the high-pressure rail and injectors to the engine.
5. Pull the fuel rail off the injectors to prevent injectors from coming out with the fuel rail.
6. Install an injector puller on the rail or injector. Tighten the puller down to force the fuel injector out of the cylinder head.
7. If needed, install new O-rings on the high-pressure injector. You may have to size the Teflon® seals to properly fit into the head. Refer to factory instructions.
8. Install a new plastic spacer, if used.
9. Most manufacturers recommend that you install a new gasket, seals, and bolts to ensure that you do not have a high-pressure fuel leak.
10. Force the new injector straight down into the cylinder head. Be careful not to break it.
11. Install any hold-down plates and torque the fuel injector retaining bolts to specifications. Overtightening or undertightening can easily result in a costly or dangerous fuel leak.
12. Re-torque the high-pressure fuel line using a crow foot wrench and torque wrench.



Fiat

Figure 42-16. When installing a multiport injector, make sure the metal retainer clips, seals, washers, and boots are in perfect condition. Some automakers suggest using new ones.

Tech Tip

Modern engines with direct fuel injection use stainless steel high-pressure fuel lines that do not rust. If you ever have to replace a high-pressure fuel line, purchase a factory replacement. Do not attempt to make a new fuel line out of mild steel, because it can fail and leak gasoline when under 2000 psi (14 MPa).

Electronic Fuel Injector Cleaning

If the EFI injectors fail the balance test and show a low drop, they may be clogged and in need of cleaning.

A ***fuel injector cleaning tool*** uses shop air pressure to force a cleaning solution through the injectors to remove deposits. As shown in **Figure 42-17**, connect the tool to the fuel rail. Following tool instructions, force the cleaning agent through the injectors. If engine performance improves, the injectors have been successfully cleaned. The cleaning agent is combustible and will burn as the engine operates.

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OTC/SPX Corp.

Figure 42-17. A fuel injector cleaner will force solvent through clogged or restricted injectors. Sometimes, this will return them to normal operation without removal.

Warning

Make sure a shop exhaust hose is connected to the tailpipe when cleaning injectors. Exhaust fumes that occur during cleaning can be more toxic than usual.

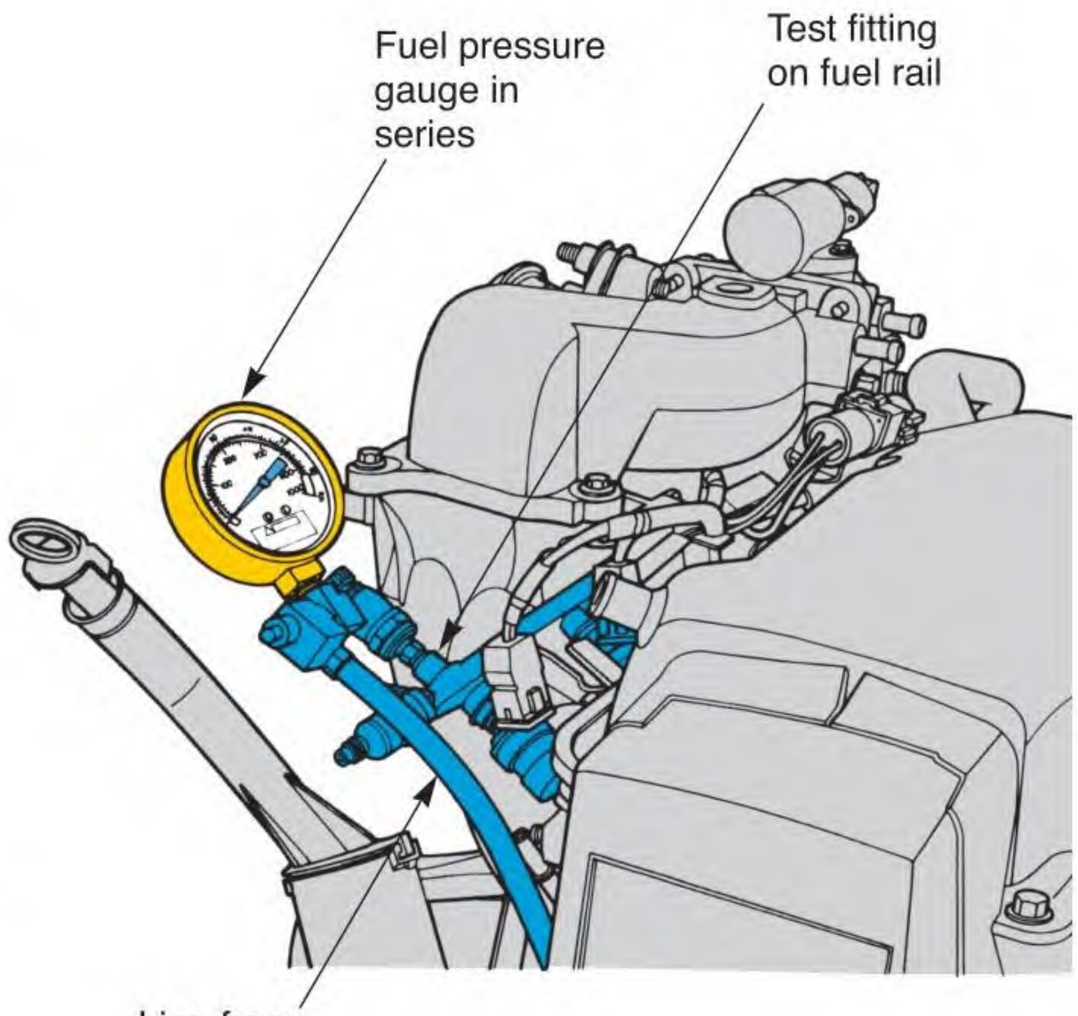
Fuel Pressure Regulator Service

A faulty ***fuel pressure regulator*** can cause an extremely rich or lean air-fuel mixture. If the regulated fuel pressure is too high, too much fuel will spray out of the injector nozzles, causing a rich mixture with too much fuel and not enough air. If the regulator bypasses too much fuel to the low pressure side of the system, not enough fuel will spray out each injector and into the engine. This causes a lean mixture with too much air and not enough fuel.

Testing the Fuel Pressure Regulator

With modern EFI systems, a scan tool will provide live data readings for high-pressure fuel rails, low-pressure fuel lines, and fuel tank pressures. You can check fuel pressure by comparing known normal fuel pressures to your scan tool readings. With low-pressure port fuel injection, you can still measure and verify actual fuel pressure with a test gauge, **Figure 42-18**.

Connect the gauge to the Schrader valve on the fuel rail with steel lines. Torque the fitting properly to avoid leakage. Start the engine and note the pressure gauge readings. Measure fuel pressure at idle and at about 3000 rpms. If low- or high-speed fuel pressure readings are not within specifications, the pressure regulator, fuel filters, fuel pumps, fuel feed hoses, or other parts may be at fault.



Ford

Figure 42-18. To check port fuel injection pressure, connect a pressure gauge to the fuel rail. Pressure should be within specifications at idle and at engine cruising speeds. If not, check the filters and pump before replacing the fuel pumps or fuel pressure regulator.

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With the engine idling, disconnect the vacuum hose going to the fuel pressure regulator. When disconnected, fuel system pressure should increase 8–12 psi over idle pressure. No change would indicate a faulty pressure regulator or a leaky or kinked vacuum line.

Tech Tip

With lower than normal fuel pressure, check the fuel pump and fuel filters *before* replacing the fuel pressure regulator. A bad electric fuel pump or partially clogged filter could be lowering fuel pressure.

With direct gasoline injection, fuel rail pressure is controlled by a solenoid on the mechanical fuel pump. The ECM will monitor and control fuel pressure by opening and closing the fuel inlet to the mechanical pump as a means of limiting super-high fuel pressure into the main fuel line, fuel rail, and fuel injectors. If a high fuel pressure solenoid fails, it can only reduce fuel pressure. For safety reasons, it is designed to only fail in the closed position to block fuel flow into the high-pressure pump.

Fuel System Sensor Service

Most EFI engine sensors can be checked with a scan tool. A scan tool will give operating values, which can be compared to specifications. However, an engine sensor can also be checked with a digital meter or a test light if the vehicle is not equipped with advanced on-board diagnostics. Scan tools are needed to quickly find and locate failed engine sensors that have affected the operation of the engine fuel system.

Oxygen Sensor Service

A failed O_2 sensor will upset an engine's air-fuel ratio, usually making it run too lean, miss, and lack power. The voltage signal from the sensor represents air-fuel ratio. If the oxygen sensor produces a false output (incorrect voltage), the control module cannot precisely control how much fuel is metered into the engine. A rich mixture or lean misfire condition could result.

Tech Tip

Oxygen sensors should be replaced at periodic intervals. After prolonged service, they become coated or fouled with exhaust by-products. As this happens, fuel economy and emissions will be adversely affected. If gas mileage is 10% to 15% lower than normal, suspect the oxygen sensor of slow response. One- and two-wire sensors should be replaced at about 50,000–60,000 miles (80,000–96,000 km). Heated three-wire oxygen sensors should be replaced at about 100,000 miles (160,000 km).

Oxygen Sensor Contamination

Depending on the type, an oxygen sensor can be expected to last from 50,000–100,000 miles. However, its life can be shortened by contamination, blocked outside air, shorts, and poor electrical connections.

Oxygen sensor contamination can be caused by:

- Leaded fuel—Leaded racing fuel or aftermarket performance products containing lead can cause oxygen sensor contamination. Lead coats the ceramic element, and the sensor cannot produce enough voltage output for control module.
- Silicone—Sources include antifreeze, RTV silicone sealers, waterproofing sprays, and gasoline additives. Silicone forms a glassy coating.
- Carbon—Carbon contamination results from rich fuel mixtures. Carbon in fuel coats the sensor.

Carbon and moderate lead contamination can sometimes be reversed. Run the engine at high speeds with a large vacuum hose (PCV hose, for example) removed. This will sometimes burn off light lead and most carbon deposits. The sensor may start working normally again.

Oxygen Sensor Inspection

Check that the outside of the sensor and its electrical connection are free of oil, dirt, undercoating, and other deposits. If outside air cannot circulate through the oxygen sensor, the sensor will not function.

An oxygen sensor generates only a tiny voltage (an average of about 0.5 volts). A poor electrical connection can prevent this small voltage from reaching the control module. Always check the sensor's electrical connections.

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Oxygen Sensor Testing

Most on-board diagnostic systems will produce a trouble code and give operating voltages indicating when the output from the oxygen sensor is not within normal parameters. When this occurs, you should perform further tests on the oxygen sensor and its circuit.

Many systems have a limp-in mode. If the oxygen sensor or some other sensor fails and produces an incorrect output, the system will go into this emergency limp-in mode. A predetermined oxygen sensor voltage (0.5 volts, for example) will be simulated by the control module and used to keep the engine running well enough to drive in for repairs.

A digital voltmeter can also be used to test the output of an oxygen sensor. Warm the engine to full operating temperature to shift the system into closed loop. The sensor must be hot (about 600°F or 315°C) to operate properly. You may have to warm the engine at fast idle for up to 15 minutes with some cars. Note that a few systems can drop out of closed loop at idle.



Caution

Use a high-impedance digital meter to measure oxygen sensor voltage. A conventional analog or low-resistance meter can draw too much current and damage the oxygen sensor.

Oxygen Sensor Output Voltage

In most cases, ***oxygen sensor output voltage*** should cycle up and down from about 0.2–0.8 volts (200–800 mV). A 0.2 volt or low reading would show a lean air-fuel ratio and a 0.8 volt or high reading would show a richer condition. A high or low reading does not always mean the oxygen sensor is bad. Another problem (leaking or clogged fuel injector, for example) could make the sensor read high or low.

A quick test to see if the oxygen sensor reacts to a change in air-fuel mixture is to pull off a large vacuum hose, like the hose to the PCV valve. This extra air should make the oxygen sensor try to richen the fuel mixture and compensate for the air leak (lean condition). The output voltage will normally go down (to about 0.2 or 0.3 volts), to signal a need for more fuel to adjust for the vacuum leak or extra air.

When the engine throttle is snapped open and closed, oxygen sensor output should also cycle up and down to show the change in air-fuel mixture.

If you block the air inlet at the air cleaner or inject propane gas into the air inlet (creating a rich mixture), the oxygen sensor voltage should increase (up to about 0.8 to 0.9 volts). The sensor should try to signal the computer that too much fuel, or not enough air, is entering the combustion chambers.

If the oxygen sensor is lazy or its voltage does not change properly as you simulate rich and lean air-fuel ratios, the oxygen sensor is faulty. You might try running the engine at high speed, with a large vacuum hose removed, to clean off light carbon contamination.

A faulty oxygen sensor will usually be locked at one voltage level and will not cycle voltage up and down. It also may not produce enough voltage.

Testing the Oxygen Sensor Circuit

If the oxygen sensor has normal voltage, you should check the circuit leading to the sensor. Measure the resistance of the wires leading to the oxygen sensor. You can use long test leads. You can also ground one end of the sensor wire and check it for continuity at the other end.

Reading an Oxygen Sensor

Reading an oxygen sensor can indicate fuel system problems, silicone contamination, and other troubles. To read an oxygen sensor, inspect the color of the sensor's tip. See **Figure 42-19**.

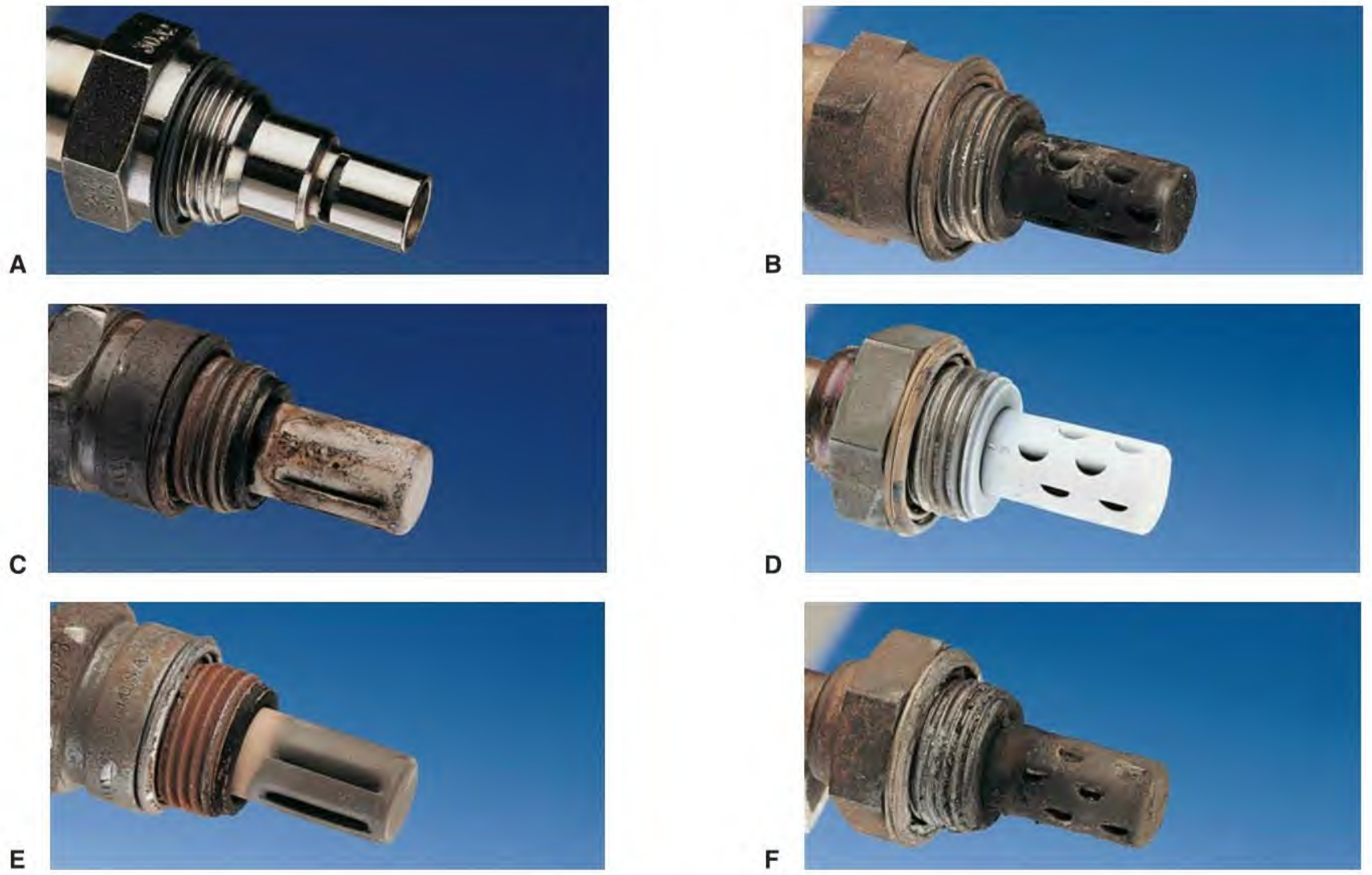
- A light gray tip is normal for an oxygen sensor.
- A white sensor tip might indicate a lean mixture or silicone contamination. The sensor must usually be replaced.
- A tan sensor tip could be lead contamination. It can sometimes be cleaned away, but a new sensor is usually needed.
- A black sensor tip normally indicates a rich mixture and carbon contamination, which can sometimes be cleaned after correcting the cause.

Note that some manufacturers recommend oxygen sensor replacement after only 12,000 miles (19,308 km) when the sensor is removed. Therefore, the oxygen sensor is normally replaced with a new one when unscrewed from the exhaust system.

Oxygen Sensor Signal Generator

An ***oxygen sensor signal generator*** is a tool for sending a false 200–800 mV signal to the control module for testing purposes. You can then alter air-fuel ratio (simulate a vacuum leak, for example) and

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Tomco Inc.

Figure 42-19. After removing an oxygen sensor, read the color and condition of its tip. This can give you information about the condition of the engine and its support systems. A—The new oxygen sensor must be identical to and have the same part number as the old one. This is a high-quality platinum oxygen sensor that is designed to provide long service life. B—A rich mixture caused by a fuel system problem has coated this sensor with black soot. C—Antifreeze contamination was caused by a leaking head gasket or a crack in the engine. D—Silicone contamination resulted from the use of too much silicone sealer during an engine rebuild. E—Lead contamination was caused by using leaded racing fuel or a lead octane additive. Check the fuel tank filler neck for modification. F—Oil contamination was caused by worn piston rings and valve seals.

perform other testing functions. Since the control module thinks it is closed loop, you can do tests without the control module tripping a trouble code or trying to compensate for your intentional modifications of engine operating conditions.

Oxygen Sensor Replacement

First, disconnect the negative battery cable. Then, separate the sensor from the wiring harness by unplugging the connector. Never pull on the wires themselves, as damage may result.

The oxygen sensor may have a permanently attached pigtail. Never attempt to remove it. Use a wrench to unscrew the sensor. Some sensors may be difficult to remove at temperatures below 120°F. Use care to avoid thread damage. Inspect the condition of the sensor.

Tech Tip

When attempting to remove an oxygen sensor with seized threads, you can unintentionally round off the hex nut with a slotted sensor socket. If this happens, cut off the sensor wires and use a six-point deep-well or spark plug socket. If the oxygen sensor's hex nut is not badly damaged, the socket should grasp and turn the "stubborn" sensor.

Coat the threads of the new sensor with anti-seize compound. Start the sensor by hand. Then tighten it with a wrench. Do not overtighten the sensor, or it may be damaged. Check fuel injection system operation after sensor installation.

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Remember the following rules when installing an oxygen sensor:

- Do not touch the sensor element with anything (water, solvents, etc.).
- Do not use silicone-based sealers on or around the exhaust system components. To prevent oxygen sensor contamination, use only "low-volatile" silicone sealers on engine components. Be sure to use these sealers sparingly. The PCV system can draw silicone fumes into the engine intake manifold and over the sensitive, easy-to-contaminate oxygen sensor.
- Before sensor replacement, repair any engine oil or coolant leaks that might contaminate the new oxygen sensor.
- Hand start the sensor to prevent cross threading.
- Do not overtighten the oxygen sensor. Overtightening can cause damage.
- Make sure the outside vents are clear so air can circulate through the sensor.
- Make sure wiring is reconnected securely to the sensor.
- Check oxygen sensor output and fuel system operation after installing the sensor.

Throttle Position Sensor Service

A ***throttle position sensor (TPS)*** signals the control module when the accelerator pedal is depressed to different positions for acceleration, deceleration, idle, cruise, and full power. The TPS sensor is a variable resistor that electrically measures the mechanical angle of the throttle valve opening as it is opened to increase airflow and engine rpms.

The throttle position sensor is usually a three-wire sensor, with one having a 5-volt dc reference voltage applied by the ECM. To change the amount of voltage and current returning to the ECM, the TPS shaft moves a sliding contact on the resistor.

For example, when the throttle is closed for engine idling, the TPS sensor might send a .45 volts dc signal (high TPS resistance limits current and voltage). If the throttle is swung fully open for maximum engine power (engine not running), a full 5-volt dc (zero resistance in TPS) return signal might be sent to the ECM.

A faulty TPS can trip several trouble codes on some systems and can cause a wide range of performance problems. Fuel metering, ignition timing, and other control module outputs can be affected. If shorted, the TPS might make the fuel mixture too rich. If open, a fuel mixture that is too lean can result.

Contact points or variable resistors can wear and fail. Since the sensor's internal sliding contacts and variable resistor are prone to wear, a trouble code for the TPS often means the sensor itself has failed and not the wiring leading to the sensor.

A bad TPS will usually have a dead, worn area on its variable resistors, resulting in false return signals for the engine throttle position or angle. The false signals can cause the engine to stumble or hesitate on acceleration. If the sensor has an internal open or short, the signal from the TPS may not change with throttle rotation, so the ECM disables the fuel and ignition systems.

Testing a Throttle Position Sensor

A throttle position sensor should produce a given amount of resistance for different throttle openings. For example, the sensor might have high resistance with the throttle plates closed and a lower resistance when the throttles are open. A scan tool, ohmmeter, or voltmeter can be used to test a throttle position sensor. The sensor can sometimes be tested at a special test terminal in the wiring harness.

Many manuals recommend checking the resistance of the throttle position sensor at different throttle openings. The manual might instruct you to measure resistance at idle, half throttle, and full throttle. If resistance is within specifications, check the wiring leading to the TPS.

Some manuals require you to measure voltage drops across the sensor at specified throttle positions. Compare your readings to specifications to determine the condition of a throttle position sensor.

Throttle Position Sensor Adjustment

Some throttle position sensors must be adjusted, while others cannot be adjusted. Many are mounted so they can be rotated on the throttle body. Either a special tester or an ohmmeter is commonly used to adjust a throttle position sensor.

You must measure sensor resistance or note tester output with the throttle at specific positions. You may have to insert a feeler gauge under the throttle lever or have the throttle plates at curb idle, for example. With the throttle plates at the correct angle, the TPS should trigger the tester or show a specified ohms value. If an adjustment is needed and possible, loosen the sensor mounting screws. Rotate the TPS until the correct ohms reading is obtained. Then, tighten the mounting screws and recheck the adjustment.

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Throttle Position Sensor Removal

To remove many throttle position sensors, you must file or grind off stakes (small welds) on the sensor screws. You might also have to drill into the screws from the bottom of the throttle body assembly. This will let you turn and remove the screws and TPS. Refer to the service manual for details.

Manifold Absolute Pressure Sensor Service

A ***manifold absolute pressure (MAP) sensor*** provides an electric signal proportional to the pressure or vacuum inside an engine intake manifold. Since engine manifold vacuum (suction) changes indicate the torque load on an engine, the MAP sensor can help keep the fuel mixture adjusted properly as the engine accelerates and decelerates. The engine ECM feeds a 5 volts dc reference signal to the MAP sensor. The MAP sensor can send a return signal between 0.4 and 4.5 volts, depending on engine load. This signal is used by the ECM to determine the proper air-fuel mixture.

The manifold absolute pressure sensor signal can also be used to help control the engine's exhaust gas recirculation system to reduce emissions. The MAP sensor might also have some effect on ignition timing and a few other control module outputs.

Testing a MAP Sensor

To test a MAP sensor, measure sensor circuit voltage or sensor resistance while applying vacuum to the unit. Use a vacuum pump on the vacuum fitting of the sensor. Apply specified vacuum levels while measuring the output of the MAP sensor.

Some manuals instruct you to measure sensor voltage at a specified test terminal. Others might have you disconnect the wires from the sensor and compare ohmmeter readings to specifications. In any case, sensor values must be within limits at the various vacuum levels. If testing at the test terminal, check the wiring harness before condemning the sensor. A poor connection or short could upset a reference voltage flowing to the sensor.

A scan tool can also be used to check MAP sensor operation. As you open the engine throttle, MAP sensor output voltage should change and return to normal idle reads on your scan tool.

A faulty MAP sensor usually will be locked or sluggish. It will not change internal resistance and its voltage signal quickly enough. A bad MAP sensor often outputs a weak voltage signal which affects the engine's air-fuel mixture. Compare your scan tool live values readings to factory specifications for idle and acceleration and watch the signal as the engine throttle valve quickly opens to increase engine manifold vacuum.

Engine Coolant Temperature Sensor Service

Most EFI systems use both an engine coolant temperature sensor and an intake air temperature sensor. If these sensors are bad, they will make the engine run either rich or lean.

The ***engine coolant temperature (ECT) sensor*** allows the ECM to richen the fuel mixture on a cold engine. The coolant temperature sensor is usually a ***thermistor*** (its internal resistance changes with temperature) that extends into an engine water jacket. The tip of the ECT sensor is submersed in engine coolant (mixture of antifreeze and water).

Most ECT sensors are fed a 5 volts dc reference voltage signal from the ECM. Any change in internal resistance will weaken or strengthen the electrical signal returning to the ECM. The ECT allows the ECM to richen the fuel mixture when the engine is cold and lean the mixture as the engine warms to full operating temperature.

A partially failed ETC sensor will prevent the ECM from adjusting the fuel injection system with engine operating temperature. A bad ECT sensor may give the ECM a false signal representing an inaccurate reading of the actual engine operating temperature. Air-fuel ratio and ignition timing are affected. If open, the sensor might affect cold engine driveability. If shorted, it might affect warm engine driveability.

For example, if the ECT sensor has failed and incorrectly sends a false signal representing a hot engine, the engine ECM will not be able to richen the fuel mixture during cold engine startup. The engine may be hard to start or may stall at idle when the engine is cold and has not reached full operating temperature.

Testing an ECT Sensor

If on-board diagnostics indicate a problem, a digital ohmmeter is often recommended for pinpoint testing an engine coolant temperature sensor. The service manual will give resistance values for various temperatures. If the ohmmeter test readings are not within specifications for each temperature value, the sensor is bad and must be replaced.

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Replacing an Engine Coolant Temperature Sensor

When replacing an engine coolant temperature sensor, use a deep socket or six-point wrench to unscrew the old unit. You might want to coat the sensor threads with an approved sealer. Then, start the sensor in the engine by hand and tighten it with a wrench. Do not overtighten the sensor or it could bottom out in the engine and be ruined.

Intake Air Temperature Sensor Service

The ***intake air temperature (IAT) sensor*** measures the temperature of the outside air entering the engine. An IAT sensor allows the ECM to make fine adjustments of air-fuel ratio and timing with changes in outside air temperature.

Like an ECT sensor, an IAT sensor is frequently a thermistor. The ECM sends a 5 volts dc reference signal to the IAT. Any change in resistance indicates a change in temperature.

If the sensor fails, it will normally trigger a trouble code, signaling you to test the sensor and its circuit. A faulty air temperature sensor can make the engine hard to start or cause the engine to run lean after it has warmed up.

A bad intake air temperature sensor usually will not have a pronounced effect on engine operation. A failed IAT sensor will slightly affect fuel metering into the engine so that fuel mileage will drop slightly. Other sensors in the system can compensate for a partially failed or slightly out-of-spec IAT sensor.

A scan tool or an ohmmeter is commonly used for checking an intake air temperature sensor. The sensor's resistance must be within specifications for certain temperatures.

Tech Tip

If the engine is cold and at room temperature, the IAT and ECT live scan tool reading should be the same. Since the cold engine and surrounding air are at the same temperature, both sensors should give a scan tool readout of about 70°F (21°C) or actual shop temperature. If the two sensors read differently, the sensor circuit with the incorrect temperature value has something wrong with it.

Mass Airflow Sensor Service

A digital ***mass airflow (MAF) sensor*** produces an ac signal that changes in frequency as airflow into the engine changes. It is usually mounted on or near the engine intake manifold.

A bad mass airflow sensor can make the engine run a little lean or rich. It may also cause the system to go into limp-in mode, as will several other sensors. If the MAF sensor is shorted or open, the ECM will begin to operate on preprogrammed values. The vehicle will perform poorly and get lower fuel economy. A faulty MAF sensor or circuit can make the engine run too rich or too lean and can trip a second code for the O_2 sensors that detect the abnormal fuel mixture.

Testing a Mass Airflow Sensor

Since there are various types of airflow sensors, you must refer to the shop manual for exact testing procedures. Some variable resistance–type sensors can be tested with an ohmmeter. Other airflow sensors contain integrated circuits, and special testing methods are required to prevent sensor damage. On late-model vehicles, a scan tool will indicate a problem with an airflow sensor. If your scan tool shows a trouble code for the MAF sensor, first view the frequency readout in live data. Compare scan tool readings to factory specifications with the engine at curb idle. You can verify that the digital MAF is faulty by testing its output with a handheld scope.

A normal MAF frequency at idle is 2–3 kilohertz. If your actual test readings are not within specifications, check for engine vacuum leaks first, since they will make the MAF sensor readings lower than normal.

An engine vacuum leak would also affect the engine throttle motor readings, since it would be trying to lower engine idle speed. If a new MAF sensor does not correct the problem and code, check for a good ground circuit to the sensor and for spec reference voltage from the ECM.

Replacing a Mass Airflow Sensor

A faulty airflow sensor must be replaced. During replacement, make sure you have the correct unit. Also, tighten all fittings carefully. An air leak after the airflow sensor will upset its operation and can trigger trouble codes.

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Servicing other EFI Sensors

The other sensors in an electronic fuel injection system are tested using the same general procedures just discussed. You would use the self-diagnosis mode, a special analyzer, or a digital meter to check each sensor. Refer to a service manual for exact procedures.

Control Module Service

When diagnostic trouble codes and/or pinpoint tests indicate a faulty control module, the module must generally be replaced. Procedures for replacing a control module vary from manufacturer to manufacturer. Always refer to an appropriate service manual for specific instructions.

The engine ECM is normally mounted under the dash, keeping the electronic circuits away from engine heat and vibration. In a few vehicles, however, the control module is in the engine compartment.

ECM Scan Tool Data

A scan tool will produce an ECM trouble code from any ECM in a multi-ECM equipped vehicle. Today's ECMs communicate through one- or two-wire digital conductors. Even a basic scan tool will indicate if any of the vehicle's ECMs are malfunctioning. The ECMs all monitor each other, so any abnormal or out-of-spec signal is recorded in memory as a trouble code for that ECM.

Idle Speed Motor Testing

A bad idle speed motor may not be able to maintain the correct engine idle speed. Engine idle speed may be too low or too high for conditions. The servo motor could have shorted windings, open windings, worn internal parts, or other problems.

To check an idle speed motor, jump battery voltage to specific terminals on the servo motor. This should make the idle speed motor plunger retract and extend as the connections are reversed. Pulling off a large vacuum hose should also make the idle motor plunger retract, lowering idle speed. A faulty motor will usually not function.

If the idle speed motor works when jumped to battery voltage, check wiring leading to the motor. The wiring harness could have an open or short. A control module or relay problem could also prevent motor operation.

An ***idle air control motor tester*** energizes the solenoid or servo motor to check its effect on engine idle speed. Refer to **Figure 42-20**. Disconnect the wiring going to the idle air motor. Connect the tester harness to the motor. As you press the Up arrow on the tester, engine idle speed should increase. As you press the Down arrow, engine idle speed should decrease. If engine idle speed does not change, you may have a bad idle air control motor, carbon-clogged air passage in the throttle body, or a vacuum leak.

Idle Air Control Valve Service

A bad idle air control valve will upset engine idle speed like a bad idle speed motor. It uses solenoid action to open and close an air passage that bypasses the throttle plates. In this way, it can increase or decrease engine idle rpms. If it fails, engine rpms will be constant and may not increase with a cold engine or decrease as the engine warms to operating temperature.

To check the idle air control valve, jump battery voltage to the windings. This should trigger the solenoid and change engine speed. If the engine speed does not change, check for carbon buildup and blockage in the passage at the idle air control valve before replacing the unit. An ohmmeter may also be recommended to check the windings.



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Figure 42-20. An idle air control motor tester will quickly determine if the motor is capable of altering engine idle speed.

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Multiport Throttle Body Service

The service of a multiport throttle body usually involves replacing dried, deteriorated gaskets and seals. Remove the throttle body from the engine. Disassemble the unit while keeping all parts organized. Inspect moving parts for wear. The throttle shaft and its bushings can wear with prolonged service, requiring replacement. Install new gaskets and seals and reassemble the unit in reverse order of disassembly.



Diagnostic Case Study

Concern: Mr. Buckley walks into the shop, upset because no one has been able to fix his 2010 Jeep Liberty. He explains to Duff that he has taken the car to three shops and none of them has corrected the problem. As he was driving the car home from another repair shop, it stalled right in front of Duff's garage.

Cause: Duff questions Mr. Buckley about the exact nature of the problem. Mr. Buckley explains that the car runs fine for about a half hour and then the engine just stops. He adds that other shops have checked the fuel pressure, the injectors, and the ignition system. A new fuel filter, ignition module, and air filter have been installed. The strange thing, according to Mr. Buckley, is that the engine will start again after about 15 minutes and will run fine for another half hour.

Duff starts the vehicle and allows it to run until it stalls. He then cranks the engine to verify the no-start condition. After allowing the vehicle to sit for a while, Duff is able to restart the engine. Duff turns the job over to one of the shop's experienced service technicians, who knows to check for "spark and fuel" when there is a no-start problem.

The technician starts the engine and allows it to run until it stalls. She then pulls a plug wire and checks for spark. A strong electric arc is seen jumping to ground.

The technician then suspects that the fuel system may be at fault. When she uses a screwdriver to depress the service valve on the fuel rail, no fuel squirts out. This indicates that there is no fuel pressure. She hooks up a fuel pressure gauge and starts the vehicle. The gauge indicates normal system pressure.

At this point, the technician suspects that something is restricting fuel flow to the engine at the time of the malfunction. She removes the fuel tank sending unit and inspects the inlet filter. The sock-type filter is coated with fuel residue. A crease in the filter indicates that the filter has been collapsing, stopping fuel flow. She determines that suction from the fuel pump is causing the restricted filter to collapse.

Correction: The technician installs a new in-tank fuel filter. She then starts the vehicle and allows it to run long enough to make sure the problem has been solved. Finally, she releases the vehicle to its owner.

Summary

- To diagnose fuel injection problems, you must use your knowledge of EFI systems, basic troubleshooting skills, factory service information, and scan tool tests.
- Modern EFI systems have extensive on-board diagnostic abilities.
- A trouble code indicates a circuit problem. Since circuit wiring and the ECM seldom fail, the sensor or actuator in that circuit is usually to blame.
- If your scan tool indicates a problem with a specific injector, use a stethoscope to listen for a distinct clicking sound as the pintle snaps up and down on its seat.
- Always use extreme caution and wear appropriate safety gear when working on a high-pressure fuel system.
- Fuel trim values indicate whether the ECM has had to lean or richen the air-fuel mixture to maintain a perfect stoichiometric mixture.
- A lean trouble code will be set if an O_2 sensor detects high amounts of oxygen in the engine exhaust. A rich trouble code means too much fuel is being injected into the cylinder for engine speed and load.
- Using a stethoscope, scan tool live readings, scope waveforms, and multimeter will help ensure that you replace only the fuel system part at fault.
- A bad injector can cause a wide range of problems including rough idle, hard starting, poor fuel economy, and engine miss.
- An inoperative EFI injector normally has shorted or open coil windings.

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- A fuel injector that opens and closes properly should produce a specific shape waveform on a scope. If voltage levels over time are not within specs, the engine ECM will trip a code identifying the bad injector by cylinder number.
- A faulty fuel pressure regulator can cause an extremely rich or lean air-fuel mixture.
- In modern fuel systems, a scan tool or laptop computer can release fuel pressure by energizing the pressure relief valve mounted on the high-pressure, mechanical fuel pump.
- A noid light is a test light used for checking electronic fuel injector feed circuits for battery power. A noid light should be used if an injector is not clicking and opening.
- An injector balance test on modern direct and port fuel injection systems involves the use of a scan tool, PC, or specialized fuel injector tester to measure the amount of fuel flowing through each injector.
- A dedicated digital fuel injection system tester uses data from injector voltage waveforms, fuel pressure sensor signals, and other fuel control sensor signals to analyze problems and calculate fuel flow through each injector.
- A fuel injector cleaning tool uses shop air pressure to force a cleaning solution through injectors to remove deposits.
- A failed O_2 sensor will upset an engine's air-fuel ratio, usually making it run too lean, miss, and lack power. If an oxygen sensor produces an incorrect voltage, the control module cannot precisely control how much fuel is metered into the engine.
- To read an oxygen sensor, inspect the color of the sensor's tip.
- A faulty TPS can affect fuel metering, ignition timing, and other control module outputs. A shorted TPS might make the fuel mixture too rich. An open TPS might result in a fuel mixture that is too lean.
- A MAP sensor provides an electric signal proportional to the pressure or vacuum inside an engine intake manifold. Since engine manifold vacuum changes indicate the torque load on an engine, the MAP sensor helps keep the fuel mixture adjusted properly as the engine accelerates and decelerates. A bad MAP sensor often outputs a weak voltage signal which affects the engine's air-fuel mixture.
- Most EFI systems use both an ECT sensor and an IAT sensor, which are usually thermistors. If these sensors are bad, they will make the engine run either rich or lean.
- A bad mass airflow sensor can make the engine run a little lean or rich, and may cause the system to go into limp-in mode. A faulty airflow sensor must be replaced.
- When diagnostic trouble codes and/or pinpoint tests indicate a faulty control module, the module must generally be replaced.
- An idle air control motor tester energizes the solenoid or servo motor to check its effect on engine idle speed.
- Multiport throttle body service usually involves replacing dried, deteriorated gaskets and seals.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

DEFI injector operating voltage

EFI injector operating voltage

EFI tester

engine coolant temperature (ECT) sensor

fuel injector boot

fuel injector cleaning tool

fuel injector impedance test

fuel injector pulsed flow test

fuel injector scope test

fuel pressure regulator

fuel pressure relief valve

fuel system monitoring

fuel trim malfunction trouble code

heater monitor

high impedance fuel injectors

idle air control motor tester

idle live readings

injector balance test

injector maximum flow test

injector pulse widths

intake air temperature (IAT) sensor

lean trouble code

long-term fuel trim

low impedance fuel injectors

manifold absolute pressure (MAP) sensor

mass airflow (MAF) sensor

noid light

oxygen sensor contamination

oxygen sensor monitoring

oxygen sensor output voltage

oxygen sensor signal generator

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peak-and-hold fuel injector
piezo fuel injectors
pintle bump
pintle response
rich trouble code
Schrader valve
short-term fuel trim
thermistor
throttle position sensor (TPS)

Activities

1. Study the fuel injection section of any shop manual given to you by your instructor. Develop a "diagnosis tree" for an injector that is not working.
2. Create a PowerPoint presentation showing various injector spray patterns. Using the presentations, explain the patterns to the class.
3. Demonstrate the proper procedure for replacement of a multiport injector and a direct injector.

Review Questions



Answer the following questions using the information provided in this chapter.

1. What four things must be used when diagnosing problems in a gasoline injection system?
2. What are idle live readings?
3. If an injector is operating, what sound should you hear when you touch the probe of a stethoscope on the top of the fuel injector body?
4. In fuel system monitoring, feedback from the _____ is used to determine fuel mixture content.
5. The ECM tries to adjust the fuel mixture as needed by altering the _____ or _____ to compensate for abnormal combustion by-products.
6. What do fuel trim values indicate?
7. What does an injector balance test measure?
8. What is measured by a fuel injector scope test?
9. Most low-pressure EFI systems have a fuel pressure relief valve located on the _____.
10. How do you perform a fuel injector balance test with an EFI tester and a pressure gauge?
11. What is pintle response and how is it checked?
12. An ohmmeter can be used to check an EFI injector coil for shorts or opens. True or False?
13. Which of the following does *not* pertain to a fuel pressure regulator?
    (A) It can cause a rich fuel mixture.
    (B) It can cause a lean fuel mixture.
    (C) It can be tested with a dwell meter.
    (D) It can be tested with a pressure gauge.
14. Fuel rail pressure in a direct gasoline injection system is controlled by a _____ on the mechanical fuel pump.
15. What type of meter should be used to test an oxygen sensor? Why?
16. A faulty oxygen sensor usually cycles voltage up and down. True or False?
17. A black oxygen sensor tip normally indicates a(n) _____ mixture and _____ contamination.
18. A throttle position sensor should produce a given amount of _____ for different throttle openings.
19. How do you adjust a throttle position sensor?
20. To test a MAP sensor, use your scan tool or measure sensor circuit voltage or sensor resistance while applying vacuum to the unit. True or False?
21. A bad engine coolant temperature sensor affects air-fuel ratio and ignition timing. True or False?
22. A(n) _____ is often recommended for testing an EFI temperature sensor.
23. Which of the following is not true of an IAT sensor?
    (A) An IAT sensor measures the temperature of the outside air entering the engine.
    (B) A bad IAT sensor greatly affects engine operation.
    (C) An IAT sensor is frequently a thermistor.
    (D) A faulty IAT sensor can cause the engine to run lean after it has warmed up.
24. If MAF frequency test readings are not within specifications, what should you check first?
25. Where is the EFI system control module normally mounted?

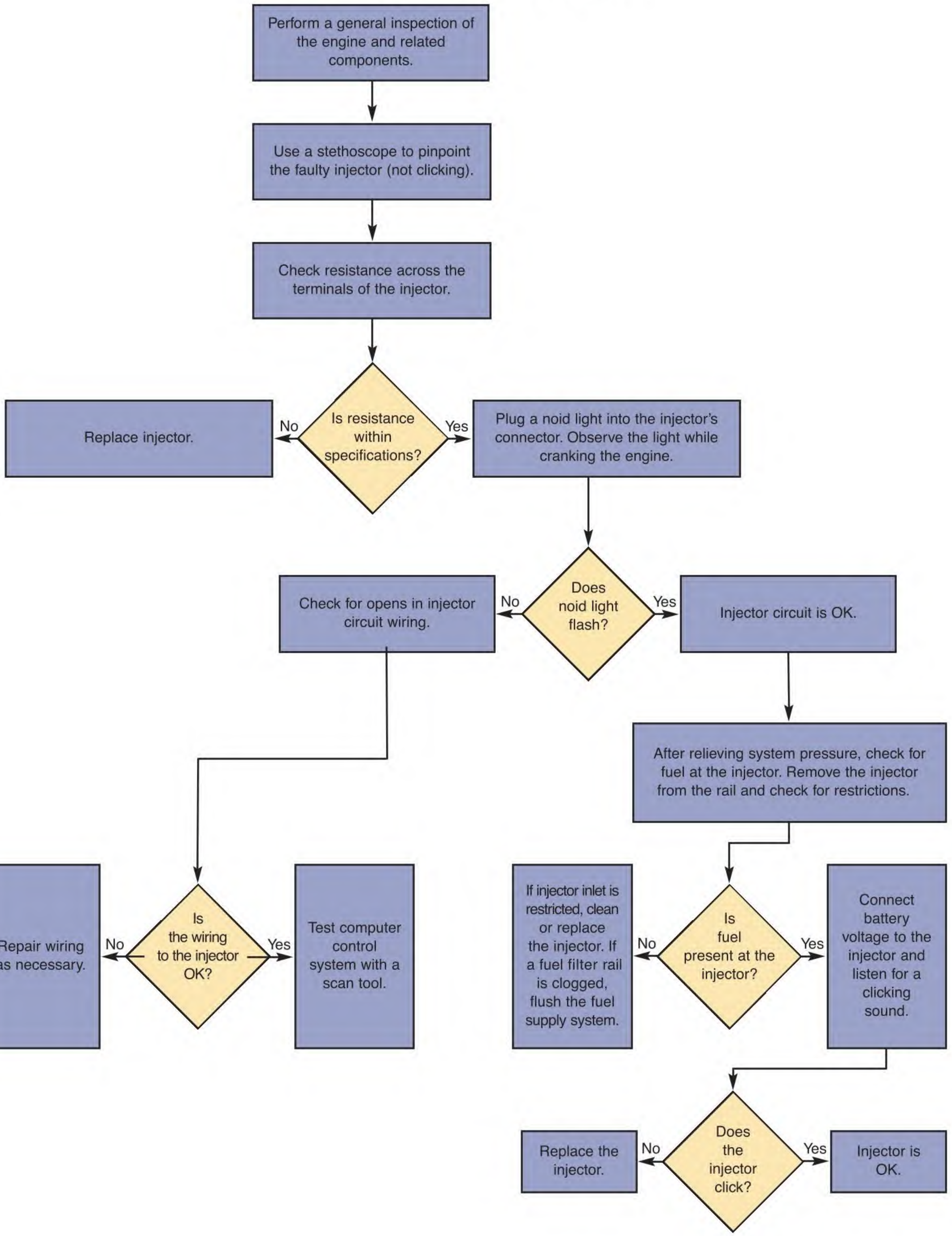
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ASE-Type Questions

1. DEFI electronic fuel injection pressure can reach this level at high engine speeds:
   (A) 50 psi.
   (B) 100 psi.
   (C) 500 psi.
   (D) 2000 psi.
2. Which injector problem can create a lean air-fuel mixture?
   (A) Dirty injector.
   (B) Leaking injector.
   (C) Stuck open injector.
   (D) All of the above.
3. Technician A says a peak-and-hold injector waveform will have two induced voltage spikes. Technician B says a peak-and-hold fuel injector circuit uses a low amount of current to open the injector and a high amount of current to hold the injector open. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. An injector balance test is being performed on an OBDII vehicle. Technician A says that during this test, each injector is shut off individually and the difference in the corresponding cylinder's power contribution is recorded. Technician B says an engine mechanical problem can cause a cylinder to fail a balance test. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. Technician A says a fuel injector pulsed flow test measures steady or maximum fuel flow with the injector pintle and nozzle held fully open. Technician B says an injector maximum flow test fires an injector several times with a normal pulse width to check pintle response. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Technician A says a fuel injector impedance test is typically performed on piezo injectors. Technician B says a fuel injector impedance test can help pinpoint intermittent problems. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. If a DEFI multiport injector is removed for service, manufacturers suggest replacing the:
   (A) Teflon® seals.
   (B) gaskets.
   (C) hold-down bolts.
   (D) All of the above.
8. A faulty fuel pressure regulator can cause:
   (A) an extremely rich fuel mixture.
   (B) an extremely lean fuel mixture.
   (C) Either A or B.
   (D) Neither A nor B.
9. After testing a fuel pressure regulator and finding pressure low, Technician A suggests checking the fuel pump before actually replacing the regulator. Technician B proposes checking the fuel filters before replacing the regulator. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. Typical oxygen sensor output should be about:
    (A) 0.5 volts.
    (B) 0.6 volts.
    (C) 0.8 volts.
    (D) 0.10 volts.

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Gasoline Injection System Diagnosis



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Chapter 43
Diesel Injection Fundamentals

After studying this chapter, you will be able to:

- Summarize the differences between gasoline and diesel engines.
- Explain the operating principles of a diesel injection system.
- Identify the major parts of a diesel injection system.
- Compare variations in the design of diesel injection systems.
- Correctly answer ASE certification test questions that require a knowledge of the fundamentals of diesel oil injection.

Diesel fuel injection is a high-pressure, mechanical/hydraulic system that delivers fuel directly into the engine's combustion chambers. It is similar to direct gasoline injection, but uses a multi-plunger fuel pump with separate injection lines to each hydraulic injector. As you will learn, passenger car diesel engines now use solenoid/hydraulic or piezo (quartz crystal) powered fuel injectors.

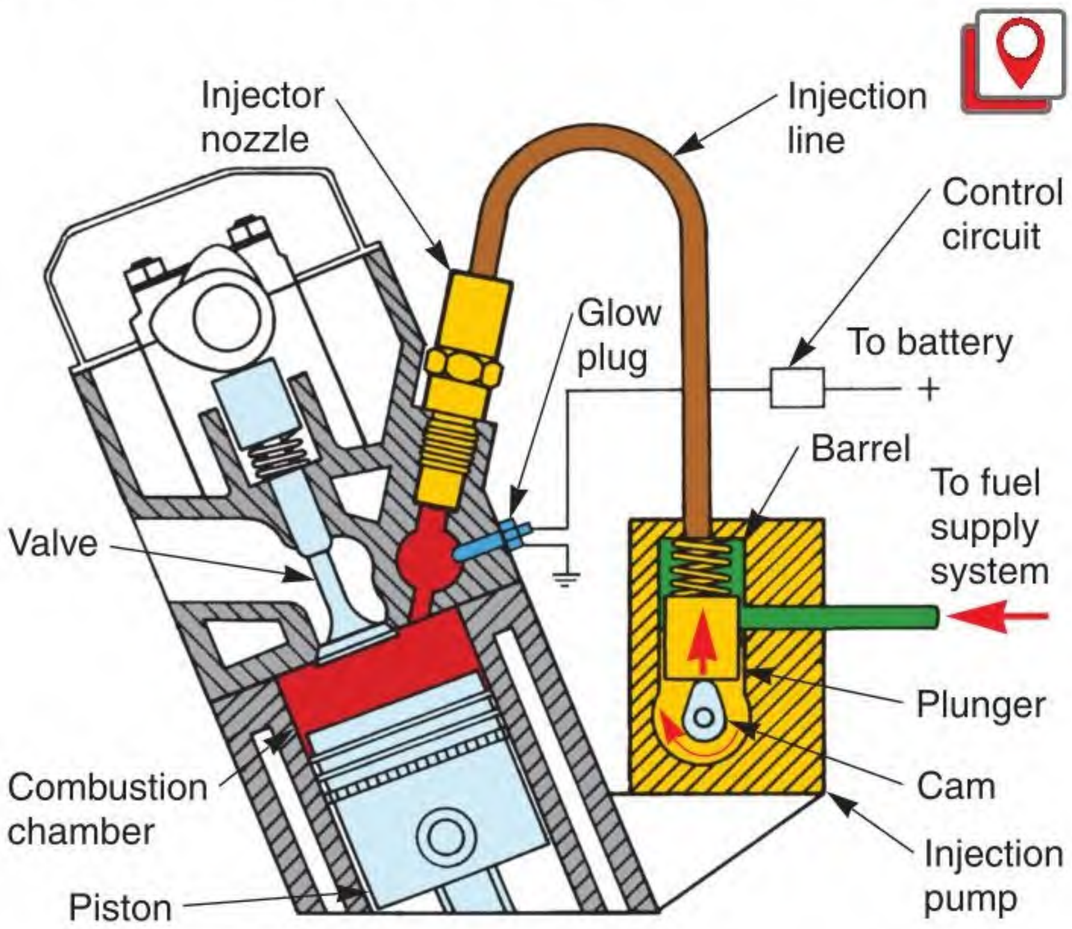
Diesel mechanical injection (DMI) is relatively simple. It uses a mechanical, high-pressure, multi-plunger/cam lobe fuel pump with electronic controls. See **Figure 43-1**.

Diesel and Gasoline Engine Differences

Before covering the parts of a diesel injection system in detail, you should review the major differences between a gasoline engine and a diesel engine. This will help you understand diesel injection.

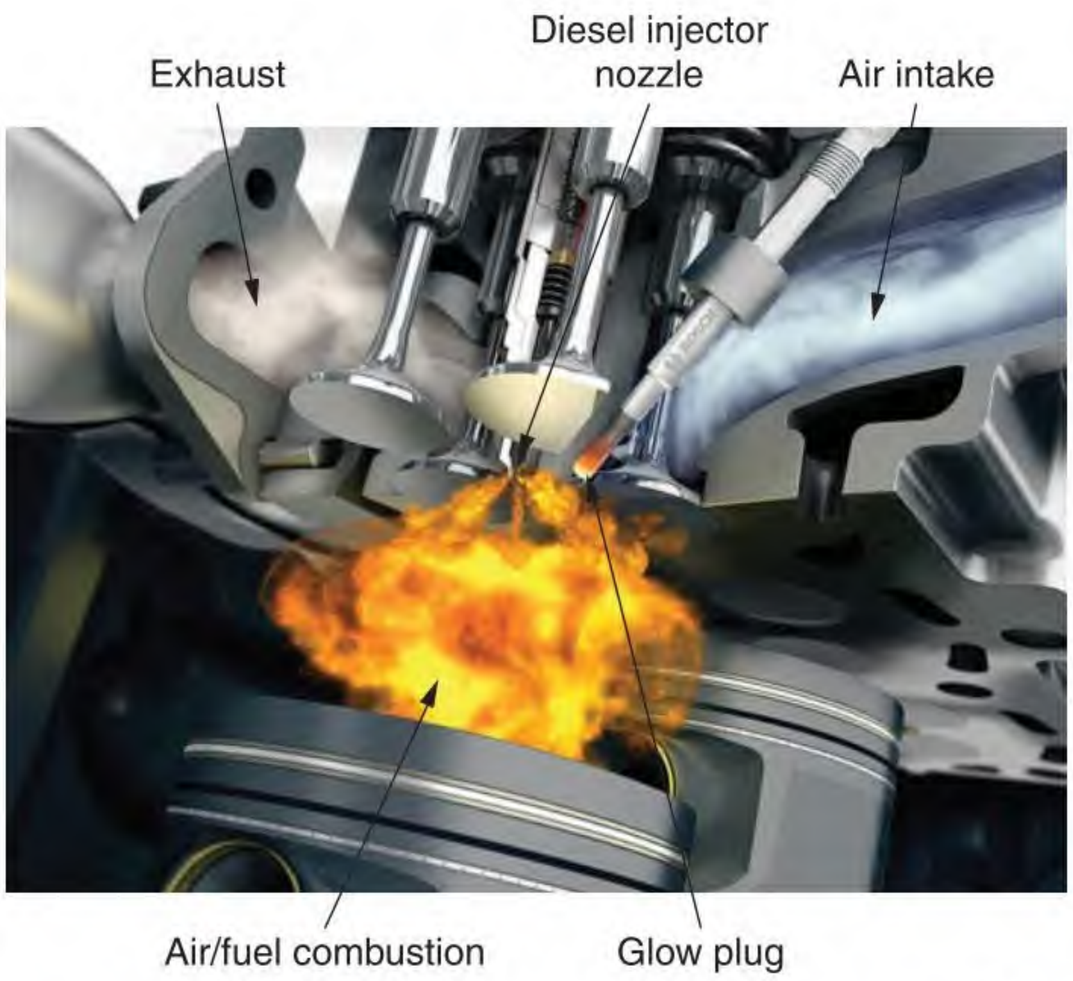
- A diesel engine uses a very high compression ratio—approximately 17:1 to 25:1. A gasoline engine's compression ratio is only 8:1 to 14:1.
- A diesel engine is a compression ignition engine because it uses the heat from compressed air to ignite the fuel. Gasoline engines are classified as spark ignition engines because they use an electric arc (from the spark plug) to ignite the fuel.
- A diesel engine has no throttle valve to control airflow into the engine. Gasoline engines use a throttle valve to control airflow and engine power.
- A diesel engine compresses air on its compression stroke. Look at **Figure 43-2**. A gasoline engine compresses only air with direct EFI or an air-fuel mixture with port EFI.

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Figure 43-1. Review the basic parts of a simplified diesel injection system. The injection pump plunger produces very high pressure to open the injector valve. A glow plug warms the air in the precombustion chamber when the engine is cold.



Bosch

Figure 43-2. Super-high injection pressures are required to force diesel fuel into high-compression combustion chambers. A glow plug or electric heating element is needed to help start combustion when a diesel engine is cold. Note the air and exhaust flow.

- A diesel engine injects fuel directly into the combustion chambers. A gasoline engine meters fuel into the intake manifold ports or into the combustion chambers.
- In a diesel engine, speed and power are controlled by the amount of fuel injected into the engine—more fuel produces more power. A gasoline engine controls engine power by regulating airflow into the engine with a throttle valve.

Basic Mechanical Injection

The fundamental parts of a diesel injection system include:

- ***Injection pump***—An injection pump is a high-pressure, mechanical pump that meters the correct amount of fuel and delivers it to each injector nozzle at the proper time.
- ***Injection lines***—Injection lines are high-strength stainless steel tubing that carry fuel to each injector nozzle. Refer to **Figure 43-3**.
- ***Injector nozzles***—Injector nozzles are spring-loaded valves that spray fuel into each combustion chamber.
- ***Glow plugs***—Glow plugs are electric heating elements that warm air in the precombustion chambers to aid in starting a cold engine.



Ford

Figure 43-3. Diesel injectors and injection lines must carry super-high pressure diesel fuel from the injection pump to the combustion chambers without leaking. Fuel lines are now made of stainless steel to resist the elements.

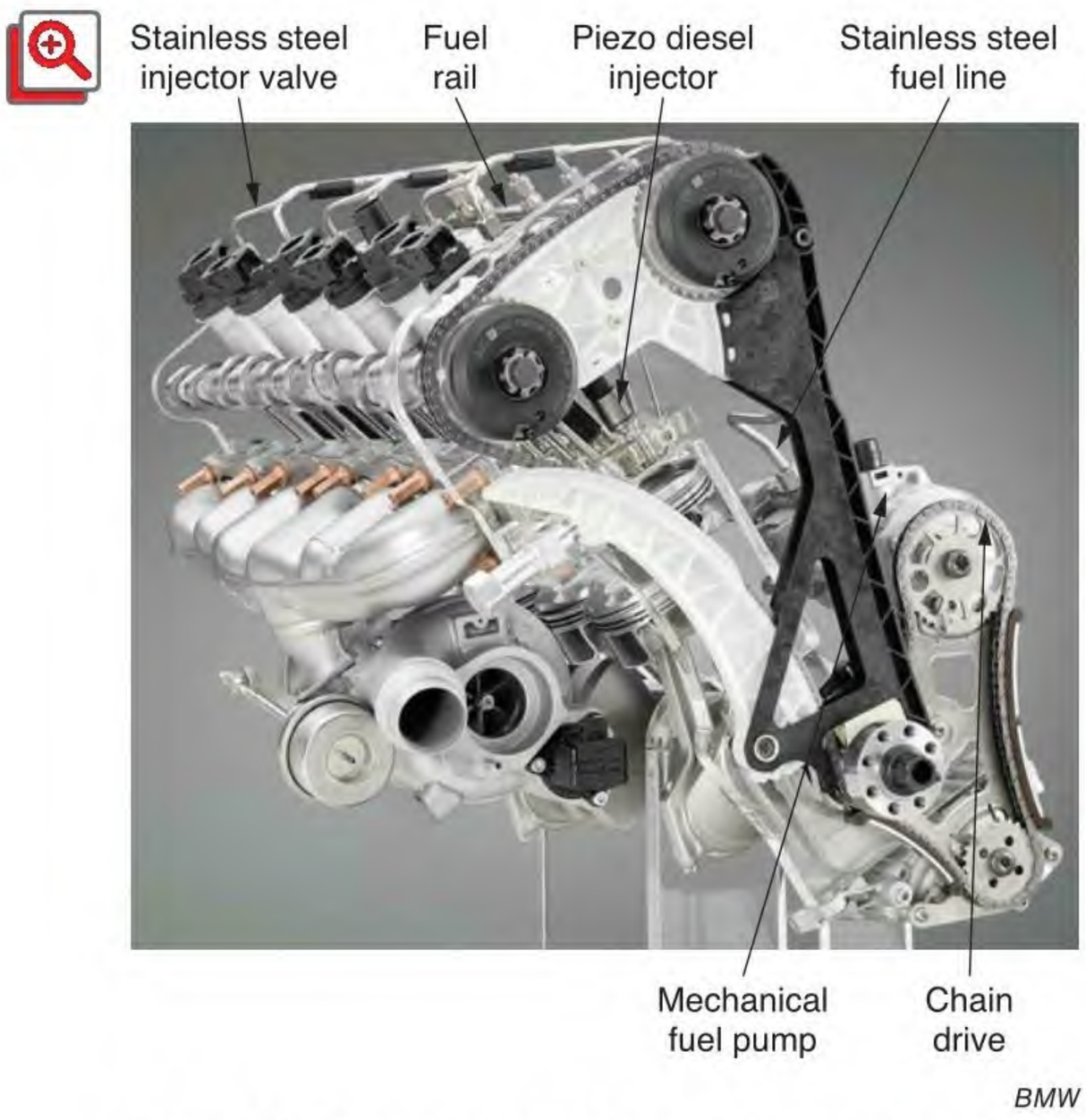
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Diesel Injection Pumps

Diesel injection pumps have several important functions:

- Meter the correct amount of fuel to each injector.
- Circulate fuel through fuel lines and nozzles.
- Produce extremely high fuel pressure.
- Time fuel injection to meet the speed and load of the engine.
- Provide a means for the driver to control engine power output.
- Control engine idle speed and maximum engine speed.
- Help close injector nozzles after injection.
- Provide a means of shutting off the engine.
- Control from ECM will change injection quantity and injection timing with changes in engine speed and load.

The diesel injection pump is normally bolted to the top or the side of the engine. Study **Figure 43-4**. The fuel supply system (fuel tank, lines, filters, conventional fuel pump) pushes clean, filtered fuel under low pressure to the injection pump. The injection pump then pressurizes the fuel. A camshaft acts as a plunger. The plunger slides up in its barrel (cylinder), compressing and pressurizing the fuel. The fuel then flows through the injection line and out the injector nozzle. A diesel injection pump is powered by the engine. Power may be transferred by a set of gears, a chain, or a tooth belt.



BMW

Figure 43-4. Note location of high pressure mechanical fuel pump on this diesel engine.

Inline Diesel Injection Pumps

An ***inline diesel injection pump*** has one plunger (piston) for each engine cylinder and can be used with all hydraulic or electro-hydraulic injectors. The plungers are lined up in a row, like the pistons in an inline engine. Refer to **Figure 43-5**.

The inline ***injection pump camshaft*** operates the plungers. It has lobes like an engine camshaft. When the engine turns the pump camshaft, the lobes push on the roller tappets to move them up and down. The ***injection pump roller tappets*** transfer camshaft action to the plungers. Like roller lifters in an engine, the roller tappets reduce friction and wear on the cam lobes.

Inline pump plungers are small pistons that push on and pressurize the diesel fuel. When the cam lobe acts on the roller tappet, both the tappet and the plunger are pushed upward. The ***barrels*** are small cylinders that hold the plungers. When the plunger slides upward in its barrel, extremely high fuel pressure is formed. The ***plunger return springs*** keep a downward pressure on the plungers and roller tappets. This holds the tappets against the camshaft when the lobes rotate away from the rollers.

Control sleeves alter the amount of fuel pushed to each injector nozzle. A ***control rod***, or ***rack***, is a toothed shaft that acts as a throttle to control diesel engine speed and power. It rotates the control sleeves to increase or decrease the injection pump output and engine power.

Delivery valves are spring-loaded valves in the outlet fittings to the injection lines. They help ensure quick, leak-free closing of the injector nozzles.

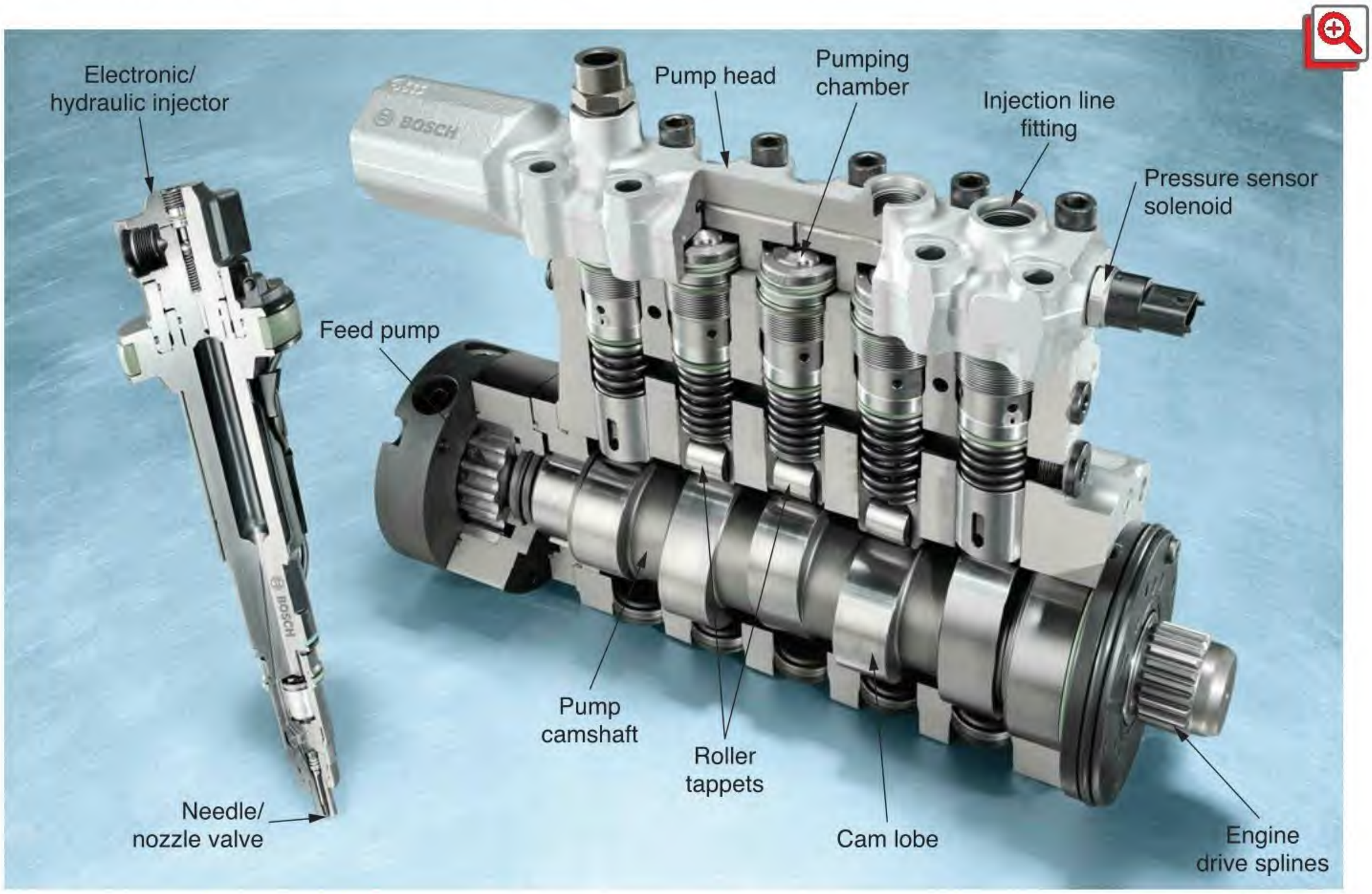
Single Outlet Diesel Injection Pumps

A single outlet mechanical injection pump forces fuel into a fuel rail, not into each injector. The engine ECM controls the high-pressure diesel pump and the solenoid or piezo injectors.

Other Diesel Injection Pump Features

There are numerous design variations of injection pumps. For details of each pump design, refer to the

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Mercedes Benz

Figure 43-5. Study the basic parts of an electro/mechanical diesel injection system. Fuel is fed through the fuel rail to the electronic/hydraulic fuel injectors. Current flow through piezoelectric elements causes the injector nozzles to open and spray fuel into the combustion chambers.

pump manufacturer's service manual. The service manual will explain the construction and operation of the particular pump.

A few additional features included in many automotive diesel injection pumps include:

- ***Electric fuel shutoff***—An electric fuel shutoff solenoid stops fuel injection when the ignition key is turned off.
- ***Viscosity compensating valve***—A viscosity compensating valve allows for different fuel weights or thicknesses and temperatures.
- ***Injection pump vent***—An injection pump vent is a small passage that allows fuel to return to the fuel tank. This helps bleed air out of the system.

Diesel Injection Lines

The ***diesel fuel supply system*** feeds fuel to the injection pump, normally using an inline electric pump. The engine-driven injection pump controls how much fuel is forced to the injector nozzles, and the high-pressure injection lines carry fuel to the injectors. The spring-loaded nozzles are normally closed. However, when the injection pump produces enough pressure, each nozzle opens and squirts a fuel charge into the engine cylinders to start combustion. A return line carries excess fuel back to the tank.

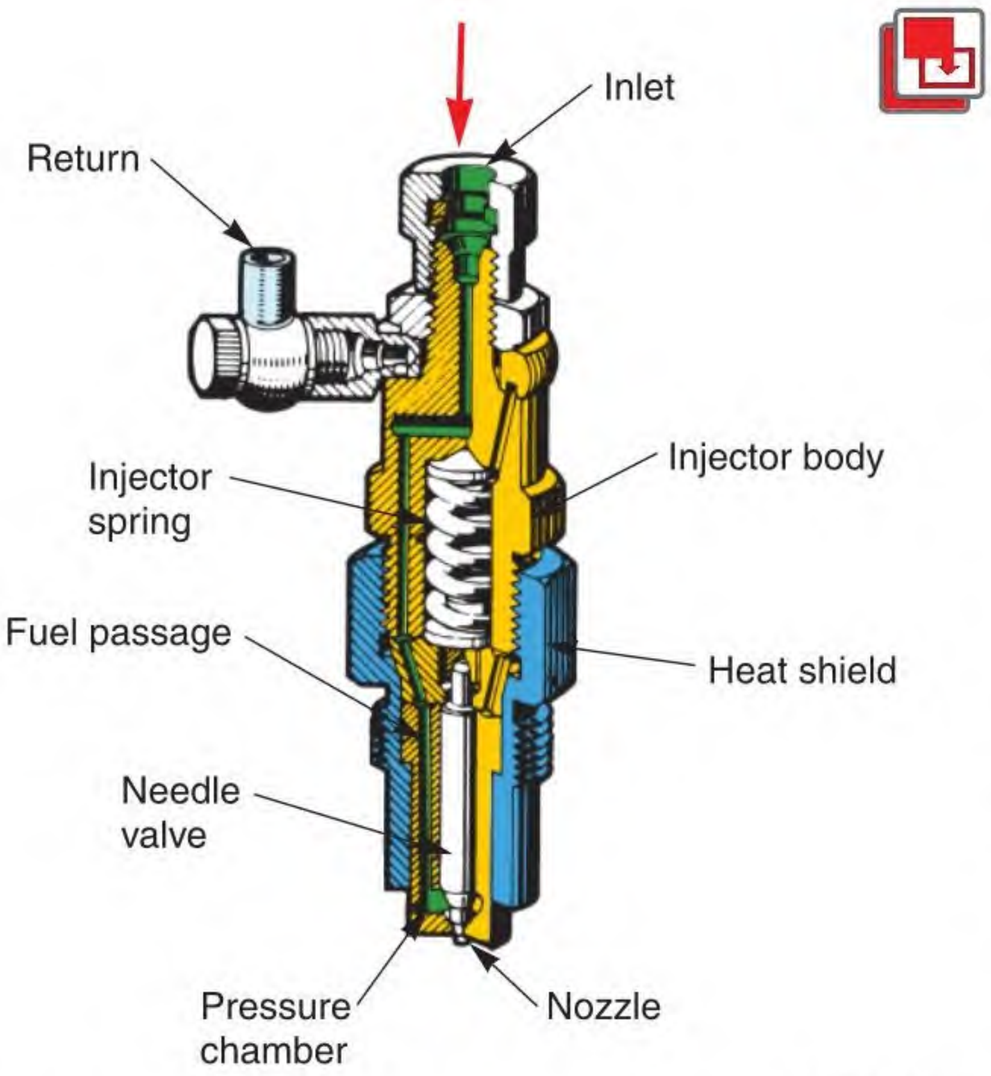
Diesel Injector Nozzles

Diesel injector nozzles are spring-loaded valves that spray fuel directly into the engine precombustion chambers. The injector nozzles are threaded into the cylinder head, with one injector provided for each cylinder. The inner tip of the injector nozzle is exposed to the heat of combustion, like a spark plug in a gasoline engine.

Hydraulic Diesel Injectors

A hydraulic injector used in large truck diesel engines is shown in **Figure 43-6**. The major parts of this type of injector include:

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Robert Bosch

Figure 43-6. Note basic diesel injector construction. Note the part names, shapes, and locations.

- ***Diesel injector heat shield***—The diesel injector heat shield helps protect the injector from engine heat. It also helps create a good seal between the injector and the cylinder head.
- ***Injector body***—The injector body is the main section of the injector, which holds the other parts. The injector body threads into the heat shield, and the heat shield threads into the cylinder head. Fuel passages are provided in the injector body. A needle seat is formed by the lower opening in the injector body.
- ***Diesel injector needle valve***—The diesel injector needle valve is a precisely machined rod with a specially shaped tip that opens and closes the nozzle (fuel opening). When the needle valve is closed, its tip seals against the needle seat in the injector body.
- ***Injector spring***—The injector spring holds the injector needle valve in the normally closed position. It fits around the needle valve and against the walls of the injector body. Spring tension helps control injector opening pressure.
- ***Injector pressure chamber***—An injector pressure chamber is formed around the tip of the injector needle valve and inner cavity in the injector body. Injection pump pressure forces fuel into this chamber to push the needle valve open.

Diesel Injector Nozzle Operation

When the injection pump produces high pressure, fuel flows through the injection line and into the inlet of the injector nozzle. Fuel then flows down through the fuel passage in the injector body and into the pressure chamber.

The high fuel pressure in the pressure chamber forces the needle valve upward, compressing the injector spring. This allows diesel fuel to spray out, forming a cone-shaped spray pattern. Some fuel leaks past the injector needle valve and returns to the fuel tank through the return lines.

Solenoid Diesel Injectors

Solenoid diesel injection uses electric-hydraulic injectors and a high-pressure pump. Refer to **Figure 43-7**. Similar to direct gasoline injection, the solenoid action is aided by hydraulic pressure to snap the injector nozzle open against spring pressure.

Tech Tip

Gasoline injectors, both solenoid and piezo, were detailed in earlier chapters. Diesel injectors must spray heavy diesel fuel, which is much thicker than gasoline. The body of the injector must be machined from thicker metal with larger internal passages to carry even more fuel pressure than direct gasoline injection.

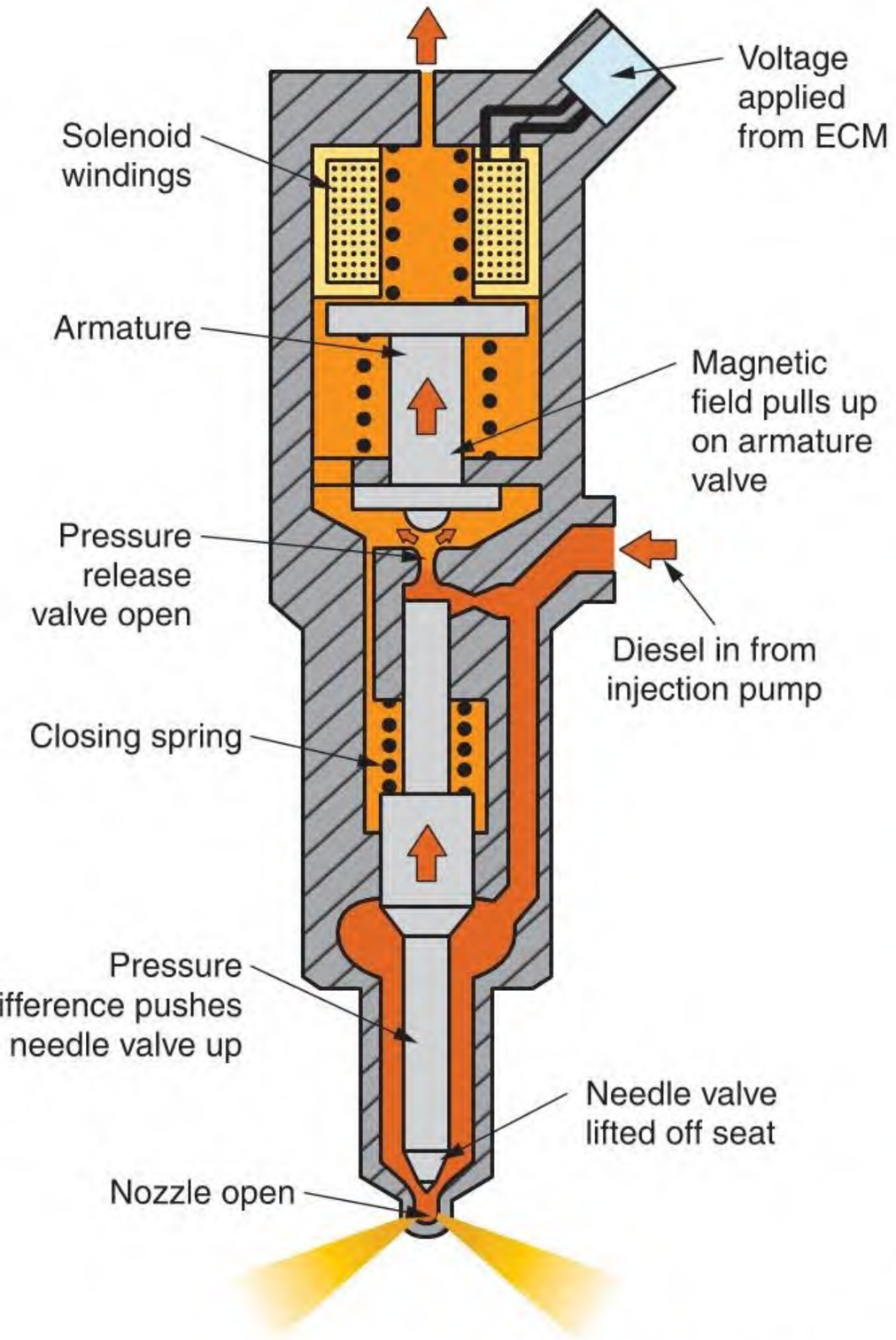
Piezo Diesel Injectors

Piezoelectric crystals produce a small output signal when exposed to physical strain or pressure. If you bend or squeeze a piezoelectric crystal, it generates a few milliamps of current. Piezoelectric crystals can also change their physical dimensions when exposed to voltage and current.

Piezo diesel injection uses a high-pressure mechanical pump and an electrically operated piezo crystal to force the injector nozzle open. Both solenoid and piezo injection are used on the engines of modern passenger diesel vehicles. The piezo element is made by cutting the quartz rack into thin wafers and then stacking or bonding them together. Look at **Figure 43-8**.

A ***piezo diesel injector*** uses a piezoelectric crystal to move the injector needle off its seat. When current is applied to the injector, the crystal expands,

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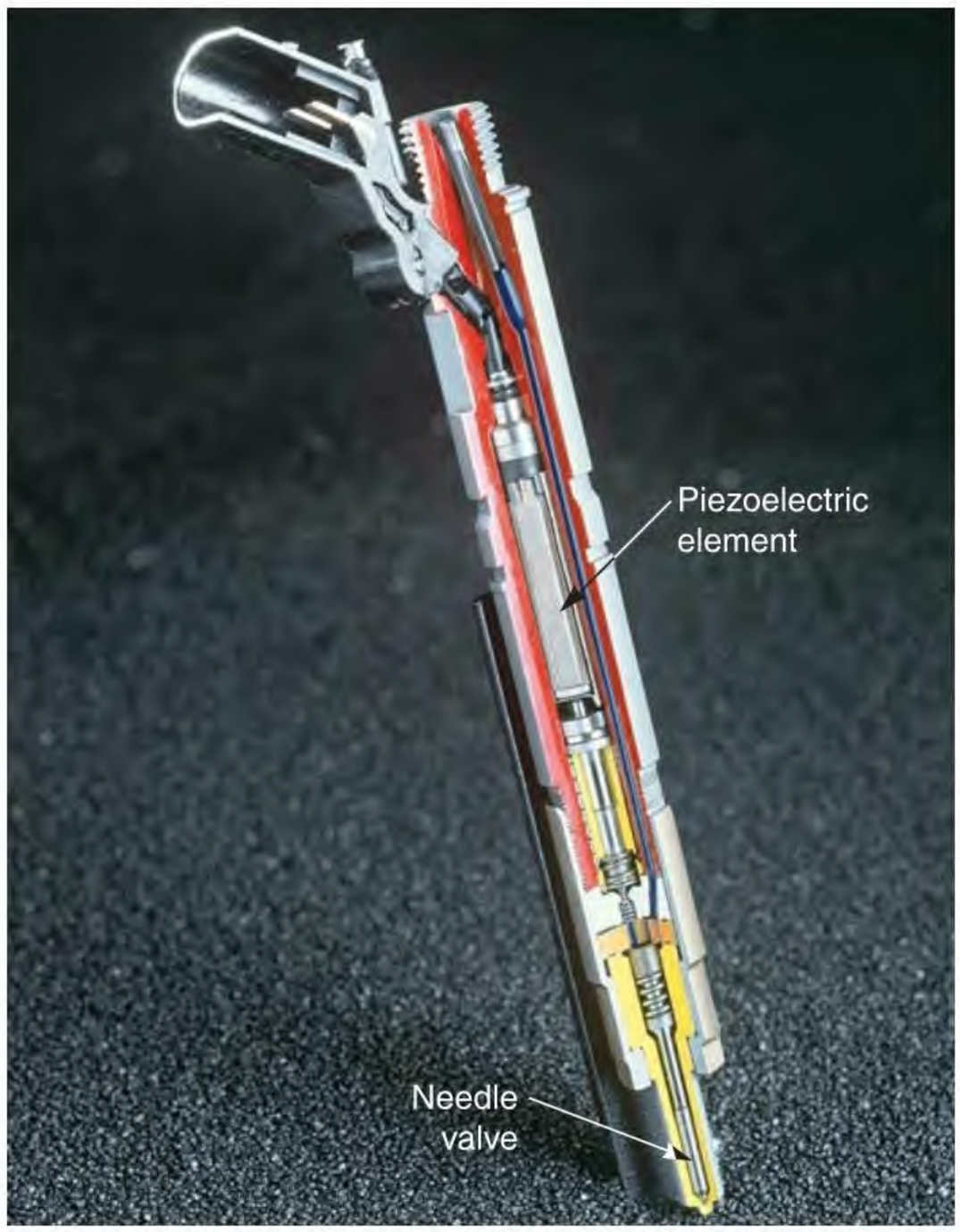
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Figure 43-7. A modern solenoid diesel injector. The solenoid electromagnet attracts the armature valve, which opens pressure relief on top of the injector needle. This allows pressure to push the needle valve up and off its seat to spray fuel. When the injector pulse ends, spring tension pushes the valve closed so spring tension can close injector nozzle.

forcing the injector needle valve open. When the polarity of the current applied to the injector is reversed, the piezoelectric crystal contracts and the needle valve closes.

Because the needle valves used in piezo fuel injectors are smaller and lighter than those used in solenoid-operated injectors, they can be snapped open and closed more quickly. A high-frequency electric signal can be sent to the piezoelectric crystal. The vibration makes the injector needle valve open and close rapidly. This allows for more precise control of injector pulse width and injection timing. Look at **Figure 43-9**.

Engines with piezo direct injectors normally have one high-pressure pump and one fuel rail per



Mercedes Benz

Figure 43-8. A piezo diesel injector provides precise fuel metering, which reduces exhaust emissions. The piezoelectric element reacts to changes in current flow to open and close the high-pressure fuel nozzle.



Bosch

Figure 43-9. Injection timing refers to when and how long diesel fuel is sprayed into the combustion chamber in relation to crankshaft rotation.

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cylinder bank. A high-power control module sends a high-voltage signal (typically 200–300 volts) to each injector. See **Figure 43-10**. Piezo electronic fuel injection systems help reduce hydrocarbon and particulate exhaust emissions, and produce a smoother, quieter, cleaner-running diesel engine.

Glow Plugs

Glow plugs are heating elements that warm the air in precombustion chambers to help start a cold diesel engine. The glow plugs are threaded into holes in the cylinder head. The inner tip of the glow plug extends into the precombustion chamber. Refer to **Figure 43-11** and **Figure 43-12**.

Glow Plug Control Circuit

A ***glow plug control circuit*** automatically disconnects the glow plugs after a few seconds of operation. See **Figure 43-13**.

The ***engine coolant temperature sensor*** checks the temperature of the engine coolant and feeds this electrical data to a control unit. Therefore, if the engine is already warm, the control unit will not turn on the glow plugs. ***Indicator lights***, also operated by the control unit, inform the driver whether or not the engine is ready to start. The glow plugs need only a few seconds to heat up.

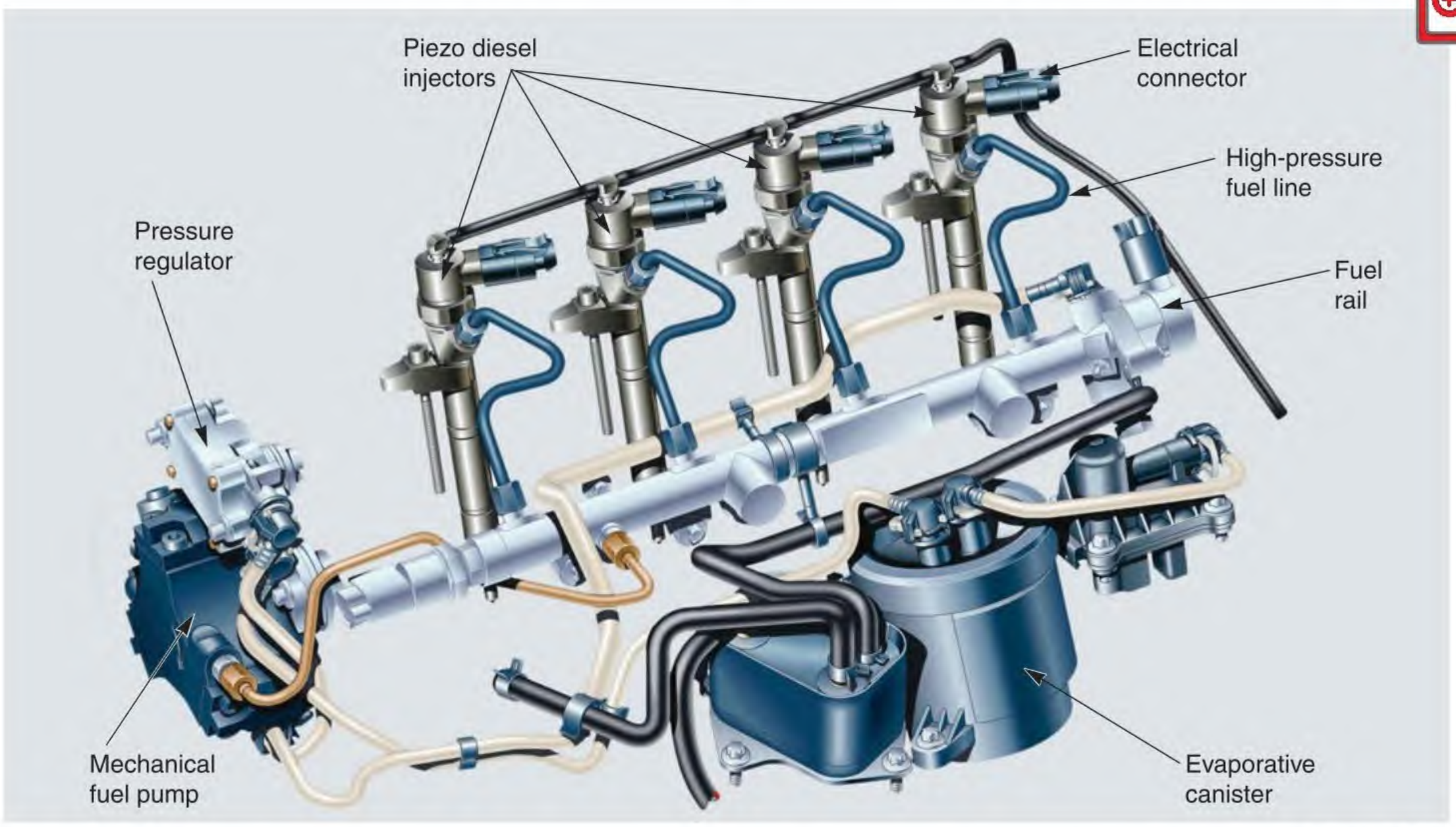
Glow Plug Operation

When the engine is cold and the driver turns the ignition switch to *Run*, a large current flows from the battery to the glow plugs. In a few seconds, the glow plug tips heat to a dull red glow.

When the glow plug indicator light goes out, the driver can start the engine. The compression stroke pressure and heat, along with the heat from the glow plugs, help the engine start easier.

Diesel Injection Timing

Diesel injection timing refers to fuel being injected into the combustion chambers in relation to the engine's piston position. It is similar to spark timing in a gasoline engine. The engine ECM uses data from the crankshaft, camshaft, fuel pressure, MAP, MAF,



Mercedes Benz

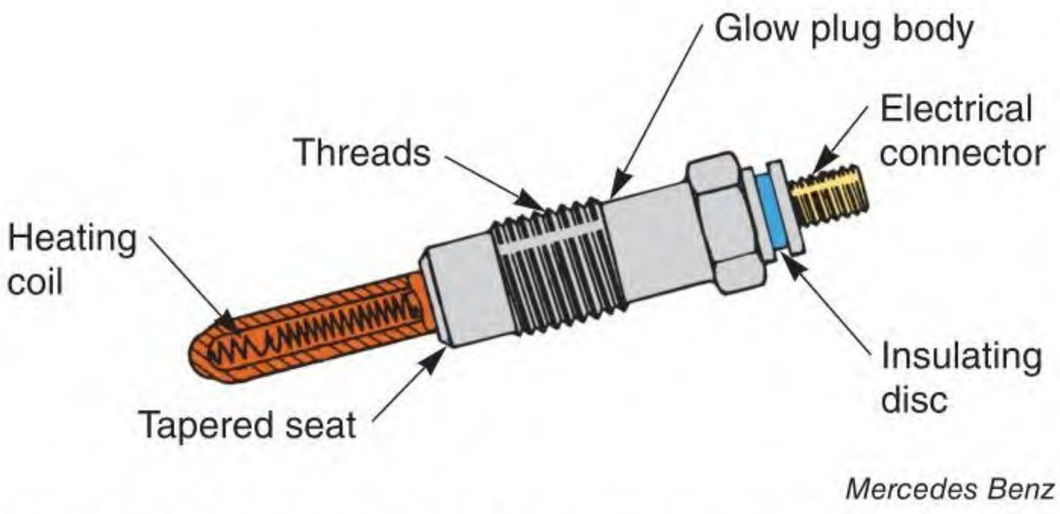
Figure 43-10. Study the basic parts of a piezo diesel injection system. The mechanical fuel pump and fuel pressure regulator feed fuel through the fuel rail and to the piezo diesel fuel injectors. Current flow through the piezoelectric elements causes the injector nozzles to open and spray fuel into the combustion chambers.

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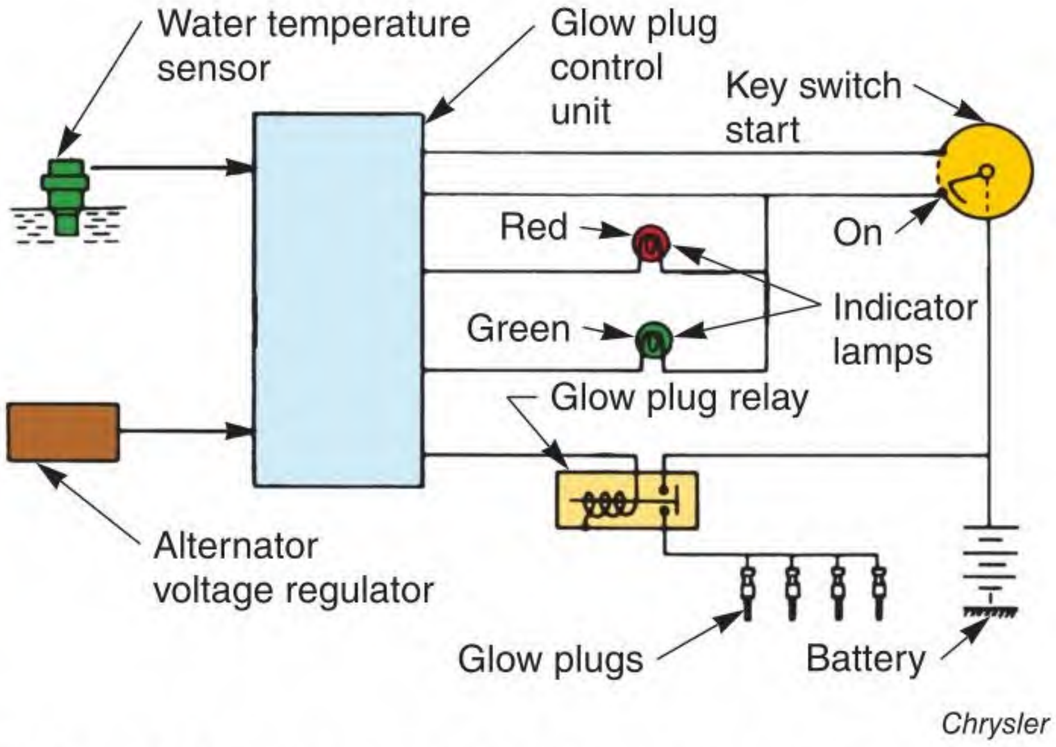
Figure 43-11. This cutaway shows how a glow plug glows red hot when electrically energized by high current flow. Remember that a diesel engine does not have an electric spark plug to initiate combustion.



Mercedes Benz

Figure 43-12. A glow plug is simply an electric heating element. Current flow through plug heats the element to warm air in the precombustion chamber so diesel fuel will "fire up" and start in cold weather.

and temperature sensors to adjust when diesel fuel is injected into its precombustion chamber. The ECM can precisely control diesel injection pump and injector nozzle timing, and fuel charge quantity.



Chrysler

Figure 43-13. Study this basic circuit for glow plugs. The control unit monitors engine temperature and informs the driver when the glow plugs have been activated long enough for the engine to start.

Diesel Injection System Accessories

Various diesel injection system accessories are used to aid in the dependability of a diesel engine. These accessories are needed because diesel fuel is susceptible to problems caused by moisture and low temperatures.

Water Detector

A ***water detector*** may be used to warn the driver of water in the diesel fuel. Such contamination is very harmful to a diesel fuel system. Water mixed with the fuel can cause corrosion of the precision parts in the injection pump and injectors.

Fuel Heater

A ***fuel heater*** is sometimes used to warm the diesel fuel, which prevents the fuel from gelling (turning into a semisolid). Though it is an optional device, it is needed in very cold climates. The heater is simply an electric heating element in the fuel line, positioned ahead of the injection pump.

Block Heater

A ***block heater*** may be used to warm the engine block in cold weather. It is a heating device that plugs into a home wall electric outlet. It keeps the engine warm overnight to make the diesel engine easier to start on cold mornings.

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Vacuum Pump

A ***vacuum pump*** is frequently used on a diesel engine to provide a source of vacuum (suction) for the vehicle. See **Figure 43-14**. Vacuum is needed for the power brakes, A/C ventilation system, and emission control devices.

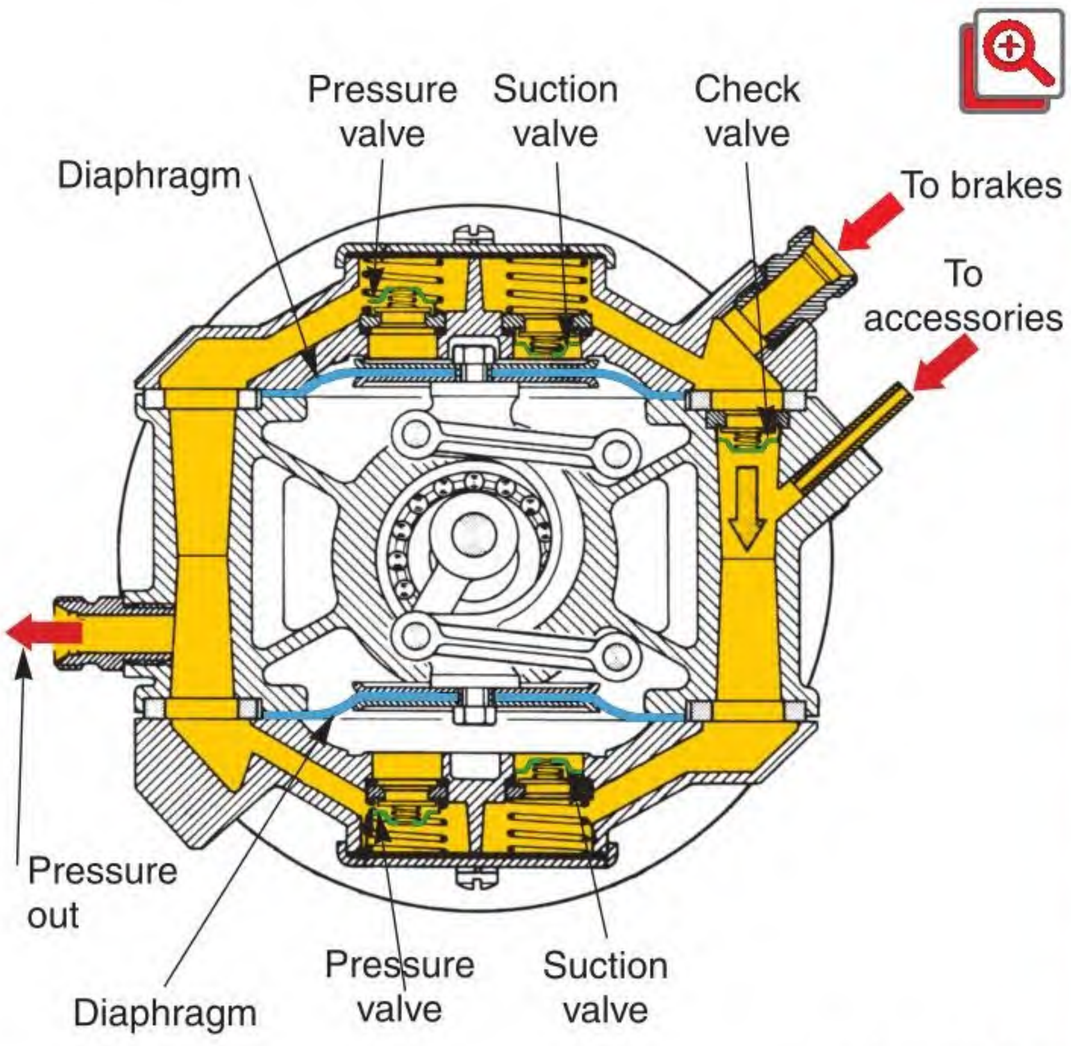
A gasoline engine has a natural source of vacuum in the intake manifold. A diesel engine has very little vacuum in the intake manifold because it does not have a throttle valve restriction. For this reason, a vacuum pump is needed.

Computer-Controlled Diesel System

A ***computer-controlled diesel system*** uses a computer, sensors, and actuators to increase the efficiency of mechanical diesel injection.

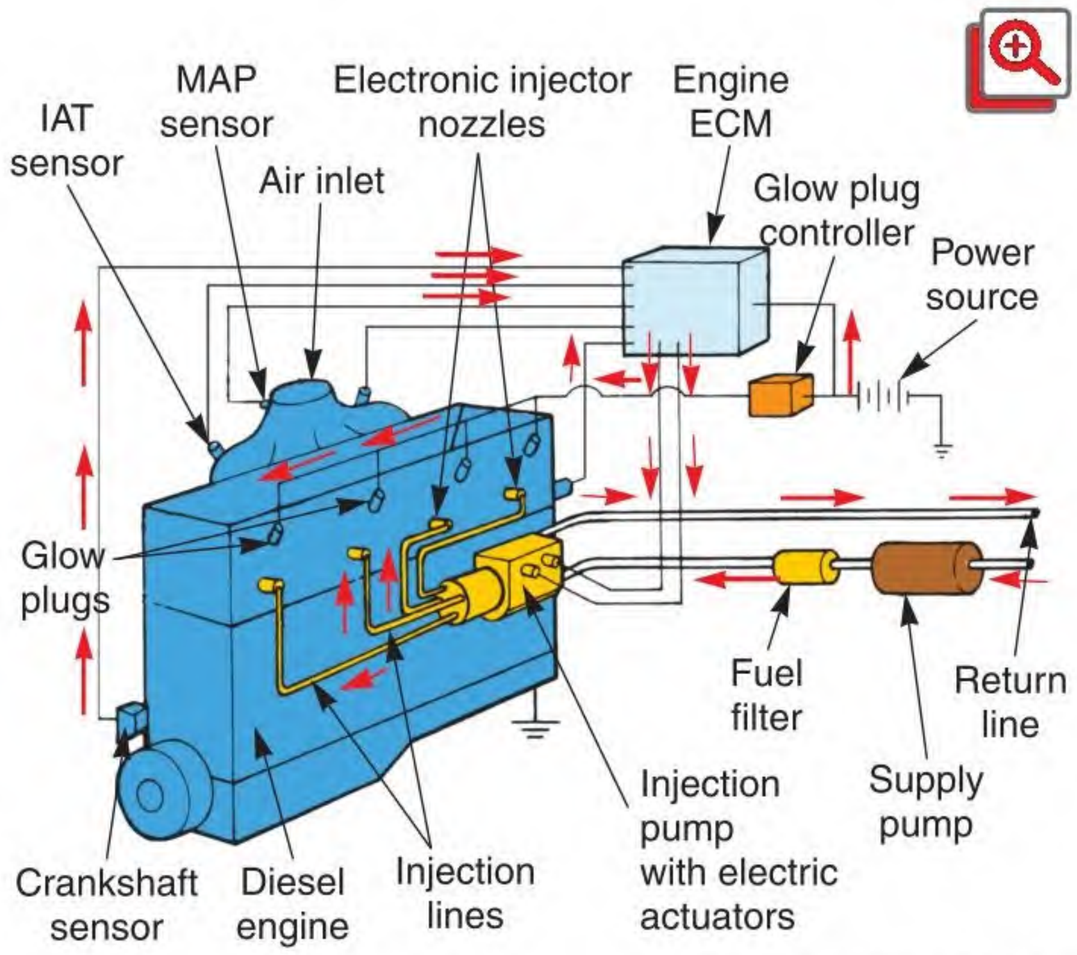
In the past, diesel injection was totally mechanical. All of the controls for the system were linkages, levers, rods, and gears. Mechanical controls were heavy and slow to react. Electronic components have been designed to replace many mechanical devices and improve efficiency. Refer to **Figure 43-15**.

Injection pump solenoids control injection timing and injection quantity. These solenoids react to signals from the computer. When energized or de-energized electrically, they can open or block fuel passages to alter pump operation.



Mercedes Benz

Figure 43-14. Note the construction of a diaphragm vacuum pump.



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Figure 43-15. Study the basic parts used in an electronic diesel injection system.

Diesel injection sensors are used to monitor engine temperature, speed, and other variables that affect fuel needs. The sensors feed signals to the computer. Diesel injection sensors are similar to those used for gasoline injection.

The ***diesel injection computer*** monitors sensor inputs and calculates the outputs for the actuators. In this way, the computer can more precisely control the mechanical, high-pressure plungers inside the diesel injection pump.

Safety First

An older diesel-powered car (with a mechanical fuel pump and no computer control) was brought into the shop for service. As the technician was working on the vehicle, the rack in the injection pump broke in the wide-open position. The engine raced to maximum speed. Unfortunately, the fuel cutoff solenoid in the injection pump had also failed and was stuck open.

With the fuel cutoff solenoid not working, turning the ignition key off had no effect. The technician had to use large pliers to crush the fuel feed line closed, shutting the engine down.

This is a rare occurrence. However, it shows how two simultaneous problems can cause strange results. Keep this in mind when troubleshooting problems.

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Summary

- A diesel fuel injection system is a high-pressure, mechanical system that delivers fuel directly into the engine combustion chambers.
- The fundamental parts of a diesel injection system include an injection pump, injection lines, injector nozzles, and glow plugs.
- A diesel injection pump meters the correct amount of fuel and delivers it to each injector nozzle at the proper time.
- Injector nozzles are spring-loaded valves that spray fuel into each combustion chamber.
- Piezo diesel injection uses an electrically operated piezo crystal to force the injector nozzle open.
- Glow plugs warm air in the precombustion chambers to aid in starting a cold engine. A diesel engine does not have an electric spark plug to initiate combustion.
- Diesel injection system accessories, such as a water detector, fuel heater, block heater, and vacuum pump, are used to aid in the dependability of a diesel engine.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

barrels
block heater
computer-controlled diesel system
control rod
control sleeves
delivery valves
diesel fuel injection
diesel fuel supply system
diesel injection computer
diesel injection sensors
diesel injection timing
diesel injector heat shield
diesel injector needle valve
diesel mechanical injection (DMI)
electric fuel shutoff
engine coolant temperature sensor
fuel heater
glow plug control circuit
glow plugs
indicator lights
injection lines
injection pump
injection pump camshaft
injection pump roller tappets
injection pump solenoids
injection pump vent
injector body
injector nozzles
injector pressure chamber
injector spring
inline diesel injection pump
inline pump plungers
piezo diesel injection
piezo diesel injector
piezoelectric crystals
plunger return springs
rack
solenoid diesel injection
vacuum pump
viscosity compensating valve
water detector

Activities

1. Prepare a multimedia presentation showing how the various parts of a diesel injection system are interrelated.
2. Create a sketch showing the relationship of a compression ratio of 17:1.
3. Research centrifugal force as a scientific principle. Relate this principle to the operation of a governor, and devise a way of demonstrating the principle to the class.

Review Questions

Answer the following questions using the information provided in this chapter.

1. A diesel fuel injection system is a high-pressure, mechanical system that delivers fuel directly to the engine combustion chambers. True or False?
2. Which of the following is *not* related to a diesel engine?
   (A) Spark ignition.
   (B) No throttle valves for air control.
   (C) Fuel quantity controls engine speed.
   (D) All of the above are related to diesel engines.
3. List and explain the four major components of a diesel injection system.
4. A diesel injection pump is powered by the _____.
5. What is the function of a plunger in an injection pump?
6. Roller tappets are commonly used in an inline injection pump. True or False?
7. Explain how an inline injection pump alters the amount of fuel forced to the injector nozzles.

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8. _____ are spring-loaded valves in the outlet fittings to the injection lines for ensuring quick, leak-free closing of the injector nozzles.
9. A(n) _____ valve allows for different fuel weights or thicknesses and temperatures.
10. An electric fuel shutoff is only used on inline injection pumps. True or False?
11. A diesel _____ is a spring-loaded valve that sprays fuel into the engine precombustion chamber.
12. List and explain the five major parts of a diesel injector.
13. _____ refers to when fuel is injected into the combustion chambers in relation to piston position.
14. Explain the purpose of a water detector.
15. A(n) _____ can be used to help keep the diesel fuel from gelling in cold weather.
16. Explain why a diesel engine, unlike a gasoline engine, needs a vacuum pump.

ASE-Type Questions

1. Diesel engine compression ratio is about:
   (A) 8:1 to 10:1.
   (B) 10:1 to 12:1.
   (C) 14:1 to 16:1.
   (D) 17:1 to 25:1.
2. Which of the following engine types does *not* use a throttle valve to control airflow into the engine?
   (A) Diesel.
   (B) Gasoline.
   (C) Carburetor.
   (D) None of the above.
3. The spring-loaded valves that spray fuel into each combustion chamber are called:
   (A) injection lines.
   (B) injector pumps.
   (C) injector nozzles.
   (D) supply or lift pumps.
4. Each of the following is a function of diesel injection pumps, *except*:
   (A) produce extremely high fuel pressure.
   (B) open injector nozzles before injection.
   (C) circulate fuel through lines and nozzles.
   (D) control engine idle and maximum speeds.
5. Power is transferred from the engine to the injection pump using a:
   (A) chain.
   (B) set of gears.
   (C) toothed belt.
   (D) Any of the above.
6. Inline diesel injection pumps are being discussed. Technician A says these pumps can be used with either hydraulic injectors or electro-hydraulic injectors. Technician B says these pumps have one plunger for each engine cylinder. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. Which of the following is used to warm air to help start a cold diesel engine?
   (A) Thermo valves.
   (B) Pintaux plugs.
   (C) Glow plugs.
   (D) Thermo sleeves.
8. Technician A says a fuel heater is used to prevent diesel fuel from gelling. Technician B says all diesel engines have fuel heaters. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Technician A says a diesel engine has a natural source of vacuum in the intake manifold. Technician B says a vacuum pump is frequently used on a diesel engine to provide a vacuum source for the power brakes, A/C ventilation system, and emission control devices. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. A computer-controlled diesel system uses all of the following components to increase efficiency, *except*:
    (A) a computer.
    (B) sensors.
    (C) actuators.
    (D) linkage.

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Credit:Stason4ik/Shutterstock.com

The components of a diesel fuel injection system include the injectors, a fuel rail, and a high-pressure injection pump.

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Chapter 44
Diesel Injection Diagnosis, Service, and Repair

After studying this chapter, you will be able to:

- Diagnose typical diesel injection problems.
- Test and replace diesel injectors.
- Test and replace glow plugs.
- Perform basic maintenance operations on a diesel injection system.
- Demonstrate safe work habits in diesel injection service.
- Correctly answer ASE certification test questions relating to diesel injection system diagnosis, service, and repair.

It is important for you to understand how to work on a diesel injection system because almost all auto manufacturers offer a diesel engine. While diesel injection service procedures are different from those for a gasoline injection system, they are still relatively simple.

Diesel Injection Maintenance

Refer to a service manual for details on periodic maintenance of a diesel injection system. In addition to changing or cleaning filters periodically, maintenance also involves inspecting the system for signs of trouble.

Fuel filters are normally located in the fuel tank (sock filter), in the fuel line (main filter), and sometimes in the injector assemblies (inlet connection screens or final filter screens). To ensure proper engine performance, these filters must be kept clean.

The main fuel filter may have a drain, which can be used to bleed off trapped water. When mixed with diesel fuel, water causes rapid corrosion and pitting of injection system components.

Diesel Injection Diagnosis

Diesel injection diagnosis requires you to use your knowledge of engine and injection system operation, and your basic troubleshooting skills. Begin diagnosis by checking the operation of the engine. Check for:

- Abnormal exhaust smoke coming out of the tailpipe.
- Excessive knock.
- Engine miss at idle or high speeds.

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- A no-start condition when engine cranks.
- Lack of power under a full load.
- Poor fuel economy.

The troubleshooting chart in the vehicle's service manual will list possible causes for these and other conditions. The service manual chart will be accurate because it is designed for one type of diesel injection system.

Engine Scanning

All late-model diesel engines are computer (ECM) controlled. You can usually connect a scan tool or diagnostic computer to quickly find diesel injection troubles. An OBD II system will monitor the injection pump solenoids, electric feed pumps, injection pump, fuel tank pressure, MAP, MAF, and crankshaft and camshaft sensors to control diesel injection timing and quantity. See **Figure 44-1**.



Bosch

Figure 44-1. This technician is using a diagnostic computer to check for trouble codes and analyze the operation of a diesel injection system.

Abnormal Exhaust Smoke

Excessive diesel exhaust smoke is normally due to incomplete combustion caused by injection system or engine troubles. A small amount of exhaust smoke is normal during initial start-up, cold engine operation, or rapid acceleration. Abnormal exhaust smoke may be black, white, or blue. See **Figure 44-2**.

The main cause of excessive black smoke is too much diesel fuel being injected into the cylinders. A rich air-fuel mixture allows carbon (ash) to blow out of the exhaust system. Black smoke may be due to problems with the injection pump, injection timing, air cleaner, injectors, fuel, or the engine itself.

White smoke occurs mainly during cold starts, when combustion efficiency is poor. The smoke usually consists of condensed fuel particles. Cold engine parts cause the fuel to condense into a liquid, which will not burn. The most common reasons for white exhaust smoke are inoperative glow plugs, low engine compression, thermostat stuck open, bad injector spray pattern, late injection timing, coolant leaking into cylinders, and cold start (injection pump) problems.

Tech Tip

White smoke in the exhaust gases can also be caused by coolant leakage into the combustion chambers. The engine may have a leaking head gasket, cracked cylinder head, or cracked block, allowing water to be burned with the diesel fuel and producing steam and white smoke.



Black smoke—rich fuel mixture



White smoke—partially burned fuel



Blue smoke—burning oil

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Figure 44-2. The color of exhaust smoke helps indicate what might be wrong with a diesel engine.

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Excessive blue smoke may be due to oil consumption from worn piston rings, scored cylinder walls, or leaking valve stem seals. White-blue smoke, however, is normally caused by incomplete combustion or injection system problems.

Excessive Knock

All diesel engines produce a faintly audible knocking sound when running. ***Diesel knock*** occurs because the fuel ignites spontaneously and burns rapidly. Very high cylinder gas pressures produce a rumble or a dull clattering sound as the auto ignition (detonation of diesel oil) expands and pushes the engine pistons down.

Ignition lag is the time span between the injection of the diesel fuel and the ignition of the fuel. It is a controlling factor that affects diesel knock. If ignition lag is too long, too much fuel will ignite at once and a mild explosion (loud knock) will result.

Abnormally loud diesel knock can be due to low operating temperatures (thermostat stuck open), early injection timing, low compression, fuel contamination, and oil consumption.

Engine Miss

A diesel engine miss results from one or more cylinders not firing (burning fuel) properly. Just as a gasoline engine will miss if a spark plug does not produce a spark, a diesel engine can also run roughly because of injection system problems.

A miss in a diesel engine can be due to faulty injectors, clogged fuel filters, incorrect injection timing, low cylinder compression, injection system leaks, air leaks, or a faulty injection pump.

Engine No-Start Condition

A no-start condition may be due to inoperative glow plugs, restricted air or fuel flow, a bad fuel shutoff solenoid, contaminated fuel, or a defective injection pump.

Slow cranking speed is a common cause of a no-start condition in a diesel engine. Being a compression-ignition engine, a diesel must crank fast enough to produce sufficient heat for combustion.

Lack of Power

When a diesel engine lacks power, check the throttle cable adjustment, governor setting, fuel filters, air filter, engine compression, and other factors affecting combustion. Keep in mind, however, that a diesel engine does not produce as much power as a gasoline engine of equal size.

Poor Fuel Economy

Poor fuel economy may be due to a fuel leak, a clogged air filter, incorrect injection timing, or leaking injectors. Normally, a diesel engine will get better fuel economy than a gasoline engine.

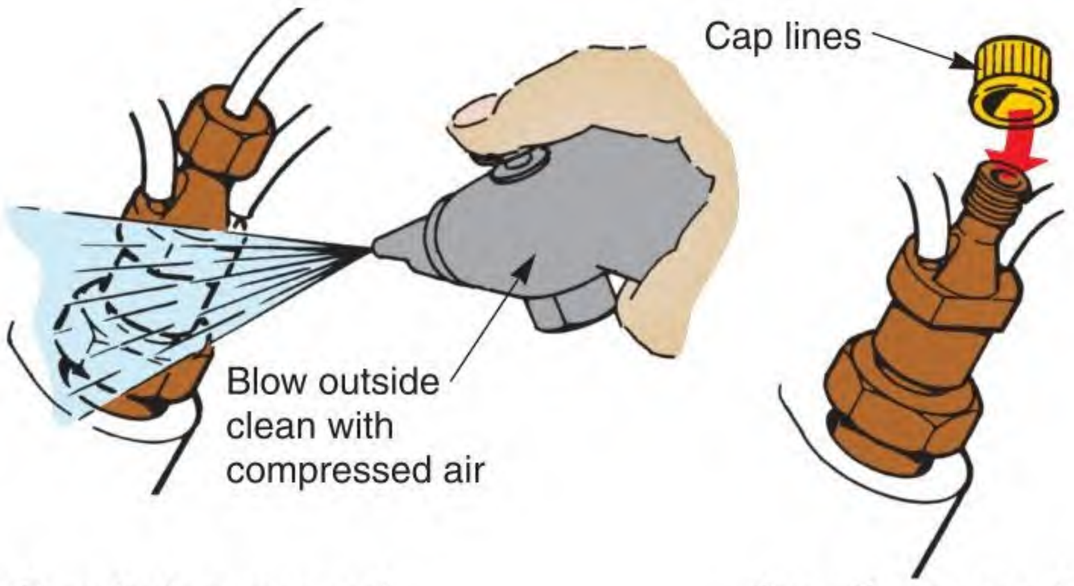
Check the EPA fuel economy values for the vehicle before measuring actual fuel economy. If the measured fuel economy is much lower than the EPA values, adjustments or repairs should be made.

Injection Cleanliness

When servicing a diesel engine, cleanliness is very important. A small bit of foreign material can upset the operation of the injection pump or the injectors. These parts have precision tolerances measured in microns (millionths of a meter). Keep this in mind during service.

A few rules of cleanliness to remember include:

- Always cap and seal any injection system fitting that is disconnected. This prevents dust from entering the system.
- Use clean, lint-free shop rags when wiping off components. Even a piece of lint could upset the operation of the injection system.
- Use compressed air and clean shop rags to remove dirt from around fittings before disassembly. Look at **Figure 44-3**.
- Do not spray water on a hot diesel engine. This could crack or warp the injection pump.



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Figure 44-3. Before removing an injection line, blow away dirt with compressed air. Cap the line after it is removed. A small amount of dirt can upset injector operation.

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Testing Diesel Injection Operation

There are several ways to check the operation of a diesel injection system. We will briefly explain the most common testing methods. Always refer to your service manual for exact instructions. Recommended testing procedures vary with the design of the injection pump, return lines, and injection nozzles.

Cylinder Balance Test

A diesel ***cylinder balance test*** involves disabling one injector at a time to check the firing of that cylinder. Just as you can remove a spark plug wire on a gasoline engine to check for combustion, you can loosen the injection line on a diesel engine to disable the injector.

Warning

When loosening an injection line, unscrew the fitting only enough to allow fuel to drip from the connection. Wear safety glasses and leather gloves, and obtain instructor approval before completing this test. Refer to the service manual for system-specific testing method information.

To perform a cylinder balance test on a diesel engine, wrap a rag around the injector and loosen the injector line fitting. When the fitting is loosened, fuel should slowly leak out of the connection. Fuel leakage will prevent the injector from opening and spraying fuel into the combustion chamber.

As the injector line is loosened, engine speed should drop and the engine should idle roughly. If "killing" a cylinder does not affect engine operation, that cylinder has not been firing. There may be a bad injector, low compression, or an injection pump problem. Further tests will be needed. Check all injectors.

With a modern diesel injection system, you can use your scan tool, laptop, or injection tester to disable a solenoid or piezo injector when checking for engine rpms to drop. You can electronically shut off each injector to make sure there is an equal power and speed drop when that cylinder is no longer making power.

Diesel Engine Compression Test

A diesel engine ***compression test*** is similar to a compression test for a gasoline engine. However, do not use a compression gauge intended for a gasoline engine on a diesel engine. The gauge can be damaged by the high pressures. A diesel compression gauge must read up to approximately 600 psi (4134 kPa).

Service Procedure

To perform a diesel compression test:

1. Remove either the injectors or the glow plugs. Refer to a service manual for instructions.
2. Install the compression gauge in the recommended port.
3. Disconnect the fuel shutoff solenoid to disable the injection pump.
4. Crank the engine and note the highest reading on the gauge.
5. Compare your compression gauge readings to specifications.

Typical compression pressure for an automotive diesel engine is 400–500 psi (2800–3400 kPa). Readings should be within about 50–75 psi (350–500 kPa) of each other. If the readings are not within this range, engine repairs are needed.

Caution

Some automakers warn against performing a wet compression test on a diesel engine. If too much oil is squirted into the cylinder, hydraulic lock and part damage could result because the oil will not compress.

Glow Plug Resistance-Balance Test

A ***glow plug resistance-balance test*** provides a safe way of finding out if each cylinder is firing. When combustion occurs in a cylinder, it raises the temperature and internal resistance of the glow plug in that cylinder.

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Service Procedure

To perform a glow plug resistance-balance test:

1. Unplug the wires to all the glow plugs.
2. Connect a digital ohmmeter across each glow plug and ground.
3. Write down the ohms reading of each glow plug.
4. Start the engine and let it run for a few minutes.
5. Shut the engine off and recheck glow plug resistance.

If a cylinder is not firing, the resistance of its glow plug will not increase as much as the resistance of the others.

Digital Pyrometer Balance Test

A ***digital pyrometer*** is an electronic device that is used to take very accurate temperature measurements. It can sometimes be used to check the operation of a diesel engine.

Touch the digital pyrometer on the exhaust manifold at each exhaust port. With the engine running, the temperature of the exhaust manifold should be almost the same at each port. If the manifold reading is cooler next to one exhaust port, that cylinder is not firing.

Injection-Pressure Test

An ***injection-pressure test*** uses a pressure transducer (sensor) and scope to measure instantaneous pressure in the injection lines or fuel rail. See **Figure 44-4**.

Connect the injection-pressure tester transducer between the injection pump and the injectors. Follow the instructions provided with the particular tester. Some injection-pressure testers allow you to check the following:

- Injector opening pressure.
- Injector nozzle leakage.
- Injection line pressure balance.
- Injection pump condition.

An injection-pressure tester enables you to pinpoint problems without removing major parts from the engine. For example, you can quickly locate a leaking injector nozzle, a clogged injector filter, or a bad injection pump. A leaking nozzle will show up as a pressure drop. A clogged filter will cause higher-than-normal pressure readings. A bad injector pump will produce lower-than-normal pressure readings.

Diesel Injection Service

As each diesel injection component is discussed in the following sections, possible symptoms, problems, and corrections for that component will be explained.

Injector Nozzle Service

A bad diesel injector usually causes the engine to miss. It may also reduce engine power or cause smoking and knocking. The injector nozzles are exposed to the direct heat and by-products of combustion. They can wear, become clogged with carbon, or be damaged. This can result in an incorrect opening pressure, incorrect spray pattern, fuel leakage, and other problems.

If you detect signs of fuel leakage, use a small piece of cardboard to find the leak. See **Figure 44-5**. While wearing work gloves, long sleeves, and a full face shield, move the cardboard around the perimeter of each fuel fitting. If there is a serious leak, fuel will strike the cardboard (and not your hand). Replace any injection line or return hose that is not in perfect condition.

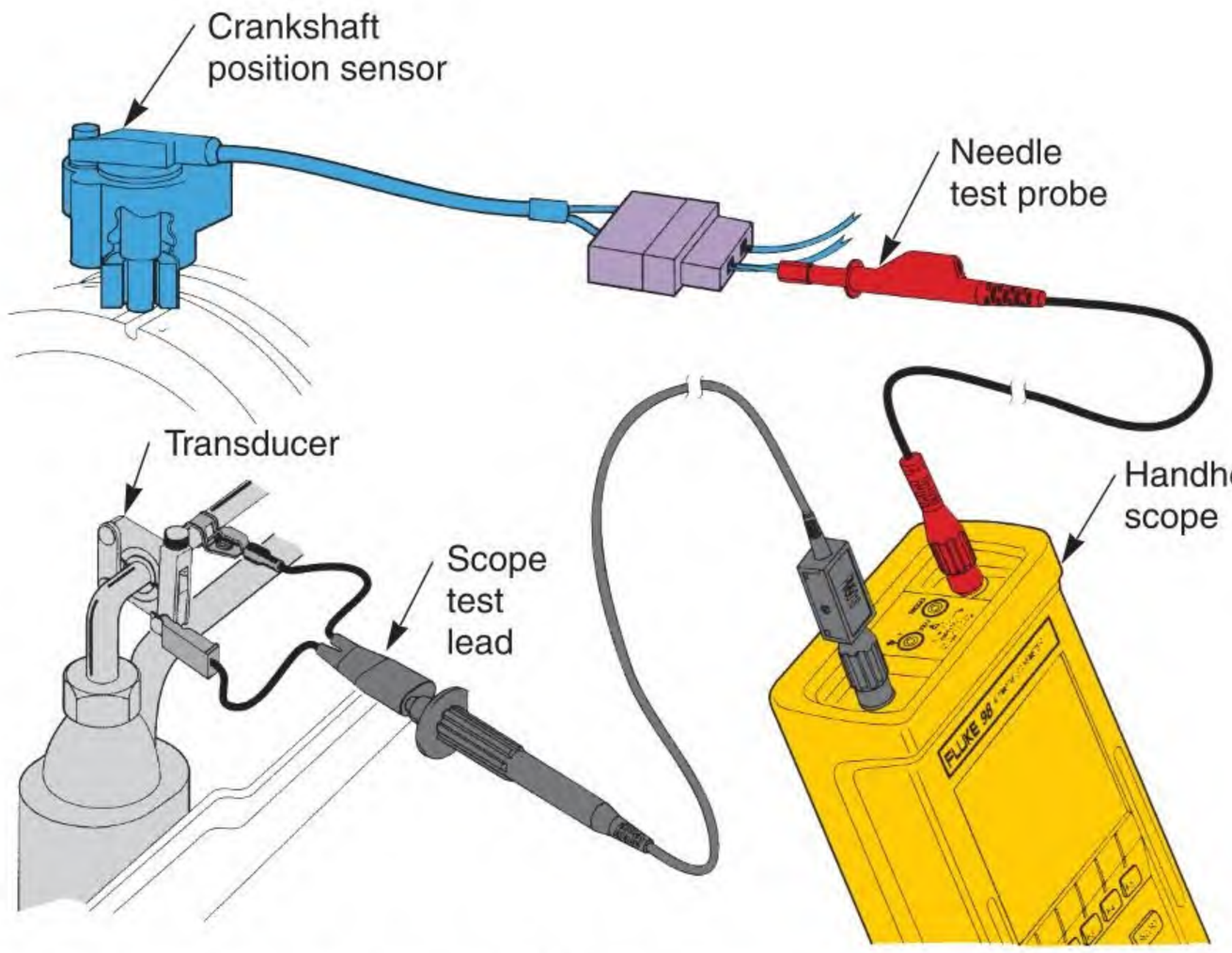
Warning

Never attempt to stop a diesel engine by covering the air inlet opening. Since there is no throttle valve, there is enough suction to cause a hand injury or to suck rags and other objects into the intake manifold.

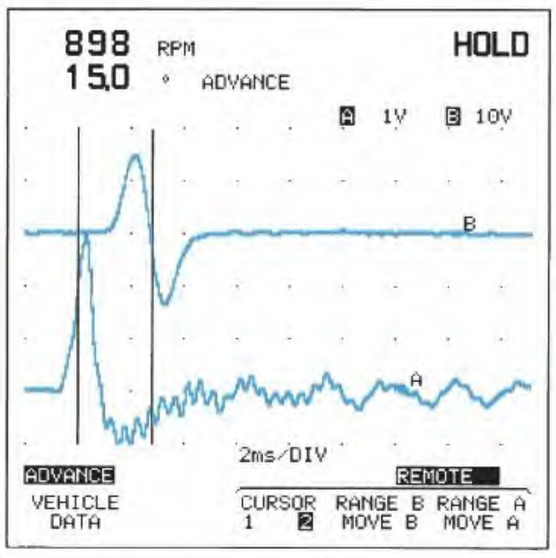
Injector Substitution

Injector substitution is an easy way to verify an injector problem. Install a good injector for the one being tested. If the cylinder fires with the good injector, then the old injector is faulty. If the cylinder still misses with the good injector, then other engine or injection problems exist. Refer to **Figure 44-6**.

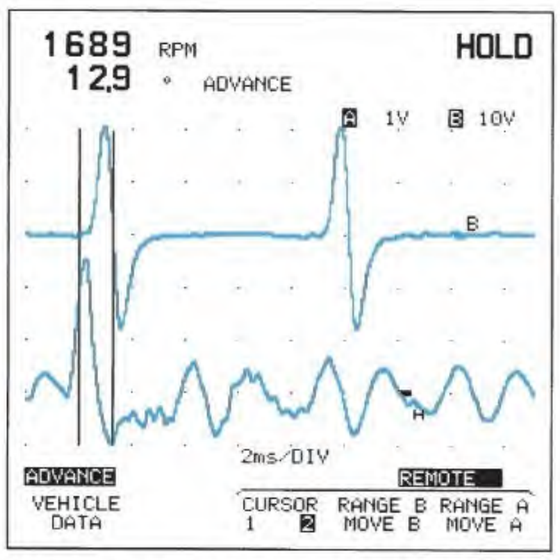
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Note the connections for injection timing measurement if the engine has a crankshaft position sensor. A transducer pickup clamps around the injection line to detect fuel pressure and flow increase from the high-pressure pump.



At low engine idle, the scope traces and digital readouts show alignment and amplitude.



When engine speed is increased to almost 1700 rpm, the scope shows advance of injection timing (injection occurs sooner).

Fluke

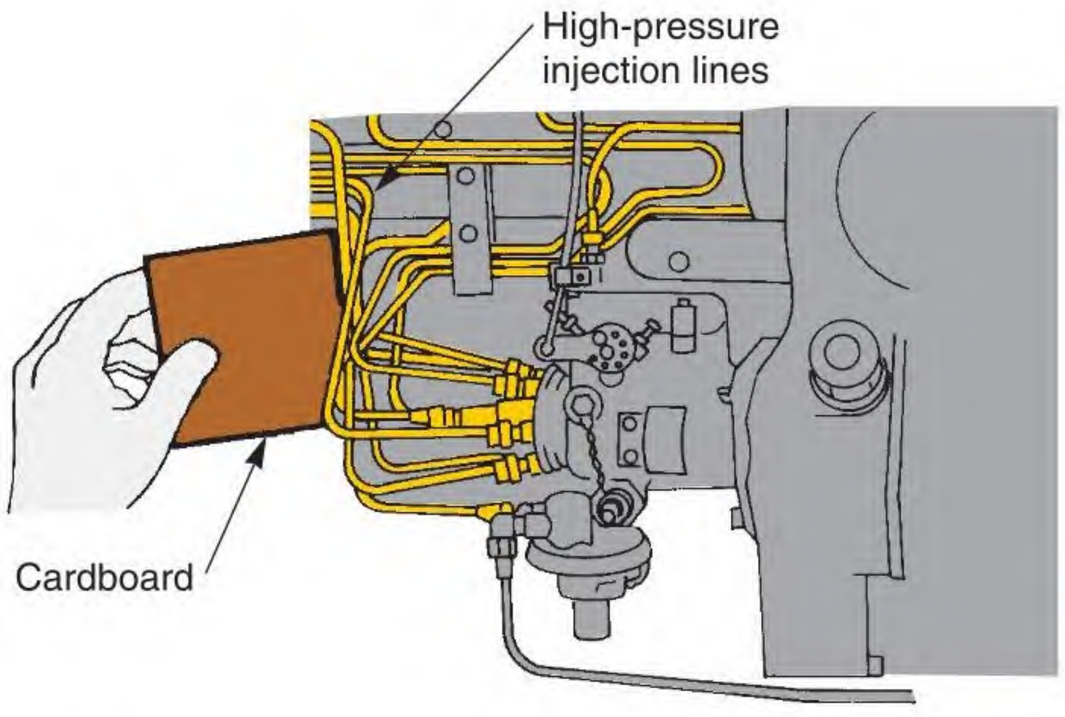
Figure 44-4. If the diesel has a crankshaft position sensor, connect a scope to the sensor and a transducer pickup tool around the No. 1 injection line. The tool will then allow you to observe advance-retard (trace movement from side to side) electronically. Rapid, jerky movement of the waveform could mean worn injection pump parts. You can also find weak sensor signal. This scope also gives numerical readout of injection advance.

Injector Removal

If your tests indicate a faulty injector, you should remove the injector for service, **Figure 44-7**. Following the directions in the service manual, disconnect the battery to prevent engine cranking. Using the appropriate tools, remove the injection line. Be careful not to bend or kink the high-pressure line.

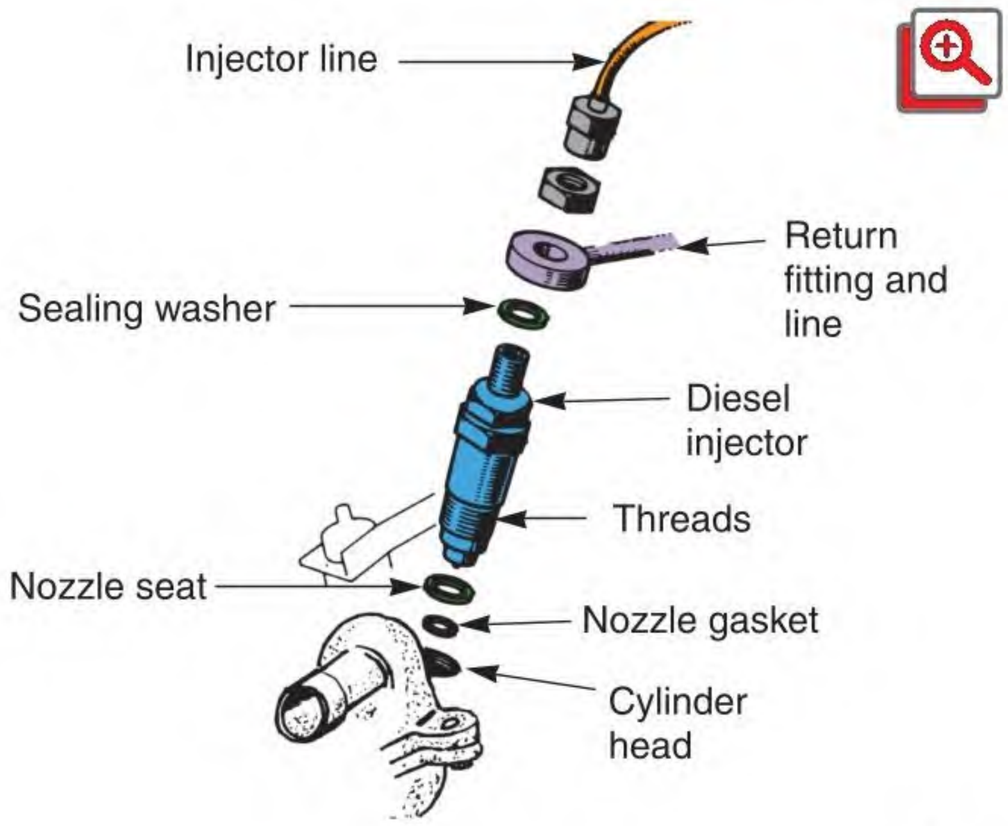
Normally, injectors are threaded into the cylinder head. They may also be held in the head with bolts and a press fit. With press-fit injectors, you may need to use a special impact tool to force them out of the head.

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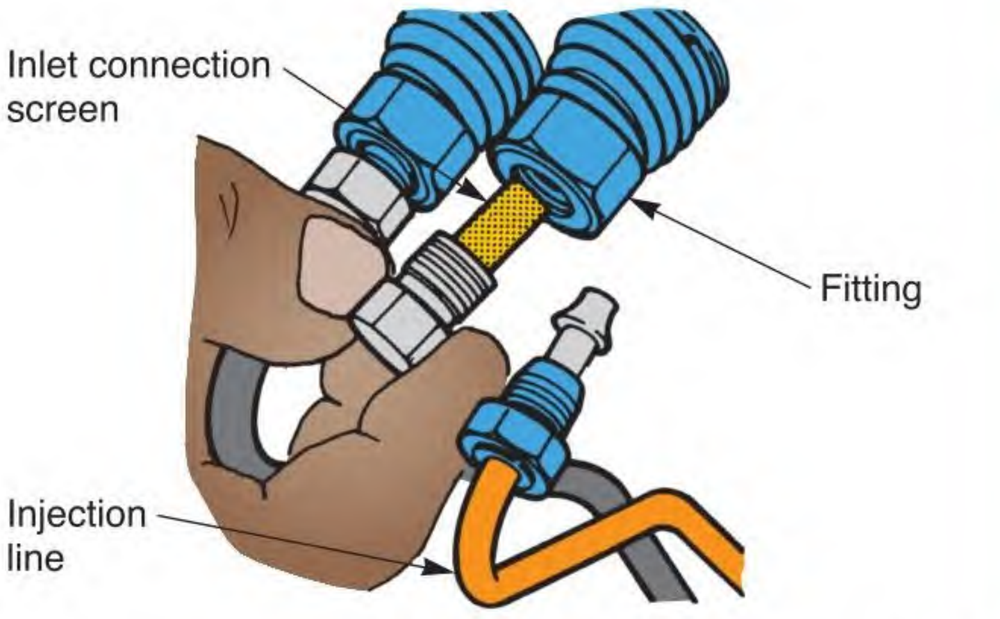
Chrysler

Figure 44-5. Use a piece of cardboard to locate injection system leaks. Remember that injection pressure is high enough to make the fuel spray puncture skin. Wear long sleeves, work gloves, and a full face shield to protect against high pressure, hydraulic leaks.



Toyota

Figure 44-7. When removing an injector, note the position of all parts. This injector screws into the cylinder head. Some are press-fit and clamped into the head.



Chrysler

Figure 44-6. Inlet connection screens at injectors are frequently used. Check them if problems point to the injection system.

Warning

Never attempt to remove an injection system component with the engine running. With 6000–8000 psi (42,000–56,000 kPa) of fuel pressure, fuel could squirt out and puncture your skin. Blood poisoning or death could result.

Service Procedure

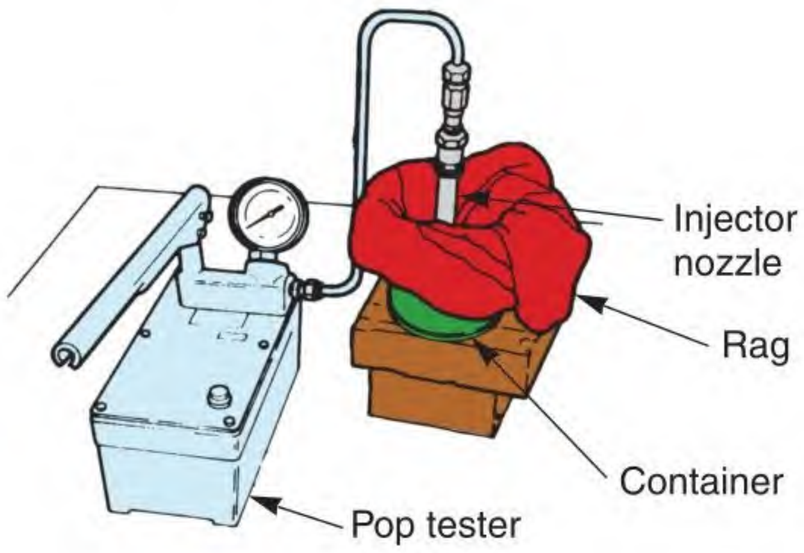
To use a pop tester:

1. Fill the tester reservoir with the correct calibration fluid (test liquid). Do not use diesel fuel because it is too flammable and test results may not be reliable.
2. Open the tester valve and pump the tester handle.
3. As soon as solid fluid (no air bubbles) sprays out of the tester, close the valve.
4. Connect the injection nozzle to the tester as shown in **Figure 44-8**.
5. To check injector opening pressure, purge any remaining air from the nozzle by pumping the tester lever up and down. Then, pump the handle slowly while watching the pressure gauge.
6. Note the pressure reading when the injection nozzle opens.
7. Repeat the test until you are sure you have an accurate reading.

Pop Testing Diesel Injector Nozzles

A ***pop tester*** is a device for checking a diesel injection nozzle while the nozzle is out of the engine.

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Ford

Figure 44-8. To use a pop tester, mount the injector on the tester. Point the injector into an approved catch container. Surround the container with rags to prevent splashing. Pump the tester handle while observing the spray pattern, opening pressure, and leakage. Follow directions for the specific tester.

Typical diesel injector opening pressure is approximately 1700–2200 psi (12,000–15,000 kPa). If opening pressure is not within the service manual specifications, rebuild or replace the injector.

To check the injector's ***spray pattern***, operate the pop tester handle while watching the fluid spray out of the injector nozzle. As shown in **Figure 44-9**, there should be a narrow, cone-shaped mist of fluid. A solid stream of fuel, an uneven spray, an excessively wide spray, or a spray filled with liquid droplets indicates that the injector requires service or replacement.

To check ***injector leakage***, slowly operate the tester handle to maintain a pressure that is lower than the nozzle opening pressure. Many auto manufacturers recommend a pressure about 300 psi (2000 kPa) below opening pressure. With this pressure, the diesel injector should not leak or drip for 10 seconds. Leakage would point to a dirty injector nozzle or worn components.

Tech Tip

Some diesel injectors make a chattering sound during operation; others do not. All nozzles, however, should make a swishing or pinging sound when spraying fuel.

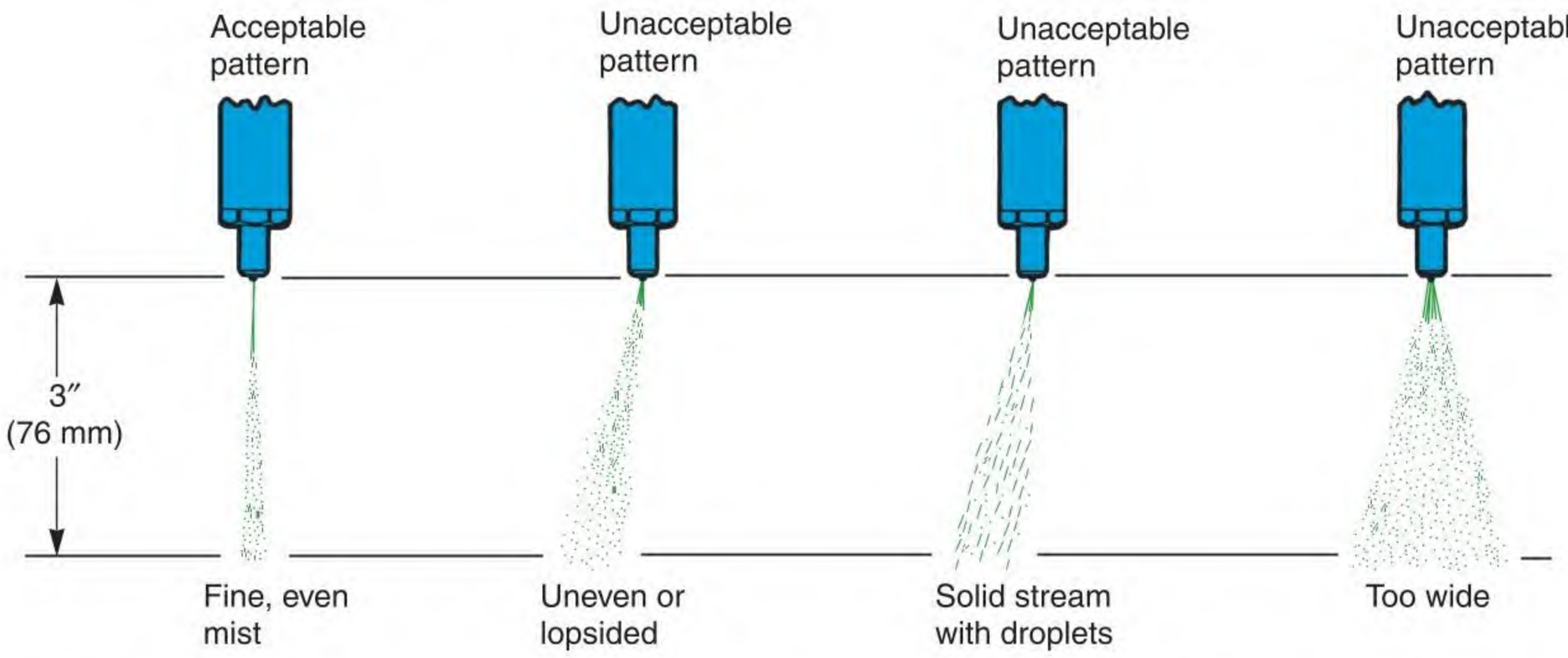
Installing Diesel Injectors

When installing a diesel injector, coat the threads with anti-seize compound. Use a new heat shield or seal to prevent compression leakage. Screw the injector into the cylinder head by hand. Then, torque it to the recommended specification. Reconnect the injector line without bending it. Tighten the connection properly.

Reconnect the wire on the fuel shutoff solenoid and start the engine. Check the system for leaks and proper operation. In a few cases, you may be required to bleed air out of the system. Refer to a service manual for exact details.

Caution

Always double-check that all fittings have been torqued before starting the engine.



Chrysler

Figure 44-9. Study typical diesel injector spray patterns. An acceptable spray produces uniform mist of fuel. An unacceptable spray is uneven and does not have proper mist density.

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Glow Plug Service

Inoperative glow plugs will make a diesel engine hard to start when cold. There will not be enough heat from compression alone to ignite the fuel. If only one or two glow plugs are inoperative, the engine may miss while cold.

If glow plug problems are indicated, use a test light to check for voltage to the glow plugs. Touch the test light on the feed wires to the glow plugs. A clip-on ammeter can also be used to check current to the glow plugs. An incorrect current to the glow plugs can be caused by the supply circuit or by the glow plugs themselves.

An ohmmeter can be used to determine the condition of the glow plugs. Connect the ohmmeter between each glow plug terminal and ground. See **Figure 44-10**. The resistance should be within specifications. If the resistance is too high or low, replace the glow plug.

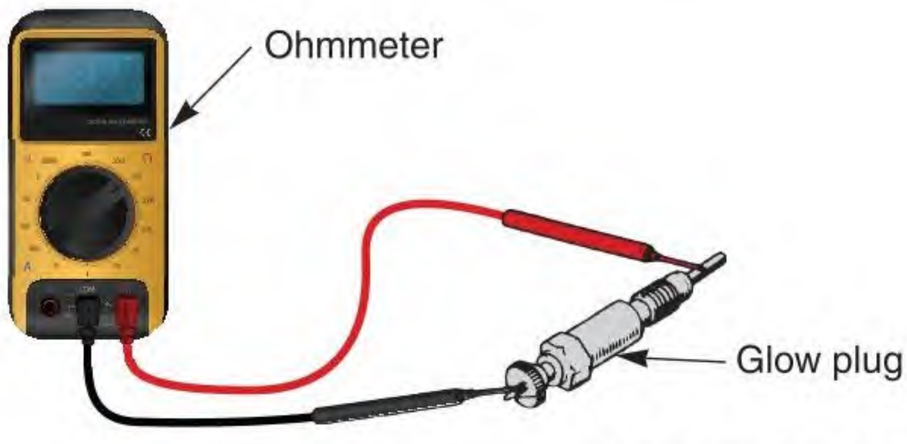
Glow Plug Replacement

To remove a glow plug, disconnect the wires going to it. Then, use a deep-well socket and ratchet to unscrew the glow plug.

Warning

A glow plug can reach temperatures above 1000°F (550°C), which can cause serious burns to your hand. Use extreme caution when removing glow plugs from the engine.

When the glow plugs are removed, inspect each one closely. Look for damage or a heavy coating of carbon. A carbon buildup can insulate the plug, making the engine hard to start. Clean any glow plugs that are to be reused. Replace all plugs that are faulty.



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Figure 44-10. Glow plug condition can be checked with a common ohmmeter. Plug resistance must be within specifications.

When installing the glow plugs, coat their threads with anti-seize compound. Start the plugs by hand and then tighten them to specifications. Overtightening can easily damage a glow plug.

Injection Pump Service

A bad injection pump can prevent an engine from running and cause engine missing, smoking, and other problems. The injection pump is usually a trouble-free unit. However, a pump may require replacement, repair, or adjustment due to water contamination, prolonged service, leaking seals, or physical damage.

Most shops install a new or factory-rebuilt diesel injection pump when internal parts are faulty. The injection pump is a very precise mechanism. Specialized tools and equipment are needed for repair work.

It is sometimes possible to replace leaking external gaskets and seals without major pump disassembly. On most pumps, other external parts (idle stop solenoid, vacuum valve, cold advance solenoid, fuel shut-off solenoid) can also be replaced in the shop. Refer to your service manual for details.

Service Procedure

To replace a diesel injection pump:

1. Crank the engine until the No. 1 piston is at TDC.
2. Study the timing marks on the pump and engine. Making note of the position of the timing marks will make reinstallation easier.
3. Disconnect the battery cable to prevent accidental cranking and fuel injection.
4. Remove the injection lines, wires, linkages, and fasteners to allow pump removal.
5. Cap all lines to keep out dust and dirt.
6. Carefully lift off the old pump.
7. Transfer parts (solenoids, vacuum valves, drive sprocket, etc.) from the old pump to the new pump.
8. Install the new pump on the engine.
9. Align the timing marks noted during disassembly.
10. Torque all fasteners and lines properly.
11. Before starting the engine, adjust injection timing as described in the next section.

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Caution

Never hammer or pry on an injection pump housing. Also, be careful not to drop an injection pump. It can be damaged easily and is very expensive to replace.

Computerized Diesel Injection Service

Diagnosing and repairing a diesel system that is controlled by a computer is similar to working on other computer-controlled systems. Modern diesel engines have extensive self-diagnostics, which help indicate the location of problems. You can use a digital meter, scope, or an advanced tool to check for opens and shorts in wiring and to pinpoint test the sensors and actuators.

Diesel Injection Service Rules

When servicing a diesel injection system, remember these basic rules:

- Always cap lines and fittings to prevent the entry of foreign matter.
- Never pry on or drop a diesel injector or injection pump. They can be damaged.
- Remember that high pressure inside a diesel injection system can cause serious injury.
- Clean around fittings before they are disconnected.
- Adhere to all torque specifications. This is extremely important on a diesel engine.
- Never use a bent, frayed, or kinked injection line.
- Some diesel injection systems must be bled (air removed) after repairs.
- Place a piece of screen mesh over the air inlet when the engine is operated without the air cleaner. Rags and other objects can be sucked into the engine. ***Do not*** cover the air inlet with your hand while the engine is running because injury may result.
- Check fuel filters and water separators periodically. Water can corrode expensive injection system parts.
- Follow all safety rules concerning ventilation and fire hazards.
- Wear safety glasses when working on a diesel injection system.
- When in doubt, refer to a service manual for the vehicle being serviced. The slightest mistake could upset engine performance or cause engine damage.

Diagnostic Case Study

Concern: Mr. Berkos brings his diesel truck into the shop, complaining of an engine miss. Duff questions Mr. Berkos about the nature of the problem. "My engine misses and shakes right after it starts on a cold morning," Mr. Berkos says. "The strange thing is that the problem seems to go away after the truck runs for a while."

Cause: Duff knows that a diesel engine miss during warm-up is generally a sign of glow plug or injector problems. Duff asks Mr. Berkos to leave the truck overnight so the engine can be started cold. The next morning, Duff starts the engine in an attempt to recreate the problem. Not only is the engine hard to start, but it misses just as Mr. Berkos had explained.

Duff assigns the repair to the shop's diesel specialist, who suspects a glow plug problem. The technician inspects the engine compartment for obvious problems, but finds none. He then starts the cold engine and uses an inductive ammeter to check for current at the glow plug wires. All the glow plugs show normal current draw when measured, except one. Using an ohmmeter, the technician checks the resistance of the glow plug that is not receiving the specified current. The ohmmeter shows infinite resistance, indicating an open in the glow plug heating element.

Correction: The technician installs a new glow plug to replace the "dead" one. The engine is again allowed to cool overnight. The next morning, the engine starts easily and does not seem to miss.

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Summary

- Refer to a service manual for details on periodic maintenance of a diesel injection system.
- Excessive diesel exhaust smoke is normally due to incomplete combustion caused by injection system problems or engine troubles.
- Ignition lag is the time span between the injection of the diesel fuel and the ignition of the fuel.
- A diesel cylinder balance test involves disabling one injector at a time to check the firing of the cylinders.
- A glow plug resistance-balance test provides a safe way to find out if each cylinder is firing.
- A bad diesel injector usually causes the engine to miss. It may also reduce engine power or cause smoking and knocking.
- A pop tester is a device used to check injector spray pattern, opening pressure, and leakage.
- Inoperative glow plugs will make a cold diesel engine hard to start.
- A bad injection pump can keep the engine from running or cause engine missing, smoking, and other problems.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

compression test
cylinder balance test
diesel knock
digital pyrometer
glow plug resistance-balance test
ignition lag
injection-pressure test
injector leakage
injector substitution
pop tester
spray pattern

Activities

1. Prepare a multimedia presentation on the steps for troubleshooting the injectors in a vehicle that has abnormal exhaust smoke. Use the presentation to demonstrate the steps to your class.
2. Perform a cylinder balance test on the engine's injectors.
3. Using an ohmmeter, demonstrate the proper method for checking the condition of a glow plug.

Review Questions

Answer the following questions using the information provided in this chapter.

1. To ensure proper engine performance, fuel filters must be kept clean. True or False?
2. Explain the most common reasons for excessive white smoke from a diesel engine.
3. Which of the following is *not* a normal cause of excessive diesel knock?
   (A) Long ignition lag time.
   (B) Low engine-operating temperature.
   (C) Early injection timing.
   (D) All of the above are normal causes of excessive knock.
4. A diesel engine does *not* produce as much power as a gasoline engine of equal size. True or False?
5. Explain a diesel cylinder balance test.
6. The typical range of compression pressure for an automotive diesel engine is _____400–500 psi.
7. Why do many service manuals warn against doing a wet compression test on a diesel?
8. A glow plug resistance-balance test relies on the fact that glow plug electrical resistance _____ with temperature.
9. How can a digital pyrometer be used to check the operation of a diesel engine?
10. What four values do some on-car injection-pressure testers allow you to measure?

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11. Which of the following should *not* be done when removing a diesel injector?
    (A) Disconnect battery.
    (B) Bend injection line out of the way.
    (C) Use impact tool if needed.
    (D) All of the above should be done when removing a diesel injector.
12. Explain the use of a pop tester.
13. Which of the following can be used to test diesel glow plug system operation?
    (A) Test light.
    (B) Ammeter.
    (C) Ohmmeter.
    (D) All of the above.
14. Glow plugs can reach temperatures above _____°F (550°C).
15. Some diesel injection systems must be bled after repairs. True or False?

ASE-Type Questions

1. Which of the following is sometimes located in the injector assemblies?
    (A) Sock filter.
    (B) Main filter.
    (C) Final filter screens.
    (D) All of the above.
2. Diesel injection parts are machined to precision tolerances measured in:
    (A) inches.
    (B) microns.
    (C) millimeters.
    (D) centimeters.
3. Which smoke color indicates engine oil is entering the combustion chamber?
    (A) Blue.
    (B) Black.
    (C) White.
    (D) All of the above.
4. Abnormally loud diesel knock can be caused by each of these *except*:
    (A) oil consumption.
    (B) rich fuel mixture.
    (C) fuel contamination.
    (D) early injection timing.
5. This is *not* a cause of diesel engine miss.
    (A) Air leak.
    (B) Faulty injectors.
    (C) Clogged fuel filters.
    (D) Shorted fuel cutoff solenoid.
6. Which of these tests involves disabling one injector at a time?
    (A) Cylinder balance test.
    (B) Injection-pressure test.
    (C) Diesel compression test.
    (D) Digital pyrometer balance test.
7. Compression pressure for an automotive diesel engine is:
    (A) 50–75 psi.
    (B) 100–200 psi.
    (C) 300–375 psi.
    (D) 400–500 psi.
8. When checking diesel injection nozzles with a pop tester, Technician A believes the tester reservoir should be filled with the correct diesel fuel. Technician B feels the tester reservoir should be filled with the correct calibration fluid. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
9. When replacing an injection pump, which of the following needs to be transferred from the old pump to the new pump?
    (A) Solenoids.
    (B) Vacuum valves.
    (C) Drive sprockets.
    (D) All of the above.
10. Technician A says that when servicing a diesel injection system, lines and fittings should always be capped to prevent debris from entering the system. Technician B says that when operating the engine without an air cleaner, the air inlet should be covered with a rag to prevent debris from being drawn into the engine. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Chapter 45
Exhaust System Technology and Repair

After studying this chapter, you will be able to:

- Describe the basic parts and construction of an exhaust system.
- Compare exhaust system design differences.
- Perform exhaust system inspection and repairs.
- Demonstrate an understanding of proper procedures and safety precautions for exhaust system service.
- Correctly answer ASE certification test questions on exhaust system operation and service.

Specialized chains of repair shops that do nothing but repair and replace exhaust system parts can be found all over the country. By knowing how to quickly find and replace failed or failing parts, exhaust system technicians can earn a very good living. Apprentice openings for mechanics who can safely and professionally replace mufflers, headers, exhaust pipes, and catalytic converters are widely available.

Exhaust System Operation

The ***exhaust system*** performs several important functions. It quiets engine operation by muffling the sound of exhaust gases shooting out of the exhaust ports in the cylinder heads. It also carries exhaust gases from the engine to the rear of the vehicle without leakage. If exhaust gases were to leak out under the floor pan, toxic exhaust fumes could be pulled into the vents and passenger compartment. This makes proper exhaust system repair extremely important!

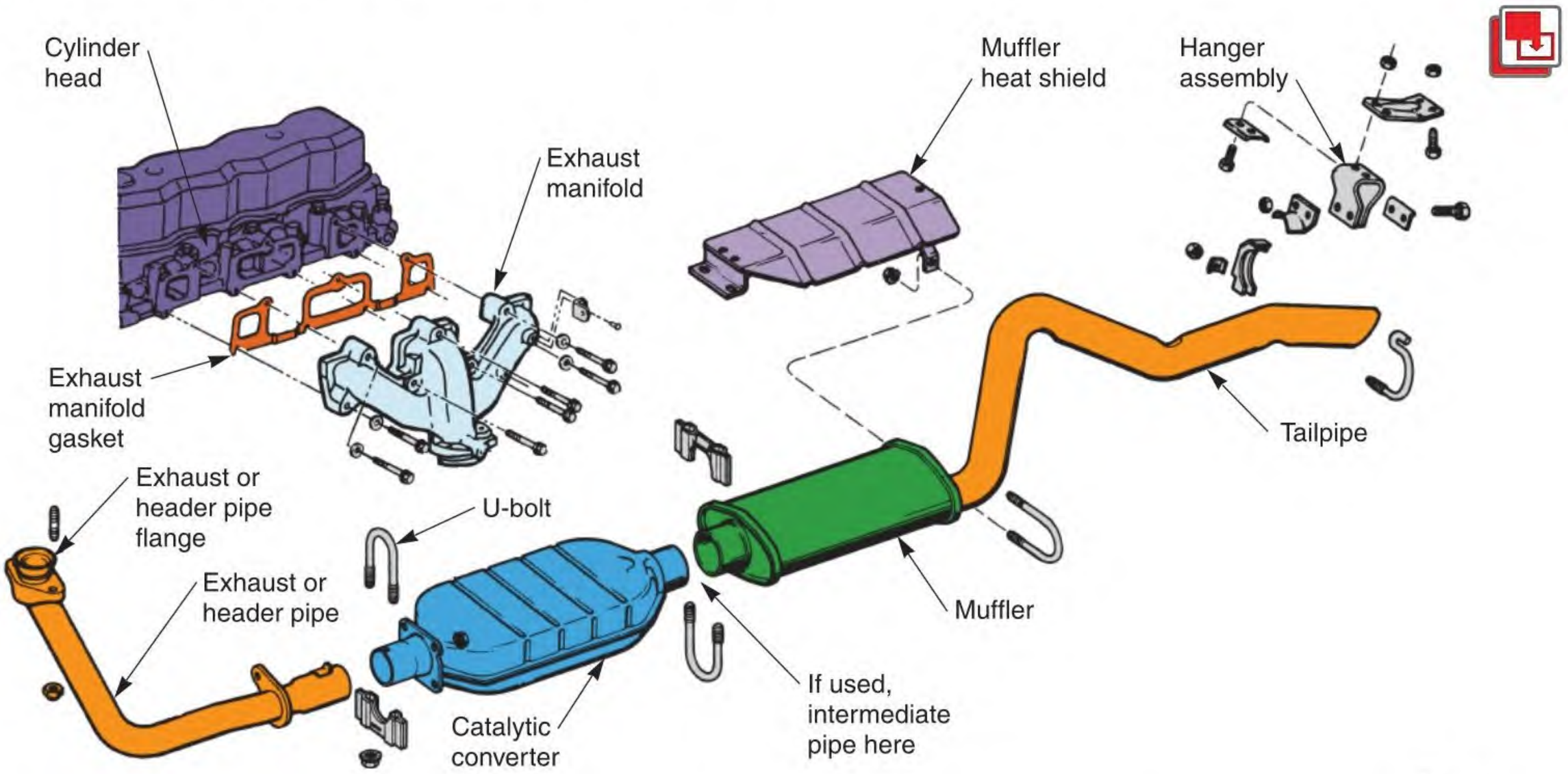
The exhaust system performs several other functions. Toxic fumes (unburned, partially burned, and excessively burned petroleum-based chemicals) remaining in the engine exhaust gases are treated and purified by the exhaust system. The exhaust system also gives feedback on the percentage of oxygen in burned gases to calculate and adjust the engine's fuel injection system. In engines equipped with a turbocharger (exhaust-driven blower), the exhaust system helps increase engine power and efficiency.

Exhaust System Parts

Typical exhaust system parts, which are shown in **Figure 45-1**, include the following:

- ***Exhaust manifold***—The exhaust manifold connects the cylinder head exhaust ports to a header pipe.

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Chrysler

Figure 45-1. Note the parts of a typical exhaust system. Exhaust comes out of the cylinder head, moves into the manifold, and then through the system.

- ***Header pipe***—The header pipe is made of steel tubing that carries exhaust gases from the exhaust manifold to the catalytic converter.
- ***Catalytic converter***—The catalytic converter is an enclosed, high-temperature afterburner that consumes and chemically treats pollutants in the engine exhaust.
- ***Intermediate pipe***—The intermediate pipe is a piece of steel tubing that carries exhaust gases from the catalytic converter to the muffler.
- ***Muffler***—The muffler is a sheet metal chamber that dampens pressure pulsations to reduce exhaust noise.
- ***Tailpipe***—The tailpipe consists of tubing that carries exhaust gases from the muffler to the rear of a car body. One or two tailpipes should be visible at the rear of the vehicle. They should extend out as far as the rear body overhang or bumper.
- ***Hangers***—Hangers are used to secure the exhaust system to the underside of the vehicle.
- ***Heat shields***—Heat shields are metal plates that prevent exhaust heat from transferring to the fuel lines, floor, transmission, and engine.
- ***Exhaust system clamps***—Exhaust system clamps are large U-bolts for connecting parts of the exhaust system together.

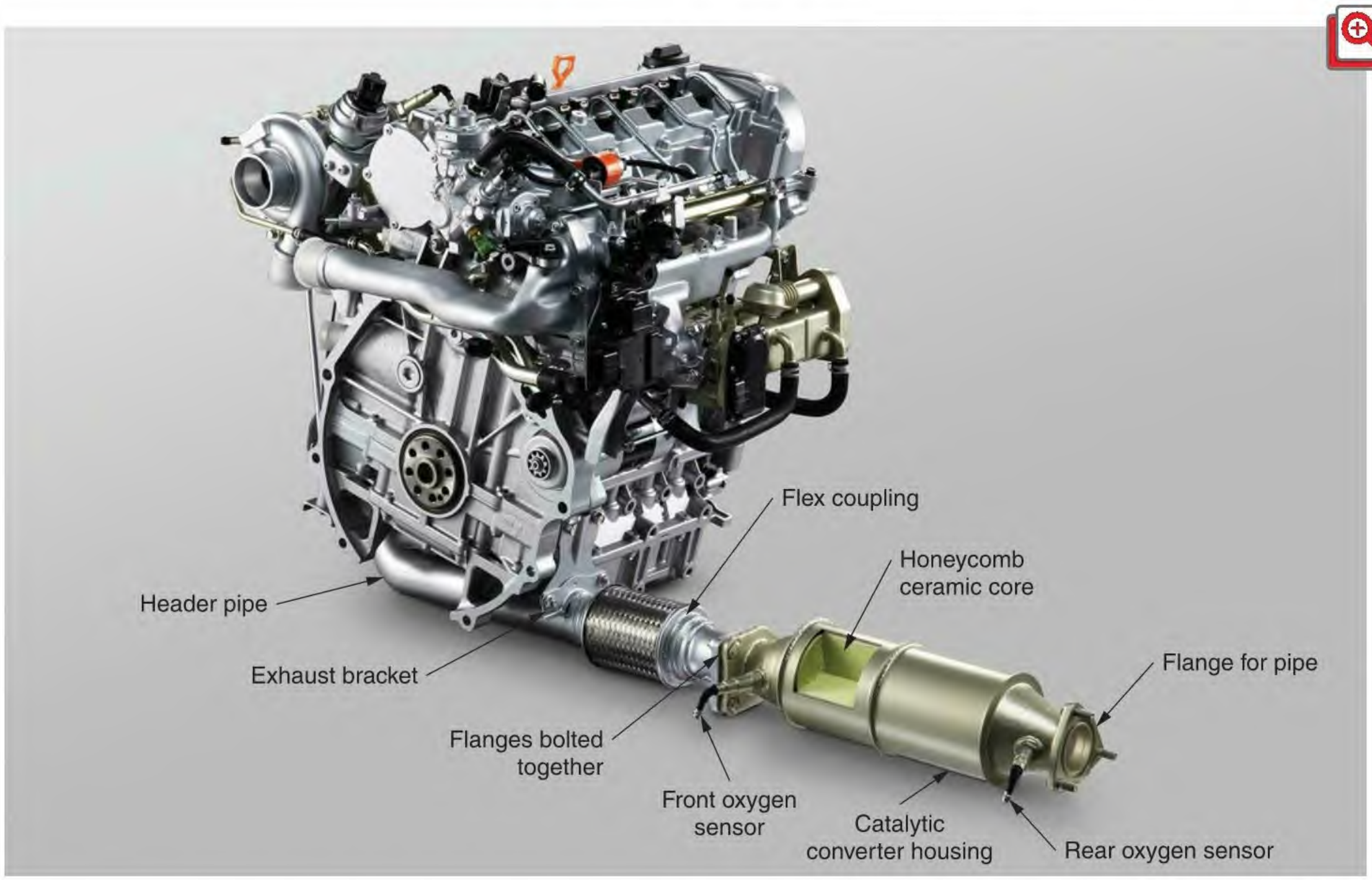
When an engine is running, extremely hot gases blow out of the cylinder head exhaust ports and enter the exhaust manifold. The exhaust gas temperatures drop as the gases flow through the header pipe, catalytic converter, intermediate pipe, muffler, and tailpipe.

Some header pipes are connected to the exhaust manifold by a spring-loaded coupling. The coupling compresses and holds the "doughnut" seal (high temperature O-ring) between the exhaust manifold and header pipe. This design allows the engine to move on its motor mounts without moving the exhaust system and damaging the exhaust. Other systems contain a flex coupling that allows the engine to move on its mounts without disturbing the rest of the exhaust system. See **Figure 45-2**.

Exhaust Back Pressure

Exhaust back pressure is the pressure developed in the exhaust system when the engine is running. Exhaust back pressure can be measured by installing a pressure gauge in the front (No. 1) oxygen sensor's threaded hole. Rev the engine while reading your gauge to measure actual exhaust back pressure. ***High back pressure*** indicates a restriction in the system, usually a clogged catalytic converter. High back pressure reduces engine power and performance. A well-designed exhaust system should have ***low back pressure***.

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Honda

Figure 45-2. A flex coupling after the header pipe allows the engine to move without jarring and moving the rest of the exhaust system. Note that the catalytic converter has been cut away to expose the ceramic core.

The catalytic converter causes most of the exhaust system back pressure. Aftermarket, high-flow catalytic converters are available to increase engine performance while reducing exhaust emissions. The sizes of the exhaust pipes, catalytic converters, and mufflers all influence exhaust back pressure. Larger pipes, a free-flowing muffler, and "high-flow cats," for example, would reduce back pressure, increase gas mileage, and increase engine horsepower.

Single and Dual Exhaust Systems

A ***single exhaust system*** has one path for exhaust flow through the system. Typically, it has only one header pipe, a main catalytic converter, a muffler, and a tailpipe. The most common type of exhaust system, a single exhaust system is used on the smallest four-cylinder engines and on up to large V-8 engines.

A ***dual exhaust system*** has two separate exhaust paths to reduce exhaust back pressure. It is essentially two single exhaust systems connected to the engine, **Figure 45-3**. A dual exhaust system is often used on high-performance engines. It lets the engine "breathe" better at high rpms.

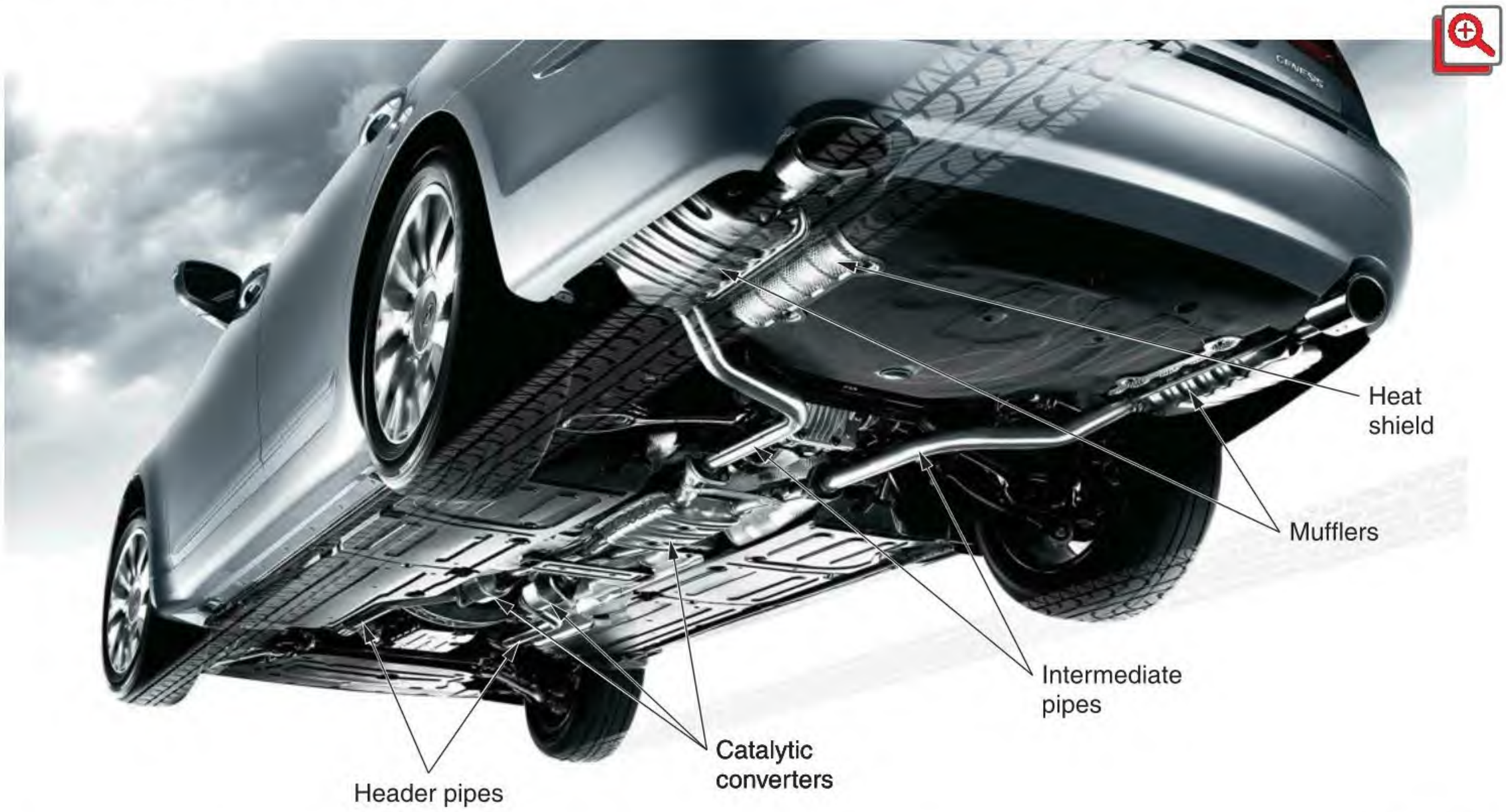
A ***crossover pipe*** is used on some dual exhaust systems to connect the right and left header pipes together to equalize back pressure for a slight increase in engine power with natural aspiration.

Exhaust Manifold

An exhaust manifold bolts to the cylinder head to enclose the exhaust port openings. The manifold is usually made of cast iron. High-flow, high-performance manifolds, commonly called ***headers***, are sometimes made of stainless steel or lightweight steel tubing. See **Figure 45-4**.

The cylinder head mating surface is machined smooth and flat. An exhaust manifold gasket is commonly used between the cylinder head and manifold to help prevent leakage. The outlet end of the exhaust manifold has a round opening with holes for stud bolts or cap screws. A gasket or an O-ring (***exhaust manifold doughnut***) seals the connection between

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Hyundai

Figure 45-3. This vehicle is equipped with a dual exhaust system. Note that there are two separate exhaust paths.



Ford

Figure 45-4. This high-performance exhaust manifold is fabricated from steel tubing. The large, smooth exhaust passages created by the tubing help improve exhaust gas flow.

the exhaust manifold outlet and header pipe to prevent leakage.

Exhaust Pipes

The ***exhaust pipes*** (header pipe, intermediate pipe, and tailpipe) are usually made of rust-resistant steel tubing. One end of each pipe may be enlarged to fit over the end of the next pipe. The inlet end of the header pipe has a flange for securing the pipe to the exhaust manifold studs.

Heat Shields

Heat shields are located in areas where the exhaust system components (especially the catalytic converter and muffler) are close to the vehicle's body or near the ground. The shields reduce the amount of heat transferred into the body and protect items under the vehicle. Refer to **Figure 45-5**.

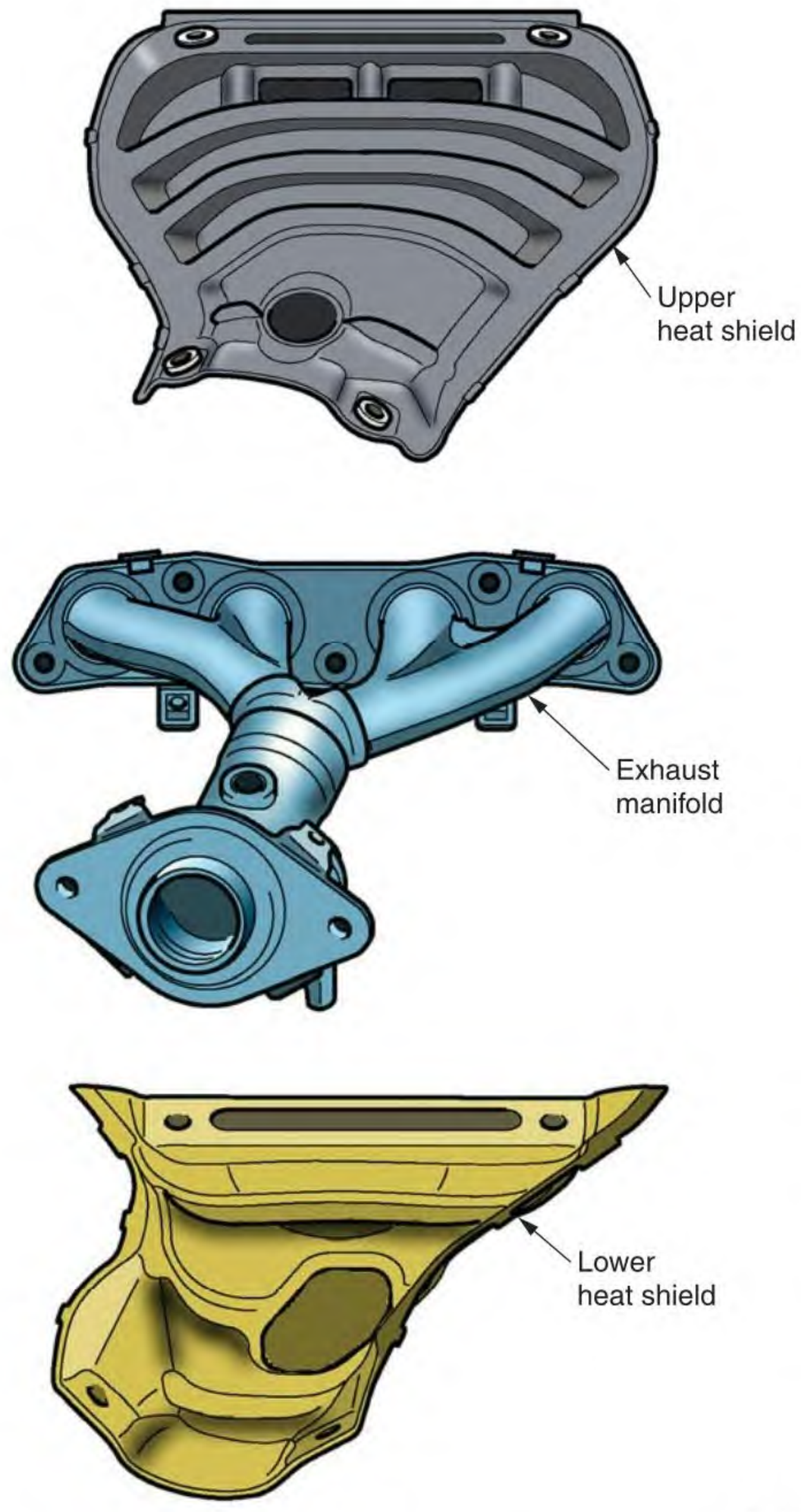
Warning

Always reinstall all exhaust system heat shields. If the heat shields are not installed, undercoating, carpeting, dry leaves on the ground, and other flammable materials could easily catch the entire vehicle on fire!

Catalytic Converter

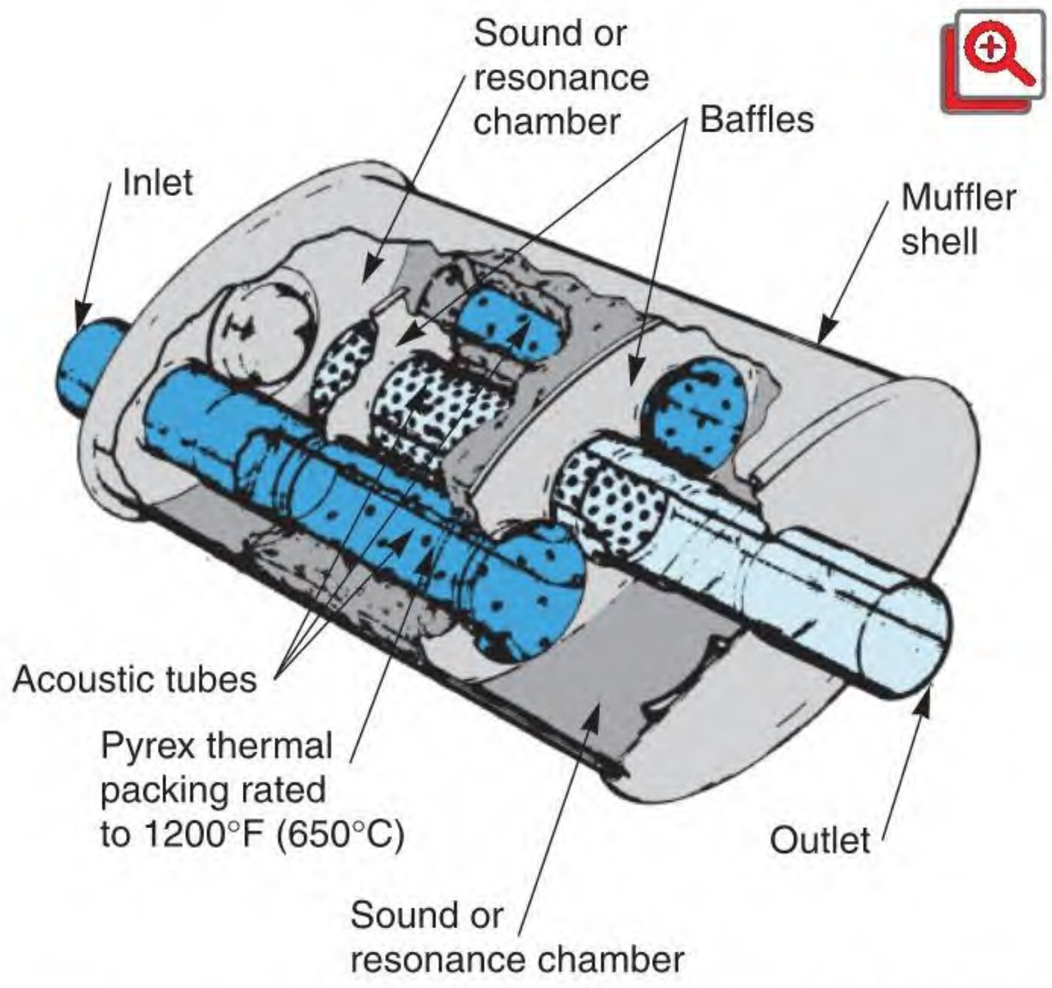
A catalytic converter is an afterburner used to reduce the amount of exhaust pollutants entering the atmosphere. One or more catalytic converters can be located in the exhaust system.

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Toyota

Figure 45-5. These heat shields are designed to protect engine components from the heat given off by the exhaust manifold.



American Exhaust Industries

Figure 45-6. Mufflers contain baffles, resonance chambers, and acoustic tubes to reduce exhaust noise.

Muffler

A muffler reduces the pressure pulses and quiets the resulting noise produced by the engine exhaust. When an engine is running, the exhaust valves are rapidly opening and closing. Each time an exhaust valve opens, a blast of hot gas shoots out of the engine. Without a muffler, these exhaust gas pulsations would roar very loudly. Look at **Figure 45-6**.

Exhaust System Service

Exhaust system service is usually needed when a component in the system rusts and begins to leak. Engine combustion produces water and acids. Therefore, an exhaust system can corrode and fail in a relatively short time.

A leaking exhaust can allow toxic gases to flow through any opening in the car's body and into the passenger compartment. People have died from engine exhaust fumes!

Exhaust System Inspection

To inspect an exhaust system, raise the car on a lift. Use a droplight and, while wearing safety glasses, closely inspect the underside of the exhaust parts for problems such as rusting, loose pipe connections, and gas leaks. Pay particular attention to the muffler and all pipe connections, gaskets, and pipe bends. ***Exhaust leaks*** will often show up as gray or white carbon lines coming from openings.

Warning

Parts of the exhaust system can be very hot. If the engine has been recently running, do not touch the header pipe, heat riser, collector, catalytic converter, or muffler. Touching these can result in serious burns.

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To check an exhaust system for leaks, start and idle the engine. Raise the vehicle on a lift and secure the lift's mechanical latches. Use a stethoscope with only the plastic tube attached (not the metal probe) to listen for leaks. Pass the hose around any point of possible gas leakage. When the stethoscope hose is moved next to any leak, the sound you hear will be amplified to a roar. Find any other gas leaks and repair or replace parts as needed.

Catalytic Converter Temperature Check

A ***catalytic converter temperature check*** quickly tests for an inoperative converter catalyst. A "dead cat" means that the catalytic agent is no longer re-burning the exhaust fumes and treating the engine's exhaust gases. The failed catalytic converter will fail to heat up and further oxidize the carbon oxides and NO_x.

Service Procedure

To perform a catalytic converter temperature check:

1. Attach a shop vent hose to the tailpipe(s).
2. Warm the engine and catalytic converter to full operating temperature.
3. Place and secure the vehicle on a lift.
4. Touch a temperature probe on the front or inlet end of the suspect catalytic converter. Record the temperature.
5. Touch your temperature probe on the rear of the converter near the outlet pipe. Record the temperature.
6. Subtract the rear temperature reading from the front temperature reading.

A good catalytic converter will have an approximately 100°F (38°C) difference in temperature, front to rear. If the catalytic converter is lighting up and burning toxic exhaust fumes, it suggests the rear of the catalytic converter is hotter than the front.

If the two catalytic converter temperature readings are almost the same, the converter is clogged or burned up and should be replaced. The problem may also be an inoperative air injection system that is starving the catalytic converter of oxygen required for the re-burning of toxic fumes in the exhaust gases.

Exhaust System Back Pressure Test

An ***exhaust system back pressure test*** measures the amount of resistance to gas flow in the vehicle. This test should be performed when scan tool readings indicate something is wrong with the O_2 sensor circuits or with the catalytic converters.

Service Procedure

To perform an exhaust system back pressure test:

1. Remove the front oxygen sensor before the catalytic converter.
2. Install a test pressure gauge in the threaded hole for the oxygen sensor. If the engine has air injection, you can also install a test gauge in the metal lines in the air injection system going to the exhaust manifold.
3. Measure and record the exhaust back pressure at idle. At idle, exhaust back pressure should be less than about 1 psi (7 kPa). A higher reading means something is blocking exhaust gas flow at low engine speeds.
4. Increase engine speed and note any increase in the exhaust pressure gauge reading. At about 2000 rpms, exhaust back pressure should be less than approximately 3 psi (21 kPa).

If exhaust back pressure is high, this usually means the catalytic converter is plugged and burning internally. Also check for a rusted muffler that rattles when shaken. The baffles in old, rusted mufflers can collapse and block normal exhaust flow. Badly rusted pipes can have a thin sheet of metal separate inside the pipe, causing blockage of all exhaust flow.

Engine Vacuum Test

An ***engine vacuum test*** is another easy way to check for a clogged or restricted exhaust system.

Service Procedure

To perform an engine vacuum test:

1. Connect your test vacuum gauge to any vacuum line on the engine that pulls suction at idle.
2. Start and idle the engine while reading the vacuum gauge.

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3. As you watch the vacuum gauge, use the throttle lever on the engine to increase engine speed to about 2,500 rpms.
4. The vacuum reading should initially drop and then rise if there are no restrictions in the exhaust system.
5. If the vacuum reading drops with the engine at a steady 2,500 rpms, the engine is having a tough time pumping exhaust gases into the exhaust system. A vacuum drop at higher engine speed indicates high exhaust back pressure and a restriction or gas flow problem.
6. Find and replace the restricted exhaust system part.

Exhaust System Repairs

Faulty exhaust system parts must be removed and replaced. If only the muffler is rusted, a new muffler can be installed in the existing system. After prolonged service, several parts or the entire exhaust system may require replacement.

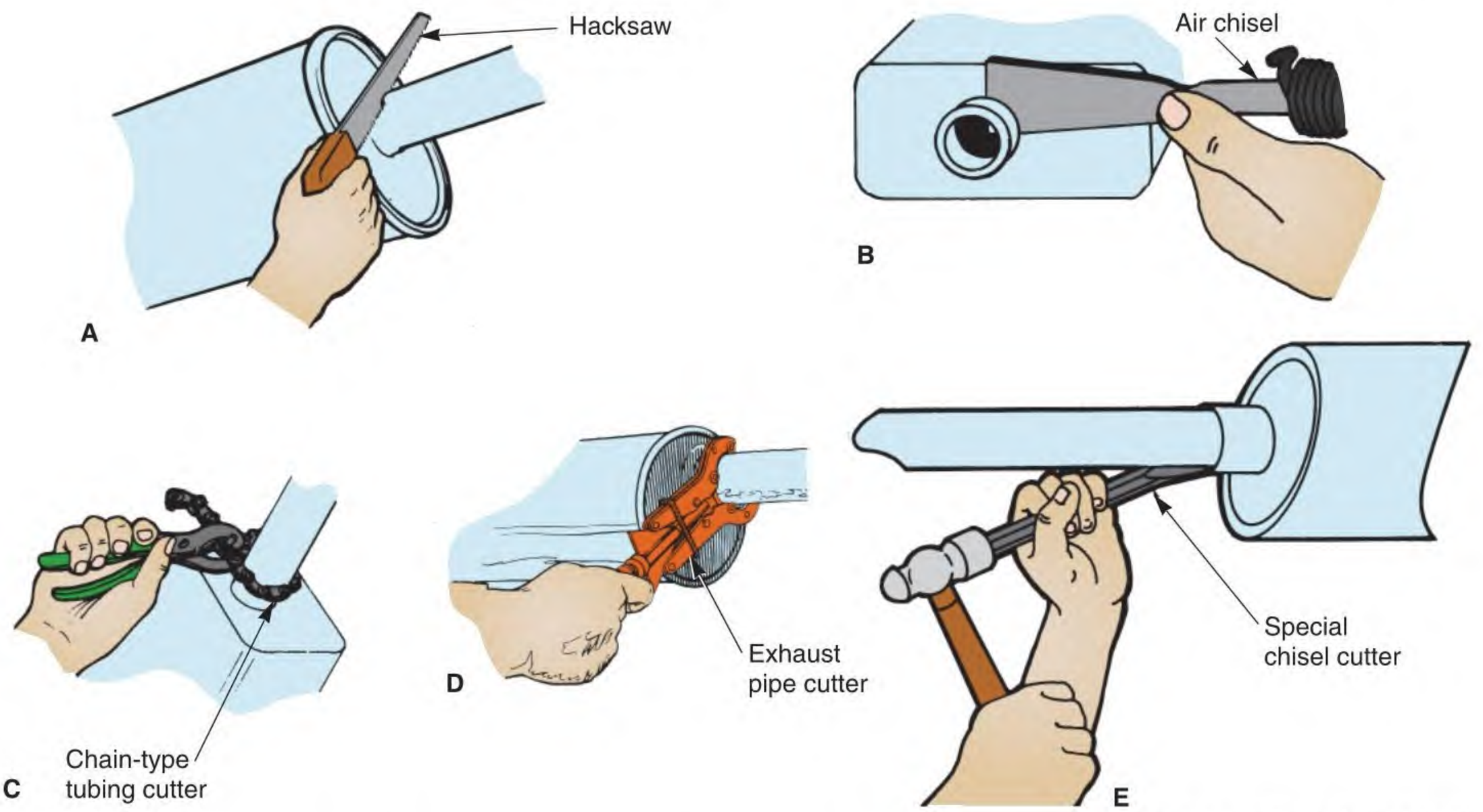


AP Parts

Figure 45-7. Rust penetrant or solvent will ease the removal of badly rusted fasteners.

When repairing an exhaust system, remember the following:

- Use rust penetrant on all threaded fasteners that will be reused. This is especially important on the exhaust manifold flange nuts or bolts. Refer to **Figure 45-7**.
- Use an air chisel, cut-off tool, cutting torch, or hacksaw to remove faulty parts. Make sure you do not damage parts that will be reused. See **Figure 45-8**.

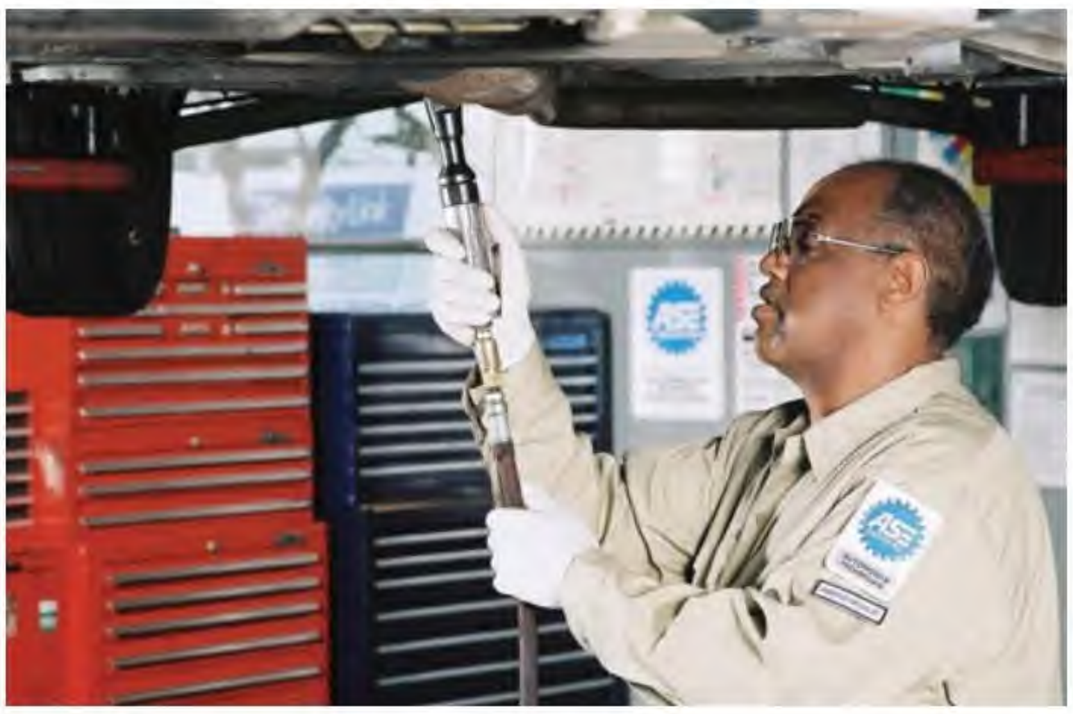


AP Parts, Lisle, and Florida Dept. of Voc. Ed.

Figure 45-8. Note the various methods used to remove exhaust system parts. A—A hacksaw will cut off old exhaust pipes but not very quickly. B—An air chisel is the fastest method of cutting off old exhaust parts. Be very careful not to let the tool slip off. C—A chain-cutter wrench cuts all the way around steel tubing. D—An exhaust pipe cutter is similar to a chain cutter. It must be pulled back and forth so its cutting rollers can penetrate metal. E—A pointed cutting chisel allows you to hammer cut a slot in old pipes so they will come off more easily.

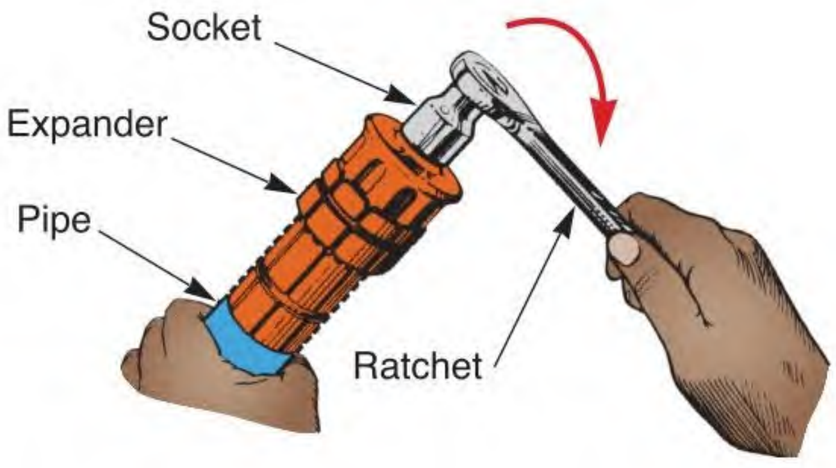
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- Use a six-point socket and ratchet or an impact wrench for fastener removal. This method will usually allow quick fastener removal without rounding off the fastener heads. Refer to **Figure 45-9**.
- Wear safety glasses or goggles to keep rust and dirt from entering your eyes.
- Obtain the correct replacement parts.
- Use a pipe expander to enlarge pipe ends as needed, **Figure 45-10**. A pipe shaper can be used to straighten dented pipe ends, **Figure 45-11**.
- Position all clamps properly, **Figure 45-12**.
- Install any necessary adapters.
- Make sure all pipes are fully inserted.
- Double-check the routing of the exhaust system. Keep adequate clearance between the exhaust system components and the vehicle's body and chassis. See **Figure 45-13**.
- Tighten all clamps and hangers evenly. Torque the fasteners only enough to hold the parts. Overtightening will smash and deform the pipes, possibly causing leakage. See **Figure 45-14**.



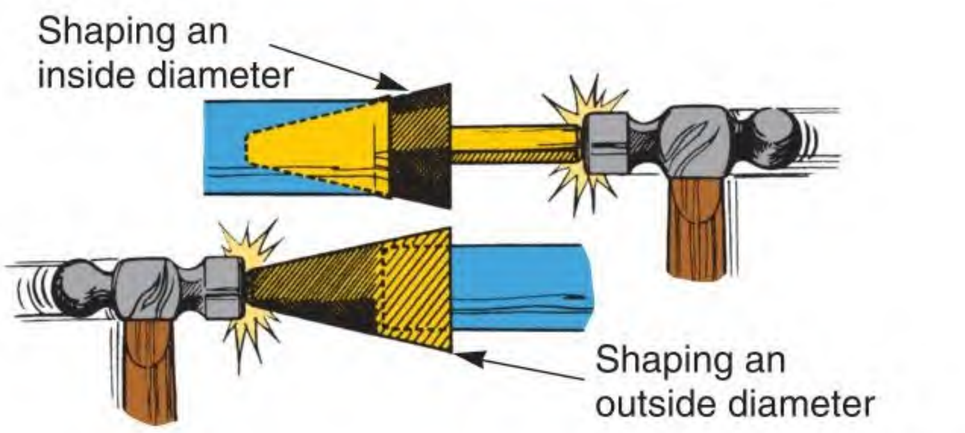
ASE

Figure 45-9. Technicians use impact guns and air ratchets to quickly remove and install exhaust system fasteners. Rust penetrant or the heat of a gas torch may be required to free frozen bolts to avoid breakage. If you break off a manifold stud bolt, you may have to completely remove the manifold for fastener repair.



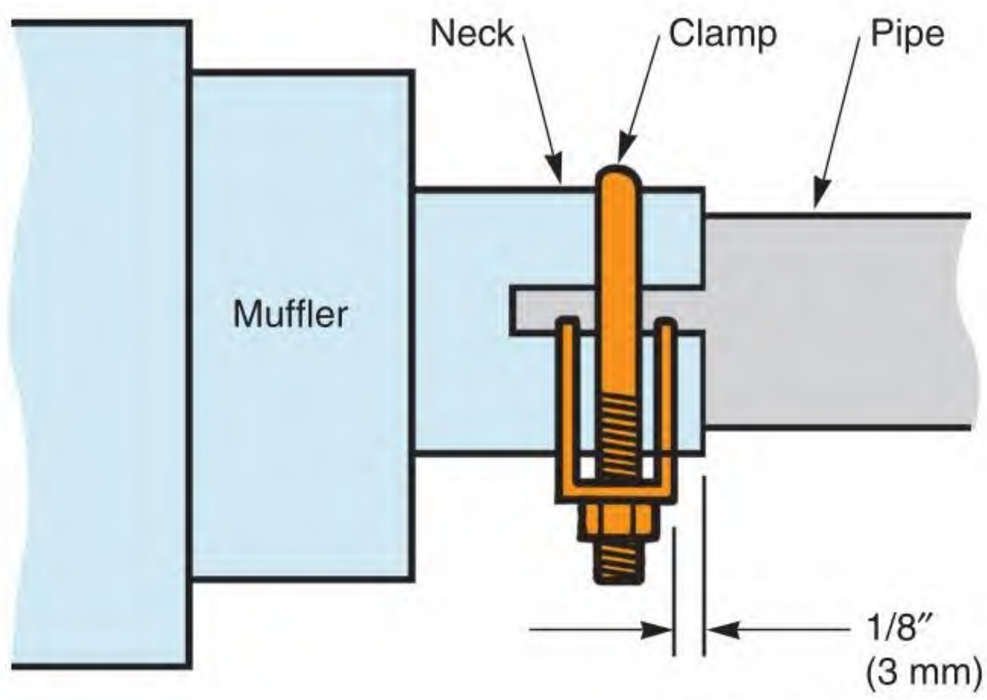
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Figure 45-10. A pipe expander enlarges the inside and outside diameters of pipes. One pipe should slide over and fit the other tube diameter.



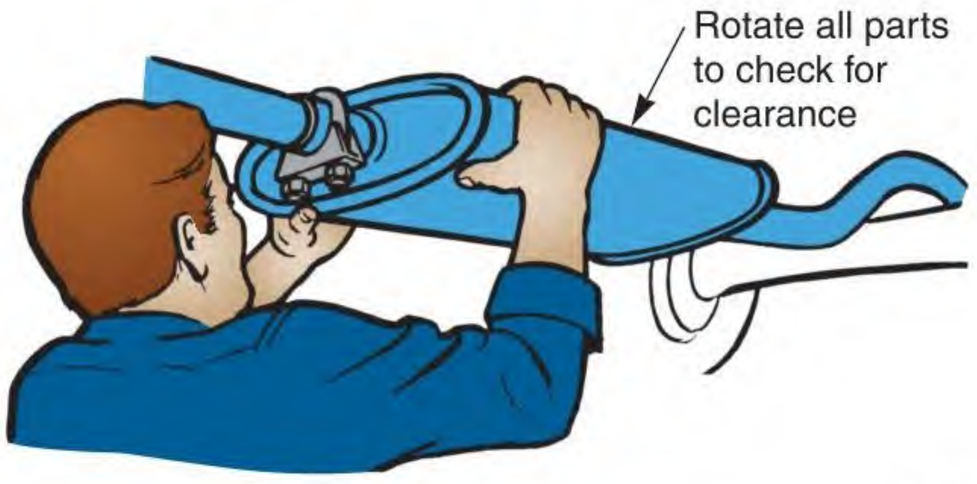
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Figure 45-11. A pipe shaper rounds the internal diameter of dented pipe ends.



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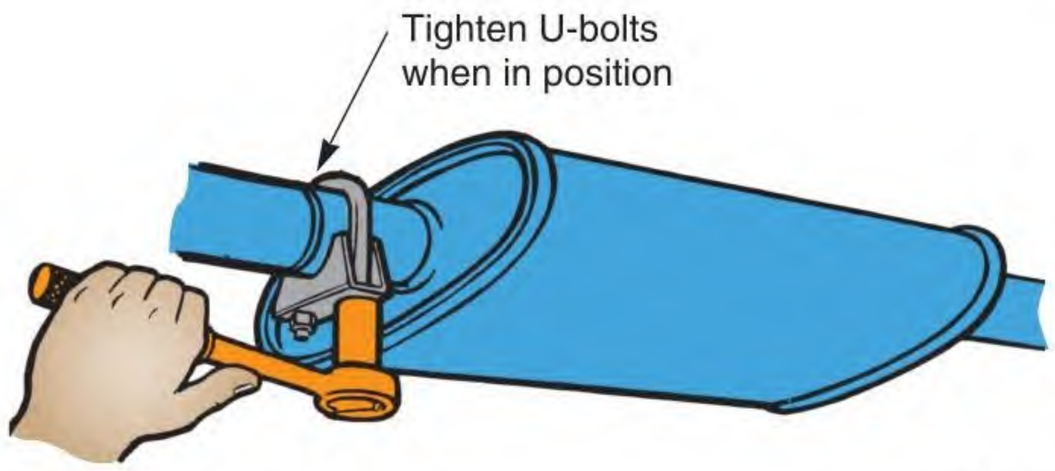
Figure 45-12. Make sure muffler clamps are installed correctly. The clamp must be positioned around both pipes. If not, one pipe can pull out of the other.



AP Parts

Figure 45-13. Make sure all parts are lined up properly and double-check the exhaust system-to-car clearance before you tighten the clamps.

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AP Parts

Figure 45-14. After checking clearance, tighten all clamps evenly and properly. After tightening the clamps, you should be able to shake the exhaust system without it hitting and rattling on the underbody of vehicle.

- When replacing an exhaust manifold, use a gasket and check sealing surface flatness. If the manifold is warped, it must be machined flat. Torque the exhaust manifold bolts to specification.
- Always use new gaskets and O-rings, **Figure 45-15**.
- Check heat valve operation using the information in a service manual.
- Install all heat shields.
- Check the system for leaks and rattles after repairs.

Stainless Steel Exhaust System Repairs

Many new vehicle exhaust systems are made of stainless steel. Stainless steel will not rust and will provide much longer service life than ordinary steel systems.

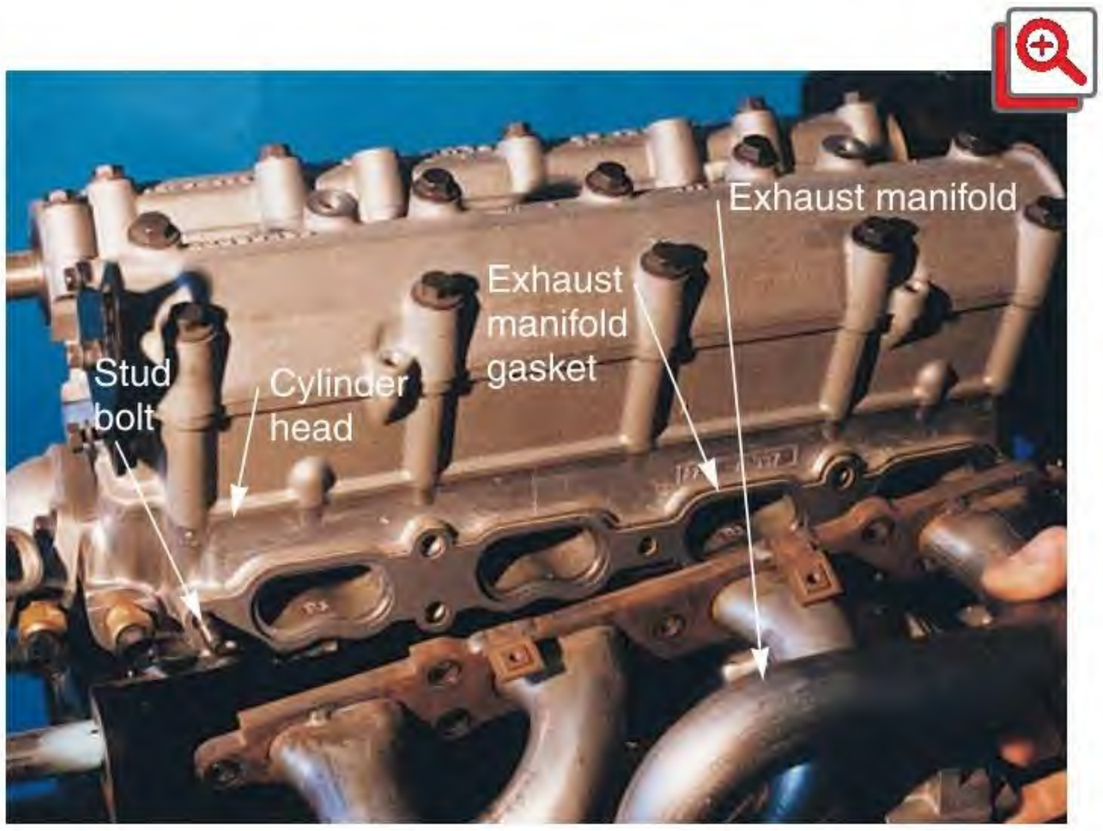
When servicing stainless steel exhaust systems, use heavy-duty clamps designed for this type of system. Conventional muffler clamps are not strong enough and may allow dangerous exhaust gas leakage. They will not compress the stiff stainless steel pipe enough to make a good connection.

When cutting or welding stainless steel, use the correct rod or wire material. Keep in mind that stainless steel does not react in the same manner as carbon steel when heated near its melting point. Stainless steel can be "red hot" when it looks cool.

Safety First

A technician was cutting off an old rusty muffler with an air-operated impact chisel when the tool threw a sharp metal shard toward his face. Unfortunately, the technician was not wearing the proper protective gear and the shard lodged in his eye. While doctors were able to remove the embedded metal shard, the technician now has impaired vision in the injured eye.

Always wear safety goggles or a full face shield and safety glasses when cutting sheet metal, especially when working under a vehicle. Wear welding goggles and a leather body protector if using a torch to cut off old exhaust parts.



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Figure 45-15. The exhaust manifold gasket is held in position as all fasteners are started by hand. Torque the fasteners to recommended value in a crisscross pattern.

Summary

- An exhaust system quiets engine operation and carries exhaust fumes to the rear of the vehicle.
- An exhaust manifold connects the cylinder head exhaust ports to the header pipe.
- The header pipe is steel tubing that carries exhaust gases from exhaust manifold to catalytic converter or muffler.
- A catalytic converter is a device for removing pollutants from engine exhaust.
- The intermediate pipe is tubing sometimes used between the header pipe and muffler or the catalytic converter and muffler.
- A muffler is a metal chamber for damping pressure pulsations to reduce exhaust noise.

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- Heat shields are metal plates that prevent exhaust heat from transferring into another object.
- When repairing an exhaust system, use rust penetrant on all threaded fasteners that will be reused.
- Check the exhaust system for leaks and rattles after repairs.
- When servicing stainless steel exhaust systems, use heavy-duty clamps designed for this type of system.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

catalytic converter
catalytic converter temperature check
crossover pipe
dual exhaust system
engine vacuum test
exhaust back pressure
exhaust leaks
exhaust manifold
exhaust manifold doughnut
exhaust pipes
exhaust system
exhaust system back pressure test
exhaust system clamps
hangers
header pipe
headers
heat shields
high back pressure
intermediate pipe
low back pressure
muffler
single exhaust system
tailpipe

Activity

1. Research the internal combustion process and produce a cutaway sketch of an exhaust system. Use it to explain why high back pressure will reduce engine power.

Review Questions

Please do not write in this text. Place your answers on a separate sheet of paper.

1. An exhaust system _____ engine operation and carries _____ to the rear of the car.

Match each of the following exhaust system parts with its definition.

2. _____ Heat shield.
3. _____ Catalytic converter.
4. _____ Intermediate pipe.
5. _____ Hangers.
6. _____ Header pipe.
7. _____ Tailpipe.
8. _____ Muffler clamp.
9. _____ Exhaust manifold.
10. _____ Muffler.

A. U-bolt for connecting parts of exhaust system.
B. Tubing that connects exhaust manifold to rest of system.
C. Chamber for damping out pressure pulsations.
D. Carries exhaust from muffler to rear of car body.
E. Connects cylinder head exhaust ports to header pipe.
F. Prevents heat from transferring into other objects.
G. Connects exhaust manifold to tailpipe.
H. Device for removing pollutants from exhaust.
I. Pipe between catalytic converter and muffler.
J. Connects exhaust system to underside of car body.

11. Define the term *exhaust back pressure*.
12. A dual exhaust system is commonly used on small, high-fuel-economy engines. True or False?
13. An exhaust _____ is bolted to the cylinder head and encloses the exhaust port openings.
14. When is exhaust system service commonly needed?
15. List sixteen rules to remember when servicing an exhaust system.

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ASE-Type Questions

1. Technician A says that the exhaust system can help quiet engine operation by muffling the sound of exhaust gases shooting out of the exhaust ports. Technician B says that the exhaust system can lower emissions by treating the exhaust gases. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Each of the following is a major part of an exhaust system, *except:*
   (A) muffler.
   (B) hangers.
   (C) flyweights.
   (D) header pipe.
3. Back pressure is being discussed. Technician A says that high back pressure is an indication of a restriction in the exhaust system. Technician B says that a well-designed exhaust system should have low back pressure. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. In some dual exhaust systems, a(n) _____ connects the right and left header pipes together to equalize back pressure for a slight increase in engine power.
   (A) heat shield
   (B) catalytic converter
   (C) exhaust pipe
   (D) crossover pipe
5. Which of the following is used to reduce the amount of exhaust pollutants entering the atmosphere?
   (A) Heat shields.
   (B) Catalytic converter.
   (C) Pyrex thermal packing.
   (D) Cylinder head exhaust ports.
6. Technician A says to use the metal tip of a stethoscope to listen for an exhaust system leak. Technician B says to remove the metal tip from the stethoscope so leaks can be heard through the rubber or plastic hose. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. Technician A says that a good catalytic converter should have a 10°F temperature difference front to rear. Technician B says catalytic converter temperature readings should be uniform front to back. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. Technician A says an exhaust system back pressure test should be performed when scan tool readings indicate problems with the catalytic converters. Technician B says that back pressure should be less than 3 psi at idle. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Technician A says to use a six-point socket to loosen and remove exhaust system fasteners without stripping nut and bolt heads. Technician B says to use rust penetrant on corroded exhaust system fasteners. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. Technician A says that overtightening exhaust system clamps can cause leakage. Technician B says that conventional exhaust system clamps can be used in stainless steel exhaust systems. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Exhaust System Diagnosis

Condition	Possible Causes	Correction
Excessive exhaust noise (under hood).	1. Damaged exhaust manifold. 2. Manifold to cylinder head leak. 3. EGR valve leakage: a. EGR valve to manifold gasket. b. EGR valve to EGR tube gasket. c. EGR tube to manifold tube nut. 4. Exhaust flex joint. a. Spring height, installed not correct. b. Exhaust sealing ring defective. 5. Pipe and shell noise from front exhaust pipe.	1. Replace manifold. 2. Tighten manifold and/or replace gasket. 3. a. Tighten nuts or replace gasket. b. Tighten nuts or replace gasket. c. Tighten tube nut. 4. a. Check spring height, both sides (specification is 32.5 mm, 1.28 inch) look for source of spring height variation if out of specification. b. Inspect seal for damage on round spherical surface. If no damage is evident, check for exhaust obstruction causing high back pressure on heavy acceleration. 5. Characteristic of single wall pipes.
Excessive exhaust noise.	1. Leaks at pipe joints. 2. Burned or blown or rusted out muffler, tailpipe of exhaust pipe. 3. Restriction in muffler or tailpipe. 4. Converter material in muffler.	1. Tighten clamps at leaking joints. 2. Replace muffler or muffler tailpipe or exhaust pipe. 3. Remove restriction, if possible or replace as necessary. 4. Replace muffler and converter assemblies. Check fuel injection and ignition systems for proper operation.
Exhaust system mechanical noise.	1. Improperly aligned exhaust system. 2. Support brackets loose, bent, or broken. 3. Incorrect muffler or pipes. 4. Baffle loose in muffler. 5. Manifold heat control valve rattles. 6. Worn engine mounts. 7. Damaged or defective catalytic converter.	1. Align system. 2. Tighten or replace brackets. 3. Install correct muffler or pipes. 4. Replace muffler. 5. Replace thermostatic spring. 6. Replace engine mounts. 7. Repair or replace converter.
Engine lacks power.	1. Clogged muffler. 2. Clogged or kinked exhaust or tailpipe. 3. Muffler or pipes too small for vehicle. 4. Catalytic converter clogged or crushed shut.	1. Replace muffler. 2. Replace pipe. 3. Install muffler and pipes of the correct size and type. 4. Replace with new converter.

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Chapter 46
Turbochargers and Superchargers—Construction, Operation, and Repair

After studying this chapter, you will be able to:

- Explain the basic parts of a turbocharging system.
- Use a scan tool and multimeter to diagnose engine boost pressure problems.
- Describe the construction and operation of a turbocharger and its waste gate, intercooler, knock sensor, and other major components.
- Remove and replace a turbocharger and waste gate.
- Summarize the construction and operation of a supercharger and its electromagnetic clutch, intercooler, and control circuitry.
- Demonstrate an understanding of safety procedures for working on turbochargers and superchargers.
- Correctly answer ASE certification test questions on turbocharger and supercharger service and repair.

Most automakers are now manufacturing passenger vehicles with either supercharged or turbocharged engines. Air in the engine's intake manifold is pressurized above atmospheric pressure by a large air pump, which is often called a blower. The blower helps force more oxygen into the engine's cylinders for more violent combustion. The industry trend is toward turbochargers because turbocharged engines are more fuel efficient and can develop more total horsepower than supercharged engines.

This chapter will explain how superchargers and turbochargers work and describe the differences between them. You will see how each is constructed and lubricated. You will also learn how to diagnose, service, and repair turbochargers, superchargers, intercoolers, waste gates, blow off valves, knock sensors, electromagnetic supercharger pulleys, and other parts.

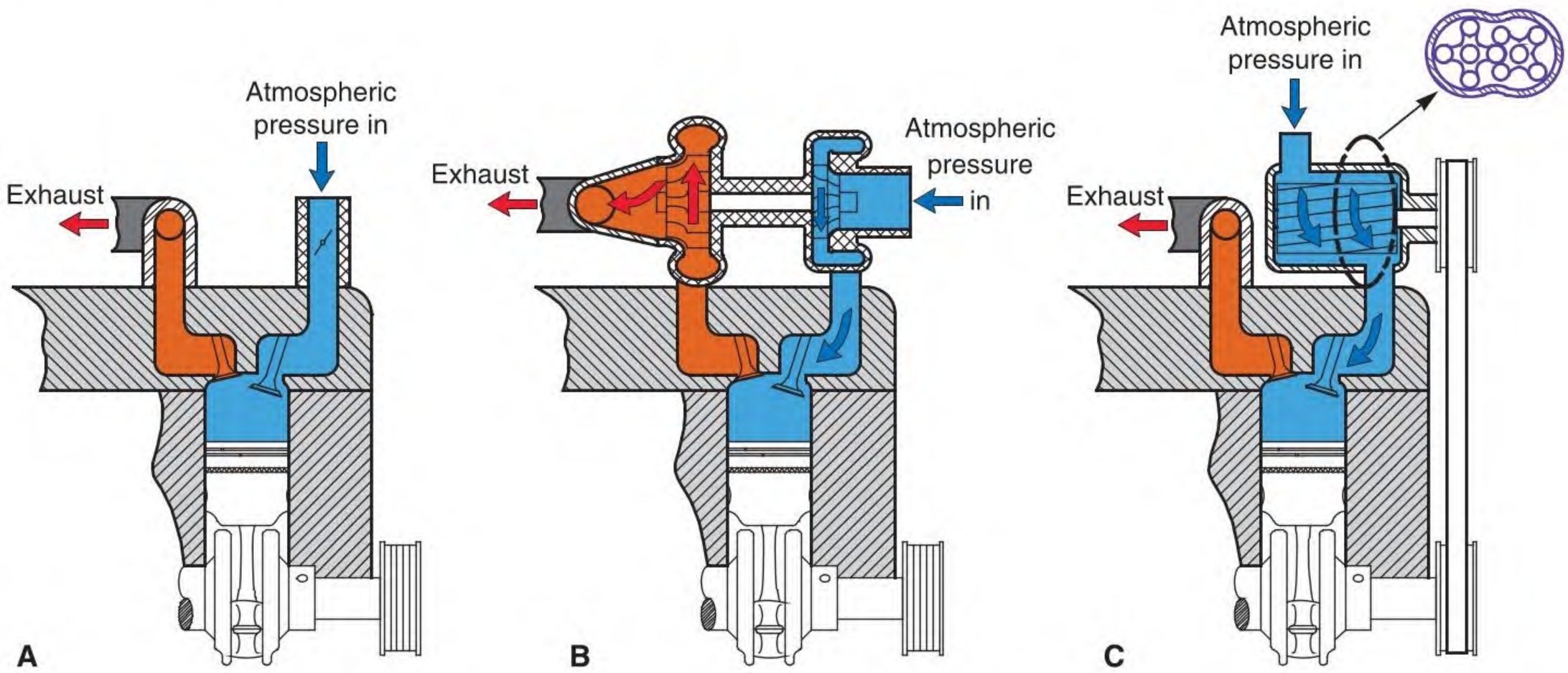
Engine Aspiration

The term ***engine aspiration*** refers to how air enters the engine, or how the engine breathes. An engine can be classified as normally aspirated, supercharged, or turbocharged. Study **Figure 46-1**.

Engine power is limited by an engine's volumetric efficiency. ***Volumetric efficiency*** is a measure of an engine's ability to draw air into its cylinders during the intake strokes. A high volumetric efficiency means the engine "breathes" easily because of good intake port, valve, combustion chamber, and camshaft design. However, most engines do not have high volumetric efficiency. Restrictions to airflow through the intake manifold and cylinder head result in pumping losses. As a result, these engines do not produce as much horsepower as theoretically possible for their size.

A ***normally aspirated engine***, also called an ***atmospheric engine***, uses atmospheric pressure

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Figure 46-1. A—A normally aspirated engine only uses atmospheric pressure to force the air-fuel charge into cylinders. B—A turbocharged engine uses exhaust gases to spin a turbine. The turbine pressurizes the intake manifold and forces the air-fuel charge into the cylinders. C—A supercharged engine uses a belt, chain, or gears to spin a compressor (blower). The blower pressurizes the intake manifold and forces the air-fuel charge into the cylinders.

(14.7 psi, or 100 kPa, at sea level) to push air into the engine. With outside air pressure as a moving force, only a limited amount of fuel can be burned on each power stroke.

Turbocharged and supercharged engines use an air pump, or blower, to increase pressure of the intake air. The increased pressure, which is called boost, helps improve volumetric efficiency and increase power output while also reducing exhaust emissions. Most production superchargers and turbochargers provide a ***boost pressure*** of 4–10 psi (30–70 kPa) above atmospheric pressure inside the intake manifold plenum.

A ***turbocharger***, or "***turbo,***" is an air pump driven by engine exhaust gases. Turbochargers are commonly used on passenger cars, trucks, and competition vehicles. Because a turbocharger is spun by hot gases leaving the engine, it helps burn and utilize wasted heat energy flowing and expanding through the engine's exhaust header. Factory turbocharged engines produce upwards of 600 horsepower and are emissions compliant.

A ***supercharger*** is a large engine-driven air pump that is driven by a belt, a chain, or gears. Superchargers are found on large diesel truck engines and high-performance passenger car engines. Supercharged gasoline passenger car engines easily develop 500 horsepower. Although a supercharger greatly increases engine power, it also takes considerable engine power to spin the supercharger because of its large drive belt.

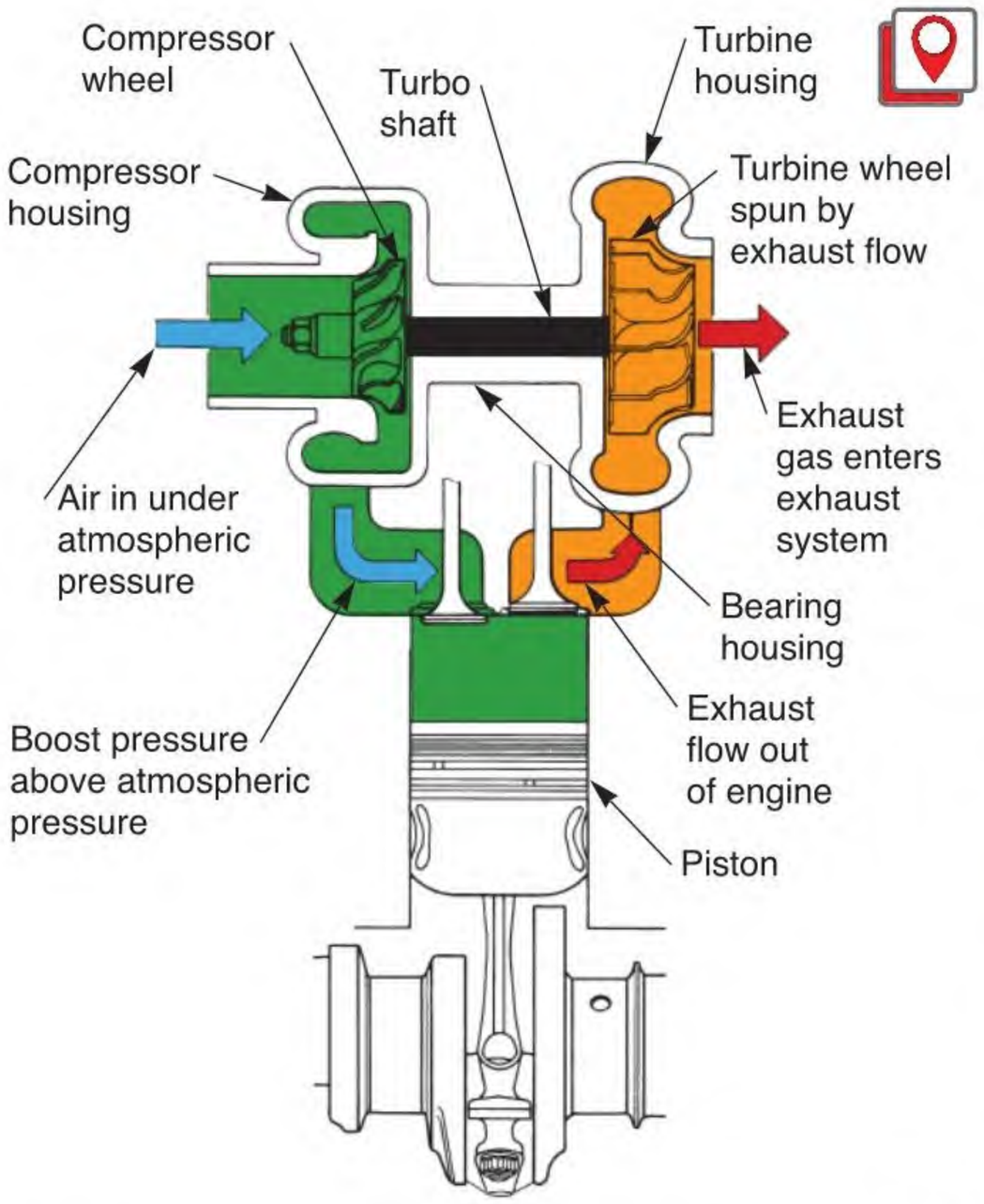
Turbochargers

By harnessing exhaust energy, a turbocharger can improve engine efficiency (fuel economy and emission levels). This is especially true with diesel engines.

The basic parts of a turbocharger are shown in **Figure 46-2**. These parts include:

- ***Turbine wheel***—The turbine wheel is an exhaust-driven fan that turns the turbo shaft and compressor wheel.
- ***Turbine housing***—The turbine housing is the outer enclosure that routes exhaust gases around the turbine wheel.
- ***Turbo shaft***—The turbo shaft is a steel shaft that connects the turbine and compressor wheels. It passes through the center of the bearing housing.
- ***Compressor wheel***—This driven fan forces air into the engine intake manifold under pressure.
- ***Compressor housing***—The compressor housing is the outer enclosure that surrounds the compressor wheel. Its shape helps pump air into the engine.

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Chrysler

Figure 46-2. Study the parts of this turbocharger. The turbine wheel spins a shaft and a compressor wheel. The compressor wheel then pressurizes the air entering the engine for more power output.

- ***Bearing housing***—The bearing housing is the enclosure around the turbo shaft that contains bearings, seals, and oil passages.

Turbocharger Operation

When the engine is running, hot exhaust gases blow out through the open exhaust valve ports and into the exhaust manifold. The exhaust manifold and connecting tubing route these gases into the turbine housing. As the gases pass through the turbine housing, they strike the fins or blades on the turbine wheel. When engine load is high enough, there is enough exhaust gas flow to rapidly spin the turbine wheel.

Since the turbine wheel is connected to the compressor wheel by the turbo shaft, the compressor wheel rotates with the turbine. Compressor wheel rotation pulls air into the compressor housing. Centrifugal force throws the air outward. This causes air to flow out of the turbocharger and into the engine cylinder under pressure. Look at **Figure 46-3**.

Turbo Lag

Turbo lag refers to a short delay before the turbo develops sufficient boost (pressure above atmospheric pressure) to meet engine demands. When the car's accelerator pedal is pressed down for rapid acceleration, the engine may lack power for a few seconds. This is caused by the compressor and turbine wheels not spinning fast enough. It takes time for the exhaust gas to bring the turbo up to operating speed.

Modern turbo systems suffer very little from turbo lag. Their turbine and compressor wheels are so light that they can accelerate up to speed quickly. Some engines use two smaller turbines, called sequential turbos or twin turbos, to reduce rotating mass and turbo lag.

Variable Vane Turbochargers

A ***variable vane turbocharger*** uses a set of hinged blades mounted inside the turbine housing to control exhaust gas flow over the turbine wheel or fan. To almost eliminate turbo lag, the turbo vanes can be angled to aim more exhaust flow toward the outer circumference of the turbine wheel. This will accelerate the turbo up to high rpms more quickly. With the vanes in this position, low engine speeds (about 1500 rpms) and less exhaust gas flow can still spin the turbo wheels fast enough to build boost pressure for improved performance.

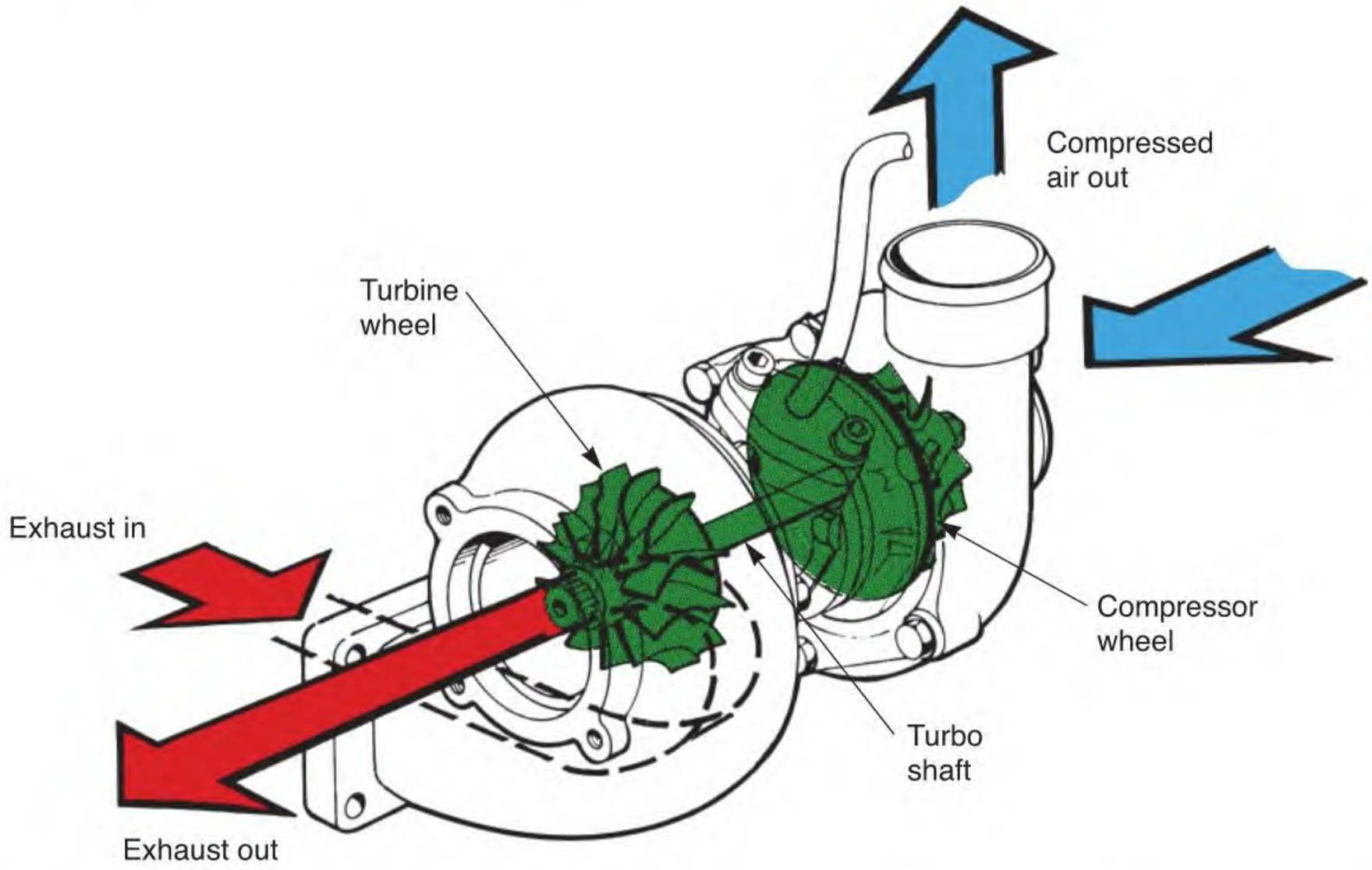
Then, as boost develops near maximum, the engine ECM can energize a servo motor or solenoid to retract the vanes and direct exhaust gas flow over the full face of the turbine wheel for even higher boost levels. Look at **Figure 46-4**.

Turbocharger Locations

Turbochargers are normally bolted to the side, top, or front of the engine. Exhaust tubing routes engine exhaust gases into the inlet of the turbine housing. Tubing or a hose also connects the outlet of the compressor housing to the engine intake manifold. Small 4-cylinder engines normally have only one turbo. Larger V or flat engines can have twin turbochargers, one for each bank of cylinders.

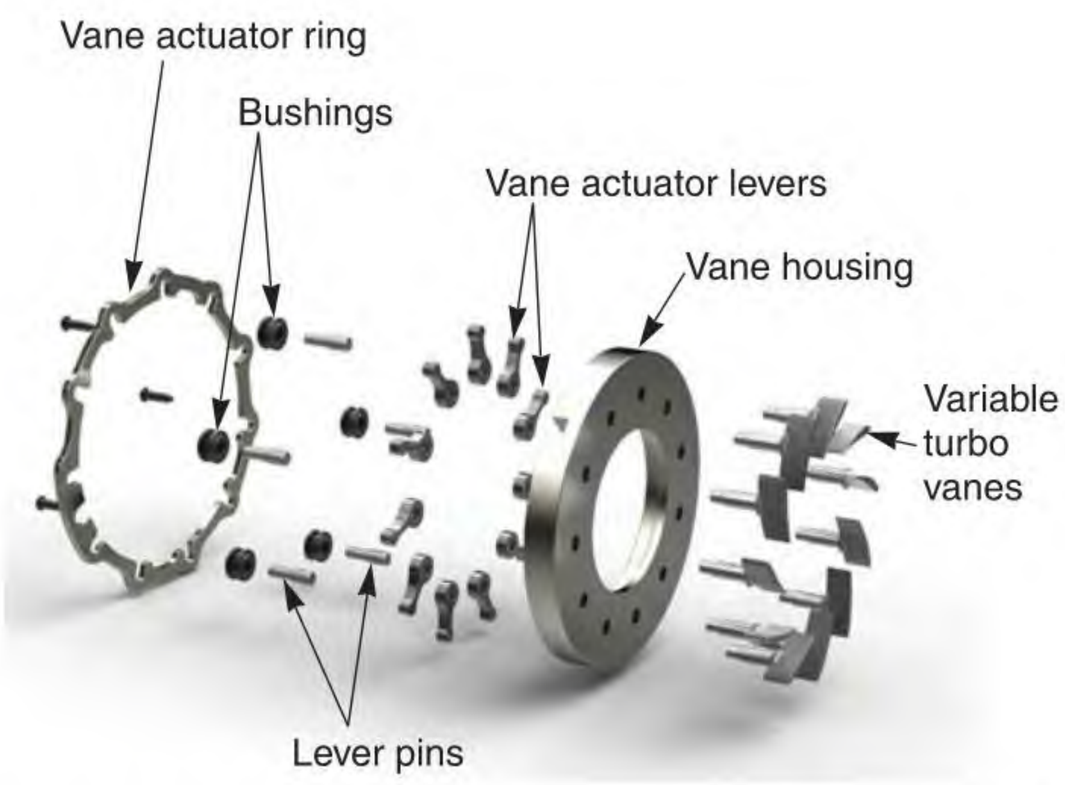
Theoretically, the turbocharger should be located as close to the engine exhaust manifold as possible. Then, a maximum amount of exhaust heat will enter and expand inside the turbine housing. When the hot gases blow onto the spinning turbine wheel, they are still burning and expanding to help rotate the turbine. See **Figure 46-5**.

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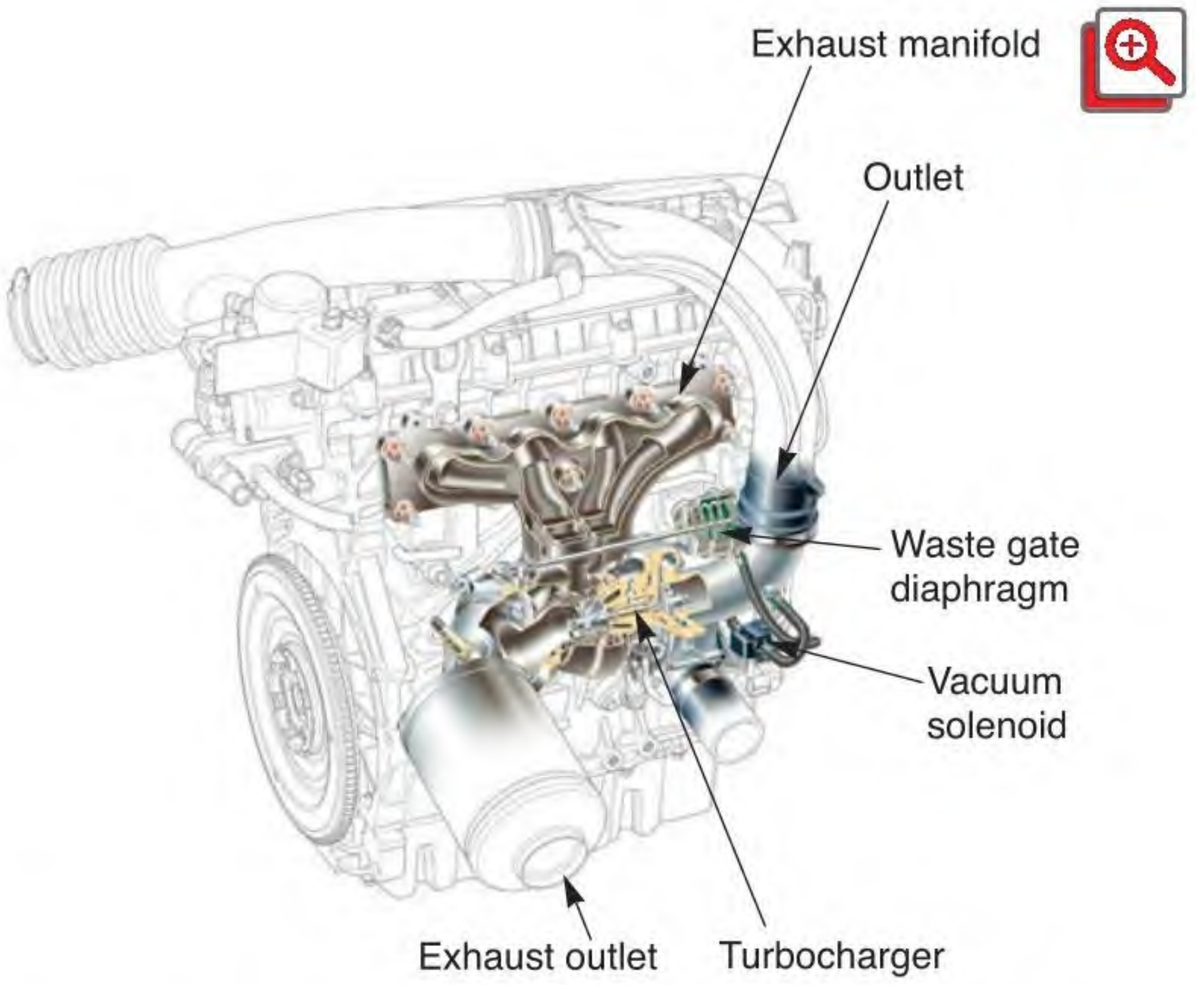
Saab

Figure 46-3. Exhaust flow spins the turbine wheel shaft and the compressor wheel. Normally, wasted energy in the exhaust is used to increase compression stroke pressure in the cylinders for more violent combustion.



Porsche

Figure 46-4. The various parts of one manufacturer's variable vane turbocharger are shown here. This advanced design uses adjustable vanes to change the "angle of attack" of air flowing through the turbo impeller housing. The vanes can be moved to direct more or less air over the turbine wheel. For example, as engine speed increases, the ECM can extend the vanes to reduce boost pressure without changing turbo rpms.



Volvo

Figure 46-5. The turbocharger is generally located as close to the exhaust manifold as possible. In this system, the turbine housing is an integral part of the exhaust manifold.

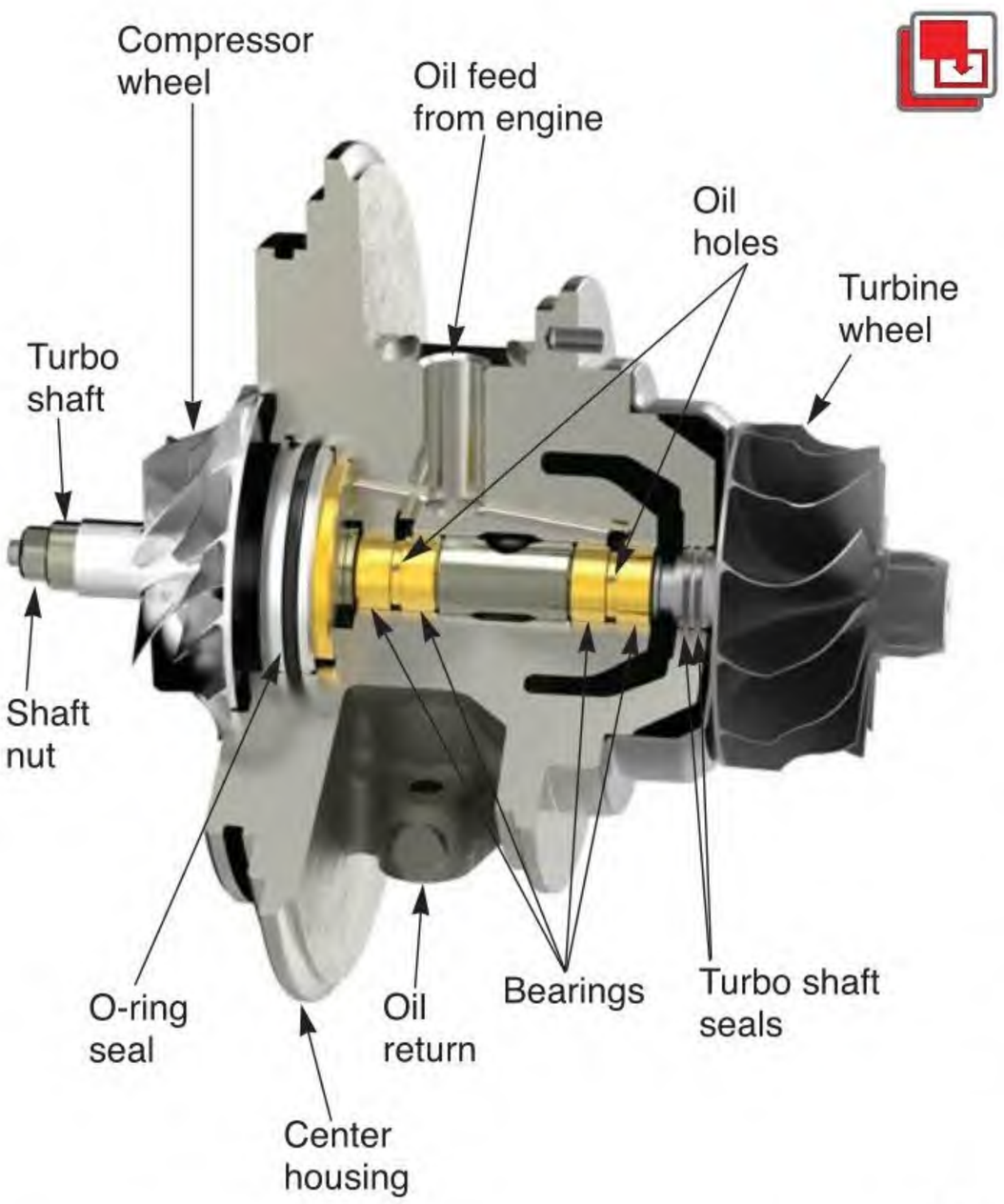
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Turbocharger Lubrication

Turbocharger lubrication is needed to protect the turbo shaft and bearings from damage. A turbocharger can operate at speeds up to 100,000 rpms. For this reason, the engine lubrication system forces motor oil into the turbo shaft bearings. See **Figure 46-6**.

Oil passages are provided in the turbo housing and bearings. An oil supply line runs from the engine to the turbo. With the engine running, oil enters the turbo under pressure. See **Figure 46-7**.

Sealing rings (piston-type rings) are placed around the turbo shaft at each end of the turbo housing. They prevent oil leakage into the compressor and turbine housings. A ***drain passage*** and ***drain line*** allow oil to return to the oil pan after passing through the turbo bearings.



Bosch

Figure 46-6. Study this cutaway view of an actual turbocharger. Note the turbo shaft bearings in gold. Engine oil is fed to these bearings under reduced pressure. A constant supply of clean oil is needed to keep the turbo bearings at speeds reaching almost 100,000 revolutions per minute. Also note the small seals at the ends of the turbo shaft that prevent oil leakage and engine smoking.

Waste Gate

A ***waste gate*** limits the amount of boost pressure developed by the turbocharger. A waste gate consists of the following:

- ***Waste gate diaphragm***—The waste gate diaphragm is a flexible membrane that reacts to different amounts of boost pressure.
- ***Waste gate diaphragm spring***—The waste gate diaphragm spring is a coil spring that holds the waste gate valve in the normally closed position to build boost pressure.
- ***Waste gate valve***—The waste gate valve is a poppet, flap, or butterfly valve that can open to bypass exhaust gases away from the turbine wheel to control boost pressure.
- ***Waste gate housing***—The waste gate housing is an airtight, metal container that encloses the diaphragm chamber and has a pressure hose fitting to measure boost pressure.
- ***Waste gate pressure line***—The waste gate pressure line is a hose that connects the waste gate with a source of intake manifold pressure.

A waste gate is a butterfly or poppet-type valve operated by a diaphragm assembly that allows exhaust to bypass the turbine wheel. See **Figure 46-8**. Intake manifold pressure acts on the diaphragm to control waste gate valve action. The valve controls the opening and closing of a passage around the turbine housing.

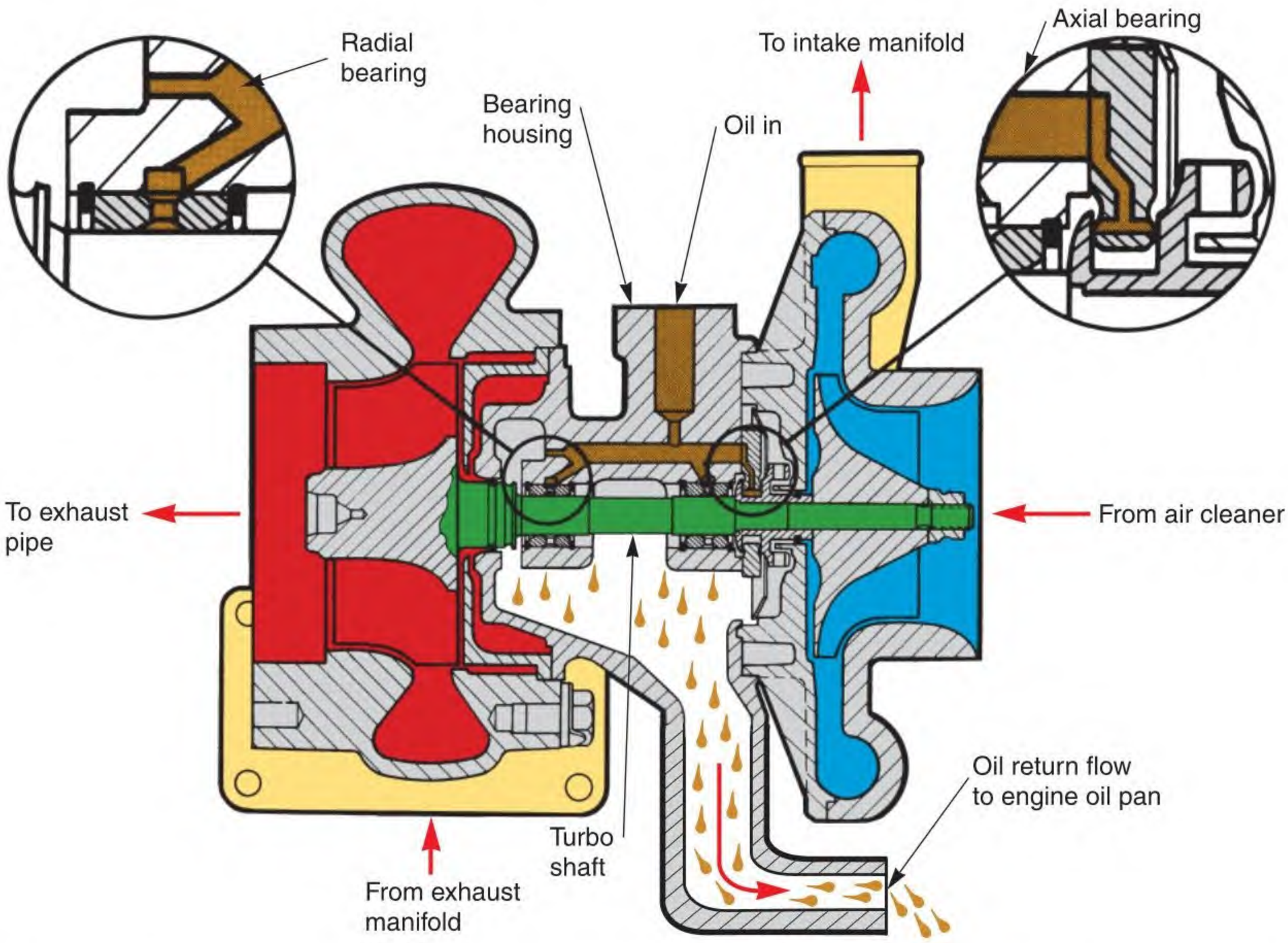
Without a waste gate, the turbo could produce too much pressure in the combustion chambers. This could lead to detonation (spontaneous gasoline combustion) and severe engine damage.

Waste Gate Operation

Under partial load, the system routes all the exhaust gases through the turbine housing. The waste gate is closed by the diaphragm spring. This ensures that there is adequate boost to increase engine power. The basic operation of a turbocharger waste gate is shown in **Figure 46-9**.

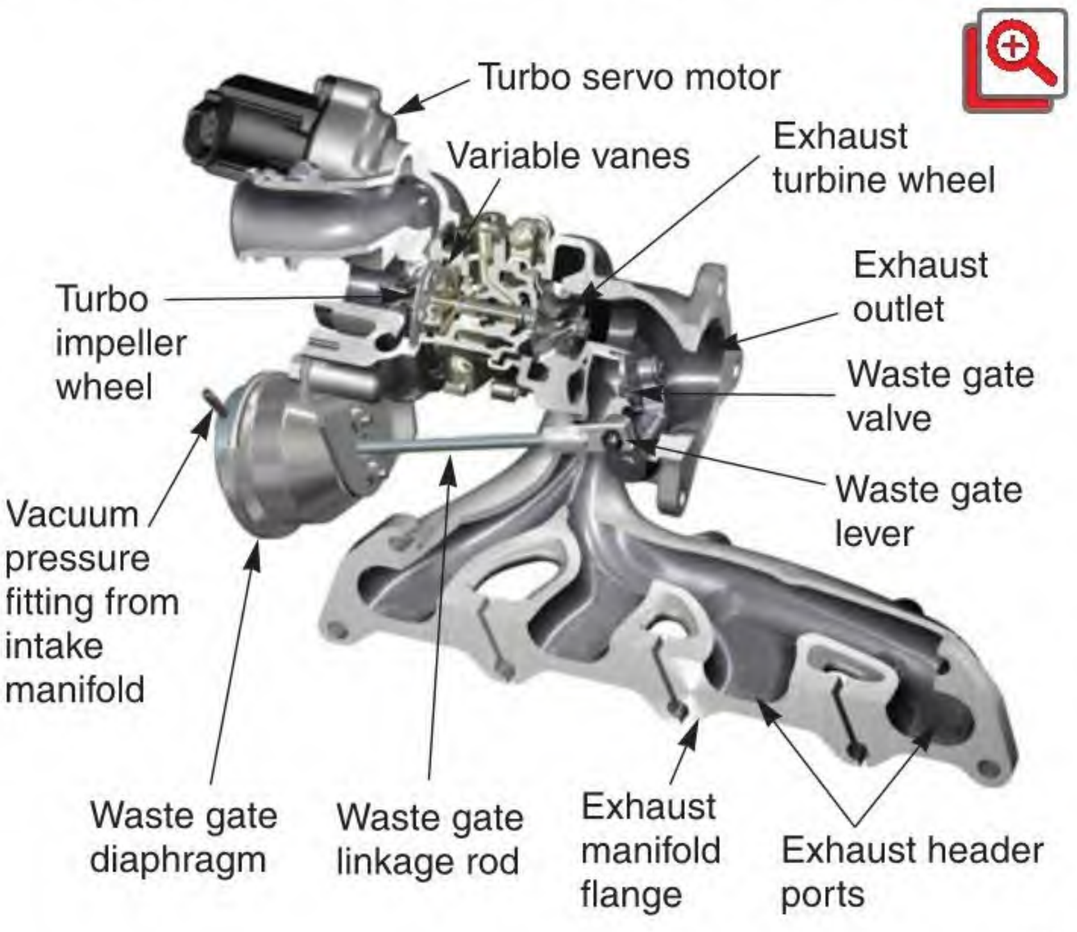
Under full load, boost may become high enough to overcome the diaphragm spring pressure. Manifold pressure compresses the spring and opens the waste gate valve. This permits some of the exhaust gases to flow through the waste gate passage and into the exhaust system. Less exhaust is left to spin the turbine. Boost pressure is limited to a preset value.

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Audi

Figure 46-7. High turbo speed requires pressure lubrication. Engine oil is fed to the turbo through the oil line. Oil flows through bearings and then drains into the oil pan through larger gravity feed drain line.



VW

Figure 46-8. Study this variable vane turbo and waste gate assembly. Modern turbine and compressor wheels are small, light, and spin up to speed quickly. The ECM-controlled servo shapes the airflow over the impeller to help bring the turbo up to speed without turbo lag and turbo over-speed damage.

Turbocharger boost pressure is the maximum allowable intake manifold pressure the turbo system should build under a full engine load. Most turbocharged vehicles have boost pressure gauges on their dashes. Turbocharged passenger vehicles have a ***gasoline engine boost pressure*** averaging around 10–15 psi (69–103 kPa).

Diesel engine boost pressure will run a turbocharger inlet air pressure of up to 20 psi (138 kPa). Diesel engines are constructed thicker and heavier because diesel fuel requires more compression pressure to ignite.

Turbo Blow Off Valve

A ***turbo blow off valve***, or ***dump valve***, is an air pressure release valve that limits maximum boost pressure as the engine throttle valves are closed rapidly for deceleration. The blow off valve is located between the turbo compressor wheel and the intake manifold or cylinder head (individual intake port

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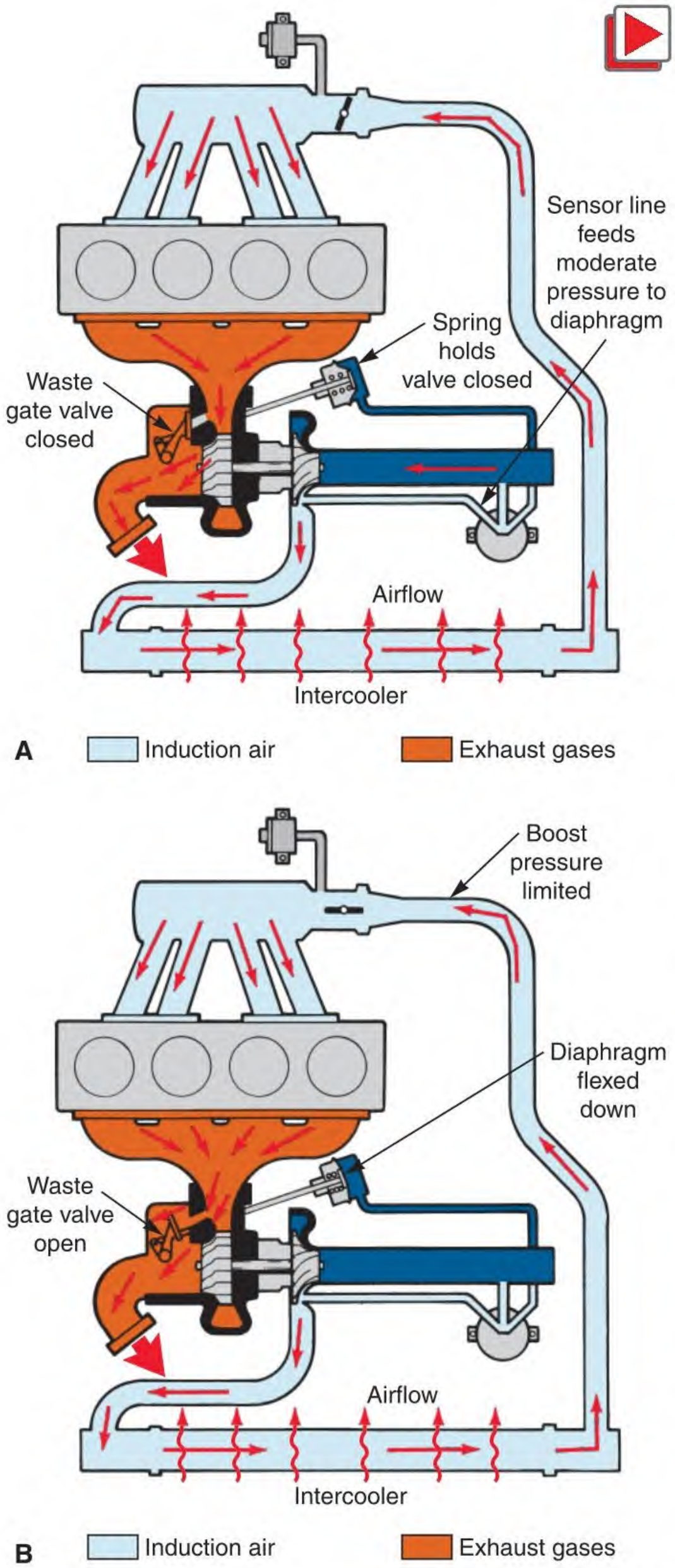


Figure 46-9. Waste gate operation. A—As long as boost pressure is not too high, the waste gate remains closed, and all exhaust gases are directed against the turbine wheel blades. B—When boost reaches a preset level, the waste gate is opened, and some of the exhaust gases are diverted from the turbine wheel blades.

throttle plates). It prevents a sudden increase in boost pressure that would result when the throttle valve blocks compressed boosted air pressure from entering the engine's intake manifold. You can sometimes hear the blow off valve hiss when a turbo engine under boost slows for braking. Without a blow off valve, the turbocharger could be damaged by the sudden pressure spike that could slam the high-speed compressor wheel to a stop. Also, the impeller wheel and its shaft could be broken without a release of excess boost pressure to the atmosphere.

Turbocharger Intercooler

A ***turbocharger intercooler*** is an air-to-air heat exchanger that cools the air entering the engine. It is a radiator-like device mounted at the pressure outlet of the turbocharger. See **Figure 46-10**.

When you compress air, its temperature increases. Since hot air contains less energy-providing oxygen by volume, it will produce less power. A cooler charge of air is denser and can be mixed with more fuel to increase combustion and engine power.

Outside air flows over and cools the fins and tubes of the intercooler. Then, as the air flows through the intercooler, heat is removed. By cooling the air entering the engine, engine power is increased. Cooling also reduces the tendency for engine detonation.

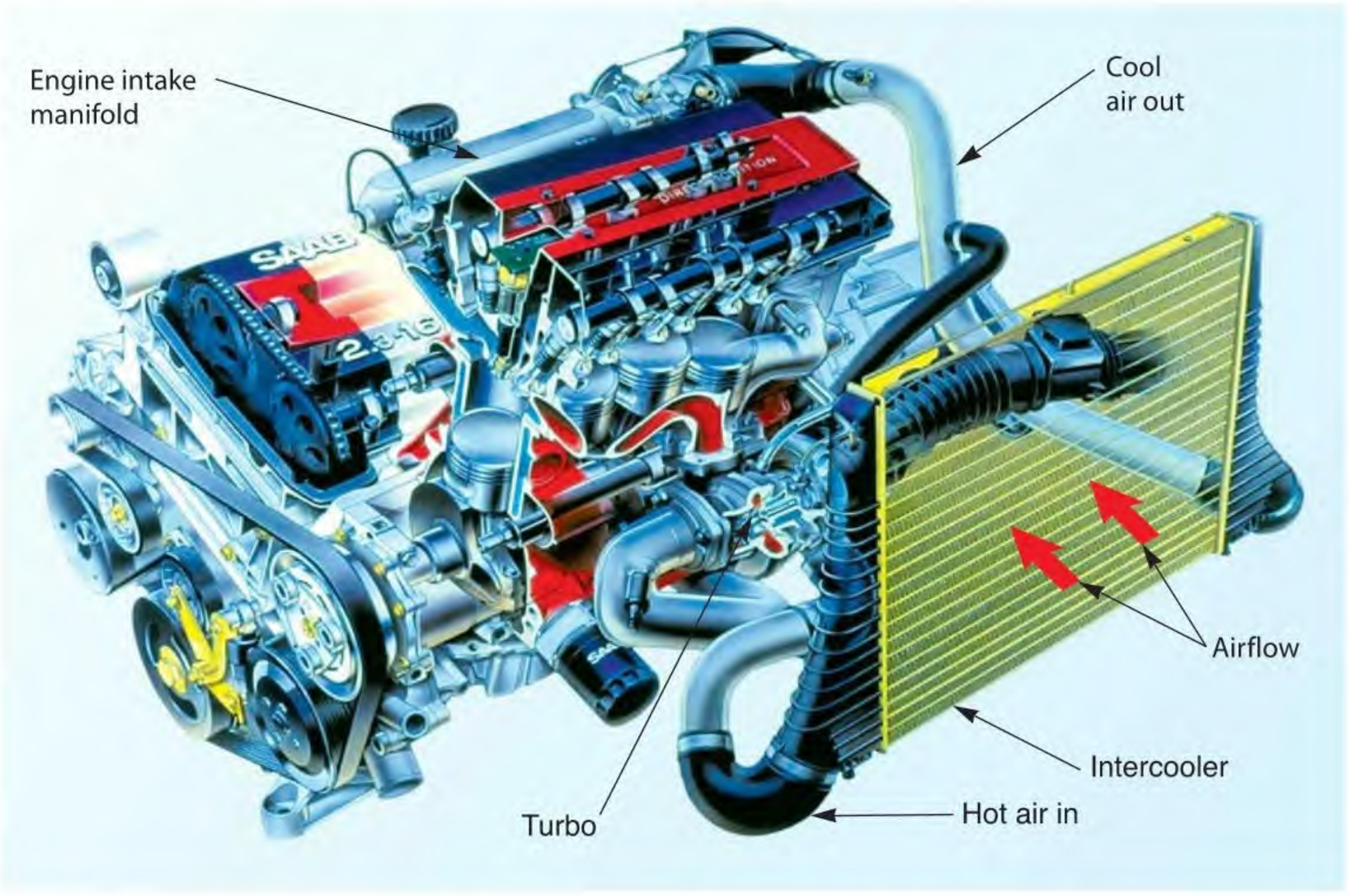
Sequential Turbocharger Systems

A ***sequential turbocharger system***, also called a ***twin turbocharger system***, uses two electronically controlled turbochargers that operate as needed. This system is sometimes used to help avoid turbo lag.

During low-engine-speed operation, only one turbocharger functions or provides boost pressure. The exhaust control valve and an intake control valve are closed, isolating the second turbocharger. The exhaust bypass valve is closed to divert exhaust gases away from the turbine in the second turbocharger. All exhaust gases are routed to the first turbocharger.

As the boost pressure reaches a predetermined level, the exhaust bypass valve opens to allow exhaust gases to flow to the turbine of the second turbocharger. This helps smooth out the boost from the second turbocharger. As the engine speed increases, the intake and exhaust control valves are opened. This allows the second turbocharger to provide added boost. The waste gate limits the maximum boost of the system.

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Saab

Figure 46-10. An intercooler is an air-to-air heat exchanger or radiator. It cools the air charge entering the engine for increased horsepower output.

The size of the two turbochargers also helps reduce turbo lag. The first turbocharger is smaller than the second turbocharger. This allows the first turbocharger to spin up to speed very quickly for initial boost. Then, the second, larger turbocharger provides more boost at higher engine speeds. Refer to **Figure 46-11**.

Turbocharged Engine Modifications

A turbocharged engine normally has several modifications to allow it to withstand the increased horsepower. These modifications include:

- Lower compression ratio.
- Stronger forged rods, pistons, and crankshaft.
- Higher volume oil pump and separate oil cooler.
- Larger cooling system radiator for the engine.
- O-ring type head gasket.
- Heat-resistant valves.
- Knock sensor (ignition retard system).

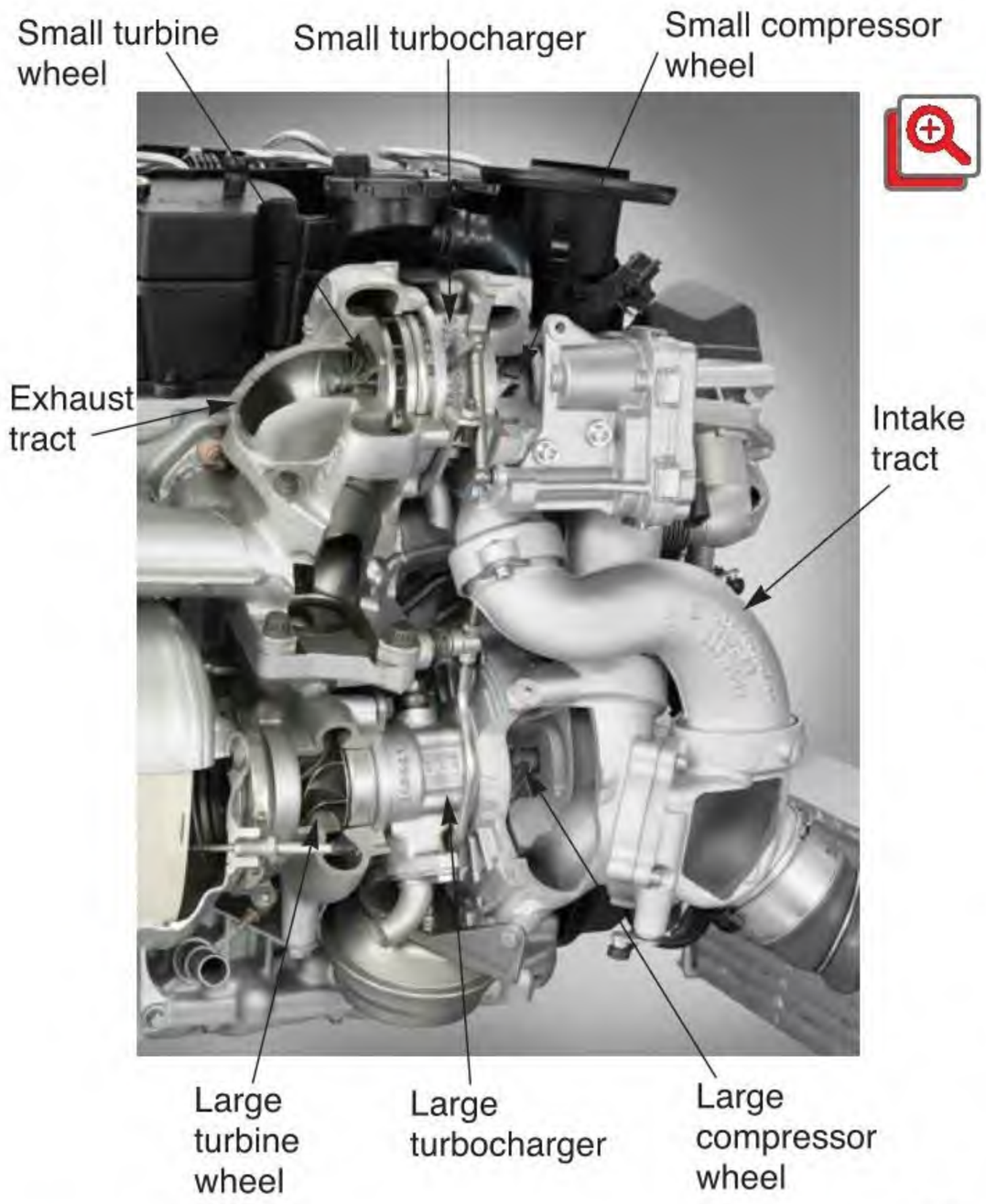
Turbo Computer Control

As with other engine systems, the vehicle's main computer (engine ECM or body ECM) often controls the turbocharger. The ECM operates the waste gate and retards the ignition timing when needed. Several sensor input signals are sent to the ECM. These commonly include inputs from the MAP (absolute up to boost pressure), air temperature sensor, knock sensor, throttle position sensor, and other system-sharing sensors. This is shown in **Figure 46-12**.

The MAP is the main sensor controlling turbocharger boost pressure. It is installed in the intake tract between the turbo outlet and the intake plenum. Until any turbo spins fast enough to build air pressure, the engine intake manifold will contain a vacuum (negative pressure) during initial acceleration. Then, as turbo speed increases to start building added airflow, the vacuum decreases to become a boost (positive pressure) through the intake manifold and into the combustion chambers of the engine. A turbo MAP sensor is calibrated to read both vacuum and boost to monitor turbocharger pumping efficiency.

The engine ECM uses preprogrammed data to determine if boost pressure or ignition timing should be altered. The computer must limit boost and timing advance to prevent detonation knock and possible engine damage. It can then produce electrical signals to a solenoid to open the waste gate or change other engine operating parameters.

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BMW

Figure 46-11. Study the construction of a sequential turbocharger setup. The small turbo operates at low engine speeds, when exhaust back pressure is low, to reduce turbo lag. When the large turbo spools up fully, both turbo units operate in series to build higher boost pressure. Note that only the larger turbo has a waste gate.

A ***knock sensor*** signals the engine control module if the engine begins to knock (detonate or ping). The sensor is mounted on the engine cylinder block or head. It works somewhat like a microphone. When it "hears" a knocking sound (high frequency vibration), it sends an electrical signal (sharp voltage spike) back to the ECM. The control module then retards ignition timing, increases the fuel injected, or opens the turbo waste gate to prevent engine destruction.

Turbocharging System Service

Turbocharging system problems usually show up as the following:

- ***Low boost pressure*** results in a lack of engine power. A boost gauge will not read specification boost upon rapid acceleration.
- Leaking turbo seals can cause engine oil consumption and blue exhaust smoke.
- Damaged turbine/compressor wheels can cause a loud vibration noise or they can keep the turbo from spinning or spooling up normally.

To protect a turbocharger from rapid shaft and bearing wear, most automakers recommend that motor oil be changed about every 3000 miles, or 4827 km. This is over twice as often as for naturally aspirated engines. Because turbo fans can spin as fast as 100,000 rpms, the turbo bearings and shaft are very sensitive to oil contaminants and oil breakdown. Engine and turbocharger lubricating oil must be kept clean to ensure long turbocharger bearing life.

Scanning a Turbocharging System

Use a scan tool to check for trouble codes relating to the turbocharging system. Late-model OBD II systems may show codes for the knock sensor, TPS, MAP, MAF, ECT, waste gate solenoid, and other devices. These codes can all affect the operation of a turbocharging system.

Tech Tip

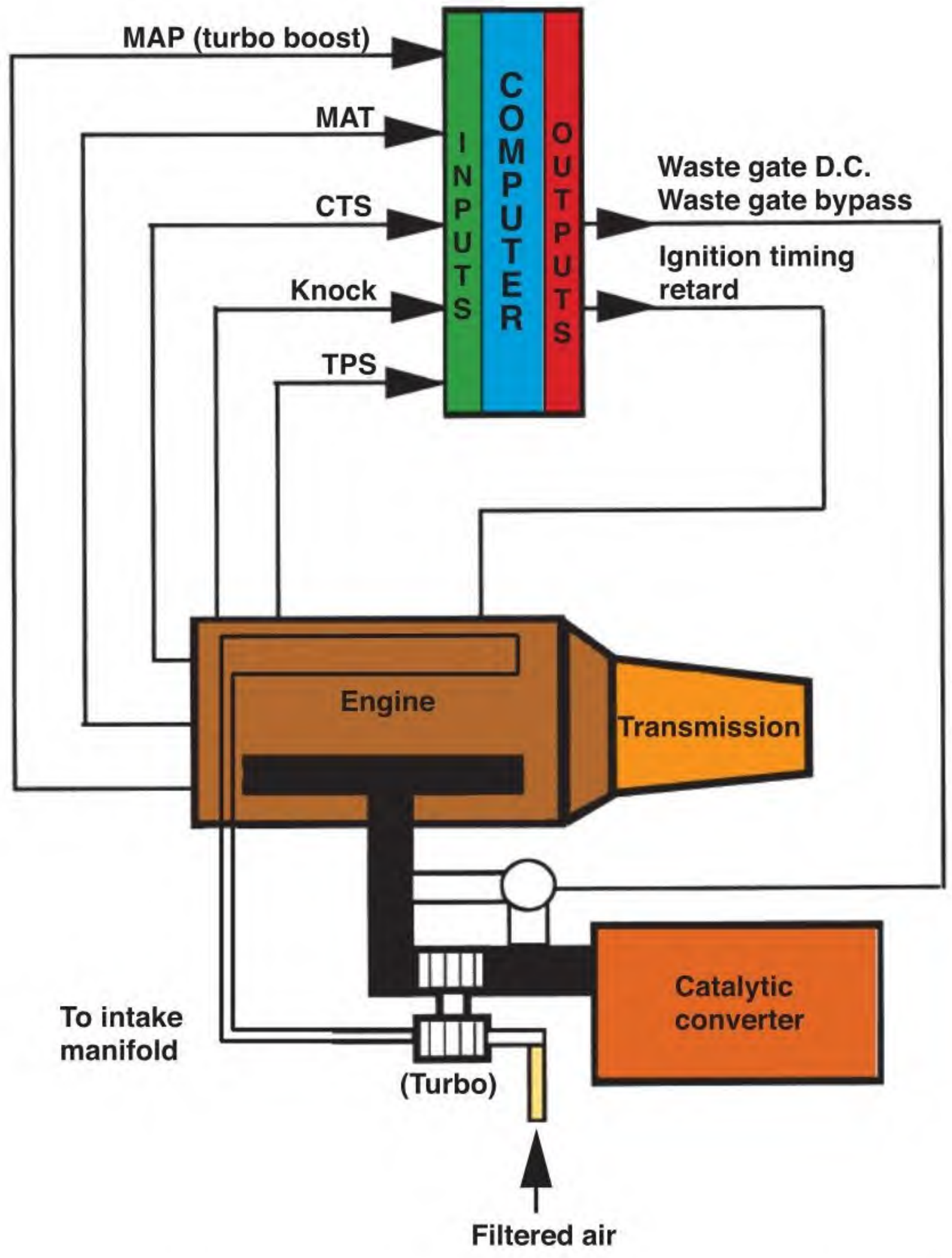
Mechanical problems can confuse on-board diagnostic systems and scan tools and produce false readings. For example, a worn piston pin can knock, fooling the knock sensor into thinking the engine is detonating. The knock sensor will then mistakenly retard ignition timing and lower boost pressure. A trouble code might be tripped, signaling engine detonation when in fact a worn piston is causing the problem. Keep this in mind when using a scan tool. Refer to a factory service manual for a detailed troubleshooting chart. It will list the common troubles for the particular turbocharging system.

Inspecting Turbocharger System

Several checks can be made to determine turbocharging system condition:

- Check connection of all vacuum lines to the waste gate and oil lines to the turbocharger.
- Use a regulated low-pressure air hose to check for waste gate diaphragm leakage and operation, **Figure 46-13**.

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OTC/SPX Corp.

Figure 46-12. Note the main controls of a basic turbocharging system: MAP, MAT, crankshaft, knock, and throttle position sensors. The knock sensor is the most important sensor in a turbo system. Since maximum boost produces better power and efficiency, many engines operate on the verge of detonation at maximum boost with pump gas octane levels.

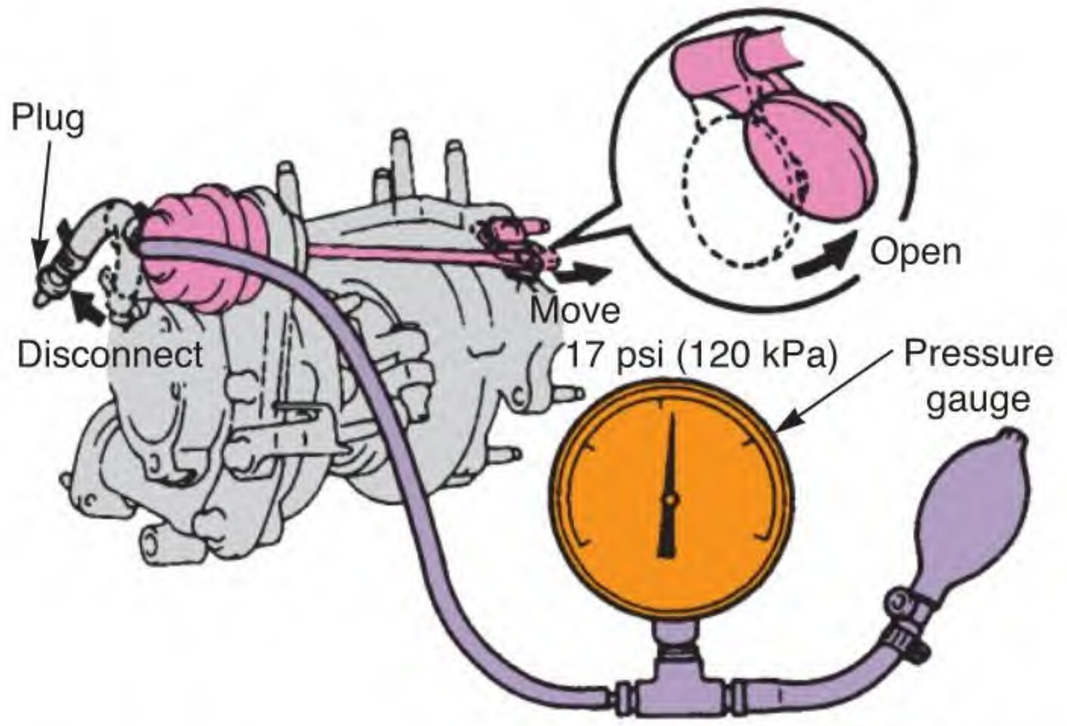
- Use the dash gauge or a test gauge to measure boost pressure. If needed, connect the pressure gauge to an intake manifold fitting. Compare the gauge readings to specifications.
- Use a stethoscope to listen for bad turbocharger bearings.
- Remove the inlet ductwork to the turbocharger and look inside the air intake.

To check the turbocharger itself, shut off the engine and let it cool down. If you find damage on the impeller or compressor blades (bent, broken, gouged, marred, or missing fins), the turbo must be rebuilt or replaced.

Turbocharger Service

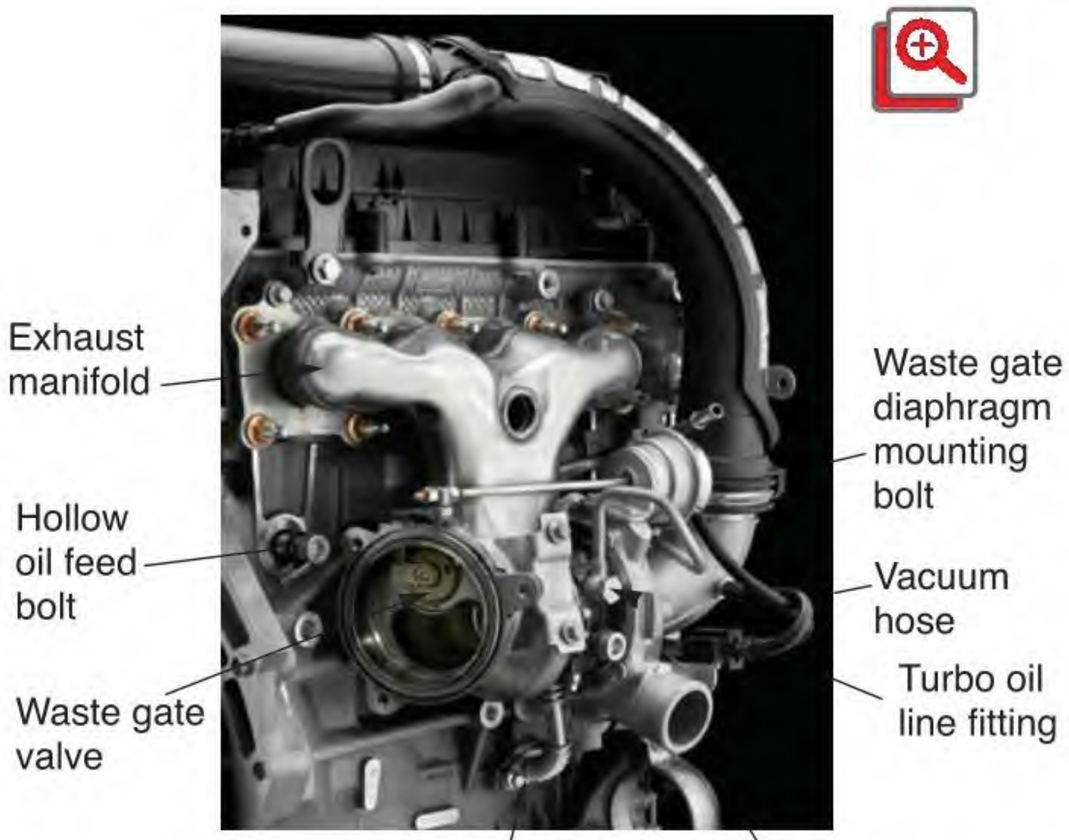
Checking the condition of the inside of the turbocharger requires removing the turbocharger from the engine. See **Figure 46-14**. Specific removal procedures vary by manufacturer.

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Figure 46-13. To check a turbo waste gate for proper operation, disconnect the pressure hose from the waste gate. Then apply specified pressure to the waste gate diaphragm chamber. The lever arm and valve should move.



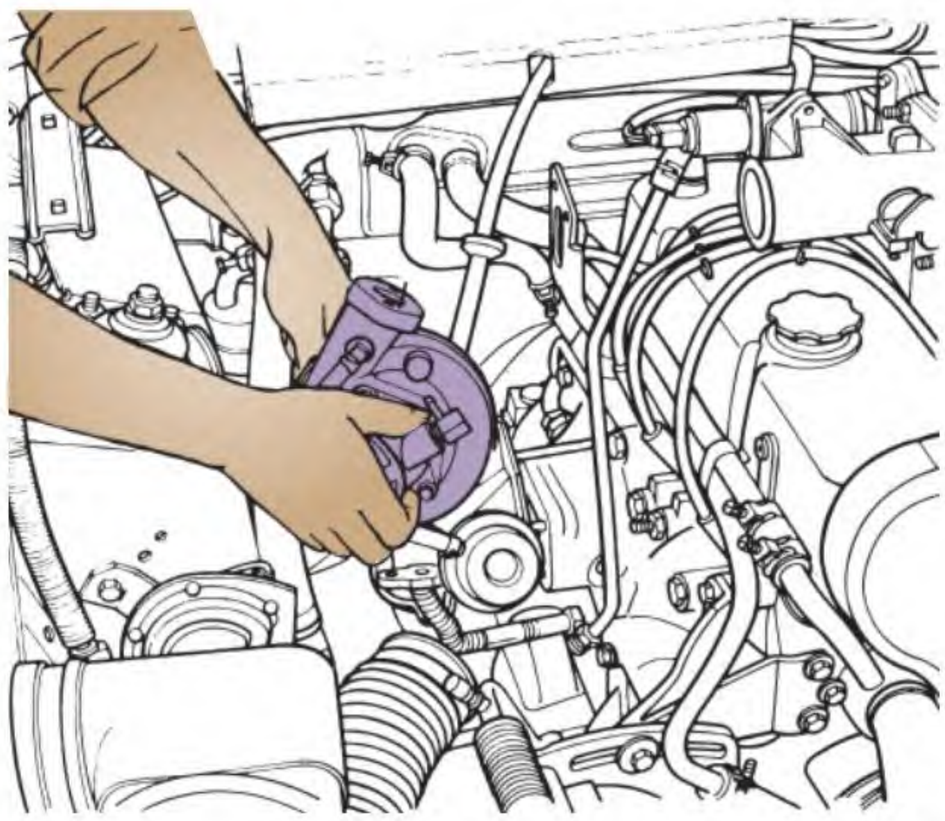
Volvo

Figure 46-14. Study how a turbo and waste gate are bolted or mounted on the engine so you know how to remove them for service.

Service Procedure

The basic steps for turbocharger removal are:

1. Remove the engine covers, air cleaner, and related air intake ducting going to turbo inlet.
2. Remove the turbocharger heat shields and braces.
3. Remove the exhaust outlet pipe or exhaust down pipe.
4. Remove the boost control line, small oil supply line, and larger oil return or drain line.
5. Remove the waste gate actuator vacuum line, linkage, and EGR tube if required.
6. Remove the bolts attaching the turbocharger to the exhaust manifold. You may have to remove the whole exhaust manifold and turbo as an assembly. Refer to factory instructions if in doubt.
7. Remove the turbocharger from the engine without striking the vehicle fenders, **Figure 46-15**.



Ford

Figure 46-15. After removing mounting fasteners and any other parts, a turbocharger can be lifted off for replacement. A turbo cannot be repaired in shop. A new unit is normally installed.

After removing the unit, place it on a workbench. Before disassembling the turbo, scribe an alignment mark on both housings. This will allow you to reassemble the two intake and exhaust housings in perfect alignment. Then, open the housing and inspect the interior of the turbo for oil contamination and other problems.

Caution

Never use a hard metal object or sandpaper to remove carbon deposits from a turbine wheel. If you gouge the wheel, it can vibrate and destroy the turbo when it spins up to speed. Use only a *soft* wire brush and solvent to clean turbo wheels.

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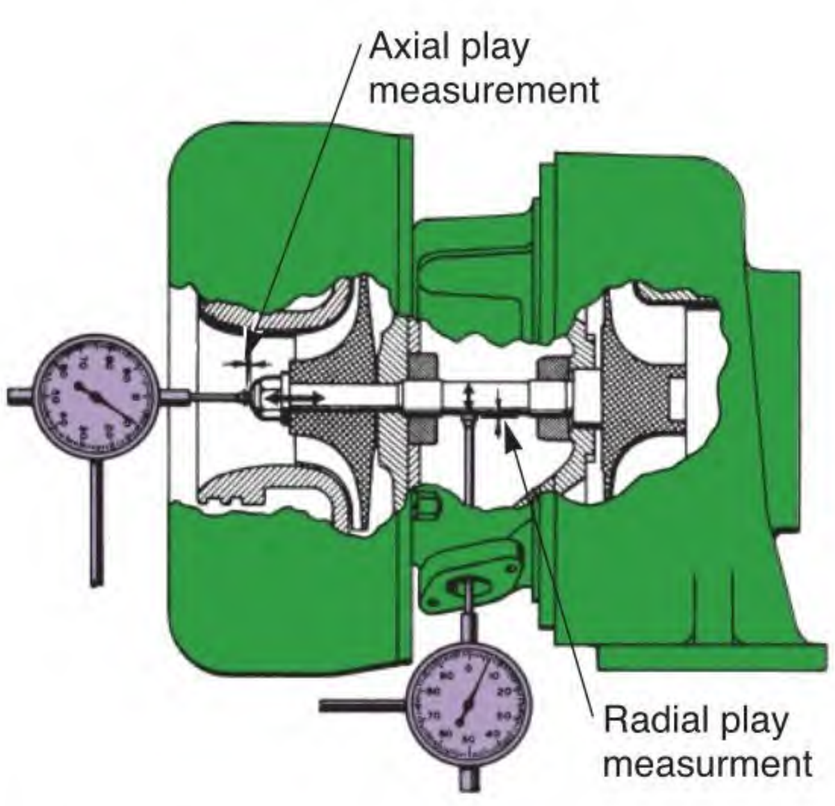
Check the turbine and compressor wheels closely. They should be clean and free of damage. Even the slightest imperfection could throw the wheels out of balance and cause severe vibration or turbo disintegration. Make sure the turbine assembly spins freely when rotated by hand.

Turbocharger clearances, shaft endplay, and runout should be checked with a dial indicator to verify the condition of the unit. See **Figure 46-16**. Always refer to the manufacturer's specifications, since clearances vary. Typically, ***turbo shaft endplay*** should be .001″ (0.03 mm) to .003″ (0.08 mm) and ***turbo shaft radial runout*** should be .003″ (0.08 mm) to .006″ (0.15 mm).

If the turbocharger oil return line becomes restricted or blocked, oil pressure can push oil past the oil seals and into the intake and exhaust tracts. A clogged turbocharger oil return line can cause blue engine smoke, fouled spark plugs, or a damaged catalytic converter. To check for blockage, remove the return line at the turbocharger and blow air back through the line. If you find blockage, it is best to replace the line with a new one instead of trying to remove the restriction.

When overhauling a turbocharger, it is very important that you do nothing to upset the balance of the turbocharger wheels. If you bend the turbo shaft and loosen even one blade slightly, the turbocharger will be out of balance and may self-destruct the first time it spins up to boost pressure.

When disassembling the turbocharger housings or wheels, mark their position. Use a scratch awl to make very small alignment marks. When loosening the wheel nut, be careful not to bend the turbo shaft. It is best to use a T-handle and socket to loosen the turbo shaft nuts without side-loading the shaft.



Waukesha

Figure 46-16. A dial indicator will quickly check radial and axial play at turbo shaft. If not within specifications, replace or rebuild turbocharger.

Installing a Turbocharger

Many turbocharger problems are not repaired in the field. Most technicians install a new or rebuilt unit. When installing a turbocharger, you should do the following:

- Make sure the new turbo is an exact replacement. Compare part numbers, fitting diameters, etc.
- Use new flange gaskets and seals.
- Torque all fasteners to specifications.
- Change the engine oil and flush the oil lines before starting the engine, if needed.

If the failure was oil related, check the oil supply pressure in the feed line to the turbocharger. Many feed lines have a small orifice to restrict oil flow to the turbo. When measuring oil feed pressure to the turbo, install your test gauge after this orifice or restriction. Compare your oil pressure reading to the turbo to specifications.

Waste Gate Service

An inoperative waste gate can cause either too much or too little boost pressure. If the waste gate is stuck open, the turbocharger will not produce boost pressure and the engine will lack power. If the gate is stuck closed, detonation and engine damage can result from excessive boost.

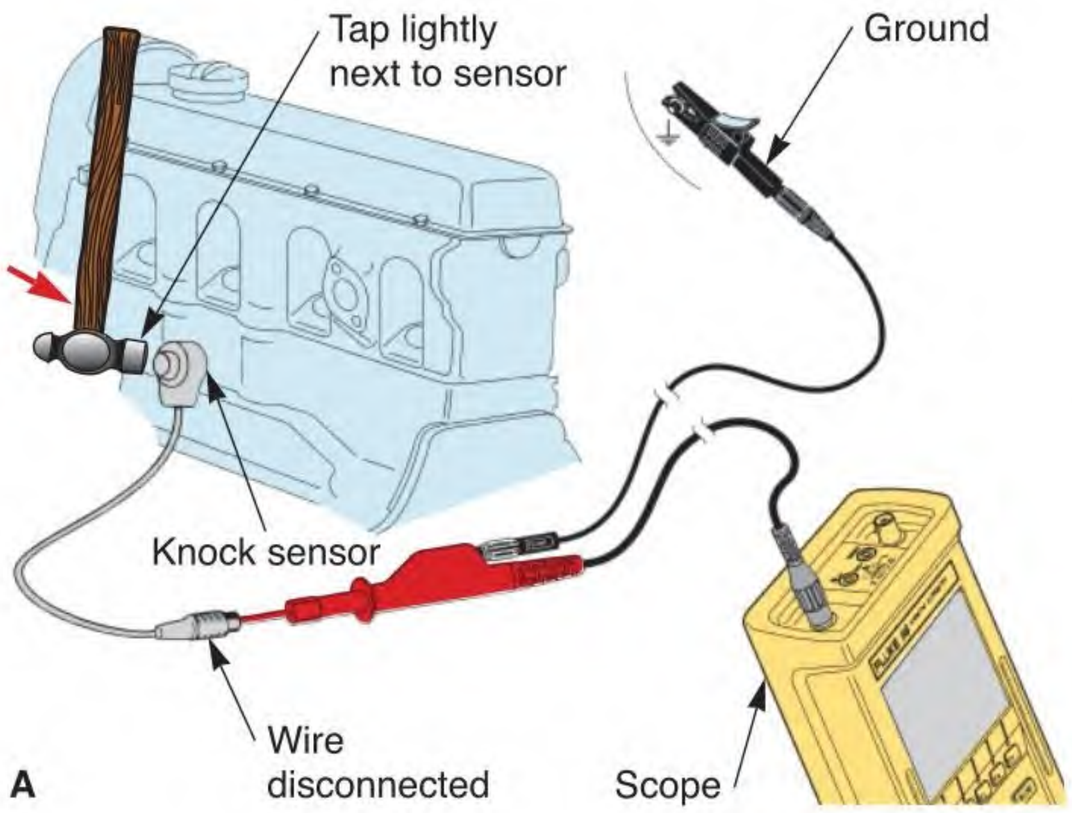
Before replacing the waste gate, always check other parts. Check the knock sensor and the ignition timing. See **Figure 46-17**. Make sure the vacuum pressure lines are all connected properly. If the waste gate is controlled by a solenoid, test the ECM signal to the solenoid and verify that it is functioning and controlling vacuum to the waste gate diaphragm. Follow service manual instructions when testing or replacing a waste gate.

Waste gate removal is relatively easy. Simply unbolt the fasteners, remove the lines, and lift the unit off the engine. Refer to **Figure 46-18**. Many manuals recommend waste gate replacement, rather than in-shop repairs.

Superchargers

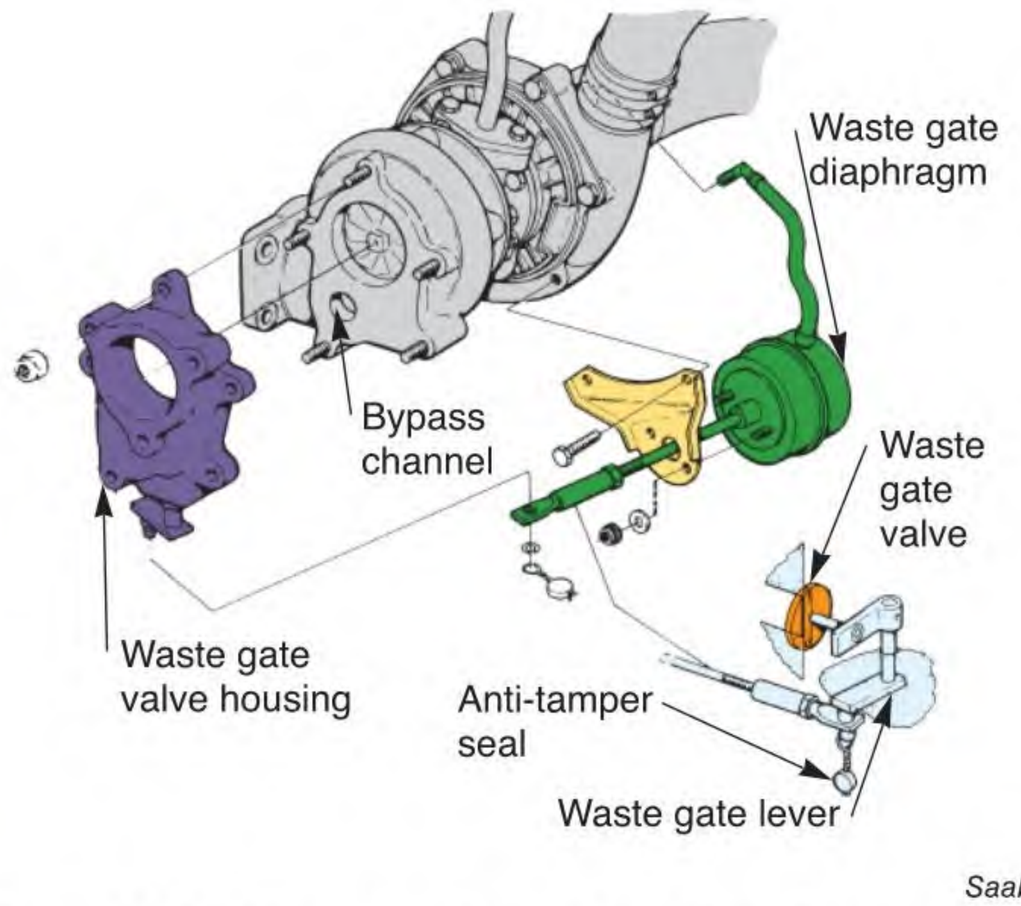
A supercharger is a compressor or blower driven by an engine belt, chain, or gears. Unlike a turbocharger, it is not driven by engine exhaust gases. Most

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Fluke

Figure 46-17. A—To test a knock sensor, attach test leads from handheld scope multimeter to ground and to single wire leaving sensor. Tap on the engine block lightly right next to the knock sensor. B—If the knock sensor is working, it will generate a weak voltage spike of less than a volt. If no voltage spike or a weak spike is generated, the knock sensor is faulty.



Saab

Figure 46-18. The waste gate normally bolts to the side of the turbo housing. A linkage rod connects diaphragm with valve mechanism. Also note the seal that prevents tampering with boost setting. Although overboost will increase power, it can also cause engine damage.

passenger car superchargers are driven by a large serpentine belt powered by the crankshaft pulley, **Figure 46-19**.

The ***supercharger belt*** drives the rotors inside the supercharger. As the rotors turn, they compress the air inside the housing and force the air, under pressure, into the engine intake manifold.

An ***intercooler*** is commonly used between the supercharger outlet and the engine to cool the air and increase power (cool charge of air carries a denser charge of oxygen needed for complete combustion of fuel). Refer to **Figure 46-20**.

The ***supercharger drive pulley*** is connected to one of the timing gears by the shaft, which is inside the supercharger extension housing. The drive pulley draws power from the crankshaft through a large serpentine belt.

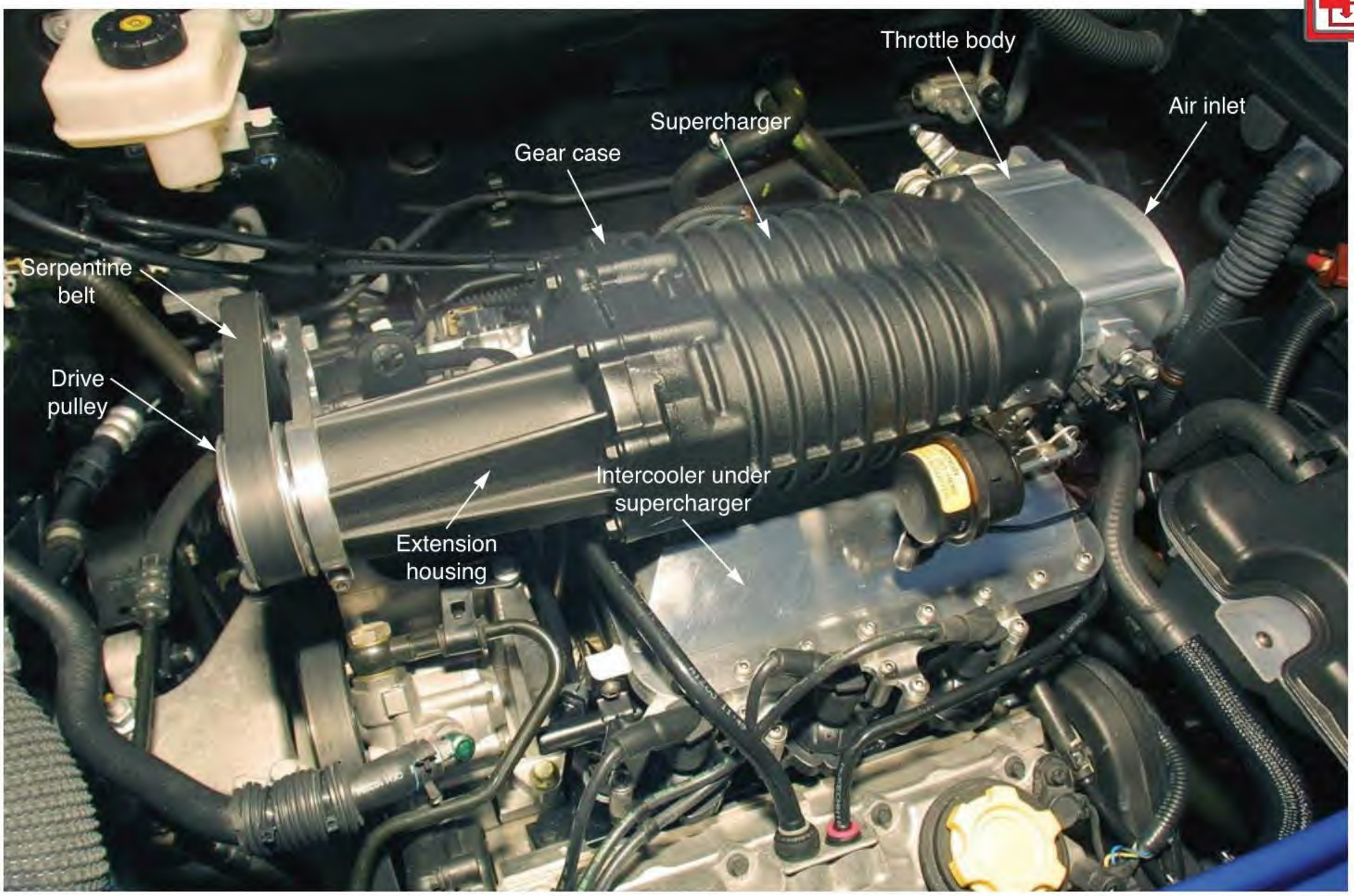
An ***electromagnetic clutch*** is sometimes used to disengage the drive pulley and belt from the blower. See **Figure 46-21**. When the supercharger is disengaged, the ECM routes airflow around the supercharger and into the engine directly. With the supercharger disengaged, the engine operates on normal aspiration (atmospheric pressure) without the pumping losses of a supercharger.

Superchargers have the advantage of not suffering from turbo lag. A supercharger will instantly produce boost pressure at low engine speeds because it is mechanically linked to the engine crankshaft. This low-speed power and instant throttle response is desirable in a passenger car when passing other vehicles and when entering interstate highways.

A ***supercharger assembly*** consists of:

- A supercharger housing that encloses rotors and routes air into the intercooler.
- Supercharger rotors that spin and pressurize air.
- Two rotor timing gears that transfer torque from one rotor to the other.
- Extension housing that supports the supercharger drive pulley.

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Land Rover

Figure 46-19. A supercharger is normally mounted on top of the intake manifold. Note the basic parts of this supercharger.

- A drive pulley that transfers torque into the gears and rotor in the supercharger.

The ***supercharger housing*** is the large aluminum enclosure for the rotors, rotor bearings, and drive gears. The inside of the housing is precision machined to form airflow chambers of equal size. The supercharger housing is normally bolted to the intake manifold. The throttle body is mounted at the inlet of the supercharger, as shown in **Figure 46-21**.

The ***supercharger rotors*** are meshing, twisted blades or fans that spin to produce pressure inside the supercharger housing. The rotors fit precisely in the supercharger housing and are supported by sealed ball or needle bearings. Refer to **Figure 46-22**.

Supercharger timing gears keep the two rotors timed and spinning at the same speed. The timing gears are attached to the rotors and are enclosed in the gear case, which is formed as part of the supercharger housing. One timing gear is driven by the drive pulley; the other is driven by the first timing gear. The rotor gears operate in a bath of oil. A small reservoir is formed into the front of the supercharger housing. As the timing gears spin, they are splash lubricated to prevent wear on the gear teeth. Refer to **Figure 46-23**.

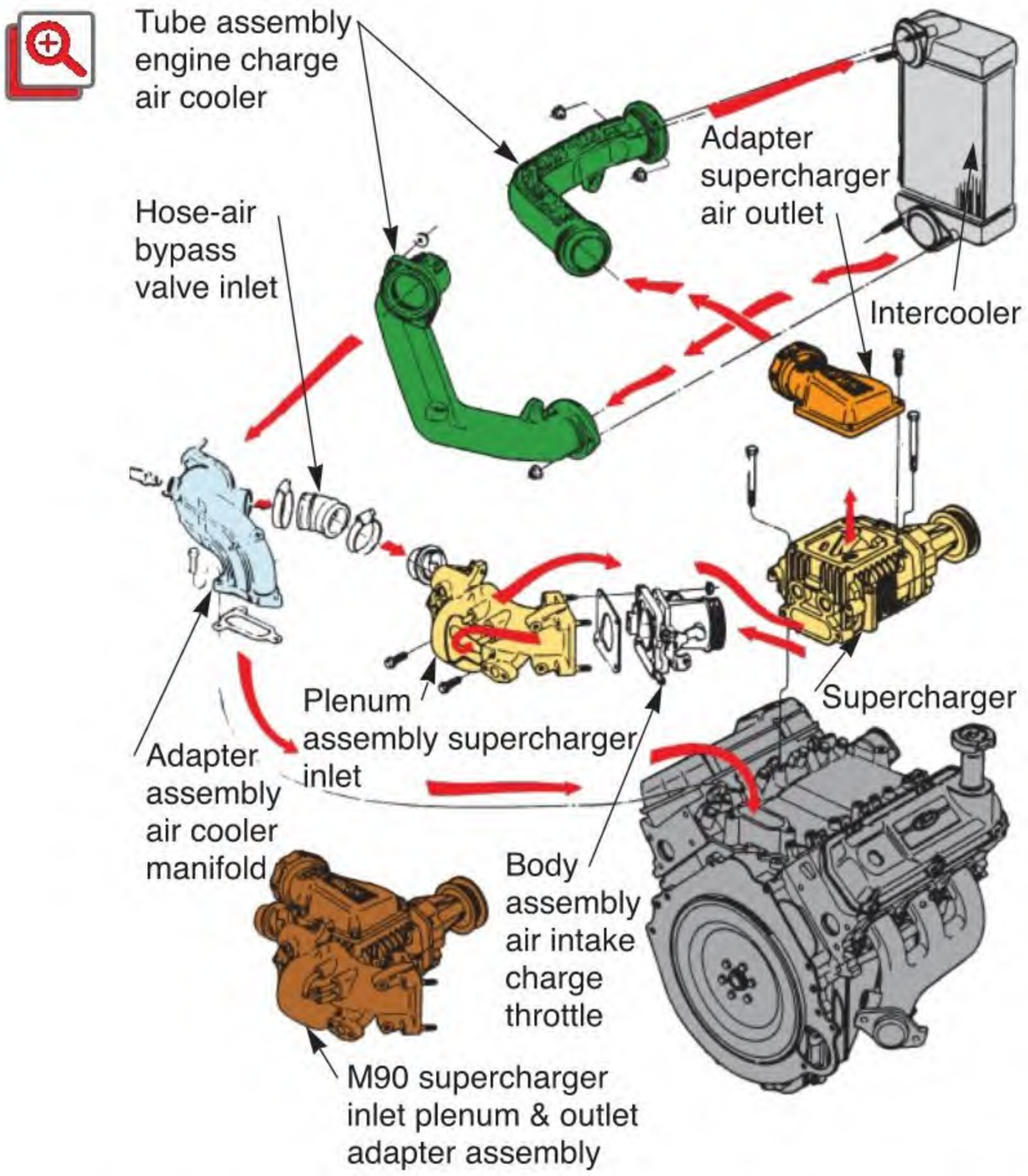
The ***supercharger extension housing*** is bolted to the front of the supercharger housing. It encloses a shaft that connects one of the supercharger timing gears to the drive pulley. It also contains a large, sealed bearing for the drive pulley.

Supercharger Bypass Valve

A ***supercharger bypass valve*** is used to improve engine efficiency by providing maximum boost only when needed. Refer to **Figure 46-24**.

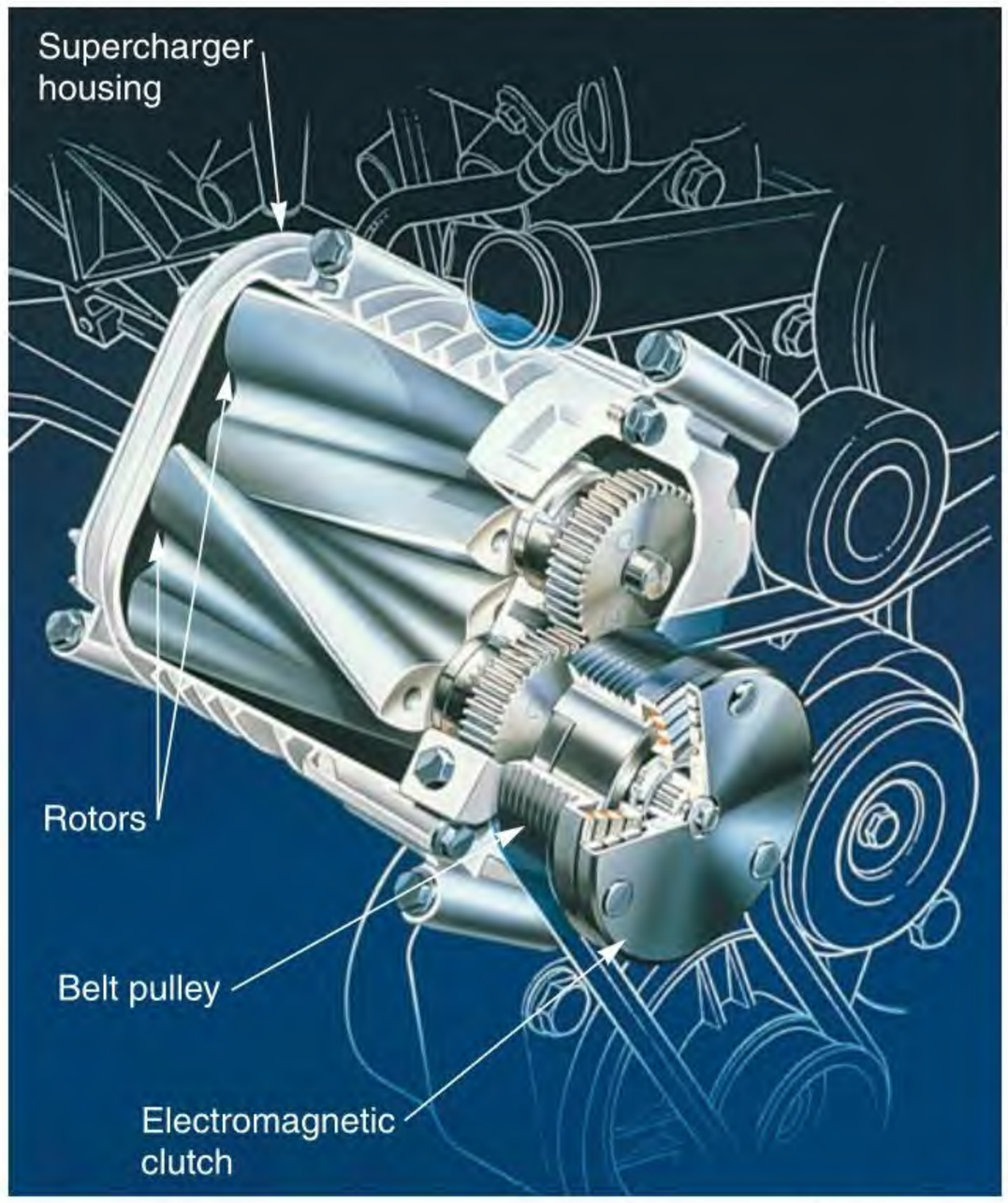
Under normal cruising conditions (low load), the bypass valve is held open to allow boost pressure to flow back up into the intake air. This reduces boost pressure and parasitic pumping losses to improve fuel economy.

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Ford

Figure 46-20. Note how parts fit together on supercharged engine. Most superchargers bolt or mount on top of the engine. Trace flow of air through components.



Mercedes-Benz

Figure 46-21. Cutaway of a supercharger. The rotors in this unit spin at speeds up to 12,000 rpms to pressurize incoming air. A supercharger is normally driven by a belt running up from the engine crankshaft pulley. An electromagnetic clutch engages and disengages blower rotors as needed. The supercharger might only engage at full throttle when there is demand for more engine power. Air is bypassed around supercharger for natural aspiration at low engine speed and load levels.

When the driver presses on the accelerator pedal for full power and rapid acceleration, the bypass valve closes. All boost pressure flows into the engine.

Supercharger Operation

When the accelerator pedal is pushed to the floor for passing or getting up to highway speed, the supercharger spins faster to provide more boost. If the supercharger is equipped with an electromagnetic clutch, a switch sends power to the electromagnetic clutch on the supercharger pulley. This engages the supercharger and the rotors spin. Engine power is instantly increased.

Most superchargers used on production vehicles provide 4–10 psi (30–70 kPa) of boost. Larger units that provide much more boost are used on racing engines and diesel trucks. The supercharger normally uses two rotors that compress air entering the engine. This pressurized air is fed into the intake manifold where it is mixed with fuel before being pulled into the combustion chamber.

Supercharging has the advantage of instant air pressure increase on demand. With a turbocharger, there is a slight delay in pressure and power increase (turbo lag) as the unit builds up speed. This delay does not occur with a supercharger because it is driven by the crankshaft.

Supercharger Intercooler

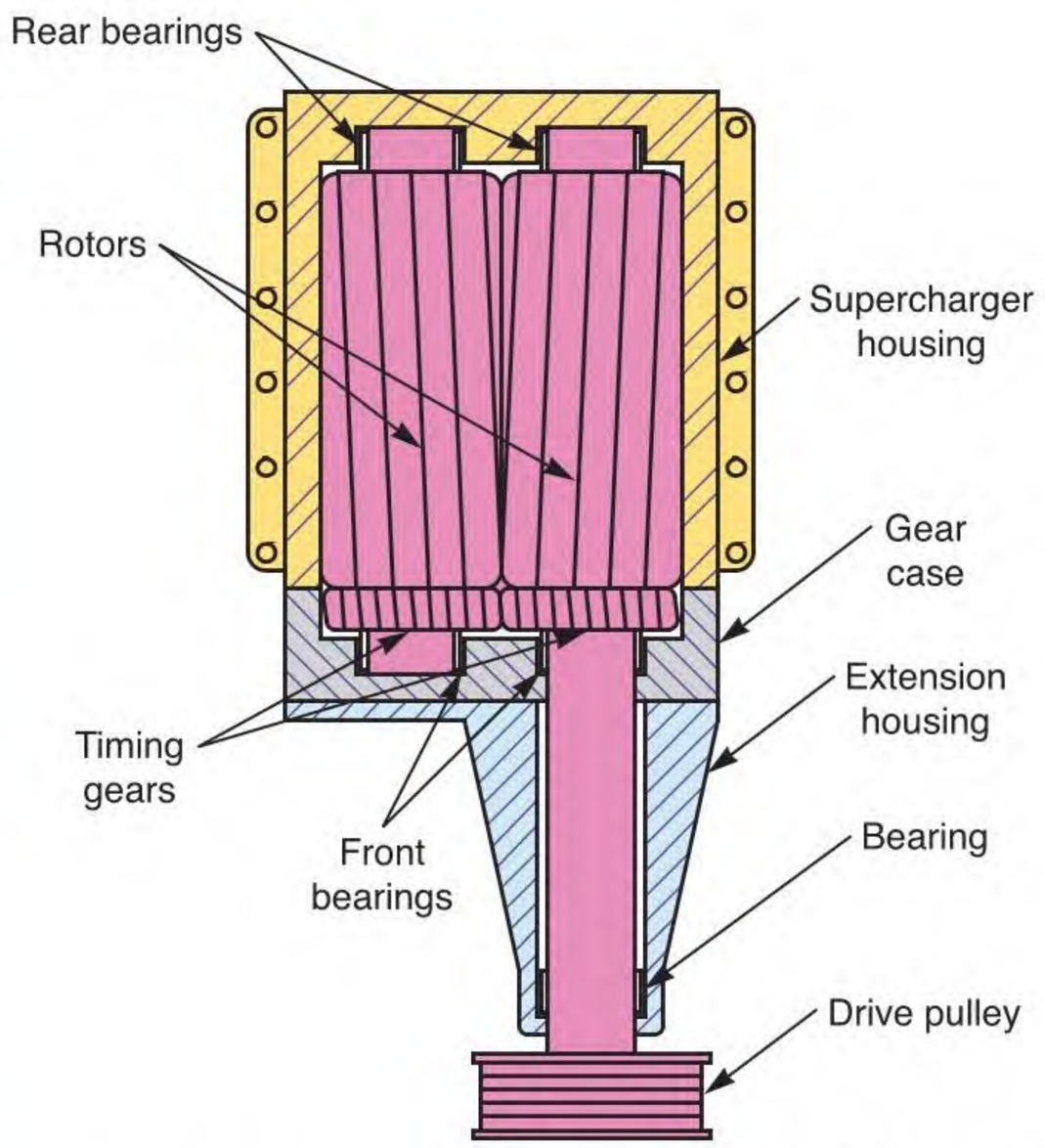
When the supercharger compresses the air and produces boost, the air is heated. This heat must be removed to avoid detonation. Detonation can damage pistons, crack cylinder heads, or blow out spark plugs. A ***supercharger intercooler*** removes heat from the compressed air before it enters the engine. The intercooler provides the engine with a cooler, more dense

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Chrysler

Figure 46-22. Superchargers normally have two large rotors that can pump a large volume of air into the engine.



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Figure 46-23. Note how supercharger timing gears and bearings keep both rotors spinning together with little clearance to compress air.

charge of air than if the supercharged engine did not have an intercooler. A supercharger intercooler system consists of the following components:

- Intercooler.
- Intercooler coolant.
- Intercooler lines.
- Intercooler pump.
- Intercooler radiator.

The ***intercooler*** is an air-to-liquid heat exchanger mounted between the supercharger and the engine. It consists of cooling tubes surrounded by cooling fins, similar to an engine radiator. The hot boost air leaving the supercharger flows through the intercooler fins and over the cooling tubes. Since the temperature of the coolant in the intercooler is lower than the hot boost air, heat is transferred from the air to the fins, cooling tubes, and into the coolant. The coolant carries this heat away from the intercooler.

The ***intercooler coolant*** is a mixture of 50% water and 50% antifreeze. A small reservoir is normally provided for servicing the coolant.

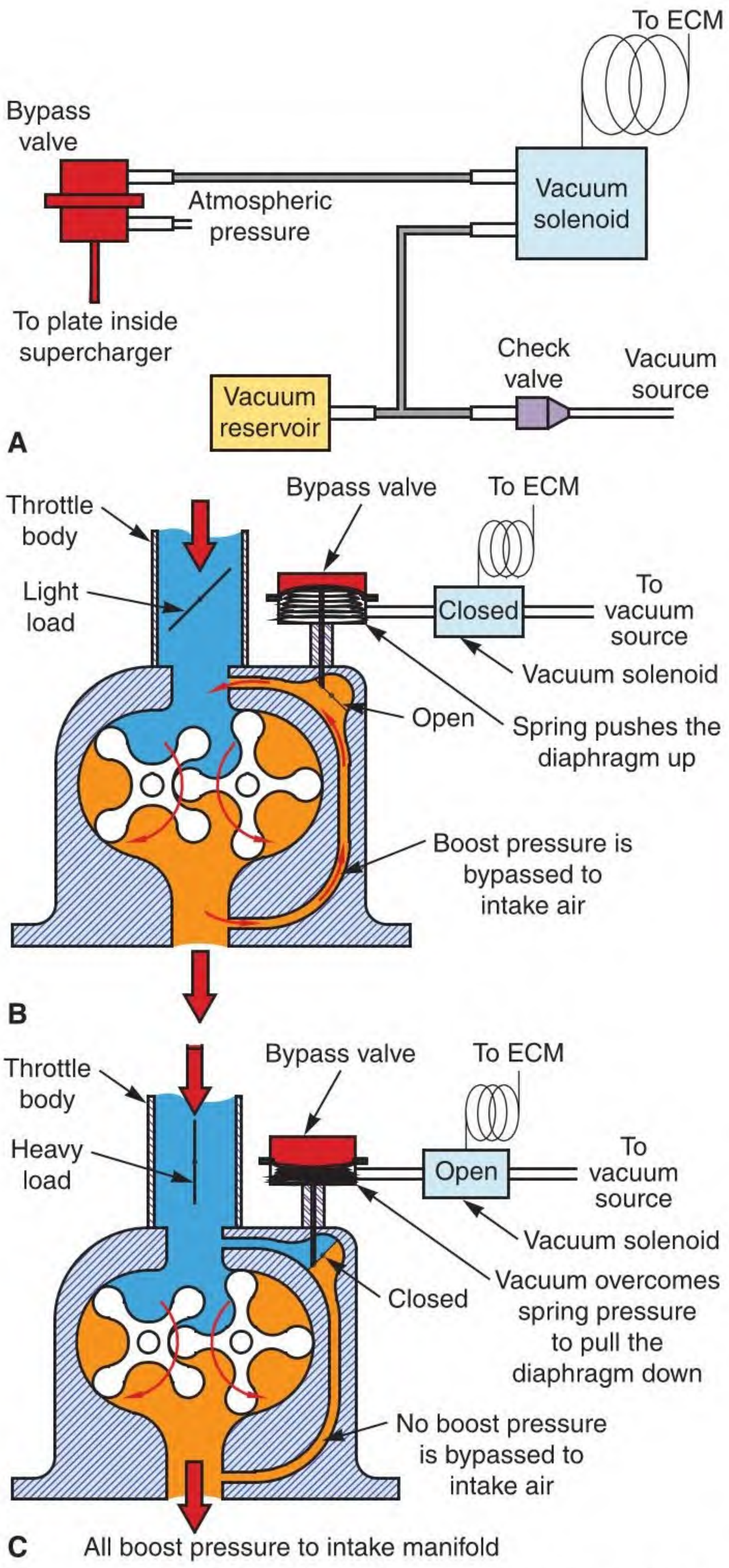
The ***intercooler radiator*** is a small heat exchanger for transferring heat from the intercooler coolant to the outside air. It is often mounted in the lower, front of the engine compartment. The intercooler radiator is positioned so that cool outside air can flow through the radiator fins.

Intercooler lines carry the coolant from the intercooler to the intercooler radiator and back to the intercooler. The lines can be metal or rubber. An ***intercooler pump*** forces the coolant through the system. This small electric water pump keeps the coolant circulating through the cooling tubes and intercooler radiator.

Supercharger System Service

Many of the problems and tests associated with turbochargers relate to superchargers as well. Service may be required after extended use. The most common causes of supercharger failure are worn bearings or damage to the impeller and housing.

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Figure 46-24. A—This is a schematic for a typical supercharger bypass valve control system. B—When the engine is under full load, the ECM sends a control signal to open the vacuum solenoid. Vacuum pulls the diaphragm down, which closes the bypass valve. All supercharger boost pressure enters the intake manifold. C—When the engine is under light load, the ECM closes the vacuum solenoid. Spring pressure pushes the diaphragm up, which opens the bypass valve. Some of the supercharger boost pressure is returned to the inlet, reducing the amount of boost pressure that enters the intake manifold.

Some supercharger noise or whine is normal. When a supercharged vehicle is accelerated, a loud whine or "scream" can usually be heard. This is the sound of the large supercharger rotors pulling air into the engine under full boost.

The most common supercharger service operations include replacement of the drive belt, checking supercharger oil, and supercharger replacement. Supercharger service can also involve tests and repairs to the intercooler, intercooler pump, bypass valve mechanism, and other support components.

Caution

Owners sometimes install a smaller drive pulley to increase rotor speed and boost pressure. This can result in supercharger or engine failure. Boost pressure that is higher than the factory specifications can cause severe detonation, which can result in cracked heads, broken piston crowns or skirts, spark plugs blown out of the head, and other major damage. Warn customers that modifications to a supercharged engine can void the manufacturer's warranty.

Scanning a Supercharging System

Use a scan tool to help find supercharging system problems on vehicles equipped with on-board diagnostic systems. The scan tool will show any diagnostic trouble codes and system electrical values. You can check the operation of the knock sensor, manifold pressure sensor, and other devices that control supercharging.

Supercharger System Diagnosis

When diagnosing supercharger system problems, inspect the unit for obvious problems first. Are there signs of drive belt slippage? Does the belt squeal when the engine is started? Are there any visible fluid leaks and is the supercharger oil reservoir full? Other symptoms of problems with the supercharger system include internal noises, low oil level in the reservoir, pressure or vacuum leakage, or out-of-specification boost pressure.

A rattling noise from the supercharger indicates rotor bearing failure and mechanical contact between the spinning rotors and the inside of the supercharger

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housing. A knocking noise indicates possible drive gear teeth breakage. A loud growling noise may indicate either bearing failure or teeth breakage.

If the supercharger drive belt is squealing from excess slippage, there may be internal drag or the unit may be locked up. Squealing could indicate bearing seizure or other internal mechanical failure.

Place a stethoscope against the ends of the supercharger housing to isolate any bearing noises, as shown in **Figure 46-25A**. Failed supercharger bearings will make a loud rumble when the probe is placed over the bearings on the housing. If the unit is not too hot, you can also place your hand on the supercharger housing to feel for vibration caused by rotor-to-housing contact. See **Figure 46-25B**.

A close visual inspection and partial disassembly are often needed to verify supercharger failures. Quite often, new seals or gaskets can be installed to correct pressure or vacuum leakage. However, if major mechanical problems are found in the supercharger, the unit should be replaced. For example, a supercharger explosion, resulting from a backfire or rotor failure, can crack the housing and allow oil leakage from the unit. In this case, the unit should be replaced.



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Figure 46-25. Make initial checks of the supercharger if you suspect it is not working properly. A—Use a stethoscope to listen for abnormal sounds inside the supercharger. B—If the supercharger is not too hot, feel for excessive vibration from damaged rotors.

Measuring Supercharger Boost Pressure

Install a pressure gauge to measure actual boost pressure. See **Figure 46-26**. Refer to the manufacturer's service information for the correct connection point. Compare actual boost pressure to specifications for the engine speed. If boost is low, check the pressure regulator circuit or check for internal rotor or housing damage.

Low Boost

A supercharged engine may fail to generate proper boost pressure due to the following reasons:

- A broken or slipping drive belt.
- An inoperative electromagnetic drive pulley mechanism.
- An inoperative pressure bypass valve system.
- Physical wear or damage inside the supercharger.
- A badly clogged air filter or an obstruction in the air intake.

If there is low or no boost pressure, make sure the electromagnetic clutch is engaging if the vehicle is equipped with one. Also, make sure the supercharger is spinning. If the supercharger is spinning, check for loose or disconnected vacuum lines to the bypass valve.

To check the operation of the bypass valve, apply vacuum to the diaphragm, **Figure 46-27A**. Make sure the level or arm on the bypass valve moves as vacuum is applied.

If the bypass valve diaphragm is good but the bypass valve is not working, check the vacuum solenoid that controls vacuum to the bypass diaphragm. Make sure the ECM is sending a proper signal to the solenoid. See **Figure 46-27B**.

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Figure 46-26. A test pressure can be used to compare scan tool boost pressure with actual boost pressure. Compare your idle, acceleration, and boost pressures by test-driving car with the gauge on the dash.



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Figure 46-27. If supercharger boost levels are low, check the pressure control valve and air control solenoid. A—A handheld vacuum/pressure pump will check the action of the bypass diaphragm. It should move the pressure control valve and not hold pressure (not leaking air). B—A technician is checking the operation of the boost solenoid with a digital voltmeter. The engine ECM should apply battery voltage across the solenoid when needed. The solenoid should make a "click" sound when voltage is applied from the ECM or from test leads connected to the battery.

Overboost

If a supercharged engine has too much boost, or ***overboost***, the engine may seem to have more power than normal, accelerate (rev up) too quickly, and detonate or knock under high-load conditions. Too much supercharger boost can be caused by a bypass valve stuck closed, often due to carbon buildup or a mechanical problem. An electronic control problem or engine modification may also lead to overboost.

Supercharger Belt Replacement

To replace a supercharger belt, first remove the belt cover, **Figures 46-28A** and **46-28B**. Usually, two or three small bolts secure the belt cover. To avoid injury, disconnect the battery to prevent accidental engine cranking.

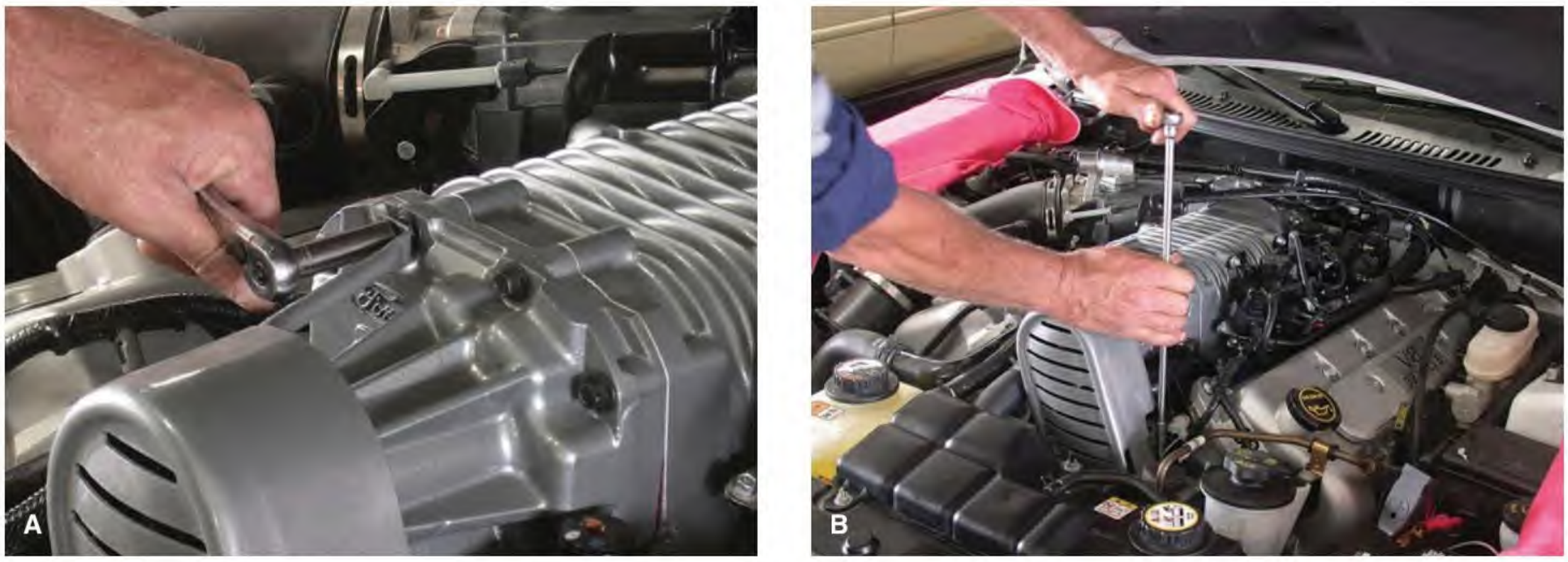
A long wrench or special service tool is often needed to compress the tension spring so that the belt can be slid off of the supercharger drive pulley, **Figure 46-28C**. With the belt off, you can rotate the supercharger pulley by hand to check for dry bearings, rotor-to-housing contact, or supercharger timing gear failure. See **Figure 46-28D**. Any roughness or binding when you turn the supercharger pulley by hand indicates mechanical problems.

Supercharger Clutch Service

Some superchargers are equipped with an electromagnetic clutch for engaging and disengaging the supercharger. This clutch works just like an air conditioning compressor clutch. When current is sent to the clutch coil, the clutch plates are pulled together to lock the inner and outer hubs. The engine belt drives the outer hub. The inner hub is connected to the turbocharger shaft. In this way, the supercharger is engaged only when high boost is needed to increase engine power.

If the electromagnetic clutch fails to engage, first check for a bad clutch coil. Disconnect the clutch wiring harness and apply battery voltage to the coil

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Figure 46-28. Note basic steps for removing a supercharger drive belt. A—Remove shroud or cover over supercharger belt. B—A long extension is needed to reach this belt cover bolt. C—Pry on the belt tensioner so the belt can be slipped off its pulley. D—With the drive belt removed, rotate the supercharger pulley by hand to feel for binding or damage inside the unit.

using jumper wires. This should engage the clutch. A loud click should be heard as the clutch engages. You can also use a multimeter to check for an open in the coil windings. The coil should have a low resistance. Infinite resistance indicates an open in the windings. If the clutch engages when jumped, check for the proper signal from the ECM.

Supercharger Replacement

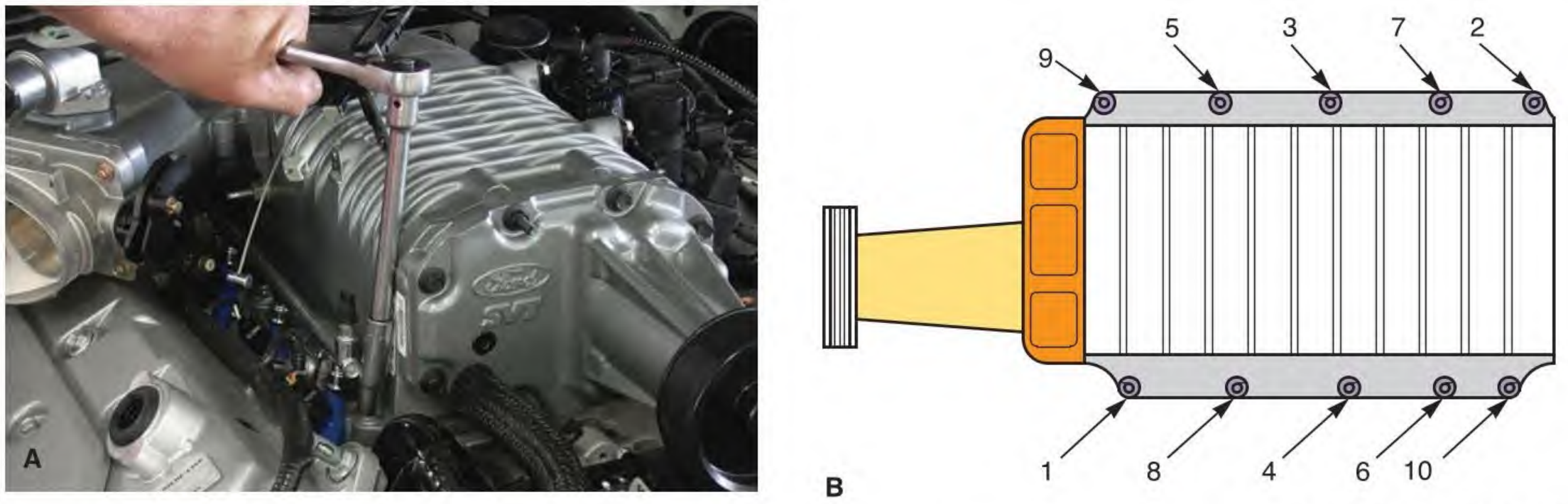
If supercharger removal is needed, follow the instructions given in the service manual. Procedures vary based on engine and supercharger design. Generally, first remove any parts that will interfere with supercharger removal. This includes the air plenum, drive belt, wires, hoses, lines, and throttle cable or linkage.

Next, remove the bolts that secure the supercharger to the engine, **Figure 46-29A**. Free the gasket with light prying. Then, lift the unit off the engine.

Superchargers are not normally serviced in the field and are simply replaced as a unit. However, seal kits are available that typically include the gaskets, oil seals, and special oil for the supercharger. These items are easily serviced.

To install the supercharger, use a new base gasket and apply sealer as recommended in the service manual. Then, slowly lower the supercharger onto the engine without damaging the gasket or breaking the sealant bead. Start all bolts by hand. Then, use a torque wrench to tighten the bolts in the recommended torque sequence, **Figure 46-29B**.

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Figure 46-29. A—A technician is removing supercharger mounting bolts. All supercharger mounting bolts must be torqued to specifications in a crisscross pattern during installation. B—A typical bolt tightening sequence for a supercharger is shown.

Reinstall the supercharger drive belt and related parts. Reinstall any accessories and fill the supercharger with the correct oil. Start and warm the engine while watching and listening for problems. Test drive the vehicle. Make sure the engine has normal power, does not have abnormal noises, and does not smoke under hard acceleration and deceleration.

Intercooler Service

Problems with the intercooler system are similar to the problems that develop in the engine cooling system. Problems include an inoperative pump, deteriorated coolant, leaking intercooler radiator or intercooler, and leaking hoses or lines.

During service, check the level and condition of the coolant in the intercooler reservoir. This reservoir is usually located on the side of the intercooler radiator or engine compartment.

Warning

Never open an intercooler system that is under pressure. The operating temperature of intercooler coolant is hot enough to cause severe burns. Remove the intercooler radiator cap slowly to verify that the system is not under pressure.

If the intercooler coolant is low, there may be a system leak. Pressure test the system as you would the engine cooling system. A special adapter may be needed to install the pressure tester on the intercooler reservoir. Do not exceed the pressure rating given on the reservoir cap. If the pressure is exceeded, the intercooler, intercooler radiator, or intercooler coolant lines may be damaged.

With the intercooler system pressurized, check for leaks in the lines or hoses, pump, intercooler radiator, and intake manifold. If the pressure gauge "bleeds down" and the engine misses or white smoke comes out of the tailpipe, the intercooler unit is the likely source of the leak. The coolant is leaking into the intake manifold and being burned in the cylinders. In this case, the intercooler must be removed and repaired or replaced.

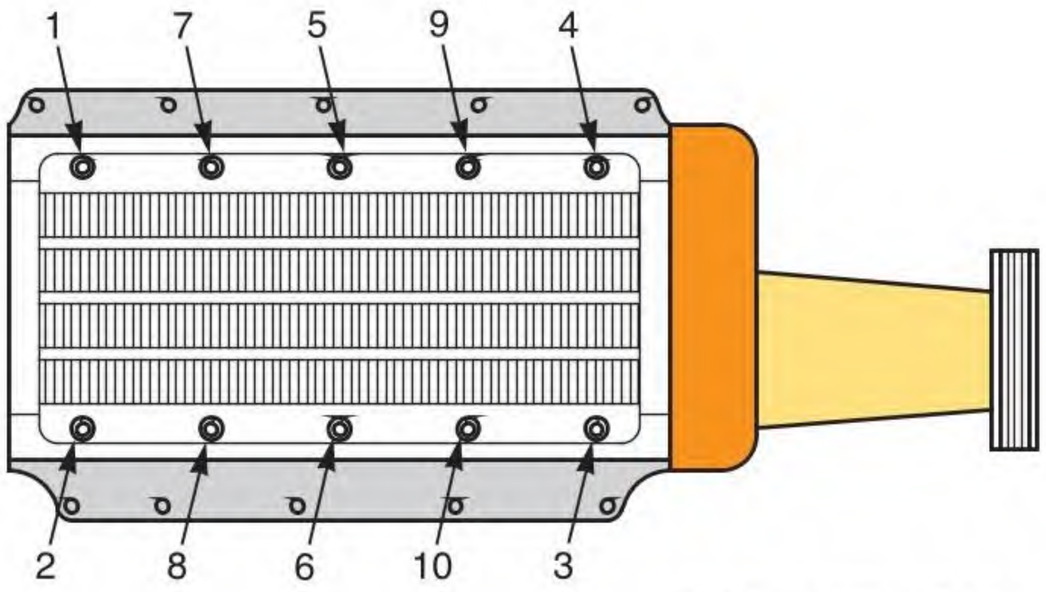
Intercooler Replacement

The intercooler on most supercharged V-6 and V-8 engines is mounted under the supercharger. Once the supercharger is removed, you can easily access the bolts securing the intercooler. Remove the bolts and separate the intercooler from the engine.

Once the intercooler is removed, inspect it for any signs of coolant leakage. If needed, send the intercooler to a radiator shop for pressure testing. A radiator shop can also flush the intercooler to remove scale or deposits in the cooling tubes.

When reinstalling the intercooler, carefully clean all gasket surfaces. Apply sealer as recommended and fit the new gaskets. Without hitting and damaging any of the fins, carefully lower the intercooler into place. Torque the intercooler fasteners to specifications in the specified pattern, **Figure 46-30**.

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Figure 46-30. A typical torque sequence for installing an intercooler is shown.

Supercharger Oil Service

To service the oil in the supercharger, remove the oil plug or dipstick. With the vehicle level, the oil should be even with the threaded hole in the oil reservoir or the correct level on the dipstick, depending on the design. Refer to the service manual for the proper procedure for checking the oil level. If needed, use a flashlight to illuminate the inside of the hole. A small length of wire can also be used as a dipstick. The supercharger oil should be almost level with its fill hole.

To replace the supercharger oil, use a hand pump to remove the existing oil. Fill the reservoir with the factory-recommended oil. Then, replace the supercharger oil level/fill plug. Supercharger oil service is illustrated in **Figure 46-31**.



Ford

Figure 46-31. Servicing the supercharger oil. A—Remove the oil plug if the unit does not have a dipstick. B—Check the oil level in the oil plug hole or on the dipstick. C—Use a hand-held pump to remove the old oil. Then, fill the supercharger with new oil. D—Replace the oil plug and tighten to specifications.The 3.5-liter V6 engine is capable of producing 365 horsepower and 420 lb ft of torque. Proper operation of the cooling and lubrication systems is critical to long engine life.

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Safety First

A technician was working on a supercharged passenger car engine. He was leaning in over the fender looking for problems when his feet slipped out from under him. His hand accidentally slipped between the supercharger belt and its pulley. Even though the engine was idling slowly, the pulley severely cut three of his fingers.

Doctors were able to save the technician's fingers, but he never regained full use of his hand. Although the technician still works on cars, he takes safety much more seriously.

To avoid injuries such as this one, be aware of the conditions on and around the engine work area.

Summary

- Normal aspiration means the engine uses only outside air pressure to cause airflow into the combustion chambers.
- Turbocharged and supercharged engines normally have several modifications to make them withstand the increased horsepower.
- The major parts of a turbocharger are the turbine housing, turbine wheel, turbo shaft, compressor wheel, compressor housing, and bearing housing.
- Turbo lag is a short delay period before the turbo develops sufficient boost and is caused by the compressor and turbine wheels not spinning fast enough.
- Boost is any pressure above atmospheric pressure in the intake manifold.
- Adequate lubrication is needed to protect the turbo shaft and bearings from damage.
- A turbocharger can operate at speeds up to 100,000 rpms. For this reason, the engine lubrication system forces engine oil into the turbo shaft bearings.
- A waste gate limits the maximum boost pressure developed by the turbocharger.
- A turbocharger intercooler is an air-to-air or air-to-liquid heat exchanger that cools the air entering the engine.
- A supercharger normally consists of the housing, rotors, timing gears, extension housing, and drive pulley.
- A supercharger bypass valve may be used to improve engine efficiency by providing maximum boost only when needed.
- Most superchargers are driven directly off the engine crankshaft through a belt, chain, or gears. However, some have an electromagnetic clutch that allows the supercharger to be engaged and disengaged.
- A supercharger intercooler removes heat from the compressed air before it enters the engine.
- A supercharger intercooler system consists of the intercooler, intercooler coolant, intercooler lines, intercooler pump, and intercooler radiator.
- Usually, a supercharger will fail because of worn bearings or damage to the impeller and housing.
- A rattling noise from the supercharger indicates rotor bearing failure and mechanical contact between the spinning rotors and the inside of the supercharger housing.
- A knocking noise indicates possible drive gear teeth breakage.
- When a supercharged engine fails to generate proper boost pressure, it is often due to a broken or slipping drive belt, an inoperative electromagnetic drive pulley mechanism, an inoperative pressure bypass valve system, physical wear or damage inside the supercharger, or a badly clogged air filter or an obstruction in the air intake.
- Overboost can be caused by a bypass valve stuck closed, an electronic control problem, or engine modification.
- Problems with an intercooler system are similar to the problems that develop in the engine cooling system.
- Superchargers are not normally serviced in the field and are simply replaced as a unit.
- The supercharger drive belt is a normal wear item that requires periodic replacement.

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Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

atmospheric engine
bearing housing
boost pressure
compressor housing
compressor wheel
diesel engine boost pressure
drain line
drain passage
dump valve
electromagnetic clutch
engine aspiration
gasoline engine boost pressure
intercooler
intercooler coolant
intercooler lines
intercooler pump
intercooler radiator
knock sensor
low boost pressure
normally aspirated engine
overboost
sealing rings
sequential turbocharger system
supercharger
supercharger assembly
supercharger belt
supercharger bypass valve
supercharger drive pulley
supercharger extension housing
supercharger housing
supercharger intercooler
supercharger rotors
supercharger timing gears
turbine housing
turbine wheel
turbo
turbo blow off valve
turbo lag
turbo shaft
turbo shaft endplay
turbo shaft radial runout
turbocharger
turbocharger boost pressure
turbocharger intercooler
twin turbocharger system
variable vane turbocharger
volumetric efficiency
waste gate
waste gate diaphragm
waste gate diaphragm spring
waste gate housing
waste gate pressure line
waste gate valve

Activities

1. Using knowledge of atmospheric pressure, demonstrate to the shop class why a turbocharger or supercharger will increase engine power.
2. Collect literature from dealerships and perform Internet research on turbocharged and non-turbocharged engines. Develop a table of horsepower-to-displacement ratios. (Divide the rated horsepower by the number of cubic inches or liters of displacement for each engine.) Prepare a report of your findings and present them to the class.

Review Questions

Answer the following questions using the information provided in this chapter.

1. Define *normal aspiration*.
2. What is the basic purpose of turbocharging or supercharging?
3. List the six basic parts of a turbocharger.
4. List four engine modifications normally found on turbocharged or supercharged engines.
5. Describe the operation of a turbocharger.
6. _____ is the short delay before the turbo develops sufficient boost.
7. What is the function of a waste gate?
8. Why is an intercooler needed on turbocharged and supercharged engines?
9. Describe the basic operation of a sequential turbocharger system.
10. A(n) _____ should be used to check turbocharger clearances, shaft endplay, and runout.
11. List the five basic parts of a supercharger.
12. What is the purpose of a supercharger bypass valve?
13. A supercharger intercooler:
    (A) cools the air coming into the air inlet.
    (B) is typically an air-to-air heat exchanger.
    (C) cools the air coming out of the supercharger.
    (D) results in a cooler, less dense charge of air entering the intake manifold.
14. List four problems that may be indicated by low supercharger boost pressure.
15. List three problems that may result in overboost.

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ASE-Type Questions

1. A turbocharged vehicle has a severe detonation problem. Engine power is good and initial ignition timing is within specifications. Technician A says that the trouble could be in the knock sensor. Technician B says the waste gate could be stuck closed. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Technician A says that a normally aspirated engine is equipped with a supercharger. Technician B says that a normally aspirated engine is equipped with a turbocharger. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. All of the following are basic components of a turbocharger, *except*:
   (A) bearing housing.
   (B) turbine wheel.
   (C) transfer pump.
   (D) turbo shaft.
4. Technician A says that with a supercharged engine, there is a slight delay in pressure and power increase because the unit must build up speed. Technician B says that a supercharger is driven by a belt connected to the crankshaft pulley. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. Technician A says that volumetric efficiency is a measure of how much air an engine can draw in on its power strokes. Technician B says that a normally aspirated engine is limited by its volumetric efficiency. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Technician A says that boost refers to any pressure above atmospheric pressure in an engine's combustion chambers. Technician B says that boost refers to any pressure above atmospheric pressure in an engine's intake manifold. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. A loud growling noise can be heard coming from the supercharger. Technician A says that the noise may indicate rotor bearing failure. Technician B says that the noise may indicate drive gear teeth breakage. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. The boost on a supercharger is measured and it is found that the supercharger is producing no boost. Technician A says that the ECM may not be sending a signal to engage the electromagnetic clutch. Technician B says that the supercharger bypass valve may be stuck closed. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. As a supercharger intercooler system is pressure tested, the engine begins to run rough and white smoke can be seen coming out of the tailpipe. Technician A says that the cylinder head may be cracked. Technician B says that the problem may be caused by bent cooling fins on the intercooler. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. The electromagnetic clutch on a supercharger is not engaging. Technician A says to check for the proper signal from the ECM. Technician B says that the clutch coil should have high resistance in its windings. Who is correct?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Section 7

Cooling and Lubrication System Technology

Chapter 47
Cooling System Technology

Chapter 48
Cooling System Testing, Maintenance, and Repair

Chapter 49
Lubrication System Fundamentals

Chapter 50
Lubrication System Diagnosis, Testing, and Repair

The cooling and lubrication systems are designed to prevent engine damage and wear. The cooling system removes excess combustion heat and maintains a constant engine operating temperature. The lubrication system reduces friction and wear between internal engine parts. If these systems are not operating properly, an engine can destroy itself in a matter of minutes. Aluminum pistons can literally melt and weld themselves to the cylinder walls, bearings can seize, and major parts can crack or warp.

This section details the operation, construction, diagnosis, and repair of modern cooling and lubrication systems. Study it carefully! This information will help you pass ASE Test A1, *Engine Repair,* and Test A8, *Engine Performance*.



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Chapter 47
Cooling System Technology

After studying this chapter, you will be able to:

- Summarize the functions of engine, supercharger, turbocharger, DEFI, and HV (hybrid vehicle) cooling systems.
- Explain the operation and construction of major cooling system components found in modern vehicles.
- Compare cooling system design variations.
- Explain the function of antifreeze.
- Identify safety procedures to follow when working with any engine, supercharger, HV motor-generator, HV battery, HV transmission, or HV engine control module.
- Compare hybrid air and liquid (water) cooling systems.
- Correctly answer ASE certification test questions on cooling systems found in modern passenger vehicles.

This chapter begins by explaining the design, construction, and operation of cooling systems. Cooling systems for supercharger intercooler systems are then presented. Finally, hybrid cooling systems for the high-voltage HV battery, HV engine control module, and hybrid motor-generator are discussed. You must fully understand how different cooling systems work before learning to service and repair them.

Vehicle Cooling Systems

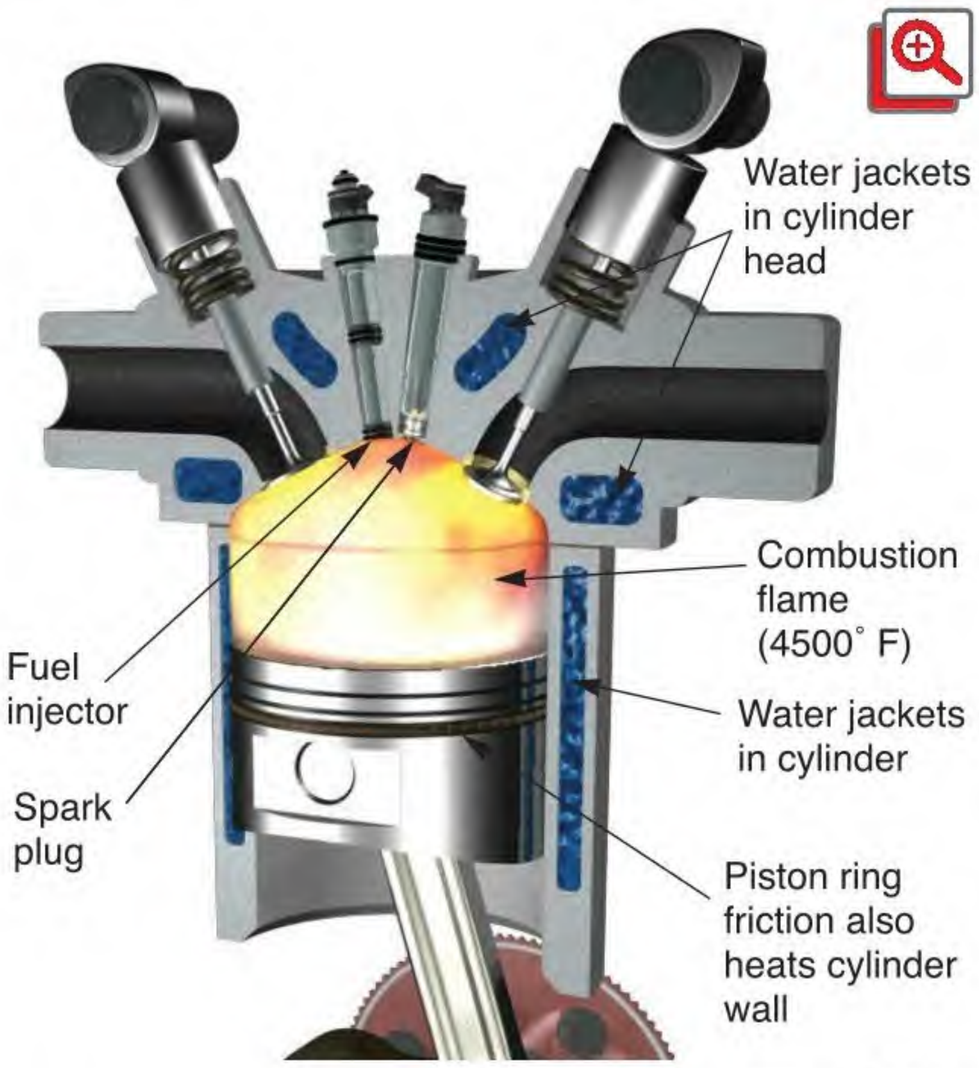
A modern passenger vehicle can have several ***cooling system*** types, each designed to control the operating temperature of a mechanical and electrical assembly. Many assemblies on today's vehicles generate internal heat during operation, including the internal combustion engine, a supercharger or turbocharger, an HV battery, or the huge hybrid drive motor-generator.

Without a properly operating cooling system, an engine can "self-destruct" in a matter of minutes. Refer to **Figure 47-1**. Internal engine parts can overheat and partially melt, causing the engine to "lock up", or seize (reciprocating assembly no longer moves freely).

Specific Cooling Systems

An engine, supercharger, turbocharger, battery pack, and high-power control circuit must not get too hot or damage will result. During startup, a cooling system must help the assembly warm to operating temperature quickly to lower emissions and wear. After the assembly has warmed up, the cooling system must maintain a constant operating temperature to prevent overheating.

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Figure 47-1. The combustion flame can be as hot as 4500°F. Aluminum pistons and cylinder heads melt at only 1220°F. This temperature difference shows the importance of coolant circulation through the head and block water jackets to remove heat.

The following are the most common types of cooling systems found on modern gas, diesel, hybrid, and electric drive trains:

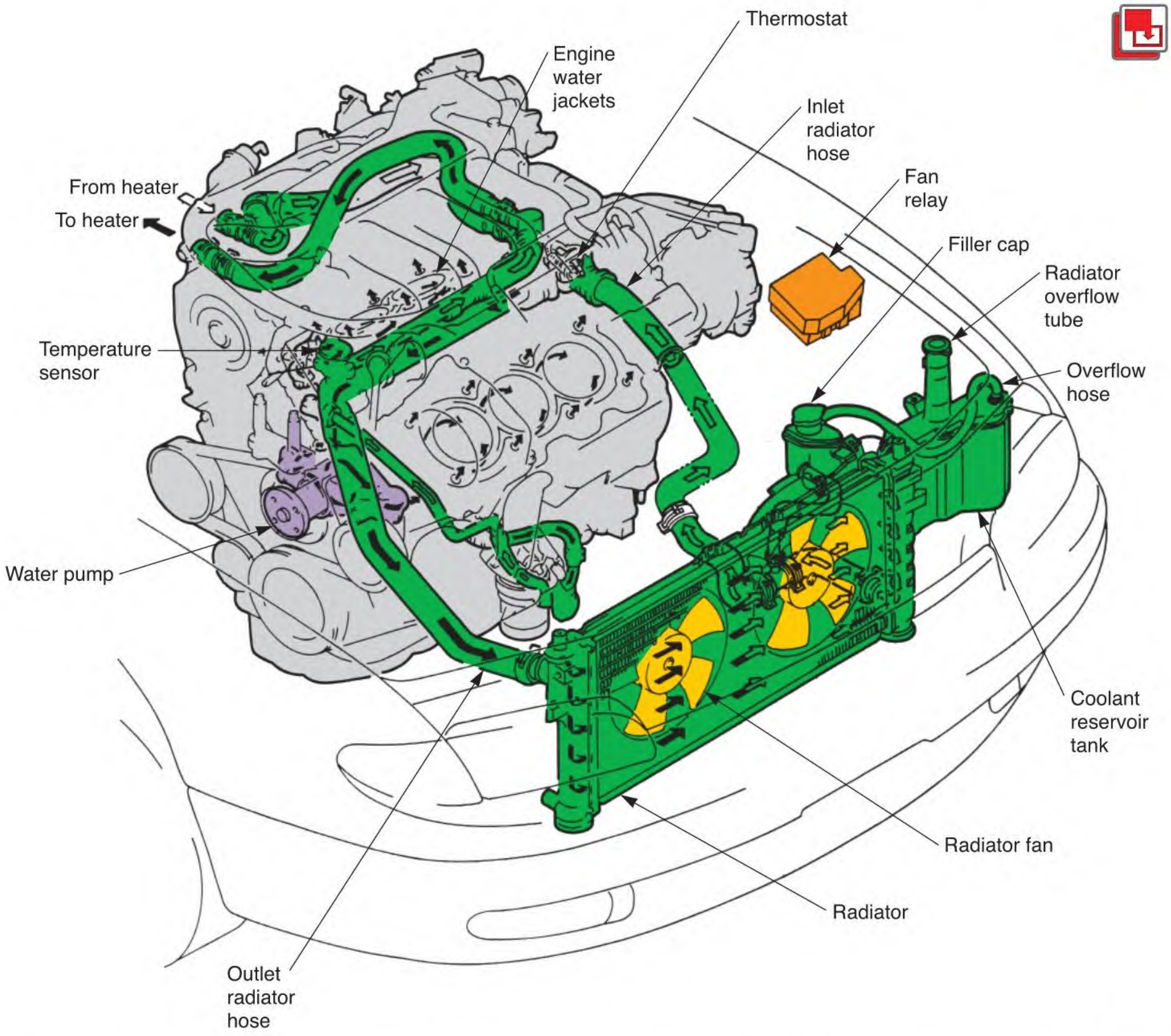
- ***Engine cooling system***— An engine cooling system controls the operating temperature of the cylinder heads and cylinder block. It must make the steel and aluminum engine warm up quickly without exceeding the factory-specified operating temperature. It must also provide a means for warming the passenger compartment in cold weather. See **Figure 47-2**.
- ***Supercharger cooling system***—A supercharger cooling system must keep the ***blower intercooler temperature*** cooler than the engine's operating temperature. When air is compressed, air temperature increases. If the blower and the air being forced into the engine get too hot, gasoline combustion can detonate and explode. To prevent this, a supercharger cooling system forces a liquid coolant through an intercooler mounted under the supercharger.
- ***Turbocharger cooling system***—A turbocharger cooling system forces coolant through the turbo bearing housing to keep the turbo from overheating under prolonged high boost. While compressing air entering the engine, the hot exhaust gases blowing over the turbine wheel and through the turbine housing can make the turbo housing glow red hot. A turbocharger cooling system prevents heat from burning up seals, bearings, or the turbine wheel.
- ***HV battery cooling system***—HV battery cooling uses air or a liquid to remove battery cell heat when under prolonged high amperage draw. Most vehicles use an electric motor blower fan to force outside air through the battery pack housing to keep it cool. The warm air is then exhausted through ducts. The electric drive trains of high-power hybrids force coolant into and between the battery pack modules to prevent overheating damage to the plates in the cells. Air cooling may not be sufficient with super, high-watt-hour HV batteries.
- ***HV motor-generator cooling system***—HV motor-generator cooling uses liquid coolant to prevent motor-generator overheating in full-electric and hybrid gas-electric vehicles. Coolant lines run through the stator housing on large, high-power, three-phase ac motor-generator assemblies. With plug-in hybrids, the motor-generator can operate for 50 miles (80 km) under full electric propulsion, which generates high temperatures. The circulation of liquid coolant carries motor-generator heat to a heat exchanger or to the engine cooling system.
- ***HV engine control module cooling system***—HV engine control module cooling forces air or a liquid through or over an aluminum heat sink surrounding the high-power transistors for each leg of the three-phase. The power transistors must handle over 240 volts each. Three power transistors handle over 600 volts of ac three-phase, with hundreds of amps in each orange cable. When an HV engine control module circuit gets too hot, power transistors can go into thermal runaway, capacitors and resistors can burn, and printed circuit boards can burn out. The HV engine control module must control tremendous amounts of electrical energy and the resulting heat.

Cooling System Functions

A cooling system performs several functions:

- Removes excess heat from the engine.
- Maintains constant engine operating temperature.
- Helps a cold engine quickly reach operating temperature.
- Provides heat for the passenger compartment.

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Mazda

Figure 47-2. Study the basic names and locations of parts in a cooling system. This will help you as each part is explained in detail.

Removing Engine Heat

Most combustion heat is used to produce expansion and pressure for piston movement. Some combustion heat flows out with the exhaust gas or flows into the metal parts of the engine. Without removing this excess heat, an engine could be seriously damaged in a matter of minutes.

The burning air-fuel mixture produces a tremendous amount of heat. Combustion flame temperature can reach 4500°F (2500°C). Iron melts at around 2750°F (1510°C). Steel melts at around 2500°F (1370°C). Aluminum turns to a liquid at even lower temperatures, 1220°F (660°C). The combustion flame is similar to the blast of fire blown out by an oxyacetylene cutting torch. Imagine the potential catastrophic damage to the metal engine parts (aluminum pistons, aluminum head, steel valves, stainless steel fuel injector tip, steel spark plug electrodes) without combustion flame heat removal.

Maintaining Operating Temperature

Engine operating temperature is the temperature the engine coolant (water and antifreeze mixture)

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reaches under normal running conditions. Typically, an engine's operating temperature is between 180°F (82°C) and 210°F (99°C).

When an engine warms to operating temperature, its parts expand. This ensures that all part clearances are correct. It also ensures proper combustion, emission output levels, and engine performance.

Reaching Operating Temperature Quickly

An engine must warm up rapidly to prevent poor combustion, part wear, oil contamination, reduced fuel economy, increased emissions, and other problems. A cold engine suffers from several problems. For instance, the aluminum pistons in a cold engine will not be expanded by heat. This can cause too much clearance between the pistons and the cylinder walls. The oil in a cold engine will also be very thick, which can reduce lubrication and increase engine wear. The air-fuel mixture will not vaporize and burn as efficiently in a cold engine.

Heater Operation

A cooling system commonly circulates coolant to the vehicle's heater. The ***heater core*** is a small liquid-to-air heat exchanger mounted under the dash in the passenger compartment. Since the engine coolant is warm, its heat can be used to warm the passenger compartment.

Cooling System Types

There are two major types of automotive cooling systems: air cooling systems and liquid cooling systems. Refer to **Figure 47-3**.

Air Cooling Systems

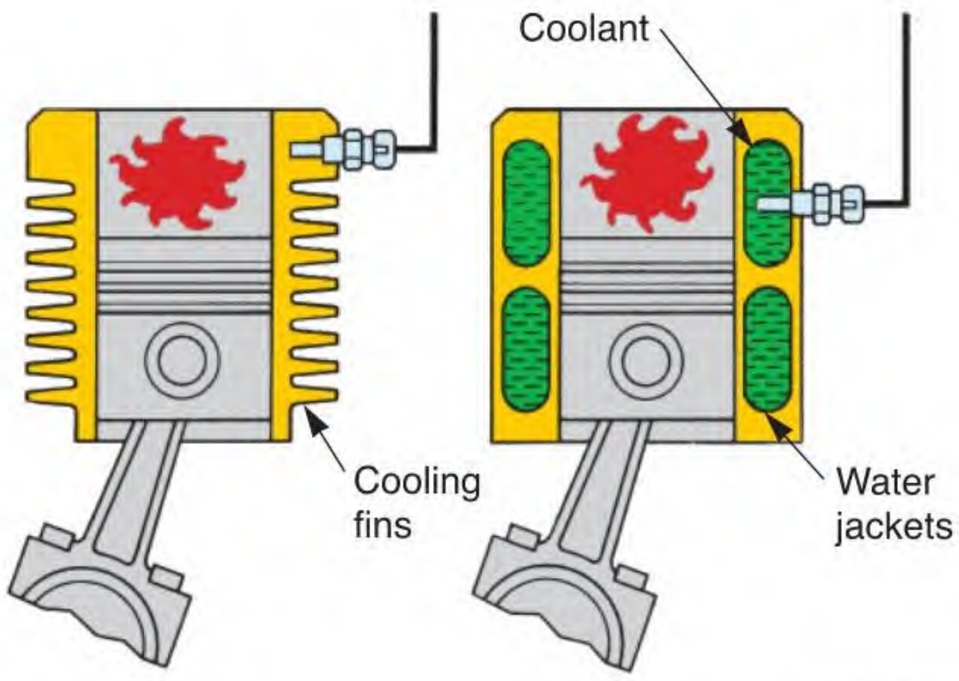
An ***air cooling system*** uses large cylinder ***cooling fins*** and outside air to remove excess heat from the engine. The cooling fins increase the surface area of the metal around the cylinder, which allows enough heat to transfer from the cylinder to the outside air. An air cooling system commonly uses plastic or sheet metal ducts and ***shrouds*** (enclosures) to route air over the cylinder fins. Temperature-controlled air flaps regulate airflow and engine operating temperature.

Liquid Cooling Systems

A ***liquid cooling system*** circulates coolant (a solution of water and antifreeze) through the water jackets in the engine's cylinder block and cylinder head. The coolant collects excess heat on metal parts and carries this heat away from the engine. See **Figure 47-4**.

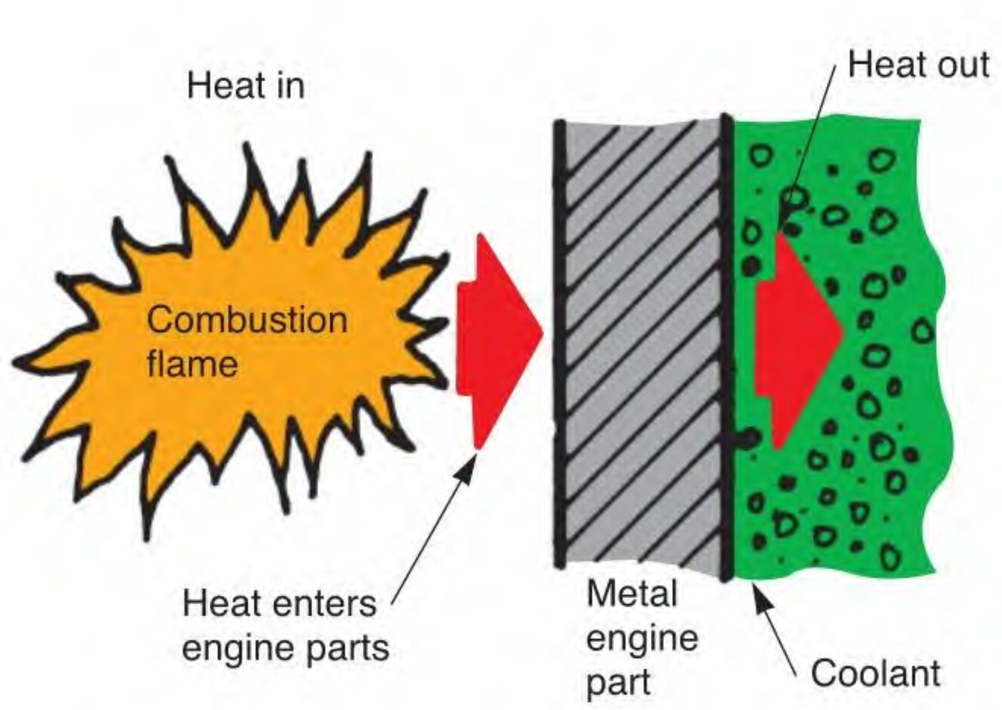
Tech Tip

Air-cooled automotive engines are rare. Most late-model vehicles have liquid-cooled engines.



Robert Bosch

Figure 47-3. An air-cooled engine has large fins on the cylinder to dissipate heat into surrounding air. A liquid-cooled engine has water jackets around each cylinder to collect heat.



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Figure 47-4. Combustion heat transfers into the cylinder wall and then into the coolant. Coolant carries heat away from the engine.

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Liquid cooling systems have several advantages over air cooling systems, including:

- More precise control of engine operating temperature.
- Less temperature variation inside the engine.
- Reduced exhaust emissions due to better temperature control.
- Improved heater operation to warm passengers.

Conventional- and Reverse-Flow Cooling

With ***conventional-flow cooling***, hot coolant flows from the cylinder head to the radiator. After being cooled in the radiator, the coolant flows back into the engine block. This is the most common coolant flow direction.

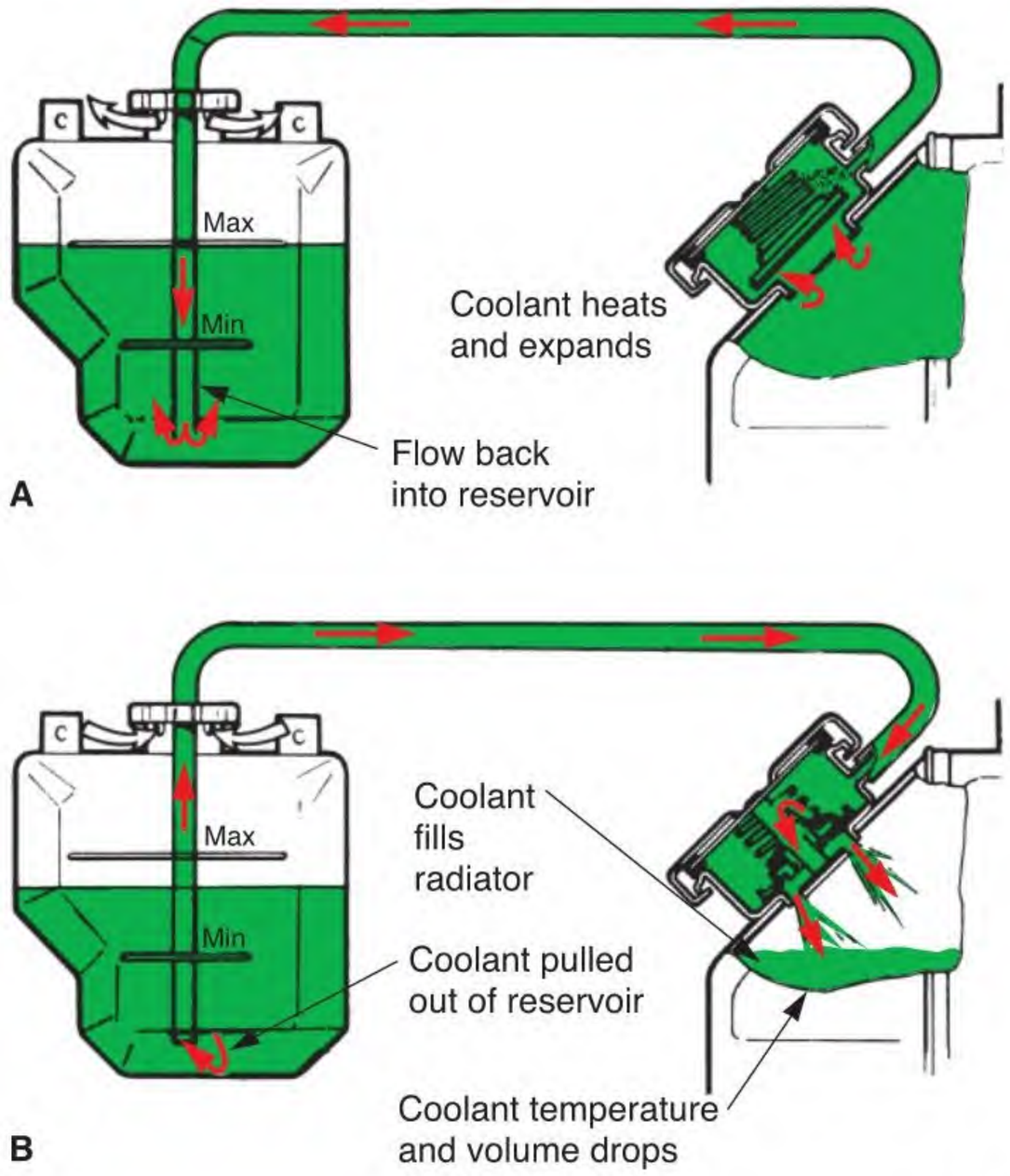
Reverse-flow cooling follows the opposite course: cool coolant enters the head and hot coolant exits the block to return to the radiator. Reversing the flow of the coolant helps keep a more uniform temperature throughout the engine, especially around the hot exhaust valves. Reverse-flow cooling can be found on high-performance engines.

Closed and Open Cooling Systems

A ***closed cooling system*** uses an expansion tank, or reservoir, and a radiator cap with pressure and vacuum valves. The overflow tube is routed into the bottom of the reservoir tank. Pressure and vacuum valve action pull coolant in and out of the reservoir tank as needed. This keeps the cooling system correctly filled at all times.

When the engine heats up, the coolant expands and opens the cap pressure valve. Instead of leaking onto the ground, the coolant flows into the reservoir. After the engine has been shut off, the coolant temperature drops and its volume decreases. This causes the vacuum valve to open. Atmospheric pressure (system suction) then forces coolant back into the radiator. This compensates for any small system leaks, keeping the system properly filled. Refer to **Figure 47-5**.

An ***open cooling system*** does not use a coolant reservoir. The overflow tube allows excess coolant to leak onto the ground. Also, it does not provide a means of adding fluid automatically. Open cooling systems are no longer used on automobiles. This system has been replaced by the closed cooling system, which requires less maintenance.



Ford

Figure 47-5. Study pressure cap operation. A—When the engine heats up, coolant expands. Excess fluid opens the cap pressure valve and coolant enters the reservoir for reuse. B—When the engine is shut off, coolant temperature drops and coolant is reduced in volume. The cap vent valve opens to let coolant flow back into the radiator.

Cooling System Parts

The basic parts of an engine cooling system are:

- ***Water pump***—The water pump forces coolant through the engine and other system parts.
- ***Radiator hoses***—Radiator hoses connect the engine to the radiator.
- ***Radiator***—The radiator transfers engine coolant heat to outside air.
- ***Fan***—The fan draws air through the radiator.
- ***Thermostat***—The thermostat controls coolant flow and engine operating temperature.

When the engine is running, the water pump forces coolant to circulate through the engine water jackets (internal passages in the engine). While the engine is cold, the thermostat remains closed, so coolant circulates inside the engine. This helps warm the engine quickly. When the engine reaches operating temperature, the thermostat opens. Heated coolant then flows through the radiator, and excess heat is transferred from the coolant to the air flowing through the radiator.

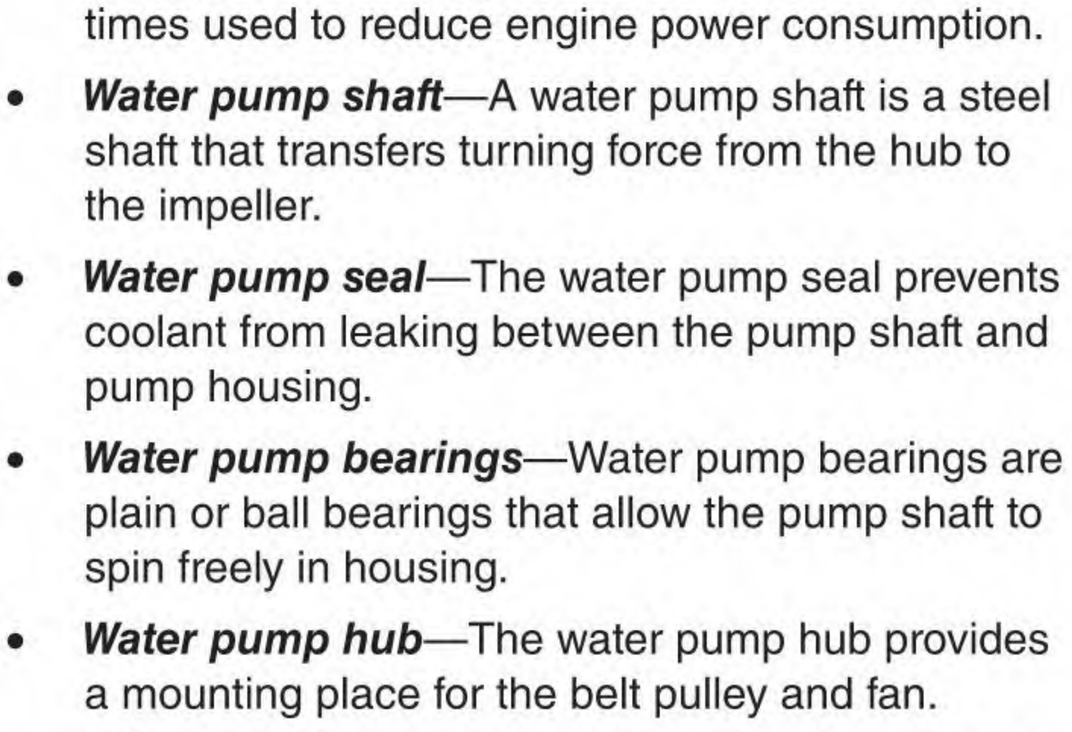
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Water Pump

The engine-driven water pump is an impeller or centrifugal pump that forces coolant through the engine block, cylinder head, intake manifold, hoses, and radiator. It is often driven by a belt running off the crankshaft pulley. In some cases, the pump is gear-driven directly off the crankshaft-sprocket and timing chain. See **Figure 47-6**.

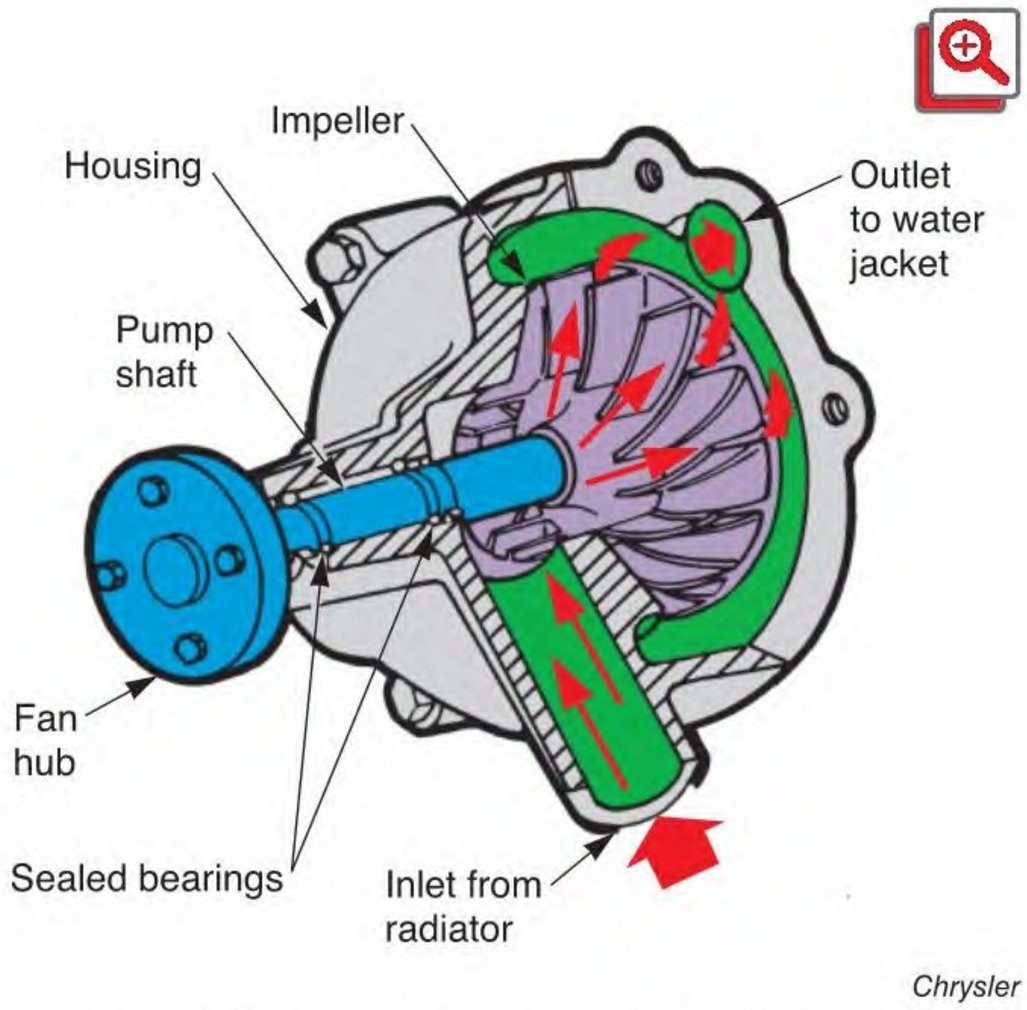
The major parts of a typical water pump (**Figure 47-7**) include:

- ***Water pump impeller***—The water pump impeller is a disk with fan-like blades with an impeller that spins and produces pressure and flow. Water pump impellers can be made of steel or plastic. The impeller blades can be curved or straight. Straight blades, like paddle wheels, are sometimes used to reduce engine power consumption.
- ***Water pump shaft***—A water pump shaft is a steel shaft that transfers turning force from the hub to the impeller.
- ***Water pump seal***—The water pump seal prevents coolant from leaking between the pump shaft and pump housing.
- ***Water pump bearings***—Water pump bearings are plain or ball bearings that allow the pump shaft to spin freely in housing.
- ***Water pump hub***—The water pump hub provides a mounting place for the belt pulley and fan.
- ***Water pump housing***—The water pump housing is an iron or aluminum casting that forms the main body of pump.



Ford

Figure 47-6. The fan belt turns the water pump pulley to operate the pump. This is a modern ribbed belt that powers all accessory units.



Chrysler

Figure 47-7. Cutaway of a simplified water pump. Note how the spinning impeller throws coolant outward to produce pressure and flow.

- ***Water pump gasket***—A water pump gasket fits between the engine and pump housing to prevent coolant leakage. RTV sealer or a rubber seal may be used instead of a gasket.

The water pump normally mounts on the front of the engine. With some transverse (sideways-mounted) engines, it bolts to the side of the engine and extends toward the front.

Water Pump Operation

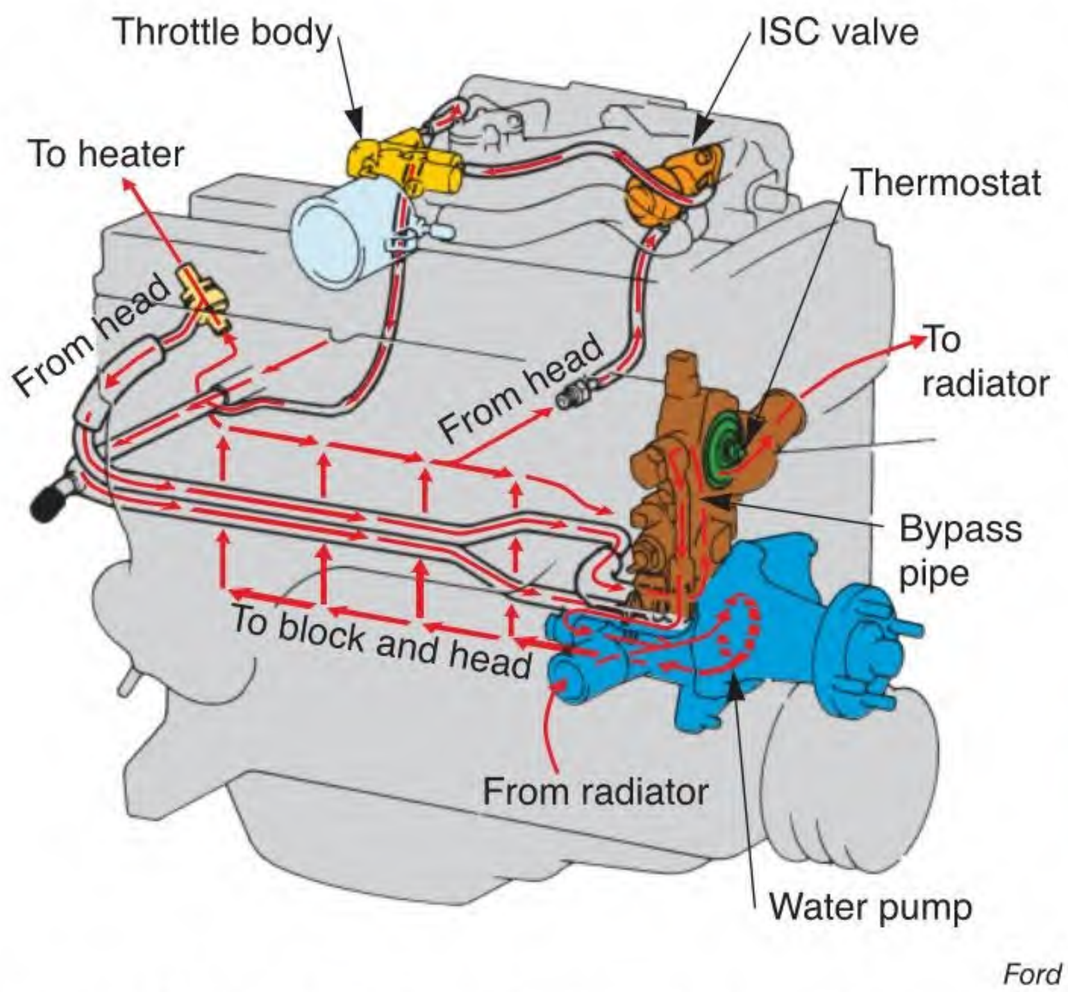
The spinning engine crankshaft pulley causes the drive belt to turn the water pump pulley, pump shaft, and impeller. The coolant trapped between the impeller blades is thrown outward by centrifugal force. This produces suction (vacuum) in the central area of the pump housing. It also produces pressure in the outer area of the housing.

Since the pump inlet opening is near the center, coolant is pulled out of the radiator, through the lower hose, and into the pump. After being thrown outward and pressurized, the coolant flows into the engine. It circulates through the block, around the cylinders, up through the cylinder head(s), through the thermostat, and back into the radiator. Look at **Figure 47-8**.

Electric Water Pump

An ***electric water pump*** uses a large dc motor and an impeller to force coolant through the engine's water jackets or through the HV cooling system. It

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Ford

Figure 47-8. The water pump pulls coolant out of the bottom of the radiator and through the engine block, heads, and intake manifold. Hot coolant then reenters the radiator for cooling.

replaces a belt-driven water pump. The electric water pump assembly often bolts to the side of the engine and has one radiator hose connected to it.

When the engine control unit senses that the engine has reached a predetermined operating temperature, it energizes the electric water pump to maintain the correct engine temperature. Since the electric water pump does not turn until needed, it allows the engine to reach operating temperature more quickly for improved efficiency. The speed of the electric water pump can also be controlled by the engine control unit to reduce energy consumption.

Radiator and Heater Hoses

Radiator hoses carry coolant between the engine water jackets and the radiator. Being flexible, hoses can withstand the vibrating and rocking of the engine on its motor mounts without breakage.

The upper radiator hose normally connects to the thermostat housing on the intake manifold or cylinder head. Its other end fits on the radiator. The lower hose often connects the water pump inlet and the radiator.

A ***molded hose*** is manufactured in a special shape, with bends to clear the cooling fan and other parts. It must be purchased to fit the exact year and make of car.

A ***flexible hose*** has an accordion shape and can be bent to different angles. The pleated construction allows the hose to bend without collapsing and blocking flow. A flexible hose is also called a universal-type radiator hose.

A ***hose spring*** is frequently used in the lower radiator hose to prevent the hose from collapsing. The lower hose is exposed to suction from the water pump. The spring ensures that the inner lining of the hose does not tear away, close up, and stop circulation.

Caution

Never remove the spring from inside a radiator hose. If you do, the hose can collapse and cause engine overheating damage.

Heater hoses are small-diameter hoses that carry coolant to the heater core.

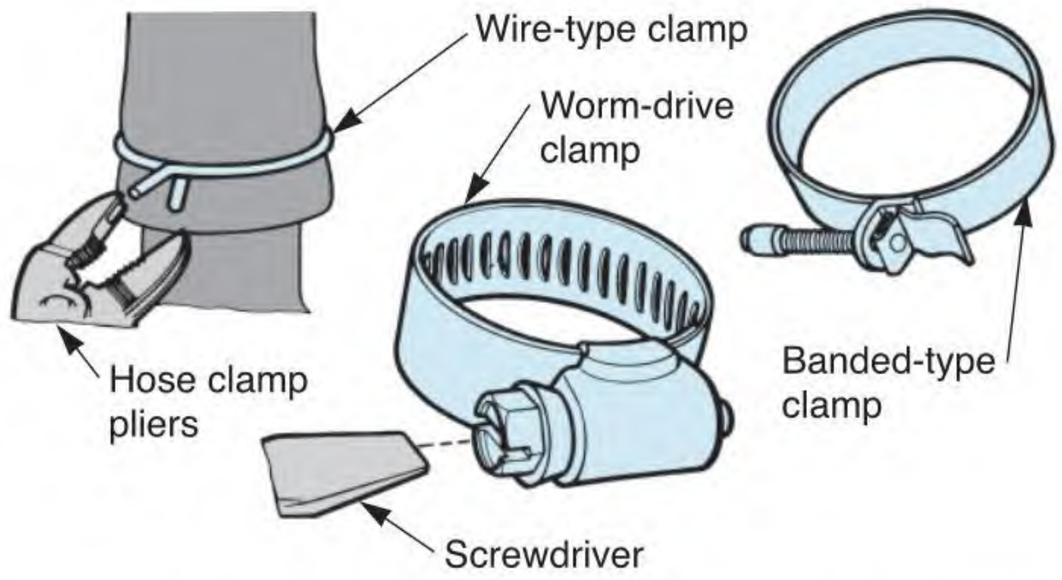
Hose clamps hold the radiator hoses and heater hoses on their fittings. A ***worm-drive hose clamp*** uses a worm gear that engages slots in the clamp strap to allow tightening around the hose. It is the most common type of replacement hose clamp. See **Figure 47-9**.

Radiator

The radiator transfers coolant heat to the outside air. The radiator is normally mounted in the front of the engine where cool outside air can flow freely through it. See **Figure 47-10**.

A radiator typically consists of six components:

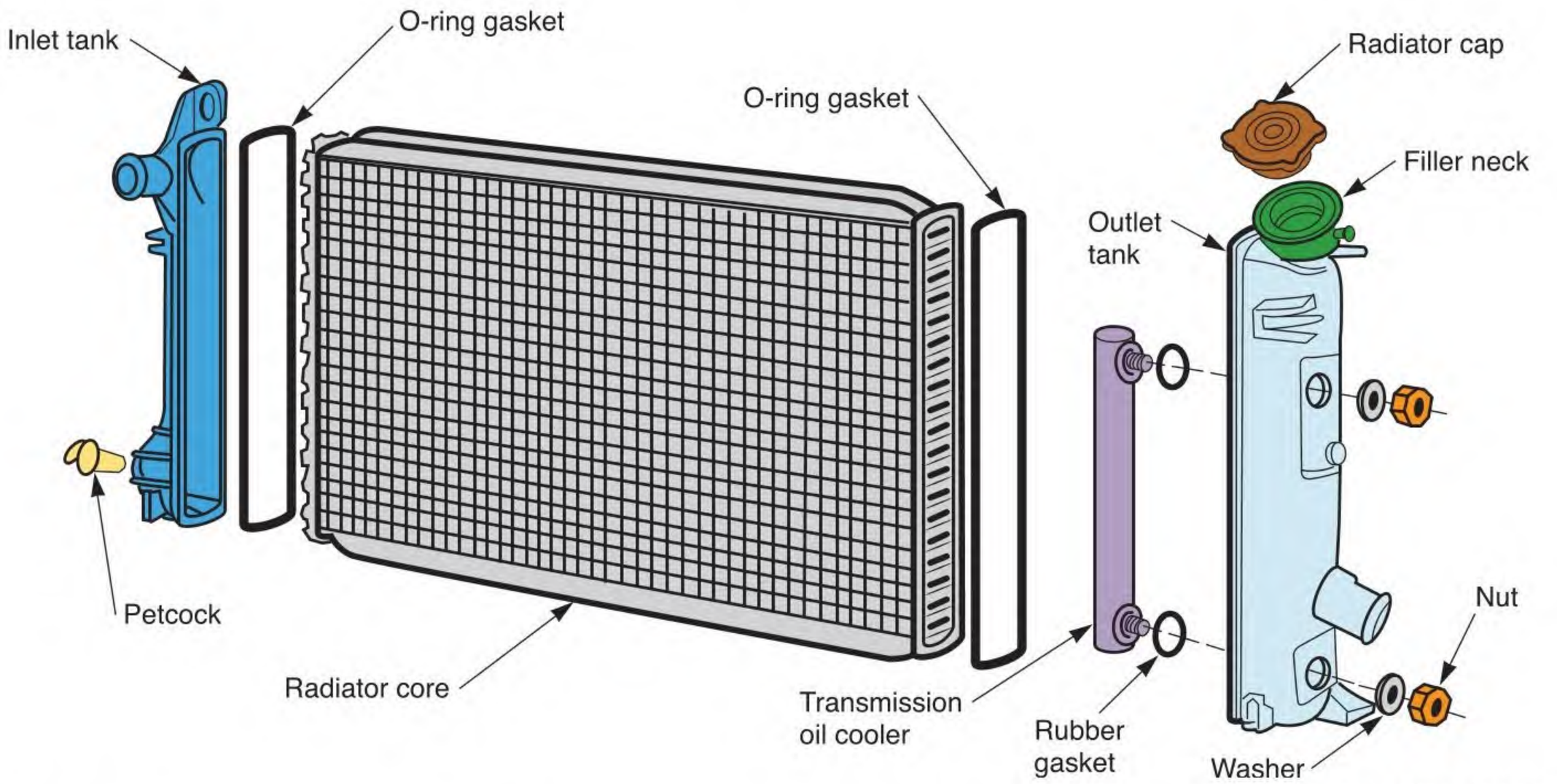
- ***Radiator core***—The radiator core is the fragile center section of a radiator and is made up



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Figure 47-9. Three basic types of hose clamps. The worm-drive clamp is the most common. A spring-type clamp requires hose clamp pliers with a groove cut in the jaws.

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Figure 47-10. Exploded view of the major parts of a radiator.

of tubes and cooling fins soldered or bonded together. This is where coolant heat is transferred into the air flowing through the coolant filled tubes running through the core.

- ***Radiator tanks***—Radiator tanks are the metal or plastic ends that fit over the core tube ends to provide storage for coolant and fittings for hoses. The radiator tanks also have fittings for large coolant hoses and sometimes small fittings for transmission oil coolers.
- ***Radiator filler neck***—The radiator filler neck is an opening for adding coolant that also holds a removable radiator pressure cap to prevent coolant from boiling when above 212°F (100°C). The radiator neck has an overflow tube connected to the coolant reservoir tank.
- ***Transmission oil cooler***—A transmission oil cooler is an inner tank for cooling automatic transmission or transaxle fluid. It is formed inside the radiator tanks and has tube fittings for the metal cooler lines running back to the transmission.
- ***Radiator petcock***—The petcock is a fitting on the bottom of the tank for draining coolant.
- ***Radiator cap***—The radiator cap pressurizes the water and antifreeze solution so that it does not boil when operating above 212°F (100°C).

Radiator Action

Under normal operating conditions, hot engine coolant circulates through the radiator tanks and core. Heat transfers into the core's tubes and fins. Cooler air flows over and through the radiator fins, so heat is removed from the radiator. This reduces the temperature of the coolant before it flows back into the engine.

Radiator Types

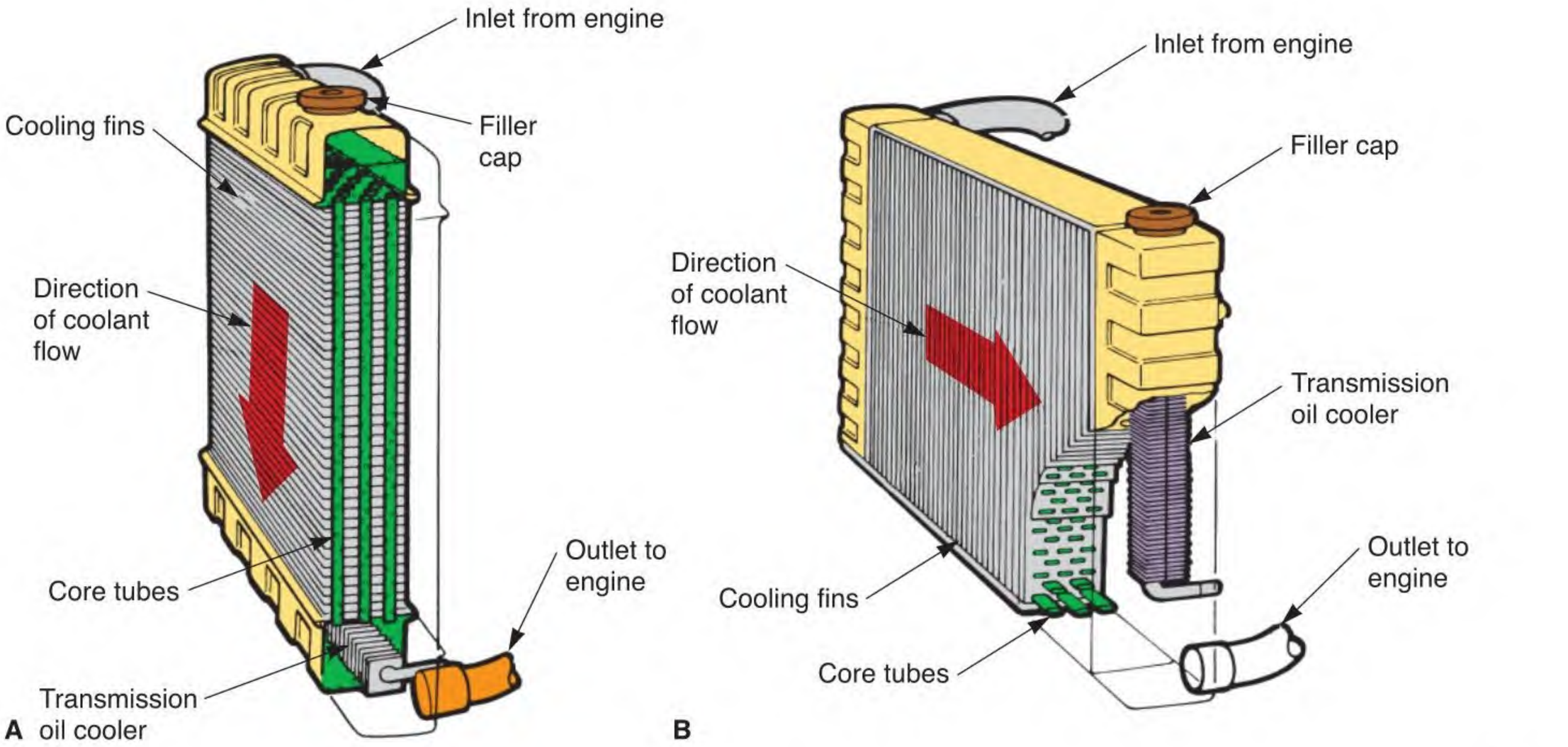
The two types of radiators are the crossflow and the downflow. Both are shown in **Figure 47-11**.

The tanks on a ***downflow radiator*** are on the top and bottom of the core, and the core tubes run vertically between the tanks. Hot coolant from the engine enters the top tank. The coolant flows downward through the core tubes. After cooling, the coolant flows out of the bottom tank and back into the engine.

A ***crossflow radiator*** is a more modern design that has tanks on the sides of the core. The core tubes are arranged for horizontal coolant flow. The tank with the radiator cap is normally the outlet tank. A crossflow radiator can be shorter than a downflow radiator, allowing for a lower hood line.

Radiator tanks can be made of metal or plastic. With metal radiator tanks, the core and tanks are soldered together. With plastic radiator tanks, rubber seals fit between the tanks and core to prevent leakage. See **Figure 47-10**.

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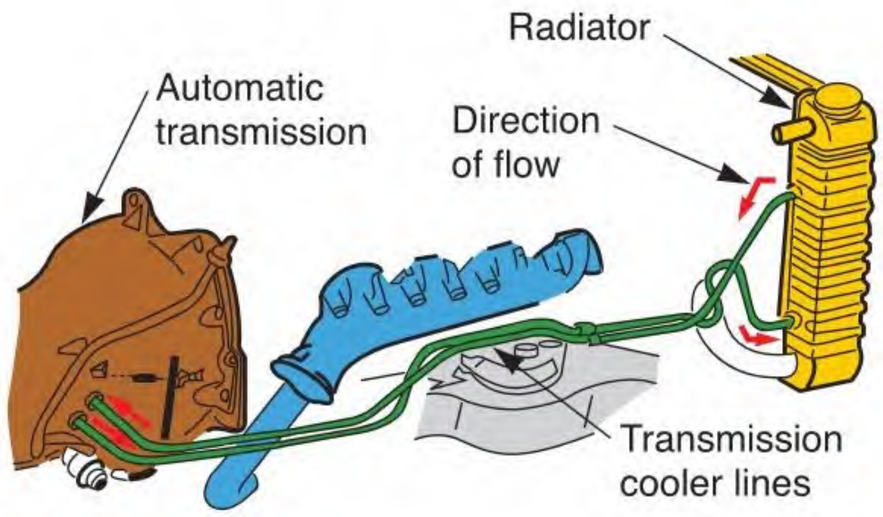
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Figure 47-11. Two types of radiators. A—A downflow radiator has core tubes running up and down. B—A crossflow radiator has cooling tubes running horizontally. The crossflow radiator is more common on late-model cars.

Transmission Oil Cooler

A transmission oil cooler is often placed in the radiator on cars with automatic transmissions or transaxles to prevent the transmission fluid from overheating. It is a small tank enclosed in one of the main radiator tanks. Since the transmission fluid is hotter than the engine coolant, heat is removed from the fluid as it passes through the radiator and cooler, **Figure 47-12**.

In downflow radiators, the transmission oil cooler is located in the lower tank. In crossflow radiators, the oil cooler is in the tank that has the radiator cap.



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Figure 47-12. Automatic transmission lines run from the transmission to the transmission oil cooler fittings.

Line fittings from the cooler extend through the radiator tank to the outside. Metal lines from the automatic transmission or transaxle connect to these fittings. The transmission oil pump forces the fluid through the lines and cooler.

Radiator Cap

The radiator cap performs several functions:

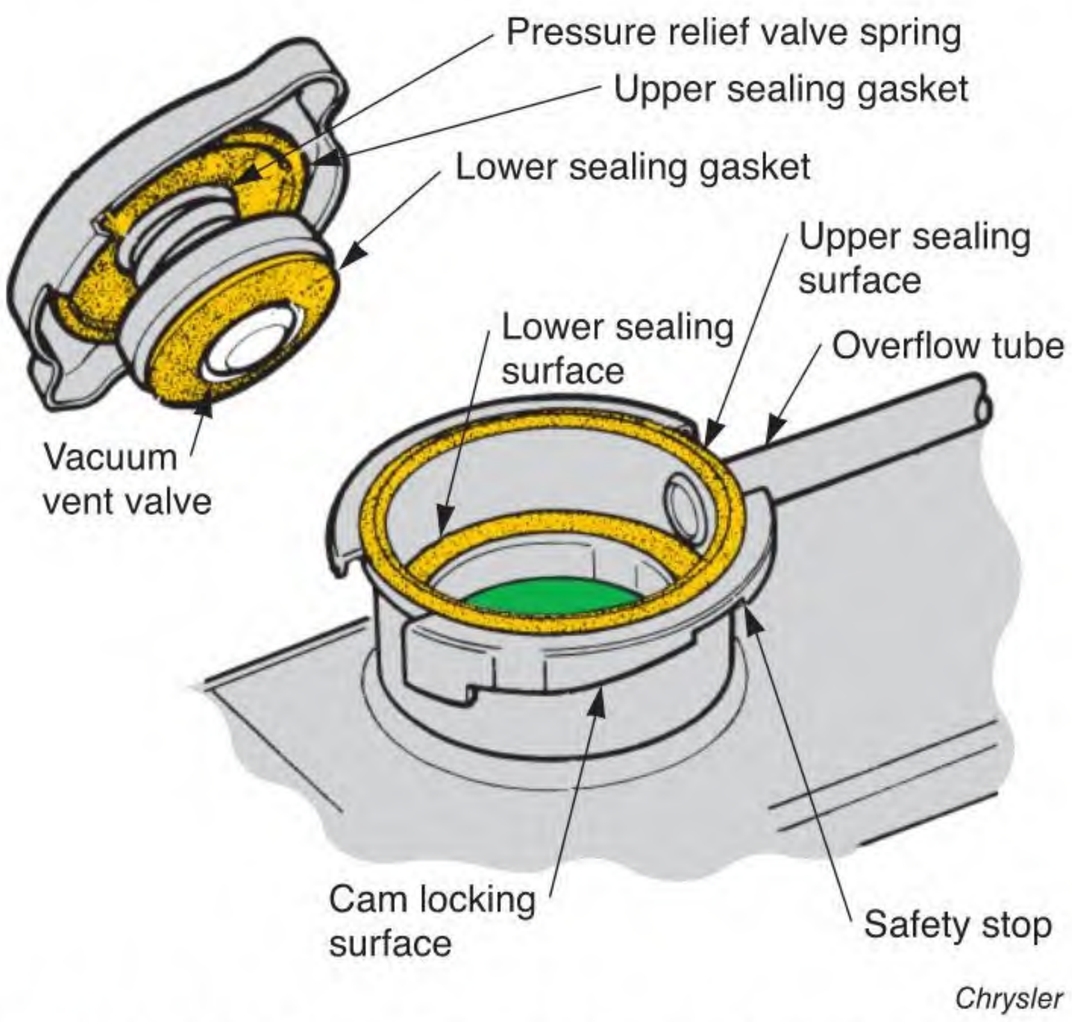
- Seals the top of the radiator filler neck to prevent leakage.
- Pressurizes the system to raise the boiling point of coolant. This keeps coolant from boiling and turning to steam.
- Relieves excess pressure to protect against system damage.
- In closed systems, it allows coolant flow between the radiator and the coolant reservoir.

The radiator cap locks onto the radiator tank filler neck or on the reservoir tank. See **Figure 47-13**. Rubber or metal seals make the cap-to-neck joint airtight. Radiator caps can be made of metal or plastic.

Radiator Cap Pressure Valve

The ***radiator cap pressure valve*** consists of a spring-loaded disk that contacts the filler neck. The spring pushes the valve into the neck to form a seal.

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Figure 47-13. A radiator pressure cap screws onto the radiator filler neck or reservoir tank. Rubber or metal seals prevent leakage.

When water is placed under pressure, its boiling point increases. Normally, water boils at 212°F (100°C). However, for every pound of pressure increase, water's boiling point goes up about 3°F (1.67°C). The radiator cap works on this principle.

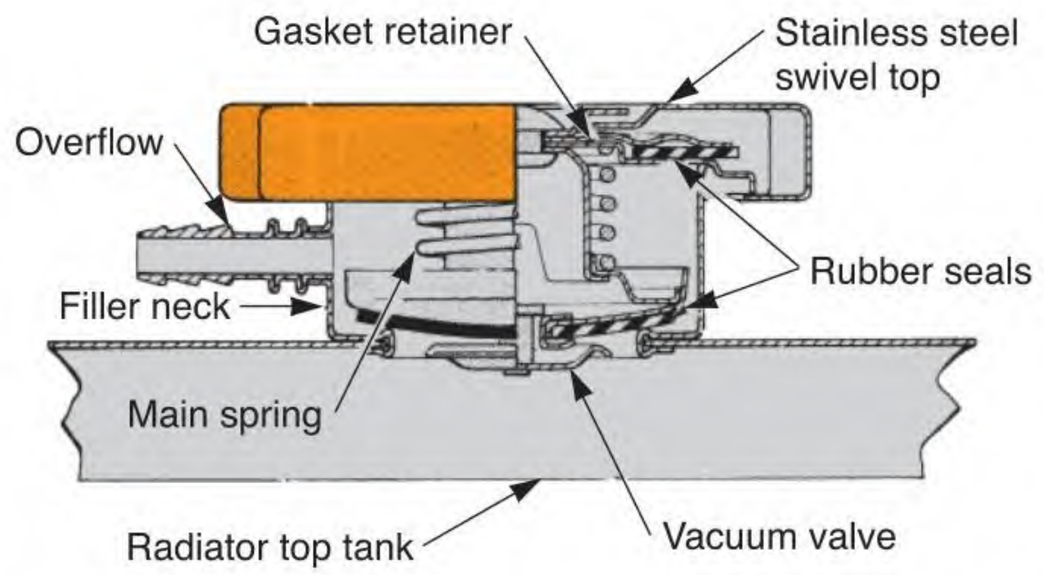
Typical radiator cap pressure is 12–16 psi (83–110 kPa). This pressure raises the boiling point of the engine coolant to 250–260°F (121–127°C). Many surfaces inside the engine's water jackets can be above 212°F (100°C) since the flame of combustion can burn at several thousand degrees.

If the engine overheats and pressure exceeds the cap rating, the pressure valve opens. Excess pressure and steam force the coolant out of the overflow tube and into the reservoir (or onto the ground in older systems). This prevents high pressure from rupturing the radiator, gaskets, seals, or hoses.

Radiator Cap Vacuum Valve

The ***radiator cap vacuum valve*** opens to allow flow back into the radiator when the coolant temperature drops after engine operation. It is often a small valve located in the center of the bottom of the cap. Look at **Figure 47-14**.

The cooling and contraction of the coolant and air in the system decreases the coolant volume and pressure. Without a cap vacuum valve, the radiator hoses and radiator tanks could collapse from outside pressure.



Chrysler

Figure 47-14. This cutaway view shows how the pressure cap installs and seals on the radiator filler neck.

Cooling System Fans

A ***cooling system fan*** pulls air through the core of the radiator and over the engine to help remove heat. It increases the volume of air flowing through the radiator, especially when the car is standing still. The fan is driven by a fan belt or an electric motor.

Engine-Powered Fans

An ***engine-powered fan*** bolts to the water pump hub and pulley. Sometimes, a ***fan spacer*** fits between the fan and pulley to move the fan closer to the radiator.

A ***flex fan*** has thin, flexible blades that alter airflow with engine speed. At low speeds, the fan blades remain curved and pull air through the radiator. At higher engine speeds, the blades flex until they are almost straight. This reduces fan action and saves engine power.

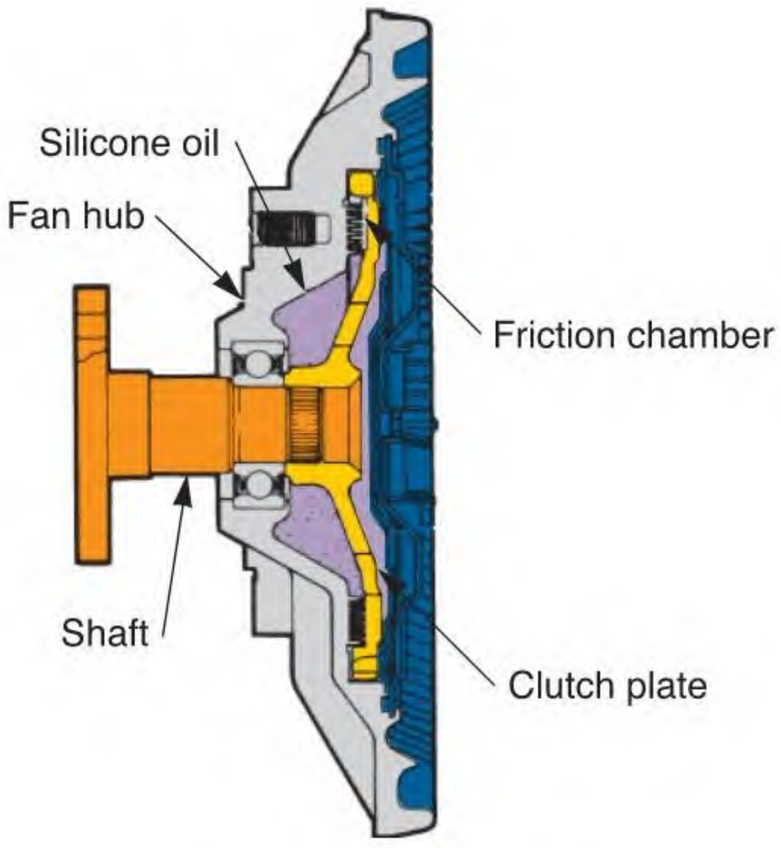
A ***fluid coupling fan clutch*** is designed to slip at higher engine speeds. It performs the same function as a flexible fan. The clutch is filled with silicone-based oil. At a specific fan speed, there is enough load to make the clutch slip, **Figure 47-15**.

A ***thermostatic fan clutch*** has a temperature-sensitive, bimetal spring that controls fan action. The spring controls oil flow in the fan clutch. When cold, the spring causes the clutch to slip, speeding engine warm-up. After reaching operating temperature, it locks the clutch, providing forced-air circulation. See **Figure 47-16**.

Electric Cooling Fans

An ***electric cooling fan*** uses an electric motor, the coolant temperature sensor, and the engine ECM to provide airflow and heat transfer out of the radiator.

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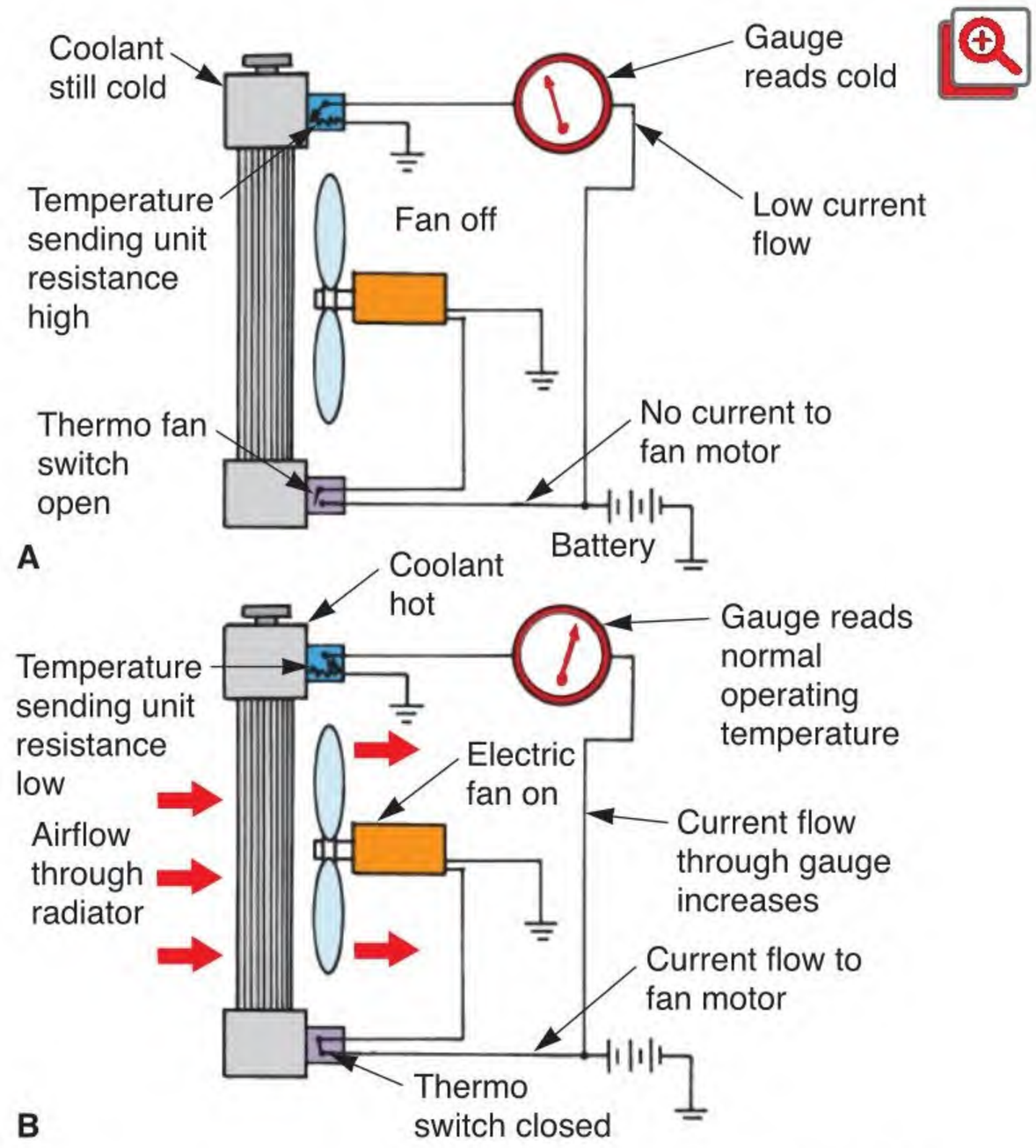
Chrysler

Figure 47-15. This is a fluid coupling fan clutch. A clutch plate operating in silicone-based oil causes enough friction at low speeds to turn fan. A high-speed load overcomes the friction, and the fan slips to save energy.

An electric fan is needed on front-wheel-drive cars with transverse-mounted engines. In these vehicles, the water pump is normally located away from the radiator. Nevertheless, electric engine fans can be used on any engine/transmission layout. Look at **Figure 47-17**.

The ***fan motor*** is a small dc motor with brushes. It mounts on a bracket secured to the radiator. A metal or plastic fan blade mounts on the end of the motor shaft to create airflow when the vehicle is not moving.

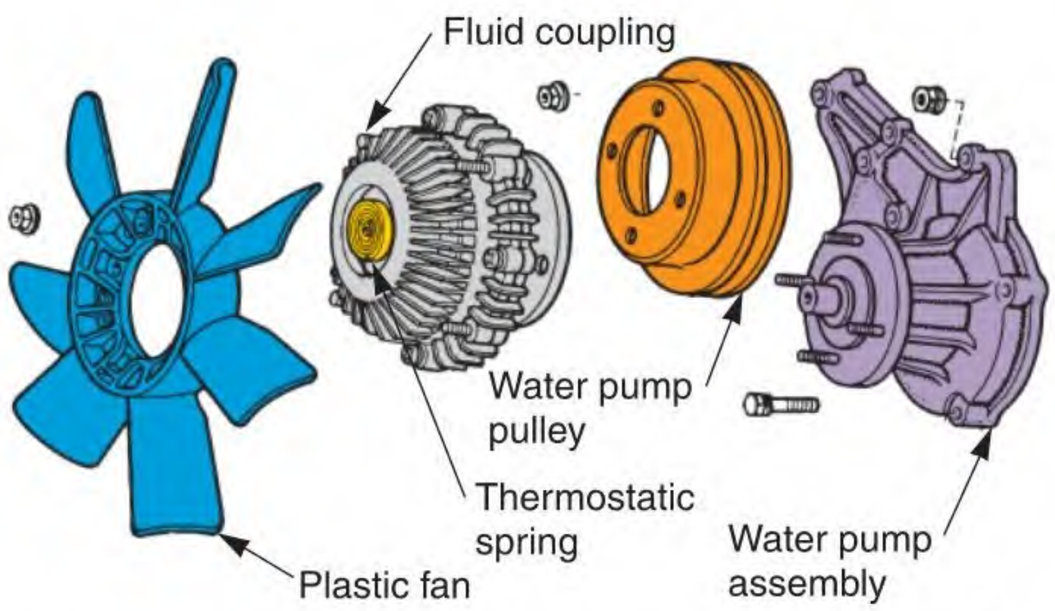
An electric fan saves energy and increases cooling system efficiency. Because the fan only functions when needed, it helps speed engine warm-up. This



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Figure 47-17. Study electric cooling fan operation. A—When the engine is cold, the thermo switch is open to prevent electric fan operation. This speeds engine warm-up. B—When the engine is at full operating temperature, the thermo switch closes. Current then flows to the fan motor to remove heat from the radiator.

reduces emissions and fuel consumption. In cold weather, the electric fan may shut off at highway speeds because enough cool air may be rushing through the grille to provide adequate cooling.



Toyota

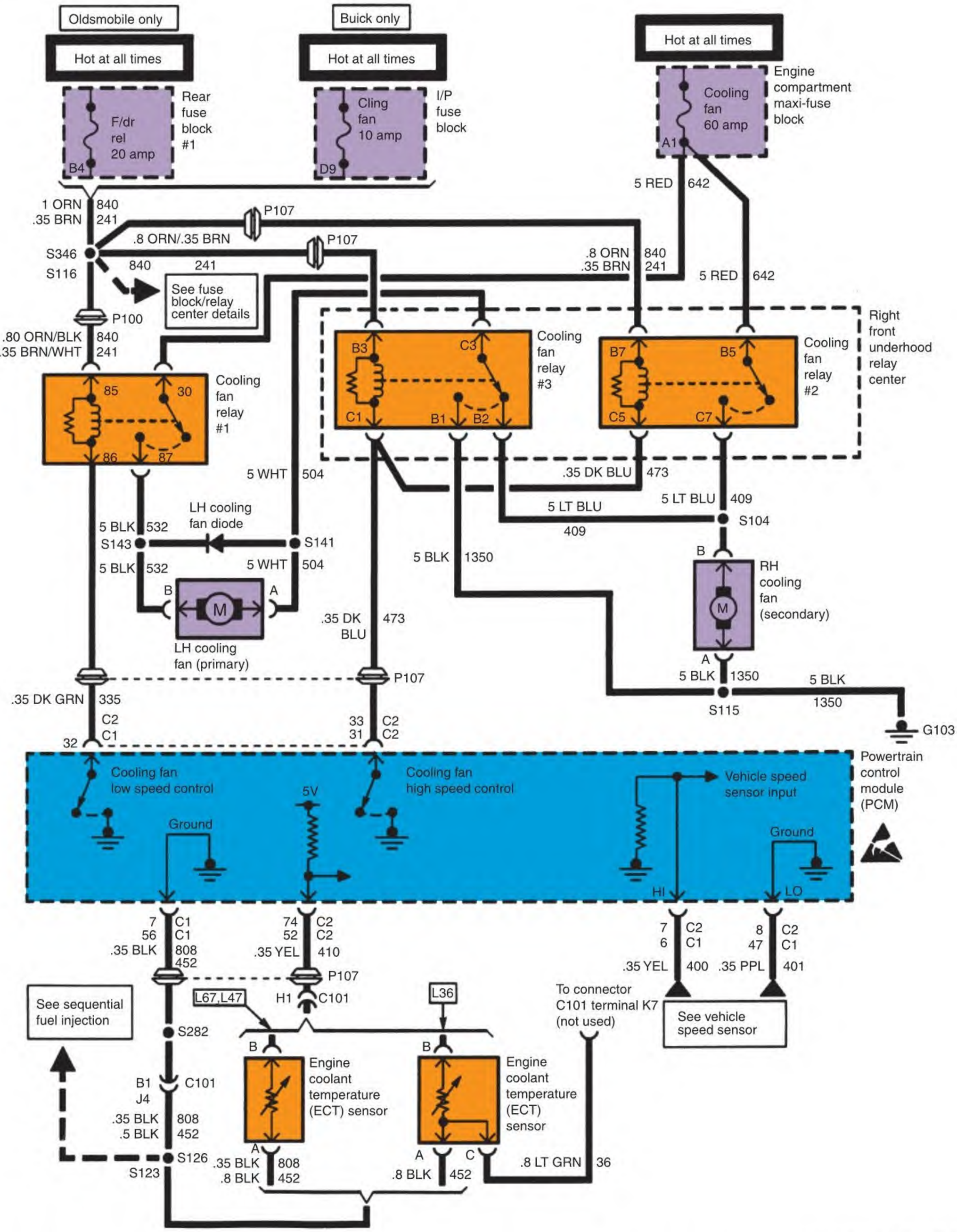
Figure 47-16. A thermostatic fan clutch is similar to a fluid coupling fan clutch. A bimetal spring is used to control clutching action. The fan only operates when the engine is hot and when the spring activates the clutch mechanism.

Electric Engine Fan Circuits

The ***fan switch*** (***thermo switch***) is a temperature-sensitive switch that controls fan motor operation. In late-model vehicles, the ***coolant temperature sensor*** (switch), fuse box relays, and engine ECM operate the engine cooling fan motors by using the temperature sensor in the radiator.

When the engine is cold, the coolant sensor and ECM do not energize the fan relay. This keeps the cooling fan from spinning unnecessarily. After warm-up, the sensor resistance changes enough to signal the ECM of the need for cooling fan operation. The ECU sends current to the fan relay coils. This closes the relay contact, and high current flows to the cooling fans to prevent engine overheating. This is illustrated in **Figure 47-18**.

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Figure 47-18. This wiring diagram shows modern electric engine fan circuit controlled by an electronic control unit. Note how the engine coolant temperature sensor (bottom) signals the powertrain control module whether to turn fans on or off. To turn fans on, the ECU sends a low-current signal to relays. The relay contact points then close to send higher current to the fan motors.

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Radiator Shroud

The ***radiator shroud*** helps ensure that the fan pulls air through the radiator. It fastens to the rear of the radiator and surrounds the area around the fan. When the fan is spinning, the plastic shroud keeps air from circulating between the back of the radiator and the front of the fan. See **Figure 47-19**. As a result, a huge volume of air flows through the radiator core. Without a fan shroud, the engine could overheat.

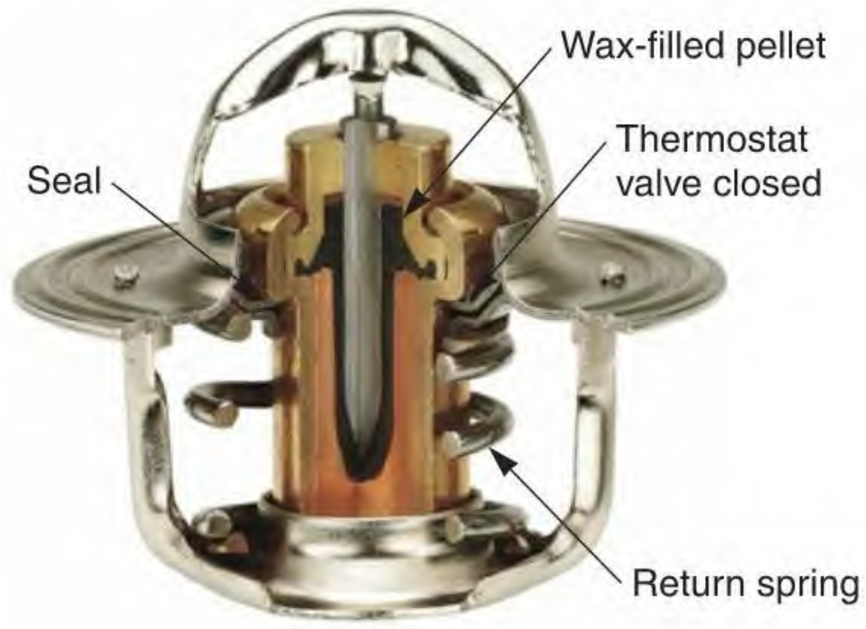
Thermostat

The thermostat expands and contracts with changes in engine temperature and controls coolant flow through the radiator. It reduces coolant flow when the engine is cold and increases coolant flow when the engine is hot.

The thermostat normally fits under a thermostat housing between the engine and the end of the upper radiator hose. Thermostats can be located at either the coolant inlet or outlet on the engine.

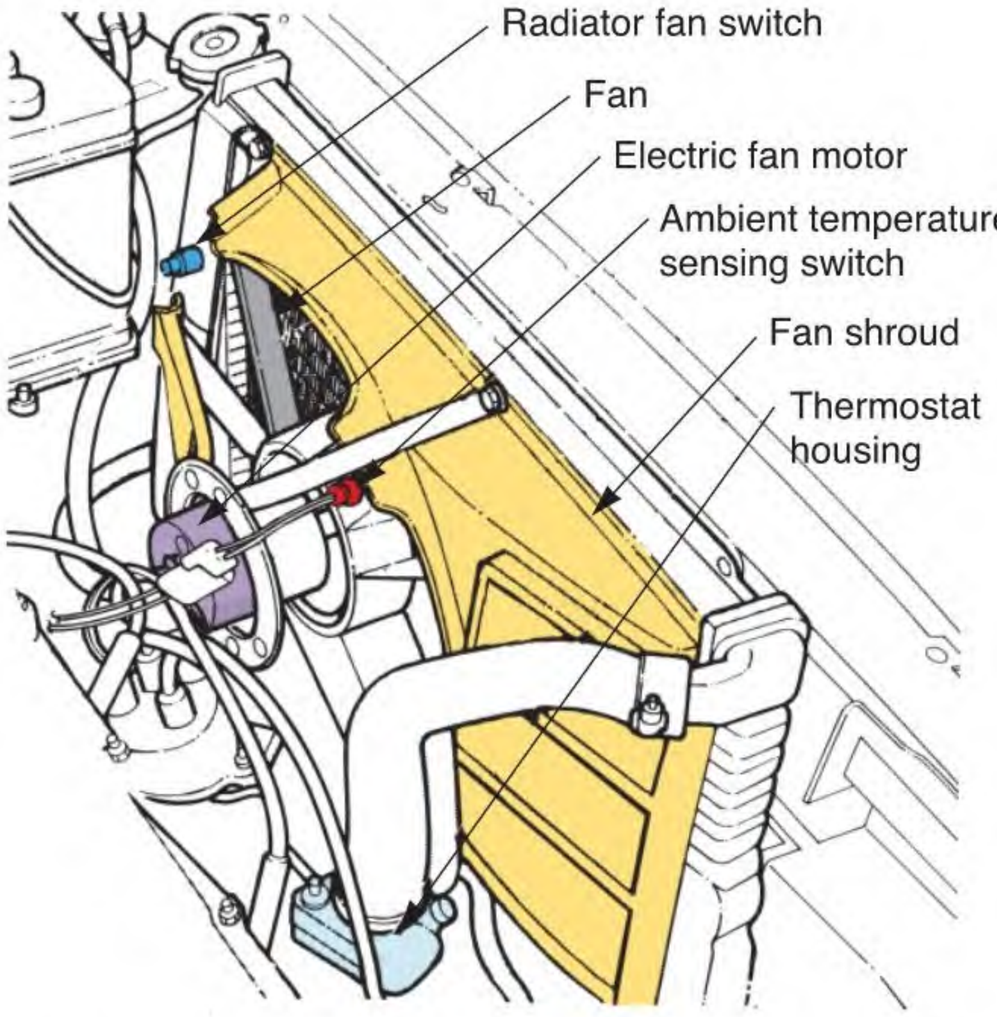
The thermostat has a wax-filled pellet contained in a cylinder-and-piston assembly. Look at **Figure 47-20**. A spring holds the piston and valve in a normally closed position. When the thermostat is heated, the pellet expands and pushes the valve open. As the pellet and thermostat cool, spring tension overcomes pellet expansion and the valve closes. See **Figure 47-21**.

A ***thermostat rating*** is stamped on the thermostat to indicate the operating (opening) temperature of the



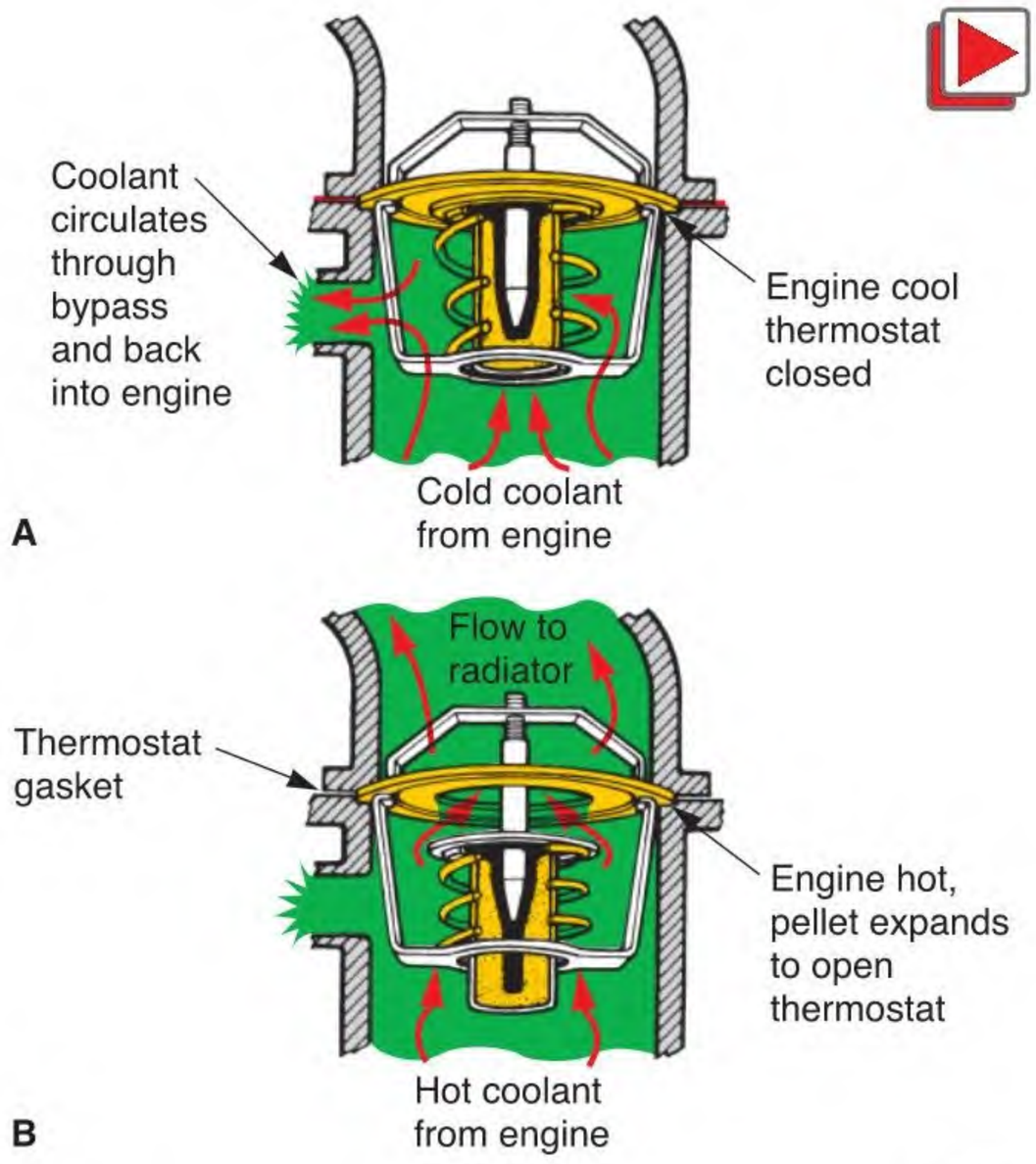
Gates

Figure 47-20. The thermostat is a temperature-sensitive valve. Note the pellet of wax enclosed in a cylinder-piston chamber. When heated, the pellet expands and pushes against spring tension to open the valve.



Chrysler

Figure 47-19. A fan shroud ensures that the fan pulls air through the radiator core. Without the shroud, air could circulate between the fan and the back of the radiator. Engine overheating could result.



Chrysler

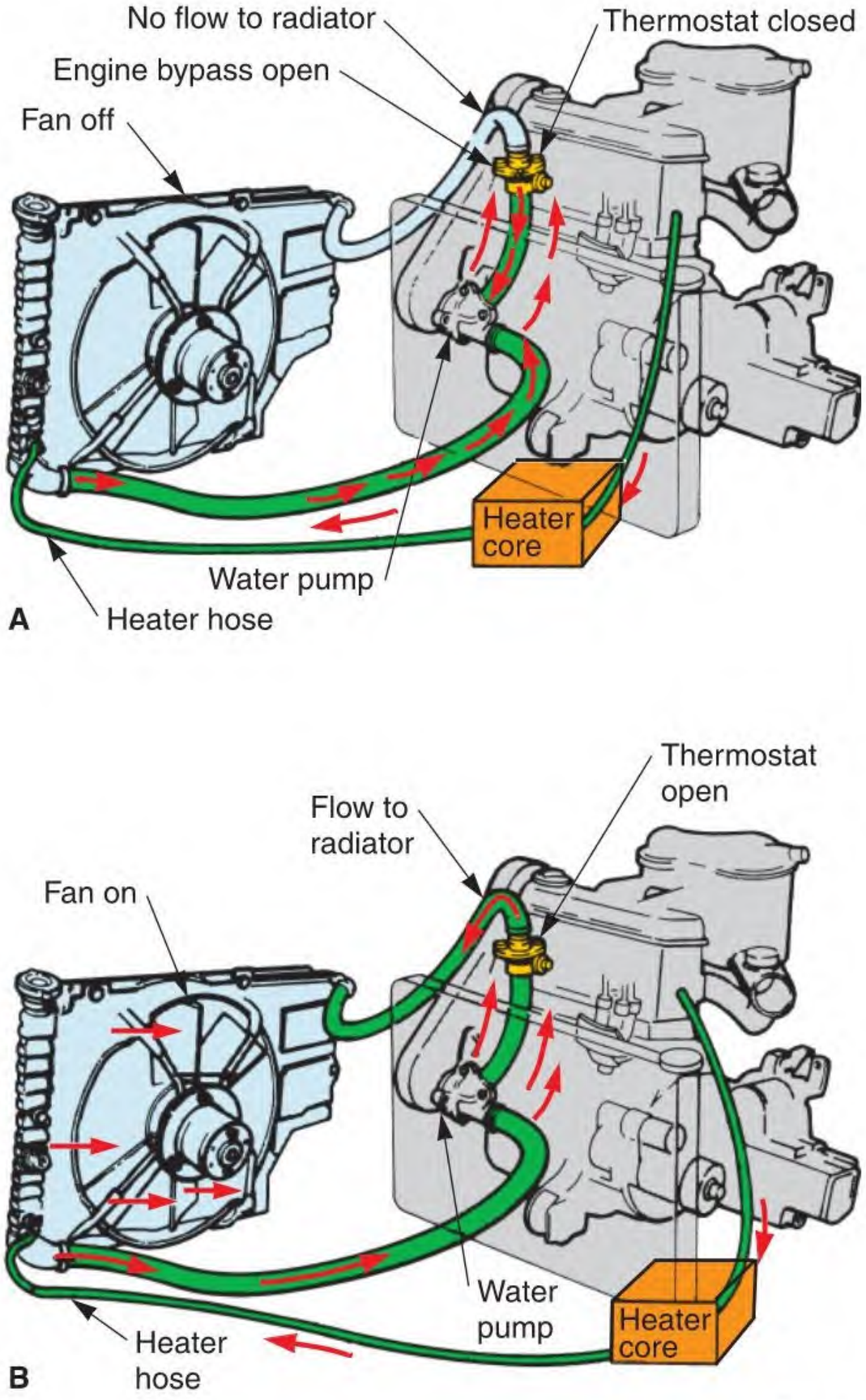
Figure 47-21. Study thermostat action. A—When coolant is cold, the thermostat remains closed due to spring tension. The water pump forces coolant to circulate in engine, but not through the radiator. B—When coolant is hot, the thermostat opens. The pump can then push coolant through the engine and the radiator.

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thermostat. Normal ratings are between 180°F and 195°F (82°C and 91°C). High thermostat heat ranges are used in modern automobiles because they reduce exhaust emissions and increase combustion efficiency.

Thermostat Operation

When the engine is cold, the thermostat will be closed and coolant cannot circulate through the radiator. Instead, the coolant circulates around inside of the engine block, cylinder head, and intake manifold until the engine is warm, **Figure 47-22**.



Chrysler

Figure 47-22. Thermostat operation. A—The thermostat does not allow coolant to enter the radiator when the engine is below operating temperature. B—When the engine is at operating temperature, the thermostat opens and allows flow into the radiator. The thermostat opens and closes different amounts to maintain correct engine operating temperature.

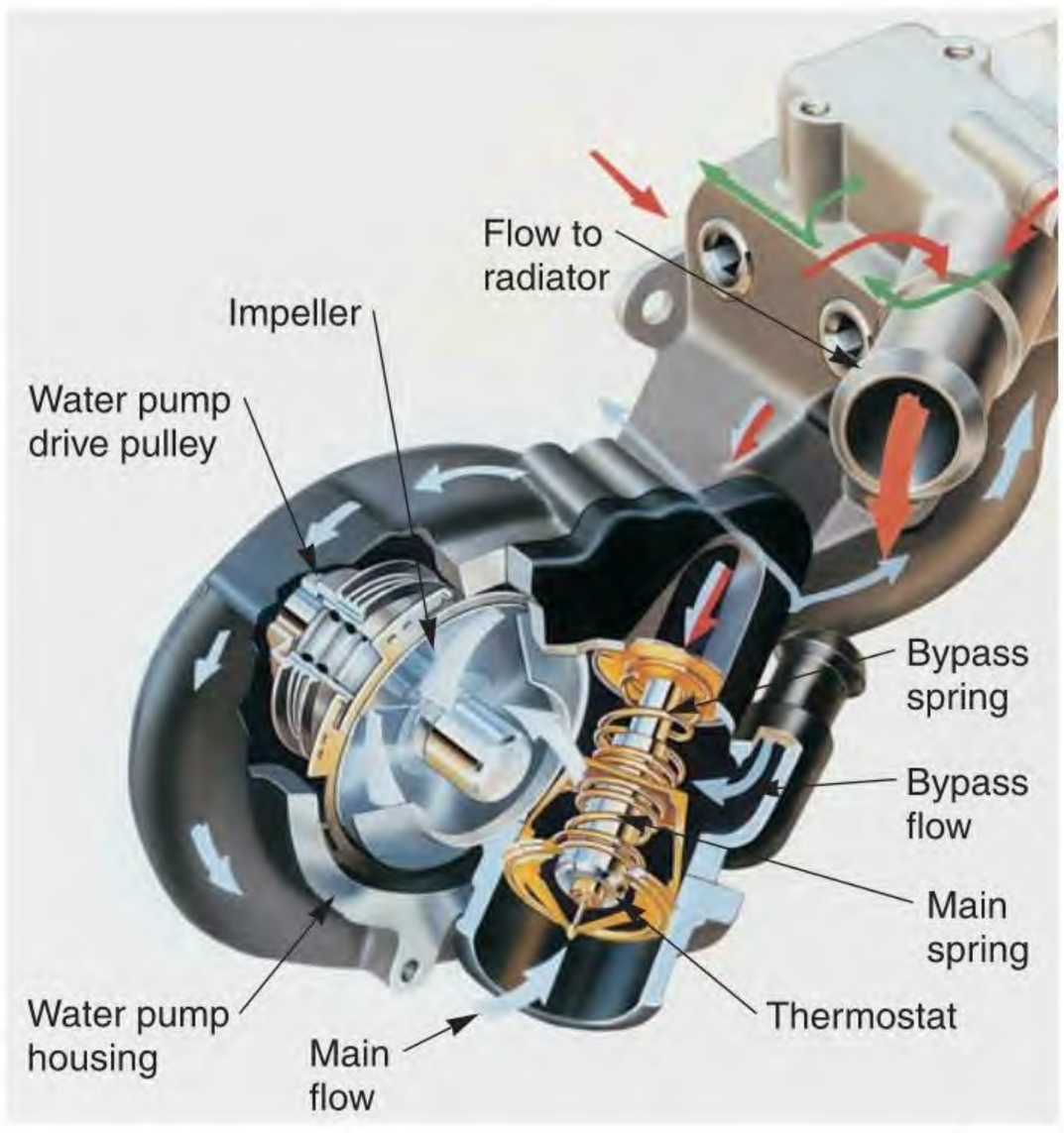
As the heat range of the thermostat is reached, the hot engine coolant causes the pellet inside the thermostat to expand. The thermostat gradually opens and allows coolant to flow through the system. Since the amount that the thermostat opens is dependent on engine temperature, the exact operating temperature of the engine can be precisely controlled.

A ***bypass valve*** and a bypass hose, or passage, permit coolant circulation through the engine when the thermostat is closed. If the coolant cannot circulate, hot spots could develop inside the engine.

A ***bypass thermostat*** has a second valve for routing all the hot coolant through the radiator, not just most of the hot coolant. The main thermostat valve regulates flow through the engine and radiator like a conventional thermostat. The added valve blocks off the bypass once the engine has reached operating temperature. See **Figure 47-23**.

Cooling System Instrumentation

Most vehicles are equipped with a temperature warning light. Some vehicles also have an engine



Cadillac

Figure 47-23. This thermostat has a conventional valve and bypass valve on the body of the thermostat. Note that it has two springs and valves built into one assembly.

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temperature gauge. It is important that you understand the operation of both.

Temperature Warning Light

A ***temperature warning light*** informs the driver when the engine is overheating. When the coolant becomes too hot, a temperature sending unit (switch) in the engine block closes. This completes the warning light circuit, and the indicator light on the dash glows, **Figure 47-24**.

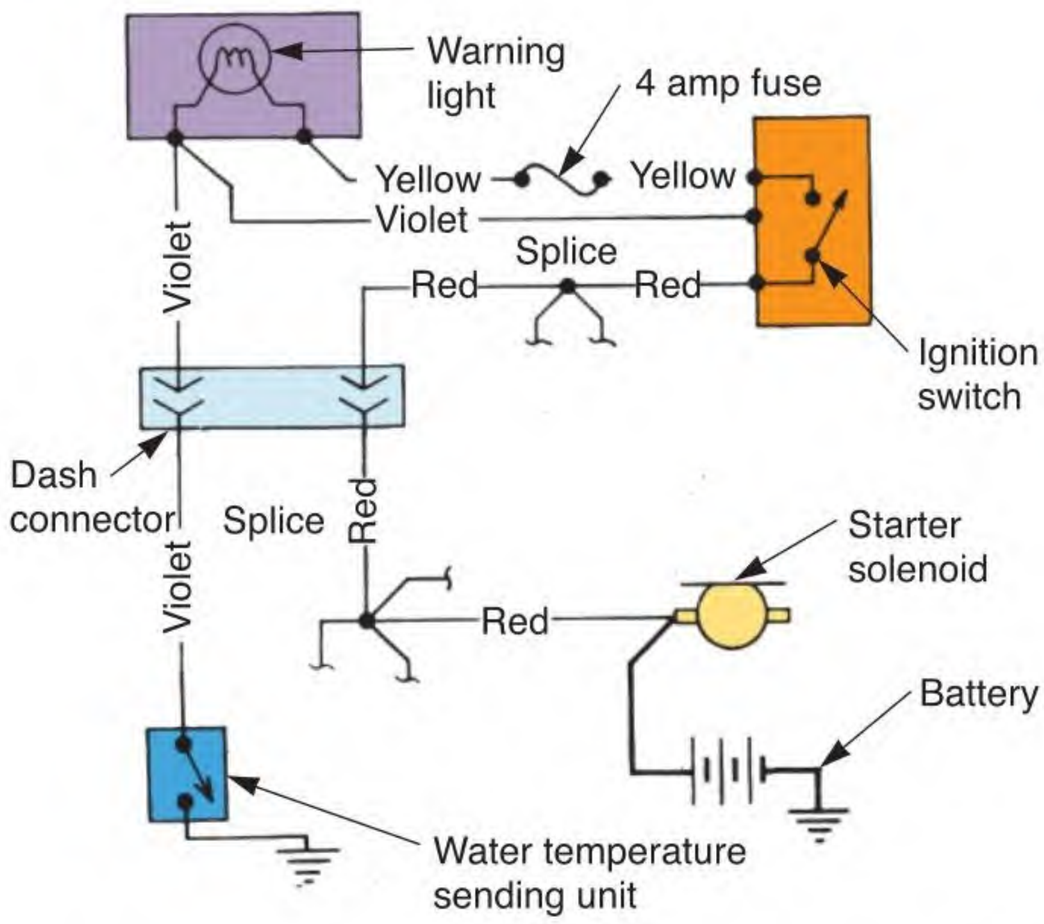
When the engine is cold or at normal operating temperature, the sending unit is open and the light remains off. The ignition switch lights the bulb when the engine is started, so the driver knows that the bulb is not burned out.

With many late-model vehicles, the engine temperature warning light is energized by the engine control module. If the sensor detects an overheating engine, the ECU sends current to the warning light.

Engine Temperature Gauge

An ***engine temperature gauge*** shows the exact operating temperature of the engine coolant. A variable resistance sending unit and a gauge are used in the circuit.

When the engine is cold, the gauge sending unit has high resistance and current does not flow to the gauge. The temperature gauge reads cold. As engine temperature increases, the resistance in the sending unit drops. Current increases in the gauge circuit. Current causes the gauge needle to deflect to the right, showing engine temperature.



Chrysler

Figure 47-24. The circuit diagram for a simple engine temperature warning light. The sending unit closes when the engine overheats to light indicator bulb.

Antifreeze

Antifreeze (usually ethylene glycol) is mixed with water to produce engine coolant. Antifreeze has several functions. It prevents winter freeze-up, prevents rust and corrosion, lubricates the water pump, and cools the engine.

Prevents Winter Freeze-Up

Antifreeze keeps the coolant from freezing in very cold weather (outside temperature below 32°F or 0°C). Coolant freezing can cause serious cooling system and engine damage. As ice forms, it expands. This expansion can produce great force. The water pump housing, cylinder head, engine block, radiator, or other parts could be cracked and ruined by internal ice formation.

Prevents Rust and Corrosion

Antifreeze also prevents rust and corrosion inside the cooling system. It provides a protective film on part surfaces. Even in hot climates, antifreeze should be used to protect internal parts from corrosion.

Lubricates the Water Pump

Antifreeze acts as a lubricant for the water pump and thermostat. It increases the service life of the water pump bearings and seals. It also prevents thermostat wear and corrosion.

Cools the Engine

Antifreeze conducts heat better than water and, therefore, cools the engine better. Using the air conditioning system, for example, increases the temperature of the air flowing through the radiator. Antifreeze can help prevent overheating in very hot weather when the air conditioning is on.

Antifreeze/Water Mixture

For ideal cooling and protection from freeze up, a 50/50 mixture of water and antifreeze is usually recommended. An equal mix of glycol antifreeze and water

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will provide protection from ice formation to about –34°F (–37°C). Higher ratios of antifreeze may produce even lower freezing temperatures, but this much protection is needed only in extreme weather conditions.

Tech Tip

Antifreeze is now sold in stores premixed with 50% water already added. It is also sold as more concentrated coolant that must be mixed with 50% water. If you buy the antifreeze that has no water added, and are willing to mix the water yourself, you will get twice as much antifreeze as the premixed for around the same price.

Caution

Plain water should never be used in a cooling system instead of antifreeze, or the four functions of antifreeze just discussed will not be provided. Also, never dilute premixed antifreeze with additional water. Too much water may allow the coolant to freeze in cold weather, cracking the expensive cylinder block and heads.

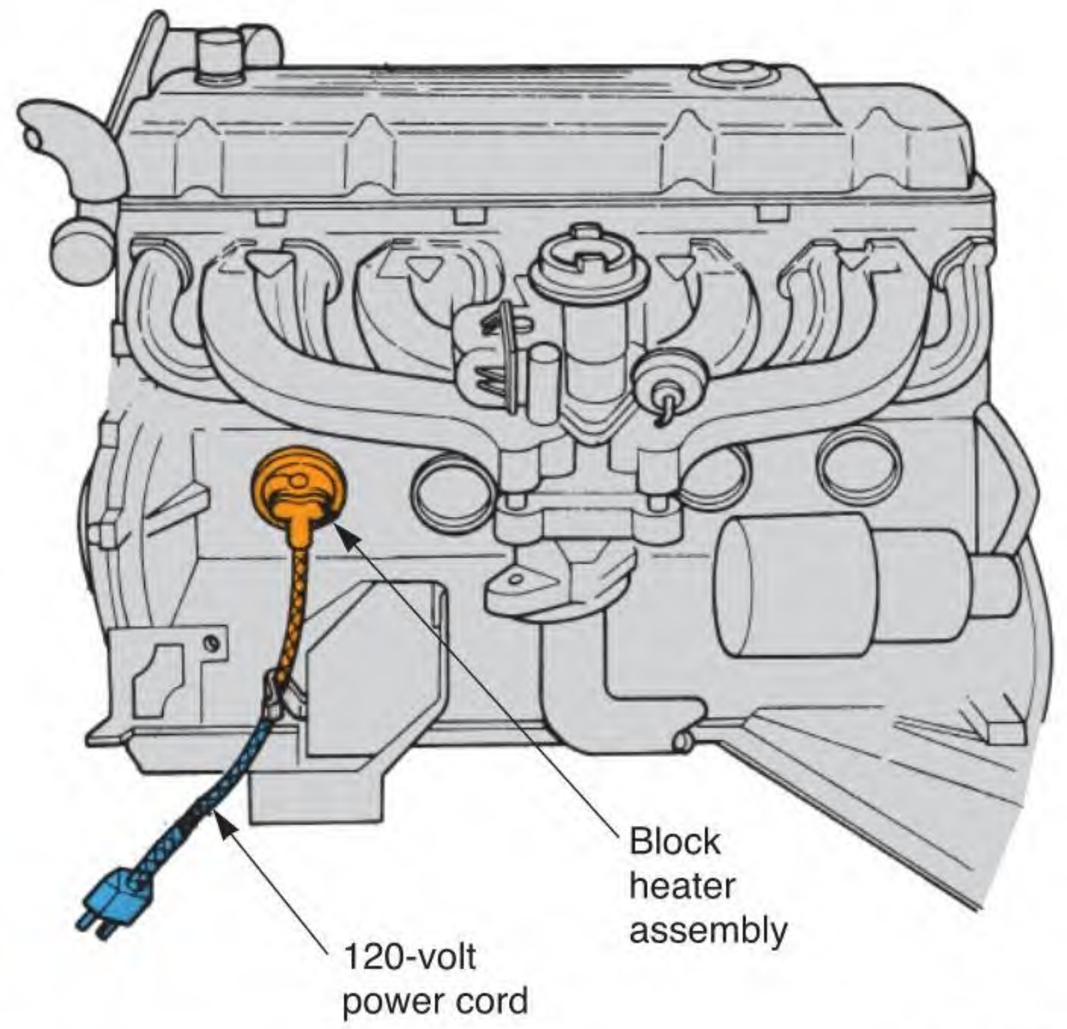
Block Heater

A ***block heater*** may be used on an engine to help with engine starting in cold weather by heating the coolant. A block heater is most commonly used on diesel engines. Diesels are harder to start in cold weather than gasoline engines because of their compression ignition.

A block heater is simply a 120-volt heating element mounted in the block water jacket. Look at **Figure 47-25**. The heater power cord is plugged into a wall outlet. This keeps the engine and coolant warm when the vehicle is not being used. Then, when the owner cranks the engine, it will start more easily.

Supercharger Cooling Systems

When a supercharger or turbocharger compresses air and builds boost pressure, the compressed air heats up. Hot air carries less oxygen for combustion than an equal amount of cooler air.



Chrysler

Figure 47-25. Block heaters plug into a home wall outlet.

A supercharger cooling system often uses its own electric water pump, hoses, and radiator to pump cool antifreeze through the supercharger intercooler. Study **Figure 47-26**. As mentioned in previous chapters, an intercooler for a supercharger is an air-to-liquid heat exchanger (radiator) mounted under or at the outlet of the compressor rotors.

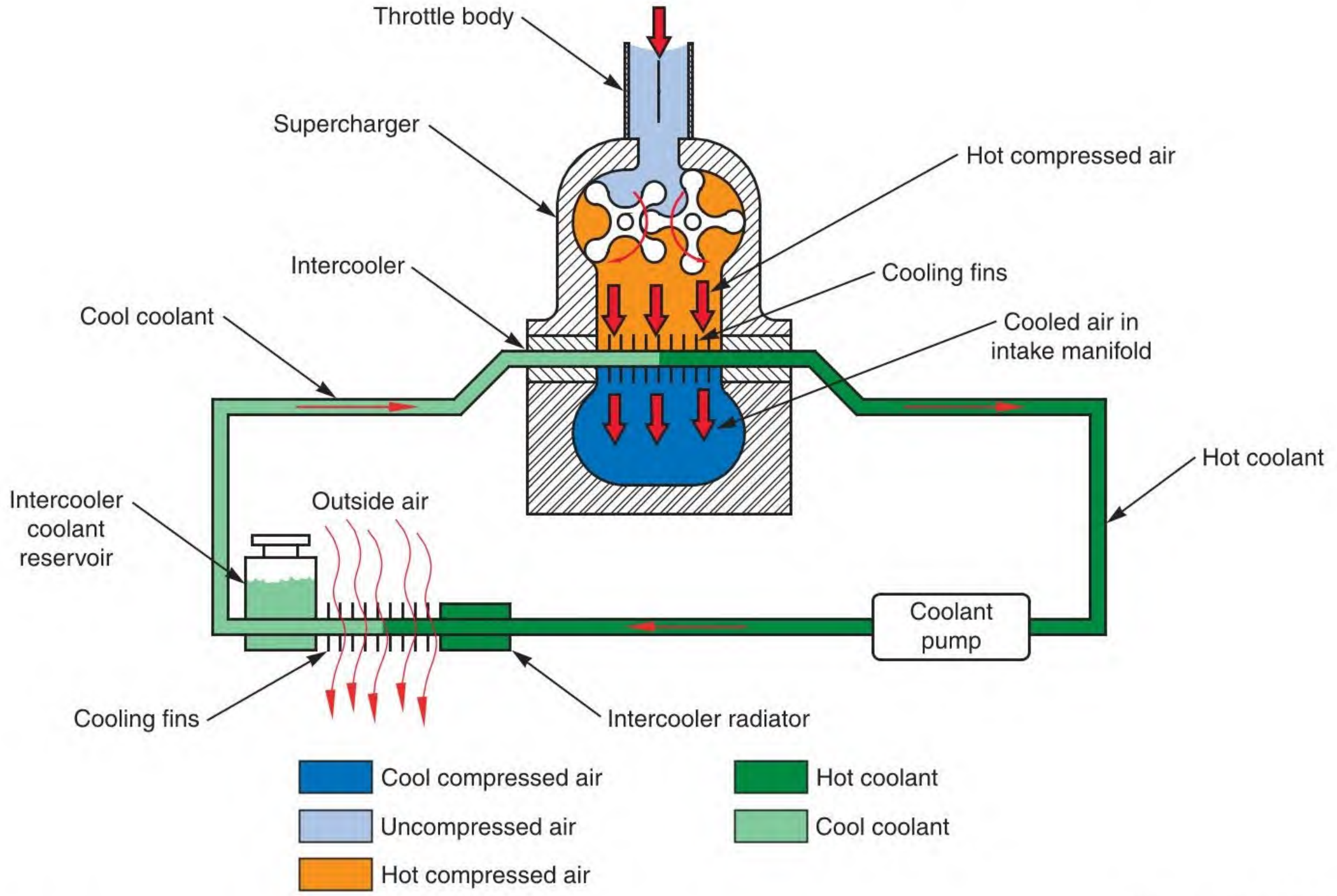
When the heated boost air flows through the intercooler fins, heat is transferred into the coolant and carried out of the inlet air. The cooler air entering the engine carries more oxygen, heat energy, and power for burning fuel. Cooler air also allows more boost pressure without engine detonation (abnormal combustion) and severe part damage. See **Figure 47-27**.

Hybrid Cooling Systems

A ***hybrid cooling system*** can use either circulated air or circulated liquid coolant to remove excess heat from components in the electric powertrain. Late-model plug-in hybrids with powerful battery packs and 100+ horsepower traction motors generate high heat and require liquid cooling of major electrical assemblies.

A ***hybrid air cooling system*** uses an electric blower fan and a system of ducts to route cool passenger compartment air around the high-voltage battery pack. The cool airflow helps pull heat away from all of the battery packs. Study **Figure 47-28**.

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Figure 47-26. Superchargers often have an air-to-liquid intercooler. The intercooler system contains a coolant that is circulated and picks up heat from the compressed air. The hot coolant is then circulated through the intercooler radiator, where heat is dissipated.

A ***hybrid liquid cooling*** system uses an electric water pump, small diameter hoses, and a separate radiator or heat exchanger to pull heat out of the HV battery, HV PCM, and motor-generator.

High temperatures can develop in several areas within a hybrid's electric powertrain:

- HV battery cells—HV battery cells can get hot when acid and metals are chemically changed into amperage. The chemical cells must force current through the electric propulsion system. These circuits and components carry tremendous amounts of electrical energy and electrically generated heat.
- HV motor-generator—The HV motor-generator can get dangerously warm without heat removal, especially in high-horsepower or watt ac motors (some over 100 horsepower or 75kW).
- HV PCM—The HV power control module would burn up in a few minutes without some form of heat removal. Not only do these circuits have to handle 600 volts ac, they have to convert and invert ac and dc flowing through huge, 00 or 000 (double- or triple-ought) power cables.

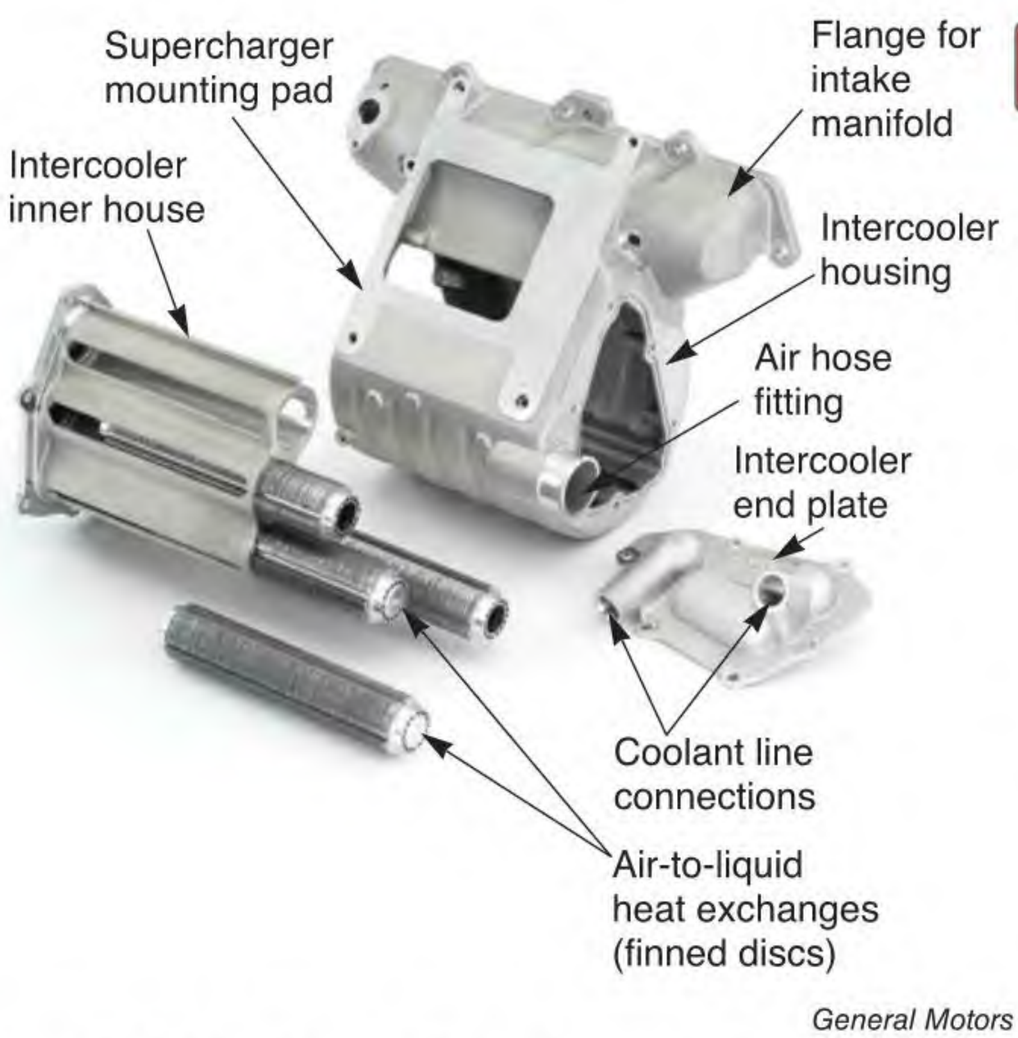
Low-power motor-generators in mild hybrids do not require an additional cooling system. When mounted in the transmission or rear axle assembly, transmission oil and the transmission cooler help limit motor-generator temperatures. However, high-power hybrids usually require forced liquid cooling to prevent motor-generator stator windings failure. Study **Figure 47-29**.

HV Battery Cooling Systems

An HV battery cooling system uses circulated air to carry heat away from the battery packs and out of the battery housing. Again, high-power electric powertrains also supplement air cooling with liquid cooling.

An ***HV battery radiator*** or small air-to-liquid heat exchanger is mounted in the battery housing. Intake air

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General Motors

Figure 47-27. Study parts of a modern supercharger intercooler. The supercharger mounts to the top of the intercooler so hot air blows over the heat exchanger core. Since the fins on heat exchangers are cooler than the air flowing over them, heat transfers into the fins and coolant.

is routed through the cool fins of the intercooler or heat exchanger before it circulates over the battery packs.

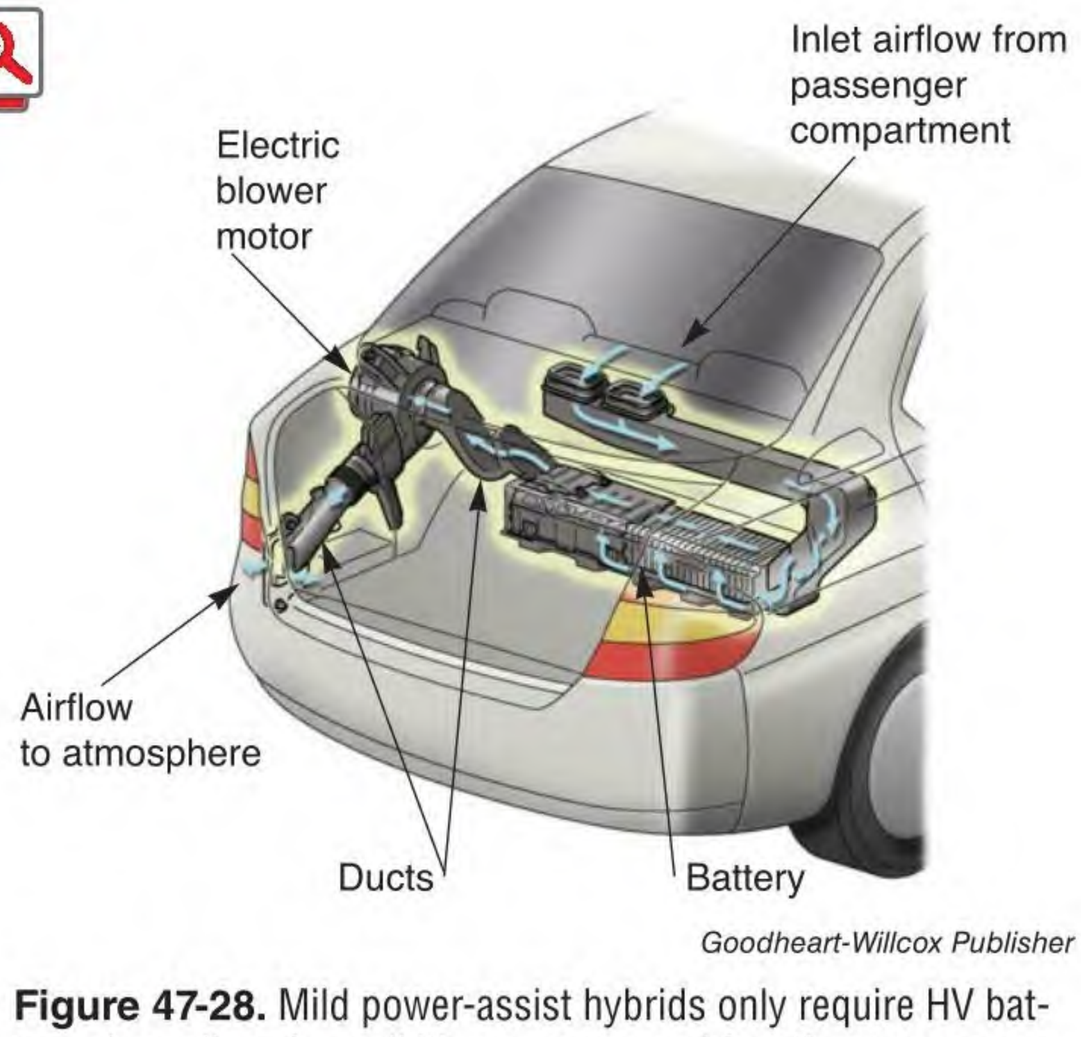
An ***HV battery fan*** can be energized by the HV ECM to force fresh air through the air-to-liquid heat exchanger and over the battery pack outer surfaces for cooling.

Motor-Generator Cooling Systems

Motor-generator cooling systems remove excess heat from the stator housing and windings by circulating coolant through its outer housing. Again, high-wattage, high-horsepower traction motors will burn up without heat removal from the stator housing. Some motor-generators and PCMs use the same electric water pump and radiator to lower coolant temperature to around 100°F (38°C), which improves motor/generator efficiency.

Motor-generator water jackets that carry liquid coolant are formed or machined inside the stator housing during manufacture. A large water jacket is often formed between the motor-generator stator housing and its outer housing for direct heat transfer into the liquid coolant. Refer to **Figure 47-30**.

Motor-generator coolant hoses carry cooled coolant to, and heated coolant from, the motor-



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Figure 47-28. Mild power-assist hybrids only require HV battery air cooling. A small blower motor and fan direct passenger compartment air though battery housing to remove battery pack heat. Motor-generators and PCM do not require additional cooling.

generator water jackets. One hose provides for a flexible connection to the electric coolant pump or engine water pump. ***Motor-generator coolant fittings*** allow rubber hoses to be clamped around the hose for leak-proof antifreeze connections. A ***motor-generator water pump*** is an electric coolant pump mounted between the system radiator and the stator housing.

HV PCM Cooling Systems

An ***HV PCM cooling system*** often uses the same electric water pump and circulated liquid coolant as the motor-generator and HV battery. See **Figure 47-31**. As discussed, high-power hybrids have their own separate cooling systems to remove heat from the high-power electrical circuits and components. This is a cooling system totally independent of the engine cooling system.

An ***HV PCM water jacket*** is formed between the inner and outer housings that surround the high-power, control circuit boards mounted on a heat sink (inner PCM housing contacting coolant).

Coolant Heat Storage System

A ***coolant heat storage system*** is needed to help keep the hybrid's piston engine warm when it is not running and the vehicle is in full electric propulsion. A

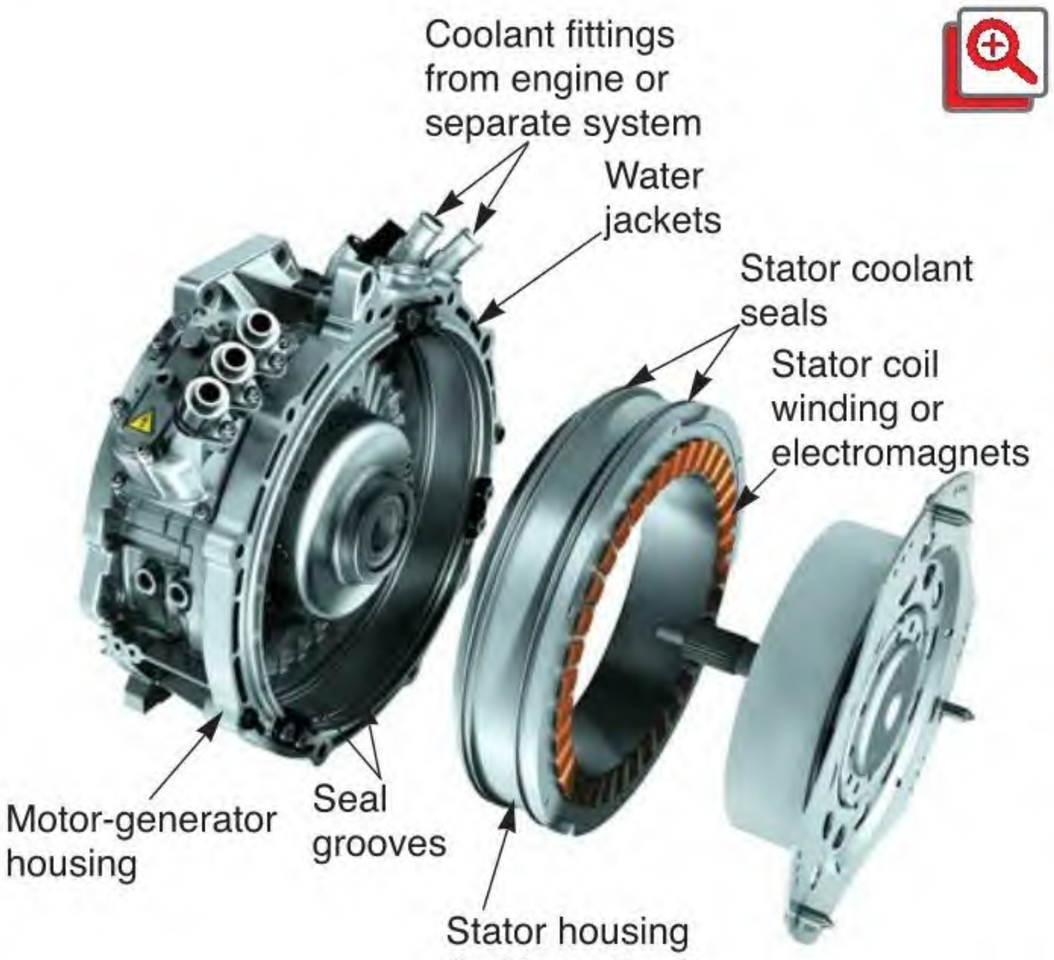
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Audi U.S.A.

Figure 47-29. The electric drive train on this vehicle uses liquid cooling in all three major hybrid units: HV battery housing, motor-generator stator housing, and HV PCM housing. A—Both air and coolant circulation remove heat from inside this HV battery housing. HV coolant is pumped through a small liquid-to-air heat exchanger or cooler core (like a heater core). An electric fan forces air through the heat exchanger fins to remove heat, allowing cooled air to flow over the battery packs and cells. B—This motor-generator is liquid cooled and has a large water jacket formed in the stator housing. C—High-power HV power control modules have their own radiator and water pump to transfer heat from circuit boards and components into the atmosphere.



Porsche

Figure 47-30. This high power motor-generator carries so much current that water or liquid cooling is required to prevent overheating damage. Study hose or line connections, water jackets, and stator housing construction.

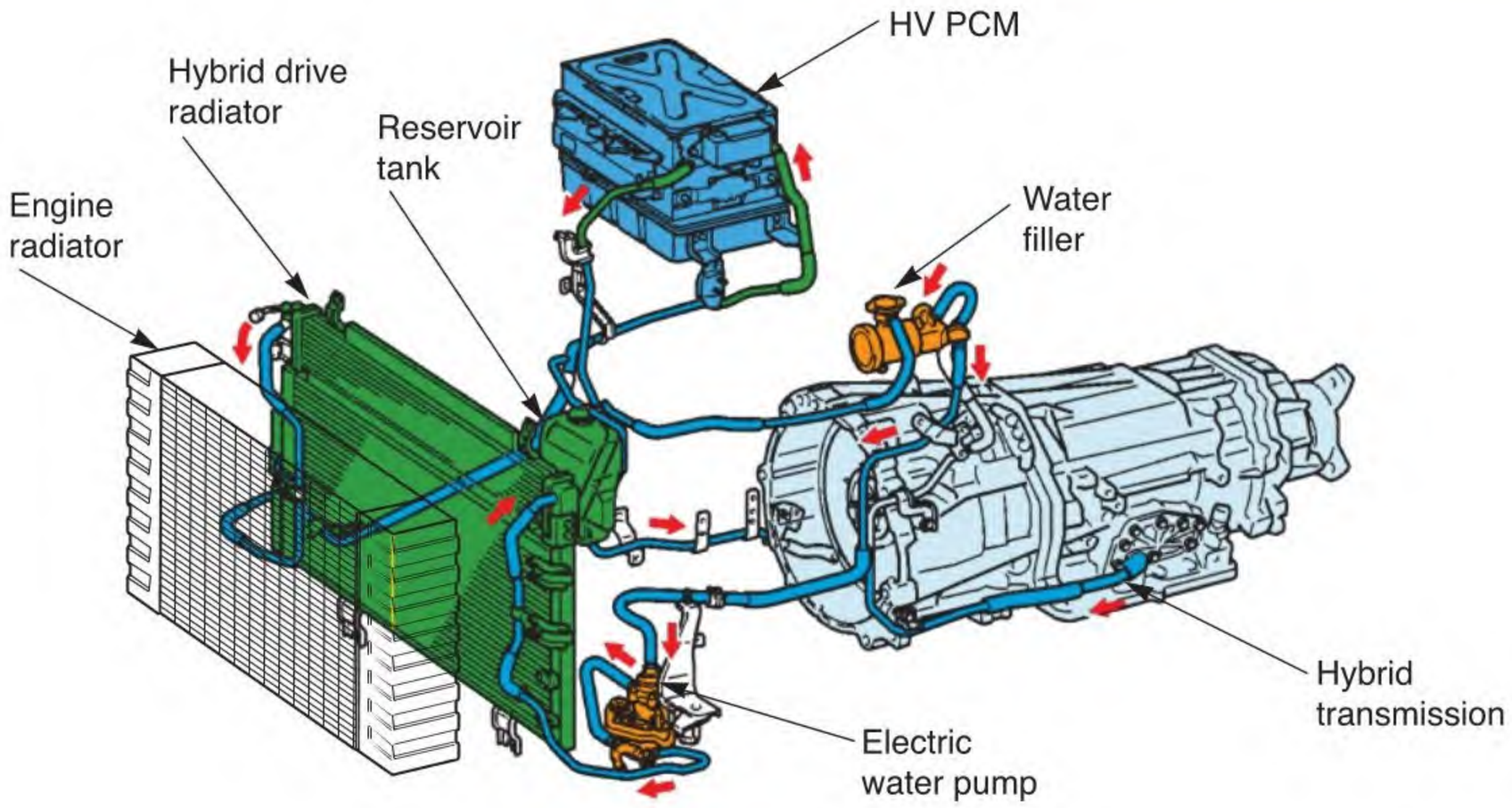
coolant heat storage system is required on gasoline engine hybrids equipped with port fuel injection. As you learned, a cold engine is an inefficient and polluting power source. An engine burns its fuel more cleanly and with more power when its internal metal surfaces are kept warm. The heat stored in the coolant is recirculated inside the engine intake ports to prevent liquid fuel from condensing onto the port walls before the intake stroke.

Tech Tip

Hybrids with DEFI gasoline engines do not suffer from cold start problems because only air flows past the engine intake valves and fuel is injected into the combustion chambers and cylinders directly. There is no fuel sprayed inside the intake manifold that could condense into an unburnable liquid on metal surfaces inside the manifold, cylinder head ports, and intake valve.

Workplace Skills

Make an operating temperature chart. Over the years, an operating temperature chart will help you become the best troubleshooter in the shop. Developing the habit of checking the temperature of all major parts will help you find and prevent vehicle engine and hybrid drive problems. For example, if an exhaust manifold is running hotter than normal, it indicates that the combustion flame shooting past the engine



Toyota

Figure 47-31. Study how this liquid cooling system connects to separate hybrid radiator, electric water pump, reservoir, transmission, filler neck, and HV PCM.

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exhaust valves might be excessively hot. Through your knowledge of engine operation, you would realize that any number of problems (low cylinder compression, burned valve, advanced camshaft timing, retarded ignition timing, rich low-speed fuel mixture, etc.) might cause a huge flame to form inside the exhaust manifold. If one exhaust manifold is at normal operating temperature and the other is hotter than normal, you know to suspect that something is wrong in that bank of engine cylinders.

If you work in a large dealership that repairs only one make of cars, your temperature chart will be even more valuable to you as a diagnostic technician. Measure the operating temperature of the major driveline assemblies with a laser thermometer, including the engine, radiator, engine block, exhaust manifold, intake manifold, cylinder head, water pump, alternator, motor-generator, HV ECM, and HV battery. Record actual part operating temperatures for these major parts and assemblies and sort them by vehicle year, make, and model to make your own vehicle operating temperature chart.

Summary

- Vehicle cooling systems must remove excess heat from the engine, maintain a constant engine operating temperature, increase the temperature of a cold engine quickly, and provide a means for warming the passenger compartment.
- Engine operating temperature is typically between 180°F (82°C) and 210°F (99°C).
- The two major types of automotive cooling systems are air cooling systems and liquid cooling systems.
- The basic parts of an engine cooling system are the water pump, radiator hoses, radiator, fan, and thermostat.
- The radiator transfers coolant heat to the outside air and is normally mounted in front of the engine.
- A transmission oil cooler is often placed in the radiator on cars with automatic transmissions to prevent transmission fluid overheating.
- The thermostat senses engine temperature and controls coolant flow through the radiator.
- Antifreeze, usually ethylene glycol, is mixed with water to produce the engine coolant. It prevents winter freeze up, prevents rust and corrosion, lubricates the water pump, and cools the engine.
- A block heater may be used on a diesel engine to aid engine starting in cold weather.
- A supercharger cooling system often uses its own electric water pump, hoses, and radiator to pump cool antifreeze through the supercharger intercooler.
- A hybrid cooling system can use either circulated air or circulated liquid coolant to remove excess heat from electrical/electronic components in the electric powertrain.
- An HV battery cooling system uses circulated air to carry heat away from the battery packs and out of the battery housing.
- Motor-generator coolant hoses carry cooled coolant to, and heated coolant from, the motor-generator water jackets.
- An HV PCM cooling system is a cooling system totally independent of the engine cooling system.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

air cooling system
antifreeze
block heater
blower intercooler temperature
bypass thermostat
bypass valve
closed cooling system
conventional-flow cooling
coolant heat storage system
coolant temperature sensor
cooling fins
cooling system
cooling system fan
crossflow radiator
downflow radiator
electric cooling fan
electric water pump
engine cooling system
engine operating temperature
engine temperature gauge
engine-powered fan
fan
fan motor
fan spacer
fan switch
flex fan
flexible hose
fluid coupling fan clutch
heater core
heater hoses

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hose clamps
hose spring
HV battery cooling system
HV battery fan
HV battery radiator
HV engine control module cooling system
HV motor-generator cooling system
HV PCM cooling system
HV PCM water jacket
hybrid air cooling system
hybrid cooling system
hybrid liquid cooling
liquid cooling system
molded hose
motor-generator coolant fittings
motor-generator coolant hoses
motor-generator water jackets
motor-generator water pump
open cooling system
radiator
radiator cap
radiator cap pressure valve
radiator cap vacuum valve
radiator core
radiator filler neck
radiator hoses
radiator petcock
radiator shroud
radiator tanks
reverse-flow cooling
shrouds
supercharger cooling system
temperature warning light
thermo switch
thermostat
thermostat rating
thermostatic fan clutch
transmission oil cooler
turbocharger cooling system
water pump
water pump bearings
water pump gasket
water pump housing
water pump hub
water pump impeller
water pump seal
water pump shaft
worm-drive hose clamp

Activities

1. Using the information contained in the chart on most antifreeze containers, construct a line graph to show the relationship between water/antifreeze mixture and the low-temperature protection provided. (For example, the usual 50/50 mixture protects against freezing to temperatures as low as –34°F.)
2. Develop sketches to show how the expansion tank (coolant reservoir) functions in a closed cooling system. Make a visual media presentation from your sketches and use them to describe the expansion tank function to the class.

Review Questions

Answer the following questions using the information provided in this chapter.

1. What are the four functions of a cooling system?
2. Why has the liquid cooling system replaced the air types?
3. How do closed and open cooling systems differ?
4. List and explain the five major parts of a cooling system.
5. Typically, an engine's operating temperature is between _____ and _____ °F (_____ and _____ °C).
6. List and explain the seven major parts of a water pump.
7. Which of the following does *not* relate to radiator construction?
   (A) Core.
   (B) Filler neck.
   (C) Tanks.
   (D) Impeller.
8. Explain the differences between *downflow* and *crossflow* radiators.
9. How does an automatic transmission oil cooler work?
10. List the four functions of a radiator cap.
11. Typical radiator cap pressure is _____ to _____ psi (_____ to _____ kPa), which raises the boiling point of the coolant to about _____ to _____ °F (_____ to _____ °C).
12. A(n) _____ is a temperature-sensitive switch that controls an electric engine cooling fan.
13. Why is a radiator shroud used?
14. Summarize the operation of a cooling system thermostat.
15. A temperature _____ (switch) on the engine is used to operate the temperature warning light.
16. List four functions of antifreeze.
17. For ideal cooling, a mixture of _____ is typical.
    (A) 30% water, 70% antifreeze
    (B) 50% water, 50% antifreeze
    (C) 20% water, 80% antifreeze
    (D) 70% water, 30% antifreeze
18. How is a block heater helpful with a diesel engine?

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19. A hybrid vehicle cooling system removes heat from what three main electric powertrain components?
20. A hybrid's piston engine is kept warm when it is not running and the vehicle is in full electric propulsion by a(n) _____.
    (A) coolant heat storage system
    (B) electric fan
    (C) block heater
    (D) All of the above.

ASE-Type Questions

1. Which of the following system parts controls coolant flow through a radiator?
    (A) Fan.
    (B) Radiator.
    (C) Thermostat.
    (D) Temperature sensor.
2. An engine's operating temperature is usually between:
    (A) 82°F and 99°F.
    (B) 100°F and 120°F.
    (C) 125°F and 150°F.
    (D) 180°F and 210°F.
3. A water pump normally mounts:
    (A) under the engine.
    (B) on the back of the engine.
    (C) on the front of the engine.
    (D) Any of the above.
4. Which of the following may be used to prevent coolant leakage between the water pump housing and engine?
    (A) Gasket.
    (B) RTV sealer.
    (C) Rubber seal.
    (D) All of the above.
5. Each of the following is a radiator component *except*:
    (A) core.
    (B) petcock.
    (C) oil cooler.
    (D) bypass valve.
6. Which of the following is *not* a function of a radiator cap?
    (A) Absorb heat.
    (B) Seal radiator top.
    (C) Pressurize system.
    (D) Relieve excess pressure.
7. When a thermostat is closed, which of these permits coolant circulation through the engine?
    (A) Bypass hose.
    (B) Bypass valve.
    (C) Both of the above.
    (D) None of the above.
8. Antifreeze serves each of these functions *except*:
    (A) lubricate water pump.
    (B) prevent winter freeze-up.
    (C) prevent rust and corrosion.
    (D) control engine temperature.
9. Supercharger cooling systems are being discussed. Technician A says that hot air carries more oxygen for combustion than an equal amount of cooler air. Technician B says that such a system often uses its own electric pump, hoses, and radiator to pump cool antifreeze through the supercharger intercooler . Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
10. Technician A says high-power electric powertrains supplement HV battery air cooling with liquid cooling. Technician B says that a coolant heat storage system is required on gasoline engine hybrids equipped with port fuel injection. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Credit: Joe Belanger

Proper cooling system maintenance and service is critical. A cooling system failure will leave the driver stranded and can result in severe damage to the vehicle.

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Chapter 48
Cooling System Testing, Maintenance, and Repair

After studying this chapter, you will be able to:

- List common cooling system problems and their symptoms.
- Describe the most common causes of system leakage, overheating, and overcooling.
- Perform a combustion leak test and a system pressure test.
- Check the major parts of a cooling system for proper operation.
- Replace faulty cooling system components.
- Drain, flush, and refill a cooling system.
- Describe safe working practices to use when testing, maintaining, or repairing a cooling system.
- Correctly answer ASE certification test questions on cooling system troubleshooting and repair.

A cooling system is extremely important to the performance and service life of an engine, as well as a hybrid gas-electric powertrain. Major engine and HV drive system damage can occur in minutes without the proper removal of excess heat. An engine generates heat by burning gasoline or diesel fuel. An HV powertrain generates heat by producing and consuming huge amounts of electrical energy.

Combustion heat can collect in metal engine parts. The excess heat can cause engine damage, such as:

- Melted pistons.
- Cracked or warped cylinder heads.
- Burned exhaust valves.
- Burned or "blown" head gaskets.
- Damaged radiator and heater hoses.
- Cracked engine exhaust manifolds.
- Cracked or warped plastic intake manifolds.

To prevent these costly problems, the engine cooling system must be kept in good operating condition.

Electrically-generated heat can also build inside the HV battery, HV power control module, and large motor-generator. Any of these expensive, high-voltage, high-wattage powertrain components can fail without adequate heat removal or cooling.

As an auto service technician, you must be able to locate and correct cooling system problems quickly and accurately. It is equally important that you know how to maintain cooling systems for superchargers and electric drive trains. This chapter will help you develop these skills.

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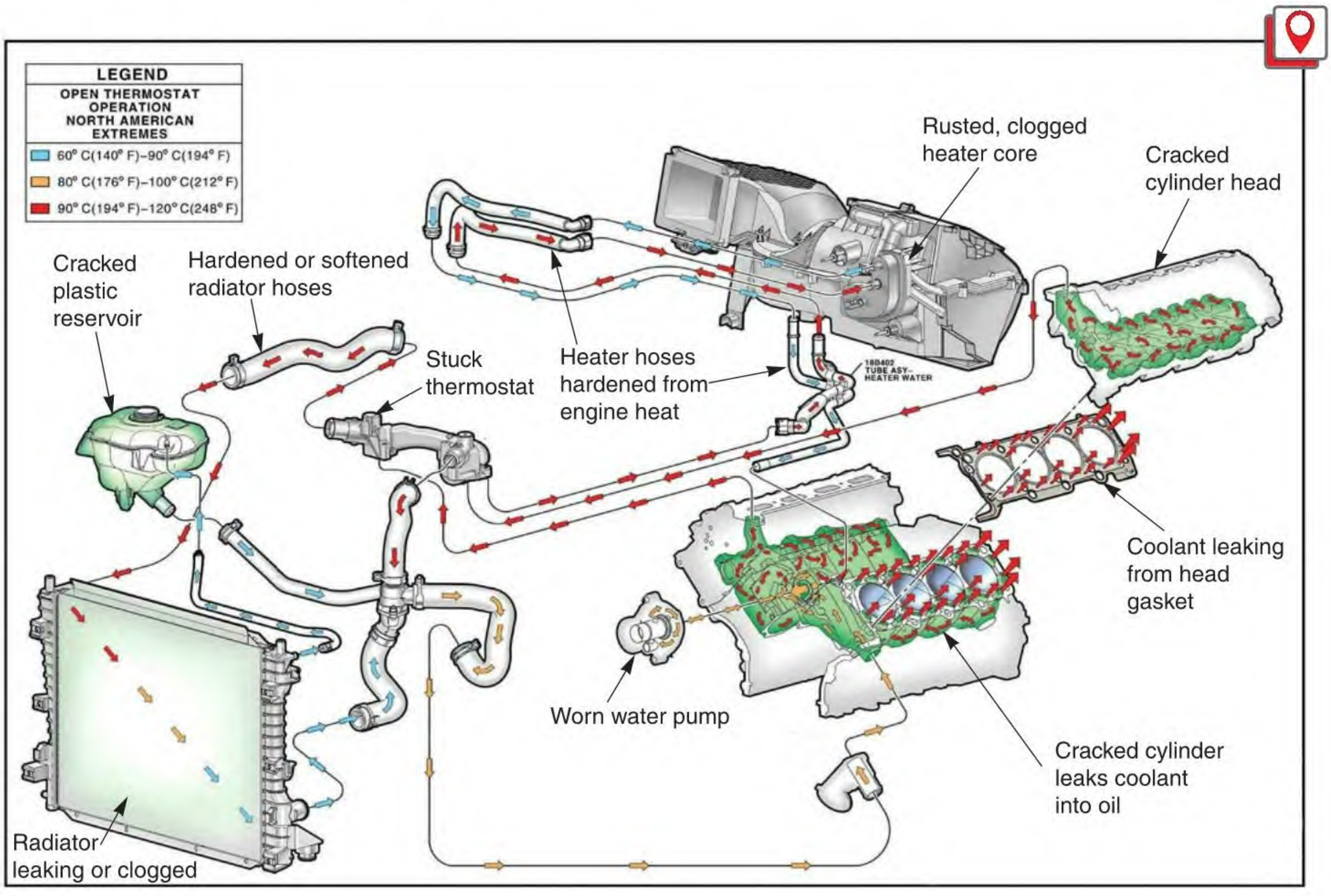
Cooling System Troubleshooting

The first step toward diagnosing cooling system problems involves gathering information. Talk to the vehicle owner or the service writer to find out as much as possible about the symptoms of the problem. For example, you might ask the following questions:

- Can you describe the cooling system problem (temperature light on, overheating, visible steam, or coolant loss)?
- When does the problem seem to occur (all the time, at highway speeds, when idling, in all-electric mode, when engine starts, when engine is hot or cold)?
- When did the problem begin?
- Have any other engine or electric powertrain repairs been performed (new thermostat, hoses, motor-generator, transmission, or engine repairs)?
- Have you noticed any coolant leaks (puddles on the ground, wetness around the engine)? If so, where are leaks located?
- Are there any unusual noises that might be related to the cooling system (engine grinding, hissing of steam, HV electrical humming)?

The answers to these kinds of questions can lead you to the source of the problem(s), even before you connect a scan tool. Collecting this information will help you eliminate the least likely problem sources so you can concentrate on the most probable causes of the malfunction. See **Figure 48-1**.

After gathering information from the vehicle owner and the scan tool reading, verify the complaint—test-drive the car, inspect the engine compartment, and listen to engine noises. Make sure you have found the exact cause and correction before starting disassembly and repair.



Ford

Figure 48-1. A properly functioning cooling system is an important part of the engine. This illustration shows some problems that can occur in cooling systems.

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Cooling System On-Board Diagnostics

Modern on-board diagnostic systems will trip a trouble code when circuits are operating out of range, such as engine cooling, transmission cooling, motor-generator cooling, and power control circuit cooling for the electric drive train. Circulation of both air and coolant is required to keep mechanical and electronic systems working properly.

Vehicle diagnostic systems monitor coolant and air temperatures in all systems that generate high heat levels. They primarily read sensor signals for coolant level, engine oil temperature, water pump drive-belt tension, and engine knock due to engine overheating, to name a few. OBD systems also measure ambient or outside temperature of the air surrounding the engine and high-power, electric drive train. Use your scan tool to analyze the system when the malfunction indicator light is on.

If the vehicle being repaired is a hybrid gas-electric or full-electric drive, OBD will read both coolant and air temperatures as a fail-safe system. The engine ECM will monitor the operating temperatures of the coolant and air circulating through the HV battery pack housing. It will measure temperatures of the motor-generator stator housing, the HV PCM heat sink, and the HV coolant liquid (antifreeze and water solution) that flows through (or over) one or all of the high-energy assemblies. Scan for stored trouble codes and observe actual operating temperatures from all vehicle sensors.

If a vehicle has been sitting in the shop overnight, for example, compare the scan tool readings for all temperature sensors. Note the temperature readings for engine coolant, engine air inlet, supercharger coolant, and HV coolant. All temperature sensors should read approximately the same part or air temperature. When you warm the engine to full operating temperature, again note all vehicle temperature readings. Record all air and coolant temperature sensor readings for both the gas and electric powertrain temperature sensors.

All scan tool readings at full operating temperature (engine, HV battery, motor-generator, HV PCM, supercharger, turbocharger) must be accurate and within specifications. If any temperature sensor does not give a correct temperature reading, the sensor with the inaccurate reading is probably at fault. A major assembly may be overheating (hot test only) or the sensor may be giving you a false reading of temperature. Either scenario requires pinpoint tests to verify the exact source of the vehicle problem.

Diagnosis Charts

A ***cooling system diagnosis chart*** should be used when problems are difficult to locate. A service manual typically contains a very accurate chart for the particular design and type of engine and cooling system. The chart will help you decide which tests and repairs are needed, and the proper sequence in which they should be performed.

Cooling System Inspection

A visual inspection frequently reveals the source of cooling system problems, as well as mechanical and HV driveline problems. Look for obvious signs of trouble:

- Coolant leaks—Antifreeze solution can be seen on the ground under the vehicle.
- Loose or missing fan belt—Fan belts can fly off the water pump pulley. Loose, slipping belts may not spin the water pump properly.
- Low coolant level—A quick glance at the translucent, plastic reservoir tank will tell you if there is enough antifreeze in the system.
- Abnormal water pump noises—A badly worn water pump will grind and chatter and restrict coolant flow.
- Leaves and debris covering the outside of the engine radiator—These obstructions can cause overheating problems.
- Coolant in the oil—If the engine oil looks white and milky, water and antifreeze have mixed with the engine lubricating oil. The engine head gaskets might be leaking coolant into the oil, or even worse, the head or cylinder block could be cracked and leaking coolant into the crankcase.
- Combustion leakage into the engine coolant—Air bubbles in the coolant indicate that the flame of the burning fuel is injecting hot exhaust gases into the engine cooling system. The hot steam in the bubbles can heat the coolant and reduce water pump efficiency, causing the engine to overheat and the radiator to overflow with steam.

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Warning

Wear eye protection and stand behind—not over—a spinning engine and high-voltage cooling system fan blade. If a small tool is dropped or a blade breaks off, you will not be injured by flying parts. Also, keep your hands and tools away from the spinning fan. Disconnect electric fans before working near or on them.

Cooling System Problems

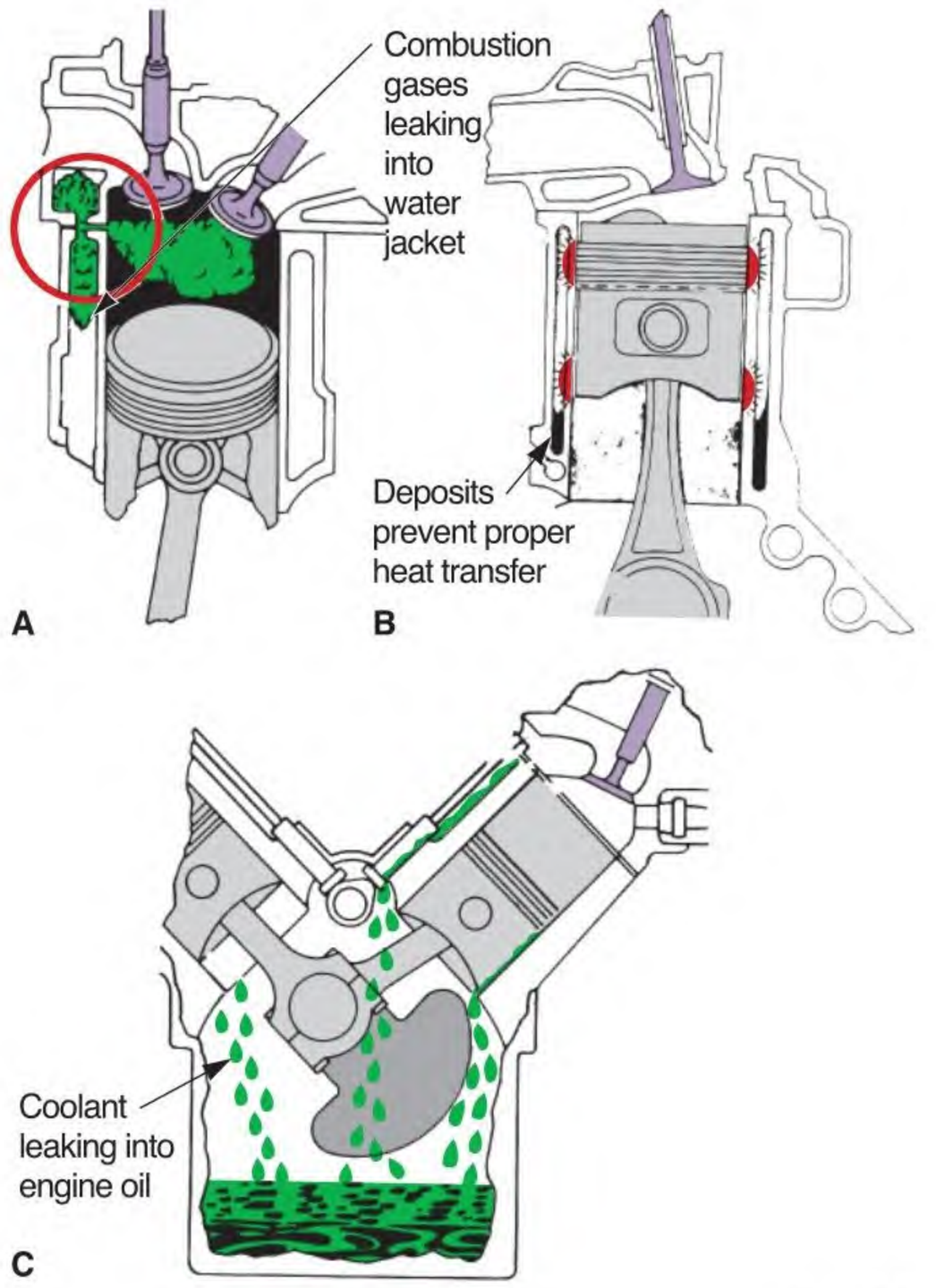
Cooling system problems can be grouped into three general categories:

- Coolant leaks—Cracks or ruptures in the system allow pressure cap action to push coolant out of the system.
- ***Overheating***—Overheating occurs when engine operating temperature is too high, the warning light is on, the temperature gauge shows hot, or coolant and steam are blowing out of the overflow.
- ***Overcooling***—Overcooling occurs when the engine fails to reach full operating temperature, resulting in poor or sluggish engine performance.

Coolant Leaks

A low coolant level may indicate an internal or external antifreeze leak out of the pressurized system. External coolant leaks show up as wet, discolored (darkened or rust colored) areas in the engine compartment or on the ground. The leaking fluid smells like antifreeze and has the same general color. If the coolant is redder in color, it means there are more suspended rust particles in coolant. Leaks can occur almost anywhere in the system, but they usually occur at hose ends or at the radiator or heat exchanger. Internal coolant leaks are often caused by a cracked engine block, cracked or warped cylinder heads, or blown head gaskets. Any internal coolant from these parts will contaminate the oil and turn it a lighter color. This is illustrated in **Figure 48-2**.

Remember to check the coolant level in late-model vehicles at the overflow tank, or plastic coolant reservoir. Avoid removing the pressure cap unless tests or repairs are required. Only open systems (no reservoir) require that you remove the pressure cap to check coolant level.



Deere & Co.

Figure 48-2. Engine problems can affect the cooling system. A—A blown head gasket can allow combustion gases to enter the coolant creating bubbles that may be seen in the radiator or blowing into the reservoir tank. B—Mineral deposits in water jackets of the engine can prevent proper heat transfer, which results in overheating. C—A cracked part or a blown head gasket can allow coolant to leak into the engine oil. The oil will turn milky white when contaminated with coolant.

Warning

Never remove a radiator cap when the engine is hot. The pressure release can make the coolant begin to boil and expand into steam vapor. Boiling coolant could spurt out of the radiator filler neck, causing severe burns!

Remember, water boils at 212°F and modern cooling systems operate at 250°F. Removing the pressure cap can cause scalding steam to shoot out of the radiator.

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Tech Tip

With today's sloped, rounded hood lines, the trend is to put the radiator filler neck on or near the engine or on the overflow tank instead of on the radiator. The higher filler location is needed to help purge air from the cooling system.

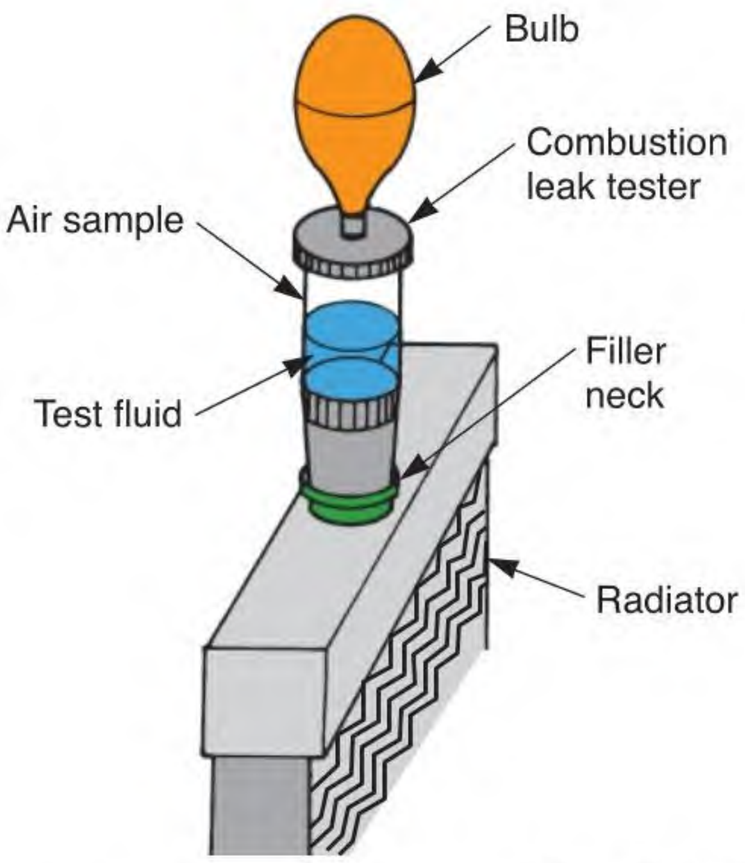
Combustion Leak Test

A ***combustion leak test*** checks for the presence of combustion gases in the coolant. This test should be performed when signs point to a blown head gasket, cracked block, or cracked cylinder head (overheating, bubbles in the coolant, or a rise in the coolant level upon starting).

Service Procedure

To perform a combustion leak test (**Figure 48-3**):

1. Place a ***block and head tester,*** sometimes called a ***combustion leak tester,*** in the radiator filler neck or the reservoir.
2. Start the engine.
3. Squeeze and release the tester bulb. This will pull air from the cooling system through the tester.



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Figure 48-3. Use bulb to draw a sample of radiator air into the combustion leak tester. If the test fluid turns yellow, engine problems are allowing combustion gas into the cooling system.

The fluid in the ***block tester*** is normally blue. The chemicals in exhaust gases cause a reaction in the test fluid, changing its color. A combustion leak will turn the fluid yellow. If the fluid remains blue, there is no combustion leakage.

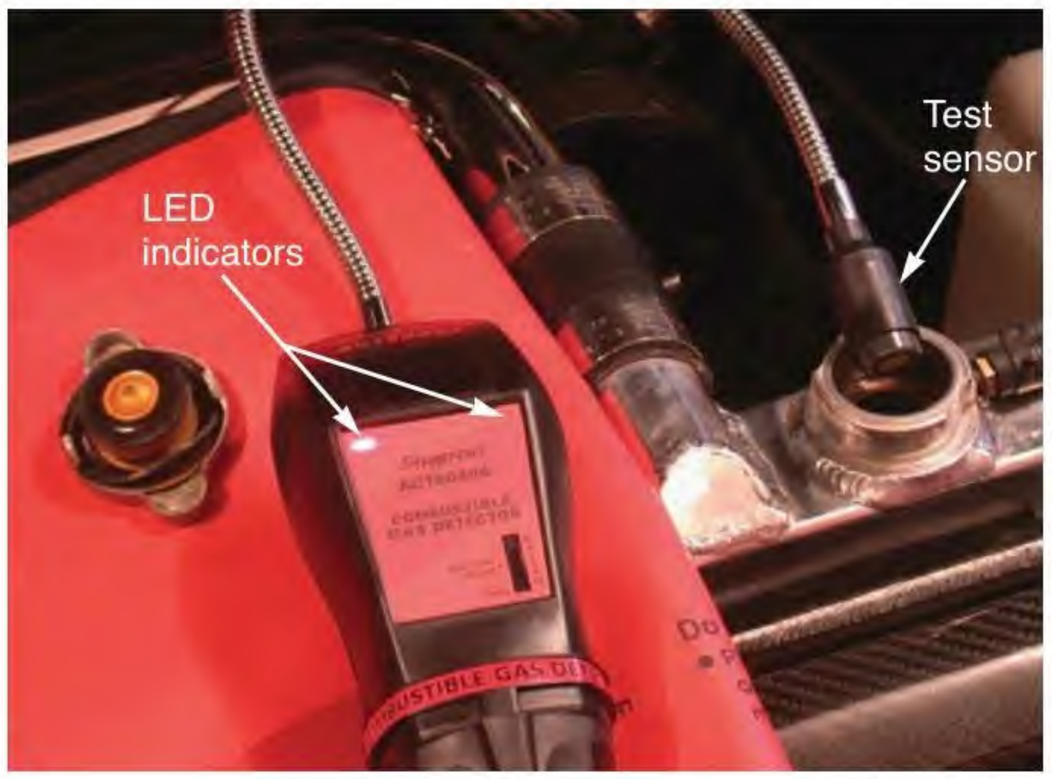
If combustion leakage is indicated, short out spark plugs one at a time. Test the cooling system with each plug shorted. When the fluid does not change color, the cylinder being shorted out has a combustion leak.

Combustion leakage into the cooling system is very damaging. Exhaust gases mix with the coolant and form very corrosive acids. The acids can eat holes in the radiator and corrode other components. An exhaust gas analyzer will detect combustion leakage into coolant. See **Figure 48-4**.

Coolant in Oil

When water, antifreeze, and oil mix, the solution turns milky white in color. If a milky white solution is found in the engine oil or in valve covers, it is an indication of a coolant leak. The cause may be one of the same problems that creates combustion leakage (blown head gasket, cracked head or block, or leaking intake manifold gasket on V-type engines).

It is possible to have both combustion leakage into the coolant and coolant leakage into the engine oil. When mixed with engine oil, antifreeze can cause engine damage. The antifreeze can collect and burn on the cylinder walls, causing piston and cylinder gumming or scoring. Always correct the engine problem causing internal leakage.



Snap-on Tool Corp.

Figure 48-4. Exhaust gas analyzer. Hold the test sensor over the coolant filler neck and accelerate the engine. LED indicators light when a combustible gas is detected, indicating internal combustion leakage.

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Cooling System Pressure Test

A ***cooling system pressure test*** is used to quickly locate leaks in the radiator, water pumps, hoses, engine, or HV component. Low air pressure is forced into the sealed liquid-cooling system, which causes coolant to pour or drip from any leak in the cooling system. See **Figure 48-5**. A ***pressure tester*** is a hand-operated air pump used to pressurize the cooling system for leak detection.



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Figure 48-5. Pressure testing a cooling system. A—Choose the correct size tester cap to fit the radiator filler neck. B—Install the pressure tester cap on the filler neck. C—Attach the hand pump to the tester cap. D—Read the pressure rating stamped on the top of the radiator pressure cap. E—Pump the tester handle until the pressure gauge reading equals the radiator cap pressure rating. Then, look for leaks.

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Service Procedure

To perform a cooling system pressure test:

1. Disconnect or disable the battery for safety.
2. Make sure the cooling system has had enough time to cool down before opening the system to release the pressure. The engine, HV powertrain, or supercharger should be cool enough to touch with your hands without being burned.
3. Slowly remove the radiator pressure cap to relieve any residual pressure with coolant loss.
4. Find the correct size tester cap to fit the radiator filler neck. The diameter of the tester cap must match the radiator filler neck opening.
5. Press the correct test cap straight down with both hands while turning it clockwise.
6. Make sure the test cap has sealed properly over both lugs on the radiator filler neck.
7. Attach the hand pump to the test cap on the cooling system radiator.
8. Pump the maximum rated pressure (pressure rating is stamped on the top of the radiator pressure cap) into the system by pumping the tester handle. A cooling system test pressure of around 14 psi (96 kPa) is typical.
9. Do not exceed maximum factory-rated cooling system pressure or you could damage the radiator, heat exchangers, and burst coolant hoses.
10. Use a shop light to inspect for coolant leakage around and under the engine or major hybrid cooling system parts. If you find a small puddle of antifreeze under the engine, for example, look straight up from the puddle—chances are you will find the leaking part. If needed, raise the car on a lift to view the point of the coolant leak.
11. With pressure in the system, inspect all parts for coolant leakage. Check all hose fittings, gaskets, and engine freeze (core) plugs. Look under the water pump and around the radiator.
12. If a coolant leak is found, tighten, repair, or replace parts and gaskets, as needed.

Caution

Do not pump too much pressure into any type of liquid cooling system, or part damage (radiator, hose, or gasket) may result. Never exceed the radiator cap or system operating pressure when testing.

Radiator Cap Pressure Testing

A ***radiator cap pressure test*** measures the cap opening pressure and checks the condition of the sealing washer. Cracks, tears, a bad seal, or damaged sealing surfaces can reduce system pressure.

Service Procedure

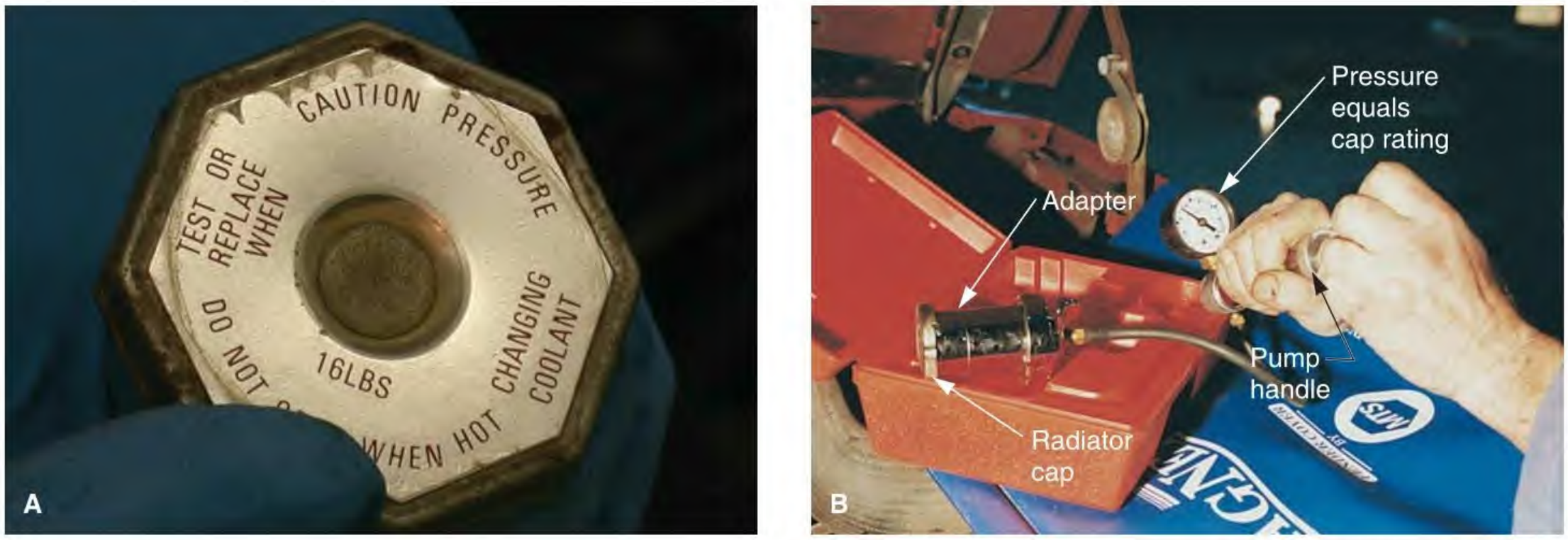
To perform a radiator cap pressure test:

1. Make sure the cooling system is not under pressure.
2. Carefully remove the radiator cap.
3. Inspect the radiator cap and filler neck sealing surfaces. Check for cracks or tears in the seal. Check the filler neck sealing surfaces for nicks or dents. Replace the cap or have the neck repaired, as needed.
4. Install the radiator cap on the pressure tester using the adapter. See **Figure 48-6**.
5. Pump the tester to pressurize the cap. The cap should release air when its rated pressure (pressure rating stamped on the cap) is exceeded. It should also hold the rated pressure for at least one minute. If not, install a new cap.

Engine Overheating

Engine and electric drive train overheating is a serious problem that can cause major engine and electric propulsion system damage. The driver may notice the engine temperature light glowing, the temperature gauge reading high, or the coolant boiling. Boiling coolant will expand and blow out through the overflow as steam.

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Figure 48-6. Pressure testing the radiator cap. A—Inspect the cap for damage or seal deterioration. Also, note the pressure rating stamped on the cap. B—Install the adapter and radiator cap onto the pressure tester, and pump to pressurize the cap.

Tech Tip

Modern scan tools and OBD II systems provide temperature sensor readings, or operating values. This might be helpful when trying to solve engine overheating and other related problems.

There are many common causes of engine overheating:

- Low coolant level—The coolant level in the engine and radiator drops too low due to a leak or lack of maintenance.
- Rust or scale—Accumulations of corrosion debris and acid in the coolant clog the radiator core or build up in the water jackets.
- Stuck thermostat—An engine water flow control valve that fails to open normally will restrict coolant flow.
- Retarded ignition timing—Late ignition timing allows the combustion flame to blow out through an open exhaust valve, which transfers too much heat into the exhaust valves, ports, and manifold.
- Loose fan belt—When a water pump drive belt slips under load, coolant circulation is reduced and the engine's operating temperature increases.
- Bad water pump—A broken pump shaft or damaged impeller blades prevent normal pumping action.
- Collapsed lower hose—Suction from water pump may flatten the hose if the spring is missing or the hose is badly deteriorated and softened from an oil leak.
- Missing fan shroud—When a fan shroud is missing or damaged, air circulates between the fan and the back of the radiator, reducing airflow through the radiator.
- Ice in coolant—Too much water in the coolant may form ice that can crack engine blocks and cylinder heads, block circulation, and cause overheating.
- Engine fan problems—Fan clutch or electric fan troubles can prevent adequate airflow through the radiator or heat exchanger, resulting in engine, supercharger, or HV part overheating and failure.
- Open temperature sensor—An open temperature sensor keeps the fan motor from energizing to remove heat.

Inspect the outside of the radiator for debris, such as leaves and dirt, which can limit air circulation through the core. If necessary, use a water hose to wash debris out of the core. Spray water from the back of the radiator to push debris out of the front. Many technicians use a garden hose and air blow nozzle to clean out bottom of the radiator core fins. Blow air backwards through washed-off fins to remove any debris lodged inside the radiator core.

Any of these problems, or others, can make the engine overheat. You must use your knowledge of system operation and basic testing methods to find the source of the problem.

Some engines are protected from overheating damage caused by a loss of coolant. The engine control module uses data from the engine temperature sensor to detect overheating. The computer then cuts off spark to one cylinder at a time in a controlled

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sequence. Ignition timing, throttle response, and fuel injection quality are also altered to limit top speed. Outside air pulled into the "dead cylinders" cools the engine and prevents overheating damage.

Engine Overcooling

Overcooling may be indicated by slow engine warm-up, insufficient warmth from the heater, low fuel economy, or sluggish engine performance. Overcooling reduces fuel economy because more combustion heat transfers into the metal parts of the engine, leaving less heat to produce expansion of gases and pressure on the pistons. Overcooling can also cause increased wear on engine or electric drive parts. Because parts are not at full operating temperature, their clearances are too great—the parts will not expand enough to produce the correct fit.

The following conditions can cause cooling system overcooling:

- Thermostat stuck open—A thermostat that is stuck open allows too much antifreeze circulation for proper heat transfer into and out of the liquid coolant.
- Thermostat stuck closed—A thermostat that is stuck closed prevents almost all coolant circulation, causing rapid engine overheating.
- Locked fan clutch—When the fan operates all the time, excess airflow through radiator is produced.
- Shorted fan switch—An electric fan that runs all the time increases warm-up time.
- Shorted temperature sensor—When the temperature sensor is shorted, the electric cooling fan runs constantly, even with ignition turned off.

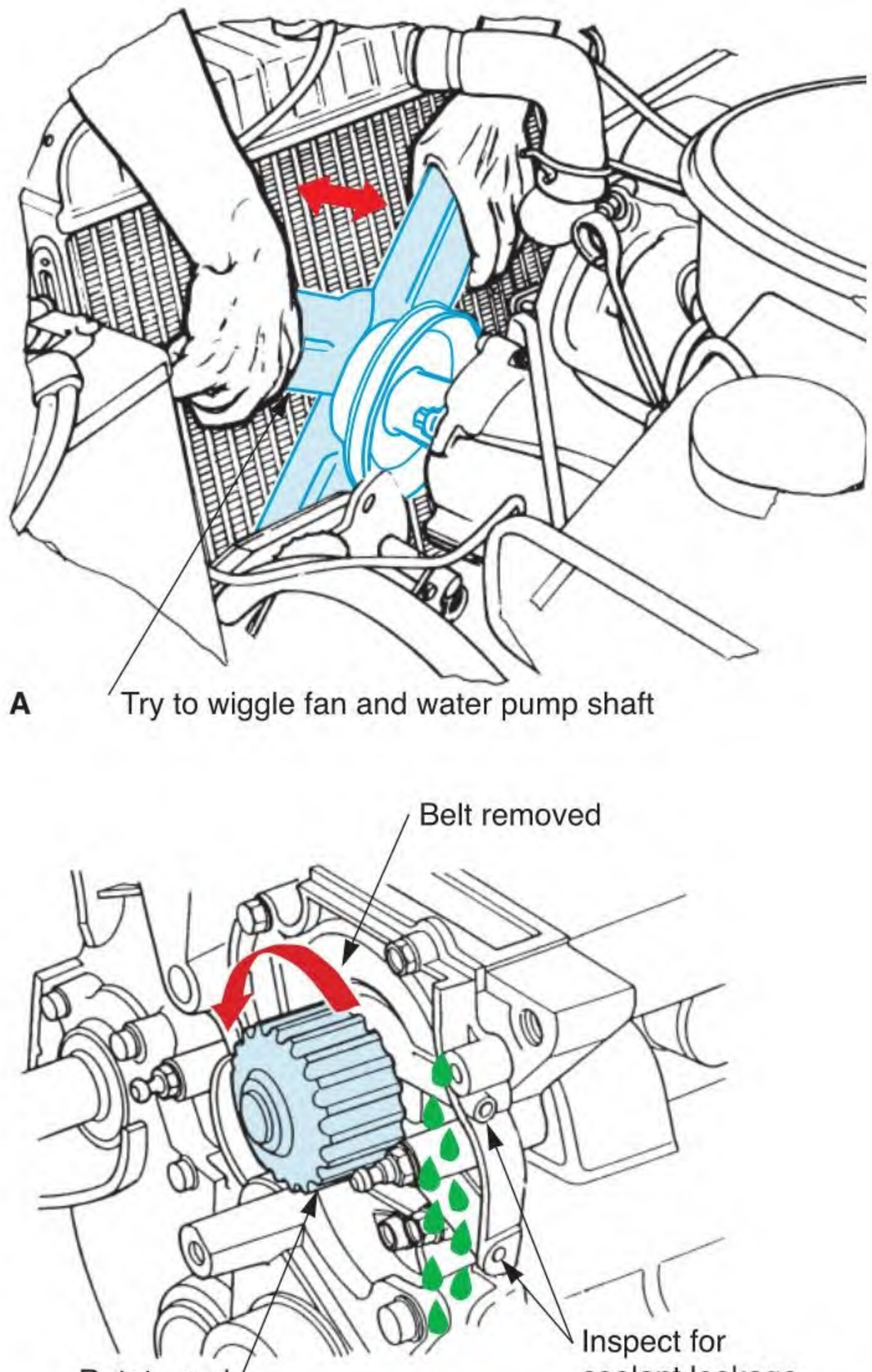
Water Pump Service

A bad water pump may leak coolant (worn seal), fail to circulate coolant (broken shaft or damaged impeller), or produce a grinding sound (faulty pump bearings). Rust in the cooling system and lack of coolant are common reasons for pump failure. These conditions can speed seal, shaft, and bearing wear. An overtightened drive belt is another common cause for premature water pump failure. Excess belt tension will overheat the water pump bearings and make them fail prematurely.

Checking a Water Pump

To check for a bad water pump seal, pressure test the system and watch for leakage at the pump. Coolant will leak out of the small drain hole at the bottom of the pump or at the end of the pump shaft. A leaking water pump must be replaced.

To check for worn water pump bearings, try to wiggle the fan or pump pulley up and down. On vehicles equipped with a serpentine belt, you may need to remove the drive belt and turn the water pump pulley by hand to check for problems. Look at **Figure 48-7**. If



Chrylser and Honda

Figure 48-7. A visual inspection can identify water pump problems. A—Wiggle the engine fan to check for water pump bearing wear. The pump shaft should not wiggle, and coolant should not leak. B—On engines that use large drive belts and electric fans, you may need to remove the belt to check water pump condition. Turn the pump pulley by hand to check for roughness or looseness.

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the pump shaft is loose in its housing, the pump bearings are badly worn and pump replacement is usually necessary. A stethoscope can also be used to listen for worn, noisy water pump bearings.

To check water pump action, warm the engine and then shut it off. Squeeze the top radiator hose while someone restarts the engine. You should feel a pressure surge (hose swelling) if the pump is working. If you do not feel a pressure surge, pump shaft or impeller problems are indicated. You can also watch for coolant circulation in the radiator with the engine at operating temperature.

Removing a Water Pump

Service Procedure

To remove a water pump on any engine:

1. Make sure the cooling system is not under pressure and that the battery is disconnected.
2. Carefully remove the radiator cap.
3. Place a drain pan under the radiator.
4. Open the drain valve.
5. Allow the radiator to completely drain.
6. Close the drain valve.
7. Remove the fan belt(s).
8. Unbolt all brackets and other components preventing pump removal. Often, the air conditioning compressor, power steering pump, or alternator must be moved out of the way to allow removal of the water pump.
9. Remove the radiator hose(s) from the water pump.
10. Remove the bolts holding the water pump to the engine. Keep all the bolts organized to aid reassembly. Never use excessive force when trying to remove an old water pump. It is easy to overlook hidden bolts that secure the pump.
11. Make sure all bolts are out and lightly tap the rear or side of the pump housing with a mallet to free the pump.
12. Scrape off all the old gasket or sealer material from the engine. The engine-to-pump mating surfaces must be perfectly clean to prevent coolant leakage when the new pump is installed. Be careful not to gouge or scratch the sealing surfaces, especially on aluminum parts.

    Refer to the service manual if you are not sure how to remove the water pump.

Tech Tip

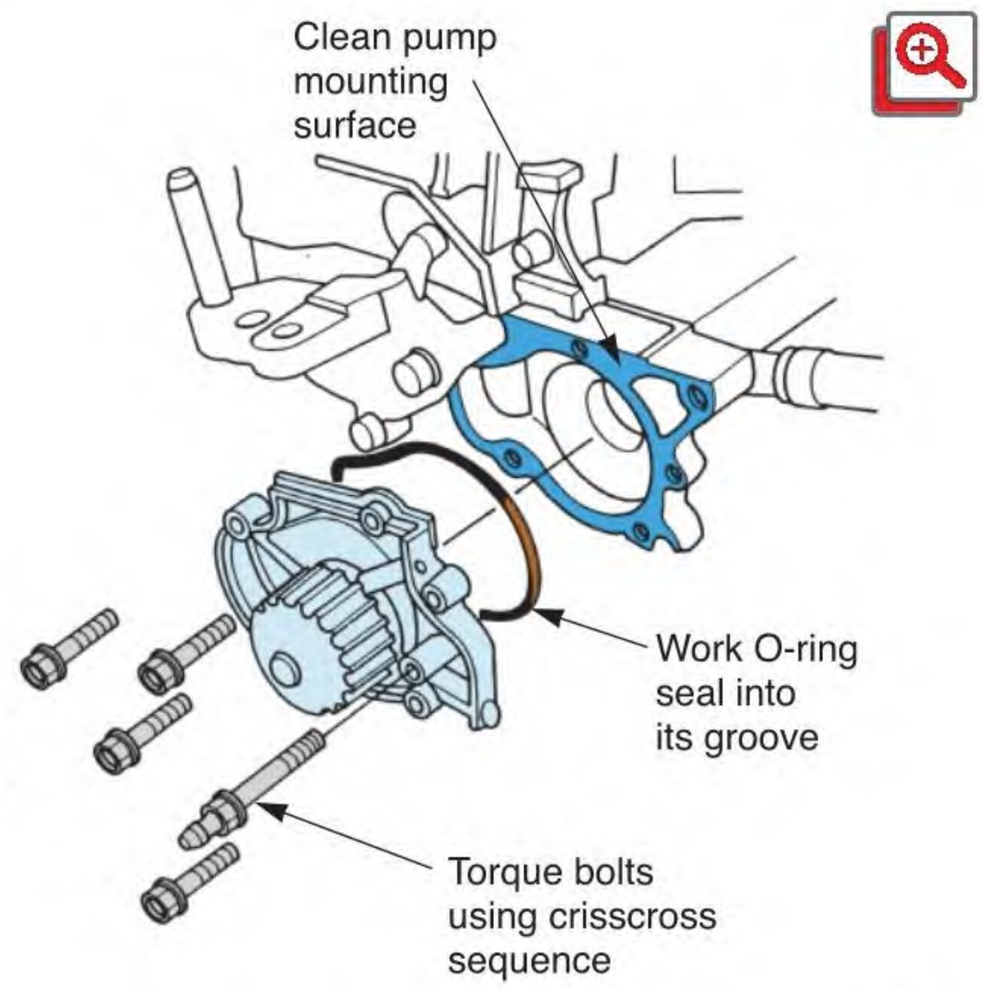
A water pump rebuild involves pump disassembly, cleaning, part inspection, worn part replacement, and reassembly. However, few technicians rebuild water pumps anymore—most purchase new or rebuilt pumps. Rebuilding a water pump takes too much time and is not cost effective. Electric HV water pumps cannot be rebuilt and must be replaced.

Installing a Water Pump

To install a water pump gasket, use an approved sealer to adhere the new gasket to the pump. This will keep the gasket in alignment over the bolt holes during pump installation.

To use a chemical gasket (sealer used in place of fiber gasket), apply a bead of approved sealer (usually anaerobic or RTV) around the pump sealing surface. Form a continuous bead of consistent width (about 1/8″ or 3 mm).

If the water pump uses an O-ring seal, work the new seal down into the bottom of its groove in the pump or engine. Leakage will result if the seal pops out of its groove and does not reach the bottom. See **Figure 48-8**. Refer to the service manual, if needed.



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Figure 48-8. This water pump uses an O-ring seal instead of a gasket or sealer. Make sure the seal is in place to prevent leakage after assembly.

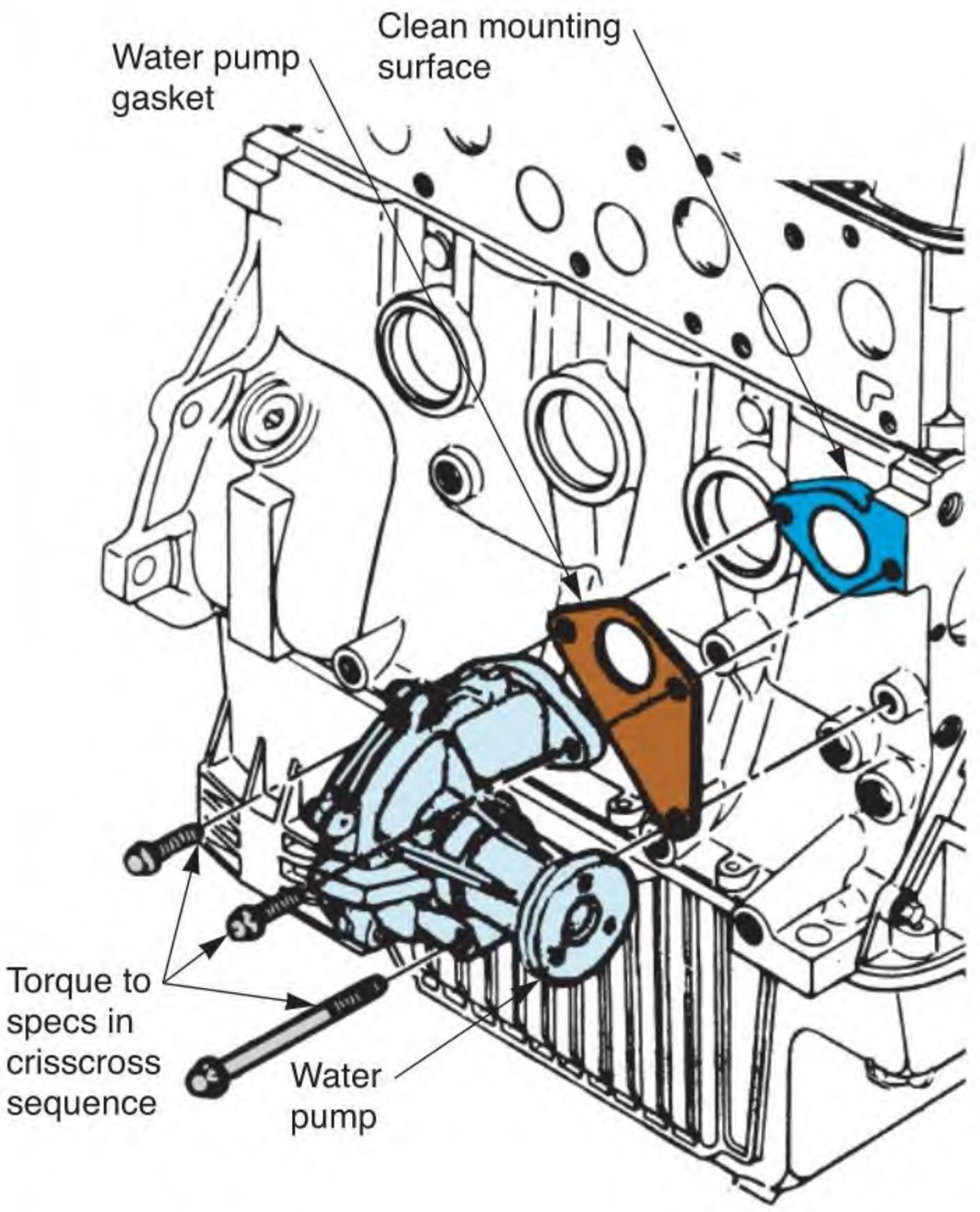
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Service Procedure

After installing the gasket or sealer, the water pump should be installed as follows:

1. If using a water pump gasket, apply an approved adhesive to the water pump and stick the new gasket to the pump. To use sealer in place of a gasket, place a continuous bead of approved silicone RTV sealer about 1/8" (3 mm) wide around the pump sealing surface. If the water pump uses a rubber O-ring seal, fit the entire circumference of the seal into its groove. If required, use heavy grease or non-hardening sealer to help secure the seal in its groove.
2. Fit the pump onto the engine and move it straight into place. Do not shift the gasket or break the sealant bead.
3. Start all the bolts by hand. Screw them in two turns. See **Figure 48-9**. Check that all bolt lengths are correct. Each bolt should be sticking out the same amount.
4. Tighten all the fasteners to 1/2 of full torque in a crisscross pattern.
5. Tighten all of the fasteners to 3/4 of full torque in a crisscross pattern.
6. Tighten all of the fasteners to full torque in a crisscross pattern.
7. Tighten all of the fasteners to full torque one more time to ensure proper torque.
8. Reinstall the radiator hose(s) onto the water pump.
9. Attach any brackets or components that were removed to allow access to the water pump.
10. Reinstall the fan belt(s), as needed. Make sure the fan belt has the proper tension.
11. Fill the radiator with coolant.
12. Start the engine and look for leaks. Allow the engine to reach operating temperature.
13. Verify coolant flow through the radiator.
14. Install the radiator cap.

Refer to a shop manual for detailed directions on pump service for the exact vehicle make and model.



Honda

Figure 48-9. When tightening water pump bolts, use a crisscross pattern to compress the gasket evenly. Use a torque wrench, if there is enough room to use one.

Tech Tip

A common mistake novice mechanics make is accidentally mixing up bolt lengths when installing a water pump. Many water pump designs have three or four bolt lengths that vary by a fraction of an inch. If you install even two water pump bolts in the wrong holes, you can damage threads or the engine cylinder block, or the new water pump can leak the new coolant profusely. If you accidentally bottom out an over-length bolt, it can easily crack a soft aluminum cylinder block at its water jacket.

After starting all the bolts in the water pump, check that all bolts are sticking out the same amount. This will ensure that all bolt lengths are correct for their hole depths. Checking for correct bolt lengths is important when installing any part, cover, pan, or housing that uses multiple fasteners for assembly. Severe engine damage can result from installing a bolt that is too long for its threaded hole.

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Thermostat Service

A stuck thermostat can cause engine overheating or sometimes engine overcooling. If the thermostat is stuck shut, very little coolant will circulate through the radiator. As a result, engine overheating could make the coolant boil. With a hybrid cooling system, a stuck thermostat can make the coolant and HV powertrain components overheat, but not as severely as engine combustion heat.

If a thermostat is stuck open, too much coolant may circulate through the radiator. The engine may not reach proper operating temperature and may run poorly for extended periods in cold weather. Consequently, engine efficiency (power, gas mileage, and driveability) will be reduced.

Thermostat Testing

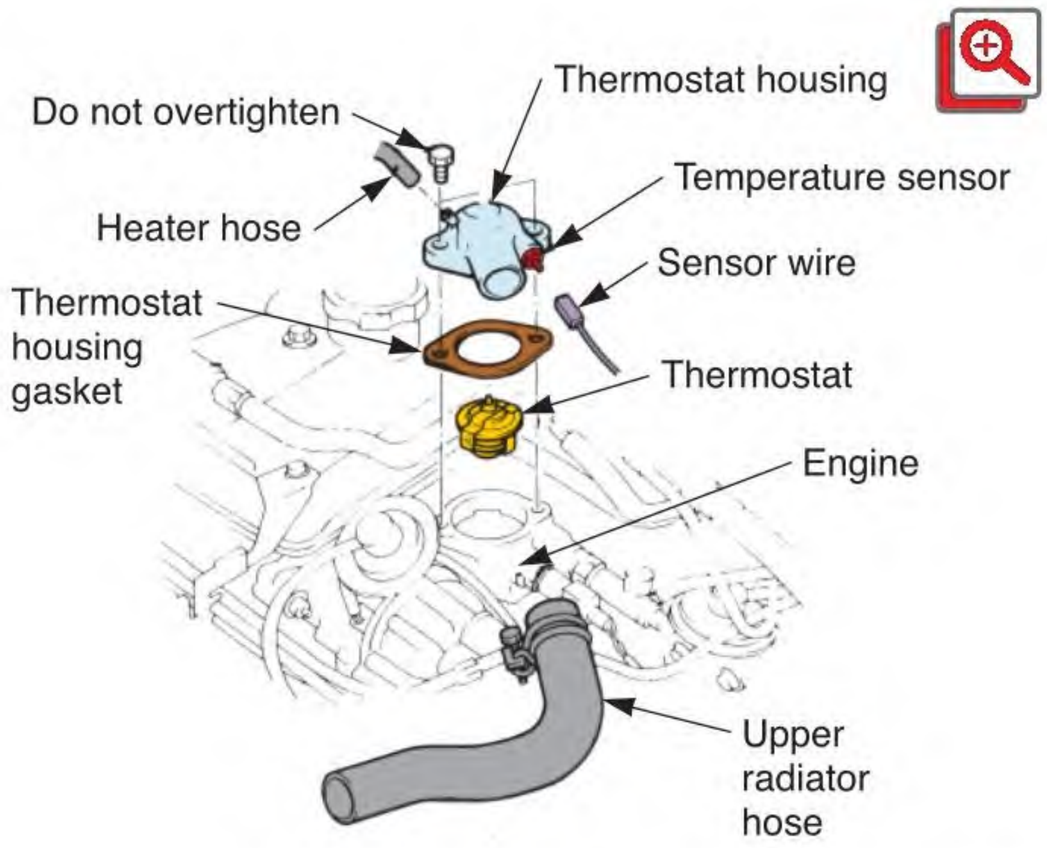
To check a thermostat, watch the coolant through the opening in the radiator neck (if provided). When the engine is cold, coolant should not flow through the upper area of the radiator. When the engine warms, the thermostat should open and you should see the coolant circulate past the opening in the top of the radiator. If coolant does not start circulating and the engine overheats, this indicates a bad thermostat.

In some instances, the thermostat may have to be removed from the engine for testing in a container of water on a hot plate. The thermostat should open when heated to its operating temperature.

You can also use a digital thermometer to check part temperatures. For example, touch the thermometer probe to the engine near the thermostat and to the thermostat outlet hose. If the engine reaches operating temperature but the outlet hose stays cool, the thermostat is not opening. If the thermostat does not open at the correct temperature, it is defective and should be replaced, **Figure 48-10**.

Thermostat Replacement

The ***thermostat housing*** is a pot metal, aluminum, or plastic enclosure that holds the thermostat in place on the engine. The thermostat and housing are normally located on the top or side of the engine. Thermostat housing bolts clamp the housing against the cylinder head, intake manifold, or cylinder block. With newer vehicles, the thermostat can also be located on the side of the mechanical water pump housing. The service manual will give all cooling system part and component locations and torque values.



Toyota

Figure 48-10. The thermostat is normally in housing at the engine end of the upper radiator hose. Remove the housing bolts and pop out the old thermostat. Be careful not to damage the thermostat housing.

Service Procedure

To remove the thermostat:

1. Make sure the cooling system is not under pressure.
2. Carefully remove the radiator cap.
3. Place a drain pan under the radiator.
4. Remove the upper radiator hose by loosening its clamp. Pull and twist on the hose to free it from the thermostat housing.
5. Remove any wiring connector or vacuum hose going to the thermostat housing.
6. Use a 3/8″ air or hand ratchet to quickly remove the two or more bolts holding the thermostat housing to the engine, as shown in **Figure 48-11A**. Note any difference in bolt lengths so they can be reinstalled correctly without causing engine damage.
7. Lift off the housing. You may have to tap the housing free with a rubber or plastic mallet. Use a set of pliers to grasp and pull the old thermostat from the engine. See **Figure 48-11B**.

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Caution

Be careful not to damage the thermostat housing. The housing is often made of aluminum or "pot metal" and will break easily. Use light mallet taps and prying to free the gasket.

8. Insert a rag into the housing and clean the mating surfaces. This may include scraping all the old gasket material off the thermostat housing and the sealing surface on the engine if this type of seal is used. Do not gouge or nick the sealing surface or leakage may result.
9. Make sure the thermostat housing is not warped. Place it on a flat surface and check for gaps between the housing and surface with feeler gauges. If the housing is warped, file or sand the surface flat to prevent coolant leakage.
10. Wipe all engine and housing mating surfaces clean with a shop towel.

When choosing a replacement thermostat, be sure to purchase an exact replacement using the part number and temperature rating for the year, make, and model of the engine. Just because the thermostat fits in the housing does not mean it will function as designed. The wrong thermostat can cause slow engine warm-up or engine overheating in warm weather. Some thermostats have a check ball or bleed pin to help purge air from the coolant. Make sure the replacement thermostat has either of these devices.

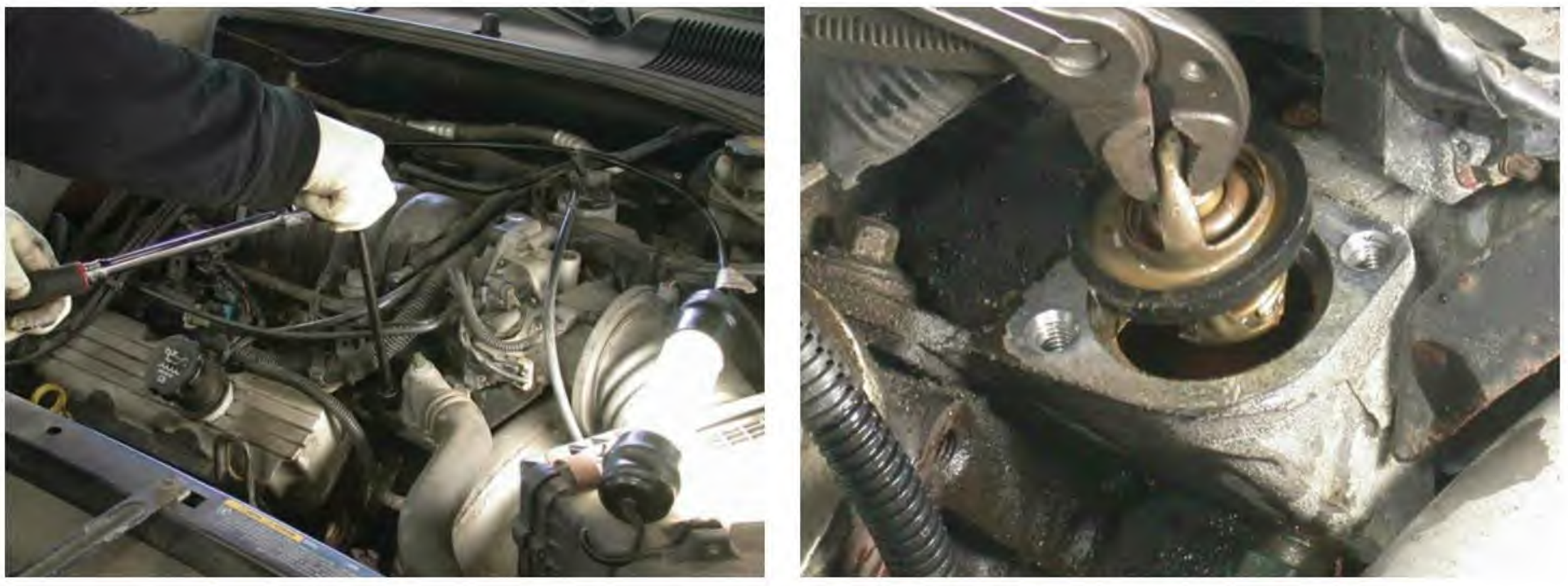
Service Procedure

To install the replacement thermostat:

1. Make sure the temperature rating of the new thermostat is correct.
2. Install the O-ring into its groove in the engine or thermostat housing. The seal must fit fully into its groove. Use a nonhardening adhesive/sealer to hold the rubber O-ring in place. Do not shift the seal out of place when installing the thermostat housing.

Tech Tip

A rubber ***thermostat housing seal*** is used instead of a gasket with some engine designs. In many cases, this O-ring can be reused if it is not damaged. If the O-ring shows any signs of hardening, swelling, or nicks, replace it. See **Figure 48-12**.



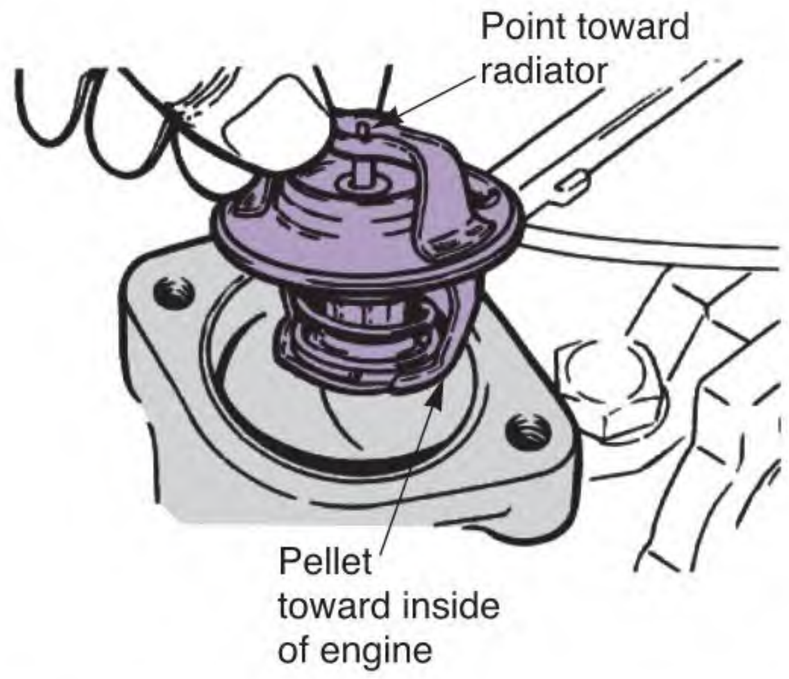
A B

Goodheart-Willcox Publisher

Figure 48-11. Thermostat removal. A—Use a ratchet, an extension, and a socket to remove bolts holding the thermostat housing to the engine. Light taps or prying may be needed to free the housing. B—After the housing has been removed, pliers can be used to pull the old thermostat out.

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3. Normally, the rod (pointed end) on the thermostat should face the radiator hose and away from the inside of the engine. The pellet chamber cylinder should face the inside of the engine, or away from the radiator hose. See **Figure 48-13**.
4. Position the new gasket with approved sealer. Make sure all bolts line up. Start the fasteners by hand.
5. Slowly torque the thermostat housing bolts to specifications in a crisscross pattern to pull the housing squarely down on the mount. Little torque (5–10 foot-pounds) is needed to keep low pressure coolant from leaking. Remember, never overtighten the bolts on a soft aluminum or pot metal thermostat housing. These housings are prone to breakage.
6. Fill the radiator with coolant, **Figure 48-14**.
7. Start the engine and check for leaks.
8. Verify that there is no coolant flow in the radiator while the engine is cool.
9. Verify coolant flow through the radiator once the engine reaches operating temperature.
10. Reinstall the radiator cap.
11. Once pressure builds in the cooling system, check again for leaks.

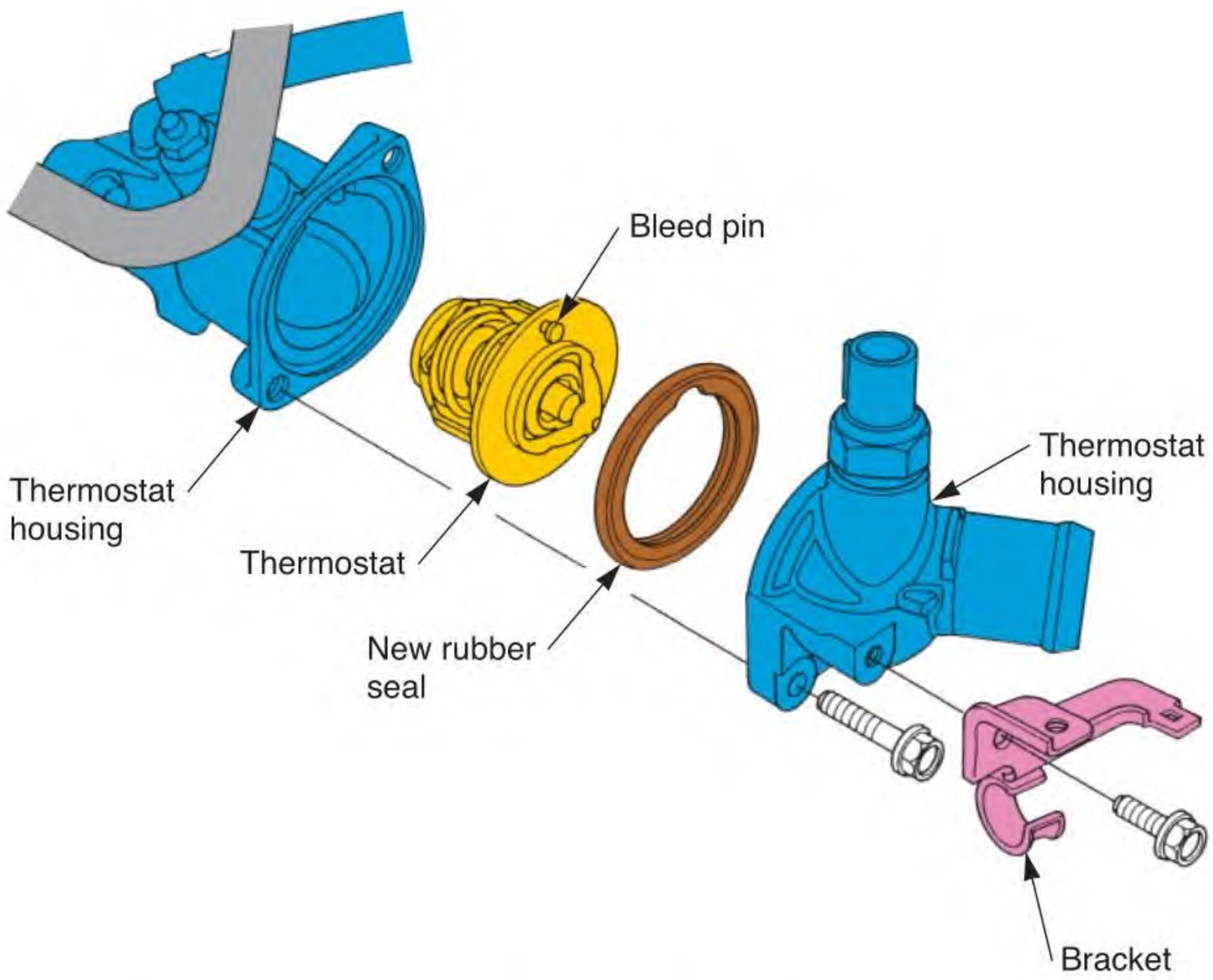


Chrysler

Figure 48-13. Install the new thermostat centered in the housing with the pellet toward inside of engine.

Caution

With some engines, the thermostat housing, cooling system filler neck, radiator hose nipple, water pump, and overflow tube are all combined into one plastic housing. Be careful not to damage this component while working, because complex housing can be very expensive to replace.



Honda

Figure 48-12. This thermostat uses a special O-ring seal. A new seal should be installed anytime the thermostat is removed.

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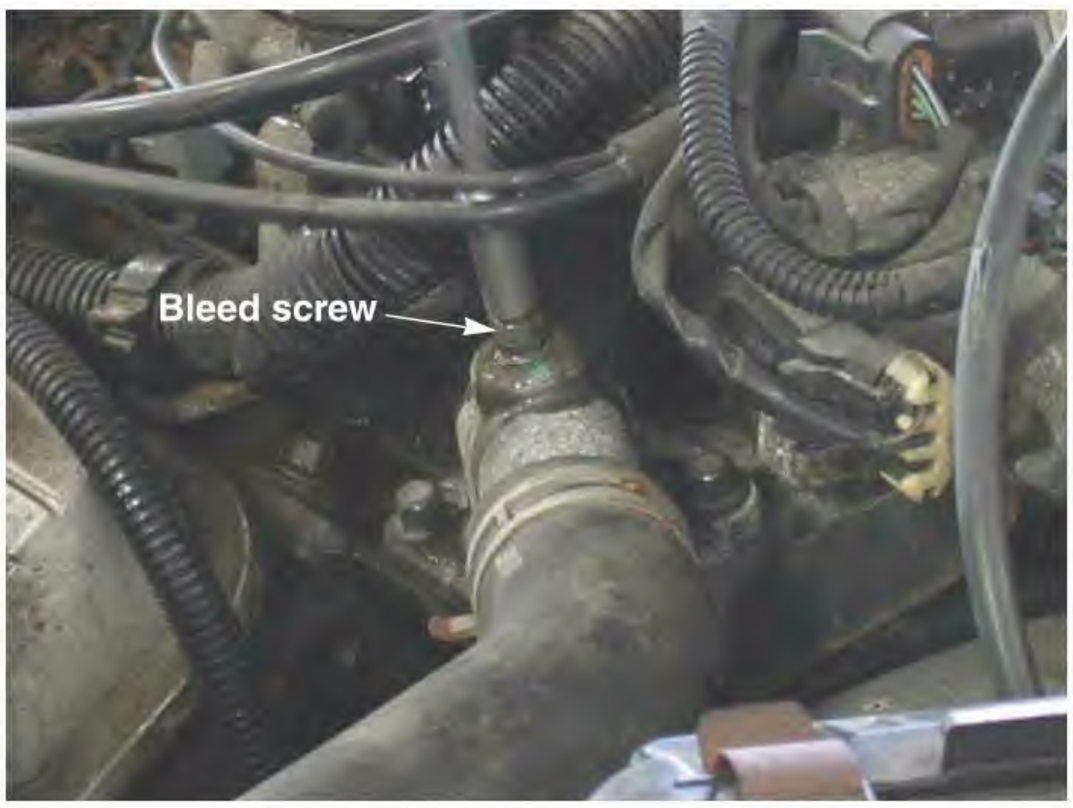


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Figure 48-14. Avoid coolant spills by installing a special cap into the radiator filler neck. A funnel can be inserted into the center of the cap.

Bleeding the Cooling System

A ***cooling system bleed screw***, or ***bleed valve***, is sometimes provided to help remove trapped air when refilling the cooling system. See **Figure 48-15**. Many late-model cars with low hood lines require a bleed screw to empty air pockets formed in areas of the system. Some systems have more than one bleed screw.



Goodheart-Willcox Publisher

Figure 48-15. If provided, use the bleed screw to remove trapped air from the cooling system. Fill the system with coolant, install the radiator cap, and start the engine. Crack open the bleed screw until all air is purged.

Air trapped in the cooling system can cause engine overheating or damage (cracking or warpage) to the parts near the air pocket and hot spot. A ***hot spot*** is an area in the engine suffering from a buildup of combustion heat. A hot spot may be created by an air pocket in an engine's water jacket.

Service Procedure

To bleed the cooling system:

1. Fill the system with coolant.
2. Start the engine and warm to full operating temperature.
3. Crack open the bleed screw until all the air is purged from the system, and coolant leaks from the valve.
4. After the system cools again, remove the radiator cap.
5. The coolant level should be at the top of the filler neck. If not, add coolant.
6. Install the radiator cap. Fill the antifreeze reservoir tank to the full mark and cap tightly. Watch for coolant leaks until the engine warms to full operating temperature again.

Warning

Never fully remove a cooling system bleed screw or any other cooling system component (hose, fitting, plug, sensor) with the engine at full operating temperature. Steaming hot coolant could spray out. Wear safety glasses and gloves when working with a hot cooling system.

Cooling System Hose Service

Old radiator hoses and heater hoses are frequently the cause of cooling system problems. After a few years of use, hoses deteriorate and may become soft and mushy or hard and brittle. Cooling system pressure can rupture the hoses, resulting in coolant loss.

Engine heat is the most common cause of hose hardening. The heat "cooks" the rubber and removes its elasticity. Hardened hoses become very brittle and crack from engine vibration. Hardened hoses often

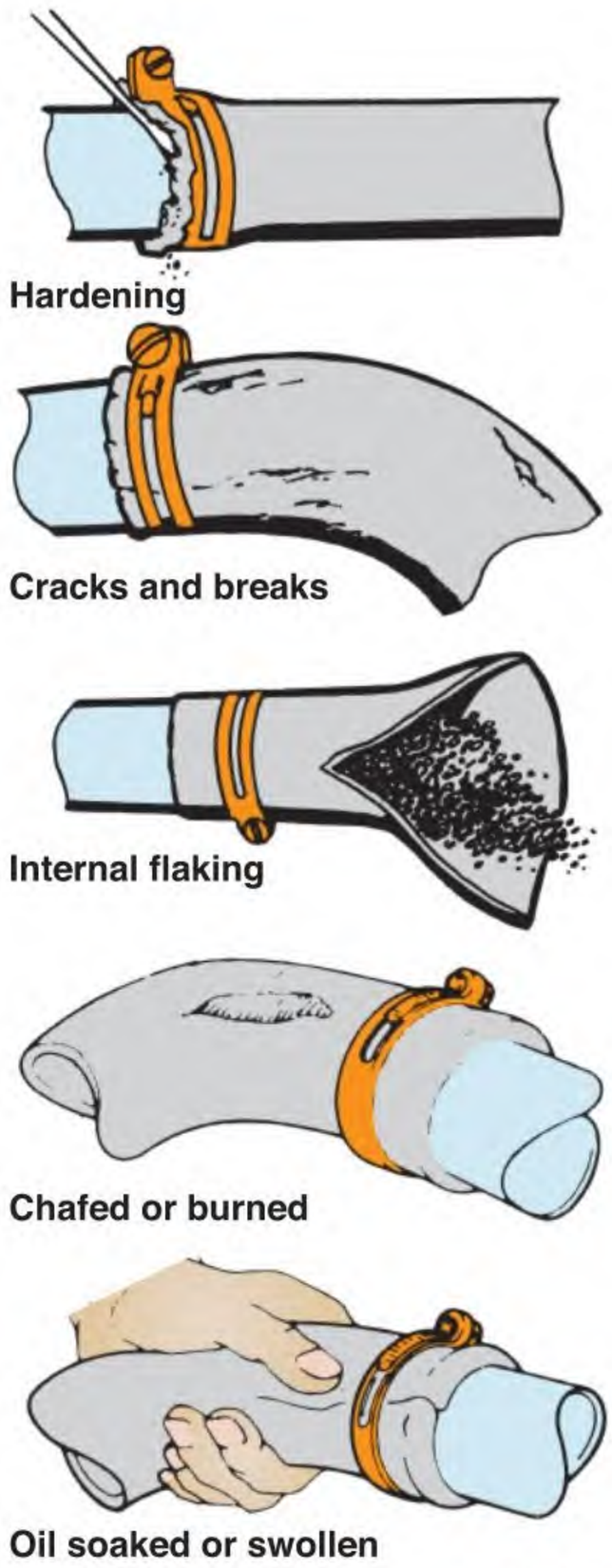
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crack and leak where they connect to other parts. To check for hardened hoses, squeeze the hoses with your hand. If you cannot squeeze the hose with your fingers, replace it.

Softened hoses may have been contaminated with oil or other fluids that break down the rubber in the hose. A softened hose is weakened and will usually swell, which can result in a rupture and leak. A softened lower radiator hose can collapse from the suction of the water pump. A collapsed hose restricts coolant circulation and causes overheating. The spring inside the lower radiator hose normally prevents hose collapse. The lower radiator spring must extend almost the full length of the hose to reach the engine and radiator fittings. If the lower radiator spring is missing or has been removed, the new hose can weaken and collapse in a few months of heating and cooling cycles. Keep this in mind when troubleshooting engines or cooling systems.

Checking Cooling System Hoses

Inspect the radiator and heater hoses for cracks, bulges, cuts, or any other signs of deterioration or damage. Look at **Figure 48-16**. Squeeze the hoses to check whether they are hardened or softened. Flex or bend the heater hoses and watch for surface cracks. If any problem is detected, the affected hoses should be replaced.



Gates Rubber Co. and Ford

Figure 48-16. Check cooling system hoses for these kinds of problems.

Coolant Hose Replacement

Service Procedure

To replace a hose:

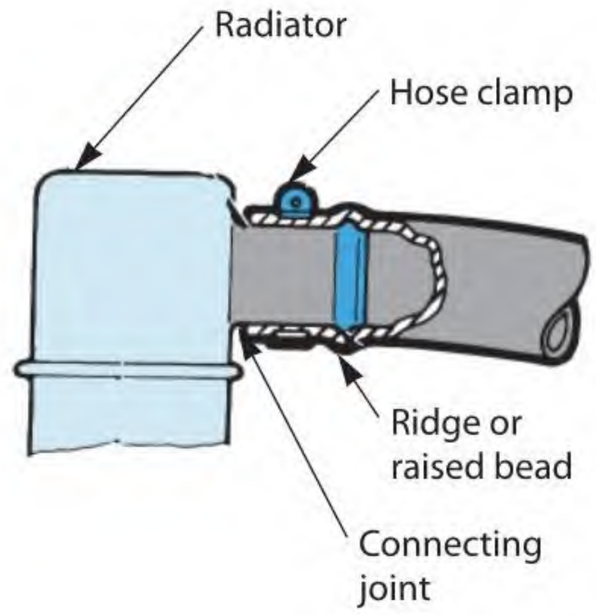
1. Make sure the cooling system is not under pressure.
2. Remove the radiator cap slowly and carefully, since there may still be some residual pressure in the system.
3. Place a drain pan under the radiator.
4. Open the drain valve. Allow coolant to flow into the drain pan until empty. Close the drain valve.
5. Loosen the hose clamps. Refer to **Figure 48-17**.
6. Pull hose off fitting. You may need to cut a slit in the old hose to aid removal.
7. Clean the metal hose fittings with a scuff pad. Wipe clean.
8. If metal hose fittings are pitted with corrosion, coat the metal hose fittings with a nonhardening sealer.
9. Apply the new hose onto the fitting. You may need to push, slide, or apply the hose sideways to ensure proper fitting. Some technicians use a nonhardening sealer as a lubricant to help the hose slide on more easily.

Tech Tip

Some radiator hoses have metal ends with large O-rings and snap rings. To remove this type of hose, use a pick tool to free the snap ring from its groove. This will allow you to pull the hose from the radiator or engine fitting. To install this type of hose, fit the snap ring into its groove first. Then force the hose onto the radiator or engine fitting until you hear the clicking sound of the snap ring popping into the fitting. See **Figure 48-18**.

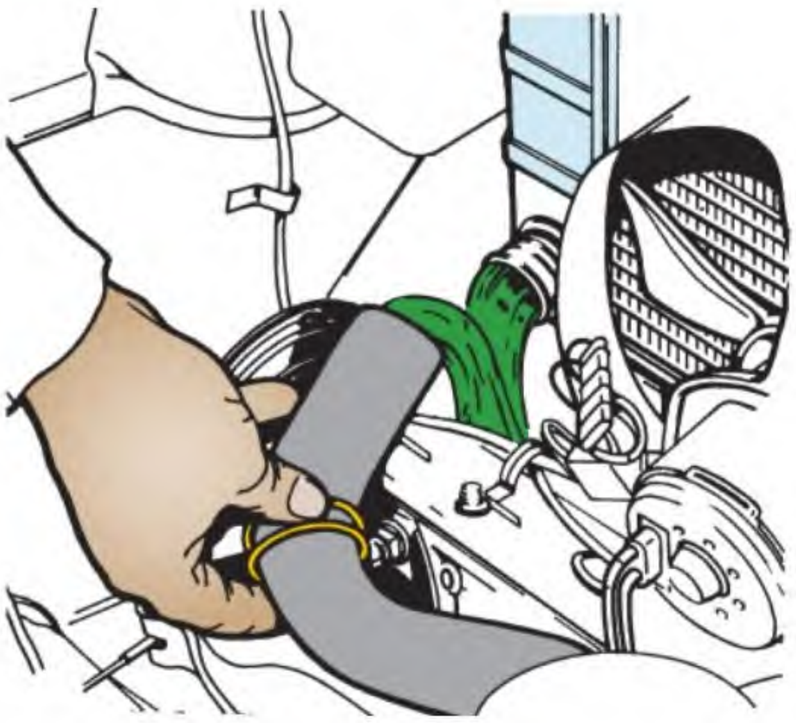
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10. Position the hose clamps so they are fully over the metal hose fitting. Make sure the clamp is held square on the hose when tightening.
11. Tighten the clamps just enough to prevent coolant leakage. You should see the clamp compress slightly into the soft rubber to provide adequate clamping and sealing action. See **Figure 48-19**.
12. Fill the cooling system with antifreeze.
13. Replace the radiator cap.
14. Inspect for coolant leaks as the engine warms, or perform a leak test.



Chrysler

Figure 48-19. Slide on a new hose and clamp. Make sure the clamp is positioned inside the bead on the fitting. Tighten the clamp and check for leaks.



Ford

Figure 48-17. Loosen the hose clamp. Twist and pull the hose off the fitting. Cut off the old hose, if needed.



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Figure 48-18. Snap rings used on the metal ends of some radiator hoses require the use an additional tool for removal.

Freeze Plug Service

A leaking engine ***freeze plug*** (***core plug***) is a frequent cause of coolant loss and overheating. Since the engine's freeze plugs are thinner than the metal in the engine block or head, they will rust through before other parts of the engine.

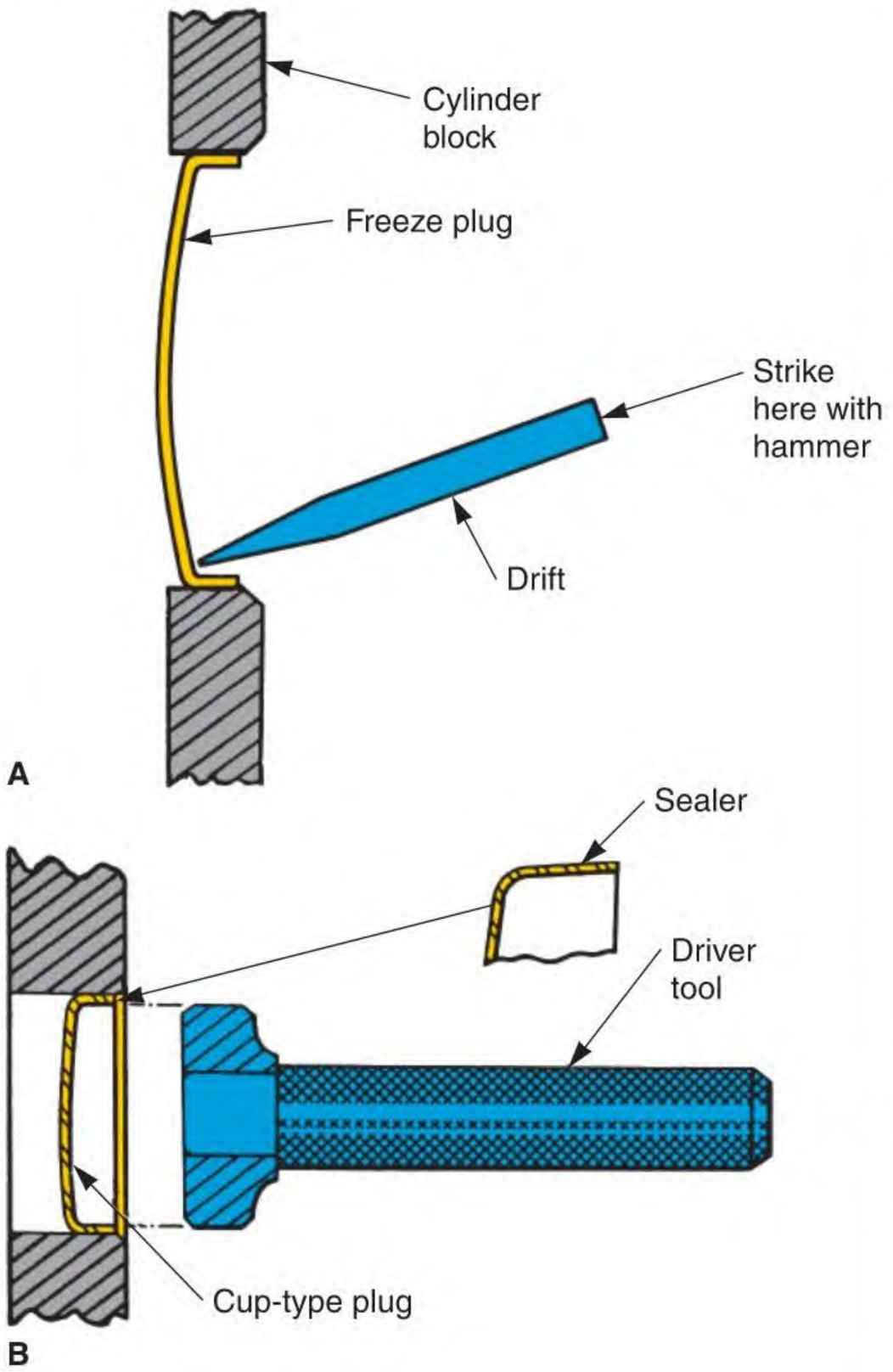
Service Procedure

To replace a freeze plug (**Figure 48-20**):

1. Drive a drift or large full-shank screwdriver through the plug.
2. Pry the plug sideways without scraping the engine block or cylinder head. Pop the core plug out by pushing on the backside of the plug with a pry bar.
3. Sand the core plug hole in the engine by hand with 120 grit sandpaper.
4. Wipe off the sealing surface with a clean shop towel.
5. Coat and plug the plug hole with nonhardening sealer.
6. Drive a new freeze plug squarely into position.

Expansion freeze plugs are available for tight quarters. After removing the old core plug and cleaning the plug hole, you can hand fit the expansion freeze plug into the engine. By tightening a nut on the replacement plug, the freeze plug will expand and lock

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Ford

Figure 48-20. Freeze plug replacement. A—Drive a drift or full-shank screwdriver through the old plug and pry it out. B—After cleaning and coating the plug hole with sealer, drive the new freeze plug into place. Drive the plug in squarely and to the proper depth.

into the plug hole. This allows the plug to be installed in tight quarters without hammering.

Radiator Service

When tests reveal that the radiator is leaking, it must be removed from the vehicle for service. Most radiator repair work is performed in specialized radiator repair shops—engine repair technicians rarely attempt radiator repairs. Radiator shops have the facilities to properly disassemble, clean, solder, adhesive bond, reassemble or repair, and pressure test any radiator. See **Figure 48-21**. Many late-model vehicles have radiators with plastic components. Special sealers, seals, and repair techniques are needed on these radiators. Additionally, the radiator in some late-model vehicles is designed to be replaced rather than rebuilt.

Radiator Removal and Installation

Service Procedure

To remove an engine or hybrid cooling system radiator:

1. Disconnect the battery to prevent engine starting or shorting wires.
2. Make sure the cooling system has cooled down and is not under pressure.
3. Carefully remove the radiator cap to relieve any residual pressure.
4. Drain all coolant from the system into a catch pan. Refer to **Figure 48-22**.

Warning

Wipe up any antifreeze spills immediately. You do not want someone to slip and fall on the hard concrete shop floor.

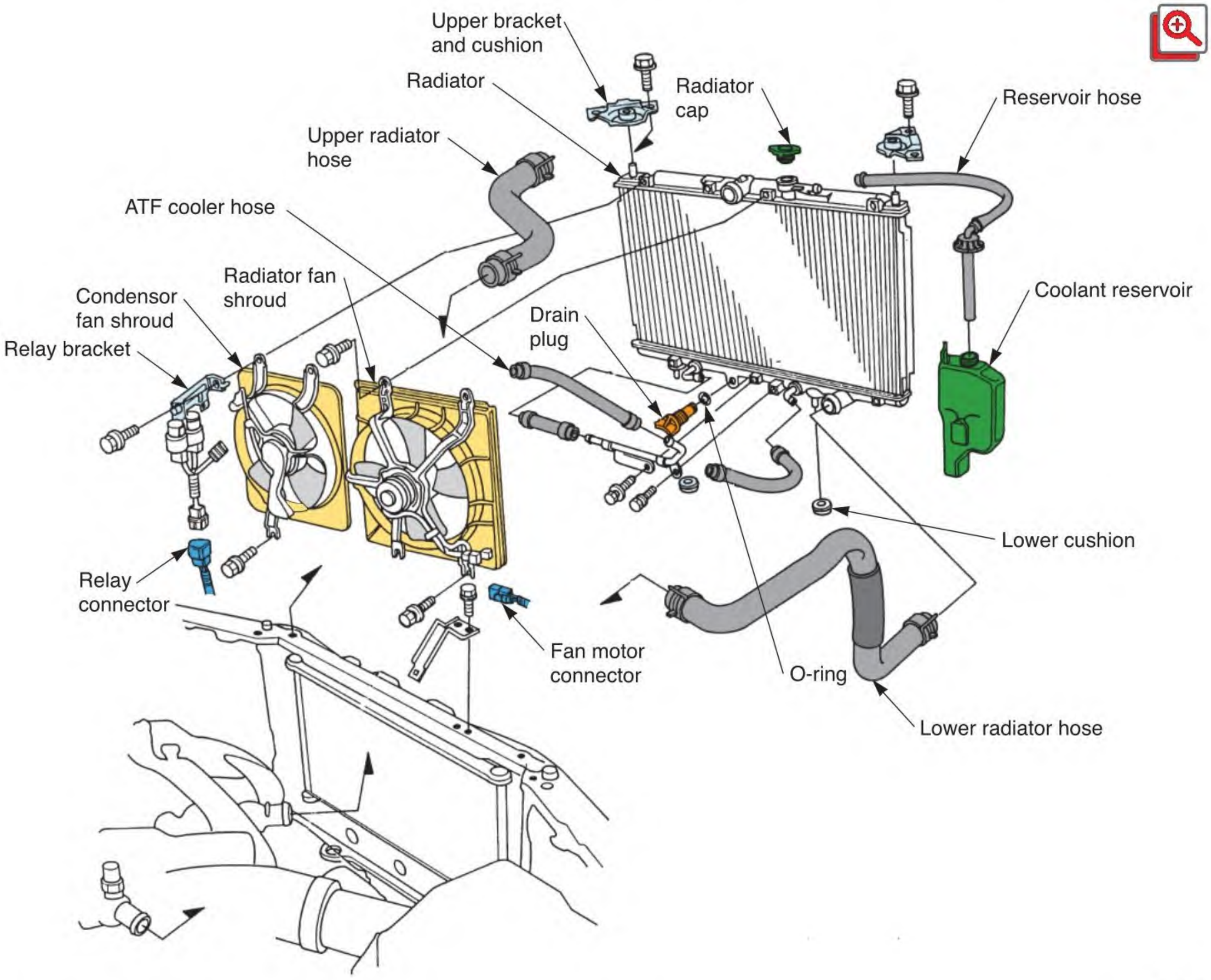
5. Loosen the radiator hose clamps and pull off the radiator hoses and oil cooler lines. Light prying may be needed to free badly stuck hoses.
6. Unplug any sensor wiring on the radiator tanks, as well as any wiring for electric cooling fans. Sometimes the fans must be removed from the radiator, or they may lift out while still attached to the radiator.
7. Remove all fasteners holding the radiator to its supports and to the vehicle.
8. Carefully lift the radiator out of the vehicle.

To install the new or repaired radiator, follow these steps in reverse order. Make sure the rubber mounts are in place in their brackets, and carefully lower the radiator into place without hitting and damaging it on the engine or body structure. Refer to the service manual for specific procedures for radiator removal and installation.

Radiator Repair

Once out of the vehicle, the radiator can be sent to a radiator shop for rebuilding. A radiator shop specializes in radiator repair, and has facilities to properly disassemble, clean (rod out), repair, reassemble, and

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Honda

Figure 48-21. This exploded view shows how electric fans, radiator, and hoses fit together.

pressure test a radiator. Few technicians try to fix a radiator in a general repair shop.

Radiator shops can solder pinhole leaks. They have special cleaning tanks for loosening and removing scale built up inside the radiator. A radiator shop can also remove the tanks and solder in a new core, if needed.

Tech Tip

Most shops do not repair plastic radiators. It is generally cheaper to replace a plastic radiator than it is to rebuild it. Also, avoid installing used radiators. With a used unit, you must be concerned with radiator condition. A used radiator could be rusted and ready to leak.

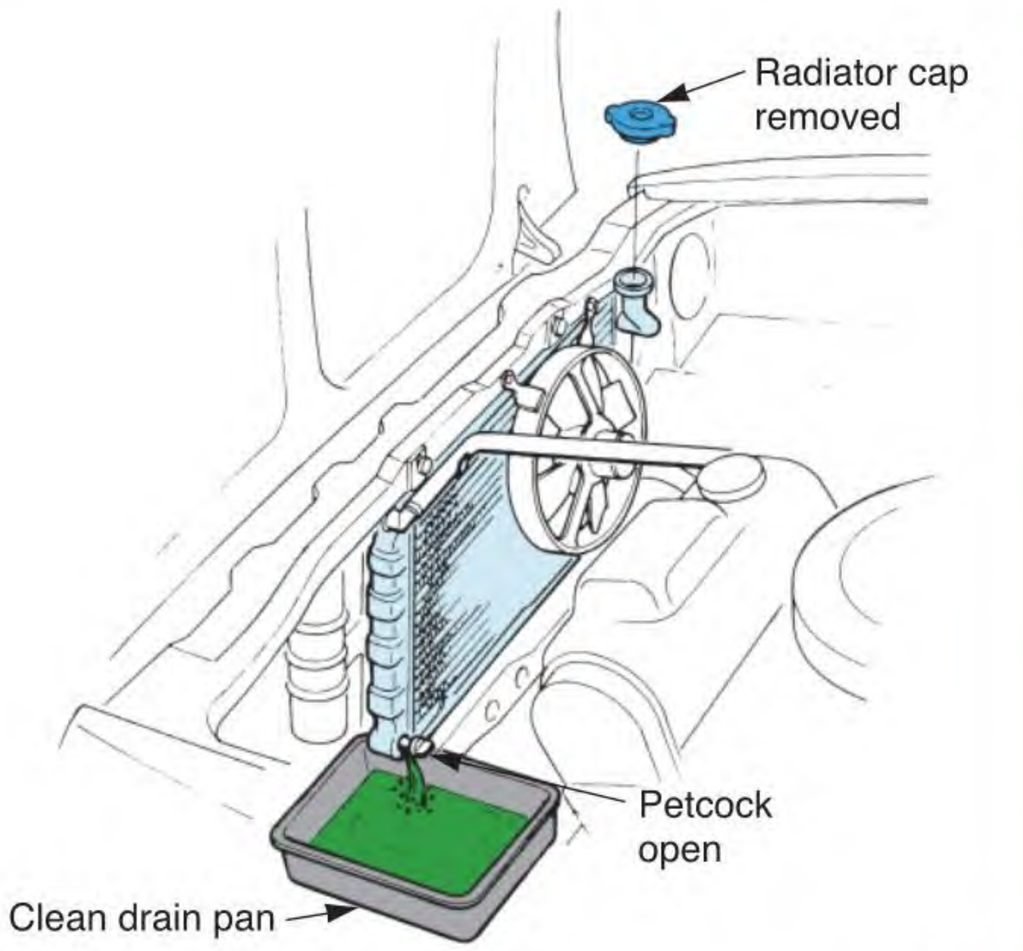
Engine Fan Service

A faulty engine cooling fan can cause overheating, overcooling, vibration, and water pump damage. Always check the fan for bent blades, cracks, and other problems. Flexible fans are especially prone to these problems. If any troubles are found, replace the fan.

Warning

A fan with cracked or bent blades is extremely dangerous. Broken blades can be thrown out with great force, causing severe lacerations!

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Honda

Figure 48-22. To drain coolant, remove the radiator or reservoir cap. Place a pan under the drain fitting and turn the petcock. Many have left-hand threads and must be turned clockwise to open.

Electric Fan Service

Most electric cooling fans are controlled by a heat-sensitive switch or sensor located somewhere in the cooling system (radiator, engine block, or thermostat housing). When the engine is cold, the switch keeps the electric fan motor off to speed engine warm-up. Then, when a predetermined temperature is reached, the switch closes and the fan begins to cool the engine.

Many electric cooling fans are now controlled by the engine ECM and temperature sensor on the radiator. The ECM grounds the normally hot fan motor windings to complete the circuit and turn the cooling fans on.

Testing an Electric Fan

Service Procedure

To test an electric cooling fan:

1. Verify that the fan stays off when the engine and cooling system are cool or cold (ignition key in *Run* position).
2. Start and idle the engine. The cooling fan(s) should begin spinning when the engine reaches full operating temperature (measured with laser thermometer or on scan tool).
3. Make sure the fan motor is spinning at a normal speed and is forcing air through the radiator.
4. If the fan does not function when the engine is warm, check the fuse, electrical connections, fan relay, and motor supply voltage.
5. If power (and ground) is applied across the fan motor windings by the ECM and/or its relay, and the motor fails to spin the fan blades, then the fan motor needs to be replaced.
6. If the engine is warm and voltage is not supplied across the fan motor, use a multimeter to check the action of the radiator temperature sensor or switching sensor. The radiator temperature sensor or switch should have almost zero resistance when the engine is warm. Resistance should be infinite when the engine is cold.
7. Make sure the ground circuit for the fan motor has almost zero resistance.

If these tests do not locate the trouble, there may be a defective relay, connection, ECM, or other problem. Refer to a factory service manual for instructions.

Some new cars have a fan ECM that controls the radiator fan. It will trip specific trouble codes for the fan motor, temperature sensors, or the ECM itself when circuit problems are detected. If the trouble code indicates something is wrong with the fan ECM, this usually means the fan ECM is faulty and requires replacement.

Belt-Driven Fan Service

A loose fan belt will slip and squeal, and may rotate the water pump and fan too slowly. As a result, the engine may overheat. A loose fan belt could also fly off its pulleys. Always inspect the condition and tension (tightness) of fan belts when servicing a cooling system. If a fan belt is cracked, frayed, glazed (hard, shiny surface), or oil soaked, it should be replaced.

Most manufacturers recommend using a ***belt tension gauge*** to measure belt tightness. Use of the gauge ensures that the belt is not too tight or too loose. An overtightened belt will fail quickly and may damage other parts.

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Warning

Keep your hands away from a moving engine belt. The belt can pull your fingers into the pulleys, causing severe hand injuries.

Service Procedure

To test a thermostatic fan clutch:

1. Spin the fan with the engine off. The fan should turn without the fan shaft turning.
2. Start the engine. When the engine warms, the clutch should engage.
3. Verify that air is flowing through the radiator and over the engine. You will be able to hear and feel the rush of air when the fan clutch locks up.

If the fan clutch is locked when cold or does not lock when hot, it is defective and must be replaced. Excessive play or oil leakage also indicates fan clutch failure.

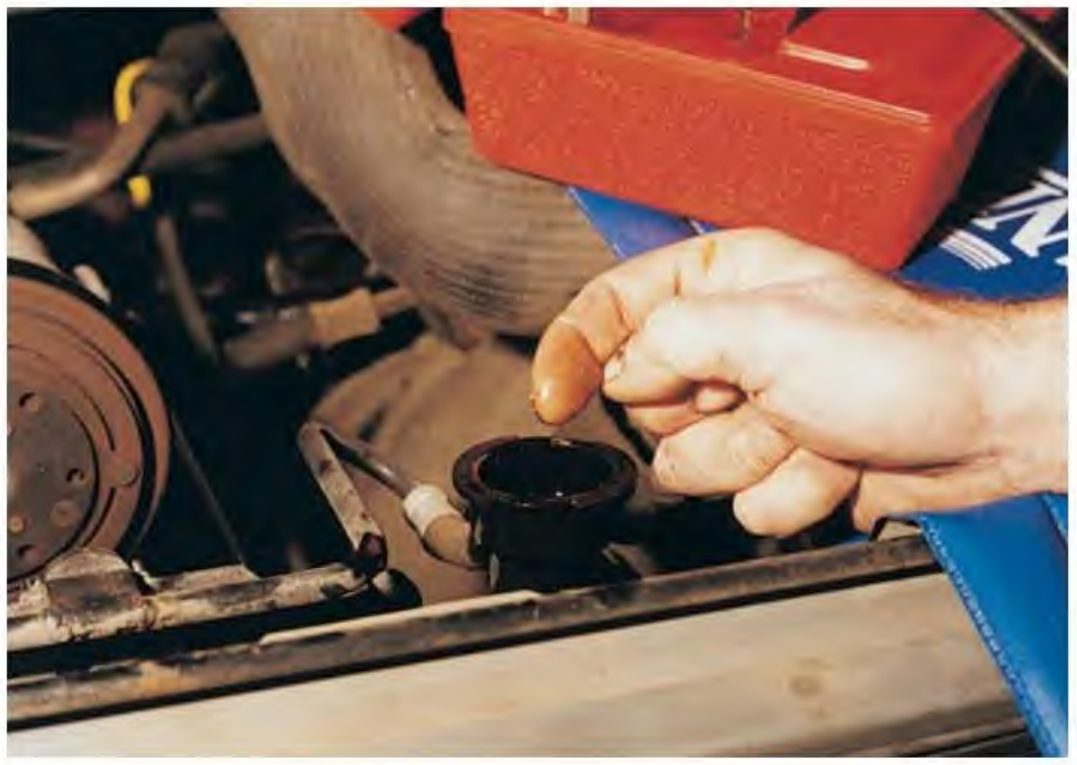
Coolant Service

The coolant, or antifreeze solution, should be checked and changed at regular intervals. After prolonged use, coolant will break down and become very corrosive. It can lose its rust preventative properties, and actually corrode the metal surface of the cooling engine. Rust will form and attempt to clog the small internal coolant passages in the radiator and heat core.

Visual Coolant Inspection

A visual inspection will help determine the coolant level and condition. Rub your finger inside the radiator filler neck or reservoir tank, **Figure 48-23**. Check for rust, oil (***internal engine leak***), scale, or transmission fluid (leaking oil cooler in radiator).

Check the coolant level during the visual inspection. With a closed system, coolant should be even with the appropriate marking on the reservoir when the coolant is at operating temperature. With an open system, the coolant level should be about 1″ (25 mm) below the top of the tank.



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Figure 48-23. To check for coolant contamination, wipe a finger inside the filler neck or reservoir tank. Badly rusted coolant requires replacement of coolant and possibly system flushing.

Coolant Voltage Testing

An old mix of antifreeze and water will become very acidic. If the coolant becomes too acidic, cooling system components can be etched and damaged. You can measure how acidic the solution is by performing a coolant voltage test. A ***coolant voltage test*** involves using a digital multimeter to measure the voltage generated by the antifreeze, which indicates the general age and condition of the antifreeze solution. It can be used with engine, supercharger, or hybrid cooling systems. Refer to **Figure 48-24**.



Snap-on Tool Corp.

Figure 48-24. To test coolant voltage, ground the black test probe and insert the red test probe into the coolant. The voltage reading indicates the acidity of the coolant.

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Service Procedure

To test coolant voltage:

1. When the system is cool, remove the radiator cap.
2. Touch the black multimeter test lead to any metal ground.
3. Dip the red multimeter test lead into the coolant.
4. Read the voltage generated by the coolant. The voltage of "good" coolant is almost zero, or less than 0.5 volts dc when measured coolant to ground. The voltage of "bad" coolant is any voltage reading above 0.5 volts dc, or one-half volt direct current across the coolant and a good metal ground.

If the solution generates a voltage above 0.5 volts, the antifreeze mixture should be drained and replaced immediately. In this case, the antifreeze has actually changed chemically into a weak battery acid that generates and conducts current into ground, causing electrolysis and further system corrosion. Additionally, sensors and control modules in the vehicle may be affected by this "stray" voltage.

Changing Coolant

Service Procedure

To change engine coolant:

1. When the system is cool, slowly remove the pressure cap.
2. Place a large, shallow catch pan under the radiator.
3. Loosen the drain plug on the bottom of the radiator tank.
4. Allow the old coolant to drain into the catch pan. Study the condition of the old coolant. If the coolant is acidic or filled with rust, you should flush (clean) the system before refilling it. If the coolant looks and smells okay, you can simply refill the system.
5. Pour the old antifreeze into a recycling drum. The old antifreeze can be sent out and reprocessed to avoid waste and environmental pollution.
6. Reinstall the lower radiator hose or tighten the radiator drain plug. To avoid part damage, do not overtighten the radiator drain plug. Just snug it down enough to prevent leakage.
7. Refill the cooling system. Pour the correct mix of antifreeze and water into the radiator filler neck.
8. Start and warm the engine with the radiator cap off. Allow the engine to run for about 5 minutes.
9. The coolant level may drop when the thermostat opens. Add more coolant until the liquid stays even with the filler neck.
10. Install the radiator or reservoir cap.
11. As the engine warms and pressurizes the cooling system, check for leaks at the lower radiator hose and drain plug before releasing the car to the customer.

Note the difference between checking closed and open cooling systems. If the system has a bleed screw, crack the screw open until all air is purged. As soon as coolant leaks out, tighten the fitting or screw.

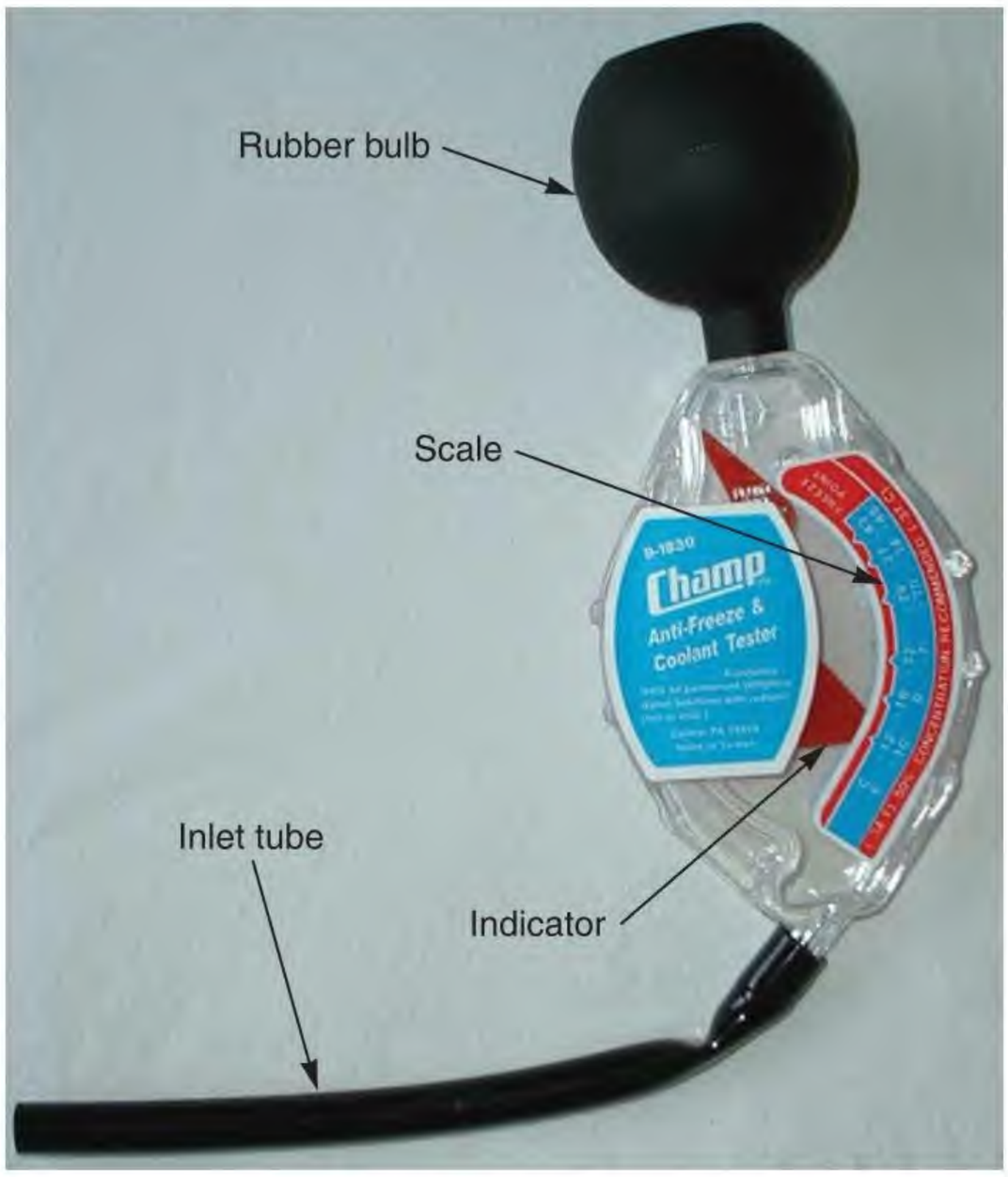
Tech Tip

Many shops use a coolant flushing machine when changing engine coolant. These machines drain, flush, and refill the system quickly and efficiently. More information on coolant flushing machines is presented later in this chapter.

Testing Coolant Strength

Coolant strength is a measurement of the coolant's antifreeze/water ratio. This ratio determines the freeze-up protection of the coolant. A ***cooling system hydrometer*** quickly measures the freezing point of the coolant. See **Figure 48-25**. Submerse the tester inlet tube in the coolant. Squeeze and release the tester bulb to fill the tester with coolant. Note the indicator reading on the tester. The freeze-up protection is noted in degrees. Add more antifreeze to the solution if freeze-up protection is too low.

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A



B

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Figure 48-25. A—A hydrometer is used to measure coolant strength. B—Draw coolant into the hydrometer and read the pointer or float.

Although seldom used anymore, a ***refractometer*** is another type of coolant strength measuring device. Draw coolant into the tester. Place a few drops of coolant on the measuring window (surface). Aim the tester at a light and view through the tester. The scale in the refractometer will show freeze protection.

Minimum Coolant Strength

Minimum coolant strength should be several degrees lower than the lowest normal temperature for the climate of the area. For example, if the lowest normal temperature for the area is –10°F (–23°C), the coolant should typically test to –20°F (–29°C).

A 50/50 mix of antifreeze and water is commonly used to provide protection for most weather conditions. For example, two gallons (7.6 L) of antifreeze is mixed with two gallons of water in a four-gallon cooling system.

Coolant Test Strips

Coolant test strips can be used to check coolant strength and pH level. To use a test strip, dip the reactive end of the strip into the antifreeze solution for approximately one second, making sure both test pads on the strip are submerged. After withdrawing the strip from the coolant, shake excess coolant from the strip and compare the color of test pads to the test strip manufacturer's color key. The color of the test pads will correspond to specific coolant strength and pH levels. Refer to **Figure 48-26**.

Tech Tip

Most test strip manufacturers recommend that you compare test pad color to specifications within one minute of removing the strip for the coolant. The pads may change color as they begin to dry, leading to inaccurate readings.

Corrosion of Aluminum

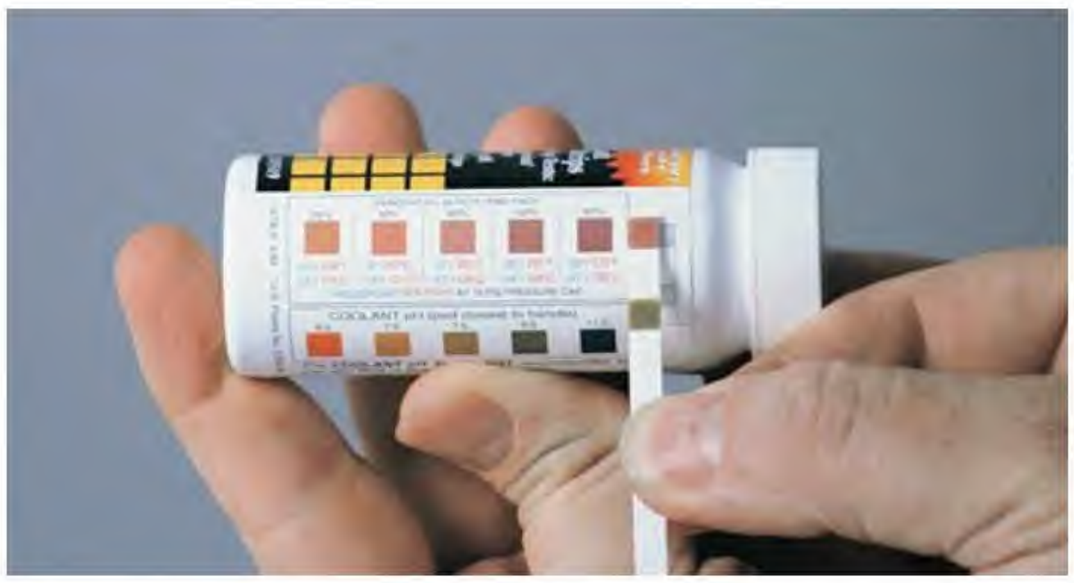
Many late-model vehicles use aluminum cooling system and engine parts. Radiators, water pumps, cylinder heads, blocks, and intake manifolds can be made of aluminum. Antifreeze designed for aluminum components must be used in these systems.

Aluminum can be corroded by some types of antifreeze. Check the vehicle's service manual or the antifreeze label for details. Most types of antifreeze are now "aluminum friendly."

Caution

The most common reason for cracked blocks and cylinder heads is improper antifreeze protection. If the water in a weak coolant solution freezes in cold weather, the ice will expand and break the engine block or cylinder heads.

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A



B

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Figure 48-26. Coolant test strips can be used to check coolant condition. A—Compare the top test pad to specifications to determine the coolant's strength. B—Compare the bottom test pad to specifications to determine the pH level of the coolant.

Flushing a Cooling System

Flushing (cleaning) a cooling system should be done when rust or scale is found in the system. Rust is very harmful to a cooling system. It can cause premature water pump wear. Rust and scale can also collect in and clog the radiator or heater core tubes. Flushing involves running fresh coolant or a cleaning chemical through the cooling system to remove contaminants.

To manually flush a cooling system, begin by draining the old coolant as explained previously. Then add a cooling system cleaning chemical to the system according to the chemical manufacturer's instructions and fill the radiator with water. Replace the radiator cap, start the engine, and set the heater controls to their hottest setting. Allow the car to run for 10–15 minutes and shut it off. After allowing the engine to cool, drain the contents of the cooling system into a container.

Next, refill the system with clean water and run the engine for another 10–15 minutes. Shut off the engine and allow it to cool. Drain the water from the cooling system. Finally, refill the cooling system with fresh coolant.

A ***coolant flushing machine*** automatically drains, flushes, and refills a car's engine cooling system. Most modern shops have one of these machines to speed repair and to reduce the consumption, waste, or improper disposal of antifreeze solution. Adapters are used to connect the coolant flushing machine to the vehicle, usually at the radiator neck and one radiator hose.

Refer to the coolant flushing machine's operating manual for specific instructions for hookup, coolant pump operation, and machine programming. Machine operation varies with manufacturer.

Many coolant flushing machines simply force new coolant through the system, displacing the old coolant. Some machines reverse flush the system. Reverse flushing involves forcing the new coolant through the system in the direction opposite that of normal flow.

Some coolant flushing machines use a chemical cleaning agent to help dissolve and wash out contaminants. These machines pull all the old coolant out of the vehicle and route the used coolant to a storage tank. The machine then reverse flushes the system using the cleaning agent.

After flushing, the machine pulls out the cleaning agent and refills the cooling system with fresh coolant. Some flushing machines have a recycling option. These machines process the used coolant and return it to the system.

Warning

Always follow manufacturer's instructions when using a cooling system cleaning agent. The chemical may cause eye and skin burns. Wear rubber gloves and full face protection.

Temperature Gauge Service

A defective temperature gauge may read hot or cold when the engine is actually at its proper operating temperature. The customer may complain that the gauge always reads cold or hot, or that the gauge pointer moves erratically.

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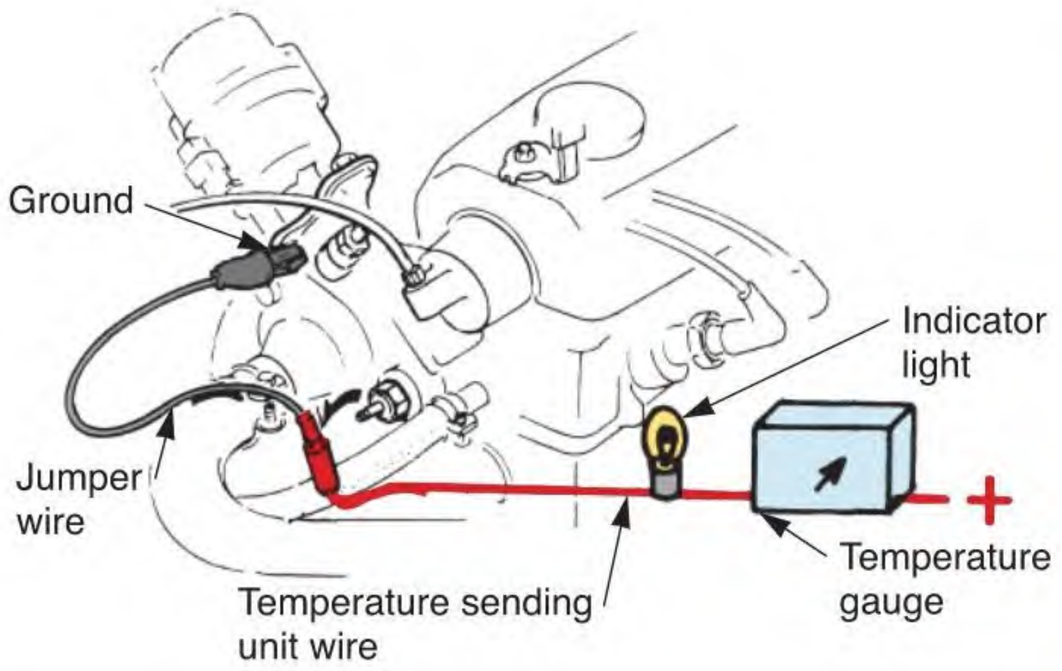
Service Procedure

The procedure for quickly testing a temperature gauge is shown in **Figure 48-27**.

1. Disconnect the wire going to the temperature gauge sending unit. The sending unit is normally located on the engine.
2. Using a jumper wire, ground the gauge wire to the engine block.
3. Turn the ignition key switch on and watch the temperature gauge. It will normally swing to hot (cause the indicator light to glow) when the wire is grounded. It should return to cold when the wire is ungrounded.

If the gauge begins to function when grounded, the sending unit is defective and should be replaced. If the gauge does not function when grounded, either the gauge circuit or the gauge is faulty.

A ***gauge tester*** can also be used to check gauge and sending unit operation. It is a special testing device with a variable resistor. To test a temperature indicating light, set the tester to a specified resistance and the temperature gauge should read as specified. The light should glow when the sending unit wire is grounded. It should go out when the wire is ungrounded.



Honda

Figure 48-27. To check the action of a temperature gauge or indicator light, you can ground the wire to the temperature sending unit. This should cause the gauge to read hot or cause the light to glow. If not, the circuit before the sending unit is faulty. If the gauge or light functions, the sending unit may be bad.

Caution

If available, use a gauge tester to check gauge and sending unit operation. Some temperature gauges could be damaged by grounding the sending unit wire. If wired to the ECM, it would be safer to use a variable resistor to ground the sending unit. Then, you can slowly lower ground resistance so as to not overload the ECM.

Supercharger Coolant Service

Many factory superchargers have a separate cooling system, independent of the engine cooling system. Service methods are the same, but supercharger cooling systems often operate at much lower pressures and temperatures. Study **Figure 48-28**. Never



A



B

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Figure 48-28. A—Check the level and condition of the intercooler coolant. B—Pressure testing the intercooler system.

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exceed the radiator cap or reservoir pressure limits when hand-pressure-testing these systems.

Hybrid Cooling System Service

Hybrid cooling system service is very similar to servicing an engine cooling system. However, instead of a belt-driven water pump, hybrid cooling systems use a small electric water pump to circulate antifreeze through the HV battery heat exchanger, and sometimes the HV motor-generator and the HV PCM. Air circulation by electric fans also helps reduce operating temperatures of the HV battery and 3-phase, high-voltage ac circuitry for the electric powertrain in hybrid vehicles.

Some hybrid battery packs have an electric fan that blows air over the battery packs to cool them. Refer to **Figure 48-29**. Other hybrid cooling systems use air and liquid cooling.

Check the hybrid cooling system for:

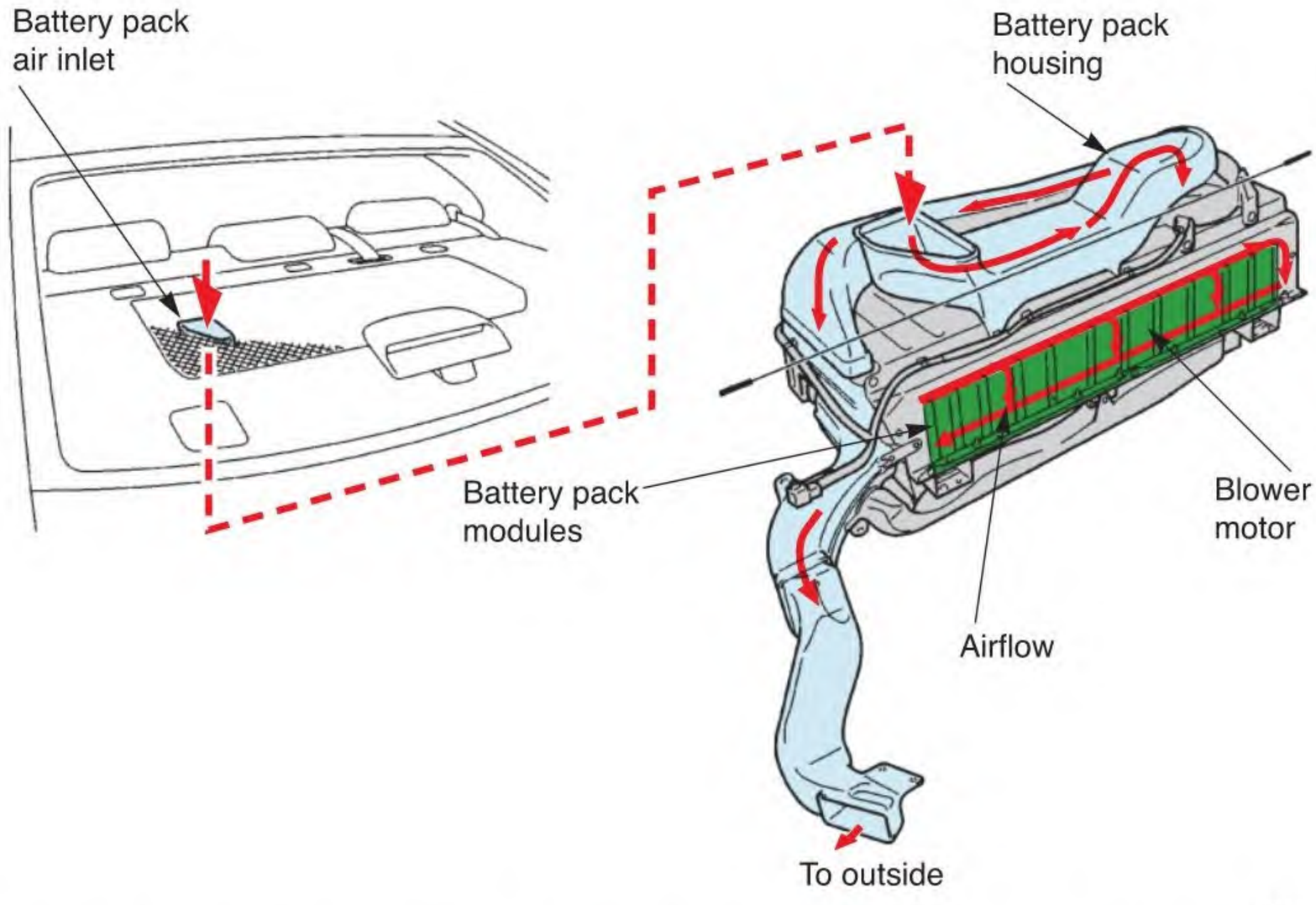
- Proper coolant level in the HV coolant reservoir.
- Obstructions of the inlet and outlet air ducts to the HV battery. The vehicle owner may inadvertently place objects over the passenger compartment air intake vent. Ductwork can also be damaged and restricted during a collision.
- Proper scan tool temperature readings for the HV battery, HV motor-generator, and HV PCM.
- Proper operation of sensors and automatic fans that should turn on when battery current load is high.
- Blower motor circuit problems or mechanical problems. If the fan comes loose from the blower motor, it will not set a trouble code but it may be noisy.
- Leaks by performing pressure test.
- Acid deterioration by performing voltage test.
- Normal electric coolant pump operation.

Any of these could potentially increase HV battery temperature enough to trip an OBD trouble code in the dash.



Diagnostic Case Study

Concern: A customer brings in his 2006 LaCrosse, complaining of engine overheating. The temperature light in the dash is illuminated and steam is escaping from under the hood.



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Figure 48-29. Air cooling is used to remove heat from the battery pack. A blower pulls air from the passenger compartment, routes the air over the battery pack, and then forces the heated air to the outside of the vehicle.

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Cause: Duff waits for the engine to cool down and then checks the coolant level. He starts the engine and lets it run. The pump belt is intact, and the pump makes no odd noises. He tells the customer that further testing will be needed to pinpoint the problem and turns the repair over to one of the shop's service technicians.

The technician pressure checks the system, but does not find any leaks. The radiator cap also tests good. Since the water pump is turning and no leakage is found, the symptoms point to the thermostat.

The technician removes the thermostat from its housing. She tests the thermostat by suspending it in a container of water and raising the water temperature to the thermostat's rating. The thermostat fails to open at its rated temperature.

Correction: The technician installs a new thermostat with the correct temperature rating, as well as a new gasket. She makes sure to torque the thermostat housing bolts to specifications. After installing the new thermostat, the technician starts the engine and lets it run. The coolant temperature climbs to normal operating temperature, and then holds steady.

Summary

- Cooling systems remove heat produced by engine combustion and electrically-generated heat.
- To troubleshoot a cooling system, gather information from the vehicle owner, review on-board diagnostic trouble codes, reference cooling system diagnosis charts, and perform a visual inspection of the system.
- Coolant system problems typically involve, coolant leaks, overheating, or overcooling.
- Overcooling may be indicated by slow engine warm-up, insufficient warmth from the heater, low fuel economy, sluggish engine performance, or a low reading from the coolant temperature sensor.
- A bad water pump may leak coolant, fail to circulate coolant, or produce a grinding sound.
- A stuck thermostat can cause either engine overheating or engine overcooling.
- Air trapped in the cooling system can cause engine overheating or damage to the parts near the air pocket and hot spot.
- Hardened cooling system hoses become very brittle and crack from engine vibration.
- A softened cooling system hose is weakened and will usually swell, which can result in a rupture and leak.
- Radiator shops have the facilities to properly disassemble, clean, solder, adhesive bond, reassemble or repair, and pressure test any radiator.
- A loose fan belt will slip and squeal, and may rotate the water pump and fan too slowly.
- A faulty engine fan can cause overheating, overcooling, vibration, and water pump damage.
- Visual inspection and basic tests will help determine the coolant level and condition.
- A 50/50 mix of antifreeze and water is commonly used to provide protection for most weather conditions.
- Flushing (cleaning) of a cooling system should be done when rust or scale is found in the system.
- A defective temperature gauge may read hot or cold when the engine is actually at its proper operating temperature.
- Supercharger cooling systems often operate at much lower pressures and temperatures than engine cooling systems.
- Hybrid cooling systems may use liquid cooling, air cooling, or both, and are serviced similarly to an engine cooling system.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

belt tension gauge
bleed valve
block and head tester
block tester
combustion leak test
combustion leak tester
coolant flushing machine
coolant strength
coolant test strips
coolant voltage test
cooling system bleed screw
cooling system diagnosis chart
cooling system hydrometer
cooling system pressure test
core plug
expansion freeze plugs
flushing
freeze plug

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gauge tester
hot spot
internal engine leak
overcooling
overheating
pressure tester
radiator cap pressure test
refractometer
thermostat housing
thermostat housing seal

Activities

1. Obtain a cooling system thermostat and test it for proper opening at its rated temperature using a pan of water and stove or hot plate.
2. Demonstrate the use of a hydrometer to test coolant strength. If a refractometer is available, demonstrate its use as well.

Review Questions

Answer the following questions using the information provided in this chapter.

1. An engine can still operate for an extended period without a cooling system. True or False?
2. List seven items to look for when performing a visual inspection on a cooling system.
3. Why should you stand to one side of a spinning engine fan?
4. What can happen if you remove a radiator cap with the coolant at operating temperature?
5. A(n) _____ test checks for the presence of combustion gases in the engine coolant, indicating an engine problem.
6. Coolant that leaks into engine oil can collect and burn on cylinder walls, causing _____ gumming and scoring.
   (A) oil pan
   (B) piston and cylinder
   (C) connecting rod
   (D) camshaft
7. A cooling system _____ test uses a hand-operated air pump to find leaks in the system.
8. List and explain five common causes of engine overheating.
9. Air trapped in the cooling system could create undesirable areas of combustion heat buildup in the engine called _____.
   (A) hot spots
   (B) freeze plugs
   (C) nest spots
   (D) purge zones
10. A customer complains of sluggish engine performance and a lack of adequate warmth from the heater. Technician A says that this may not be caused by the cooling system. There may be separate problems with the engine and heating system. Technician B says that a missing or stuck open thermostat might cause these symptoms. The thermostat should be checked first before checking other possible components. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
11. How do you replace an engine freeze plug?
12. If the results of a coolant voltage test measure almost zero, or less than _____ volts dc when measured coolant to ground, the coolant is considered "good."
    (A) 8.75
    (B) 10.5
    (C) 5.0
    (D) 0.5
13. A cooling system should be _____ when rust or scale is found in the system.
14. A(n) _____ is used to measure the freezing point of cooling system coolant.
    (A) voltmeter
    (B) hydrometer or refractometer
    (C) analyzer probe
    (D) temperature gauge
15. How can you quickly determine if a dash temperature gauge is functioning?

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ASE-Type Questions

1. Which of the following is *not* a common indicator that an engine is overheating?
   (A) Boiling coolant.
   (B) Slow engine warm-up.
   (C) Glowing temperature light.
   (D) High temperature gauge reading.
2. A cooling system pressure tester is a(n):
   (A) electric tester bulb.
   (B) leak detecting fluid.
   (C) hand-operated air pump.
   (D) None of the above.
3. Overcooling may be caused by each of these *except*:
   (A) ice in coolant.
   (B) stuck thermostat.
   (C) locked fan clutch.
   (D) shorted electric fan switch.
4. When water, antifreeze, and oil mix, it turns:
   (A) pale yellow.
   (B) milky white.
   (C) transparent.
   (D) rusty brown.
5. A bad water pump may:
   (A) leak coolant.
   (B) fail to circulate coolant.
   (C) produce a grinding sound.
   (D) All of the above.
6. While discussing thermostat service, Technician A says a stuck thermostat can cause engine overheating. Technician B says a stuck thermostat can cause engine overcooling. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. Each of these is a hose problem that may affect cooling system performance *except*:
   (A) shrinking.
   (B) swelling.
   (C) cracking.
   (D) hardening.
8. A radiator shop will properly:
   (A) solder a radiator.
   (B) rod out a radiator.
   (C) disassemble a radiator.
   (D) All of the above.
9. A faulty engine fan may cause each of these engine problems *except*:
   (A) revving.
   (B) vibrating.
   (C) overcooling.
   (D) overheating.
10. Technician A says a 50/50 mix of antifreeze and water is commonly used to provide protection for most weather conditions. Technician B says that minimum coolant strength should be several degrees lower than the lowest normal temperature for the climate of the area. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Cooling System Diagnosis

Condition	Possible Causes	Correction
Temperature gauge reads low.	1. Thermostat is stuck open. 2. Temperature gauge is not connected to the coolant sensor. 3. Faulty temperature gauge. 4. Coolant level low during cold ambient temperature.	1. Replace thermostat if necessary. 2. Check the connector at the engine coolant sensor. Repair as necessary. 3. Check gauge operation. Repair as necessary. 4. Check coolant level in the overflow tank and at the radiator. Inspect the system for leaks. Repair as necessary.
Temperature gauge reads high or engine coolant warning lamp illuminates. Coolant may or may not be lost from system.	1. Trailer being towed, steep hill being climbed, vehicle being operated in slow moving traffic, or engine idling during high ambient temperatures with air conditioning on. High altitudes can aggravate these conditions. 2. Faulty temperature gauge. 3. Temperature warning lamp illuminating unnecessarily. 4. Low coolant in overflow/ reserve tank and radiator. 5. Pressure cap not installed tightly. 6. Poor seals at radiator cap. 7. Coolant level low in radiator, but not in coolant overflow/ reserve tank. This means the radiator is not drawing coolant from the coolant overflow/reserve tank as the engine cools. 8. Freeze point of coolant not correct. Mixture may be too rich. 9. Coolant not flowing through system. 10. Radiator or A/C condenser fins are dirty. 11. Radiator core is plugged or corroded. 12. Fuel or ignition system problems. 13. Dragging brakes. 14. Bug screen is being used, causing reduced airflow. 15. Thermostat partially or completely shut. 16. Electric cooling fan not operating properly. 17. Cylinder head gasket leaking. 18. Heater core leaking.	1. This may be a temporary condition and repair is not necessary. Turn off the air conditioning and drive the vehicle without any of the previous conditions. The gauge should return to the normal range. If the gauge does not return to the normal range, determine the cause of overheating and repair. 2. Check gauge. Repair as necessary. 3. Check warning lamp operation. Repair as necessary. 4. Check for cooling leaks and repair as necessary. 5. Tighten cap. 6. (a) Check condition of cap and cap seals. Replace cap, if necessary. (b) Check condition of filler neck. If neck is bent or damaged, replace neck. 7. (a) Check condition of radiator cap and cap seals. Replace cap, if necessary. (b) Check condition of filler neck. If neck is damaged, replace filler neck. (c) Check condition of hose from filler neck to coolant tank. It should be tight at both ends without any kinks or tears. Replace hose, if necessary. (d) Check coolant overflow/ reserve tank and tank hoses for blockage. Repair as necessary. 8. Check coolant. Adjust mixture as required. 9. Check for coolant flow. If flow is not observed, determine reason for lack of flow and repair as necessary. 10. Clean insects or debris from fins. 11. Replace or re-core radiator. 12. Check systems and repair as necessary. 13. Inspect brake system and repair as necessary. 14. Remove bug screen. 15. Check thermostat operation and replace as necessary. Refer to thermostats in this group. 16. Check electric fan operation and repair as necessary. 17. Check cylinder head gasket for leaks. Repair as necessary. 18. Check heater core for leaks. Repair as necessary.

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Cooling System Diagnosis

Condition	Possible Causes	Correction
Temperature gauge reading is inconsistent (fluctuates, cycles, or is erratic).	1. Temperature gauge or engine-mounted gauge sensor defective or shorted. Also, corroded or loose circuit wiring. 2. Coolant level low in radiator (air will build up in the cooling system causing the thermostat to open late). 3. Cylinder head gasket leaking, allowing exhaust gas to enter cooling system and causing thermostat to open late. 4. Water pump impeller loose on shaft. 5. Loose accessory drive belt (water pump slipping). 6. Air leak on the suction side of water pump allows air to build up in cooling system. This causes thermostat to open late.	1. Check operation of gauge and repair as necessary. 2. Check and correct coolant leaks. 3. (a) Check for cylinder head gasket leaks with a commercially available Block Leak Tester. Repair as necessary. (b) Check for coolant in the engine oil. Inspect for white steam emitting from exhaust system. Repair as necessary. 4. Check water pump and replace as necessary. 5. Check belts and correct as necessary. 6. Locate leak and repair as necessary.
Pressure cap is blowing off steam and/or coolant to coolant tank. Coolant level may be high in coolant overflow tank.	1. Pressure relief valve in radiator cap is defective.	1. Check condition of radiator cap and cap seals. Replace cap as necessary.
Coolant loss to the ground without pressure cap blowoff. Gauge is reading high.	1. Coolant leaks in radiator, cooling system hoses, water pump, or engine.	1. Pressure test and repair as necessary.
Detonation or preignition (not caused by ignition system). Gauge may or may not be reading high.	1. Engine overheating. 2. Freeze point of coolant not correct. Fuel mixture is too rich or too lean.	1. Check reason for overheating and repair as necessary. 2. Check the freeze point of the coolant. Adjust the glycol to water ratio as required.
Hose or hoses collapse when engine is cooling.	1. Vacuum created in cooling system on engine cool-down is not being relieved through coolant reserve/overflow system.	1. (a) Radiator cap relief valve stuck. Replace cap, if necessary. (b) Hose between coolant reserve/overflow tank and radiator is kinked. Repair as necessary. (c) Vent at coolant reserve/overflow tank is plugged. Clean vent and repair as necessary. (d) Overflow tank is internally blocked or plugged. Check for blockage and repair as necessary.
Electric radiator fan runs all the time.	1. Defective fan relay, control module, or engine coolant temperature sensor. 2. Low coolant level.	1. Repair as necessary. 2. Add coolant to appropriate level.
Electric radiator fan will not run. Gauge reading high or hot.	1. Fan motor defective. 2. Fan relay, powertrain control module (PCM), or engine coolant temperature sensor defective. 3. Blown radiator fan fuse.	1. Test motor and repair as necessary. 2. Test components and repair as necessary. 3. Determine reason for blown fuse and repair as necessary.

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Maintaining the proper level of clean oil is essential for engine longevity. Engine oil reduces friction, carries contaminants away from critical parts, and helps to cool the engine.

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Chapter 49
Lubrication System Fundamentals

After studying this chapter, you will be able to:

- List the basic parts of a lubrication system.
- Summarize the operation of a lubrication system.
- Describe the construction of lubrication system parts.
- Compare different lubrication system designs.
- Explain the characteristics and ratings of engine oil.
- Describe the lubrication system parts used to monitor system conditions and alert of problems.
- Explain how engine oil pressure is used to control camshaft timing and cam lobe actuation and the resulting engine valve lift.
- Correctly answer ASE certification test questions that require a knowledge of lubrication system construction and operation.

The engine ***lubrication system*** forces motor oil to high friction points between metal contact surfaces in the engine to protect them from damage. Pressure oiling is critical to the engine service life and dependability. Many high-performance gasoline engines and most diesel engines also have an oil cooling system to remove friction-generated heat from the lubricating oil.

Without a lubrication system, friction between rapidly moving, heavily loaded parts would destroy an engine in a matter of minutes. Many engine parts would quickly overheat and score or partially melt from this friction. Engine bearings, piston rings, cylinder walls, and other parts could be ruined. Without circulating engine oil, engine parts will lock up or weld together and the crankshaft will no longer rotate freely.

Some engines now have an integral oil/water/power steering combined into one large assembly. Therefore, it is critical that you understand the design and construction of engine lubrication systems.

Lubrication System Functions

Engine design and the properties of engine oil allow the lubrication system to accomplish the following functions:

- Reduce friction and wear between moving parts.
- Help transfer heat away from engine parts.
- Clean the inside of the engine by removing contaminants (metal, dirt, plastic, rubber, and other particles).
- Cut power loss and increase fuel economy.
- Prevent internal engine parts from rusting and corrosion.
- Absorb shocks between moving parts to quiet engine operation and increase engine life.

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Lubrication System Operation

A lubrication system consists of the following components:

- Engine oil—***Engine oil*** is the lubricant for moving parts in an engine.
- Oil pan—The ***oil pan*** is a reservoir or storage area for engine oil.
- Oil pump—The ***oil pump*** forces oil through all passages inside of the engine.
- Pressure relief valve—The ***pressure relief valve*** limits maximum oil pump pressure.
- Oil filter—The ***oil filter*** strains out impurities in the oil.
- Oil galleries—***Oil galleries*** are oil passages through the engine.

With the engine running, the oil pump pulls engine oil out of the oil pan. Before oil enters the pump, a screen on the pickup tube removes large particles from the oil. The oil pump then pushes the oil through the oil filter and oil galleries.

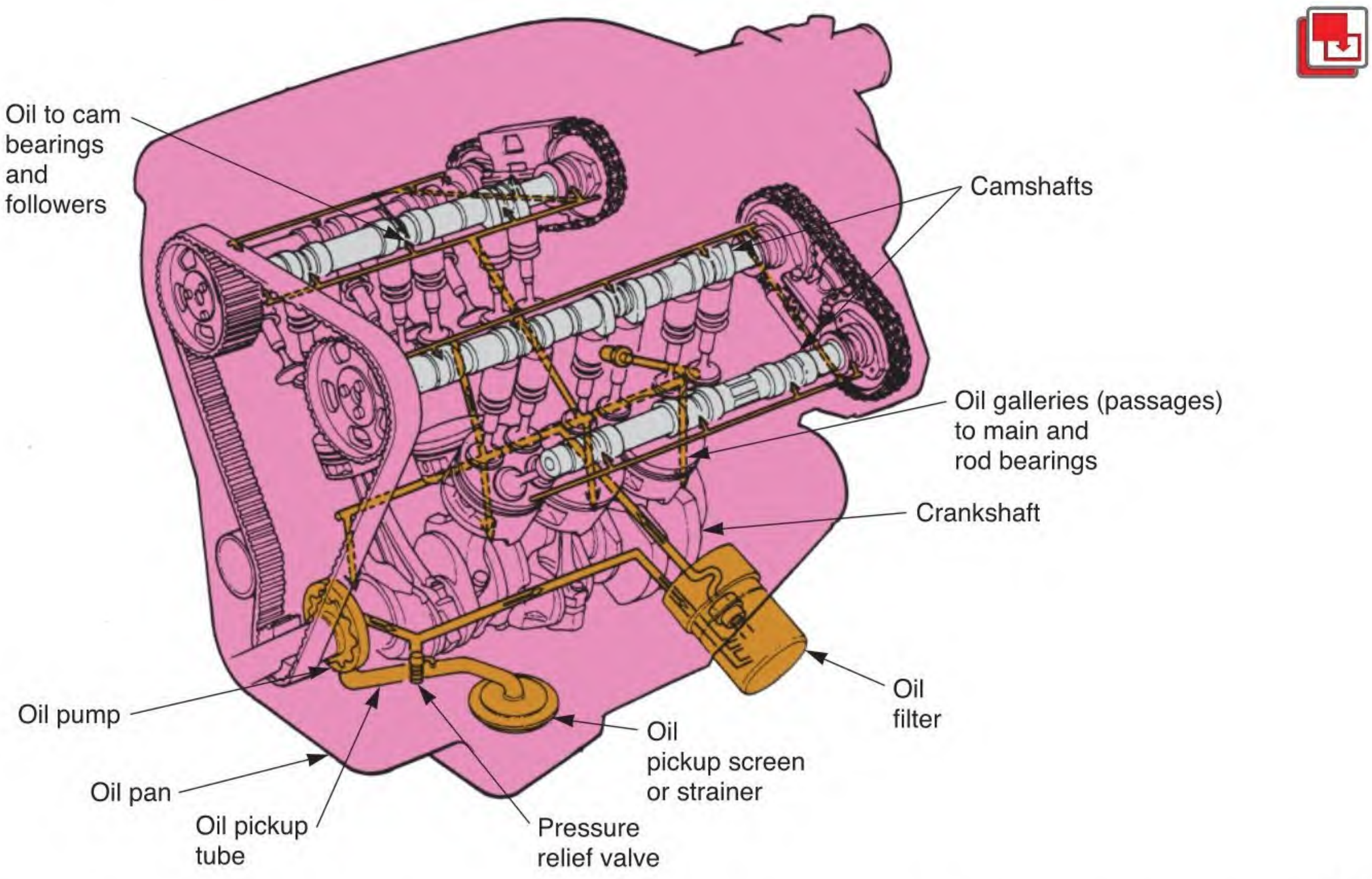
The oil filter cleans the oil, removing very small particles. The filtered oil then flows to the camshaft, crankshaft, balancer shafts, lifters, rocker arms, and other moving parts. See **Figure 49-1**.

When oil leaks out of the engine bearings, it sprays on the outside of internal engine parts. For example, when oil leaks out of the connecting rod bearings, it sprays on the cylinder walls. This lubricates the piston rings, pistons, wrist pins, and cylinders. Oil is also pumped through the cylinder head gaskets to the valve train. Gravity causes the oil to flow back down into the oil pan for recirculation.

Engine Oil

Engine oil, also called ***motor oil***, is needed to keep moving parts in an engine from making direct contact with each other. Its main purpose is to reduce friction. Engine oil is commonly refined from petroleum (crude oil), which is extracted from deep within the earth.

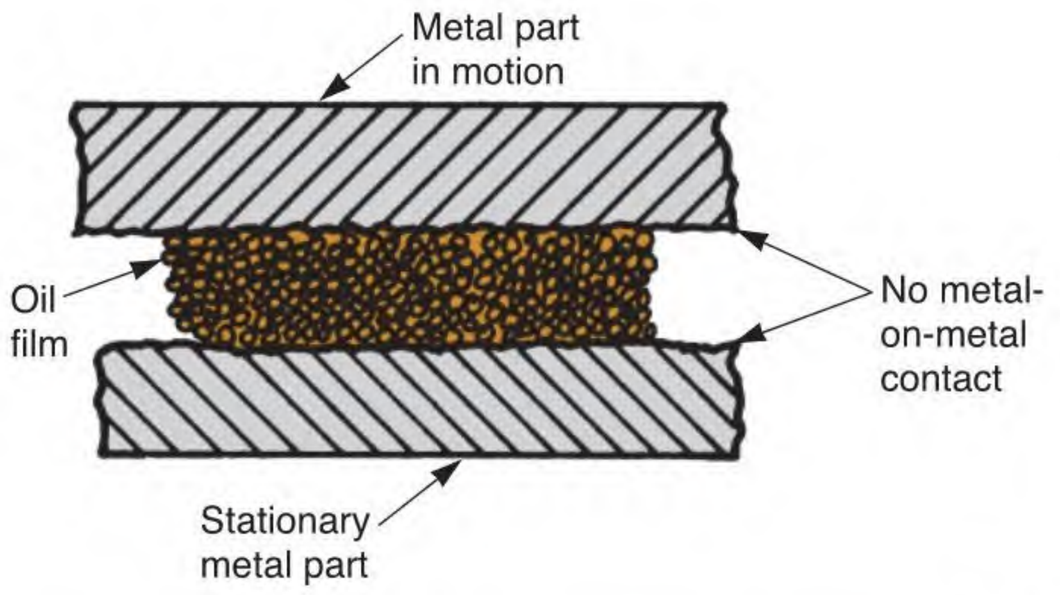
An oil film (thin layer of oil) separates engine parts to prevent metal-on-metal contact. Without the oil film, the parts would rub together and wear rapidly. See **Figure 49-2**.



Ford

Figure 49-1. Study the basic parts of a typical lubrication system. Trace the flow of oil from the pan through the engine.

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Chrysler

Figure 49-2. Close-up view of the clearance between moving parts shows how an oil film keeps parts from touching and rubbing together. The oil film separates parts to prevent friction and wear.

As discussed previously, most engine oils are made by processing and refining crude oil. Engine oils are then mixed with oil additives.

Synthetic oils are manufactured by further processing and blending crude mineral oils together with about 25% more synthesized (modified) mineral oils. Especially in extreme cold weather, synthetic oils can provide better performance than conventional motor oils because they contain engine-protecting additives. Synthetic oils can also provide longer service life, less friction, and better fuel economy than conventional oil. However, synthetic oil normally costs more than regular motor oil.

Bio-based oils, especially vegetable-based motor oils, are being developed as more environmentally friendly lubricating products. Purdue University has funded a project to develop and test such "true synthetic oils." Experimentation with metal additives shows bio-based oils to be equal to crude or mineral oil in performance and superior in reducing carbon emissions.

Oil additives increase the protective properties of mineral, vegetable, or synthetic motor oil. After oil is refined, various chemicals are added to improve hot and cold characteristics. The following are common oil additives and their functions:

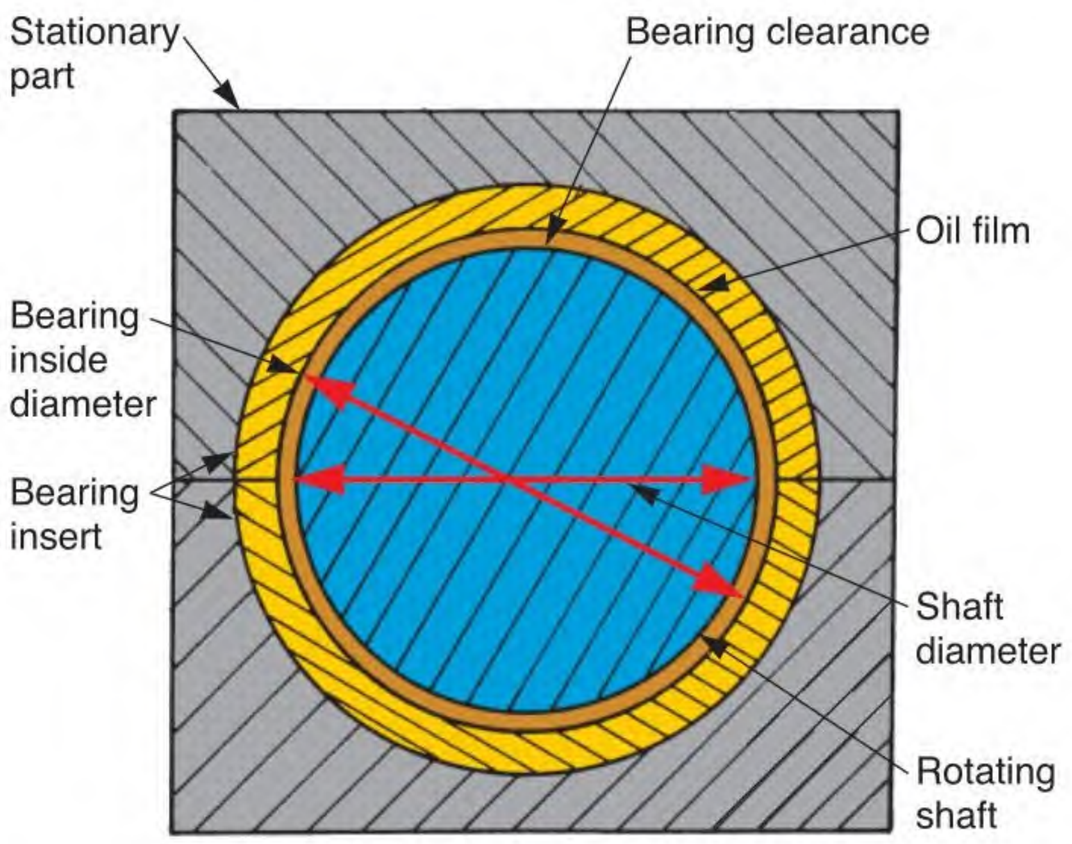
- Detergent/dispersants—Contaminants are suspended in the oil until they can be trapped in the filter or removed when the oil is changed.
- Rust and corrosion inhibitors—Metal engine parts are protected by the formation of a barrier film between the parts and their environment.
- Foam depressants—Oil foaming is prevented.
- Wear preventers—Microscopic metal particles added to mineral oil coat and seal metal surfaces.
- Pour point depressants—Low-temperature fluidity is improved.

In particular, ***phosphorous additives*** are used as a cleaning agent in motor oil to carry oil impurities to the oil filter. ***Metal additives***, such as zinc or titanium, are now added to motor oil to reduce part wear by coating internal engine parts with zinc or titanium film. Since metal has a high heat tolerance, additives aid in engine heat removal and burn resistance, and reduce carbon buildup on engine parts. The tiny metal particles actually coat the metal surfaces of engine parts with a film to limit surface wear.

Oil Clearance

Oil clearance, or bearing clearance, is the small space between moving engine parts for the lubricating oil film. The clearance allows oil to enter the bearing to prevent part contact. See **Figure 49-3**.

For example, a connecting rod bearing typically has an oil clearance of about 0.002″ (0.05 mm). This clearance is large enough to allow oil entry between the moving and the stationary parts of an engine. However, it is also small enough to keep the parts from "hammering together" and knocking during engine operation (reciprocating action). The layer of oil inside the small bearing clearance acts as a hydraulic shock absorber. The thick oil cushions and quiets moving engine parts. Without oil filling the bearing clearance, a dry rod bearing will start knocking and damaging itself very quickly.



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Figure 49-3. Oil clearance, also called bearing clearance, allows the oil film to hold the spinning shaft away from the stationary part.

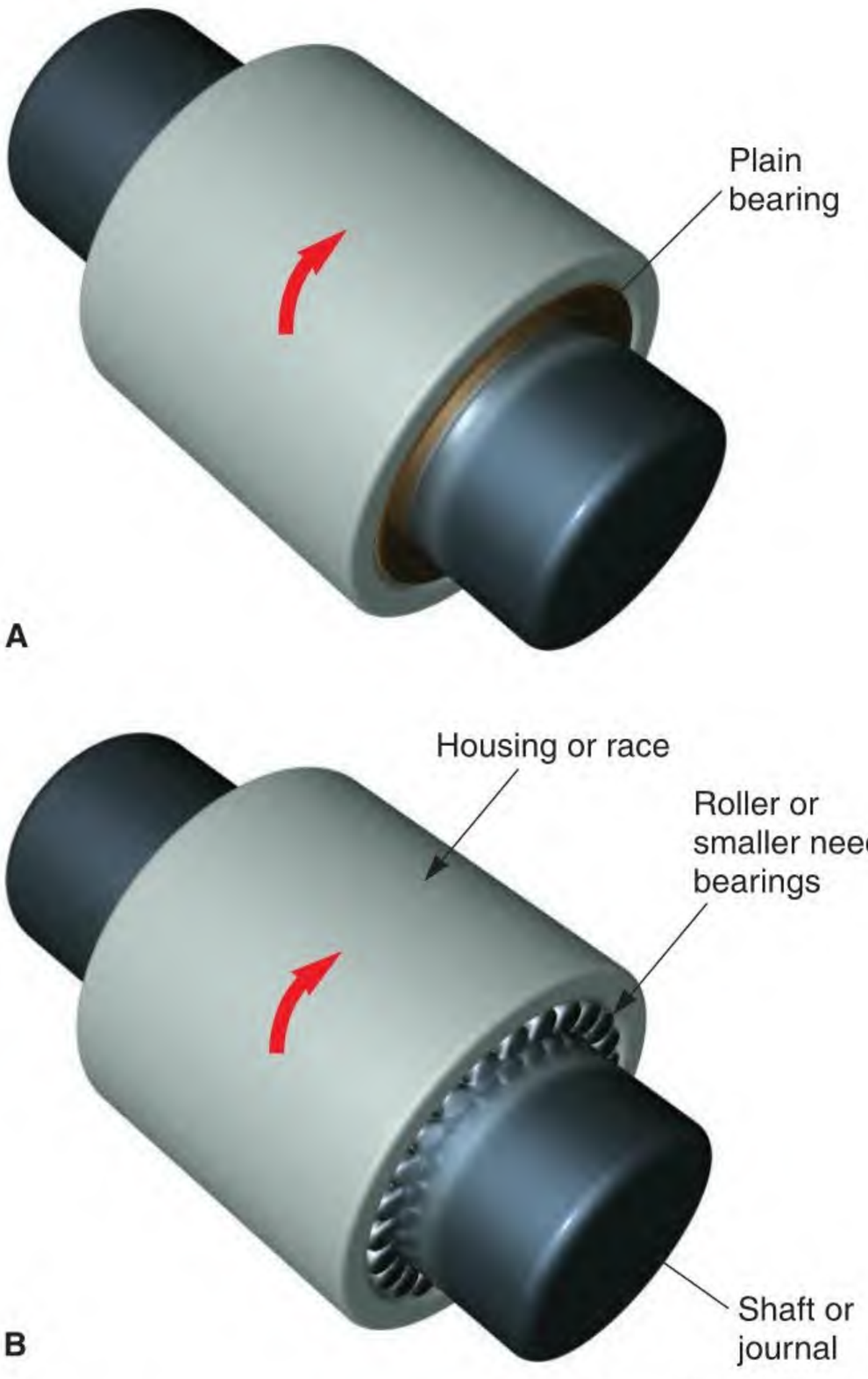
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Tech Tip

If an engine is started without oil inside its oil pan, the engine will start and run fine. However, after the oil is hammered out of the bearings, the engine connecting rods and crankshaft will hit metal on metal. The engine rods will start knocking loudly in a matter of seconds, signaling no oil pressure. This knocking can destroy connecting rod bearings in a matter of minutes.

Bearing Types

There are two basic types of engine bearings: friction bearings and antifriction bearings, **Figure 49-4**.



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Figure 49-4. Compare basic bearing types. A—A friction bearing has two smooth surfaces sliding together. B—An antifriction bearing uses balls or rollers to prevent sliding (rubbing) action.

Each type can be used in many automotive assemblies besides engines.

A ***friction bearing***, or plain bearing, has two smooth surfaces that slide on each other. It is the most common type of bearing used in an engine.

Crankshaft main bearings, connecting rod bearings, and cam bearings are normally friction bearings. They require a constant supply of oil under pressure for proper service life.

An ***antifriction bearing*** uses balls or rollers to avoid a sliding action between the bearing surfaces. Antifriction bearings are only used in a few places in an engine.

A good example of an engine antifriction bearing is a roller lifter in a diesel engine. The roller cuts high friction and wear between the camshaft lobe and the bottom of the lifter.

Antifriction bearings do not require as much lubrication as friction bearings. Usually, splash oiling is sufficient.

Oil Viscosity (Weight)

Oil viscosity, also called ***oil weight***, is the thickness or fluidity (flow ability) of the engine oil. A high viscosity oil is very thick and resists flow. A low viscosity oil is thin and flows easily.

A viscosity numbering system is used to rate the thickness of engine oil. A high viscosity number indicates relatively thick oil. A lower viscosity number denotes a thinner oil. Look at **Figure 49-5**.

The oil's ***viscosity number*** is printed on the oil container. The SAE (Society of Automotive Engineers) standardized this numbering system. For this reason, oil viscosity is written SAE 10, SAE 20, SAE 30, etc.

Engine oil viscosity commonly ranges from a thin SAE 10 weight to a thick SAE 50 weight. Auto manufacturers recommend a specific SAE viscosity for oil used in their engines.

Temperature Effects on Oil

Cold engine motor oil is very thick and resists flow. When heated, oil thins and becomes runny. This can pose a problem. The oil in a cold engine may be so thick that engine starting is difficult. The oil will not pump through the engine properly. This may increase starting motor drag and result in poor lubrication.

As engine oil heats up, it tends to become thinner and less resistant to flow. If it becomes too hot and thin, the oil film can break down and part contact can result.

It is important that the oil be thin enough for easy starting but thick enough to maintain lubrication when hot. Refer to **Figure 49-6**.

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API® Service Symbol **API® Certification Mark**

1. Performance Level:
Gasoline engine oil categories (for cars, vans, and light trucks with gasoline engines): Oils designed for gasoline-engine service fall under API's "S" (**S**ervice) categories. Look for current service categories SL and SJ. See reverse for descriptions of current and obsolete API service categories.

Diesel engine oil categories (for heavy-duty trucks and vehicles with diesel engines): Oils designed for diesel-engine service fall under API's "C" (**C**ommercial) categories. Look for current categories CI-4, CH-4, CG-4, CF-4, CF-2, and CF.

2. Viscosity: The measure of an oil's thickness and ability to flow at certain temperatures.

3. Fuel Economy Rating: The "Energy Conserving" rating applies to oils intended for gasoline-engine cars, vans, and light trucks. Widespread use of "Energy Conserving" oils may result in an overall savings of fuel in the vehicle fleet as a whole.

4. API Certification Mark: An oil displaying this mark meets the current engine protection standard and fuel economy requirements of the International Lubricant Standardization and Approval Committee (ILSAC), a joint effort of U.S. and Japanese automobile manufacturers. Most automobile manufacturers recommend oils that carry the API Certification Mark.

Guide to SAE Grades of Motor Oil for Passenger Cars

Multigrade oils such as SAE 5W-30 and 10W-30 are widely used because, under all but extremely hot or cold conditions, they are thin enough to flow at low temperatures and thick enough to perform satisfactorily at high temperatures. **Note that vehicle requirements may vary. Follow your vehicle manufacturer's recommendations on SAE oil viscosity.**

If lowest expected outdoor temperature is	Typical SAE Viscosity Grades for Passenger Cars
0°C (32°F)	5W-20, 5W-30, 10W-30, 10W-40, 20W-50
–18°C (0°F)	5W-20, 5W-30, 10W-30, 10W-40
Below –18°C (0°F)	5W-20, 5W-30

Reproduced courtesy of the American Petroleum Institute from the 2002 API Motor Oil Guide

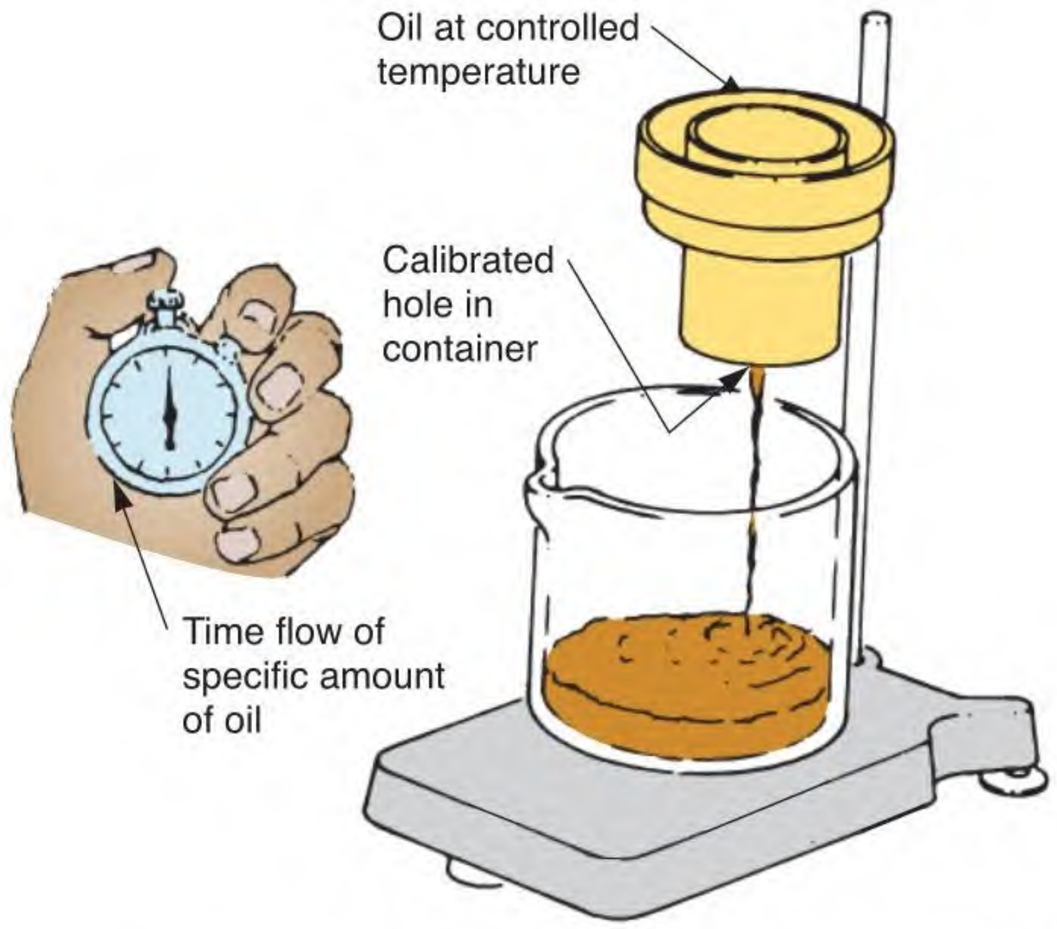
Figure 49-5. The API service symbol and certification mark identify the performance level, viscosity, and fuel economy rating.

Single-Viscosity and Multiviscosity Oils

Single-viscosity oil is rated and designed for a limited range of operating temperatures. Its viscosity is not as stable as multiviscosity oils. Examples of single-viscosity oils include SAE 20, SAE 30, and SAE 40 weight.

Multiviscosity oil, or multiweight oil, will exhibit operating characteristics of a thin, light oil when cold and a thicker, heavier oil when hot. A multiweight oil can be numbered SAE 10W-30, 10W-40, or 20W-50.

For example, a 10W-30 weight oil will flow easily (like a 10 weight oil) when starting a cold engine. It will then act as a thicker oil (30 weight) when the engine warms to operating temperature. Use of this type of oil will help the engine start more easily in cold weather and also provide adequate film strength (thickness) when the engine is hot or at full operating temperature.



Binks

Figure 49-6. An engine oil viscosity rating is determined by measuring how long the oil takes to flow through a specific opening at a specific temperature. The longer the oil takes to flow into the container, the higher the viscosity rating.

Selecting Oil Viscosity

Normally, you should use the oil viscosity recommended by the automaker. However, in a worn, high-mileage engine, higher viscosity oil may be beneficial. Thicker oil tends to seal the rings and provide better bearing protection. It may also help reduce oil consumption and smoking.

Figure 49-7 is one automaker's chart showing recommended SAE viscosity numbers for different temperatures.

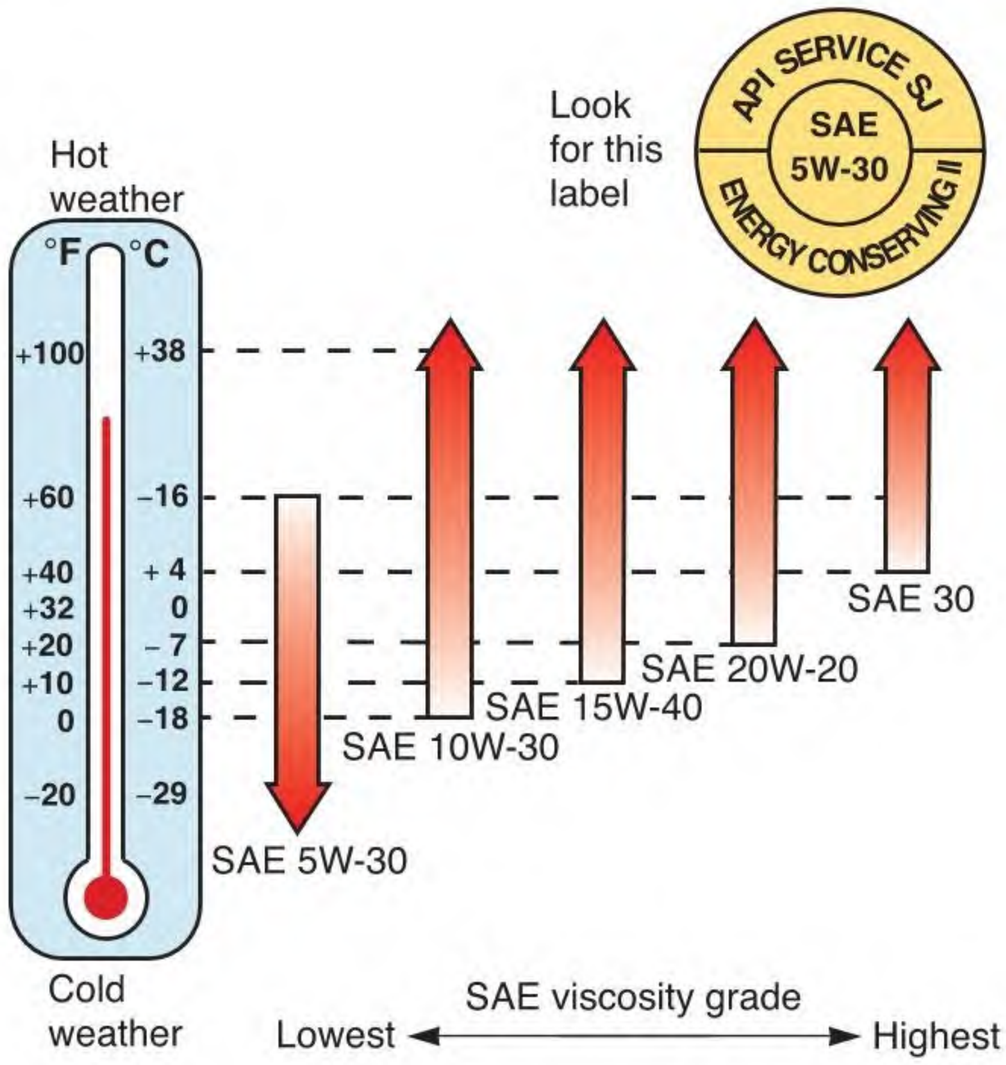
Tech Tip

Never change a high-mileage engine over to full synthetic motor oil that does not contain metal additives. New synthetics that do not contain metal additives can actually wash old metal additives off metal surfaces, resulting in rapid part wear, especially at the camshaft lobes and piston rings.

Oil Service Rating

An ***oil service rating*** is a set of letters printed on the oil bottle to denote how well the oil will perform under operating conditions. This is a performance

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Figure 49-7. Typical recommended SAE viscosity oil rating is affected by climate or average outside temperatures. Note how thicker oil is specified for higher outside temperatures. Many automakers also warn against mixing different brands and types of oil. Different oil brands often use different additives, and they may not be compatible.

standard set by the American Petroleum Institute (API), an association of oil-related companies that sets industry standards. Current API service rating categories for gasoline and diesel engines are as follows:

- SN—Introduced in 2010. Designed to reduce high temperature carbon deposits on engine parts by adding zinc or titanium for better thermal and wear protection.
- SM—Introduced in 2004. Recommended for all automotive engines currently in use. Provides improved low-temperature performance, deposit and wear protection, and oxidation resistance than previous ratings.
- SL—Meets oil warranty requirements for 2004 and older automotive engines.
- SJ—Meets oil warranty requirements for 2001 and older automotive engines.

Tech Tip

Make sure the oil used meets the engine's service requirements. The latest gasoline oil service categories meet the requirements of all earlier categories. The latest diesel engine oil service categories meet the requirements of most—but not all—earlier categories.

The service manual will give the service rating recommended for a specific vehicle. You can use a higher service rating than recommended, but never use a lower rating.

An oil with a high service rating (SN, for example) can withstand higher temperatures and loads than an oil with a low rating. It will have more oil additives to prevent oil oxidation (gumming), engine deposits (sludging), breakdown (chemical changes), foaming (formation of air bubbles), and other problems.

Engine Oiling Methods

There are two methods for lubricating engine components: pressure-fed oiling and splash oiling. See **Figure 49-8** for an oil flow diagram.

Pressure-fed oiling is provided by the oil pump to the crankshaft bearings, camshaft bearings, lifters, and rocker arm assemblies. This type of oiling is needed where load and friction are very high.

Splash oiling occurs when oil sprays out and on moving parts to provide lubrication. This type of oiling is used between parts with moderate load. Splash oiling is used on many parts, including piston rings, cylinders, camshaft lobes, and timing chains.

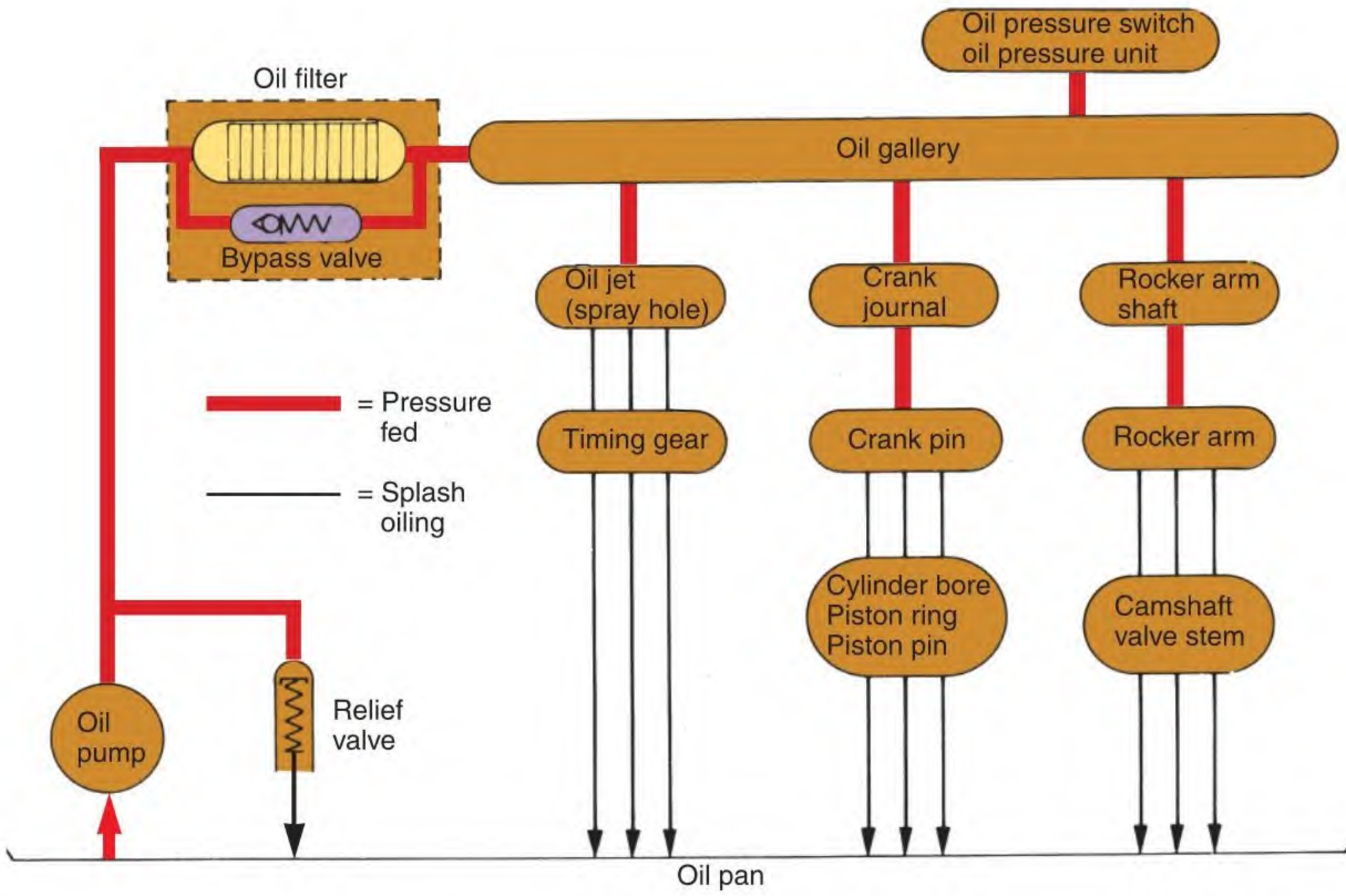
Oil Pan and Sump

The oil pan, normally made of thin sheet metal or aluminum, bolts to the bottom of the engine block. It holds an extra supply of oil for the lubrication system. Refer to **Figure 49-9**.

The oil pan drain plug allows removal of the old oil during oil changes. The oil pan gasket prevents oil leakage between the engine block and pan. Holes in the gasket are provided for the oil pan bolts, which secure the pan to the engine block.

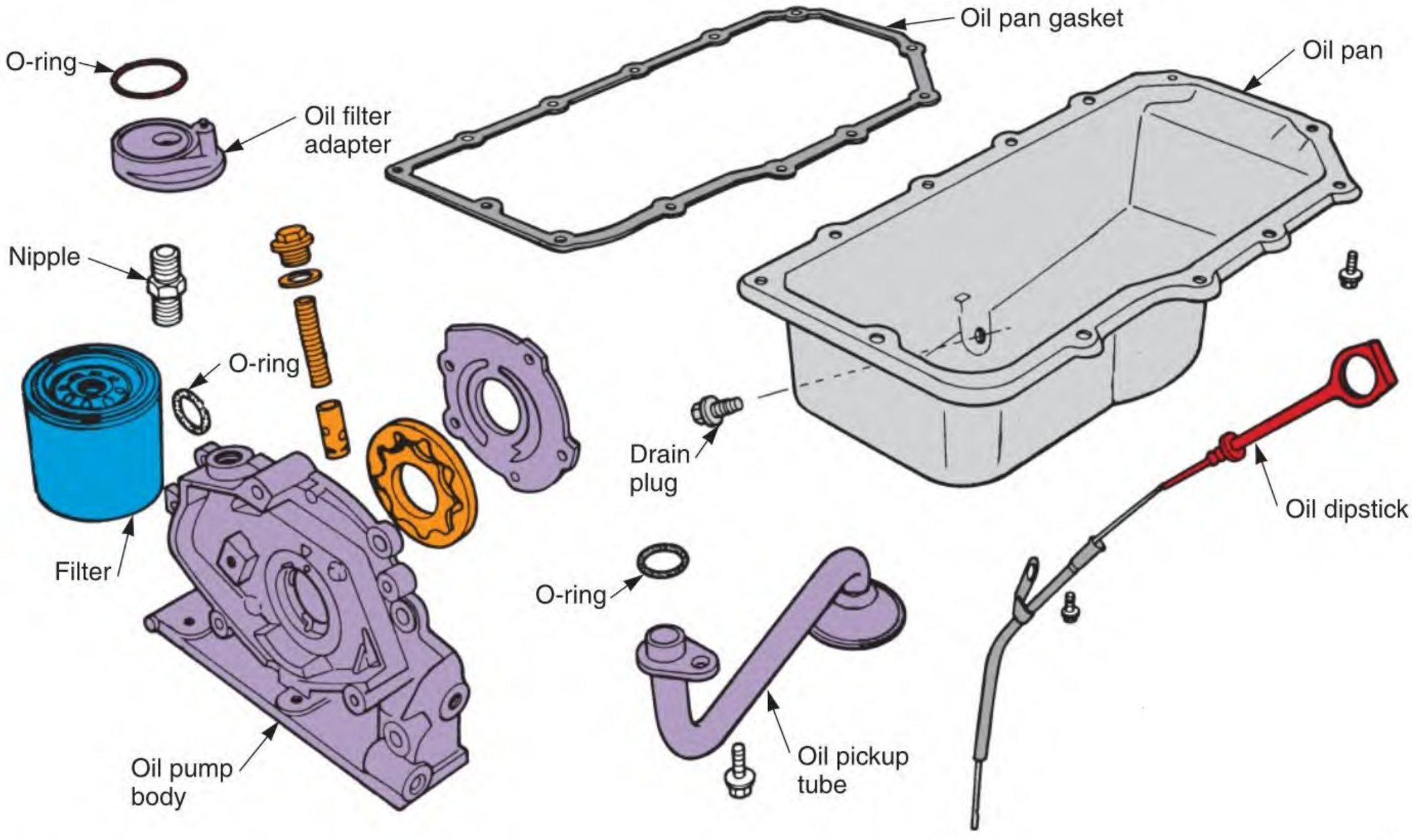
The ***sump*** is the lowest area in the oil pan, **Figure 49-10**. As oil drains out of the internal parts of the engine, it fills the sump. The oil pump can then pull oil out of the pan for recirculation.

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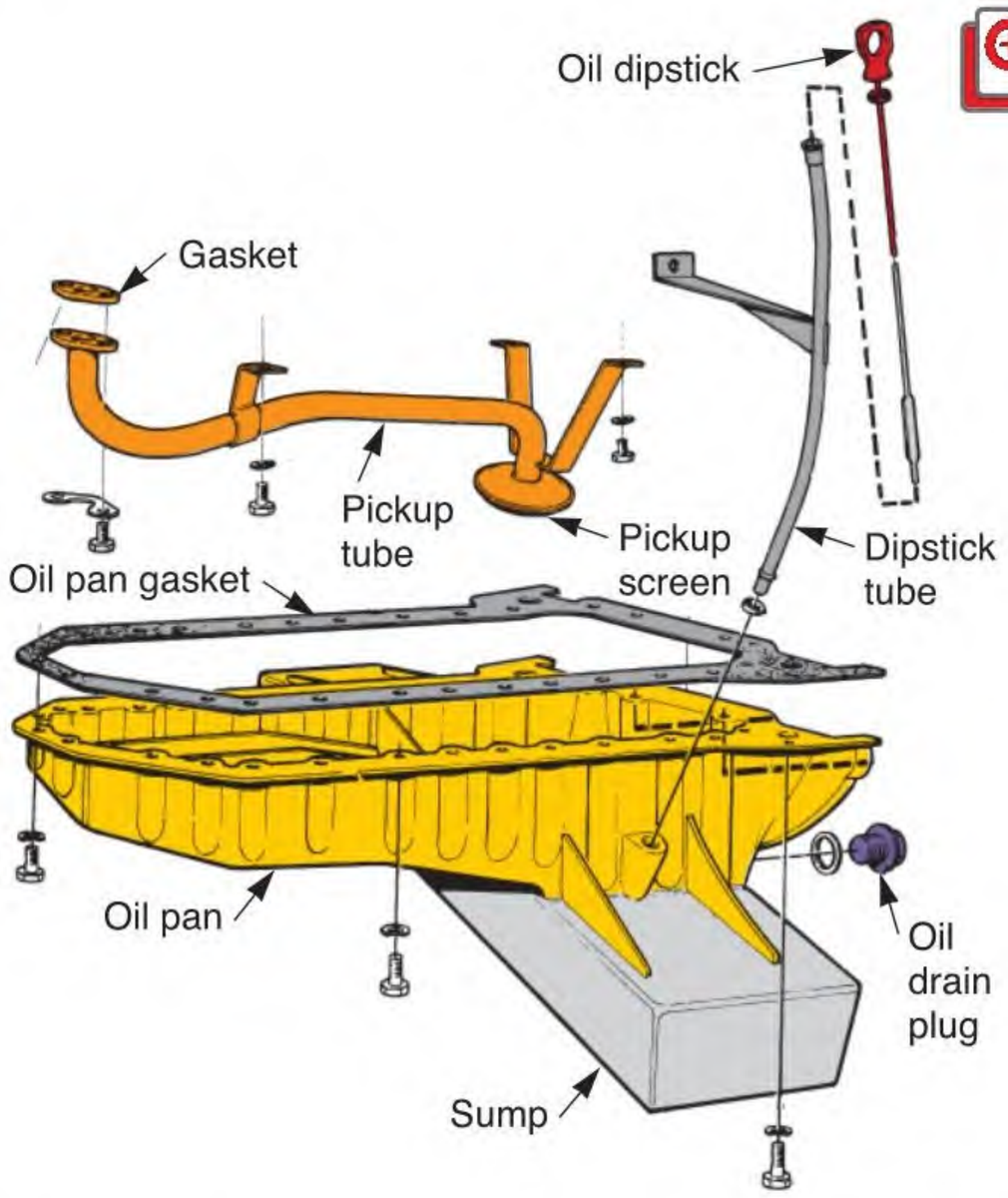
Figure 49-8. Trace through the engine oil flow diagram. This full-flow system requires all oil to pass through the filter before entering the gallery. Thicker lines represent oil under pressure. Thinner lines stand for oil draining and splashing on parts. Note the filter bypass valve and pressure valve.



Chrysler

Figure 49-9. Study lubrication system parts. Note how oil pumps are often mounted in front cover.

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Volvo

Figure 49-10. The oil pan forms the lower crankcase and sump. A gasket seals the mating surface between the block and the pan. Also note the drain plug, pickup tube and screen, and dipstick assembly.

A sheet metal ***oil pan baffle*** may be used to keep the oil from splashing up on the spinning crankshaft. This keeps the crank from stirring air into the oil (oil foaming) and reduces a fractional horsepower loss. The baffle may be an integral part of the pan or a separate part installed above the pan.

A ***structural oil pan*** is designed to add strength to the engine bottom end and cylinder block. Most of these oil pans have thick ribs and bosses to help support the crankshaft and the main bearings. Structural oil pans can be made of thick aluminum or composite materials that are light yet strong. In some designs, the main cap bolts go through the oil pan.

Dry Sump Lubrication System

A ***dry sump*** engine lubrication system uses two oil pumps and a separate oil reservoir for superior engine oiling. No oil is stored in the oil pan. The main oil pump draws oil from the reservoir and forces it to the engine bearings and other high-friction points. A second oil pump, called a ***scavenge pump***, pulls oil out of the pan and feeds it back into the reservoir.

Dry sump lubrication systems are found on exotic high-performance cars. Because no oil remains in the oil pan to be splashed onto the crankshaft, pistons, and rods, this design helps increase engine power and dependability. See **Figure 49-11**.

Oil Pickup and Screen

The ***oil pickup*** is a tube extending from the oil pump to the bottom of the oil pan. One end of the pickup bolts or screws into the oil pump or to the engine block. The other end holds the pickup screen.

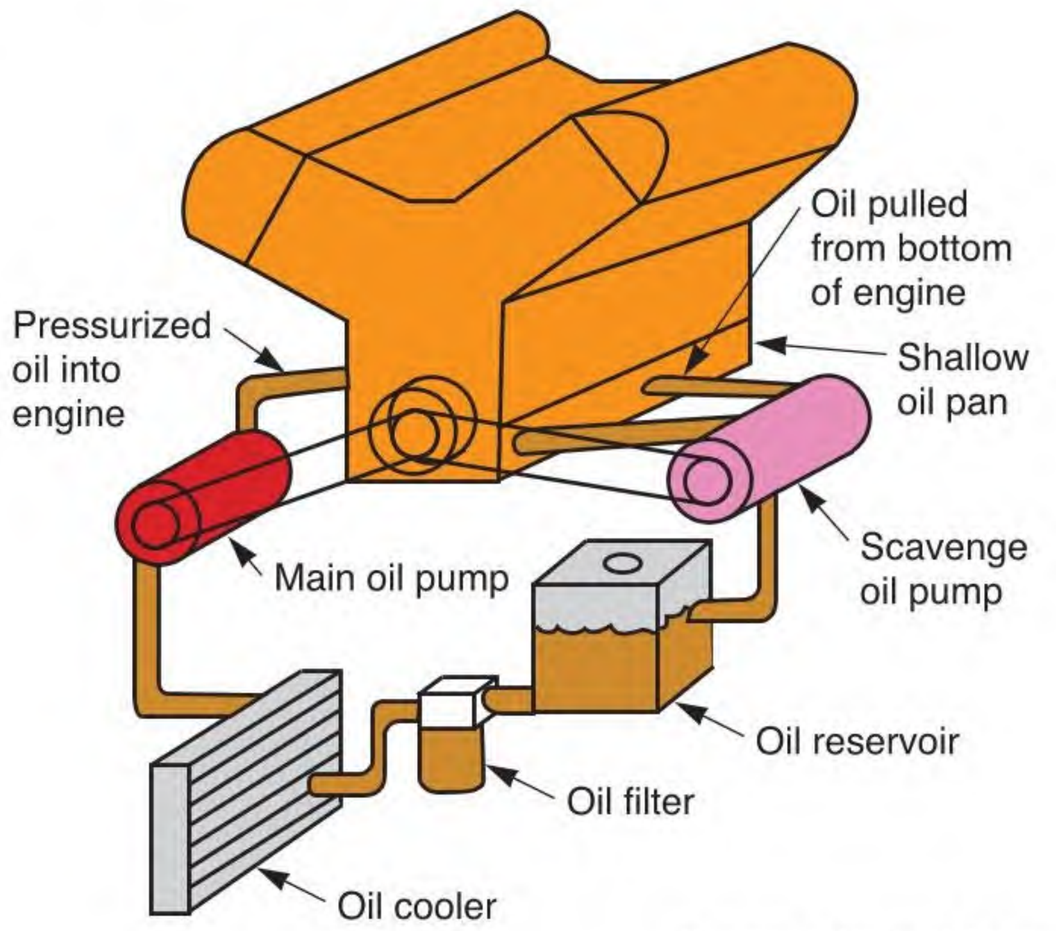
The ***pickup screen***, or strainer, is usually part of the pickup tube. Without the screen, the oil pump could be damaged by bits of valve stem seals and other debris flushed out of the engine.

Oil Pumps

The oil pump is the "heart" of the engine lubrication system; it forces oil out of the pan, through the filter and galleries, and to the engine bearings. There are three basic types of engine oil pumps: rotary, gear, and vane.

Rotary Oil Pump

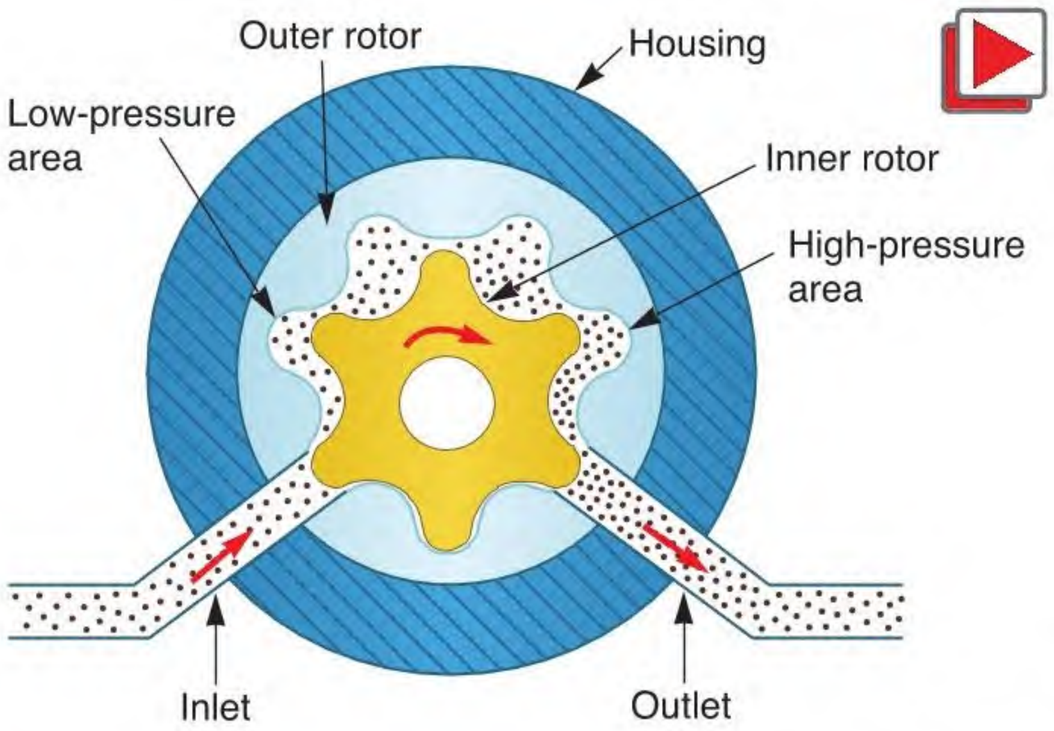
A ***rotary oil pump*** uses a set of star-shaped rotors in a housing to pressurize the engine oil. Look at **Figure 49-12**.



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Figure 49-11. Some high-performance engines have a dry sump lubrication system to help increase power and durability. The dry sump system prevents the spinning crankshaft from forcing air bubbles into the oil (oil foaming), loss of lubrication (oil pump starves for oil or air bubbles displace liquid oil), and power loss (oil splash tends to resist and slow crankshaft).

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Figure 49-12. Study rotary oil pump operation. The inner rotor is driven by the pump shaft and turns the outer rotor. This causes the outer rotor to walk around the inner rotor. The space on one side of the rotor enlarges and pulls oil into the pump. The space on the other side of the rotor is reduced to compress and force oil out.

As the oil pump shaft turns, the inner rotor causes the outer rotor to spin. The eccentric action of the two rotors forms pockets that change in size. A large pocket is formed on the inlet side of the pump. As the rotors turn, the oil-filled pocket becomes smaller as it nears the outlet of the pump. This squeezes the oil and makes it spurt out under pressure. As the pump spins, this action is repeated over and over to produce a relatively smooth flow of oil.

Gear Oil Pump

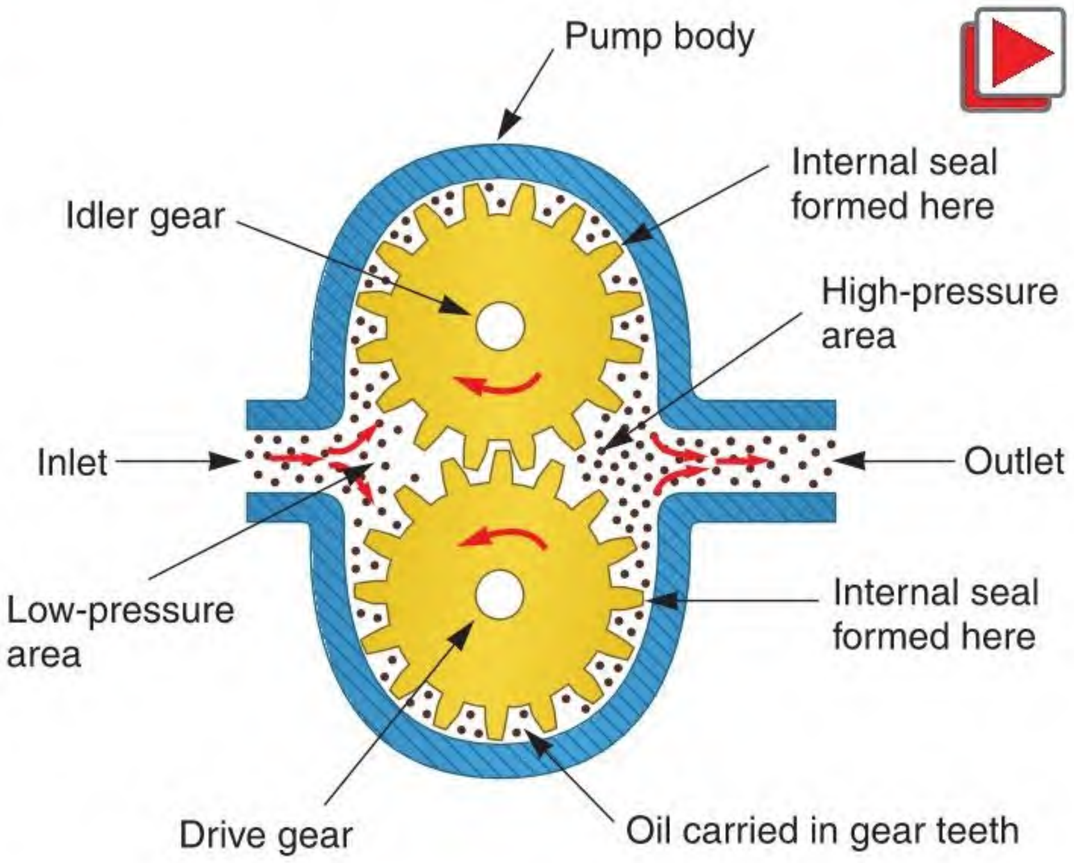
A ***gear oil pump*** uses a set of gears to produce lubrication system pressure. See **Figure 49-13**. Oil drawn into the inlet side of the pump is caught in the gear teeth and carried around the outer wall inside the pump housing. When the oil reaches the outlet side of the pump, the gear teeth mesh and seal. Oil caught in each gear tooth is forced into the pocket at the pump outlet, and pressure is formed. Oil squirts out of the pump and to the engine bearings.

Vane Oil Pump

A ***vane oil pump*** uses sliding wipers to build oil pressure. This is the newest oil pump design that provides for easy pressure and volume control.

Oil Pump Drives

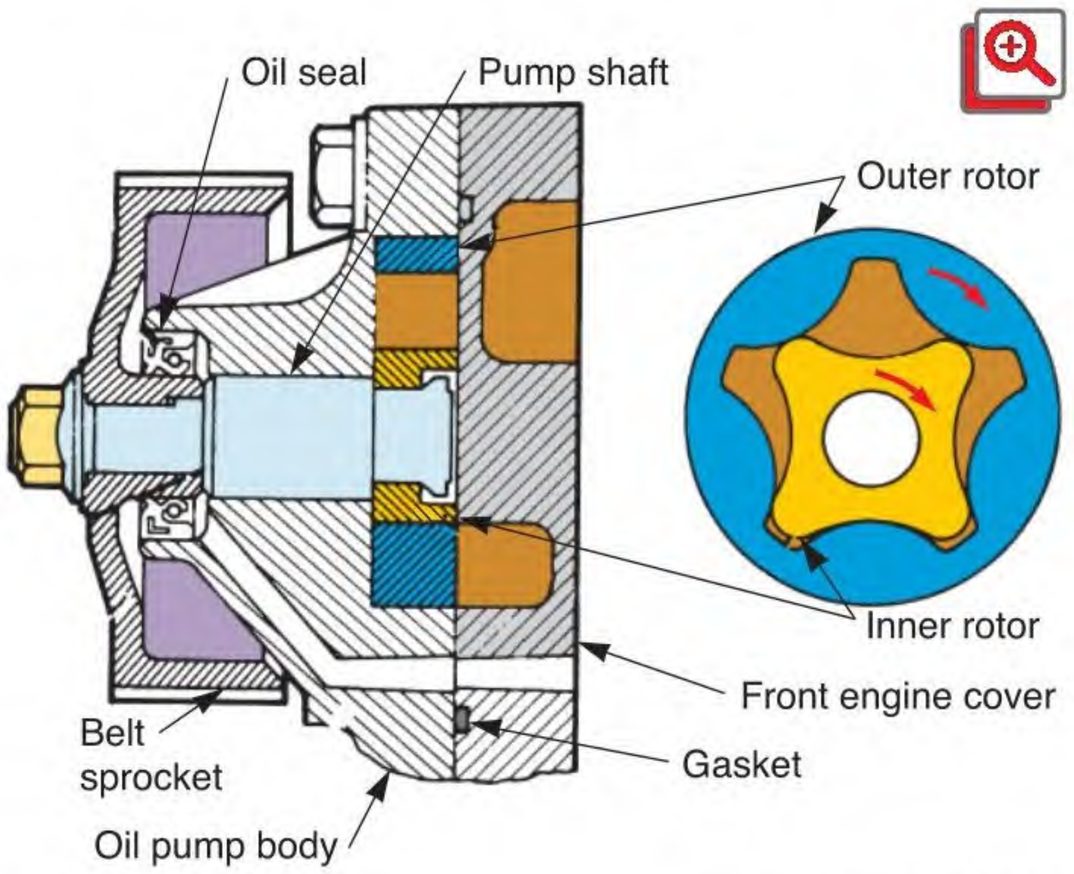
There are several methods used to drive an oil pump. A ***belt-driven oil pump*** uses a cogged belt running off the crankshaft pulley for power. This is commonly used in overhead cam engines using a timing belt. See **Figure 49-14**.



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Figure 49-13. Study gear oil pump operation. The oil pump shaft turns one gear, which drives the other gear. Oil is trapped in the teeth of the gears and carried around the housing wall. On the outlet side, oil is trapped and pressurized.

A ***gear-driven oil pump*** uses the engine timing gears for power. Some oil pumps are gear-driven off oil pan–mounted balancer shafts. This design can vary considerably from engine to engine. Gear-driven oil pumps are very dependable but costly to manufacture, making them rare.



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Figure 49-14. This oil pump is belt driven. The pump bolts to the front of the engine. This type is common with overhead cam engines using a timing belt.

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A ***crankshaft-driven oil pump*** is directly engaged to and powered by the crankshaft snout. The inner pumping element fits over and is keyed or locked to the crank snout. This type of oil pump drive is becoming more common because of its simplicity and dependability. See **Figure 49-15**.

A ***variable volume oil pump*** is capable of building high oil pressure at idle and reducing pump volume per revolution at high engine speeds for better engine efficiency. These pumps help limit engine power losses while limiting the volume and pressure of the motor oil at high rpms. The hydraulic valves that operate a variable volume oil pump can also serve as a pressure relief valve. Study **Figure 49-16**.

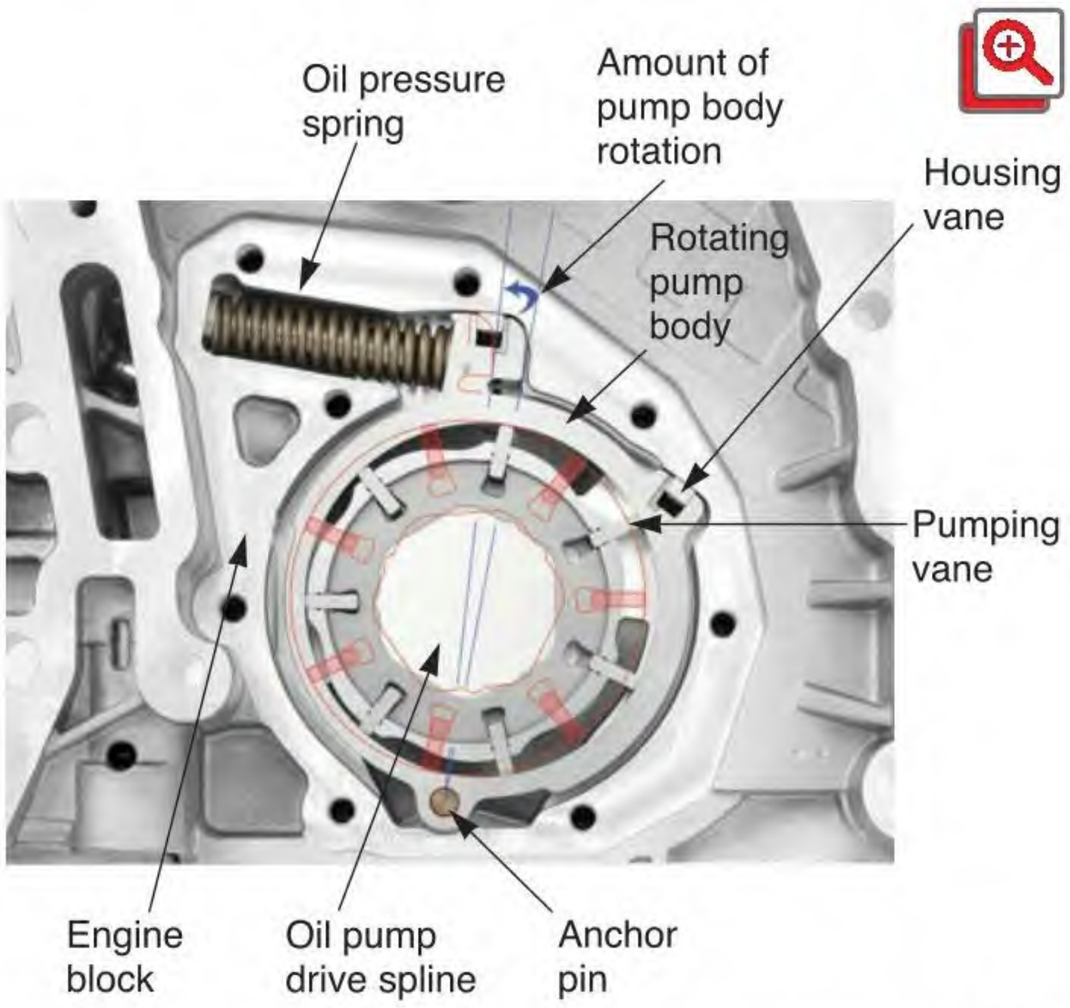
Multi-Stage Oil Pumps

Multi-stage oil pumps have gear or rotor pumping chambers in series to multiply and increase oil pressure for high-performance, high-rpm engines. Some multistage oil pumps can generate up to 100 psi of engine oil pressure at high flow rates.

Pressure Relief Valve

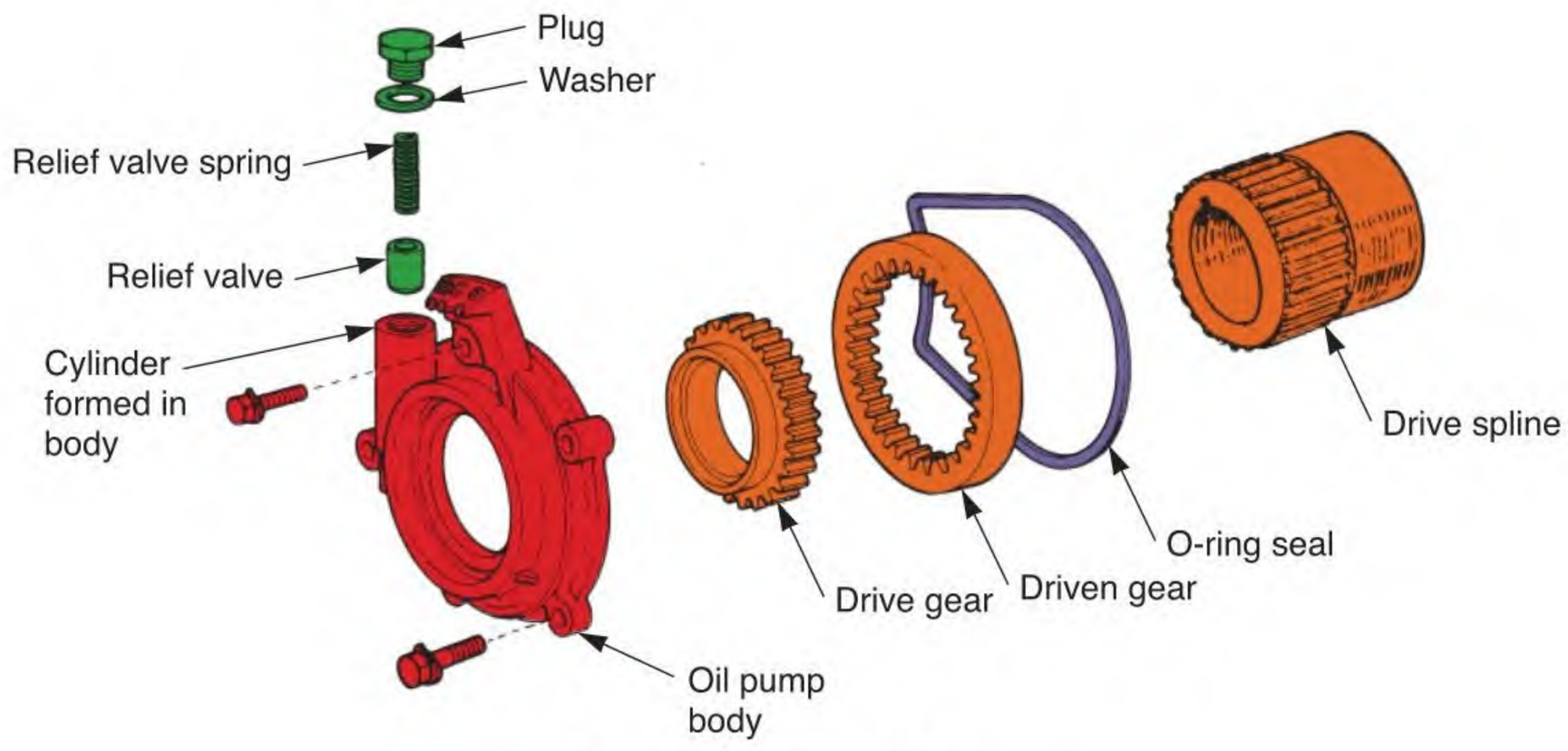
An oil pressure relief valve limits the maximum pressure that can develop in the engine oil galleries. It is a spring-loaded bypass valve in the oil pump, engine block, or oil filter housing. Refer to **Figure 49-17**.

The pressure relief valve consists of a small piston, spring, and cylinder. Under normal pressure conditions, the spring holds the relief valve closed. All the oil from the pump flows into the oil galleries and to the bearings.



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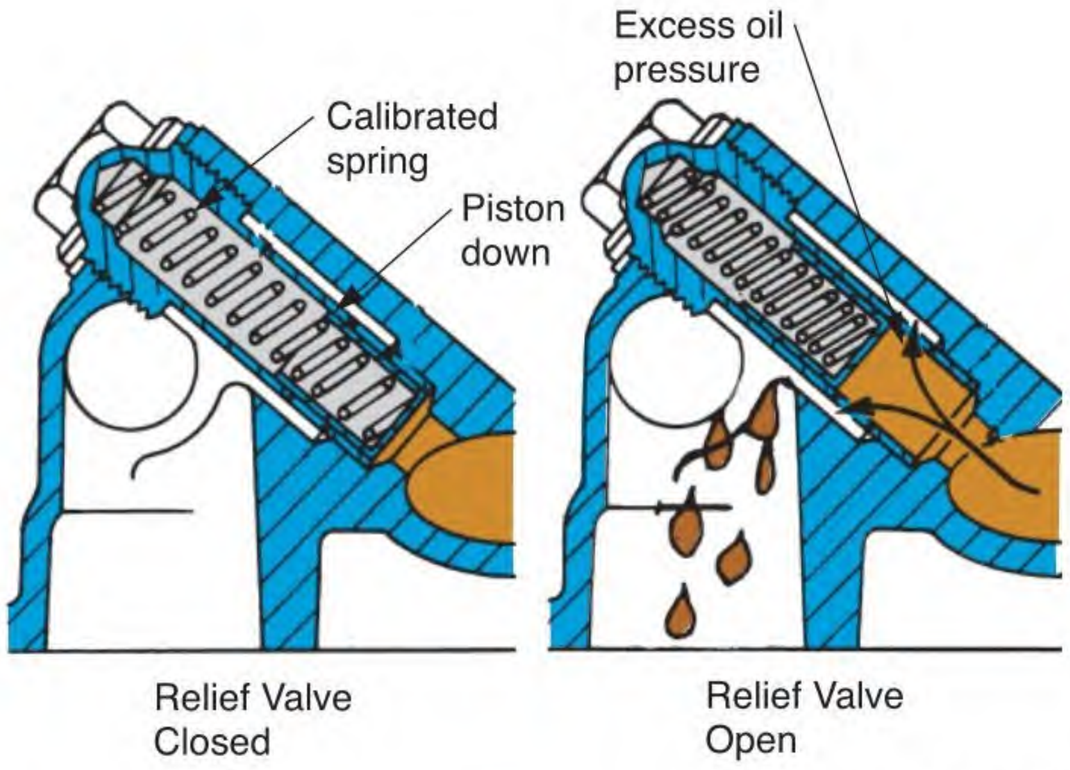
Figure 49-16. In a variable volume oil pump, the oil pressure valve and spring normally hold the pump in the high volume per revolution position. When engine speed increases to try to reduce pressure, hydraulic piston chamber on outside of pump housing is rotated to reduce pump volume per revolution at high engine speeds. These pumps help limit engine power losses while limiting the volume and pressure of the motor oil at high rpms.



Toyota

Figure 49-15. This oil pump is driven directly off the crankshaft snout. The drive spline on the crank turns the inner gear. The outer gear walks around to pump oil into block.

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Figure 49-17. This cutaway view shows construction of a pressure relief valve. A small piston or valve fits in a small cylinder. A spring holds the valve in a normally closed position. When oil pressure is too high, the spring compresses to open the valve. Excess oil bypasses the system and drains into the oil pan.

However, under abnormally high oil pressure conditions (cold, thick oil, for example), the pressure relief valve opens. Oil pressure pushes the small piston back in its cylinder by overcoming spring tension. This allows some oil to bypass the main oil galleries and pour back into the oil pan. Most of the oil still flows to the bearings, and a preset pressure is maintained.

Some pressure relief valves are adjustable. By turning a bolt or screw, or by changing spring shim thickness, the engine oil pressure setting can be altered.

Oil Filters

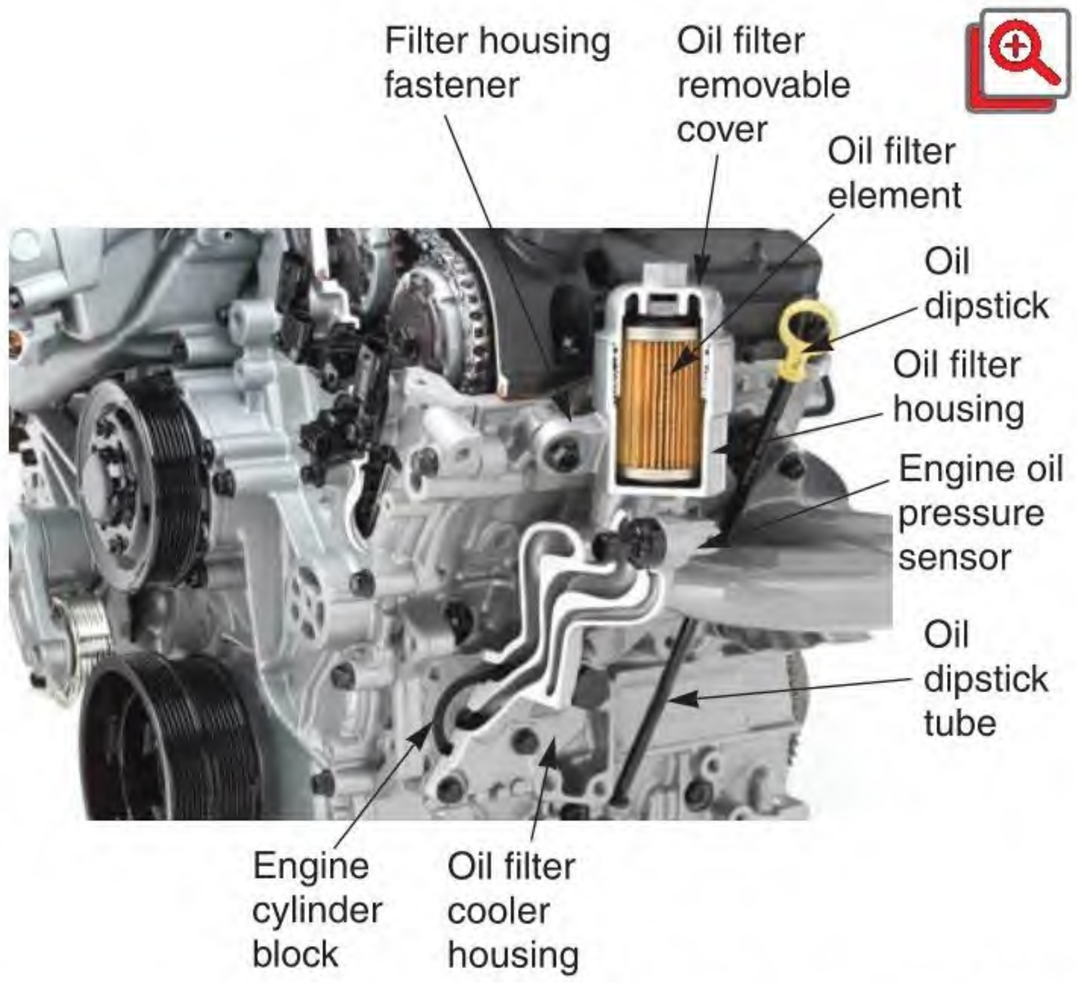
An oil filter removes small metal, carbon, rust, and dirt particles from the circulating engine oil. It protects the moving engine parts from abrasive wear. Most oil filters screw onto the side of the engine, **Figure 49-18**.

A ***filter element*** is a paper or cotton filtering substance mounted inside the filter body. The element allows oil flow but blocks and traps small debris. See **Figure 49-19**.

A ***filter bypass valve*** is commonly used to protect the engine from oil starvation if the filter element becomes clogged. The valve will open if too much pressure is formed in the filter. This allows unfiltered oil to flow to the engine bearings, preventing major part damage.

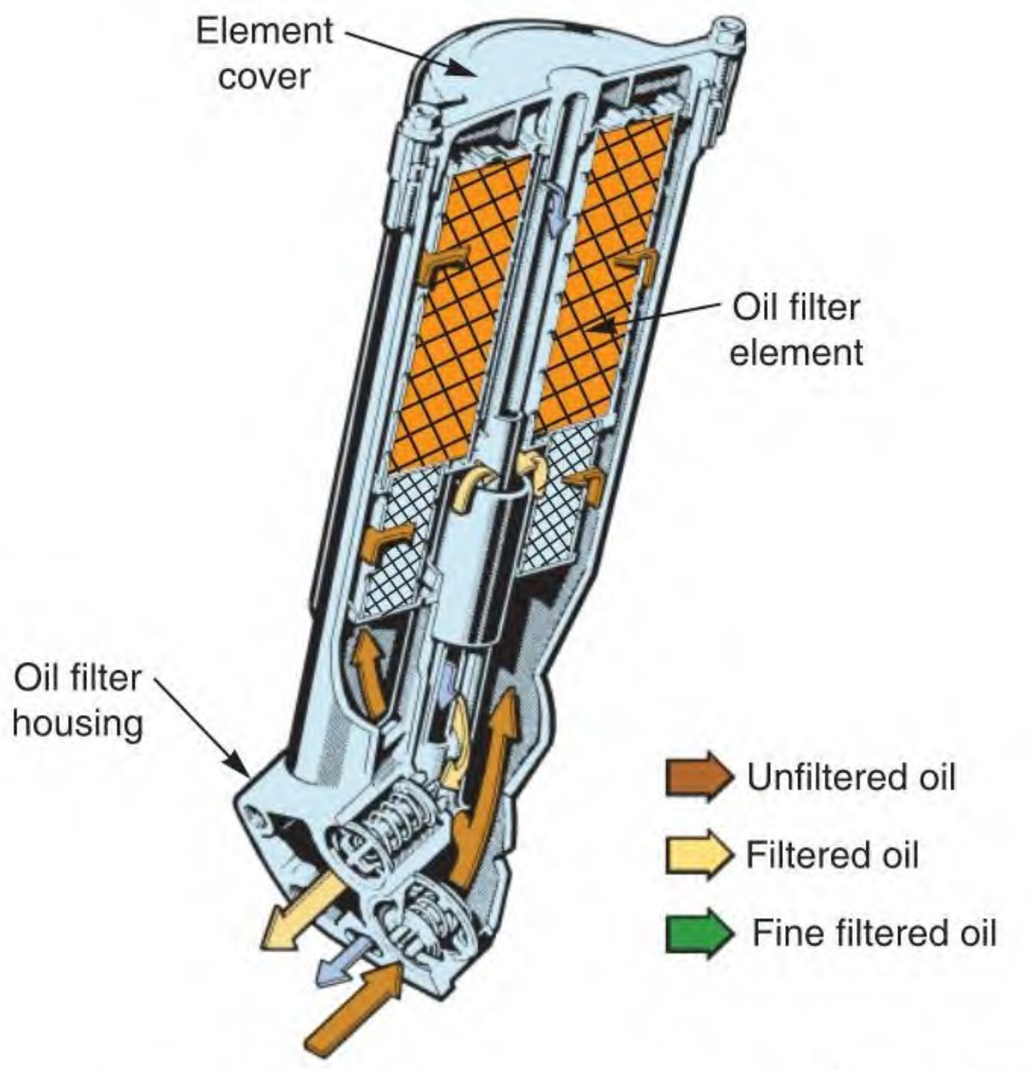
Oil Filter Types

There are two classifications of engine oil filters: spin-on filters and cartridge filters.



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Figure 49-18. This oil filter normally mounts on one side of engine block inside cast aluminum filter housing. Oil filter condition is critical to the service life of the engine.

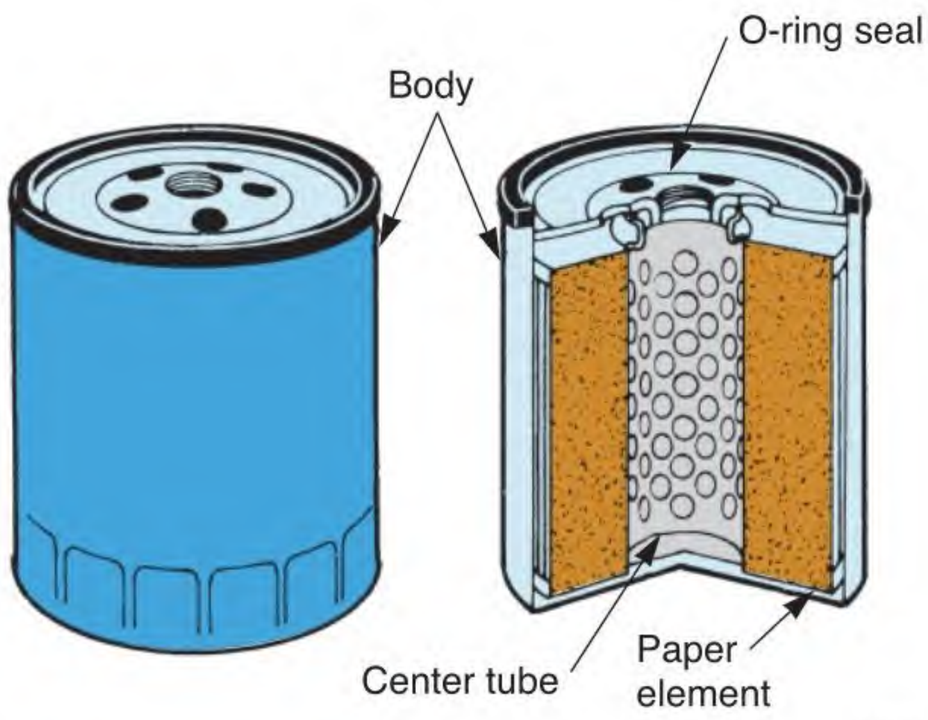


Mercedes-Benz

Figure 49-19. This is a cartridge-type oil filter. The element is removed from the housing to change the filter.

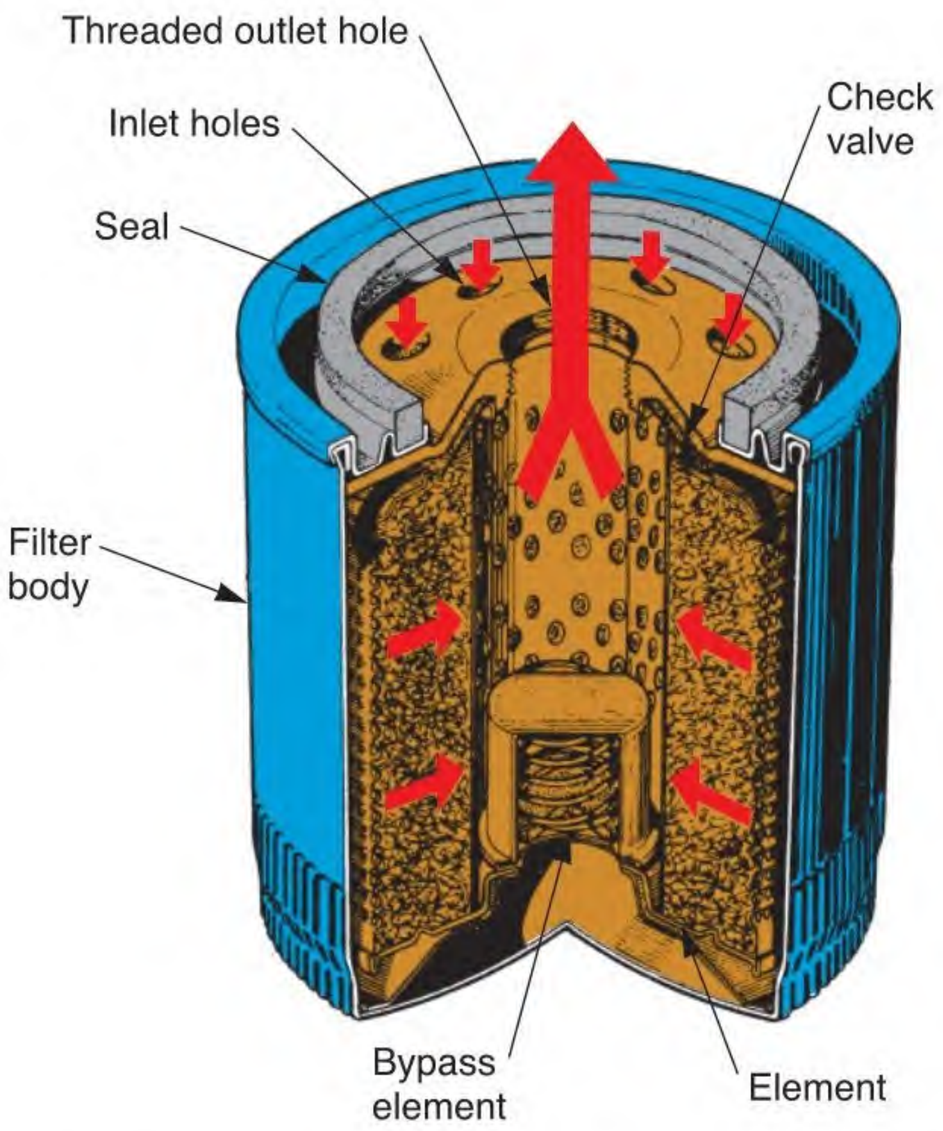
The ***spin-on oil filter*** is a sealed unit. See **Figure 49-20**. The filter element is permanently enclosed in the filter body, **Figure 49-21**. When a

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AC-Delco

Figure 49-20. A spin-on filter is the most common oil filter type. An O-ring seal prevents leakage when screwed onto its housing. The element traps debris and keeps it out of the engine.



Saab

Figure 49-21. This cutaway of a spin-on filter shows oil flow. Oil enters small holes, passes through the element, and then flows out of the center hole to the engine.

spin-on filter must be serviced, a new filter is simply screwed into place. This is the most common type of oil filter.

The ***cartridge oil filter*** has a separate element that fits in an engine-mounted housing. To service this type of filter, unscrew the cover from the top of the housing and remove the used filter element. Then, drop a new element inside the existing housing and replace the cover. A cartridge oil filter is sometimes used for heavy-duty or diesel applications and is the current trend for gasoline engines with higher oil pressures.

Tech Tip

The number one reason for premature engine failure is not changing the engine oil and filter at the recommended intervals. Decomposed oil results from excess heat and mechanical stress. The oil actually changes from a liquid to a solid, "chocolate pudding–like" substance. If you ever find extremely dirty or badly decomposed oil, warn the owner of the consequences of not changing the oil and filter at regular intervals.

Oil Filter Housing

The oil filter housing is a metal part that bolts to the engine and provides a mounting place for the oil filter. Refer to **Figure 49-22**. The housing may also have a fitting for the oil pressure sending unit or sensor, **Figure 49-23**.

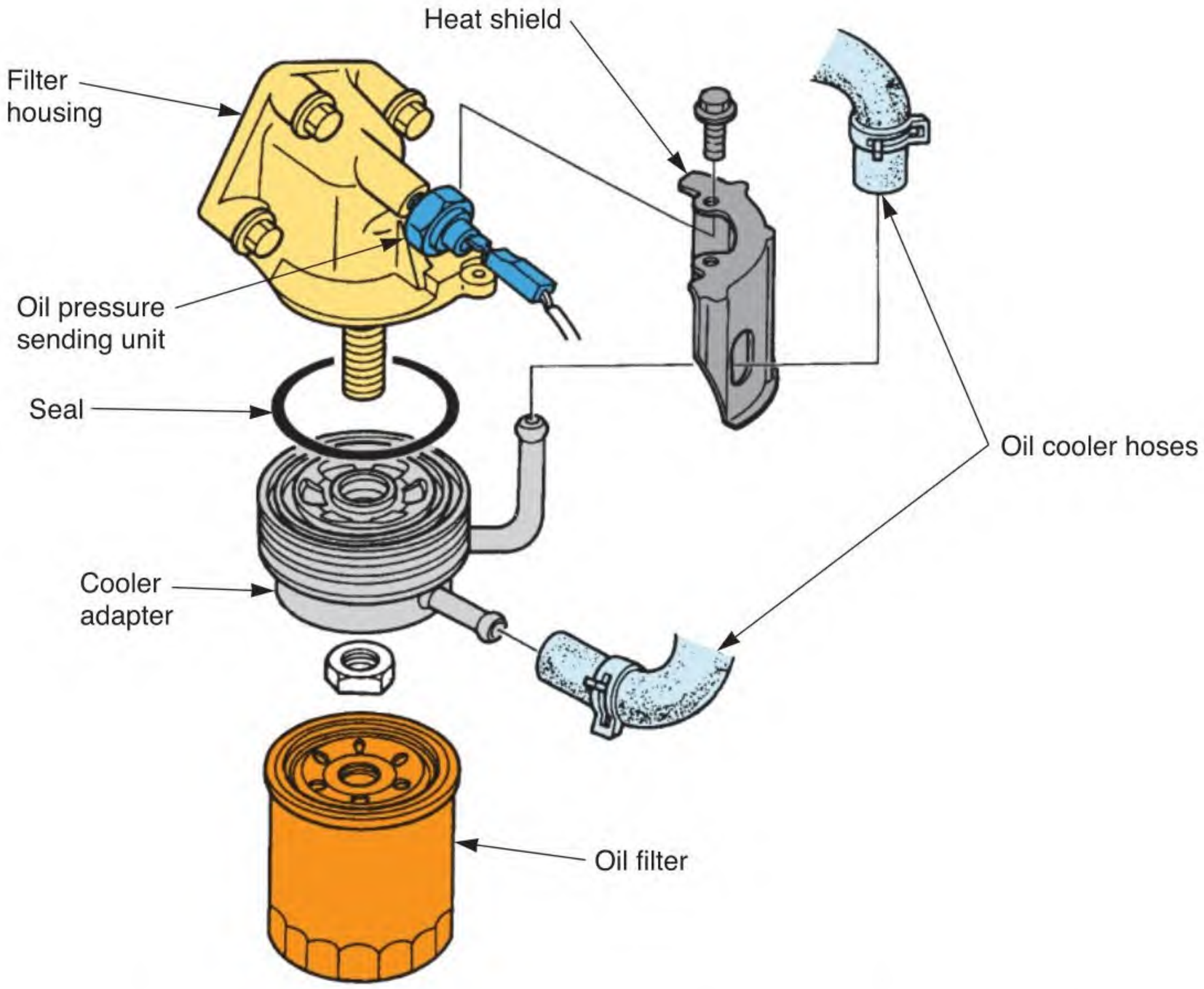
A gasket normally fits between the engine and the oil filter housing to prevent leakage. Sometimes, the pressure relief valve, filter bypass valve, and oil pump are housed inside this aluminum casing.



Ford

Figure 49-22. The oil filter housing often bolts to the side of the engine block.

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Mazda

Figure 49-23. In this setup, the oil pressure sending unit is mounted in the filter housing. Note the small oil cooler adapter that mounts between the filter and the housing. Hoses run between the adapter and an oil cooler.

Oil Cooler

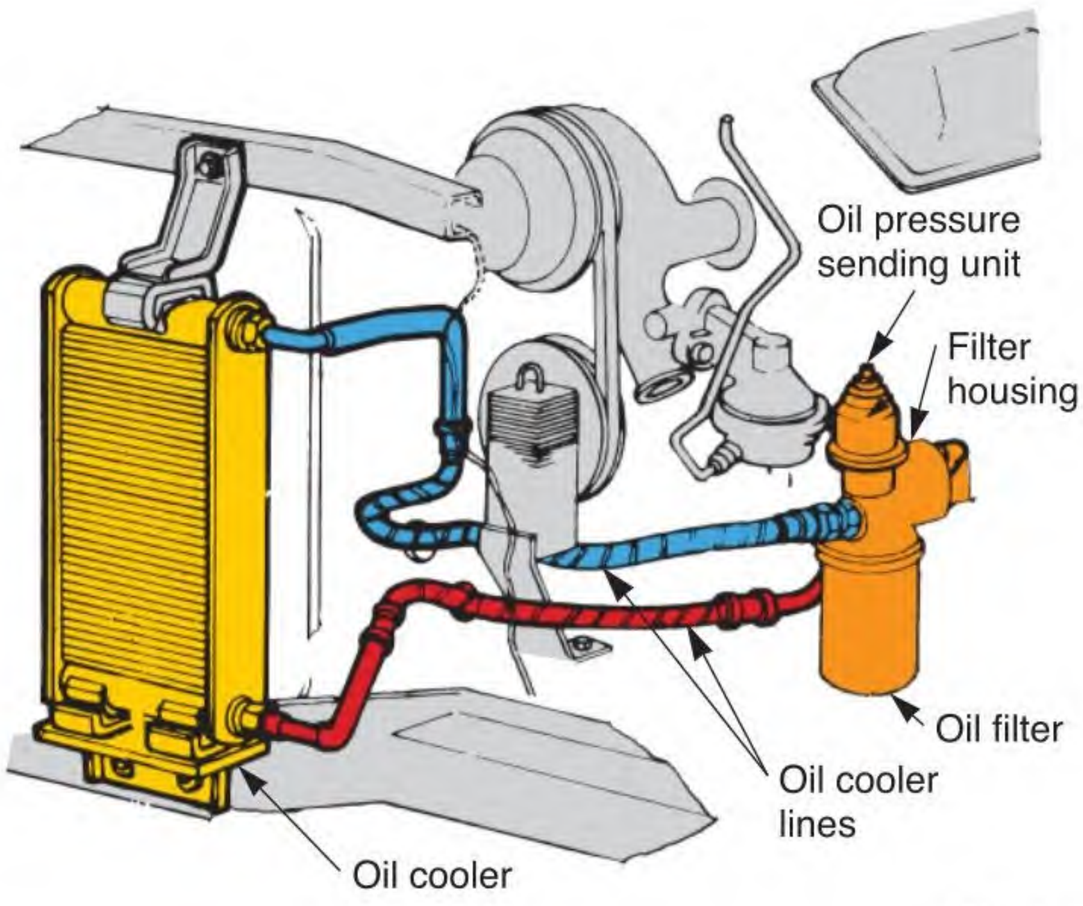
An ***oil cooler*** may be used to help lower and control the operating temperature of the engine oil. It is a heat exchanger (radiator-like device) connected to the lubrication system. Oil is pumped through the cooler for heat removal before flowing back into the engine. See **Figure 49-24**.

Oil coolers are frequently used on turbocharged engines or heavy-duty applications (trailer towing package, for instance).

Oil Galleries

Oil galleries are passages through the cylinder block and head for lubricating oil. They are cast or machined passages that allow oil to flow to the engine bearings and other moving parts.

The ***main oil galleries*** are large passages through the center or side of the cylinder block casting. Small passages feed oil to the crankshaft bearings, rod bearings, camshaft bearings, and valve train.



Chrysler

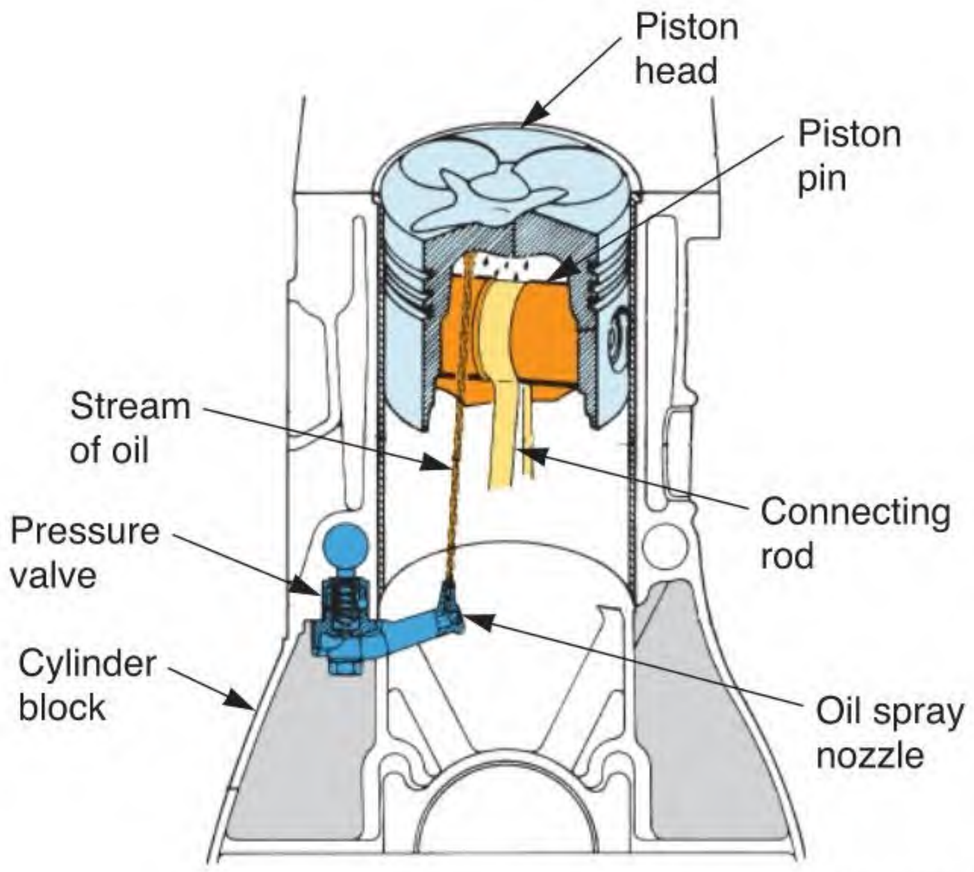
Figure 49-24. Oil coolers allow transfer of heat out of the oil and into the surrounding air, like a cooling system radiator. They are used for high performance or heavy-duty applications. High-pressure lines and hoses carry oil to and from the cooler.

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The main galleries also feed oil to smaller passages running up through the cylinder block and into the cylinder heads. Refer to **Figure 49-25**.

Oil Spray Nozzles

Oil spray nozzles are used to direct a stream of engine oil onto the bottoms of the engine pistons, timing gears or chain, and other moving engine parts. The extra oil provides added lubrication and also helps to carry heat away from the parts. See **Figure 49-26**.

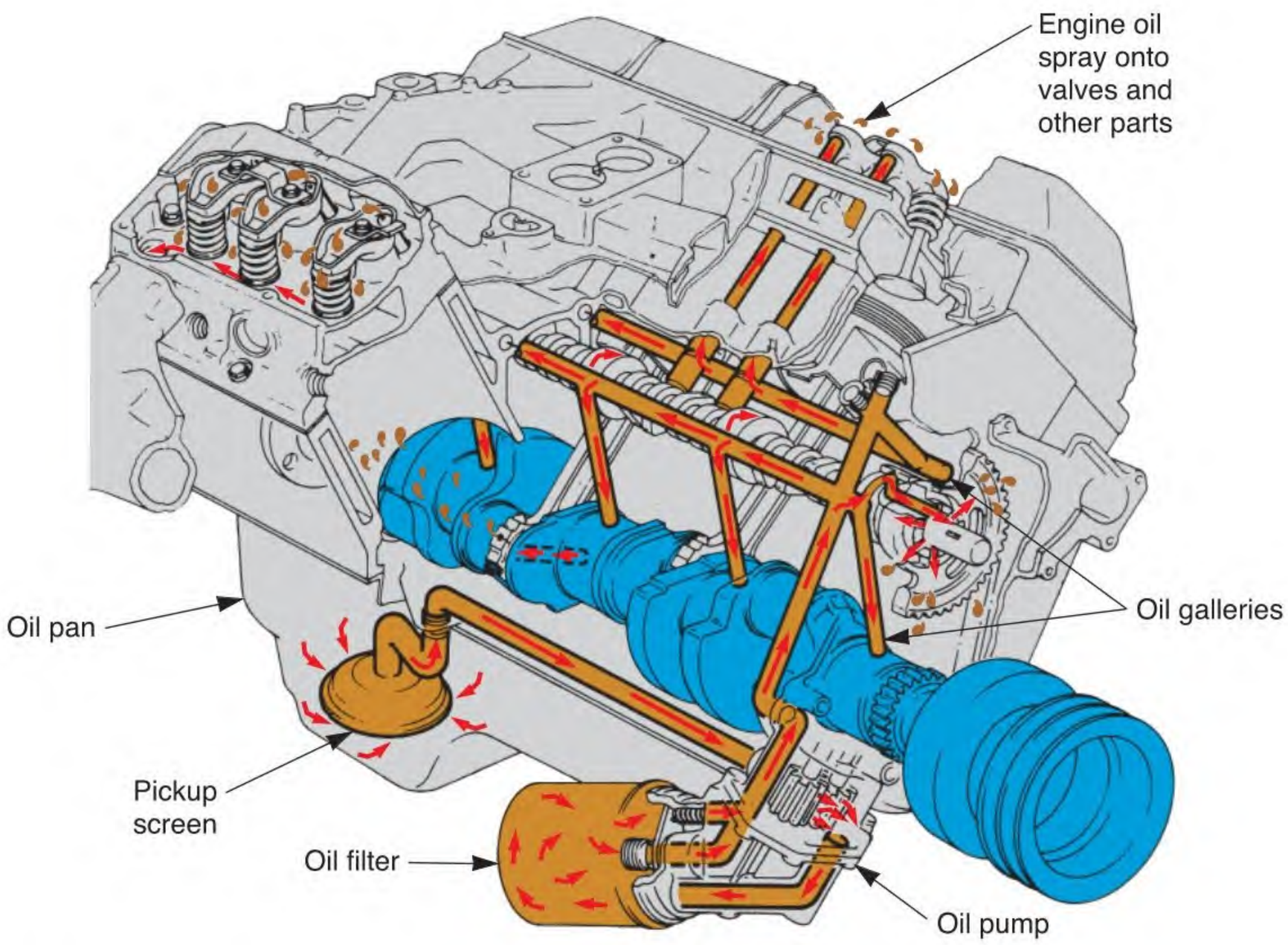


Mercedes-Benz

Figure 49-26. The oil spray nozzle squirts engine oil onto the bottom of the piston to cool the piston head and add lubrication for the wrist pin. A pressure valve in this nozzle opens only when a specific oil pressure is reached.

Positive Crankcase Ventilation System

The ***positive crankcase ventilation system*** (PCV system) draws fumes out of the engine crankcase and burns them inside the engine. The PCV system primarily prevents toxic vapors from entering and polluting the atmosphere. This system also helps prevent ***engine sludging*** ("chocolate pudding–like" oil formation), which could restrict oil circulation.



Chrysler

Figure 49-25. Oil galleries allow oil to pass through the engine. The main galleries are larger passages in the block. Note how oil flows through hollow push rods to rockers.

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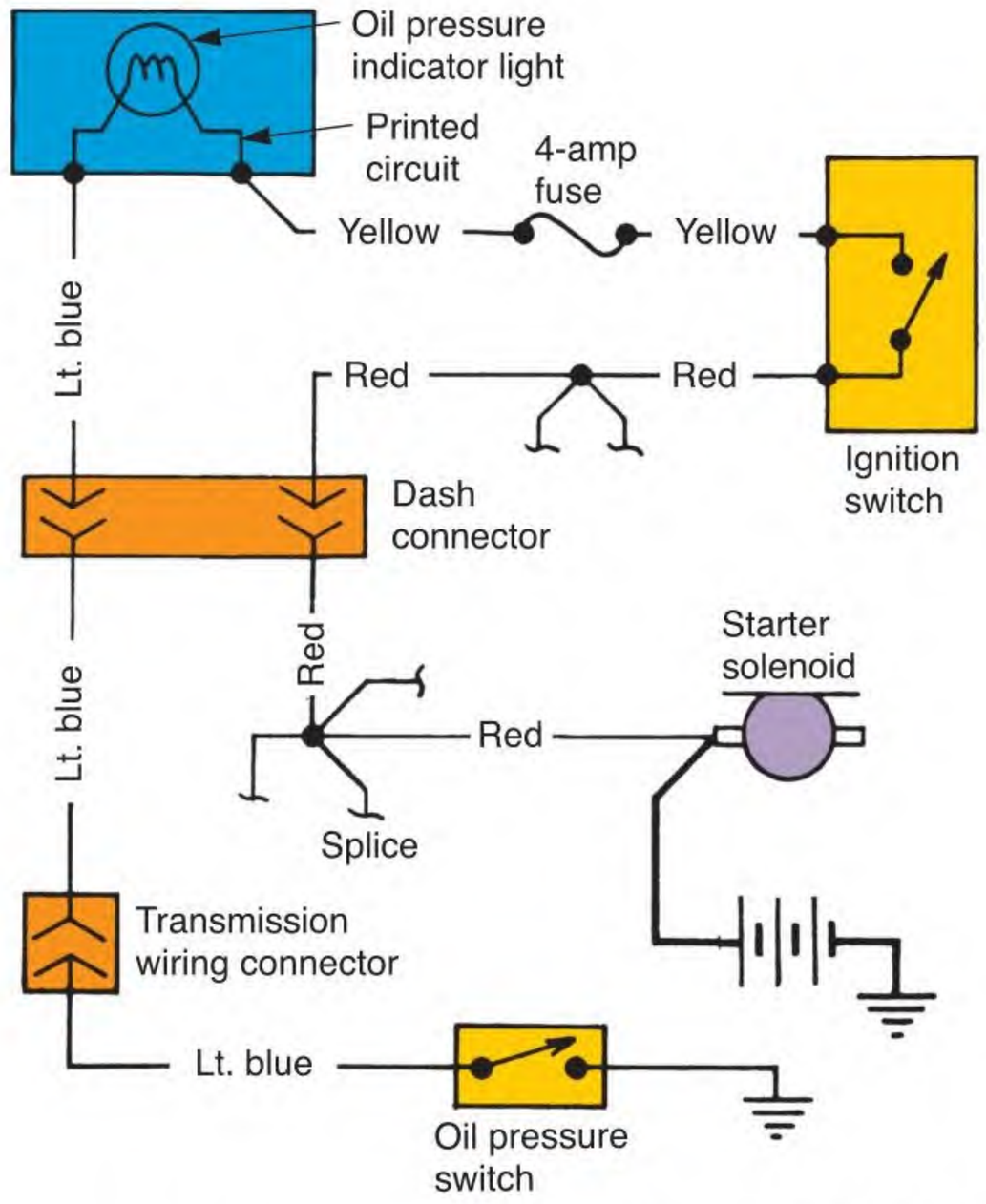
Oil Pressure Indicator

An ***oil pressure indicator*** warns the driver of a low oil pressure problem. The circuit activates a warning light in the vehicle's dash. A basic oil pressure light circuit is shown in **Figure 49-27**.

An ***oil pressure switch*** is opened and closed by oil pressure so that it can operate the dash indicator light. It screws into the engine and is exposed to one of the oil galleries.

When oil pressure is low (the engine is off or has a mechanical problem), the spring in the sending unit holds a pair of contacts closed. This completes the circuit, and the indicator light glows.

When oil pressure is normal, the oil pressure acts on a diaphragm in the sending unit. Diaphragm deflection opens the contact points to break the circuit. This causes the warning light to go out, informing the driver of good oil pressure.



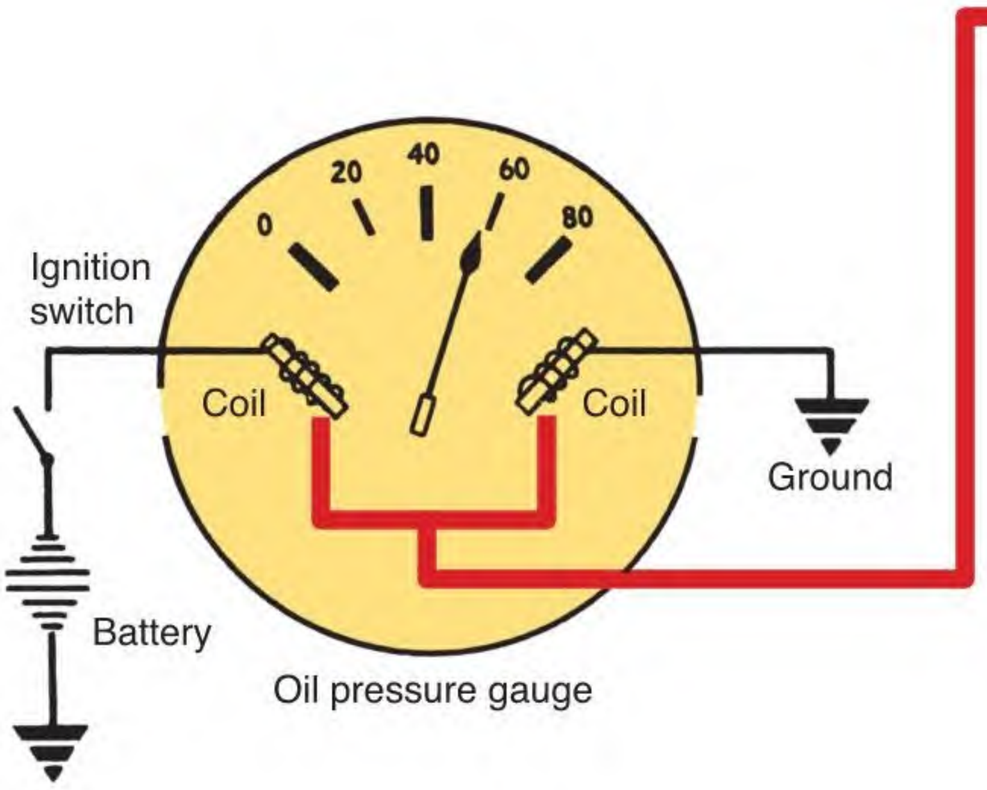
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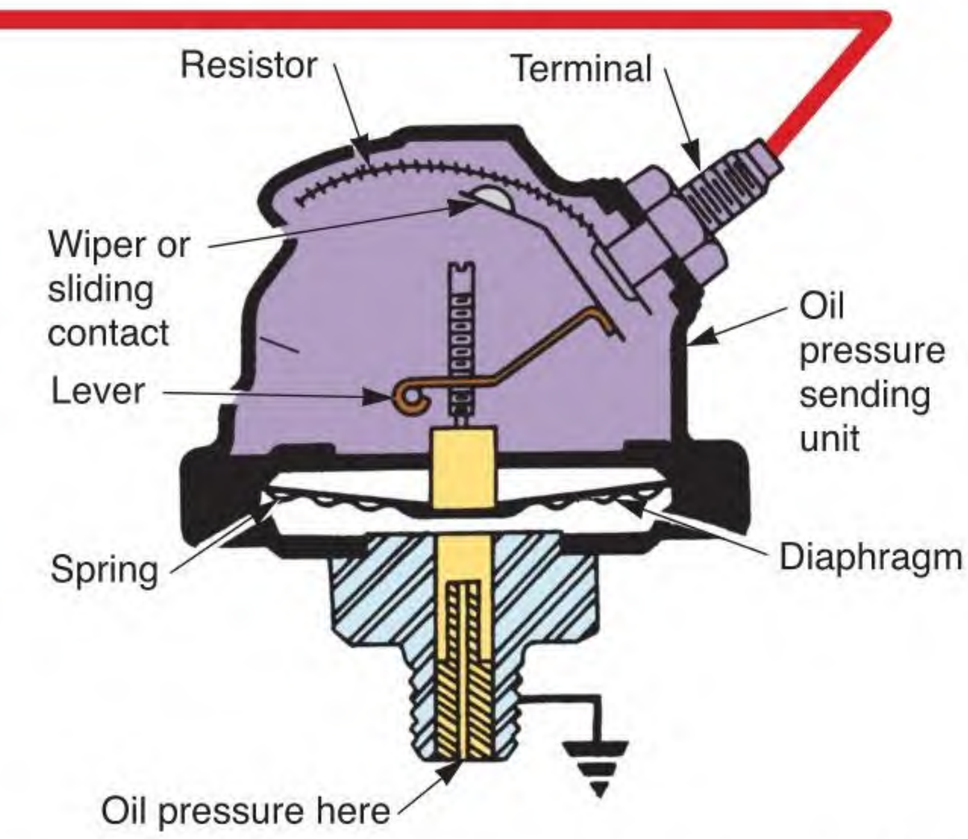
Figure 49-27. Study this wiring diagram for an oil pressure indicator light. The oil pressure switch controls current flow through the dash indicator light. Note the wire color coding for tracing wires.

Oil Pressure Gauge Circuit

An ***oil pressure sending unit*** is used to operate the ***oil pressure gauge*** and the warning light. The sending unit uses a variable resistor instead of contact points. See **Figure 49-28**.

As more oil pressure is developed, the sending unit diaphragm is deflected a proportional amount. This causes an equal amount of sending unit resistance change.





Deere & Co.

Figure 49-28. An oil pressure gauge circuit uses a variable resistance-type sending unit. Changes in oil pressure cause different amounts of diaphragm deflection. This moves the sliding contact on the resistor. Changes in resistance and current make the gauge show engine oil pressure.

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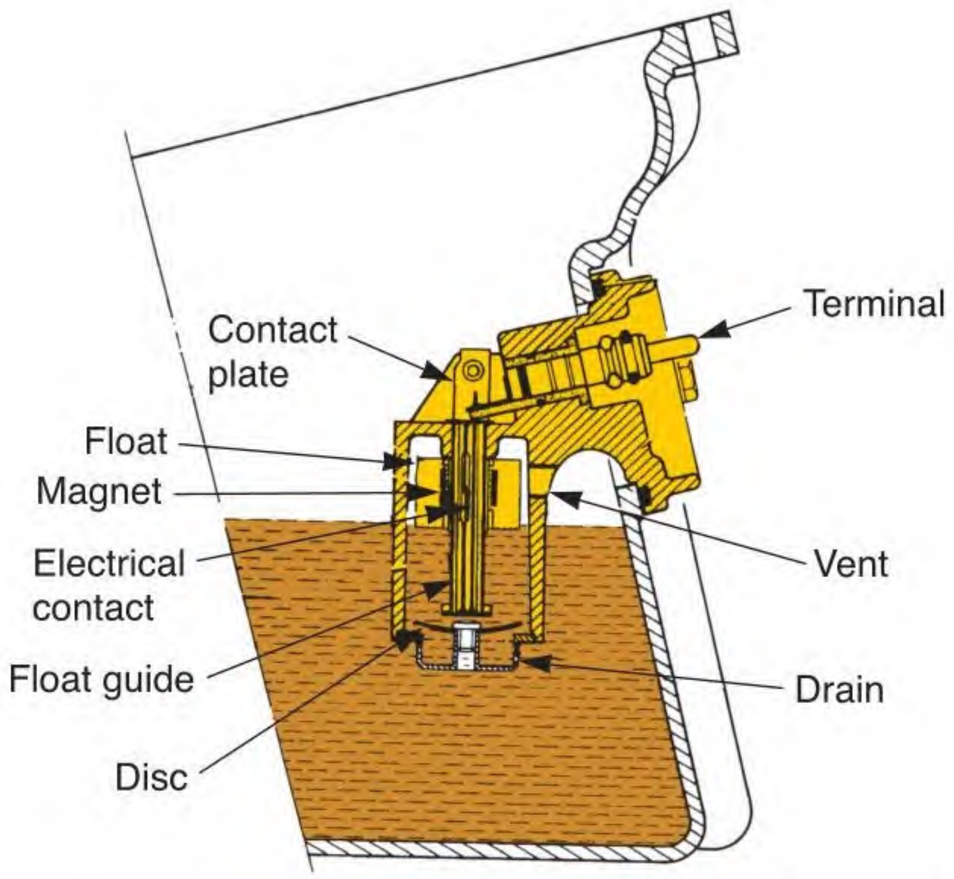
Low oil pressure causes low sending unit resistance, high current flow, and low oil pressure gauge readings. High oil pressure causes high resistance in the sending unit to allow low current flow for deflecting the pressure gauge needle to the right.

Tech Tip

Engine oil pressure must be very low (under about 10 psi at idle) before many low oil pressure warning lights will go on. Light engine bearing knock or lifter noise will often result before the warning light is energized. If oil pressure drops too low only at idle, excessive rod and main bearing clearances are indicated. Loose engine bearings are allowing too much oil flow through the bearings, which lowers engine oil pressure at low rpms.

Oil Level Sensor

Some cars are equipped with an oil level indicator that registers the actual quantity of oil in the engine. It is similar in operation to the oil pressure indicator light. An ***oil level sensor*** is used to warn the driver to add oil to the engine. The sensor is usually mounted in the oil pan and can be a float-variable resistance type or an optical-type sensor, **Figure 49-29**.



Mercedes-Benz

Figure 49-29. This low oil level sending unit uses a float and switch to operate a dash indicator. If the oil level becomes low from leakage or consumption, the float drops to close the switch and turn the dash light on. The driver then knows to add oil before the level is low enough to cause damage.

Low Oil Pressure Safety Circuit

A ***low oil pressure safety circuit*** can be used to shut off the engine if oil pressure drops too low. This will protect the engine from major damage in case of a lubrication system failure or loss of oil pressure. The circuit usually disables the ignition system to keep the engine from starting or running.

The oil pressure switch or sending unit is wired to the engine control module. If the ECM detects a dangerously low oil pressure, it disables the engine ignition system. This prevents an "uninformed driver" from continuing to drive the vehicle without oil pressure and avoids destruction of the engine.

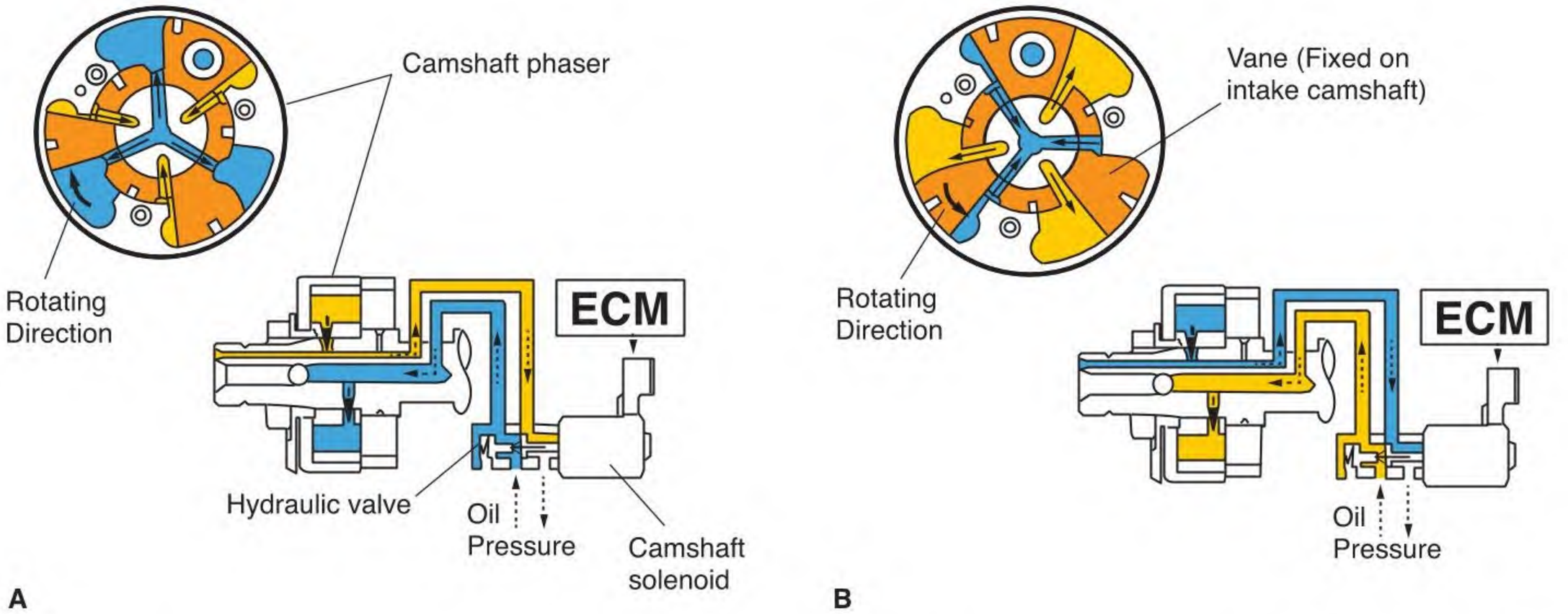
Variable Camshaft Timing

Variable camshaft timing allows engine oil pressure to operate hydraulic camshaft phaser sprockets and other hydraulic actuators in the valve train. Variable camshaft timing allows for more optimum engine performance, reduced emissions, and increased fuel efficiency compared to engines with fixed camshafts. With a conventional fixed camshaft, valve timing must be initially set for either low-rpm power or high-rpm power. For this reason, all manufacturers are going to variable cam timing.

The basic parts of a variable camshaft timing system and their functions are as follows:

- ***Camshaft phaser***—The camshaft phaser replaces the fixed chain or belt sprocket with a hydraulic camshaft timing sprocket, or cam actuator. Each camshaft phaser uses high-engine oil pressure to rotate the camshaft in relation to its drive sprocket. Refer to **Figure 49-30**.
- ***Camshaft solenoid***—This solenoid opens and closes phaser oil passages to retard or advance the camshafts in relation to crankshaft position. Oil flow control solenoids bolt to the cylinder heads, usually near the camshaft oil supply gallery.
- ***Cam phaser hydraulic valve***—This valve reacts to electric solenoid action to redirect oil flow into and out of the camshaft phaser(s). Oil flow into one chamber of the phaser might retard cam timing and advance camshaft timing in the other direction.
- ***Engine speed sensor***—Feedback on actual camshaft timing is given by this sensor.
- ECM or powertrain control module—Sensor data is analyzed by the ECM to adjust camshaft timing (and sometimes camshaft lift and duration) for ideal cam timing under any driving condition. The

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Figure 49-30. Study how a camshaft phaser advances or retards valve timing for maximum volumetric efficiency. A—With oil directed into the cam phaser in one direction, cam timing is advanced so engine valves open sooner in the 4-stroke cycle. B—With motor oil flowing into the phaser in the opposite direction, hydraulic pressure rotates the camshaft with crankshaft rotation to retard intake or exhaust valve timing.

ECM can then send electrical control pulses to the oil flow solenoids or actuators to change cam timing and cam lobe lift and duration.

The camshaft phaser contains a hydraulic motor or plunger that can move and rotate the inner half of the phaser sprocket. This in turn rotates the camshaft in relation to the engine crankshaft sprocket, timing chain, gears, or belt. The ECM automatically adjusts camshaft timing to produce the ideal valve action for any engine speed or load (power output). Modern engines can control their idle speeds by reducing camshaft lift and duration while adjusting cam timing. This ensures a clean, efficient, full fuel burn during combustion, especially at slow idle speeds or when the engine is cold.

An ***exhaust camshaft phaser*** aids in lower emissions by closing the exhaust valves before all of the end gas has been expelled from the cylinder. The exhaust valve timing can be advanced to leave some burned gases in the combustion chambers. By limiting maximum combustion temperature on the next stroke, the exhaust cam timing can replace the exhaust gas recirculation (EGR) system to lower NO_x emissions.

The ***intake camshaft phaser*** primarily increases engine power and torque by closely controlling airflow past the valves and into the cylinders. High-efficiency engines commonly use variable cam timing.

By retarding camshaft timing during installation, an engine will develop more high-speed power but less low-end torque. There is more time for the cylinders to fill with air on the intake strokes at high rpms.

By advancing camshaft timing, the same engine will make more low-rpm power and torque. This will make the engine valves open sooner to aid engine operation at idle speeds.

Variable Camshaft Lift and Duration

A variable camshaft lift and duration system is also electro-hydraulic, but it shifts the cam followers to ride on different cam lobe profiles. Similar to the system just discussed, the ECM reads sensor signals to determine engine rpms. It can then energize solenoids to direct engine oil pressure to switch the valve train to ride on top of high-speed cam lobes (longer lift, longer duration profile).

Summary

- The lubrication system forces oil to high friction points in the engine to protect moving parts from friction, wear, and damage.
- Engine oil, also called *motor oil*, is needed to keep moving parts in an engine from making direct contact.

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- A friction bearing, also called plain bearing, has two smooth surfaces sliding on each other.
- An antifriction bearing uses balls or rollers to avoid a sliding action between the bearing surfaces.
- Oil viscosity, also called *oil weight*, is the thickness or fluidity (flow ability) of the engine oil.
- Multiviscosity oil, or multiweight oil, will exhibit operating characteristics of a thin, light oil when cold and a thicker, heavier oil when hot.
- An oil service rating is a set of letters printed on the oil bottle to denote how well the oil will perform under operating conditions.
- The oil pickup is a tube extending from the oil pump to the bottom of the oil pan.
- The oil pump is the "heart" of the engine lubrication system; it forces oil out of the pan, through the engine filter, galleries, and to the engine bearings.
- A pressure relief valve limits maximum oil pressure. It is a spring-loaded bypass valve in the oil pump, engine block, or oil filter housing.
- An oil filter removes small metal, carbon, rust, and dirt particles from the engine oil. It protects the moving engine parts from abrasive wear.
- Oil galleries are small passages through the cylinder block and head for lubricating oil.
- An oil pressure switch is opened and closed by oil pressure so that it can operate the dash oil pressure indicator light.
- An oil pressure sending unit uses a variable resistor to operate the oil pressure gauge and the warning light.
- Variable camshaft timing allows engine oil pressure to operate hydraulic camshaft phaser sprockets and other hydraulic actuators in the valve train. This allows for more optimum engine performance, reduced emissions, and increased fuel efficiency.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

antifriction bearing
belt-driven oil pump
bio-based oils
cam phaser hydraulic valve
camshaft phaser
camshaft solenoid
cartridge oil filter
crankshaft-driven oil pump
dry sump
engine oil
engine sludging
engine speed sensor
exhaust camshaft phaser
filter bypass valve
filter element
friction bearing
gear oil pump
gear-driven oil pump
intake camshaft phaser
low oil pressure safety circuit
lubrication system
main oil galleries
metal additives
motor oil
multiviscosity oil
oil additives
oil clearance
oil cooler
oil filter
oil galleries
oil level sensor
oil pan
oil pan baffle
oil pickup
oil pressure gauge
oil pressure indicator
oil pressure sending unit
oil pressure switch
oil pump
oil service rating
oil viscosity
oil weight
phosphorous additives
pickup screen
positive crankcase ventilation system
pressure relief valve
pressure-fed oiling
rotary oil pump
scavenge pump
shaft-driven oil pump
single-viscosity oil
spin-on oil filter
splash oiling
structural oil pan
sump
synthetic oils
vane oil pump
variable camshaft timing
variable volume oil pump
viscosity number

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Activities

1. Visit an auto supply store. List the API service ratings (SA, SE, and so on) for several brands of 10W-30 oil. Do the ratings differ, or do all brands have the same ratings? List the price per quart for each brand that has an SL rating. Which brand represents the best buy?
2. Using either a CAD program on a computer or conventional drafting equipment, draw a cross-sectional view of a typical spin-on oil filter. Label the parts and use arrows to show oil movement through the filter.
3. Interview the manager or owner of a business that performs "while you wait" oil changes. Has he or she noticed any changes in customer habits (waiting longer between oil changes or changing more frequently, changing brands of oil, or purchasing additional services such as an air-conditioning recharge or transmission fluid change)? Does he or she expect the business to be larger, smaller, or about the same in five years? Would she or he suggest the oil change business as an opportunity for a young entrepreneur? Report to the class on your interview.

Review Questions

Answer the following questions using the information provided in this chapter.

1. What are the main functions of a lubrication system?
2. List and describe the major parts of an engine lubrication system.
3. How does engine oil protect parts from excess wear?
4. _____ is the small space between moving engine parts for the lubricating oil film.
5. Explain the difference between friction and antifriction bearings.
6. Oil _____, also called oil _____, is the thickness or fluidity of the motor oil.
7. SAE 30 weight oil is thicker and less fluid than SAE 40 weight oil. True or False?
8. What is a multiweight oil?
9. Pressure-fed oiling is *not* commonly used with:
   (A) crankshaft bearings.
   (B) camshaft bearings.
   (C) hydraulic lifters.
   (D) cylinder walls.
10. There are three basic types of engine oil pumps: _____, _____, and _____ types.
11. How does a pressure relief valve work?
12. Why is an oil filter very important to engine service life?
13. Why is an oil cooler sometimes used?
14. _____ are small passages through the cylinder head and block for lubricating oil.
15. Summarize the operation of an oil pressure gauge circuit.

ASE-Type Questions

1. Each of the following is an engine lubrication system function *except*:
   (A) cleans inside of engine.
   (B) helps cool engine parts.
   (C) prevents heat transfer.
   (D) increases fuel economy.
2. Which of the following separates engine parts to prevent metal-on-metal contact?
   (A) Oil film.
   (B) Bearings.
   (C) Galleries.
   (D) Additives.
3. Which type of bearings use balls or rollers?
   (A) Cam.
   (B) Plain.
   (C) Friction.
   (D) Antifriction.
4. Oil "viscosity" refers to a motor oil's:
   (A) fluidity.
   (B) thickness.
   (C) flow ability.
   (D) All of the above.
5. The highest API oil service rating for gasoline engines is:
   (A) CG-4.
   (B) SJ.
   (C) SN.
   (D) CF.

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6. Oil additives are used to prevent:
   (A) deposits.
   (B) foaming.
   (C) oxidation.
   (D) All of the above.
7. Pressure-fed oiling is provided by the oil pump to each of the following *except*:
   (A) lifters.
   (B) timing chain.
   (C) camshaft bearings.
   (D) crankshaft bearings.
8. Which of the following holds an extra supply of oil for a lubrication system?
   (A) Oil pan.
   (B) Oil pump.
   (C) Oil pickup.
   (D) Oil galleries.
9. While discussing oil pump drive methods, Technician A says an oil pump can be directly engaged to and powered by the crankshaft snout. Technician B says an oil pump can be driven by a cogged belt. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. A pressure relief valve can be located in the:
   (A) oil pump.
   (B) engine block.
   (C) oil filter housing.
   (D) Any of the above.

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Chapter 50
Lubrication System Diagnosis, Testing, and Repair

After studying this chapter, you will be able to:

- List common lubrication system problems and symptoms.
- Diagnose lubrication system troubles.
- Measure engine oil pressure with a test gauge.
- Change engine oil and filter and flush an oiling system.
- Locate and correct engine oil leaks.
- Remove and install an oil pan.
- Service an oil pump.
- Test and repair an oil pressure indicating light and gauge.
- Explain how to analyze the operation of camshaft phasers with a scan tool.
- Describe safe working practices to use when testing, servicing, or repairing a lubrication system.
- Correctly answer ASE certification test questions on the testing, service, and repair of engine lubrication systems.

Without a well-maintained lubrication system, an engine will "self-destruct" in a matter of minutes. Major damage to the engine bearings, crankshaft, piston rings, and other parts can result. As you will learn, a total loss of engine oil pressure can quickly damage and ruin many engine parts. No engine oil pressure can be caused by the following:

- Low oil level in the sump.
- Broken oil pump gears.
- Broken oil pump drive mechanism.
- Clogged inlet strainer in engine sump.
- Stuck-open oil pressure relief valve.
- Badly worn rod or main bearings.
- Broken valve train parts leaking large amounts of oil pressure.

Without proper circulation of clean, filtered motor oil, engine rod and main bearings, piston rings, cylinder walls, camshaft lobes, cam bearings, and costly cylinder blocks can be ruined very quickly. Without specified oil pressure and flow, the engine rings and bearings can lock up or weld together in a few miles of driving. The crankshaft cannot rotate by hand (using a breaker bar on the crankshaft snout bolt) or with the electric starting motor (12-volt or HV starting system). This is because the piston rings have welded against the cylinder walls or the bearings have heat seized.

This chapter summarizes the most common service and repair operations performed on an engine lubrication system. It prepares you for typical repair tasks, including servicing oil-operated camshaft phasers and variable lift/duration valve trains. Study this chapter thoroughly.

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Lubrication System Diagnosis and Repair

To troubleshoot an engine lubrication system, begin by gathering information. Ask the vehicle owner or service writer questions like these:

- Does the oil light flicker or stay on?
- Do you hear any abnormal engine noises?
- Has the engine been dripping oil?
- Does oil need to be added frequently?
- When was the last time the oil and filter were changed?
- Does blue smoke come out of the exhaust pipe?

This type of questioning may give you essential information for problem diagnosis. Analyze the symptoms using your understanding of lubrication system and engine operation. You should then be able to arrive at some logical possible causes of the problem.

Lubrication System Problems

The problems found in a lubrication system are limited in number and include the following:

- High oil consumption—Oil must be added to engine frequently.
- Low oil pressure—Dash gauge reads low, indicator light glows, or abnormal engine noises are present.
- High oil pressure—Gauge reads high; oil filter is swelled or ruptured.
- Defective indicator or gauge—Readings are inaccurate or there are no indicator readings.

When diagnosing lubrication system troubles, visually inspect the engine for obvious problems. Check for oil leakage, a disconnected sending unit wire, a low oil level, a damaged oil pan, or other troubles that would relate to the symptoms. See **Figure 50-1**.

Engine Sludge

Engine sludge is a thick black or brown coating of deteriorated oil that forms inside an engine when its oil and filter have not been changed at regular intervals. Sometimes called an "engine's black death," the dark oil sludge looks like thick chocolate pudding. You can check for engine sludge by inspecting the inside oil filler cap and camshaft cover on the engine. If your fingertip turns dark brown or black when rubbing over the engine's inner surfaces, engine sludge is indicated. See **Figure 50-2**.

Tech Tip

After engine oil has been used in an engine for 20,000 miles or more, the oil will chemically change into a semisolid film of sludge, coating all internal engine parts. If the oil breaks down too much, the lubricant will become so thick that it will no longer flow out of the oil pan. The engine sludge will starve the engine of motor oil, causing catastrophic damage from increased part friction. Refer to **Figure 50-3**.

Oil Contamination from Water

Engine oil contamination from water will turn oil white or yellowish in color. Rainwater can get into the oil if the air filter or oil filler cap was left uncovered while the hood was open. A cracked head, blown head gasket, or cracked cylinder block can also allow water from the antifreeze into the lubrication system. When stirred and circulated by the oil pump, the water and oil mix will fill with air bubbles, changing the color and consistency of the oil.

Tech Tip

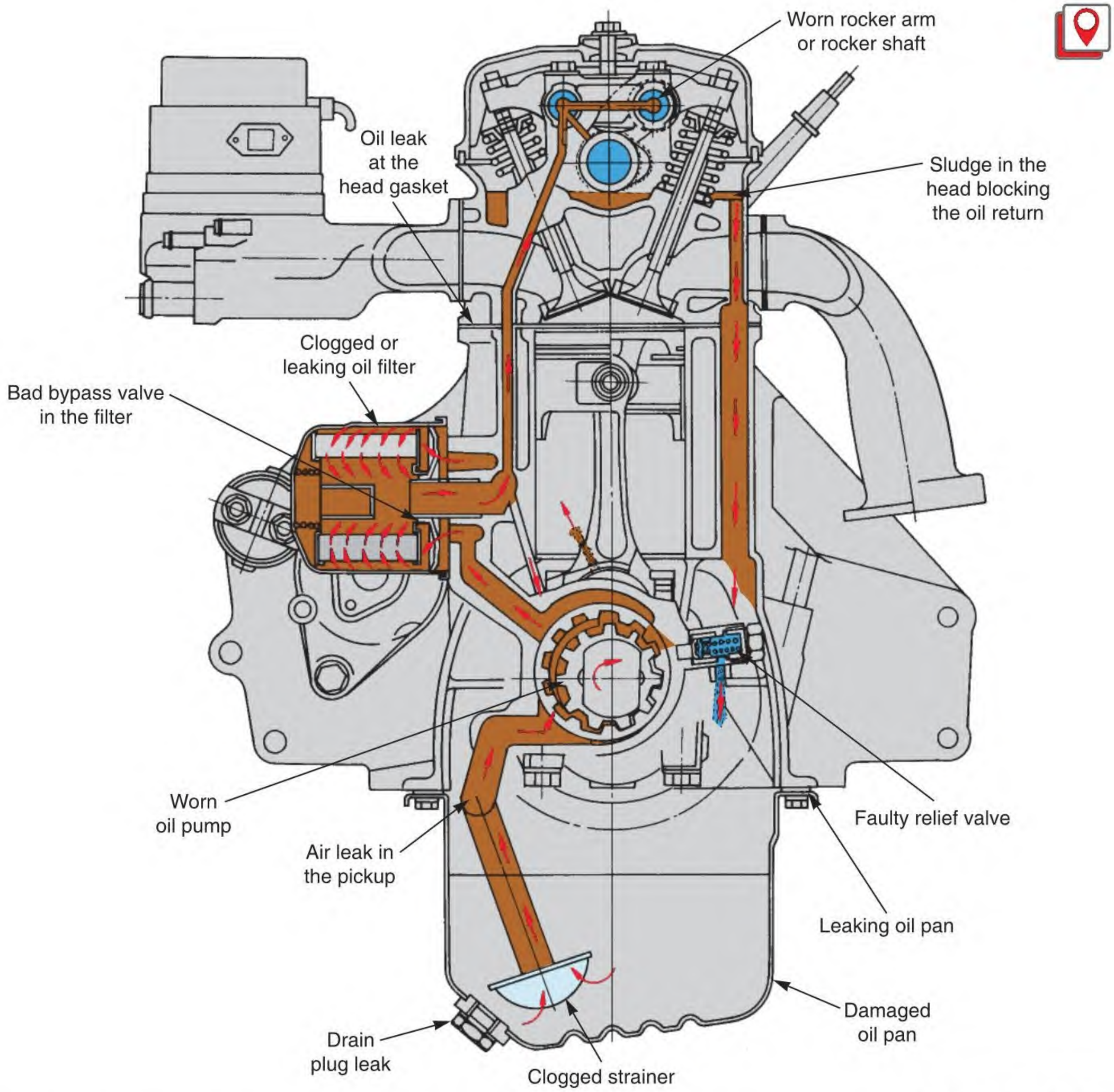
A trick for finding small amounts of water in an engine's motor oil is a basic ***oil burn test***. Hold a lit match or lighter flame against the oil on the dipstick. If there is even a slight amount of moisture (H_2O) in the oil, it will make a "cracking and popping sound" as it comes to a boil. Pure oil (no moisture), however, burns quietly, producing just blue smoke.

As always, take proper precautions when performing this or any engine experiment.

High Oil Consumption

High oil consumption is caused by external oil leakage out of the engine or by internal oil leakage into the combustion chambers. If the vehicle owner must frequently add oil to the engine, this is a symptom of high oil consumption.

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Figure 50-1. Note some of the problems that can develop with an engine lubrication system.

Remember, even new engines consume some motor oil when running. Some oil must flow past the piston rings to coat the upper area of the cylinder walls. However, good piston rings, cylinder walls, and valve seals will limit oil consumption to about one quart of oil per oil change (every 5000 miles).

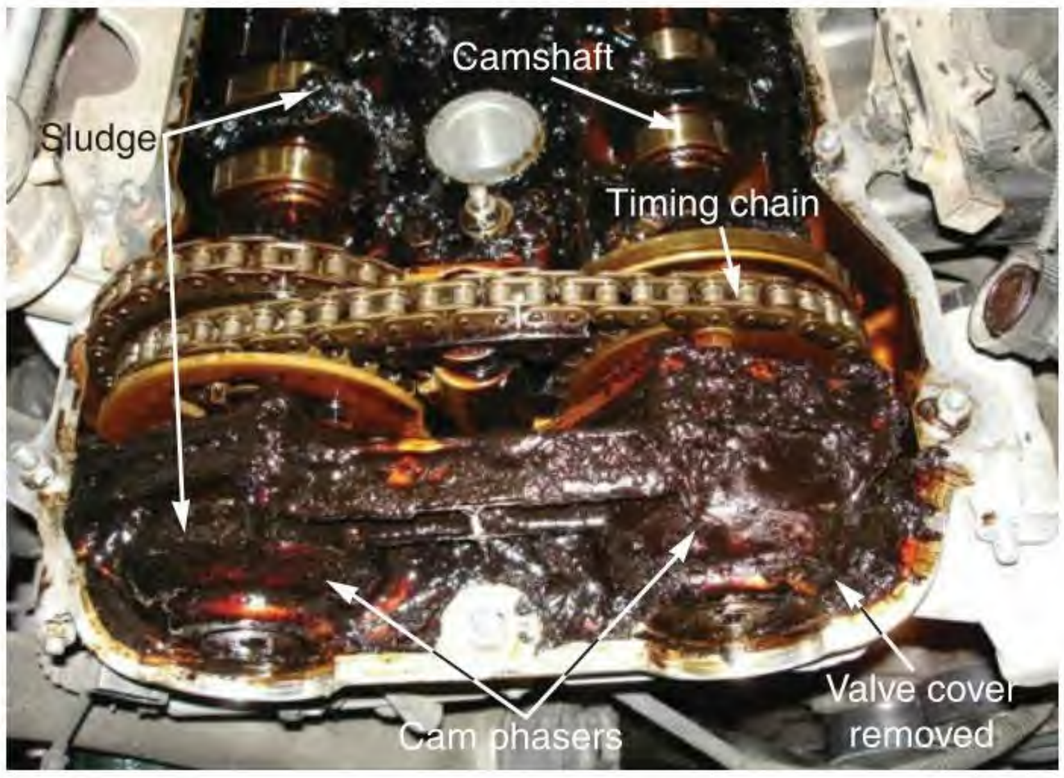
External Oil Leaks

External oil leakage is easily detected as darkened, oil-wet areas on or around the engine. Oil may also be found in small puddles under the vehicle. Leaking gaskets or seals are usually the source of external engine oil leakage.

To locate oil leakage, you may need to raise the vehicle on a lift and look for leaks under the engine. Trace the oil leakage to its highest point. The parts around the point of leakage may be washed clean by the constant flow of oil.

If necessary, steam clean or power wash the engine to remove the oil. This will let you trace the source of a leak more easily.

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Figure 50-2. This engine suffered the "Black Death" of oil sludge damage. Oil sludge blocked oil drain passages out of the head, resulting in buildup of sludge around cam phasers. The car owner, instead of having to pay a little for an oil and filter change, had to pay a lot more for a whole new engine assembly.

Oil dye is sometimes added to engine oil when checking for external oil leaks. The dye is fluorescent, and an ultraviolet light can be used to make it glow. When the light is aimed on an oil leak, the dye will appear a light yellowish-orange color. The leak can then be easily traced to its source.

After locating the point of leakage, you must service the gasket, seal, or component at fault. Oil seals are a common source of leaks. Sometimes a seal can wear a groove into its mating part.

Internal Oil Leakage

Internal oil leakage shows up as blue smoke coming out of the engine's exhaust. For example, if the engine piston rings and cylinders are badly worn, oil can leak past the ring seal on the cylinder walls and burn during combustion. When too much oil is burned in a piston engine, it creates a distinctive blue smoke from the tailpipe upon acceleration.

Tech Tip

Do not confuse black engine exhaust smoke (excess fuel in a cylinder) or white smoke (water leakage into a gasoline engine cylinder) with the blue smoke caused by motor oil being burned in cylinders.

Low Oil Pressure

Low oil pressure is indicated when the oil indicator light glows, the oil gauge reads low, or the engine lifters or bearings rattle and knock from lack of lubrication.

There are several causes of low oil pressure:

- Low oil level—Oil is not high enough in the pan to cover the oil pickup. This is the most common reason for low oil pressure.
- Worn connecting rod or main bearings—Pump cannot provide enough oil volume to adequately pressurize the engine bearings.
- Thin or diluted oil—There is low oil viscosity or gasoline in the oil. Switching to a heavier oil may solve this problem.
- Weak or broken pressure relief valve spring—Valve is opening too easily.
- Cracked or loose oil pump pickup tube—Air is being pulled into the oil pump.
- Worn oil pump—There is excess clearance between the rotor or gears and the housing.
- Clogged oil pickup screen—A reduced amount of oil is entering the pump.

A low oil level is a common cause of low oil pressure. Always check the oil level first when troubleshooting a low pressure problem, **Figure 50-4**.

Tech Tip

A few engines do not have a conventional oil level dipstick. An oil pan sensor will illuminate a low oil level indicator light in the dash if the engine needs oil. If you suspect sensor problems, you can often find and remove the plug in the dipstick test tube. After removing the plug, insert a special dipstick tool through the tube and into the oil pan to measure actual oil level. Refer to **Figure 50-5**.

High Oil Pressure

High oil pressure causes the gauge to read higher than normal and can cause the oil filter to rupture. This is seldom a problem. There are four common causes of high oil pressure:

- Pressure relief valve stuck closed—Valve is not opening at the specified pressure.

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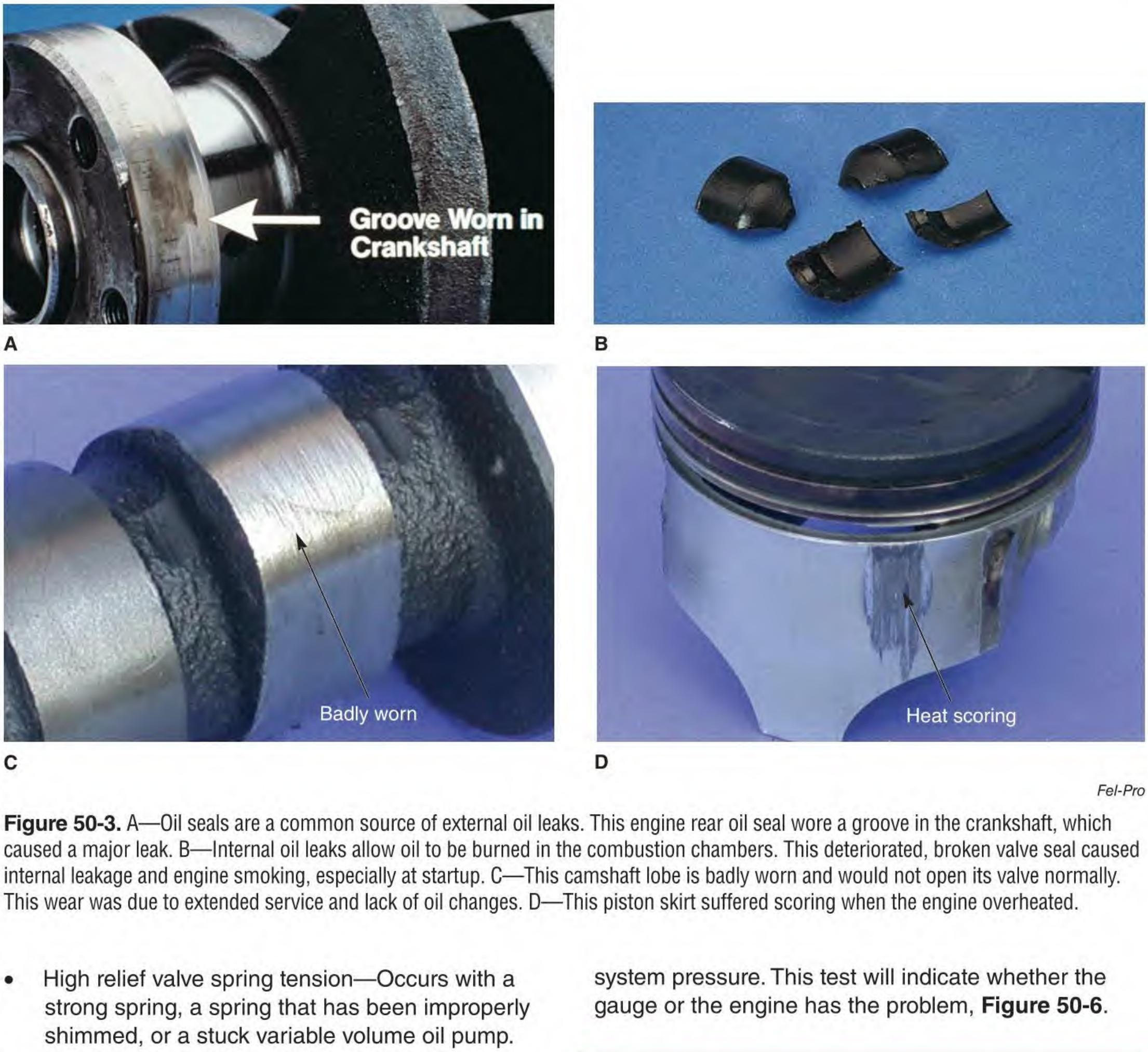


Figure 50-3. A—Oil seals are a common source of external oil leaks. This engine rear oil seal wore a groove in the crankshaft, which caused a major leak. B—Internal oil leaks allow oil to be burned in the combustion chambers. This deteriorated, broken valve seal caused internal leakage and engine smoking, especially at startup. C—This camshaft lobe is badly worn and would not open its valve normally. This wear was due to extended service and lack of oil changes. D—This piston skirt suffered scoring when the engine overheated.

- High relief valve spring tension—Occurs with a strong spring, a spring that has been improperly shimmed, or a stuck variable volume oil pump.
- High oil viscosity—Occurs when excessively thick oil or oil additives that increase viscosity are used.
- Restricted oil gallery—Occurs from a defective block casting or debris in the oil passage.

Defective Indicator or Gauge

A defective oil pressure indicator or gauge may appear to be a low or high oil pressure problem. The sending unit, circuit wiring, or gauge may be at fault.

Oil Pressure Test

An ***oil pressure test*** uses a pressure gauge installed on the engine to measure actual lubrication system pressure. This test will indicate whether the gauge or the engine has the problem, **Figure 50-6**.

Service Procedure

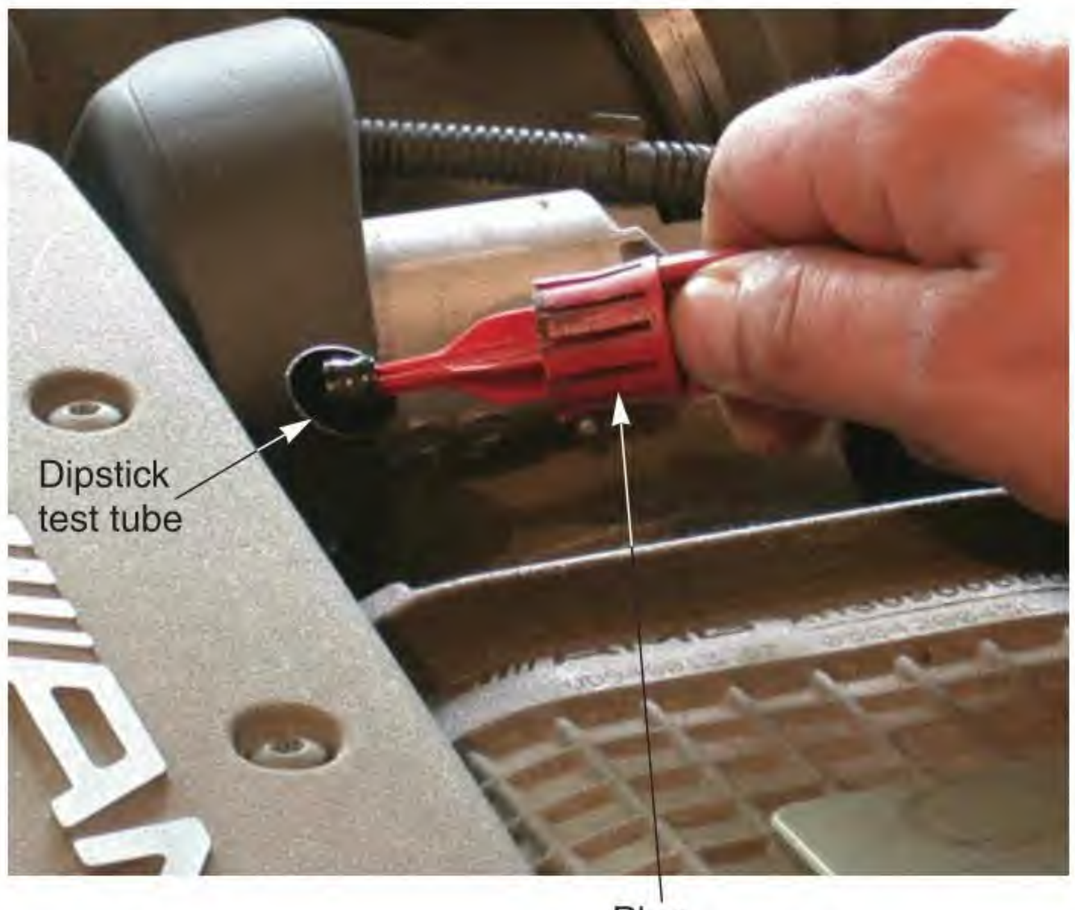
To measure actual engine oil pressure:

1. Disconnect the battery to prevent accidental engine cranking.
2. Double-check that the engine is full of oil and that the oil is clean.
3. Change the engine motor oil if it is runny, gritty (not slick to the touch), or dirty (black or dark brown).

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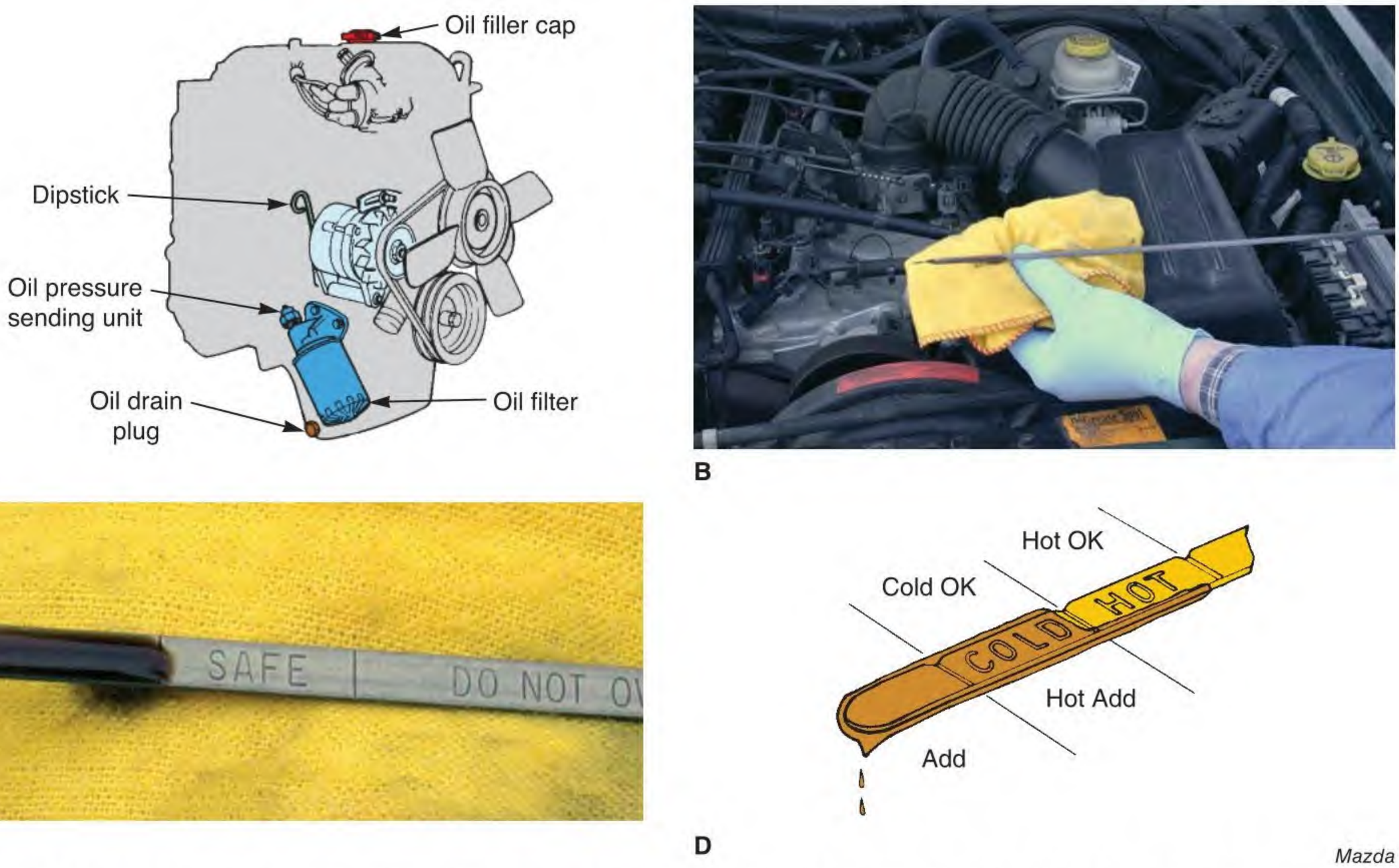
4. Remove the engine oil sending unit from the engine. Use a crowfoot socket or special-sensor socket if an open-end wrench is obstructed.
5. Screw a test fitting into the opening for the oil sending unit or oil pressure sensor.
6. Attach the oil pressure test gauge to this fitting.
7. Start and warm the engine.
8. Run the engine at the rpms specified in the service manual.
9. Read the test gauge at idle at about 3000 rpms. Note maximum oil pressure at low and high engine speeds.
10. Compare the reading to specifications.
11. If oil pressure is too low or high, make repairs as needed.

Depending on the number of miles on the engine and the type of engine, oil pressure should be at least 20 psi to 30 psi (140 kPa to 210 kPa) at idle and 40 psi to 60 psi (275 kPa to 410 kPa) at cruising speeds.



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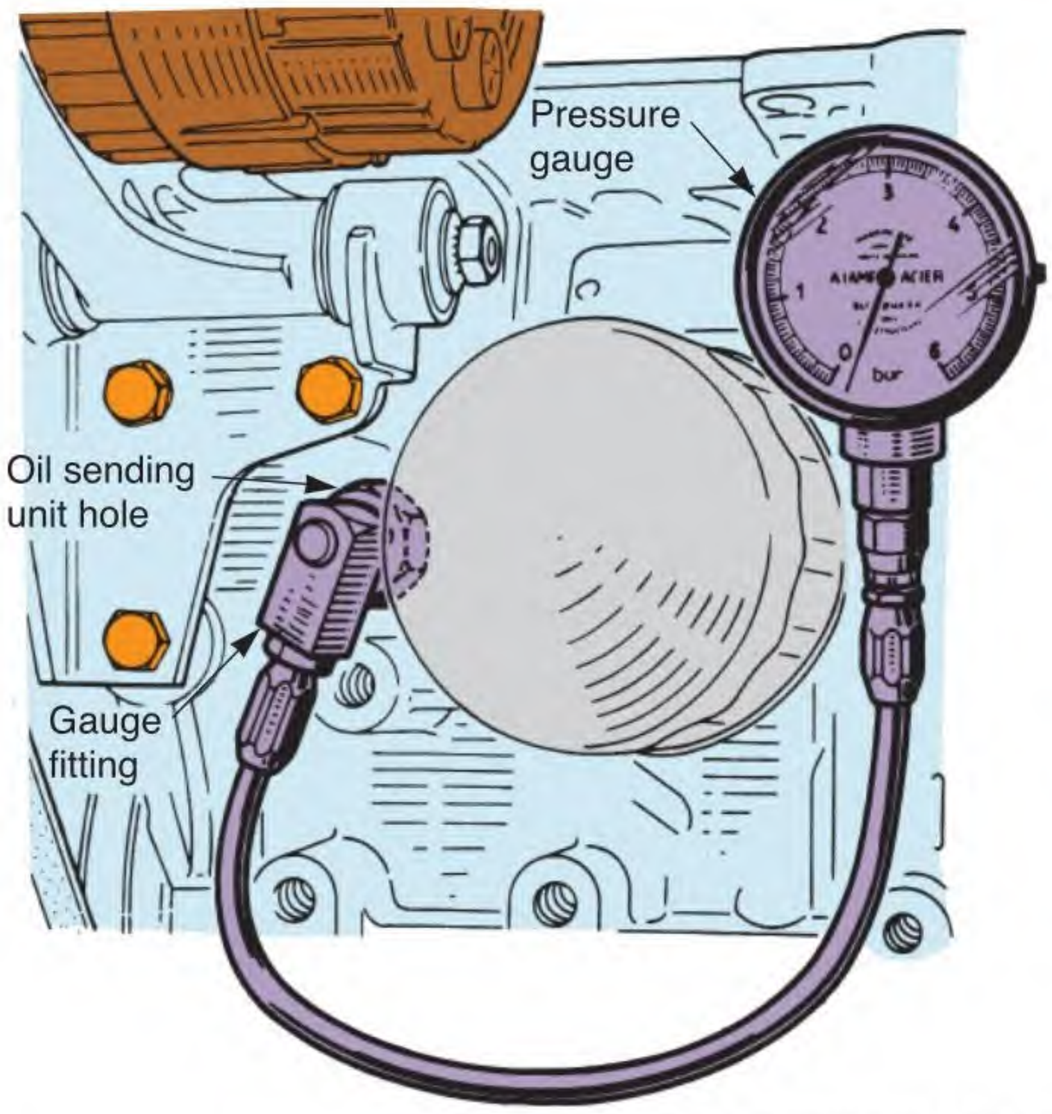
Figure 50-5. If the engine does not have a normal oil level dipstick, you can install a test dipstick into the engine oil pan through a test tube on the engine to manually check the oil level. Refer to the service manual for the location of the tube. The dipstick test tube and plug are right behind the supercharger on top of this engine.



Mazda

Figure 50-4. Checking engine oil. A—Typical locations for the filler cap, dipstick, and oil filter. B—Wipe the dipstick off, reinsert it, and remove it to get an accurate oil level reading. C—Note the highest point of oil on the dipstick. D—When checking the oil level, make sure you use the correct markings on the dipstick.

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Figure 50-6. A pressure gauge can be used to measure actual engine oil pressure. The gauge is normally screwed into the hole for the oil sending unit. Measure the oil pressure with engine warm and at the specified engine speed.

Late-model high-performance engines can have much higher oil pressure specifications. Variable volume oil pumps can produce 60 psi (420 kPa) of oil pressure at idle and up to 100 psi (700 kPa) at higher engine speeds. Check the service manual for exact oil pressure specifications for the make and model engine for both idle and high rpms.

Warning

Wear safety glasses when checking engine oil pressure. If hot oil squirts into your eye, a painful injury could result. This is especially true when working on engines with high internal oil pressures, even at curb idle speed.

Engine Oil and Filter Service

It is extremely critical that the engine's oil and oil filter are serviced regularly. Lack of oil and filter maintenance can greatly shorten engine service life.

After several thousand miles of driving, used oil will be contaminated with dirt, metal particles, carbon, gasoline, ash, acids, and other harmful substances. Corrosive chemicals and some of the smallest particles are not trapped in the oil filter. They will circulate through the engine, greatly increasing part wear and corrosion.

Oil and Filter Change Intervals

All automakers provide ***oil change intervals*** for their vehicles. These intervals specify the maximum number of miles (or kilometers) a vehicle can be driven between oil changes. If the oil is not changed at this interval, the vehicle's warranty will become void.

Service information on the specific make vehicle should be referenced. For maximum engine service life, it is best to change the engine oil and filter about every 3000 miles (4800 km). Synthetic oils can be used a little longer.

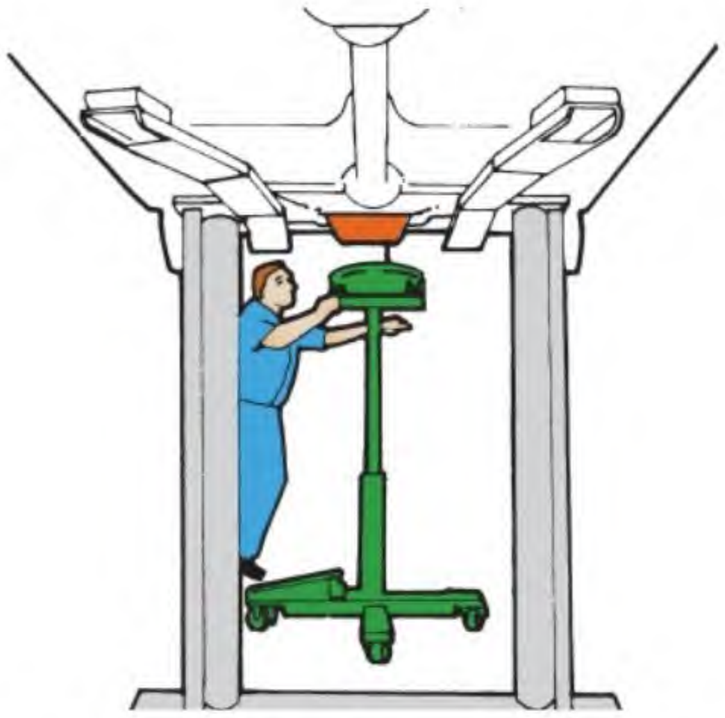
If a vehicle is only driven for short periods and then parked, its oil should be changed more often. Since the engine may not be reaching full operating temperature, the oil can be contaminated with fuel, moisture, and other substances more quickly. Diesel engines and turbocharged or supercharged engines usually require more frequent oil and filter service than naturally aspirated (non-supercharged) engines.

An older, worn engine (loose bearings, worn piston rings and cylinders) will contaminate the oil more quickly than a new engine. More combustion by-products will blow past the rings and enter the oil more quickly. Also, all bearing clearances will be larger, requiring more of the oil from the oil pump or a thicker oil to fill the increased bearing clearances. Therefore, older, high-mileage engines should have their oil changed more frequently, using a heavier oil viscosity than is specified for newer engines. The heavier oil will not only raise engine oil pressure, but also cushion and quiet minor engine knocking noises caused by worn bearings.

Changing Engine Oil and Filter

To change the engine oil, warm the engine to full operating temperature. This will help suspend debris in the oil and make the oil drain more thoroughly. Then, follow the basic steps shown in **Figure 50-7**.

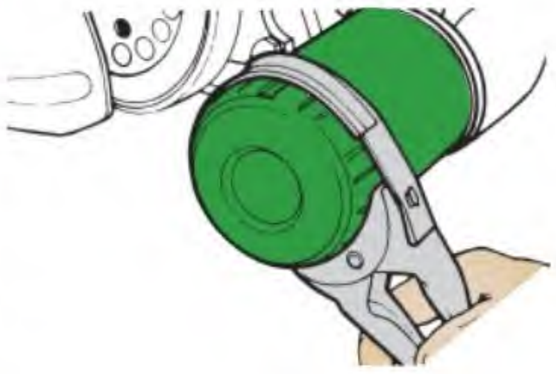
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1. Raise the vehicle and place a catch pan under the drain plug.



2. Unscrew the drain plug and allow oil to pour into the pan.



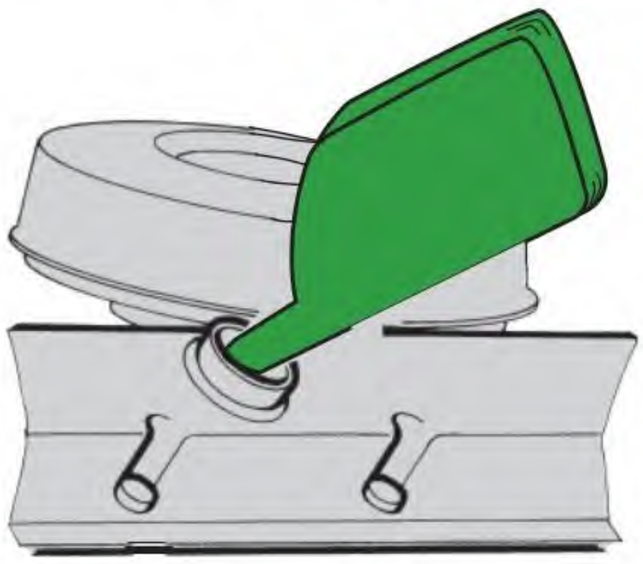
3. Use a filter wrench (turn counterclockwise) to remove the old filter.



4. Wipe clean oil on the new filter O-ring.



5. Install and tighten the new oil filter by hand. Make sure hands and filter are clean and dry.



6. Install the correct type and quantity of oil.

Chrysler

Figure 50-7. Review the steps for changing engine oil and filter.

Service Procedure

To change the engine oil:

1. Turn the engine off at full operating temperature.
2. Use a lift or floor jack to raise the vehicle in level position. Place jack stands under both ends of the vehicle to keep the car level for complete oil pan drainage.
3. Place a drain pan under the oil pan drain plug.
4. Unscrew the drain plug and allow oil to pour into the pan. Do not let hot oil pour out on your hand or arm.
5. If needed, replace the drain plug threads and the O-ring washer.
6. When all oil is fully drained and stops dripping, replace the drain plug in the oil pan. Tighten to specifications.

Tech Tip

Do not overtighten the oil pan drain plug; the threads will strip very easily. Accidentally stripping and ruining the oil drain plug threads is a common mistake that may require time-consuming oil pan replacement.

7. Move your catch or drain pan under the oil filter housing.

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8. Use a filter wrench to remove the old filter. If the engine uses an oil filter element, unscrew the cover over the element for filter replacement.
9. Wipe clean motor oil on the new filter's O-ring. This will aid proper installation without oil leakage from the seal.
10. Install the new oil filter by hand.

Tech Tip

Hand tighten spin-on oil filters; do not use a wrench. If you overtighten a spin-on oil filter, it will be very difficult to remove when it needs replacement or it may crush the seal and leak oil.

11. Use a wrench to snug down the cover on thicker metal oil filter element housings.
12. After the gasket (O-ring) makes contact, turn the filter or element cover another one-half to one full turn more.
13. Fill the engine with the correct amount and type of oil. The oil filler opening and cap are usually on one of the engine cam covers or valve covers.

Tech Tip

Consider using higher viscosity oil to reduce oil consumption and engine noise in high-mileage engines.

14. Start the engine and allow it to idle until warm. Check dash oil pressure (if gauge is available) and for oil leaks on the shop floor.
15. Turn the engine off and check the oil level.

Boosted-engines (forced induction engines) tend to push more combustion by-products (carbon ash) past the engine oil rings, engine oil valve seals, and blower oil seals and into the motor oil than naturally aspirated engines. Normal oil contamination from combustion gases and acid can fill motor oil with abrasives in about 3000 miles of normal driving.

Always recommend more frequent oil changes to customers driving turbocharged and supercharged engines. A turbo or supercharger depends upon clean, cool motor oil for long service life. A turbo compressor fan can "spool-up" to almost 100,000 rpms after a short period of turbo lag.

Tech Tip

Always send used engine oil to a recycling center. Recycling old oil not only saves our environment from pollution, but it also helps save our natural resources. Some shop heaters even burn used engine oil as an alternative to burning fuel.

Oil Pan Service

An engine oil pan may need to be removed for various reasons: to service engine bearings or an oil pump, repair a damaged pan or a stripped drain plug hole, or during an engine overhaul.

Service Procedure

To remove an oil pan:

1. Remove any bolted-on cross members, the exhaust crossover pipe, and other obstructions under the oil pan. Refer to factory detail instructions, if necessary.
2. If more clearance is needed to remove the oil pan, raise the engine off its motor mounts with a jack. This will normally allow enough clearance to slide the oil pan out from under the engine. See **Figure 50-8**.

Tech Tip

Some vehicle designs do not allow in-car oil pan removal. The engine must be lifted from the frame or unibody before the engine oil pan will come off. Check the service manual for details.

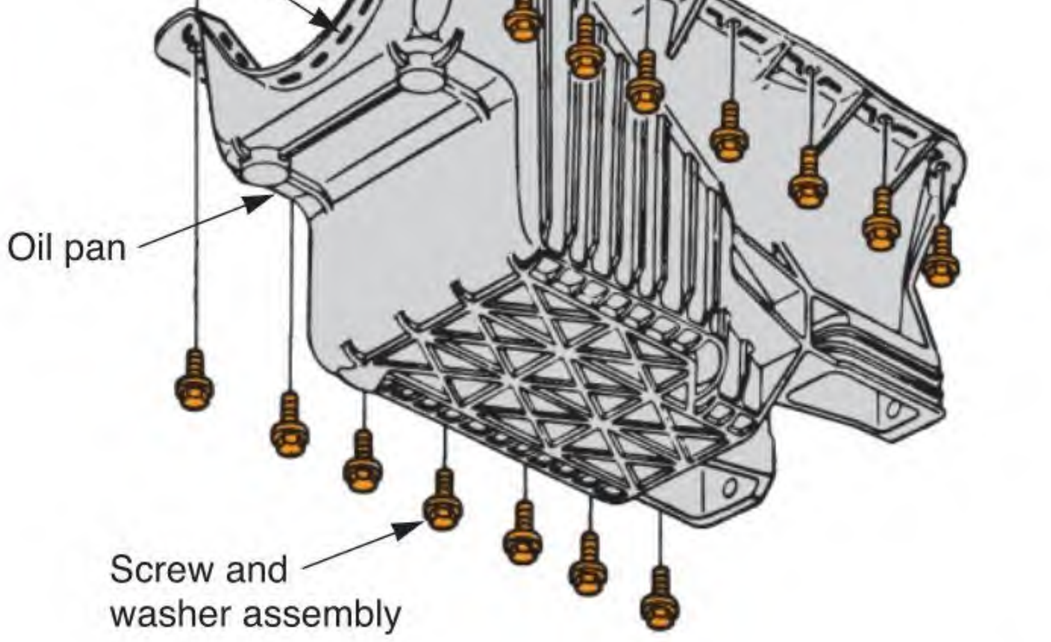
3. Drain all used oil from the pan and engine.
4. Reinstall the drain plug.
5. Unscrew the engine-to-pan bolts around the outside of the oil pan flange, **Figure 50-9**.

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6. If necessary, lightly tap on the side of the oil pan with a rubber or plastic hammer. Light mallet impacts may be needed to free the pan gasket or sealer from the cylinder block.
7. If the oil pan is stuck tight, carefully pry between the pan flange and the cylinder block without marring or nicking the sealing surfaces. Do not bend the oil pan or engine flange because oil leakage may result at the point of surface damage.
8. Using a gasket scraper or soft abrasive air tool, remove all old gasket or silicone material from the pan and engine block. Do not gouge or abrade the sealing surfaces in soft aluminum or they will leak oil.
9. Check the inside of the engine oil pan for ***engine oil debris*** (bits of rubber, plastic, aluminum, titanium, steel, brass, ductile iron, etc.). These are indications of engine mechanical problems. Also inspect the oil pump and pickup screen for debris that will help problem diagnosis. Refer to **Figure 50-10**.

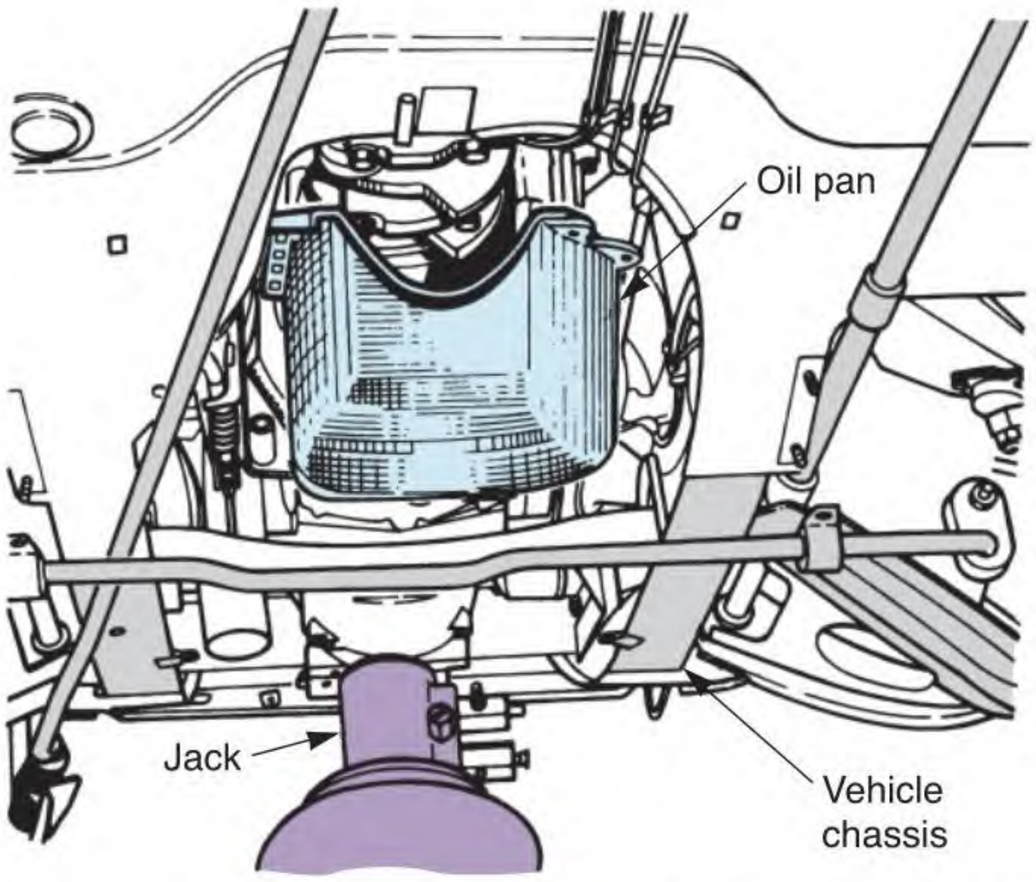
The type of debris found in motor oil indicates which engine part might have failed or broken. Examples include the following:

- Bits of hard steel may come from damaged engine bearings, crank journals, or piston rings.



Ford

Figure 50-9. The oil pan is secured by a number of bolts around the pan flange. Be careful not to bend the flange during removal.



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Figure 50-8. With some vehicles, the oil pan can be removed with the engine in vehicle. Use a jack to raise the engine off the motor mount. Then, slide the pan down and out.

- Pieces of plastic bits may be from broken timing gear teeth or other plastic engine parts.
- Pieces of hardened rubber often come from broken neoprene valve stem seals that have fallen from the cylinder head.
- Bits of aluminum may be from a broken piston skirt.

Keep the kind of material in mind when inspecting the used oil in an engine oil pan. Truck fleets often send used engine oil out to be chemically tested for contaminants. Chemical oil testing is used to better maintain engines and fix them before a major engine breakdown occurs.

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Fel-Pro

Figure 50-10. After removing the oil pan, inspect it for debris that could indicate problems. The oil pickup screen shown has picked up pieces of debris. Debris can indicate whether you have spun bearings, hardened or broken valve seals, or broken piston skirts. The type of material will give hints about trouble sources.

Installing an Engine Oil Pan

Before installing an engine oil pan, wash the pan thoroughly in cold soak cleaner. Check the drain plug hole for stripped threads. Also, lay the pan upside down on a flat workbench or use a straightedge to make sure the pan flange is not bent. If needed, straighten the flange with light hammer blows. See **Figure 50-11**.

Either a conventional gasket or silicone sealer will be recommended for oil pan installation. When installing a conventional gasket, use an approved gasket adhesive to hold the gasket in position during installation.



Fel-Pro

Figure 50-11. If the oil pan is leaking or if you had trouble removing it from the engine, use a straightedge to check for flange warpage. If the bolts were overtightened, dents can form around bolt holes. Light hammer blows will straighten the flange.

If rubber seals are used on each end of the pan, press them into their grooves dry. Then place silicone sealer where gaskets or seals come together or overlap, **Figure 50-12**. If you fail to do this, oil leakage will result.

When using a silicone sealer instead of a gasket, clean the pan and block mating surfaces with a suitable solvent. Then, run a uniform bead of sealer (about 1/8″ or 3 mm wide) around the pan or block flange as recommended. Form a continuous bead and place extra sealer at part or gasket-seal joints. See **Figure 50-13**.

Fit the pan carefully into place on the block. Be careful not to shift the gasket or smear the sealer during installation. Start all the pan bolts by hand. Then torque the bolts to factory specifications. Tighten each bolt a little at a time in a crisscross pattern. Torque specifications for thin, stamped steel oil pans range from 2 to 15 foot-pounds (0.9-6.8 kg). Torque specifications for thicker cast aluminum oil pans range from 15 to 30 foot-pounds (6.8-13.6 kg). Refer to the appropriate service literature for exact specifications.

Caution

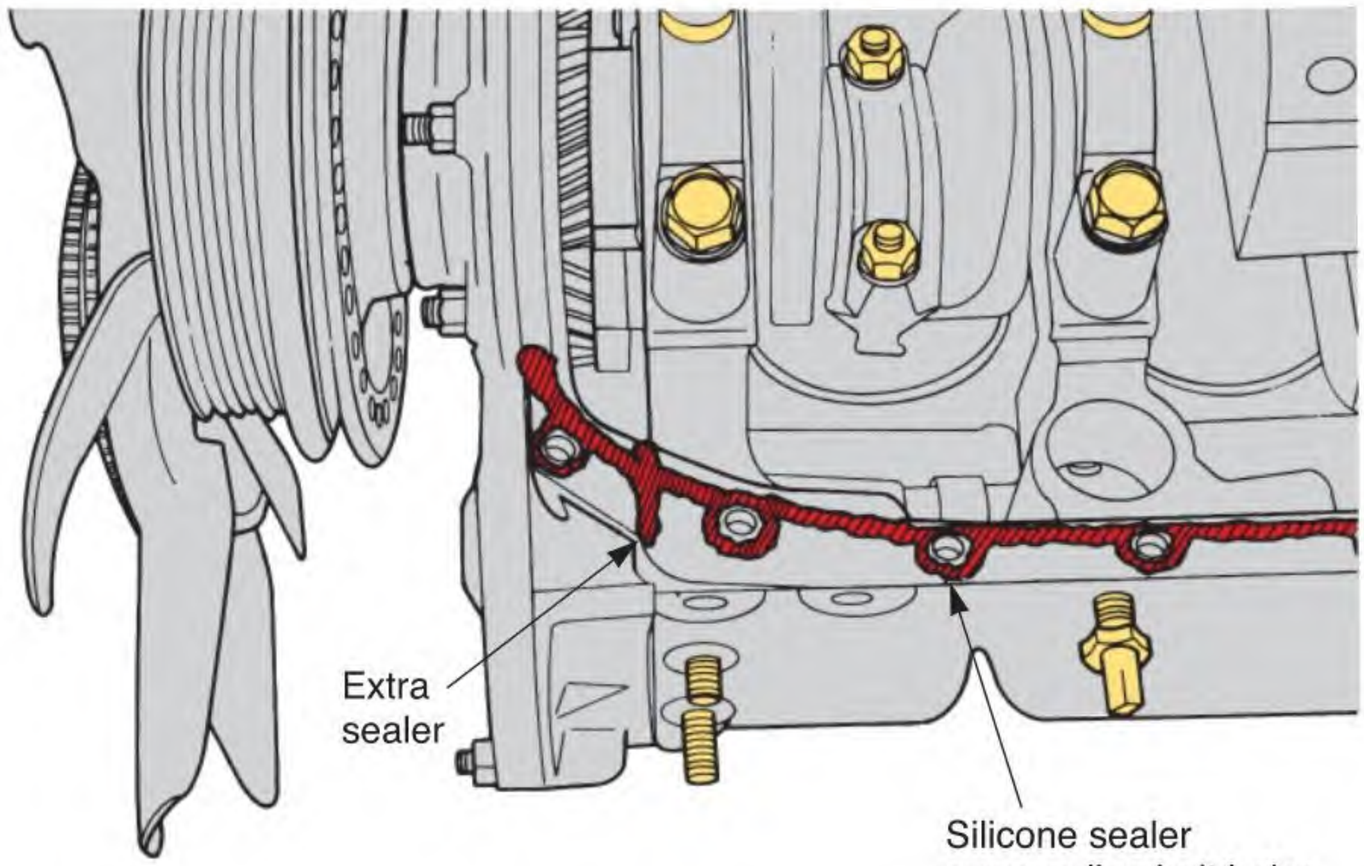
Overtightening the oil pan bolts is a common mistake. Overtightening can crush and split the oil pan gasket or warp the oil pan itself, causing oil leakage. Only moderate tightening is needed to compress the gasket and make it seal properly.



Fel-Pro

Figure 50-12. A technician is installing RTV sealer where the gasket contacts the end of the rubber seal. This will prevent leakage.

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Ford

Figure 50-13. When using silicone sealer only, clean the flange with recommended solvent. Then, carefully run a bead of sealer around the flange and all bolt holes. Use extra sealer where parts or gasket and seals butt together.

Reinstall the drain plug. You only need to snug down a drain plug to lightly compress its gasket or seal. Overtightening a drain plug can damage the threads in the pan. Fill the engine with the correct type and quantity of oil. Then start the engine and check the oil pan for leaks.

Oil Pump Service

A bad oil pump will cause low or no oil pressure and possibly severe engine damage. When inner parts of an oil pump wear, the pump may leak internally and have reduced output. The pump drive shaft can also strip in the pump or distributor, preventing pump operation. With belt drive, the belt might slip over a locked oil pump.

If pressure tests point to a faulty oil pump, remove and replace or rebuild the engine oil pump. However, make sure worn, loose engine bearings are not causing the low oil pressure problem. An open pressure relief valve will prevent a good oil pump from developing normal oil pressure.

Oil Pump Removal

Some oil pumps are located inside the engine oil pan. Others are on the front of the engine under a front cover or on the side of the engine. Removal procedures vary; refer to a shop manual for direction. Look at **Figure 50-14**.

Oil Pump Rebuild

Rather than rebuild a worn or faulty oil pump, most technicians install a new or factory-rebuilt unit. It is usually too costly to completely rebuild an oil pump in-shop. However, you should have a general understanding of how to overhaul oil pumps. Large dealerships sometimes rebuild oil pumps when the vehicle is still under warranty.

Figures 50-15 and **50-16** give the basic steps for servicing oil pumps. A factory service manual will give full instructions and specifications for the exact type of oil pump.

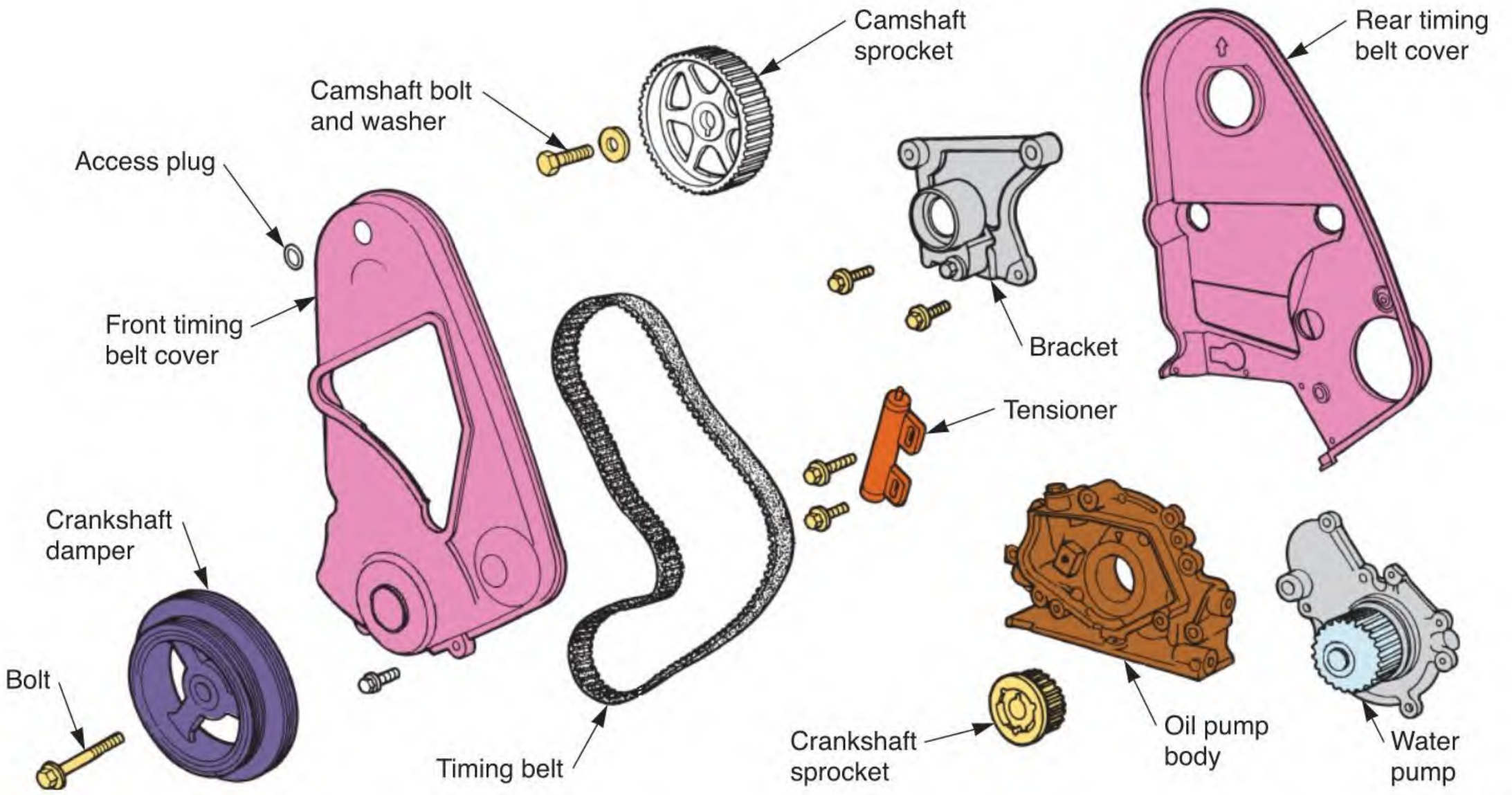
Oil Pump Installation

Before installation, prime the pump by filling it with motor oil. Pour oil into the pump inlet while turning the rotors or gears. This will ensure proper initial operation and prevent wear upon engine starting.

Install the pump in reverse order of removal. Double-check gasket position and hole alignment. Torque all bolts to specifications. If an oil pickup is used, make sure it is installed and secured properly.

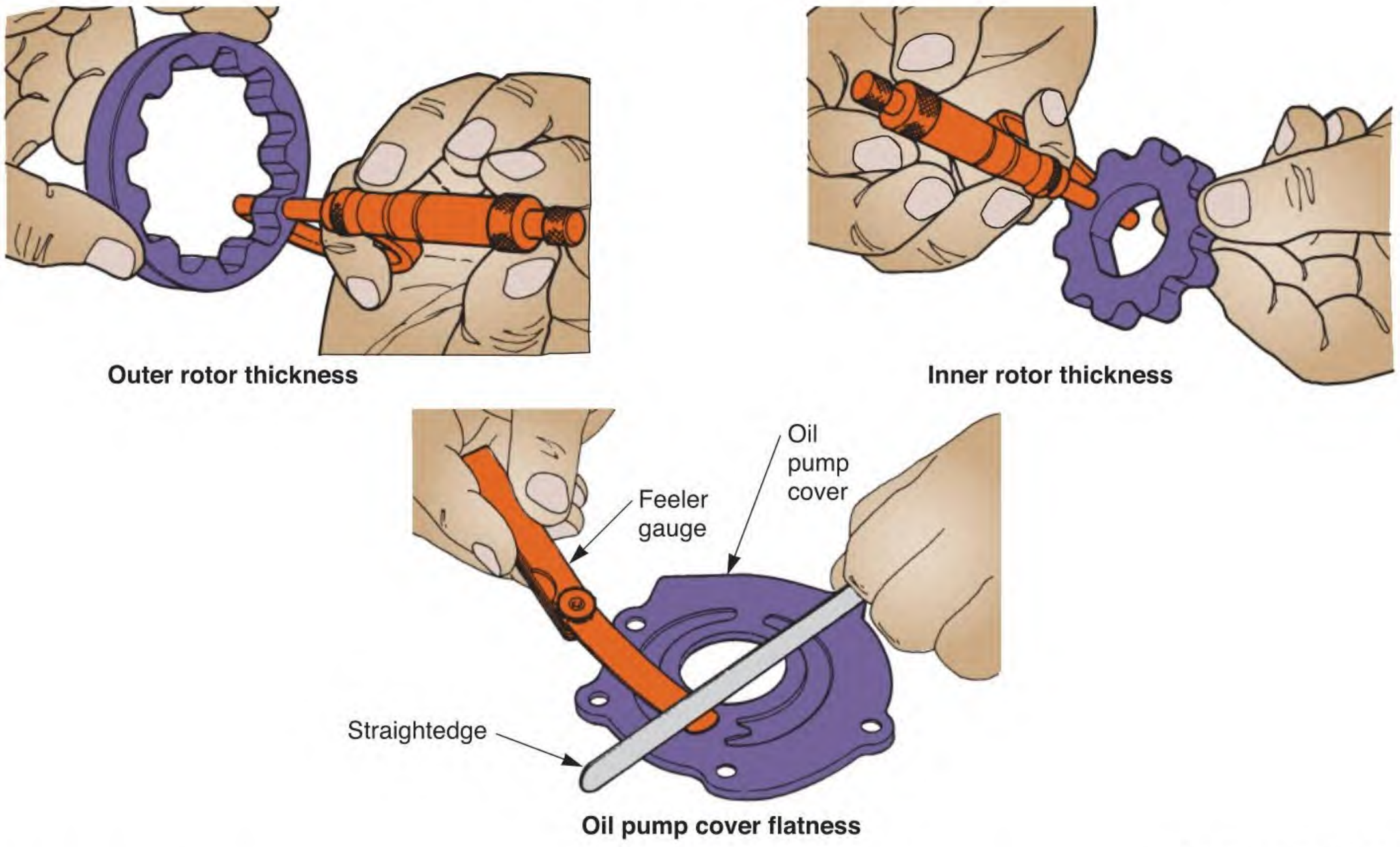
When installing a front-mounted oil pump, replace all oil seals to prevent leakage. Make sure all part sealing surfaces are washed in solvent and perfectly clean. Blow the oil pump dry with compressed air. Fill and prime the new or rebuilt oil pump before installation. Use a seal driver to force any new, press-fit oil seal into place without damaging it. See **Figure 50-17**.

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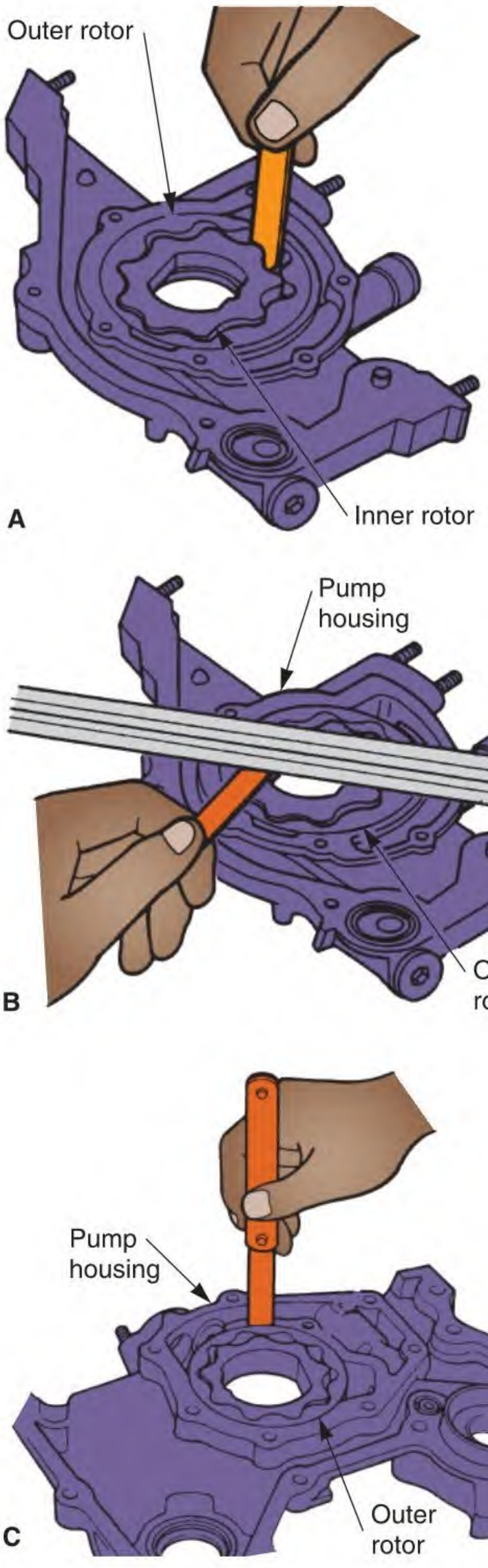
Figure 50-14. When servicing a belt-driven or crankshaft-driven oil pump, you will need to remove other parts to gain access to the pump—crank damper, timing belt cover, timing belt, belt sprocket, and other units.



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Figure 50-15. To begin the rebuild of a rotary oil pump, measure outer and inner rotor thickness. Check the oil pump cover wear with a straightedge and feeler gauge. The thickest gauge that slides under the straightedge equals wear. Compare to wear limits in the manual.

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Honda

Figure 50-16. Other steps to finish a rotary oil pump rebuild typically include these measurements. A—Measure radial clearance between the inner rotor lobe and the outer rotor. Replace parts if your measurement is larger than specifications. B—Measure housing-to-rotor axial clearance. Lay a straightedge over the rotors and see what size feeler gauge fits under the straightedge. Compare to specifications. C—Measure housing-to-rotor radial clearance. Slide the recommended size feeler gauge between pump housing and outer rotor. The thickest gauge that fits equals clearance. If not within specifications, rotor, housing, or both must be replaced.

Pressure Relief Valve Service

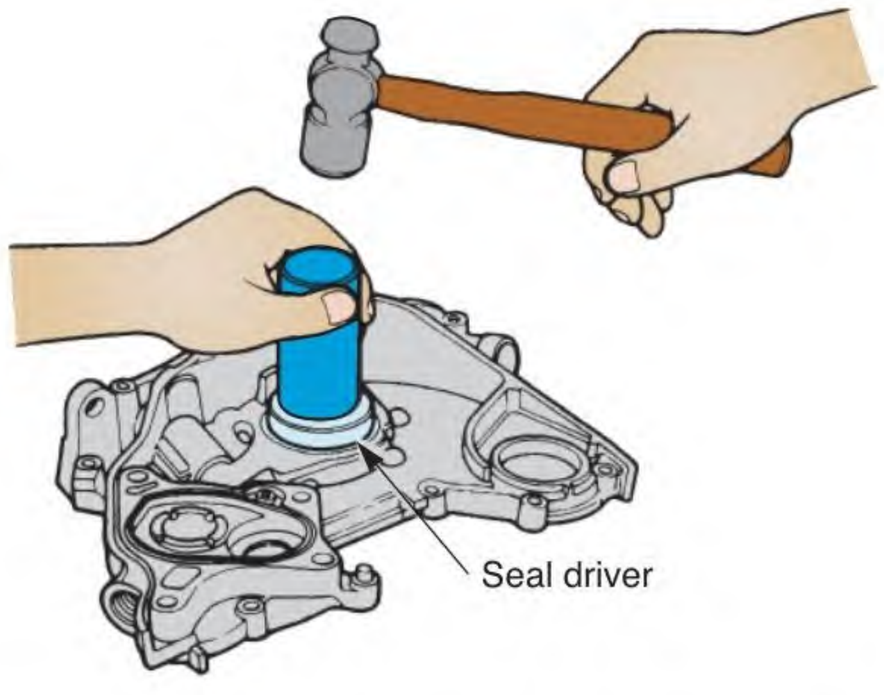
A faulty pressure relief valve can produce oil pressure problems. The valve may be located in the oil pump, filter housing, or engine block.

If symptoms point to the pressure relief valve, the valve should be disassembled and serviced. It should also be serviced during an engine overhaul. See **Figure 50-18**.

Service Procedure

To service an engine oil pressure relief valve:

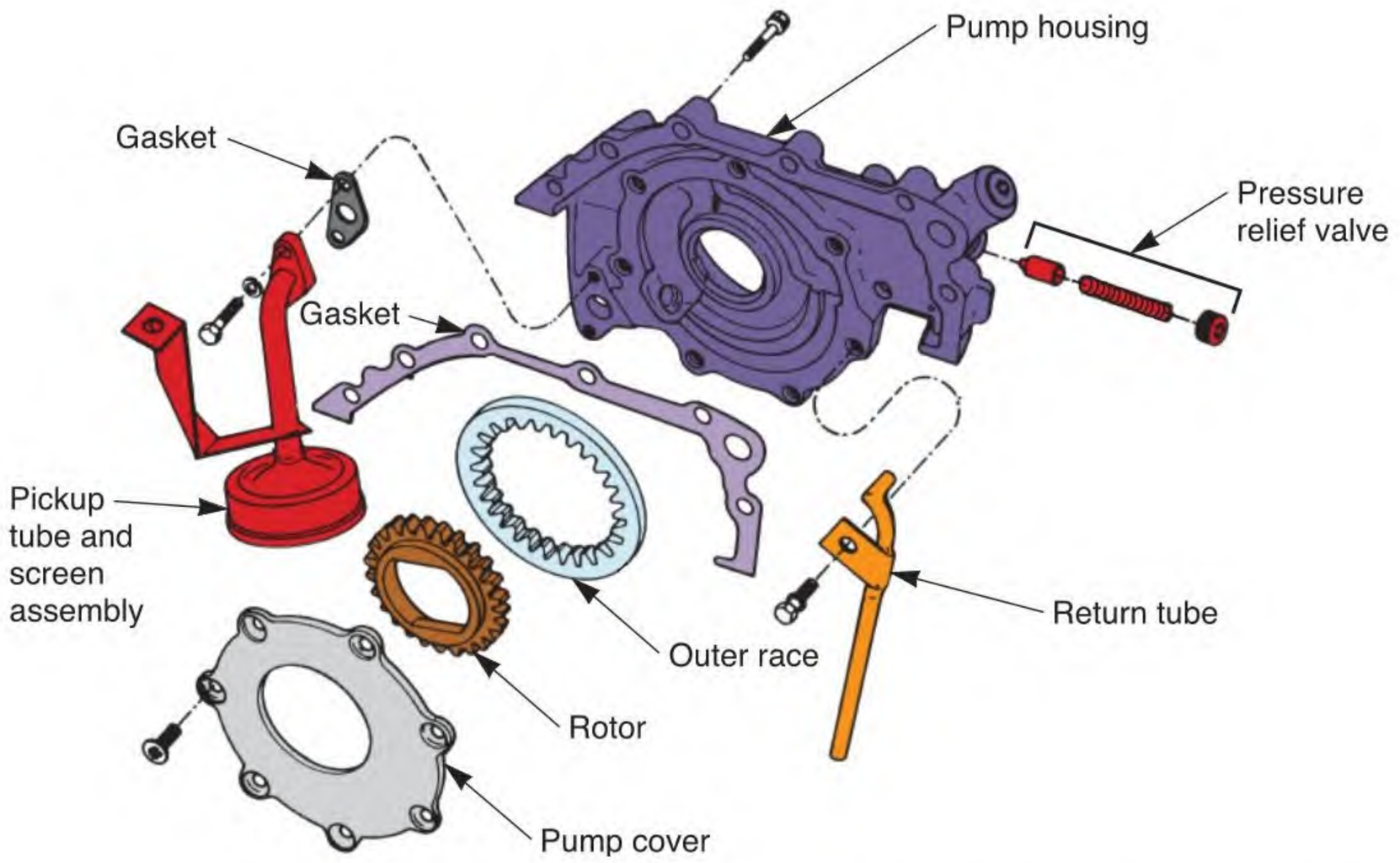
1. Remove the cup or cap holding the pressure-relief valve.
2. Slide the spring and piston out of their bore.
3. Measure ***spring free length*** and compare it to specifications. If the spring is too short or long, install a new spring.
4. If recommended, check the spring tension on a spring tester.
5. If recommended, shims can be used to increase the spring tension or adjust the opening pressure when needed.
6. Use a micrometer and small hole gauge to check valve and valve bore wear.



Honda

Figure 50-17. With front-mounted oil pumps, always install new seals when the pump is removed. Use a seal driver to force the seal into the housing.

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Ford

Figure 50-18. Exploded view shows parts of an oil pump that mounts on the front of the engine. Note pressure relief valve, oil pickup, and other parts. Refer to a shop manual for instructions on servicing.

7. Check the sides of the valve for scratches or scoring.
8. Slide the plunger in and out of its bore to check the action.
9. Replace parts as needed if any problems are found.

Oil Pressure Indicator and Gauge Service

A bad oil pressure indicator circuit can lead the customer to believe there are major engine problems. The gauge can read low or high, which may or may not indicate a lubrication system problem.

A ***faulty oil pressure switch*** or sending unit can make the indicator light glow or the gauge read low when oil pressure is normal. A flickering indicator light is often caused by a bad oil pressure switch or sending unit. A faulty switch or sending unit can also leak oil between its body and plastic housing.

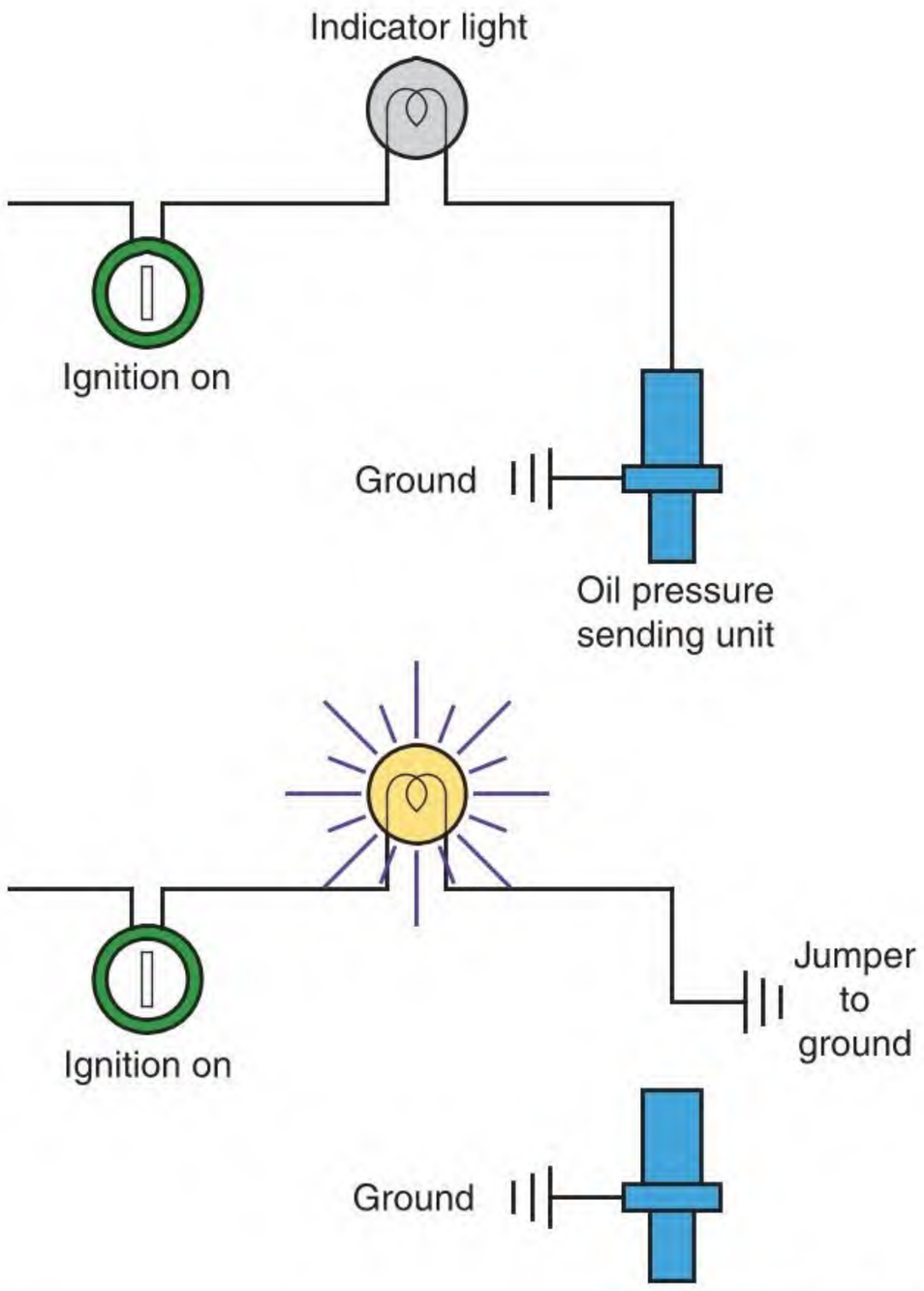
Inspect the indicator or gauge circuit for problems. The wire going to the switch or sending unit may have fallen off (no light, flickering light, improper gauge readings). The wire may also be shorted to ground (light stays on or gauge always reads high).

To check the action of the indicator or gauge, remove the wire from the switch or the sending unit. Touch it on a metal part of the engine. This should make the indicator light glow or the oil pressure gauge read maximum. If it does, the sending unit may be bad. If it does not, then the circuit, indicator, or gauge may be faulty. Look at **Figure 50-19**.

Always check the service manual before testing an indicator or gauge circuit. Some automakers recommend a special gauge tester. This is especially important with some computer-controlled systems. The tester will place a specific resistance in the circuit to prevent circuit damage. Refer to a manual for instructions.

Normally, a low oil pressure light will glow when oil pressure is below a certain value. Typically, minimum oil pressure at idle is 5–10 psi (35–70 kPa). This pressure can vary with the engine design.

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Figure 50-19. Usually, you can check the oil pressure sending unit by grounding the wire going to the unit. When the lead is grounded, the indicator light should glow.

PCV Valve Service

A PCV (positive crankcase ventilation) valve should be cleaned or replaced at regular intervals. The valve can become clogged or restricted with dirt and sludge. This can cause engine sludging and wear.

The PCV valve is usually located in the valve cover. It may also be in a breather opening in the intake manifold. Many new vehicles do not use a PCV valve. They simply route a vacuum hose from the valve cover or crankcase to an air inlet duct on the engine.

Camshaft Phaser Service

A defective ***camshaft phaser*** will lower fuel economy and engine power. The inside of the phaser could be worn and not actuating fast enough. The phaser can also be broken and locked in one cam timing location. Refer to **Figure 50-20**.

A bad camshaft phaser may or may not trip a trouble code if partially failed. If a phaser is slow and sluggish to advance or retard the camshafts, it is possible no trouble code will be set. Scan for trouble codes or an engine oil pressure signal. Check for deteriorated oil and sludge that could make the phaser stick and not rotate properly.

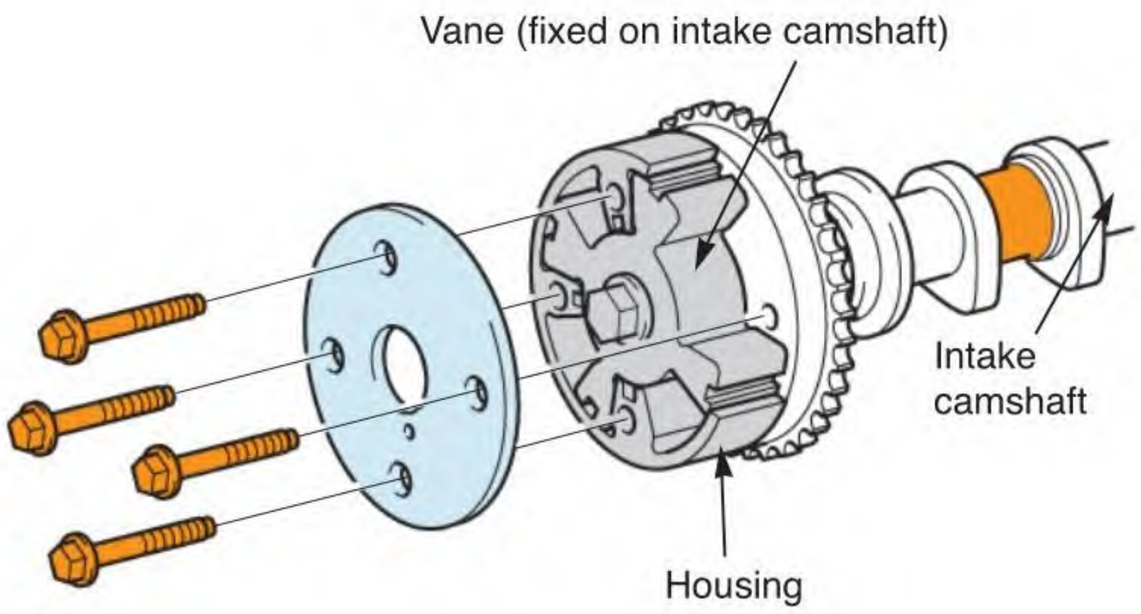
To analyze the operation of camshaft phasers with a scan tool, compare the camshaft sensors' signals for both cams at different engine speeds. The cam phaser sensor readings must be within specifications for idle, midrange, and high engine speeds. The camshaft sensors' live readings should steadily increase as engine speed is slowly increased.



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Figure 50-20. Cam phasers can suffer from internal part wear or broken cam return springs.

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Toyota

Figure 50-21. Lock the camshafts in place before removing the cam phaser.

Service Procedure

To remove a camshaft phaser:

1. Disconnect the 12-volt or hybrid battery to prevent accidental engine cranking and starting.
2. Remove any hoses, wiring, or brackets that prevent valve or camshaft cover removal.
3. Remove the valve cover or camshaft cover from the engine cylinder head. Keep all of the bolts, clips, and other parts in a tray.
4. Remove the valve cover gasket or seals. Wash the cover in cold solvent to remove burned oil and sludge. Wipe and blow the cover dry.
5. Rotate the engine crankshaft until the camshaft timing marks are aligned with specific points (bolts, holes, pins, pointers) on the cylinder heads. This will allow you to time the camshafts more easily during assembly.
6. Install a holding tool on the camshafts so they cannot rotate out of alignment with their timing marks on the engine.
7. Loosen the belt or chain tensioner and remove the timing belt or chain from around the camshaft sprocket. Refer to factory instructions if needed.
8. Remove the bolts from the front of the camshaft phasers, **Figure 50-21**.
9. Remove the center cam-to-phaser bolt, if needed.
10. Lift the phaser off of the camshaft for replacement or repair.
11. Install the new camshaft phaser in reverse order. Torque all fasteners to specifications.
12. Double-check crankshaft and camshaft timing mark alignment.

Diagnostic Case Study

Concern: Ms. Richmond brings in her 2010 Hyundai. She complains that the engine oil pressure light comes on at idle and then goes out when the engine speed is increased.

Cause: Duff checks the oil level on the dipstick. The oil level is fine. The oil is a little dirty but not badly broken down or burned. Duff then starts the engine and notes that the oil light flickers on and off at idle. He shuts off the engine and checks the wiring to the oil pressure sending unit. The wiring tests good, suggesting to Duff that the oil pressure is low at idle or the sending unit itself is bad.

Duff passes this information along to the shop's engine repair technician and asks him to make any further tests needed to pinpoint the cause of the problem. The technician removes the oil pressure sending unit from the engine. He installs an oil pressure gauge in the sender socket and starts the engine. The oil pressure gauge reads normal pressure. Because the oil pressure light illuminates even though oil pressure is normal, the technician suspects the sending unit.

Correction: The technician installs a new oil pressure sending unit, following the service manual instructions. After the new sending unit is installed, the technician starts the engine and allows it to idle. Noting that the oil light no longer flickers at idle, the technician releases the vehicle to the customer.

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Summary

- Without a properly functioning lubrication system, an engine will "self-destruct" in a matter of minutes.
- High oil consumption is caused by external oil leakage out of the engine or by internal oil leakage into the combustion chambers.
- External oil leakage is easily detected as darkened, oil-wet areas on or around the engine.
- Internal oil leakage shows up as blue smoke coming out of the exhaust.
- Low oil pressure is indicated when the oil indicator light glows, the oil gauge reads low, or the engine lifters or bearings rattle.
- An oil pressure test uses a test gauge installed on the engine to measure actual lubrication system pressure.
- Used oil will be contaminated with dirt, metal particles, carbon, gasoline, ash, acids, and other harmful substances.
- Automakers specify oil change intervals.
- A common mistake by the novice is overtightening the oil pan bolts.
- A bad oil pump will cause low or no oil pressure and possibly severe engine damage.
- Before installation, the oil pump should be primed by filling it with motor oil.
- A faulty pressure relief valve can produce oil pressure problems.
- A faulty oil pressure switch or sending unit can make the indicator light glow or the gauge read low when oil pressure is normal.
- To analyze the operation of camshaft phasers with a scan tool, compare the camshaft sensors' signals for both cams at different engine speeds.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

camshaft phaser
engine oil debris
engine sludge
external oil leakage
faulty oil pressure switch
high oil consumption
high oil pressure
internal oil leakage
low oil pressure
oil burn test
oil change intervals
oil dye
oil pressure test
spring free length

Activities

1. Use your smartphone, digital camcorder, or the school's video equipment to develop a short demonstration on how to properly check a vehicle's oil level.
2. Observe an oil change being done at a dealership service department or other facility. Take notes of the steps involved, from moving the vehicle into the bay to completion of the job. Use your notes to write a set of step-by-step instructions for a person doing an oil change for the first time.

Review Questions

Answer the following questions using the information provided in this chapter.

1. List four common lubrication system problems.
2. High engine oil consumption *cannot* be caused by:
   (A) oil leakage into combustion chambers.
   (B) leaking valve cover gaskets.
   (C) leaking exhaust manifold gaskets.
   (D) worn piston rings or cylinders.
3. List seven common causes of low engine oil pressure.
4. How do you measure actual engine oil pressure?
5. How often should a new vehicle's oil and filter be changed?
6. Why should an engine be warmed to full operating temperature before its oil is changed?
7. Some engine oil pans should have an oil pan gasket while others may use a sealant. True or False?
8. Bits of steel found in engine oil debris *cannot* be caused by damaged _____.
   (A) crank journals
   (B) engine bearings
   (C) neoprene valve stem seals
   (D) piston rings
9. Most technicians rebuild worn oil pumps in the shop. True or False?
10. A driver complains that her oil pressure warning light flickers on and off at stoplights. Technician A says that the oil level in the engine should be checked. Technician B says that the indicator light circuit could also be at fault. Who is correct?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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ASE-Type Questions

1. Each of the following problems may be found in a lubrication system *except*:
   (A) low oil pressure.
   (B) high oil pressure.
   (C) low oil consumption.
   (D) high oil consumption.
2. External oil leakage may be detected by:
   (A) high oil consumption.
   (B) oil puddles under vehicle.
   (C) oil-wet areas around engine.
   (D) Any of the above.
3. Oil dye is sometimes added to motor oil to:
   (A) detect leaks.
   (B) detect contaminants.
   (C) destroy corrosive chemicals.
   (D) determine frequency of oil changes.
4. Internal oil leakage will appear as what color smoke?
   (A) Blue.
   (B) Black.
   (C) White.
   (D) None of the above.
5. Which of the following is *not* a common cause of low oil pressure?
   (A) Worn oil pump.
   (B) Thin or diluted oil.
   (C) Leaking valve stem seal.
   (D) Clogged oil pickup screen.
6. Upon encountering an uncommon high oil pressure problem, Technician A says its cause is low oil viscosity. Technician B says the cause is low relief valve spring tension. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. At idle, oil pressure should be at least:
   (A) 0–10 psi.
   (B) 20–30 psi.
   (C) 40–60 psi.
   (D) Over 100 psi.
8. Each of these should be followed when changing engine oil and the oil filter *except*:
   (A) keep the vehicle level.
   (B) do not overtighten the pan drain plug.
   (C) use the correct amount and type of oil.
   (D) tighten the oil filter with a filter wrench.
9. An engine oil pan may need to be removed to:
   (A) service an oil pump.
   (B) repair a damaged pan.
   (C) perform an engine overhaul.
   (D) All of the above.
10. Oil changes are being discussed. Technician A says that used motor oil should be drained into the sewer system for disposal. Technician B says that it is recommended that individuals driving turbocharged or supercharged engines change their vehicle's oil in shorter intervals than a naturally aspirated engine. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

Lubrication System Diagnosis

Condition	Possible Causes	Correction
Low oil pressure.	1. Oil level low. 2. Oil too thin. 3. Defective oil gauge. 4. Bad sending unit. 5. Excessive bearing clearance. 6. Worn oil pump. 7. Loose or disconnected oil pickup. 8. Open pressure relief valve. 9. Clogged pickup screen.	1. Add oil to engine. 2. Add heavier oil. 3. Replace gauge. 4. Replace sending unit. 5. Replace bearings. 6. Replace oil pump. 7. Repair oil pickup. 8. Repair valve in pump or block. 9. Clean or replace screen.
High oil pressure.	1. Stuck pressure relief valve. 2. Incorrect relief valve spring. 3. High oil viscosity. 4. Oil gallery restriction. 5. Inaccurate indicator.	1. Repair valve. 2. Replace spring. 3. Drain oil. Replace with recommended viscosity oil. 4. Remove blockage. 5. Repair circuit. Replace gauge or sending unit, if necessary.
Swelled oil filter.	1. High oil pressure.	1. See *High oil pressure*.

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Section 8

Emission Control System Technology

Chapter 51
Emission Control System Technology

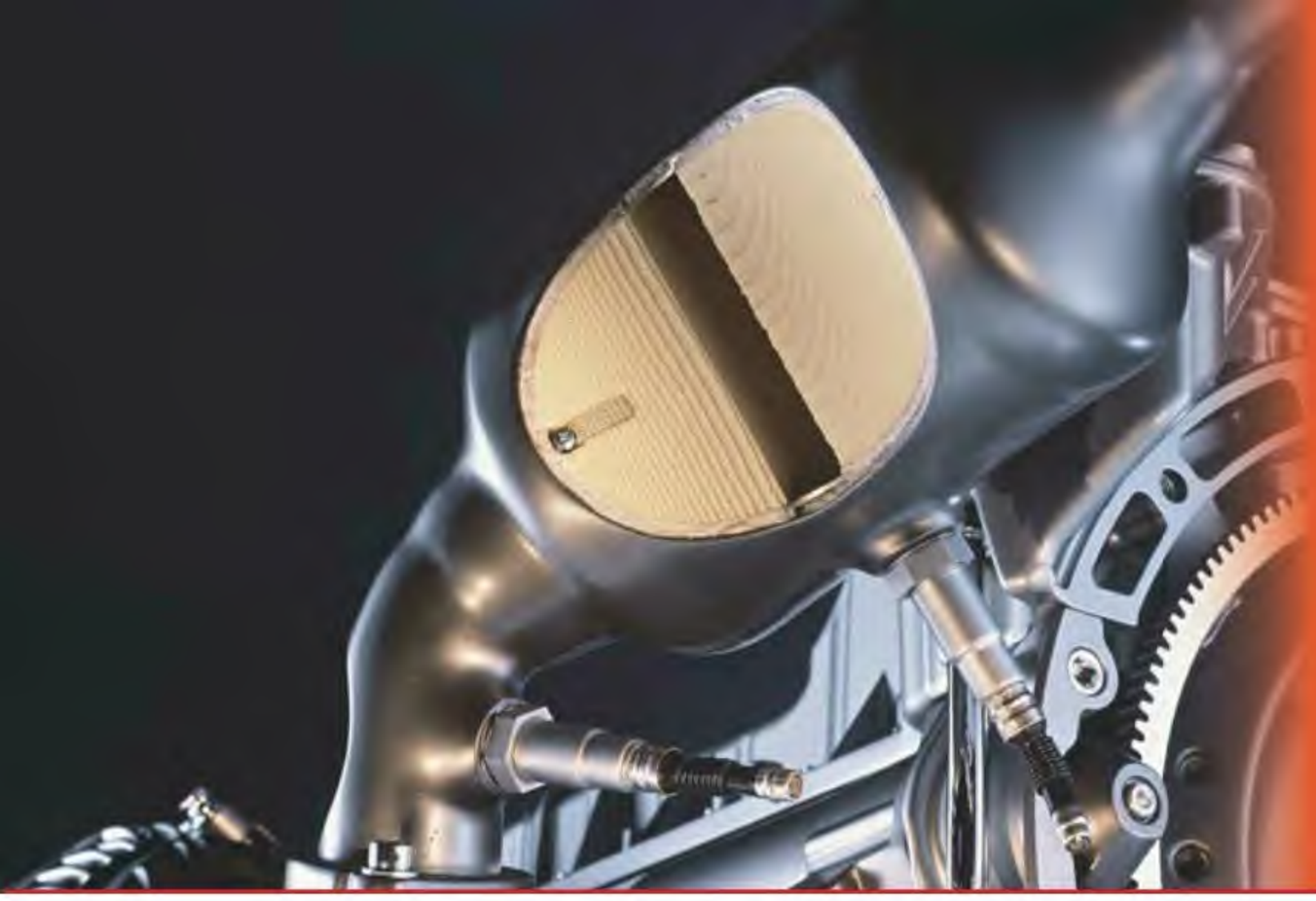
Chapter 52
Emission Control System Testing, Service, and Repair

Emission control systems protect our environment from chemical damage. They are designed to reduce the amount of toxic substances emitted by an automobile. Some systems prevent fuel vapors from entering the atmosphere; others remove unburned or partially burned fuel from the engine exhaust.

This section provides the information needed to repair emission control systems so that a vehicle operates as cleanly as possible. Not only will this information make you more employable as a technician, but it will help make our earth a pleasant, healthy place to live and breathe.

The information in this section will help you pass ASE Test A6, *Electrical/Electronic Systems*, and Test A8, *Engine Performance*.

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Chapter 51
Emission Control System Technology

After studying this chapter, you will be able to:

- Define the fundamental terms relating to automotive emission control systems.
- Explain the sources of air pollution.
- Describe the operating principles of emission control systems.
- Compare design differences in emission control systems.
- Explain how a computer or engine control module can be used to operate emission control systems.
- Explain the operation of exhaust gas sensors (oxygen sensors) as a primary control of exhaust emissions and engine air-fuel ratio control.
- Summarize how OBD II systems use multiple oxygen sensors to check air-fuel mixture and catalytic converter efficiency.
- Correctly answer ASE certification test questions that require a knowledge of emission control system operation and construction.

Emission control systems are used on motor vehicles to reduce the amount of harmful chemicals released into the atmosphere. These systems help to keep the air clean. Emission controls limit the quantity of pollutants produced and released by internal combustion engines and the storage of volatile (vaporizing) fuels. This chapter introduces emission control terminology and the parts and systems that control automobile emissions.

Air Pollution

Air pollution is caused by an excess amount of harmful chemicals in the atmosphere. It is caused by a number of factors, some natural and some man-made.

Natural air pollution is produced by erupting volcanoes, forest fires, wind-blown dust, decay of vegetation, and other natural sources. Man-made air pollution is produced by factories, home furnaces, fireplaces, and internal combustion engines. All these sources contribute to air pollution, **Figure 51-1**.

The federal government passed strict laws aimed at reducing air pollution. These laws, which are enforced by the Environmental Protection Agency (EPA) and local authorities, limit the amount of emissions that can be emitted by automobiles, factories, and other man-made sources. Auto manufacturers have implemented a number of design changes and added systems that reduce emissions to meet or exceed EPA standards. See **Figure 51-2**.

Smog

Smog is a nickname given to a visible cloud of airborne pollutants. It is a word derived from the words "smoke" and "fog." Smog is common in large cities and industrialized areas. If dense enough, smog can be

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American Petroleum Institute

Figure 51-1. Smog and other visible forms of air pollution are common in large cities and industrial areas where there is a concentration of factories, homes, and vehicles.



Chrysler

Figure 51-2. This automotive engineer is using high-tech equipment to study how well emission control systems clean engine exhaust.

harmful to humans, animals, and vegetation. It can even damage paint, rubber, and other materials.

Smog is formed when airborne pollutants combine with oxygen, nitrogen, and other elements in the presence of sunlight. The resulting yellow-gray cloud of pollution is referred to as photochemical smog.

Motor Vehicle Emissions

Motor vehicle emissions are burned and unburned pollutants produced by car, truck, bus, and motorcycle engines and their fuel systems. There are four basic types of vehicle exhaust emissions: hydrocarbons, carbon monoxide, oxides of nitrogen, and particulates.

Hydrocarbons (HC)

Hydrocarbons, abbreviated *HC*, are a form of emission resulting from the release of unburned fuel into the atmosphere. As you learned in earlier chapters, all petroleum (crude oil) products are made of hydrocarbons (hydrogen and carbon compounds). These include gasoline, diesel fuel, LP-gas, and motor oil.

Hydrocarbons are produced by incomplete combustion or by fuel evaporation. For example, hydrocarbons are produced when unburned fuel escapes from the exhaust system of a poorly running engine. They can also be produced by fuel vapors escaping from a vehicle's fuel system. Some of the additives used in gasoline are extremely reactive, which allows the unburned fuel vapors to easily combine photochemically with other elements in the air to form smog.

Hydrocarbon emissions are a hazardous form of air pollution. They can contribute to a variety of illnesses, including eye, throat, and lung irritation, and possibly cancer.

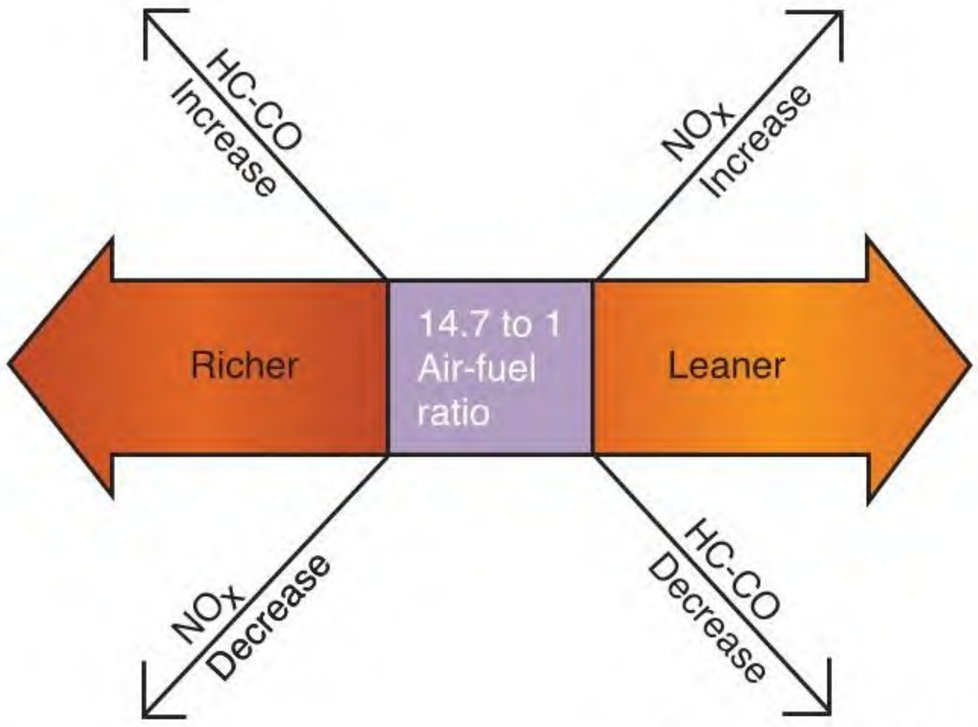
Carbon Monoxide (CO)

Carbon monoxide (CO) is an extremely toxic emission resulting from the release of partially burned fuel. It is a result of incomplete combustion of a petroleum-based fuel.

Carbon monoxide is a colorless, odorless, and deadly gas. CO prevents human blood cells from carrying oxygen to body tissues. It can cause death if inhaled in large quantities. Symptoms of carbon monoxide poisoning include headaches, nausea, blurred vision, and fatigue.

Any factor that reduces the amount of oxygen present during combustion increases carbon monoxide emissions. For example, a rich air-fuel mixture would increase CO. As the mixture is leaned, CO emissions are reduced. See **Figure 51-3**.

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Figure 51-3. Study the relationship between air-fuel ratio and emissions. Close control of the engine's air-fuel mixture helps to keep exhaust emissions at a minimum.

Oxides of Nitrogen (NO_X)

Oxides of nitrogen (NO_X) are emissions produced by extremely high temperatures during combustion. Air consists of about 79% nitrogen and 21% oxygen. With enough heat (above approximately 2500°F or 1370°C), nitrogen and oxygen in the air-fuel mixture combine to form NO_X emissions.

Oxides of nitrogen contribute to the dirty brown color in smog. They also produce ozone in smog, which causes an unpleasant odor and is an eye and respiratory irritant. Oxides of nitrogen are also harmful to many types of plants and rubber products.

An engine with a high compression ratio, lean air-fuel mixture, and high-temperature thermostat will produce high combustion heat, resulting in the formation of NO_X. This poses a problem because these same factors tend to improve gas mileage and reduce HC and CO emissions. As a result, emission control systems must interact to lower each form of pollution.

Particulates

Particulates are solid particles of carbon soot or ash and fuel additives that blow out a vehicle's tailpipe. Carbon particles make up the largest percentage of these emissions. The rest of the particulates consist of other additives sometimes used to make gasoline and diesel fuel.

While particulate emissions are rarely a problem with gasoline engines, they are a serious problem with diesel engines. You have probably seen a diesel truck or bus emitting black smoke out of its exhaust. Diesel particulates are normally caused by an extremely rich air-fuel mixture or a mechanical problem in the injection system.

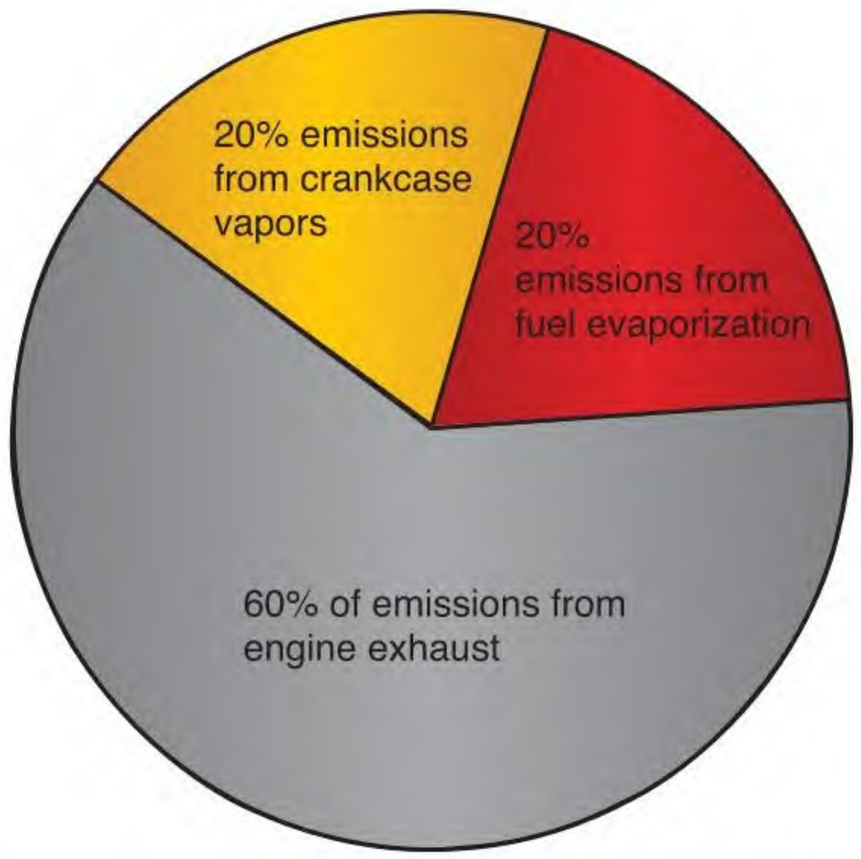
About 30% of all particulate emissions are heavy enough to settle out of the air in a relatively short period of time. The other 70%, however, can float in the air for extended periods.

Sources of Vehicle Emissions

Shown in **Figure 51-4**, the majority of vehicle emissions come from three basic sources:

- Engine crankcase ***blowby*** fumes—Engine crankcase blowby fumes are chemicals that form in the engine bottom end from heating of oil, as well as unburned fuel and combustion by-products that blow past the piston rings and into the crankcase.
- ***Fuel vapors***—Fuel vapors are various chemicals that enter the air as fuel evaporates.
- Engine ***exhaust gases***—Engine exhaust gases are harmful chemicals produced and blown out the tailpipe when an engine burns a hydrocarbon-based fuel (or most other fuels) and must be cleaned by a catalytic converter. Particulates are solid particles of soot and ash that blow out of the engine exhaust ports and into the exhaust system.

Various engine modifications and emission control systems are used to reduce air pollution from these sources.



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Figure 51-4. These are the three general sources and percentages of auto air pollution.

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Engine Modifications Related to Emission Control

Auto manufacturers agree that the best way to reduce exhaust emissions is to burn all of the fuel inside the engine. For this reason, several engine modifications have been introduced to improve combustion efficiency. Today's engines have the following modifications to lower emissions:

- Lower compression ratios allow the use of unleaded gasoline. Unleaded fuel permits the use of catalytic converters and burns completely to lower HC emissions. Elimination of lead additives also reduces particulate emissions. Lower compression ratios also reduce combustion temperatures and NO_x emissions. Although improvements in fuel control have allowed new engines to use slightly higher compression ratios (over 10:1 in some cases), they are still lower than the compression ratios used in the "muscle car" engines of the 1960s (over 11:1).
- Smaller combustion chamber surface volumes are used to reduce HC emissions. A smaller surface area in the combustion chamber increases combustion efficiency by lowering the amount of heat dissipated out of the fuel mixture. Less combustion heat enters the cylinder head and more heat is left to burn the fuel. Also, combustion chambers have simple shapes to reduce the chance of fuel condensation. A hemispherical combustion chamber typically has the smallest surface volume.
- Reduced quench areas in combustion chambers are used to lower HC and CO emissions. A quench area is produced when the engine pistons move too close to the cylinder head. When the distance between these metal parts is too close, it tends to quench (put out) combustion and increase emissions due to unburned fuel. Today's engines have redesigned cylinder heads and pistons which prevent high quench areas.
- Decreased valve overlap is used to reduce exhaust emissions and to increase engine smoothness. A camshaft with more overlap will provide greater power at higher speeds. However, the increased overlap dilutes the incoming air-fuel mixture with burned exhaust gases, requiring a richer air-fuel mixture at idle and low speeds, which increases HC and CO formation.
- Hardened valves and seats are used to prevent excessive valve wear from the use of unleaded fuel. Lead additives in fuel, besides increasing octane, also acted as a high-temperature lubricant. They reduced wear at the valve faces and seats.
- Higher operating temperatures are used to reduce HC and CO emissions. Today's engines have thermostats with higher temperature ratings. If the metal parts in an engine are hotter, less combustion heat will transfer out of the burning fuel. More heat will remain in the burning mixture to produce gas expansion, piston movement, and more complete combustion.
- Leaner air-fuel mixtures are used to lower HC and CO emissions. Leaner mixtures have more air to help all the fuel burn. More air also helps cool the cylinders, reducing the formation of NO_x.
- Wider spark plug gaps are used to properly ignite the lean air-fuel mixtures. Wider gaps produce a hotter spark, which can ignite hard-to-burn, lean air-fuel mixtures. A wide gap also reduces spark plug fouling.
- Alcohols and other clean-burning substances are added to gasoline during the refinement process. For example, the alcohol in gasohol burns cleanly while increasing the fuel's octane and knock resistance. In areas where high concentrations of air pollution are present, a specially formulated, or "oxygenated," gasoline is sold. ***Oxygenated gasoline*** contains additives that provide additional oxygen for a more complete combustion of the fuel (chemical enleanment), which reduces HC and CO exhaust emissions.

Vehicle Emission Control Systems



Several different emission control systems are used to reduce the amount of air pollution produced by automobiles. The major systems found on late-model vehicles include the following:

- Positive crankcase ventilation system—The positive crankcase ventilation system recirculates engine crankcase fumes back into the combustion chamber.
- Evaporative emissions control system—The evaporative emissions control system is a closed vent system that stores fuel vapors and prevents them from entering the atmosphere.

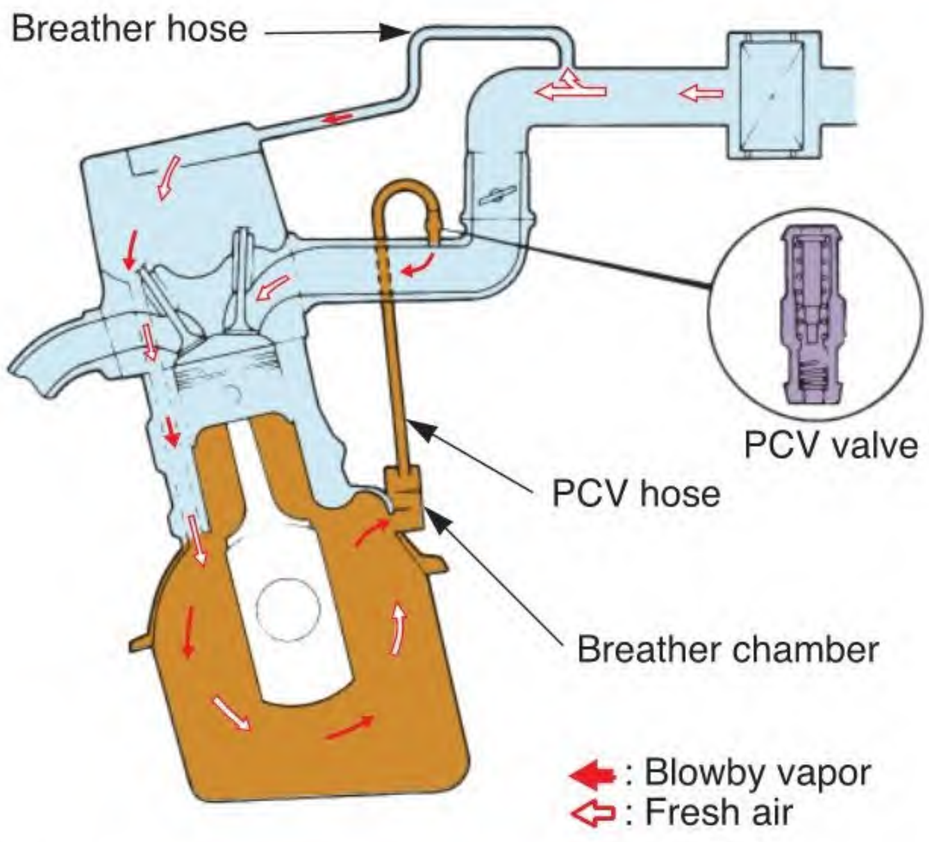
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- Exhaust gas recirculation system—The exhaust gas recirculation system injects burned exhaust gases into the engine to lower combustion temperatures and prevent the formation of NO_x.
- Air injection system—The air injection system forces outside air into the exhaust system to help burn unburned fuel.
- Catalytic converter—The catalytic converter chemically changes combustion by-products into harmless substances.
- Computer control system—The computer control system has electronic controls that monitor and interface with various systems to increase overall engine efficiency and reduce emissions.

Positive Crankcase Ventilation (PCV)

A ***positive crankcase ventilation (PCV) system*** uses engine vacuum to draw blowby gases into the intake manifold for re-burning in the combustion chambers. Look at **Figure 51-5**.

Engine blowby is caused by pressure leakage past the piston rings on the power strokes. A small percentage of combustion gases can flow through the ring end gaps or the piston ring grooves and into the crankcase. If not re-burned in the engine, these fumes would contribute to air pollution if vented to the atmosphere. If not vented from the crankcase, the gases would build to a point where engine damage would occur.



Honda

Figure 51-5. The PCV system draws vapors out of the crankcase and routes them into the engine to be burned.

Engine blowby gases contain unburned fuel (HC); partially burned fuel (CO); particulates; and small amounts of water, sulfur, and acid. For this reason, blowby gases must be removed from the engine crankcase. Blowby gases can cause the following problems:

- Air pollution (if released into the atmosphere untreated).
- Corrosion of engine parts from acid buildup in the used oil.
- Engine oil dilution from fuel contamination.
- Sludge formation from oil breakdown.

A PCV system keeps the inside of the engine clean and reduces air pollution. Older engines used an open PCV system. This system was not sealed, and gases could leak out when the engine was shut off. Open PCV systems have been completely replaced by closed PCV systems.

A ***closed PCV system*** uses a sealed oil filler cap, a sealed oil dipstick, ventilation hoses, and either a PCV valve or a flow restrictor. The gases are drawn into the engine and burned. The system stores the gases when the engine is not running.

PCV System Operation

Although designs vary and can use either vacuum or electronic control, the operation of all PCV systems is basically the same. Look at **Figure 51-5**.

A hose usually connects the intake manifold to the PCV valve. With the engine running, vacuum acts on the engine's crankcase. Air is drawn in through the engine's air cleaner, through a vent hose into a valve cover, and down into the crankcase.

After the fresh air mixes with the crankcase gases, the mixture is pulled by vacuum past the PCV valve, through the hose, and into the engine intake manifold. The crankcase gases are then drawn into the combustion chambers for burning.

An electronically controlled PCV system often uses a solenoid valve in the vacuum line leading to the valve. The engine ECM can energize or de-energize the solenoid to block or pass vacuum. This allows the computer to help control PCV operation.

PCV Valve

A ***PCV valve*** is used to control the flow of air through the PCV system. It may be located in a rubber grommet in a valve cover, in a breather opening in

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the intake manifold or plenum, or on the side of the engine block. The PCV valve varies the flow of air for idle, cruise, acceleration, wide open throttle, and engine-off conditions.

Figure 51-6 shows the action of the PCV valve under various operating conditions. At idle, the PCV valve is pulled toward the intake manifold by high vacuum. This restricts the flow of air and prevents a lean air-fuel mixture. When cruising, lower intake manifold vacuum allows the spring to open the PCV valve. However, enough vacuum is present to keep the PCV valve from completely closing. More air can flow through the system to clean out crankcase fumes. At wide open throttle or with the engine off (low or no intake manifold vacuum), spring pressure closes the PCV valve completely.

In case of an engine backfire (air-fuel mixture in the intake manifold ignites), the PCV valve plunger is seated against the body of the valve. This keeps the backfire (burning) from entering and igniting the fumes in the engine crankcase.

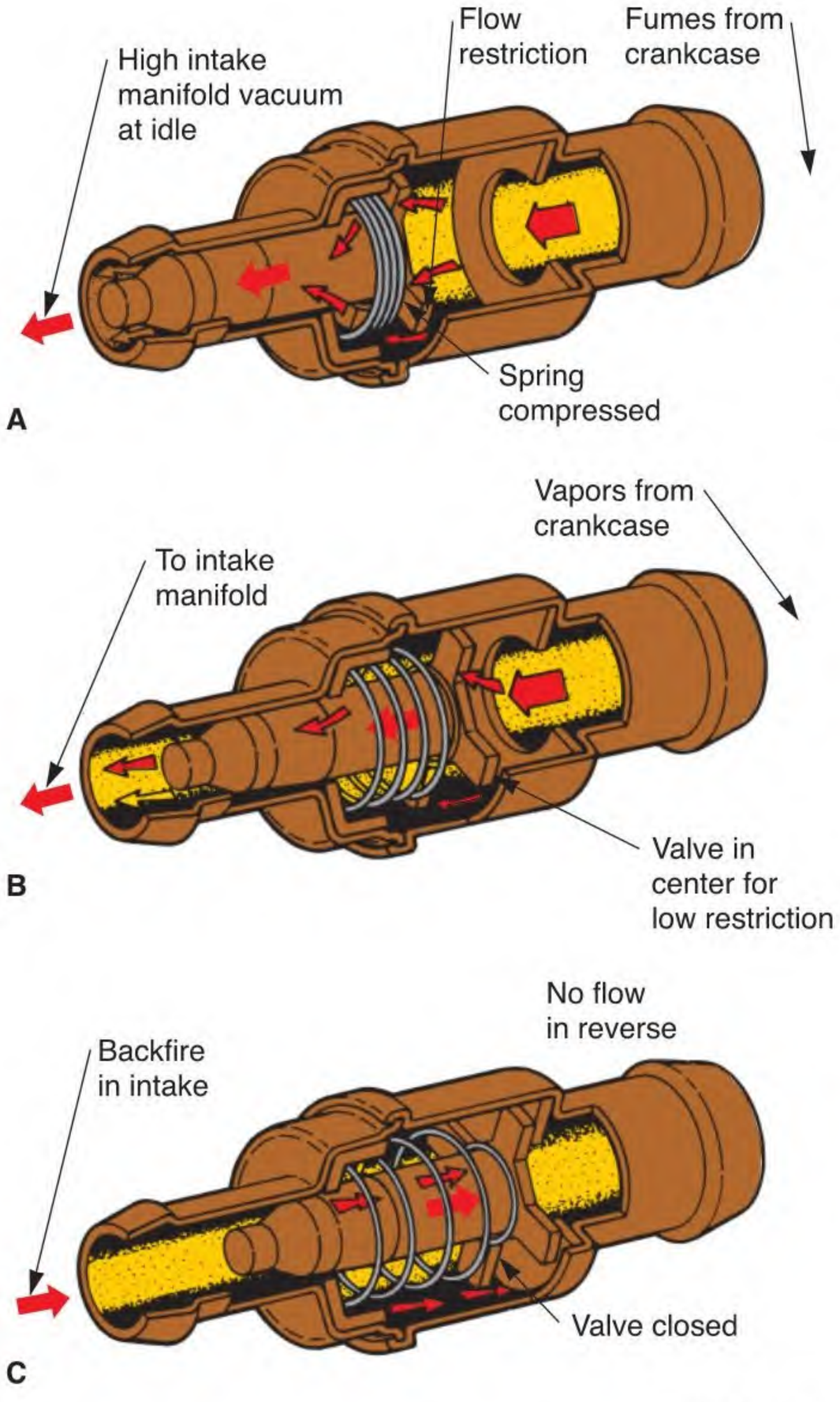


Figure 51-6. Study PCV valve operation under various operating conditions. A—At idle, high manifold vacuum pulls the plunger for minimum vapor flow. Only a small amount of vapor is drawn through the valve. B—During acceleration, intake manifold vacuum decreases. This allows the PCV valve to move to a center position for maximum flow. C—With the engine off, a spring pushes the valve against its seat. This closes the valve. A backfire will also force the valve into this position.

Electric PCV Valve

Most late-model vehicles use electronically controlled crankcase ventilation systems. An ***electric PCV valve***, which contains a small solenoid and an air valve, is controlled by the ECM to regulate engine crankcase ventilation. When energized by the ECM, the valve opens to allow the blowby gases in the engine crankcase to be routed back into the engine intake manifold for combustion. See **Figure 51-7**.

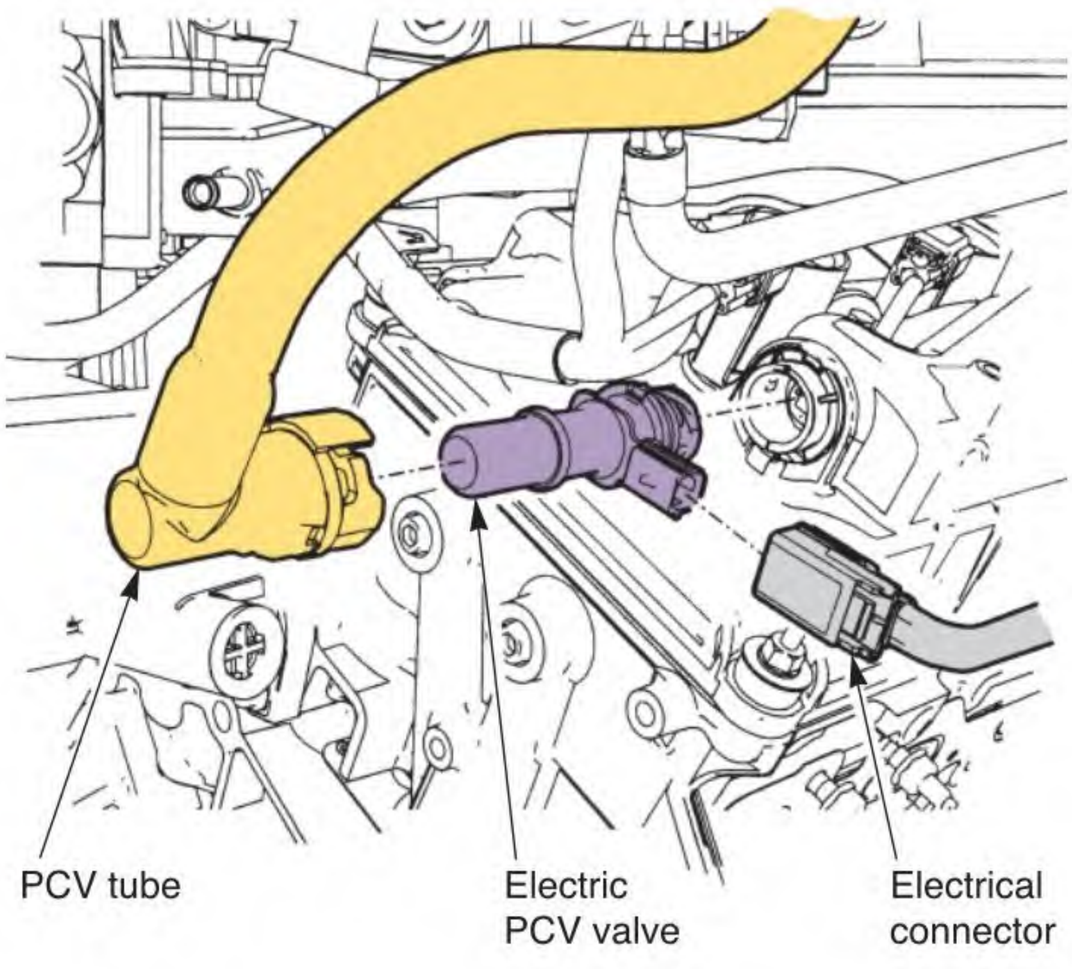


Figure 51-7. This electric PCV valve mounts in front of the camshaft cover. Two wires from the engine ECU connect to the solenoid windings. When energized and de-energized, the solenoid can open or close the air valve to control flow into the intake manifold.

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Oil-Air Separators

An ***oil-air separator*** is a device that makes oil vapors condense and flow back into the oil pan. It can be used instead of a PCV system to reduce emissions and prevent oil sludging. The separator simply allows oil mists and vapors to settle out into a liquid so that they do not continue to circulate through the engine.

Evaporative Emissions Control Systems

The ***evaporative emissions control (EVAP) system*** prevents toxic fuel system vapors from entering the atmosphere. As mentioned earlier, gasoline and many of its additives evaporate easily, especially if exposed to the atmosphere. See **Figure 51-8**.

Pre-emission-control vehicles used vented gas tank caps. Antique car carburetor bowls were also vented to the atmosphere, which caused a considerable amount of hydrocarbon emissions from unburned fuel. Today's vehicles commonly use an evaporative emissions control system to prevent this source of air pollution.

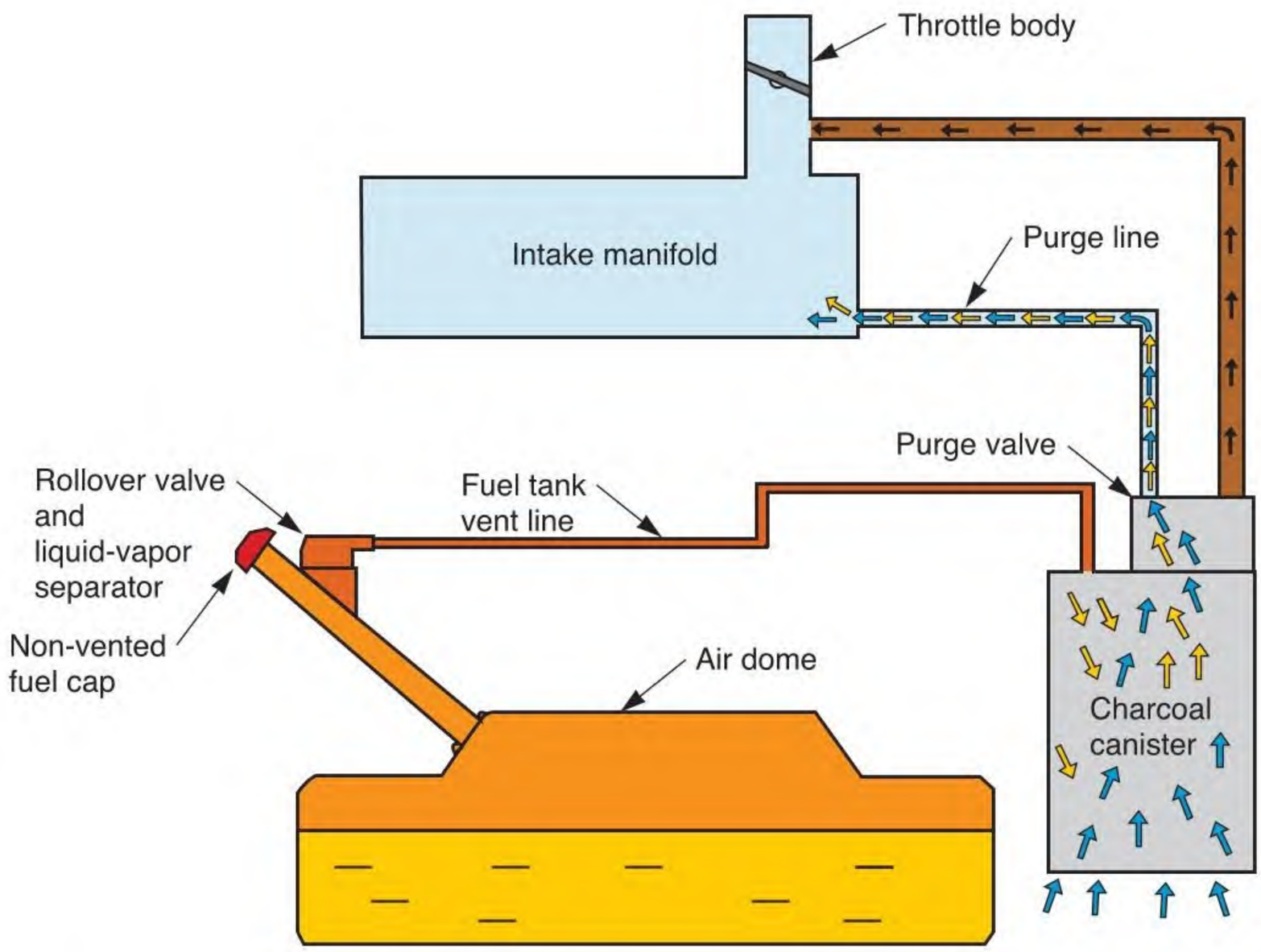
Evaporative Emissions System Components

A ***non-vented fuel tank cap*** prevents fuel vapors from entering the atmosphere through the tank's filler neck. It may contain pressure and vacuum valves that open in extreme cases of pressure or vacuum to prevent tank bulging or collapsing. When the fuel expands (from warming), tank pressure forces fuel vapors out of a vent line or lines at the top of the fuel tank, not out of the tank cap. A fuel tank vent line carries fuel vapors to a charcoal canister.

An ***air dome*** is a hump formed in the top of the fuel tank to allow for fuel expansion and tank filling without spillage. The dome normally provides about 10% air space to allow for fuel heating and the resulting volume increase.

A ***liquid-vapor separator*** is sometimes used to keep liquid fuel from entering the evaporative emission system. It is simply a small valve located above the main fuel tank. Liquid fuel condenses on the walls of the liquid-vapor separator because of the difference in temperature between the separator and the fuel. The liquid fuel then flows back into the fuel tank.

A ***rollover valve*** is used in the vent line from the fuel tank. It keeps liquid fuel from entering the vent line



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Figure 51-8. Note the parts of an evaporative emissions control system. This system draws excess fuel vapors into the engine for burning.

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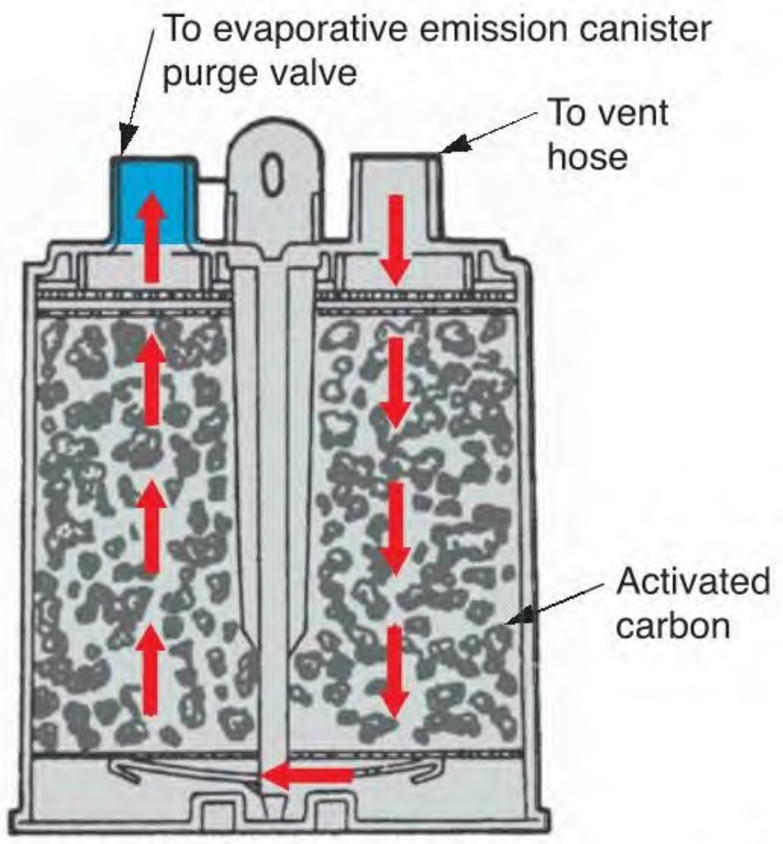
in case the vehicle rolls over during an auto accident. The valve contains a metal ball or a plunger valve that blocks the vent line when the valve is turned over.

A ***charcoal canister*** stores fuel vapors when the engine is not running. The metal or plastic canister is filled with activated charcoal granules. The charcoal is capable of absorbing fuel vapors. See **Figure 51-9**.

The top of the canister has fittings for the fuel tank vent line and the purge (cleaning) line. The bottom of the canister may have an inlet filter that cleans the outside air entering the canister.

A ***purge line*** is used for removing the stored vapors from the charcoal canister. It connects the canister to the engine intake manifold. When the engine is running, engine vacuum draws the vapors out of the canister and through the purge line.

A ***purge valve*** controls the flow of vapors from the canister to the intake manifold. This vacuum- or electrically operated valve is located on the top of the canister or in the purge line. Purge valves generally allow flow when the engine reaches operating temperature and is operating above idle speed. This helps minimize emissions when the engine is cold and prevents rough idle.

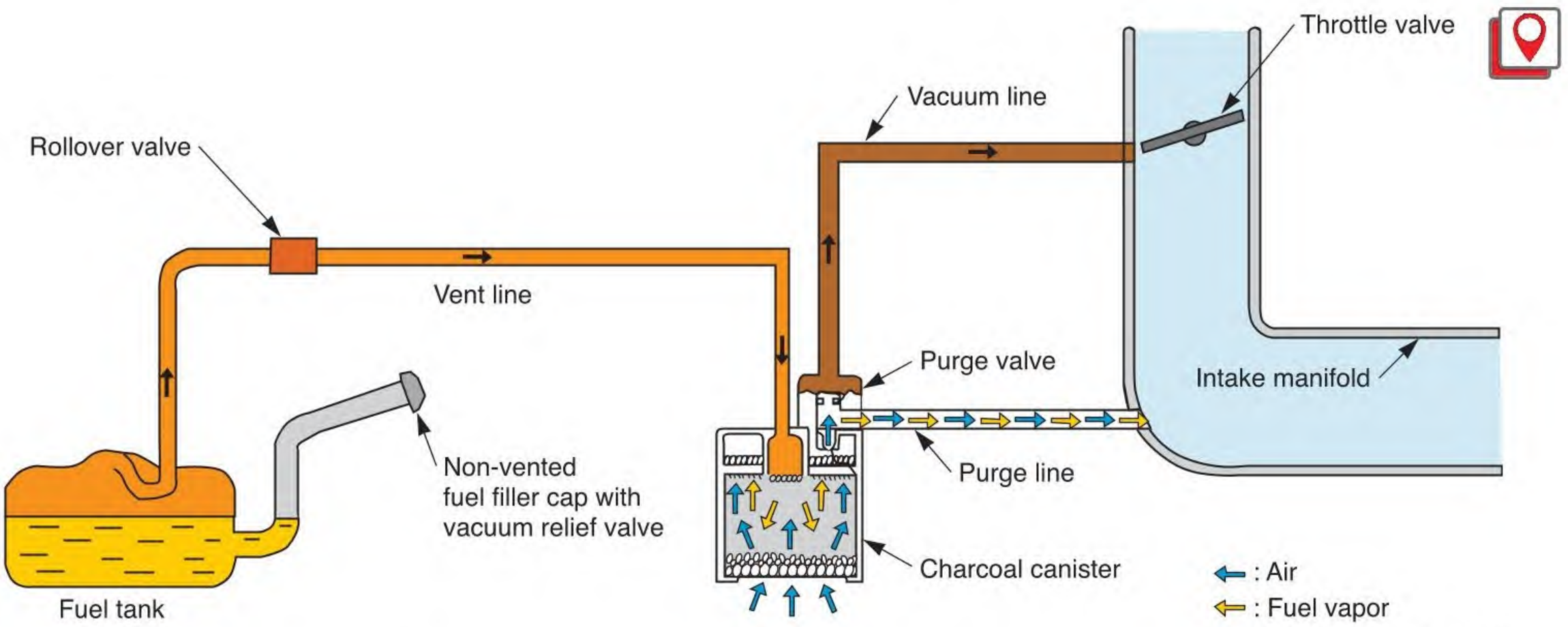


Ford

Figure 51-9. Cutaway view of a charcoal canister. The carbon granules store gasoline vapors when the engine is off. Then, when the engine starts, vacuum draws air through the bottom of the canister. This pulls vapors into the engine.

Evaporative Emissions Control System Operation

When the engine is operating above idle speed, intake manifold vacuum causes the purge valve to open. This allows gases to flow through the purge line and causes fresh air to be drawn through the small air filter in the vapor canister. The incoming fresh air picks up the stored fuel vapors and carries them through the purge line. The vapors enter the intake manifold and are pulled into the combustion chambers for burning. Refer to **Figure 51-10**.



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Figure 51-10. Study the operation of this evaporative emissions control system and its related components. Fuel tank vapors flow to the canister with the engine off. When the engine starts, vacuum pulls vapors out of the charcoal canister into the cylinders. The rollover valve will close during an auto accident when the vehicle rolls. This prevents fuel leakage and a possible fire.

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When the engine is shut off, gasoline slowly evaporates, producing unwanted vapors. These vapors flow through the fuel tank vent line and into the charcoal canister. The activated charcoal in the canister absorbs the fuel vapors and holds them until the engine is started again.

An evaporative emissions control system that contains an electronically-operated purge valve, or purge solenoid, on the charcoal canister is shown in **Figure 51-11**. The purge solenoid is normally closed to hold vapors and opens only when energized by the ECM. The ECM energizes the solenoid only after the following conditions have been met:

- The vehicle has been operating in closed loop for a specified period of time.
- The coolant temperature is within manufacturer's specifications.
- Vehicle speed is above approximately 15 mph.
- The engine is operating above idle speed.

Enhanced Evaporative Emissions Control System

As its name implies, an enhanced evaporative emission control system has several components and features not found on conventional EVAP systems. The enhanced system, which is found in OBD II vehicles, not only provides better control of fuel vapors, but also monitors the condition of the fuel system. In addition to the components found in a conventional evaporative emission system, the enhanced EVAP system contains the following:

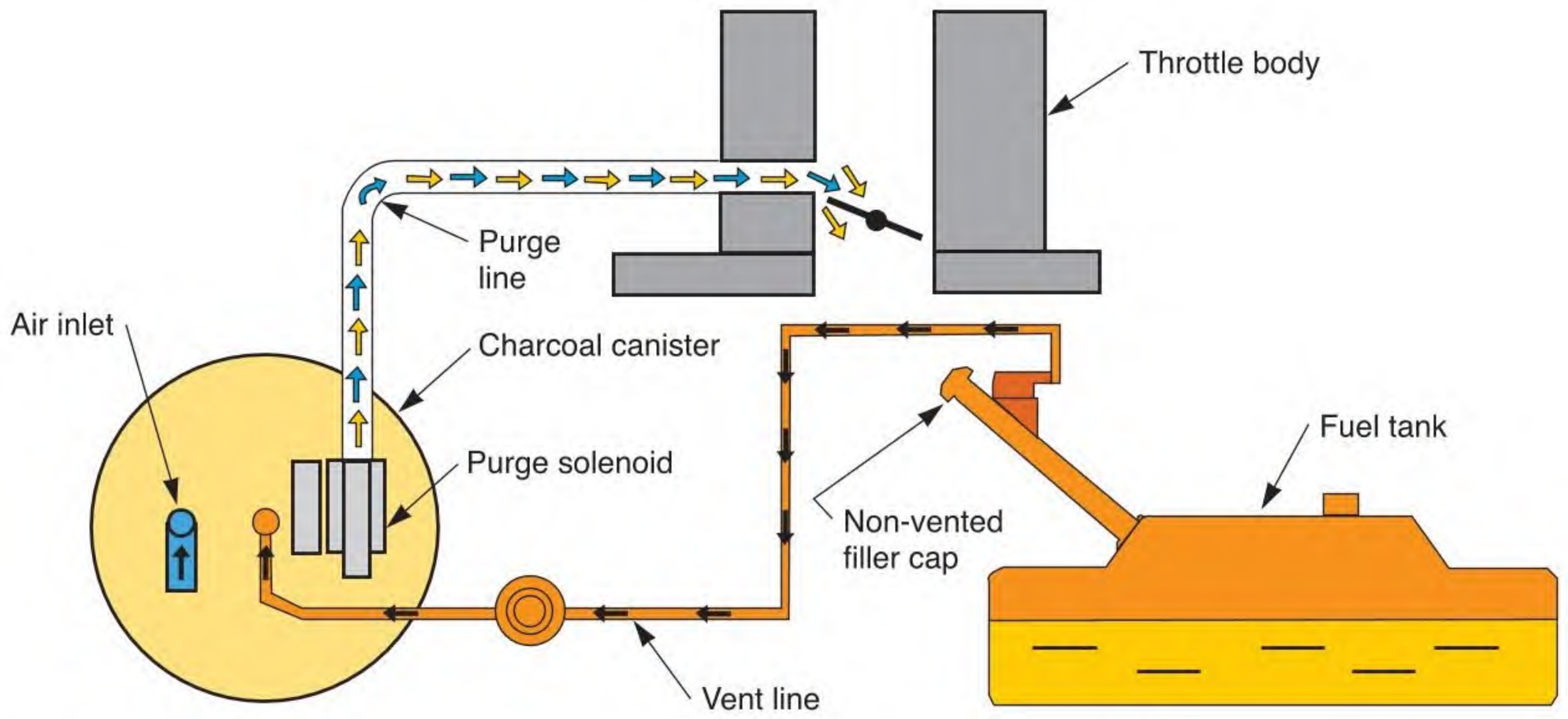
- Fuel tank pressure sensor—The fuel tank pressure sensor monitors internal fuel tank pressure and sends a signal to the control module.
- Canister vent solenoid—The canister vent solenoid is an electrically operated vacuum valve that replaces the fresh air vent used on older canisters.
- Service port—The service port is a fitting that allows the connection of service tools for testing and cleaning purposes.

The canister used in an enhanced EVAP system does not have a bottom inlet filter. Instead, fresh air is fed to the canister by the vent solenoid. The purge valve, or purge solenoid, in these systems is an electrically operated valve that controls the flow of vapors from the canister to the manifold. See **Figure 51-12**.

Enhanced Evaporative Emissions Control System Operation

The enhanced EVAP system often uses a normally closed, pulse-width modulated purge solenoid. The control module can send different length electrical pulses to the solenoid to precisely control vapor flow. When energized, the purge solenoid opens to allow vapors to be pulled into the engine.

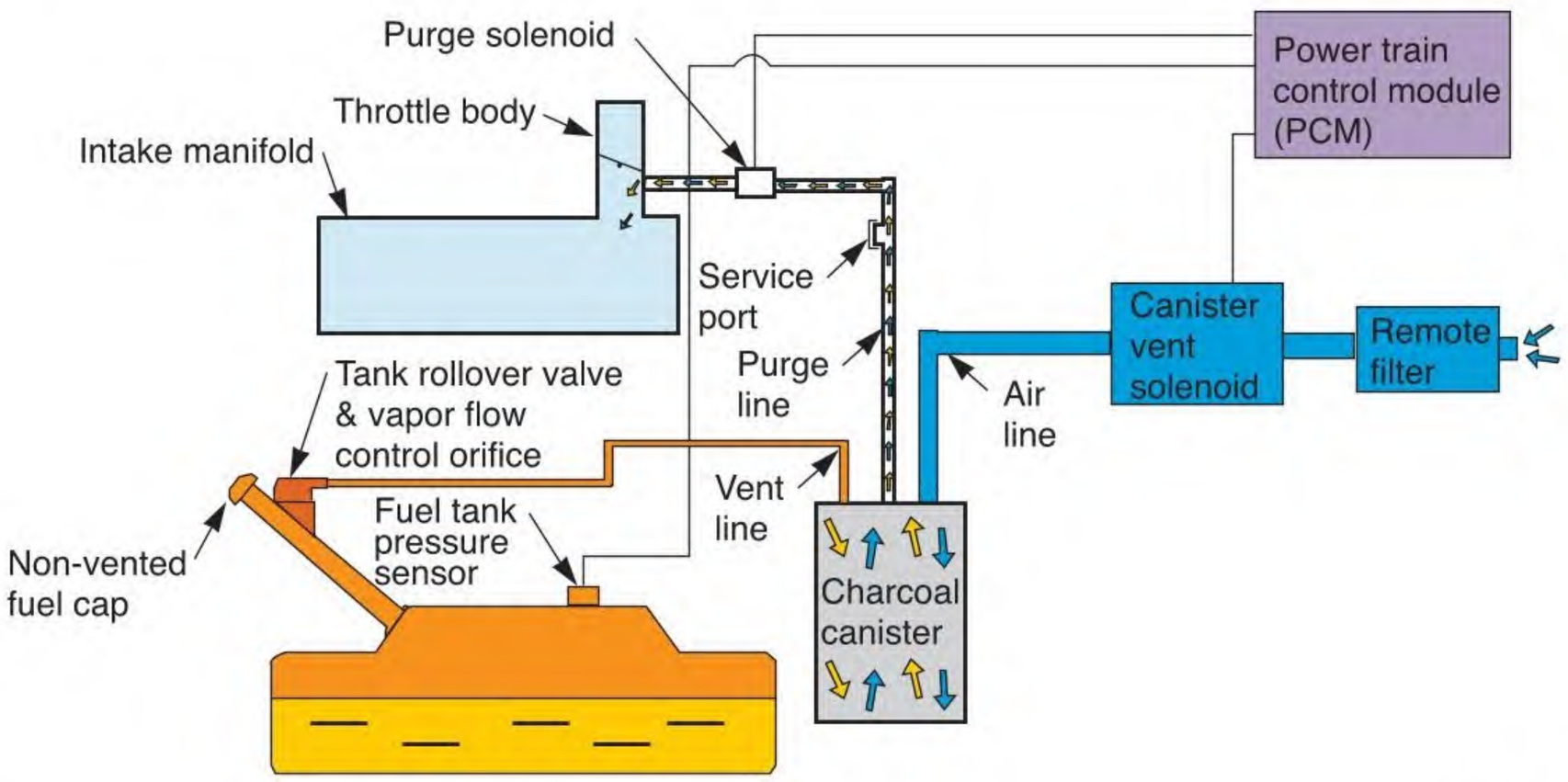
The canister vent solenoid is normally open, allowing fresh air into the canister during purge



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Figure 51-11. This evaporative emissions control system has an electronically controlled purge solenoid. The ECM opens the solenoid to allow vapors to flow from the canister to the throttle body. Compare this system to the one shown in Figure 51-10.

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Figure 51-12. A typical enhanced evaporative emission system is shown. Note the location of the purge solenoid, canister vent solenoid, and service port. This type of system is found on many late-model vehicles.

modes. When the system is in the diagnostic mode, the control module closes the vent solenoid, blocking airflow into the canister. The module then opens the purge solenoid, creating a vacuum in the system. When the control module determines that there is enough vacuum in the system (based on the tank pressure sensor signal), it closes the purge solenoid, sealing the system. The module then monitors the pressure sensor signal. If the system is properly sealed, the signal should remain steady until the control module reopens the vent solenoid.

Air Cleaner Carbon Element

An ***air cleaner carbon element*** may be used to absorb fuel vapors when the engine is shut off. After a hot engine is turned off, hot soak fumes (excess fuel vapors caused by engine heat) can collect in the throttle body. The carbon element attracts and stores these fumes. When the engine is started, airflow through the element pulls these fumes into the engine for burning.

Exhaust Gas Recirculation (EGR)

The ***exhaust gas recirculation (EGR) system*** allows burned exhaust gases to enter the engine intake manifold to help reduce NO_x emissions. When exhaust gases are added to the air-fuel mixture, they decrease peak combustion temperatures (maximum temperature produced when the air-fuel mixture burns). For this reason, an exhaust gas recirculation system lowers the amount of NO_x in the engine exhaust. EGR systems can be controlled by engine vacuum or by the engine control module.

Vacuum-Controlled EGR

A vacuum-controlled EGR system uses engine vacuum to operate the EGR valve. This system can be found on millions of older vehicles still on the road.

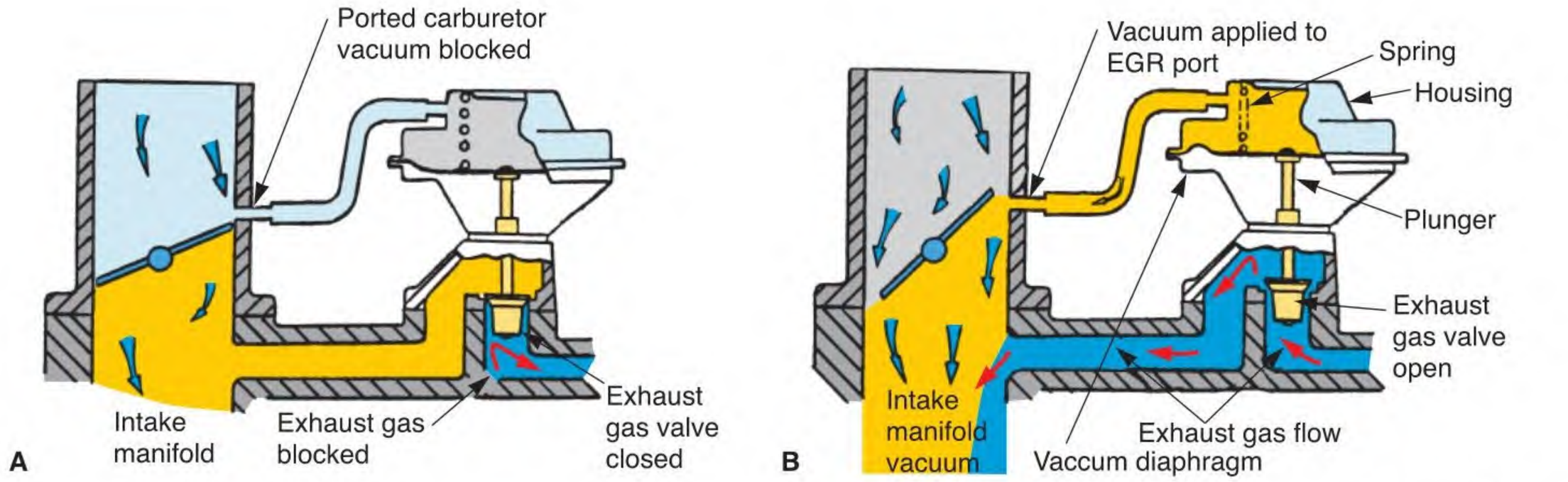
A basic vacuum EGR system is simple. It consists of a vacuum-operated EGR valve and a vacuum line from the throttle body. The EGR valve consists of a vacuum diaphragm, spring, plunger, exhaust gas valve, and a diaphragm housing. It is designed to control exhaust flow into the intake manifold. It usually bolts to the engine intake manifold. Exhaust gases are routed through the cylinder head and intake manifold to the EGR valve, **Figure 51-13**.

Vacuum EGR Operation

At idle, the throttle plate in the throttle body is closed. This blocks off engine vacuum so it cannot act on the EGR valve. The EGR spring holds the valve shut and exhaust gases do not enter the intake manifold. If the EGR valve were to open at idle, it could upset the air-fuel mixture and the engine could stall.

When the throttle plate opens to increase speed, engine vacuum is applied to the EGR hose. Vacuum

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Figure 51-13. Study basic EGR valve operation. This is an older vacuum-operated EGR, but it still shows valid principles. A—With the throttle closed at idle speed, vacuum to the EGR valve is blocked, and the valve remains closed to prevent rough idling. B—When the throttle opens for more engine speed, the vacuum port to the EGR valve is exposed to vacuum. The EGR valve diaphragm is pulled up, and exhaust gases enter the engine intake manifold without adversely affecting engine operation.

pulls the EGR diaphragm up. In turn, the diaphragm pulls the valve open.

Engine exhaust can then enter the intake manifold and combustion chambers. At higher engine speeds, there is enough air flowing into the engine that the air-fuel mixture is not upset by the open EGR valve.

Electronic-Vacuum EGR Valves

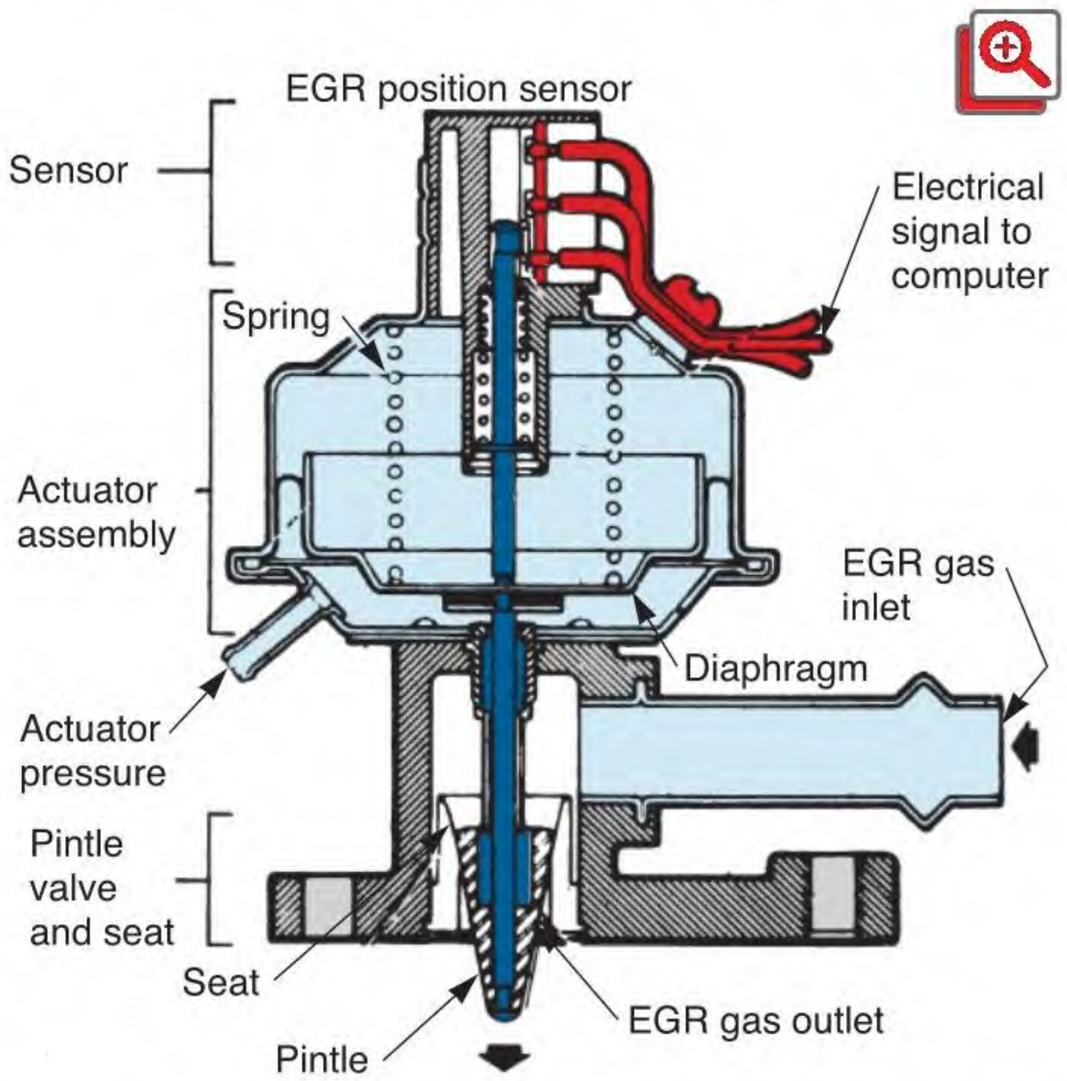
An electronic-vacuum EGR valve uses both engine vacuum and electronic control for better exhaust gas metering. An EGR position sensor is located in the top of the valve and sends data back to the ECM. This allows the ECM to determine how much the EGR valve is opened. Refer to **Figure 51-14**.

With some systems, ***EGR solenoid valves*** are used to more closely control EGR opening. See **Figure 51-15**. These valves use electric solenoids to block or pass airflow to the EGR valve. They are located in one or more of the vacuum lines going to the EGR valve. The ECM can energize the solenoids to alter when and how fast the EGR valve opens or closes to improve efficiency.

EGR System Variations

There are several EGR system variations that you might encounter, including the following:

- A back pressure EGR valve that uses both engine vacuum and exhaust back pressure to control valve action. This provides accurate control of EGR valve operation.
- An engine coolant temperature switch may be used to prevent exhaust gas recirculation when the engine is cold. A cold engine does not have extremely high combustion temperatures, so production of NO_x is minimal. By blocking vacuum to the EGR valve when the engine operating temperature is below 100°F (38°C), the driveability and performance of the cold engine are improved.



Ford

Figure 51-14. This EGR valve has a sensor connected to the vehicle's on-board computer or ECM. EGR pintle movement changes current flow through the sensor, allowing the ECM to alter engine operation.

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- The vacuum line to the EGR valve is sometimes connected into a wide open throttle valve (WOT valve). The WOT valve opens under full acceleration to provide engine vacuum or suction to the EGR valve.
- Small EGR jets have been used in the bottom of a few intake manifolds to replace the EGR valve. The jets meter a small amount of exhaust gas into the airflow before it enters the engine cylinder head ports. The jets are small enough that they do not upset the idle air-fuel mixture.

Electronic EGR System

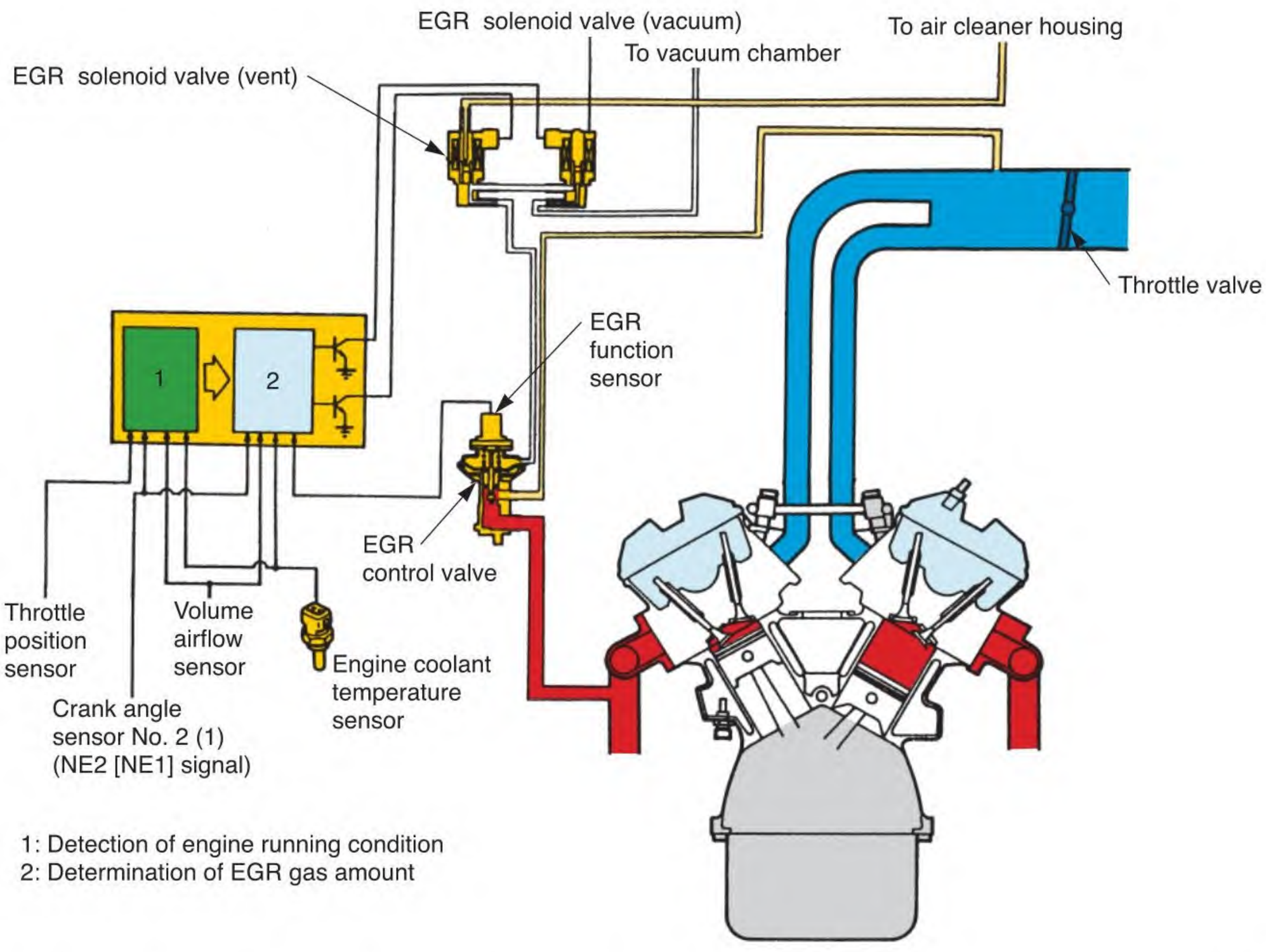
An ***electronic EGR system*** uses vehicle sensors, the ECM, and a solenoid-operated exhaust gas recirculation valve to reduce NO_x emissions. This is the most common type of EGR system used on late-model engines.

The ECM uses input data from the EGR position sensor, engine coolant temperature sensor, mass airflow sensor, throttle position sensor, crankshaft position sensor, and other sensors. The sensor signals allow the ECM to determine how much duty cycle should be sent to open and close each valve for maximum efficiency and minimum exhaust emissions, **Figure 51-16**.

The ***EGR duty cycle*** is a measurement of control current on and off time sent from the ECM. The ECM can precisely control duty cycle to meter just the right amount of exhaust gases needed to reduce NO_x emissions, **Figure 51-17**.

Electronic EGR Valves

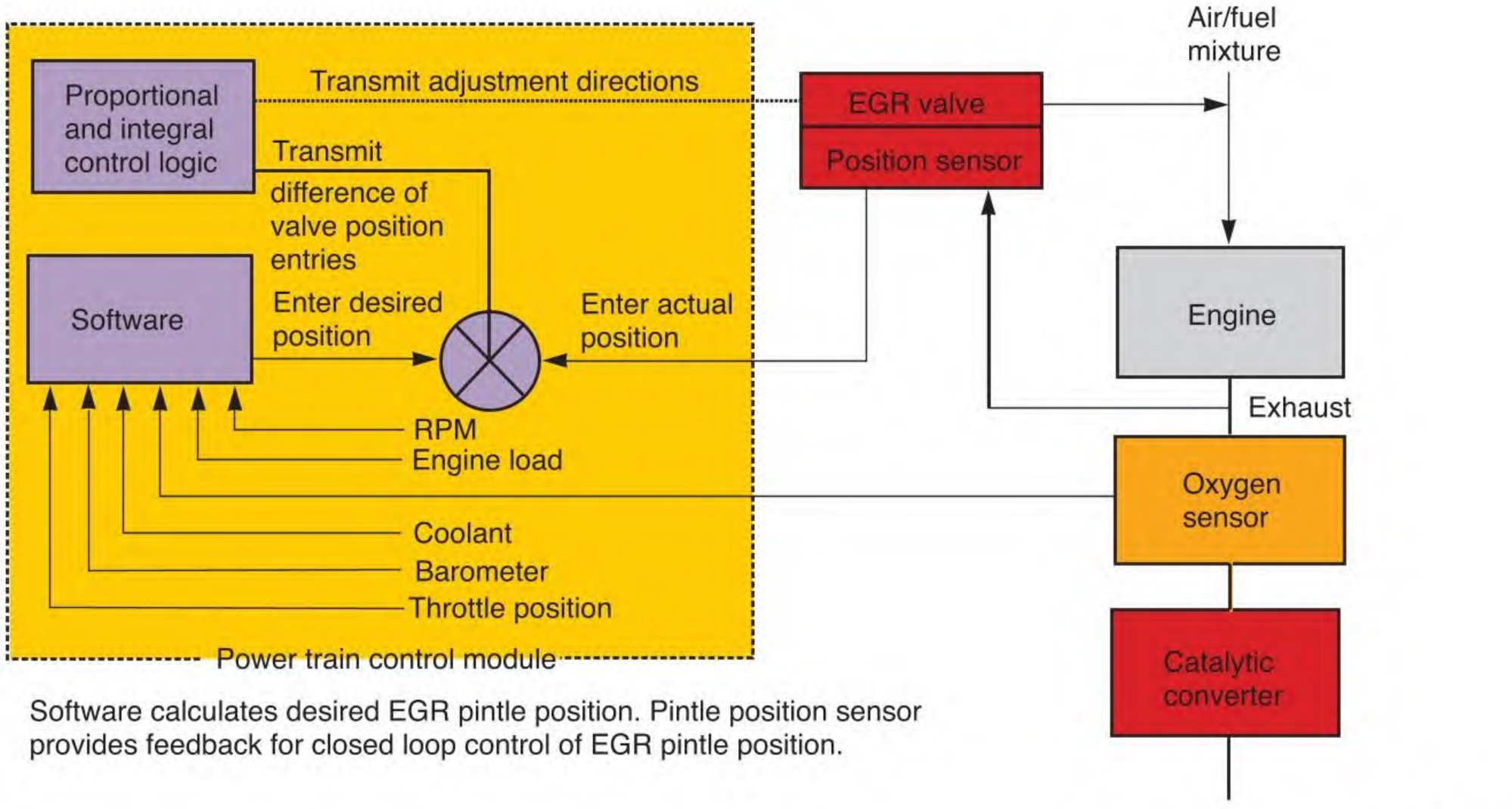
An ***electronic EGR valve***, sometimes termed a *digital EGR valve*, uses one or more electric solenoids



Mazda

Figure 51-15. This diagram shows how the control module can be used to monitor and control a vacuum-operated EGR valve. The electric solenoids can block or allow flow in the vacuum line going to the EGR valve, providing computer control for this system. The engine coolant temperature sensor allows the control to keep the EGR valve closed when the engine is cold and NO_x emissions are not a problem.

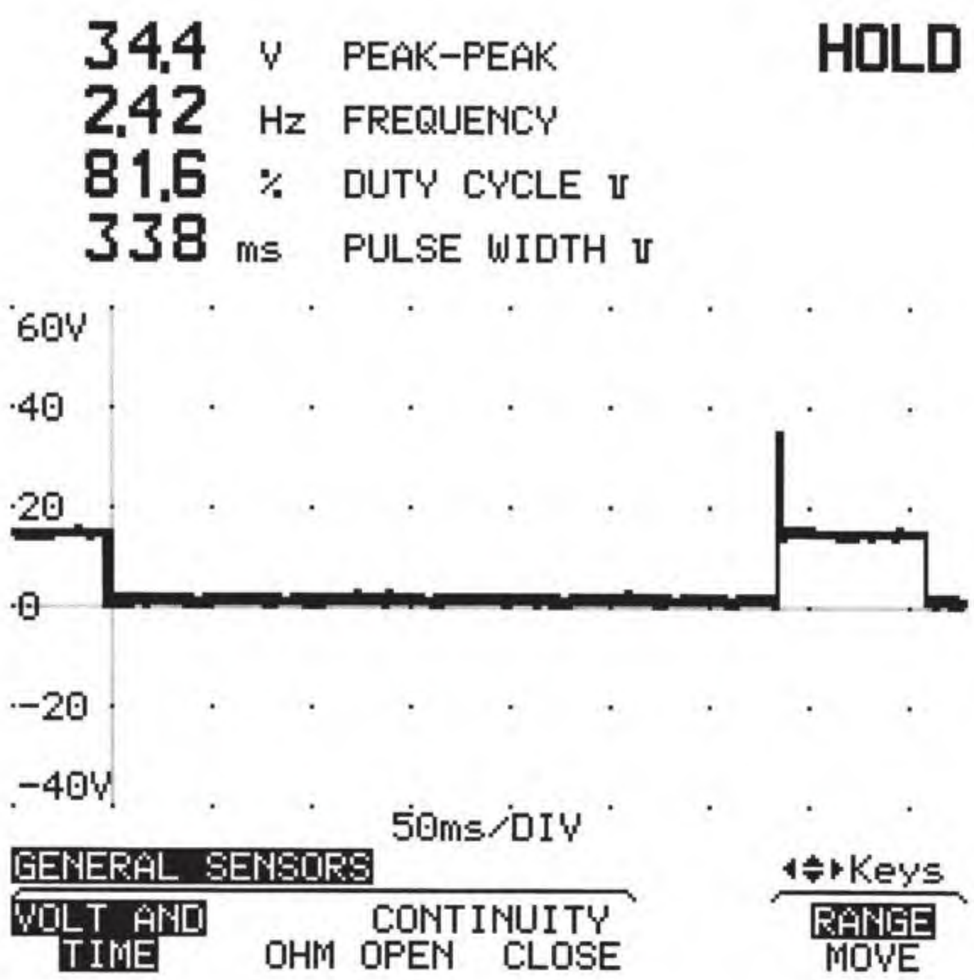
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Software calculates desired EGR pintle position. Pintle position sensor provides feedback for closed loop control of EGR pintle position.

Mazda

Figure 51-16. This block diagram shows the relationship between a power train control module and the EGR system. Programmed data in the PCM allow it to change the EGR opening cycle with various conditions for maximum efficiency.



Fluke

Figure 51-17. The duty cycle of an electronic EGR valve can be monitored with an oscilloscope or a meter with scope feature. The duty cycle, pulse width, and waveform of the valve's operation are shown.

to open and close its exhaust passages. It works without engine vacuum.

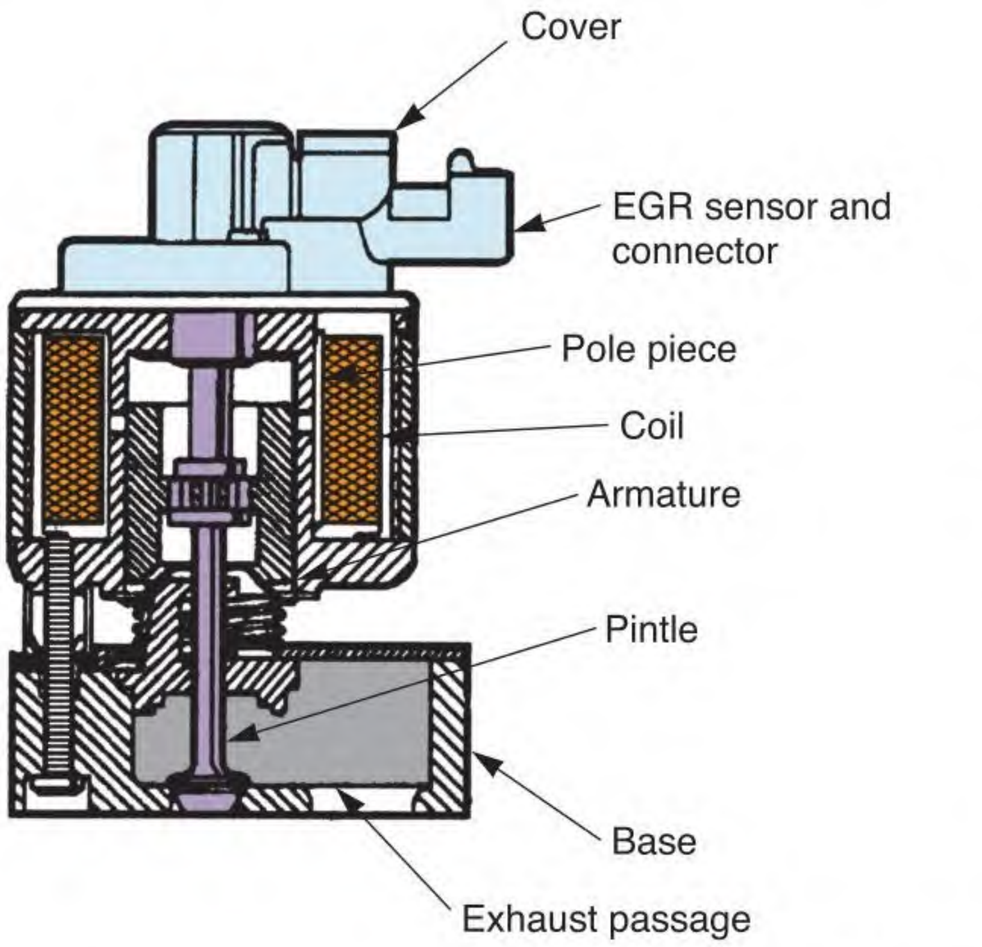
A ***single-stage EGR valve*** uses only one solenoid and valve. It is a simple, dependable EGR design. See **Figure 51-18**. To open one of the exhaust passages in the EGR valve, the ECM energizes its solenoid. When control current is sent to the solenoid windings, it pulls up on the metal armature connected to the valve. This lifts up the valve to open an exhaust recirculation passage. Exhaust gases flow through orifices (metered openings) to limit engine combustion temperatures and prevent NO_x pollution. When the ECM stops current flow to the EGR solenoid, spring tension closes the valve to prevent exhaust gas flow into the engine.

A multi-stage EGR valve uses more than one solenoid valve (usually three) to more closely match exhaust gas flow to engine needs. The solenoids mount on a base plate. When the valves are closed, they contact and seal against the base plate seats.

If only a small amount of exhaust recirculation gas is needed (combustion temperatures only slightly too hot), the ECM will only energize one of the EGR solenoids.

If combustion temperatures become hotter (engine conditions like speed, load, or outside air temperature increase), the ECM will energize the other EGR solenoids as needed to increase exhaust gas recirculation

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Figure 51-18. This cutaway view shows the components of an electronic EGR valve. When the ECM sends current to the EGR solenoid, the windings produce a magnetic field that pulls the pintle up to open the EGR valve.

flow. The added exhaust gases will decrease combustion temperatures to reduce NO_x.

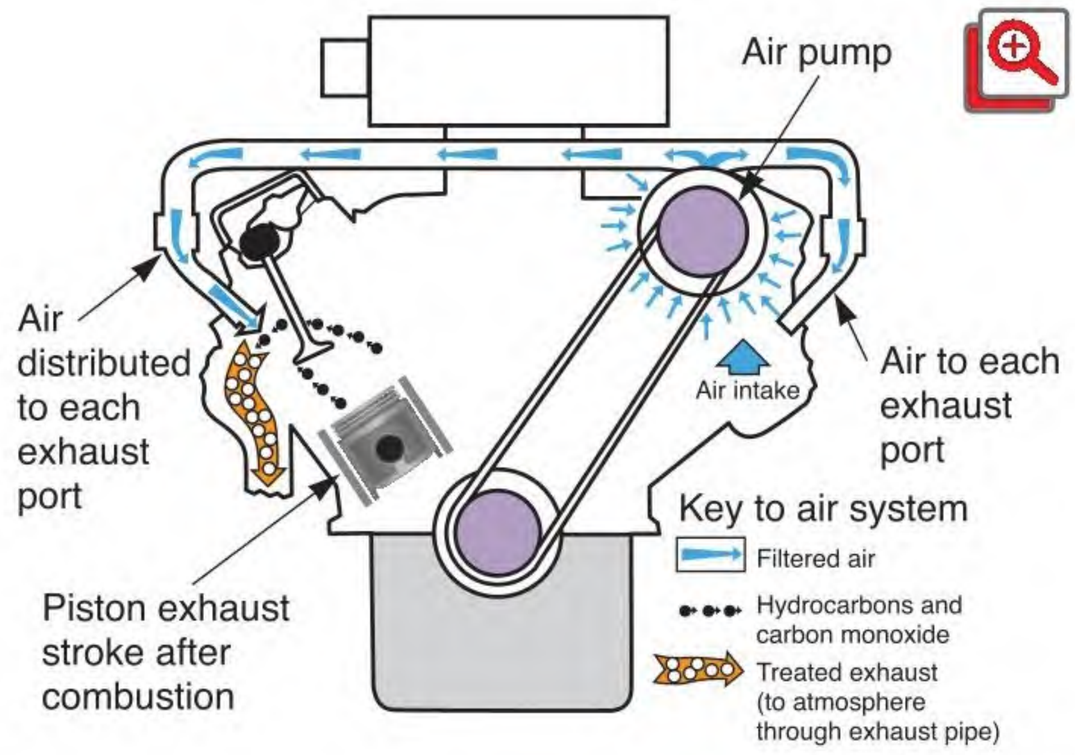
Air Injection System

An ***air injection system*** forces fresh air into the exhaust ports and, in some cases, the catalytic converter to reduce HC and CO emissions. The exhaust gases leaving an engine can contain unburned and partially burned fuel. Oxygen from the air injection system causes this fuel to continue to burn in the exhaust manifold or the catalytic converter. See **Figure 51-19**.

Air Injection System Components

The ***air injection pump*** is belt-driven and forces air at low pressure into the system. The spinning vanes, or blades, pull air in one side of the pump. The air is trapped and compressed as the vanes rotate. As rotation continues, air is forced out of a second opening in the pump. See **Figure 51-20**.

Electric air injection pumps are driven by a small dc motor, instead of being engine driven. This reduces emissions at start-up and with high engine temperatures because a more constant flow of air is produced by the electric motor. Air pump speed does not change with engine speed.



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Figure 51-19. An air injection system is sometimes used to help burn excess fuel vapors that enter the exhaust system by forcing low-pressure air into the exhaust stream. The air pump forces outside air into the exhaust manifolds. The air helps hot exhaust gases burn as they blow out of the open exhaust valves.

The ***diverter valve*** keeps air from entering the exhaust system during deceleration. This prevents backfiring (explosive burning of the air-fuel mixture outside the combustion chamber) in the exhaust system. The diverter valve also limits maximum system air pressure. It releases excessive pressure through a silencer or muffler. A plastic or rubber hose connects the pump output to a diverter valve.

An ***air distribution manifold*** is used in air injection systems to direct a stream of air toward each engine exhaust valve. Fittings on the air distribution manifold screw into threaded holes in the exhaust manifold or cylinder head.

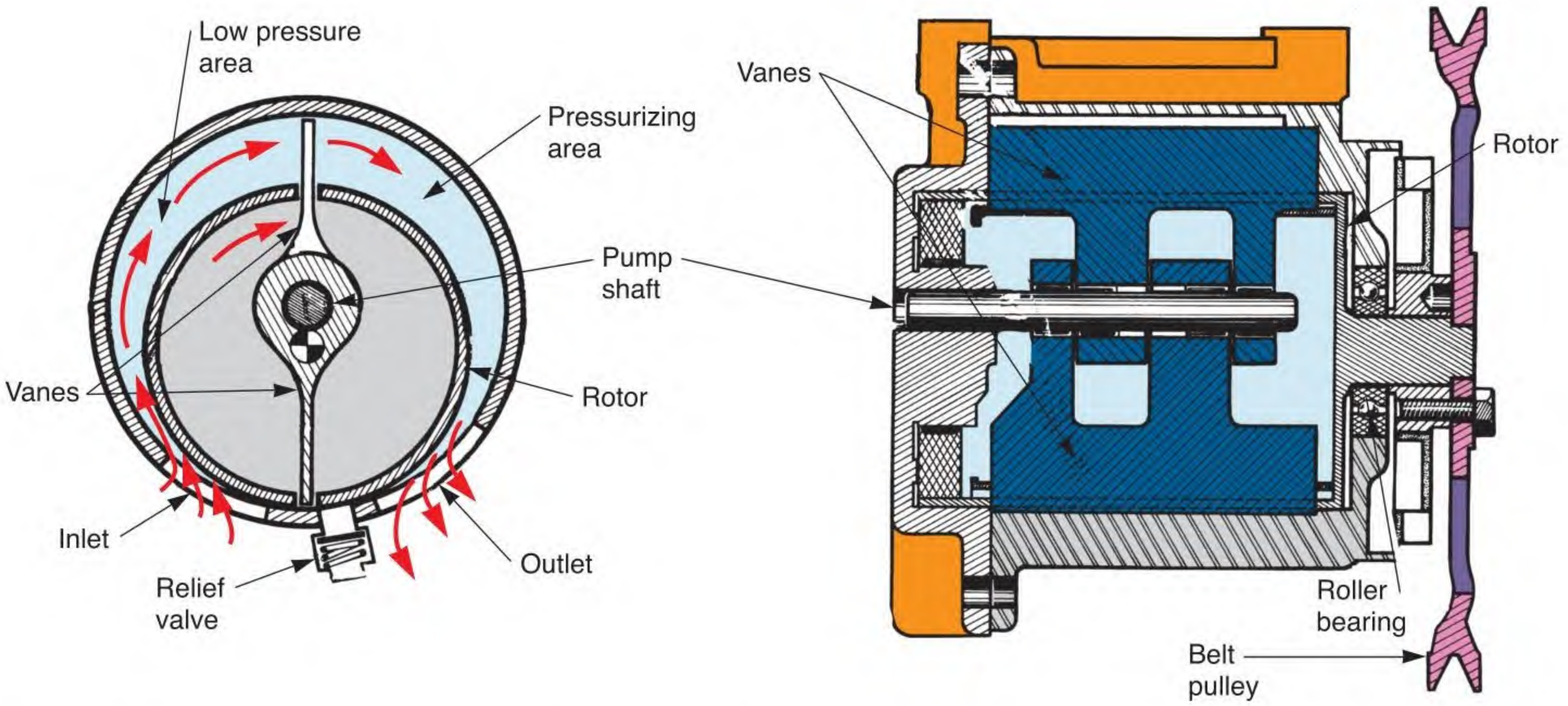
An air check valve is usually located in the line between the diverter valve and the air distribution manifold. It keeps exhaust gases from entering the air injection system.

Air Injection System Operation

When the engine is running, the spinning vanes in the air pump force air into the diverter valve. If not decelerating, the air is forced through the diverter valve, check valve, air injection manifold, and into the engine exhaust ports. The fresh air blows on the engine exhaust valves to keep any fuel burning as it leaves the engine.

During periods of deceleration, the diverter valve blocks airflow into the engine exhaust manifold. This prevents a possible backfire, which could damage the

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Figure 51-20. This cutaway shows the action inside an air pump used in an air injection system. A belt turns the pump pulley, shaft, and rotor. The vanes trap and pressurize air.

vehicle's exhaust system. When needed, the diverter valve's relief valve releases excess pressure.

Late-model vehicles can also use the air injection system to force air into the catalytic converter. This is done to help the converter burn, or oxidize, the partially burned fuel more completely. A metal line runs from the air pump to the catalytic converter. Air from this line is forced into the converter.

Pulse Air System

A ***pulse air system*** performs the same function as an air injection system. However, instead of an air pump, it uses natural pressure pulses in the exhaust system to operate aspirator valves. Refer to **Figure 51-21**.

The ***aspirator valves***, also called *check valves*, *gulp valves*, or *reed valves*, block airflow in one direction and allow airflow in the other direction. Pulse air systems can be found on older vehicles and a few newer models.

Pulse Air System Operation

Pressure in the exhaust manifold fluctuates as the engine valves open and close. The aspirator valves allow fresh air to enter the exhaust manifold on the low-pressure pulses (when exhaust valve first closes). However, they block backflow on the high-pressure pulses (as exhaust valve opens). This causes fresh air to flow through the system and into the engine exhaust manifold.

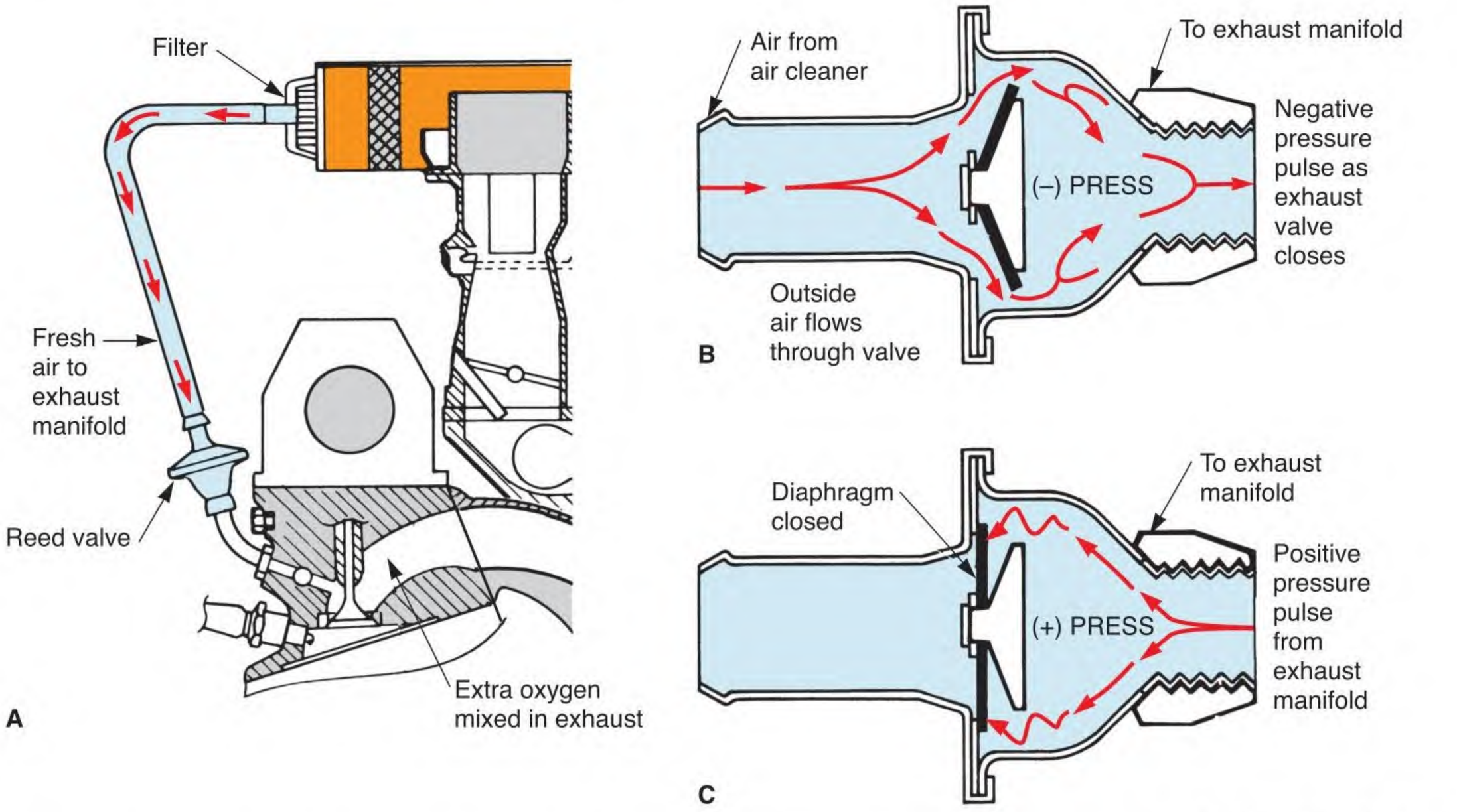
Catalytic Converter

A ***catalytic converter*** changes exhaust by-products into harmless substances. It oxidizes (burns) the HC and CO emissions that pass into the exhaust system. Extreme heat (temperatures of approximately 1400°F, or 760°C), ignites these emissions and changes them into harmless carbon dioxide (CO_2) and water (H_2O). Most converters also reduce NO_x emissions to oxygen (O_2) and nitrogen (N_2). Look at **Figure 51-22**.

A ***catalyst*** is any substance that speeds a chemical reaction without itself being changed. A catalytic converter contains a catalyst agent, usually the elements platinum, palladium, rhodium, or a mixture of these materials. Platinum and palladium treat and help burn the HC and CO emissions. Rhodium acts on the NO_x emissions. Some newer converters also use cerium to attract and release additional oxygen when needed to burn any fuel remaining in the engine exhaust stream.

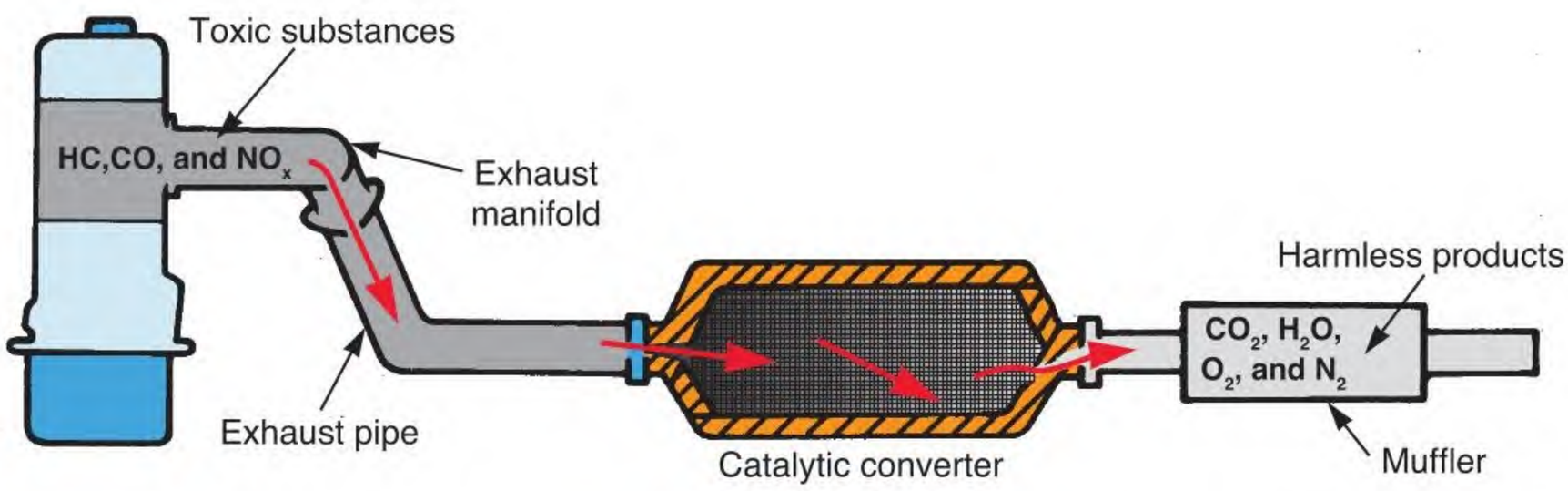
The converter's catalyst agent is coated on either a ceramic honeycomb-shaped block or, in older

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Figure 51-21. A—Pulse air injection systems do not use an air pump. Instead, aspirator valves act as check valves. B—When the exhaust valves close, they produce a vacuum pulse that allows air to enter the exhaust manifold. C—Aspirators block airflow when the exhaust valves open and produce a pressure pulse.



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Figure 51-22. A catalytic converter burns and treats exhaust emissions and changes them into harmless chemicals.

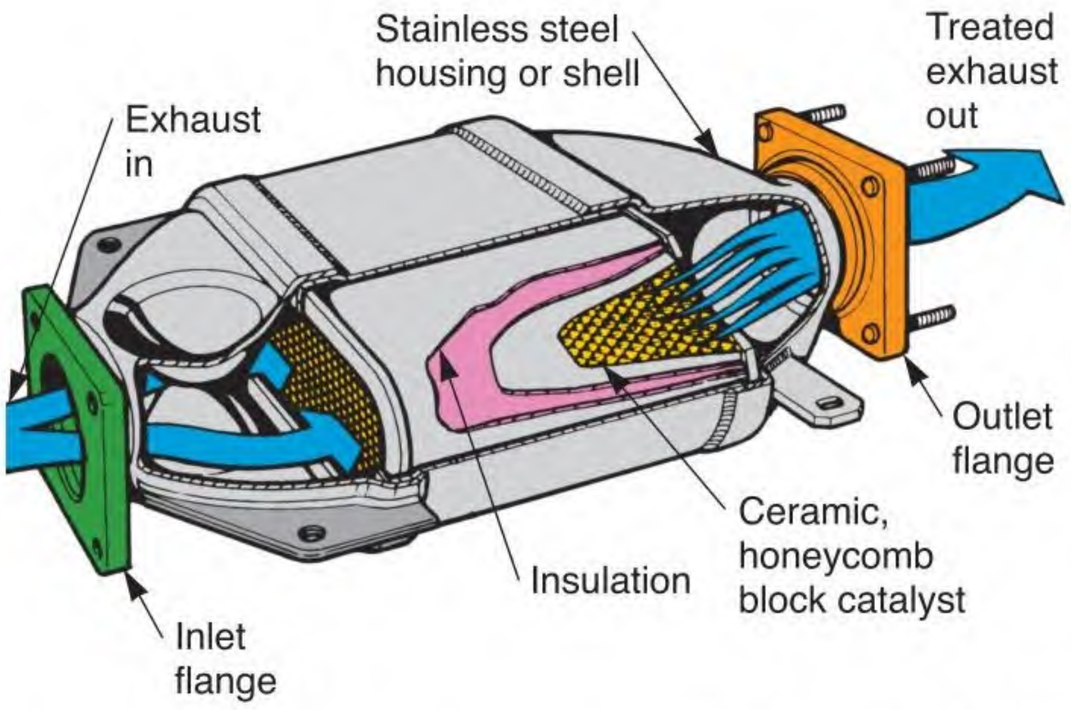
models, small ceramic beads. The catalyst is encased in a stainless steel housing that is designed to resist heat since it contains the burning fuel vapors that leave the combustion chambers. See **Figure 51-23**. The catalyst operating temperature is attained when the catalyst agents are hot enough (above 300°F or 149°C) and start to re-burn any remaining hydrocarbon emissions.

Types of Catalytic Converters

A ***mini catalytic converter*** is a very small converter placed close to the engine exhaust manifold. It heats up quickly to reduce emissions during engine warm-up. A mini catalytic converter is used in conjunction with a larger, main converter. See **Figure 51-24**.

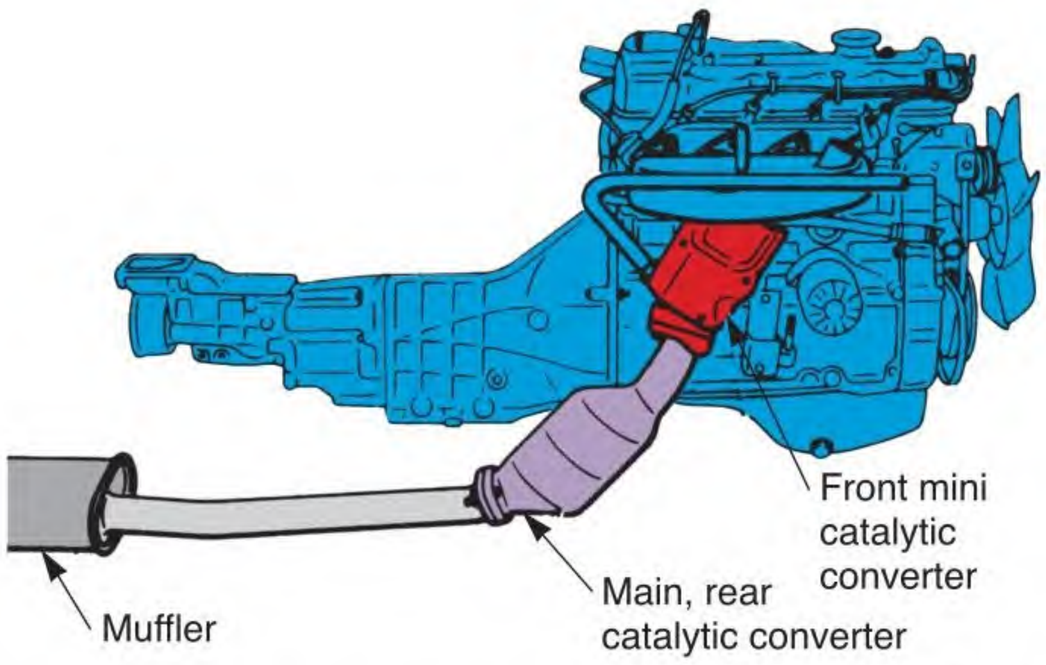
A ***two-way catalytic converter***, sometimes called an oxidation converter, can only reduce two types of

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Figure 51-23. Monolithic catalytic converters use a honeycomb-shaped block of ceramic material covered with catalytic elements to treat exhaust gases. The catalyst is enclosed in a stainless steel housing.



Chrysler

Figure 51-24. This engine uses a mini catalytic converter and a main converter. The mini converter functions right after engine startup. It heats up quickly to reduce emissions when the engine and main converter are cold.

exhaust emissions (HC and CO). A two-way converter is normally coated with platinum.

A ***three-way catalytic converter***, also termed a *reduction-type converter*, is capable of reducing all three types of exhaust emissions (HC, CO, and NO_x). A three-way converter is usually coated with rhodium and platinum.

A ***dual-bed catalytic converter*** contains two separate catalyst units enclosed in a single housing. A dual-bed converter normally has both a three-way (reduction) catalyst and a two-way (oxidation) catalyst. A mixing chamber is provided between the two. Air is forced into the mixing chamber to help burn the HC and CO emissions. Look at **Figure 51-25**.

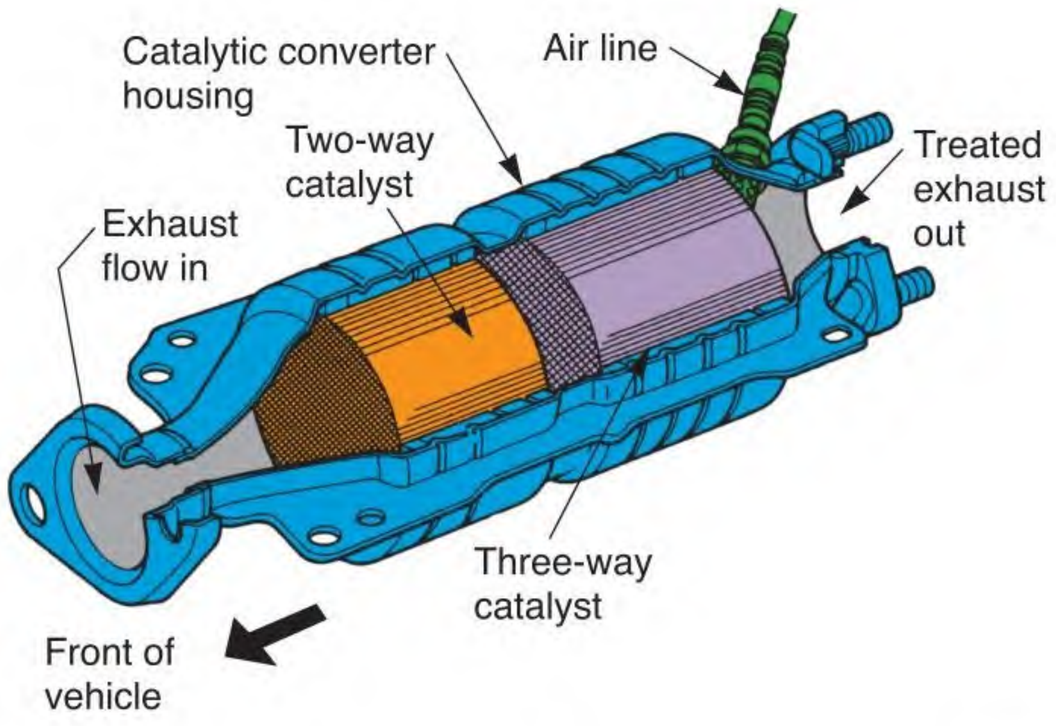
Dual-Bed Catalytic Converter Operation

When the engine is cold (below approximately 128°F or 52°C), the air injection system routes air into the exhaust manifold. Exhaust heat and the injected air are used to burn exhaust emissions. When the engine warms, the system forces air into the catalytic converter, **Figure 51-26**.

First, the exhaust gases pass through the front three-way catalyst that removes HC, CO, and NO_x. Then, the exhaust gas flows into the area between the two catalysts. The oxygen in the air flowing into the chamber causes the gases to continue to burn. The exhaust flows into the rear two-way catalyst which removes even more HC and CO.

Tech Tip

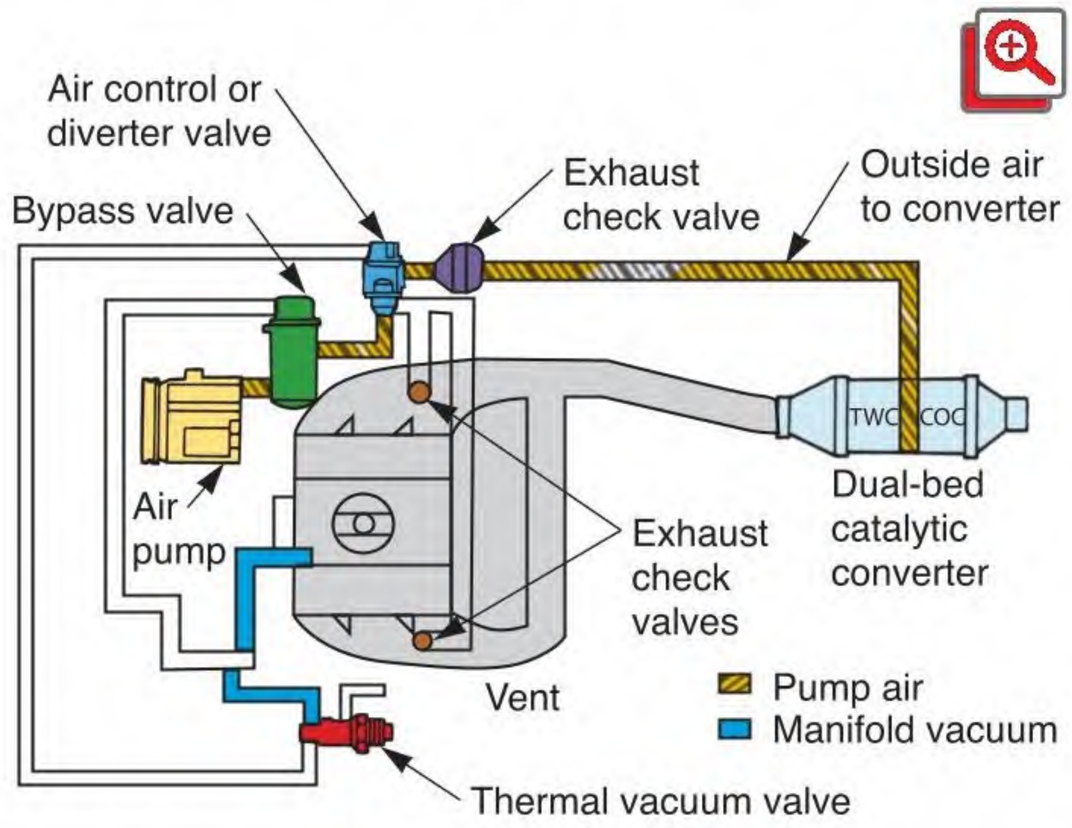
Some catalysts are coated with a material that absorbs and temporarily stores NO_x emissions. When a saturation level is reached, the on-board computer temporarily enriches the fuel mixture. This causes the converter's internal honeycomb block to glow red hot, breaking up the stored NO_x emissions into harmless by-products.



Honda

Figure 51-25. A dual-bed catalytic converter has two ceramic elements. One is a three-way catalyst. Air from an air pump is forced into the converter to aid burning and reaction.

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Figure 51-26. This diagram shows how an air pump forces oxygen into a dual-bed catalytic converter. The thermal-vacuum switch operates the air control valve. It only lets air flow to converter when the engine coolant is above set temperature.

Computerized Emission Control Systems

Computerized emission control systems use various engine, exhaust, and fuel system sensors, a three-way catalytic converter, and dual-bank O_2 sensors to reduce pollution levels emitted from the vehicle.

The ECM analyzes data from all systems that affect air pollution (engine, ignition, exhaust, air supply and air injection, and fuel injection systems) to closely monitor and control any function that can affect emissions. Refer to **Figure 51-27**.

Oxygen Sensors

Since ***oxygen sensors*** are so critical to engine performance and gas mileage, we will quickly review the operation of each type. This will ready you for the service chapters that detail the testing of actual oxygen sensor performance.

Remember that the amount of oxygen in exhaust gases is a good indicator of an engine's fuel efficiency and cleanliness. The engine ECM uses at least two oxygen sensors as the main control of the fuel injection system. The ECM tries to keep the engine running on a ***stoichiometric fuel mixture*** (theoretically perfect 14.7:1 air-fuel by weight) with changes in speed and load.

For example, a low percentage of oxygen in the engine exhaust gases indicates a rich fuel mixture (too much unburned fuel compared to oxygen). The ECM would instantly decrease injector pulse width slightly to lean the fuel mixture enough to attain stoichiometric for maximum combustion efficiency (minimum HC, CO, and NO_x emissions).

Primary and Secondary Oxygen Sensors

Newer vehicles are equipped with multiple oxygen sensors. The number of O_2 sensors used depends on the engine, application, and whether the engine has single or dual exhaust pipes.

A ***primary oxygen sensor***, also called a ***front O_2 sensor***, is used to monitor the oxygen in the exhaust gases leaving the engine. The signal from the primary sensor indicates whether the engine's air-fuel mixture is too lean or rich. All primary sensors are located before, or in front of, the catalytic converters, usually as close to the engine as possible.

A ***secondary oxygen sensor***, or ***rear O_2 sensor***, is mounted downstream in the exhaust system. Depending on its location downstream, the rear oxygen sensor can be used to either check the oxygen content of the exhaust gases entering a catalytic converter or to monitor the converter for proper operation. Any O_2 sensor mounted after a converter is referred to as a catalyst monitor. Its operation will be explained later in this chapter.

Oxygen Sensor Position

Oxygen sensor position in the vehicle is assigned a number by its location and order in relation to the engine's banks. See **Figure 51-28**. The sensor closest to the number one cylinder is denoted as *Oxygen sensor*, *Bank 1*, *Sensor 1*. If the engine is equipped with only one oxygen sensor, which is the case with OBD I vehicles, it is referred to as *Oxygen sensor*, *Bank 1*, *Sensor 1*, no matter where it is located in the exhaust system. If the engine is a V-type, sensors located in the other bank are considered to be located in *Bank 2*. Sensors further down the exhaust stream from the engine are consecutively numbered as *Sensor 2*, *Sensor 3*, and so on. In almost all cases, the sensor with the highest number, such as *Sensor 3*, is the catalyst monitor.

Heated Oxygen Sensors

A ***heated oxygen sensor***, abbreviated HO_2S, uses an electric heating element to quickly warm the sensor to operating temperature. The heating element also stabilizes the temperature and operation of the sensor. The heating element allows the ECM system to use the input sensor signals sooner.

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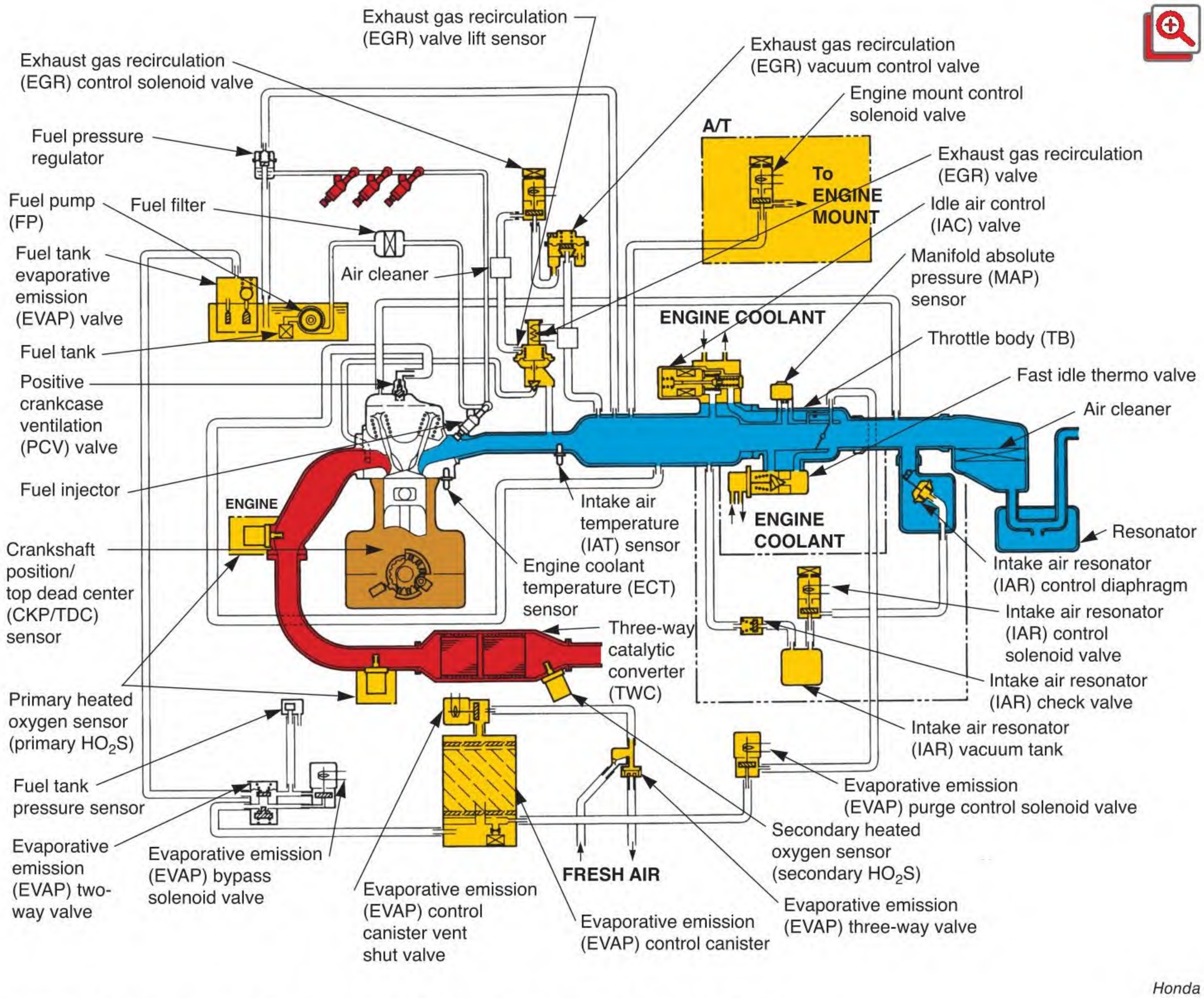


Figure 51-27. Note the various sensors used in computer-controlled emission systems.

Zirconia Oxygen Sensors

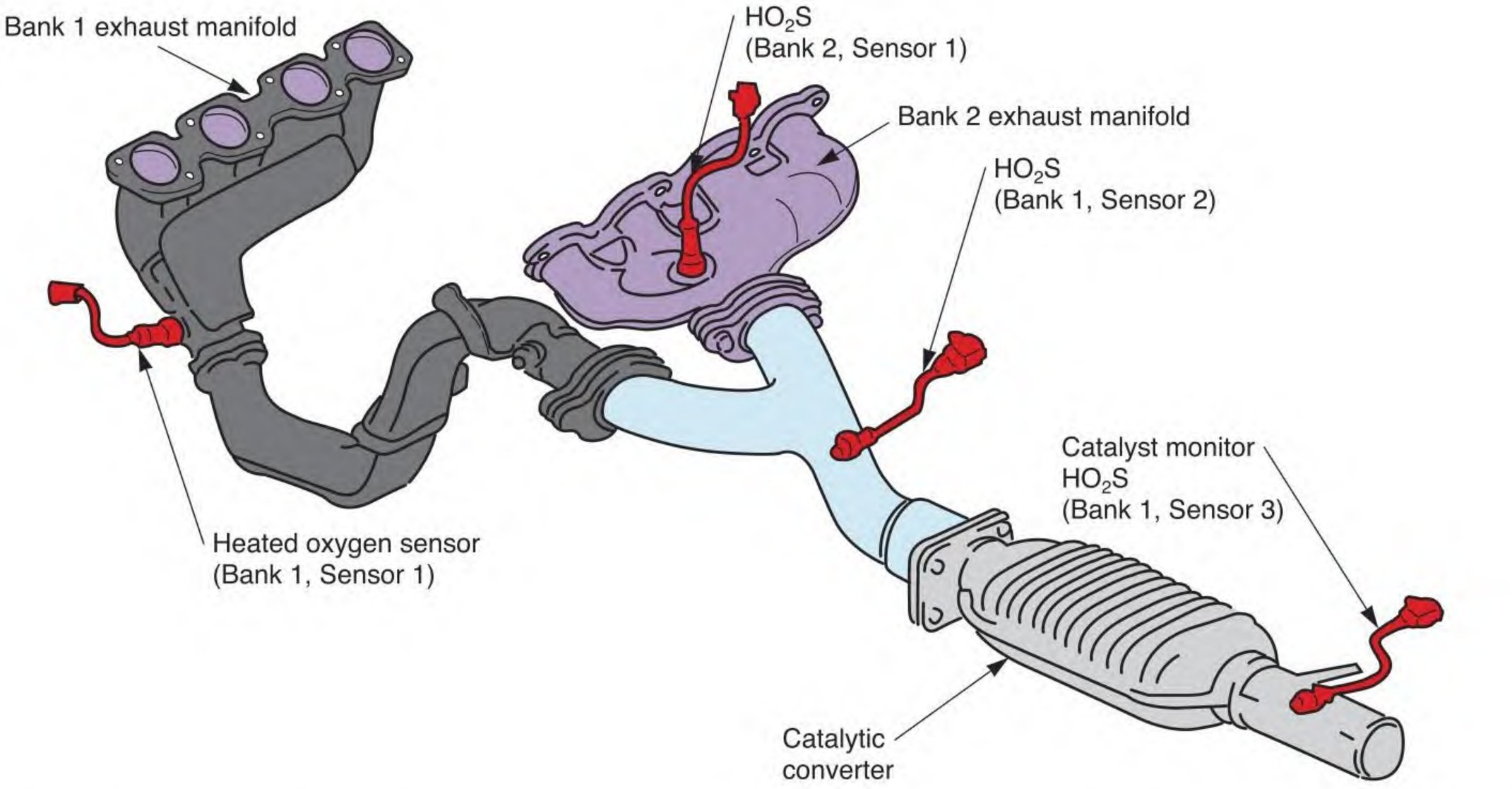
Most heated O_2 sensors are also called ***zirconia oxygen sensors*** because of their active materials. See **Figure 51-29**. Zirconia and platinum are commonly used to produce the voltage output that represents oxygen in the exhaust gases. The platinum coating on the sensor surface causes any unburned fuel to ignite, which helps the sensor to maintain its operating temperature (about 600°F or 315°C). At an operating temperature of about 600°F (315°C), the oxygen sensor's element becomes a semiconductor and generates a small voltage.

The ECM compares the voltage produced by the sensor to a reference voltage of approximately 450 millivolts (0.45 volts). For example, if the engine's air-fuel mixture is too rich, there will be almost no oxygen in the exhaust gases. See **Figure 51-30A**. A zirconia O_2 rich voltage signal would be about 600 millivolts (0.6 volts). A zirconia O_2 lean sensor voltage might read 300 millivolts (0.3 volts), **Figure 51-30B**. The ECM will then enrich the fuel mixture and try to maintain a stoichiometric (chemically correct) air-fuel mixture. See **Figure 51-31**.

Planar Oxygen Sensors

Many vehicles are equipped with ***planar zirconia oxygen sensors***. These sensors work the same way as conventional zirconia sensors, but the zirconia element, electrodes, and heater are combined in a flat,

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Figure 51-28. Several oxygen sensors are used to monitor the exhaust gases as they travel through the exhaust system. Each sensor is identified by its position in relation to the engine banks and order in the exhaust system.

laminated strip. See **Figure 51-32**. The design of this type of sensor makes it more resistant to contamination and vibration than conventional zirconia sensors. Planar sensors also light-off, or reach operating temperature, in about 10 seconds, allowing the ECM to enter closed loop twice as fast as systems with conventional heated oxygen sensors. This significantly reduces cold-start hydrocarbon emissions.

Titania Oxygen Sensors

Some late-model vehicles are equipped with titania oxygen sensors. The main difference between titania sensors and zirconia sensors is the way they produce their output signals. Zirconia sensors generate their own voltage signals. ***Titania oxygen sensors***, on the other hand, vary their internal resistance to modify a reference voltage. See **Figure 51-33**.

Titania sensors offer several advantages over zirconia sensors. They provide an oxygen content signal almost immediately after cold startup, eliminating the need for a heating element. Titania sensors are smaller than zirconia sensors and are manufactured as sealed units, making them less susceptible to outside contamination.

During operation, a constant reference voltage is sent from the ECM to the titania sensor's positive terminal. As the oxygen content of the exhaust changes, the resistance of the sensor also changes. The amount of resistance formed in the sensor determines the sensor's voltage drop and current flow to the ECM.

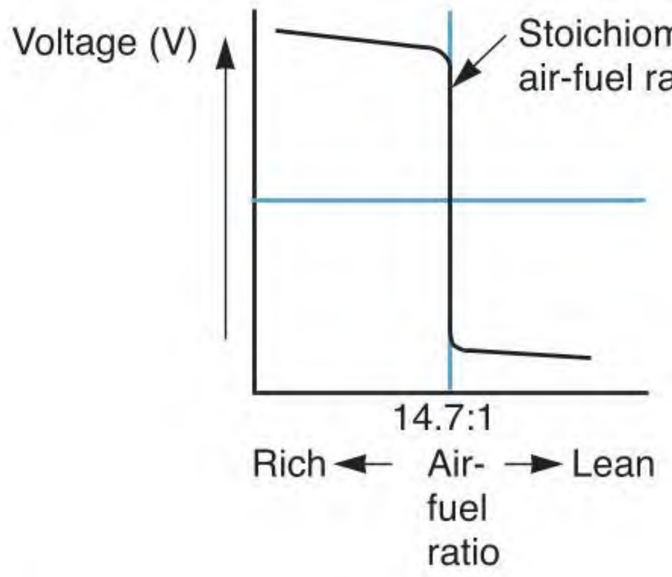
The ECM compares the sensor's voltage drop to a predetermined value. If the sensor's voltage drop is greater than this value, the ECM knows that the air-fuel mixture is too rich. If the sensor's voltage drop is too high or too low for stoichiometric, the ECM knows which way to adjust the air-fuel mixture and injector pulse width.

Wide-Band Oxygen Sensors

Wide-band oxygen sensors have been used in modified racing and high-performance engine and fuel injection systems for years. Many late-model vehicles are now equipped with wide-band oxygen sensors for better control fuel metering into the engine.

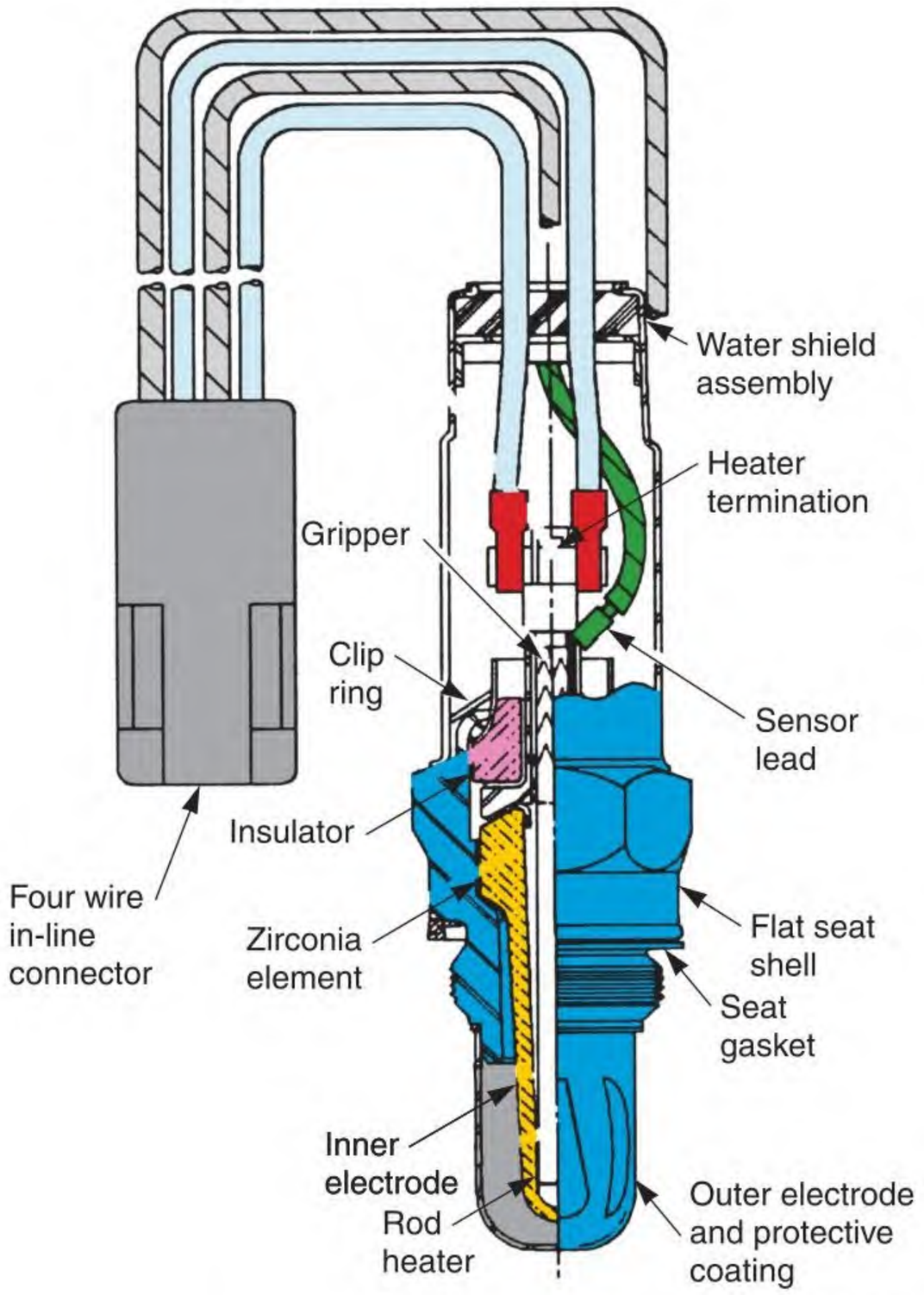
A wide-band oxygen sensor generates a variable voltage/current output signal proportional to the engine's present air-fuel ratio. When the air-fuel ratio is too lean for maximum power under acceleration, the wide-band sensor polarity and current flow out of the sensor in the positive-to-negative direction. When the air-fuel ratio is too rich, as with sudden engine deceleration, the current flows in the negative-to-positive direction.

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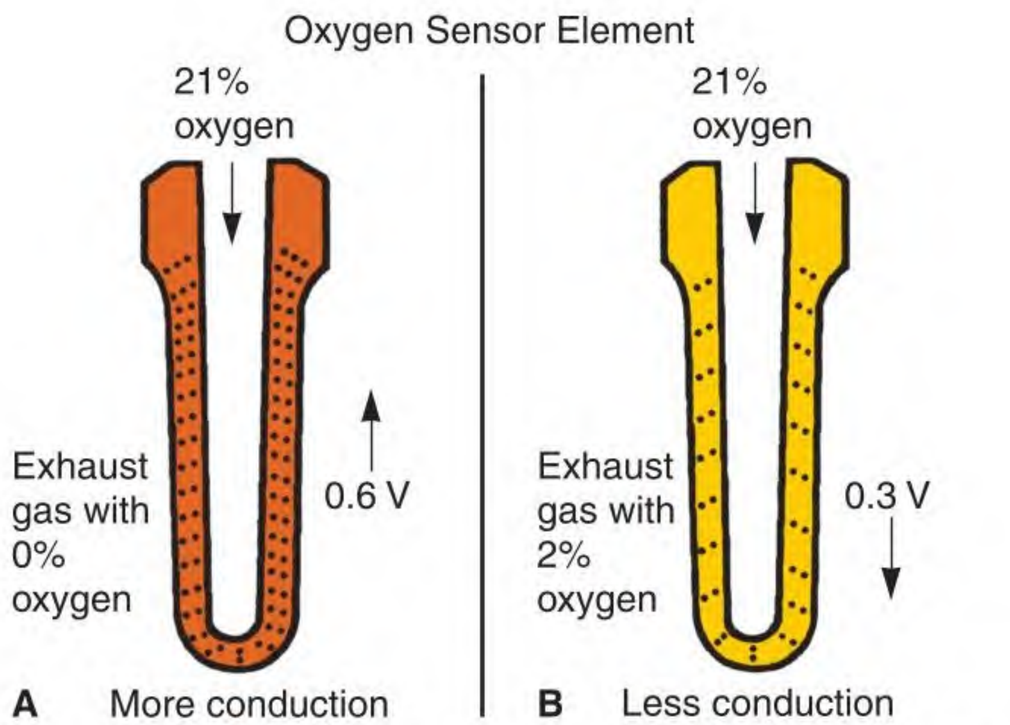
Honda

Figure 51-31. A stoichiometric air-fuel ratio is chemically correct. The oxygen sensor provides input to the ECM, which tries to maintain this ideal condition. This graph shows the relationship between oxygen sensor voltage and air-fuel ratio.



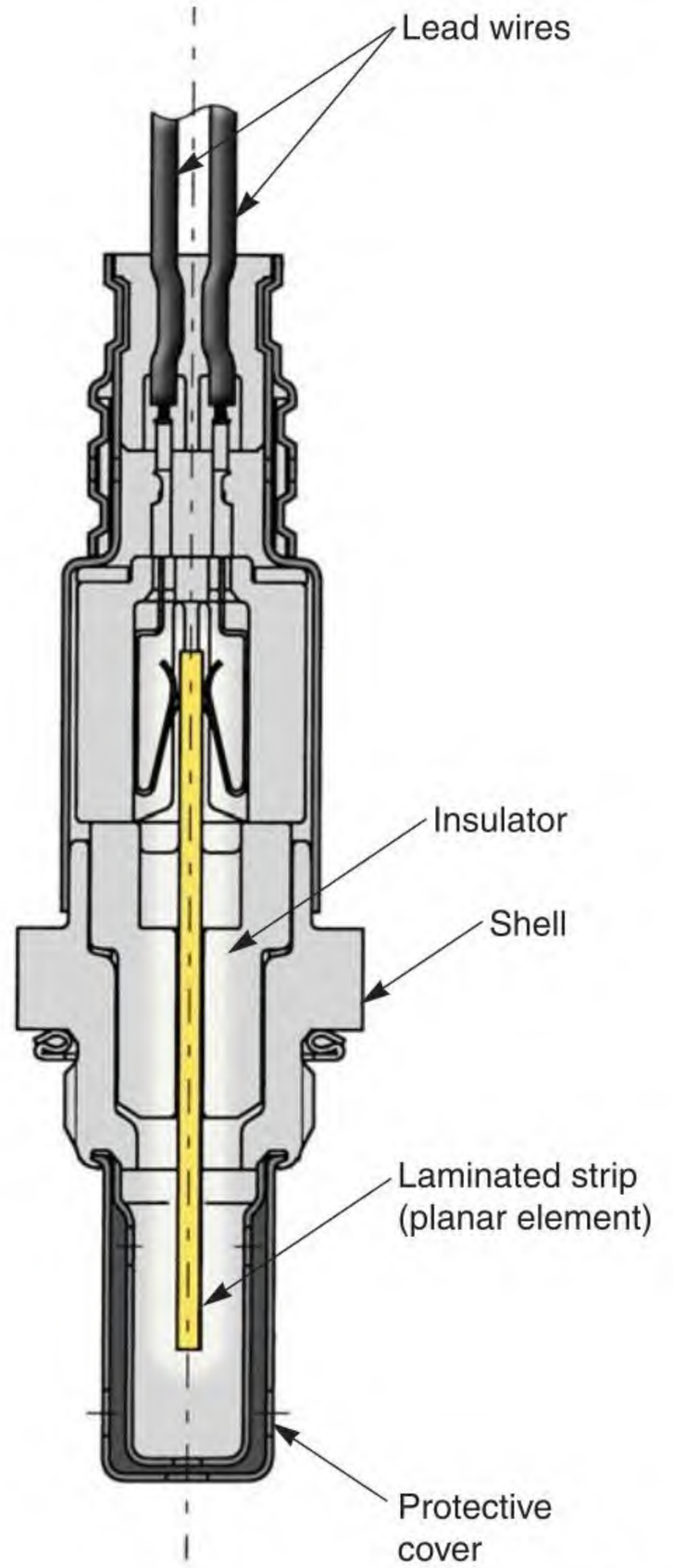
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Figure 51-29. This cutaway view shows the internal parts of a heated zirconia oxygen sensor. Study its construction.



Chevrolet

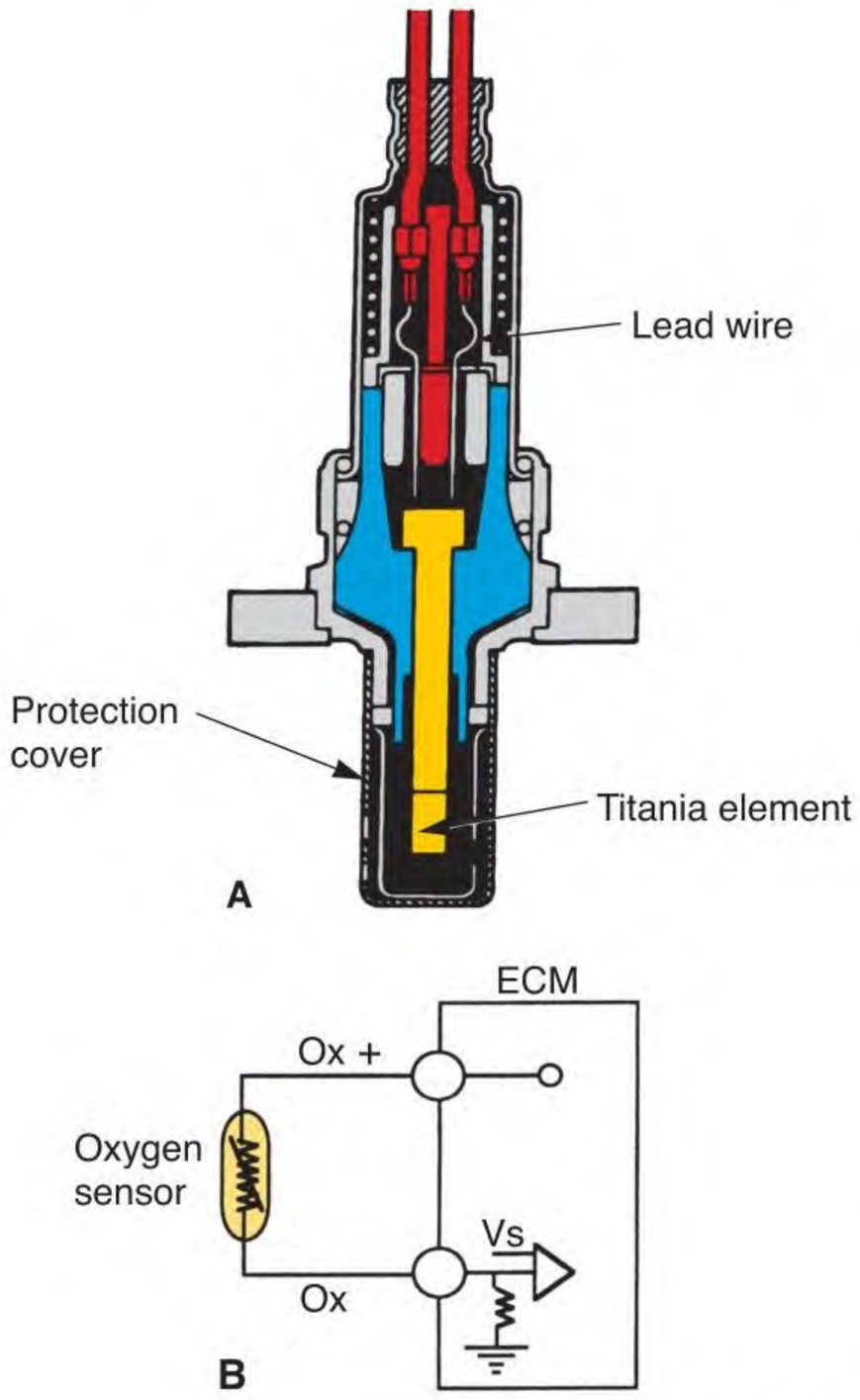
Figure 51-30. Study the operation of a heated oxygen sensor. A—There is greater voltage generation when the exhaust gas has a low oxygen content, indicating a rich mixture. B—There is less voltage generated when the exhaust has more oxygen, indicating a lean mixture.



Toyota

Figure 51-32. A cutaway of a planar sensor. Note the laminated strip, which comprises the zirconia element, the electrodes, and the heater.

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Figure 51-33. A—A titania oxygen sensor heats up quickly and does not require an electric heating element. Its internal resistance changes with the engine exhaust's oxygen content. B—Basic circuit from the titania oxygen sensor to the ECM.

Conventional ***narrow-band oxygen sensors*** simply toggle their output voltage abruptly to indicate a lean or rich condition. The output of the wide-band sensor, however, changes gradually and is directly proportional to the oxygen content of the exhaust gases. This makes it possible for the ECU to determine the exact air-fuel ratio at points other than stoichiometric (14.7:1). Wide-band exhaust gas sensors permit more accurate control of the air-fuel ratio over a wider range of extreme engine operating conditions.

OBD II Emission System Monitoring

OBD II ECMs have the ability to monitor hundreds of functions that affect emissions. The functions monitored include the following:

- Catalytic converter efficiency
- Engine misfire
- O_2 sensor output
- EGR valve action
- Fuel injection system performance
- Air injection system operation
- Evaporative emissions system operation

See **Figure 51-34**.

If any problems are detected, the ECM will set a trouble code and turn on the malfunction indicator light (MIL) to warn the driver and technician of the problem. If the problem could damage the catalytic converter, the ECM flashes the MIL once per second while the problem is occurring.

Evaporative Emissions System Monitoring

Evaporative emissions system monitoring checks components for leakage and restrictions that could increase emissions. The ECM energizes the solenoid valves to seal the system. This allows the computer to detect leaks or blockages in hoses and components. If the system does not pressurize and depressurize normally, the ECM sets a trouble code to warn of an evaporative emissions system problem.

EGR Monitoring

EGR monitoring is done when the ECM turns the EGR off while checking O_2 sensor readings. Changes in EGR valve opening and closing affect the air-fuel mixture and resulting O_2 sensor readings. If changes in the EGR valve do not affect O_2 sensor readings normally, a trouble code is produced. This is explained in more detail later.

OBD II MONITORS	ECM INPUT	DATA FROM
Air-injection system	Oxygen content leaving the catalyst	Rear oxygen sensor
Fuel-injection system	Change in the air-fuel-ratio control limits	Front oxygen sensor
Catalyst efficiency	Catalytic converter's oxygen storage capacity	Front and rear oxygen sensors
Engine misfires	Crankshaft speed and road conditions	Crank-position sensors, vehicle accelerometers, ABS sensors
Oxygen sensors	Sensor switching frequency	Front and rear oxygen sensors
Exhaust-gas-recirculation system	Change in the air-fuel-ratio control limits	Front oxygen sensor
Fuel vapor leaks	Pressure capacity of the fuel tank and lines	Leak-detection pump

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Figure 51-34. This chart shows how on-board diagnostic systems check the operation of major emission control systems.

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Air Injection System Monitoring

Air injection system monitoring uses data from the rear O_2 sensor to determine if the right amount of air (oxygen) is being injected into the engine's exhaust stream. A low amount of air (oxygen) would trip a trouble code.

Catalyst Monitor

Oxygen sensors are used to monitor the content of the waste gases in the exhaust system to better control engine operation, which reduces emissions.

OBD II systems use at least two oxygen sensors—one before the catalytic converter and one after it. The ***catalyst monitor***, also called the *rear oxygen sensor* or the *secondary oxygen sensor*, is located after the catalytic converter. It checks the oxygen content of the exhaust gases after exiting the catalytic converter to determine if the catalyst elements are working. See **Figure 51-35A**.

If the signal from the catalyst monitor becomes too similar to the engine-mounted oxygen sensor signal(s), the catalytic converter is not cleaning up the exhaust gases as it should. See **Figure 51-35B**. The ECM would then turn on the malfunction indicator light and set a trouble code to warn the driver and technician of a possible catalytic converter failure.

Engine Misfire Monitoring

Engine misfire monitoring uses the engine crankshaft position sensor to detect changes in crankshaft speed, which may indicate the engine is missing and not firing its air-fuel mixture properly. If crankshaft speed fluctuations are detected, the ECM trips a trouble code.

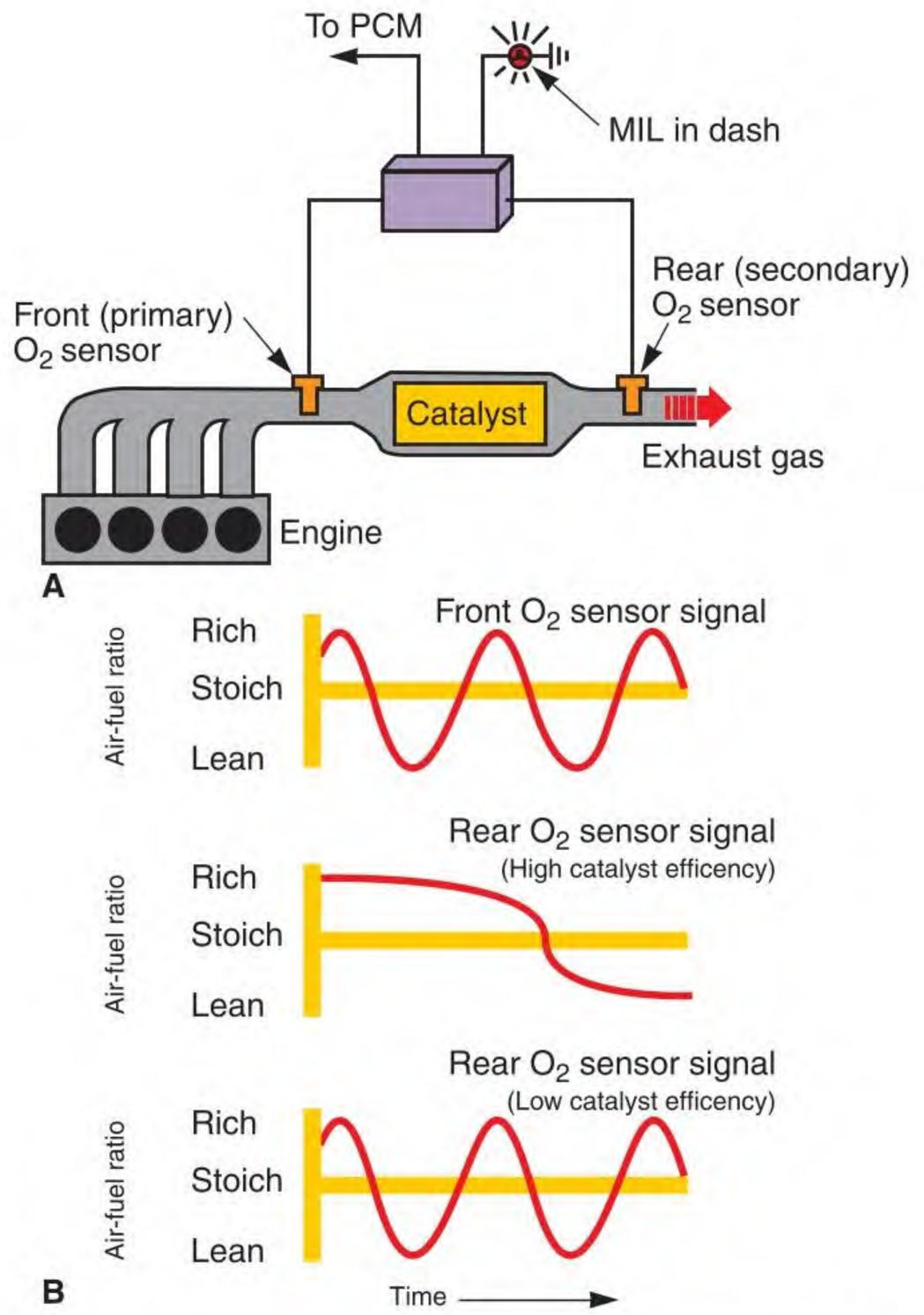
Sensor Monitoring

Sensor monitoring uses the ECM data to compare known normal sensor signal variations to actual sensor signals while operating. If the sensor signal goes out of range or normal parameter, a trouble code will be set in the ECM's memory and displayed in the dash. With an OBD II system, every sensor can be monitored for normal operation and signal values. This helps the technician quickly diagnose and fix problems to keep the vehicle running at maximum efficiency with minimum emissions.

Actuator Monitoring

Actuator monitoring uses the ECM digital data to determine if an actuator is drawing too little or too much current. In this way, the ECM system can detect problems in actuators and actuator circuits. Fuel injectors, electronic EGR valves, evaporative solenoids, high-pressure mechanical fuel pumps, and similar actuators are monitored in this way.

For example, fuel injector monitoring has the ECM check the coil windings of each injector to check for opens, shorts, or an abnormal voltage feedback signal. If an injector is shorted, the current pulse sent to open the injector will not generate voltage across the injector coil winding. The ECM can sense this lower than normal circuit resistance and "trip a double code," pinpointing the bad injector.



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Figure 51-35. A—With late-model on-board diagnostic systems, two oxygen sensors are used with each cylinder bank. The primary, or front, oxygen sensor is used to determine whether the air-fuel mixture that is being fed to the engine is correct. The secondary, or rear, sensor monitors the efficiency of the catalytic converter. If the converter is not working normally, the malfunction indicator light in the dash will illuminate. B—If the rear sensor output is the same as the front sensor output, the computer knows the catalytic converter is not working properly.

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Diesel Particulate Filter

A ***diesel particulate filter***, or particulate converter, stores and then burns the ash and soot trying to leave a diesel exhaust system. The engine ECM can alter diesel engine operating parameters (injection timing, injection quantity, cam timing, etc.) to blow a flame out of the engine exhaust ports to heat and burn the crude oil soaked soot inside the particulates filter. The heavy harmful particulates are consumed by fire, so that they do not blow out into the atmosphere unburned with the exhaust gases. A diesel particulates filter greatly reduces a diesel engine's emissions of exhaust soot and the resulting air and water pollution.

In the Rearview Mirror

A number of years ago, crankcase fumes were simply vented into the atmosphere. Before the introduction of the positive crankcase ventilation system, vehicles were equipped with road draft tube systems to remove blowby gases from the crankcase. These systems consisted of a hollow tube that extended down from the crankcase area to a point below the engine block. As the vehicle was driven, air passing over the lower end of the tube created a vacuum. This caused the vapors to be drawn from the crankcase. Fresh air entered the crankcase through a vented oil filler cap.

A road draft tube vented crankcase fumes and blowby gases out the back of the engine. The air pollution was evident from the blue smoke at the tip of the engine draft tube.

Summary

- Emission control systems are used on cars and light trucks to reduce the amount of harmful chemicals released into the atmosphere.
- Air pollution is caused by an excess amount of harmful chemicals in our atmosphere.
- Smog is a nickname given to a visible cloud of airborne pollutants.
- Hydrocarbons result from the release of unburned fuel in the atmosphere.
- Carbon monoxide is a toxic emission that results from the release of partially burned fuel.
- Oxides of nitrogen are produced by extremely high combustion temperatures.
- Particulates are the solid particles of carbon soot and fuel additives that blow out of a vehicle's tailpipe.
- A positive crankcase ventilation system uses engine vacuum to draw toxic blowby gases into the intake manifold for re-burning in the combustion chambers.
- The evaporative emissions control system prevents toxic fuel system vapors from entering the atmosphere.
- The charcoal canister stores fuel vapors when the engine is not running.
- The exhaust gas recirculation system allows burned exhaust gases to enter the intake manifold to help reduce NO_x emissions.
- An air injection system forces fresh air into the exhaust ports or the catalytic converter to reduce HC and CO emissions.
- A catalytic converter oxidizes the HC and CO emissions that pass into the exhaust system.
- Oxygen sensors monitor the oxygen content of the exhaust gases to better control engine operation and reduce emissions.
- The primary oxygen sensor is used to monitor the oxygen content of the exhaust gases to determine whether the air-fuel mixture is too lean or too rich.
- A secondary oxygen sensor checks the oxygen content after the exhaust gases have been treated to determine if the catalytic converter is working normally.
- A vehicle's computer or ECM will monitor many functions that affect emissions.
- Evaporative emission system monitoring checks components for leakage and restrictions that could increase emissions.
- Air injection system monitoring uses data from the rear O_2 sensor to determine if the right amount of air (oxygen) is being injected into the engine's exhaust stream.
- A catalyst monitor checks the oxygen content of the exhaust gases exiting the catalytic converter to determine if the catalyst elements are working properly.
- Engine misfire monitoring uses the crankshaft position sensor to detect changes in crankshaft speed, which may indicate improper fuel combustion.
- Sensor monitoring uses the ECM data to compare known normal sensor signal variations to actual sensor signals while operating.
- Actuator monitoring uses ECM software to determine if an actuator is drawing too much or too little current.

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Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

air cleaner carbon element
air distribution manifold
air dome
air injection pump
air injection system
aspirator valves
blowby
carbon monoxide (CO)
catalyst
catalyst monitor
catalytic converter
charcoal canister
closed PCV system
computerized emission control systems
diesel particulate filter
diverter valve
dual-bed catalytic converter
EGR duty cycle
EGR solenoid valves
electric air injection pumps
electric PCV valve
electronic EGR system
electronic EGR valve
emission control systems
evaporative emissions control (EVAP) system
exhaust gas recirculation (EGR) system
exhaust gases
front O_2 sensor
fuel vapors
heated oxygen sensor
hydrocarbons
liquid-vapor separator
mini catalytic converter
motor vehicle emissions
narrow-band oxygen sensors
non-vented fuel tank cap
oil-air separator
oxides of nitrogen (NO_x)
oxygen sensors
oxygenated gasoline
particulates
PCV valve
planar zirconia oxygen sensors
positive crankcase ventilation (PCV) system
primary oxygen sensor
pulse air system
purge line
purge valve
rear O_2 sensor
rollover valve
secondary oxygen sensor
single-stage EGR valve
smog
stoichiometric fuel mixture
three-way catalytic converter
titania oxygen sensors
two-way catalytic converter
wide-band oxygen sensors
zirconia oxygen sensors

Activities

1. On a late-model vehicle designated by your instructor, locate various parts of the emission control system and explain their purpose.
2. Research the chemical makeup of smog and prepare a report on it.
3. Write a report comparing the emissions produced by late-model automobile engines to the higher emissions produced by two-stroke engines used in weed eaters, snow throwers, snowmobiles, watercraft, etc. Discuss what can be done to reduce the emissions produced by two-stroke engines. Send the report to your congressman or to the EPA. Include a letter asking that more stringent regulations be placed on two-stroke engines to help minimize their negative impact on our environment.

Review Questions

Answer the following questions using the information provided in this chapter.

1. What are some causes of air pollution?
2. Which of the following agencies enforces air pollution standards?
   (A) EGR.
   (B) SAE.
   (C) ASE.
   (D) EPA.
3. Define the term *smog*.
4. List and explain the four kinds of vehicle emissions.
5. CO emissions are caused by partially burned fuel. True or False?
6. Increasing peak combustion temperature tends to reduce NO_x emissions. True or False?
7. _____ are the solid particles of carbon soot that exit a vehicle's tailpipe. They are more of a problem in diesel engines.
8. What are the three basic sources of vehicle emissions?
9. Which of the following is *not* a typical engine modification for reducing emissions?
   (A) Lower compression ratios.
   (B) Leaner air-fuel ratios.
   (C) Increased valve overlap.
   (D) Wider spark plug gaps.
10. List and explain six major emission control systems.
11. A(n) _____ system uses engine vacuum to draw toxic blowby gases into the intake manifold for burning in the combustion chambers.

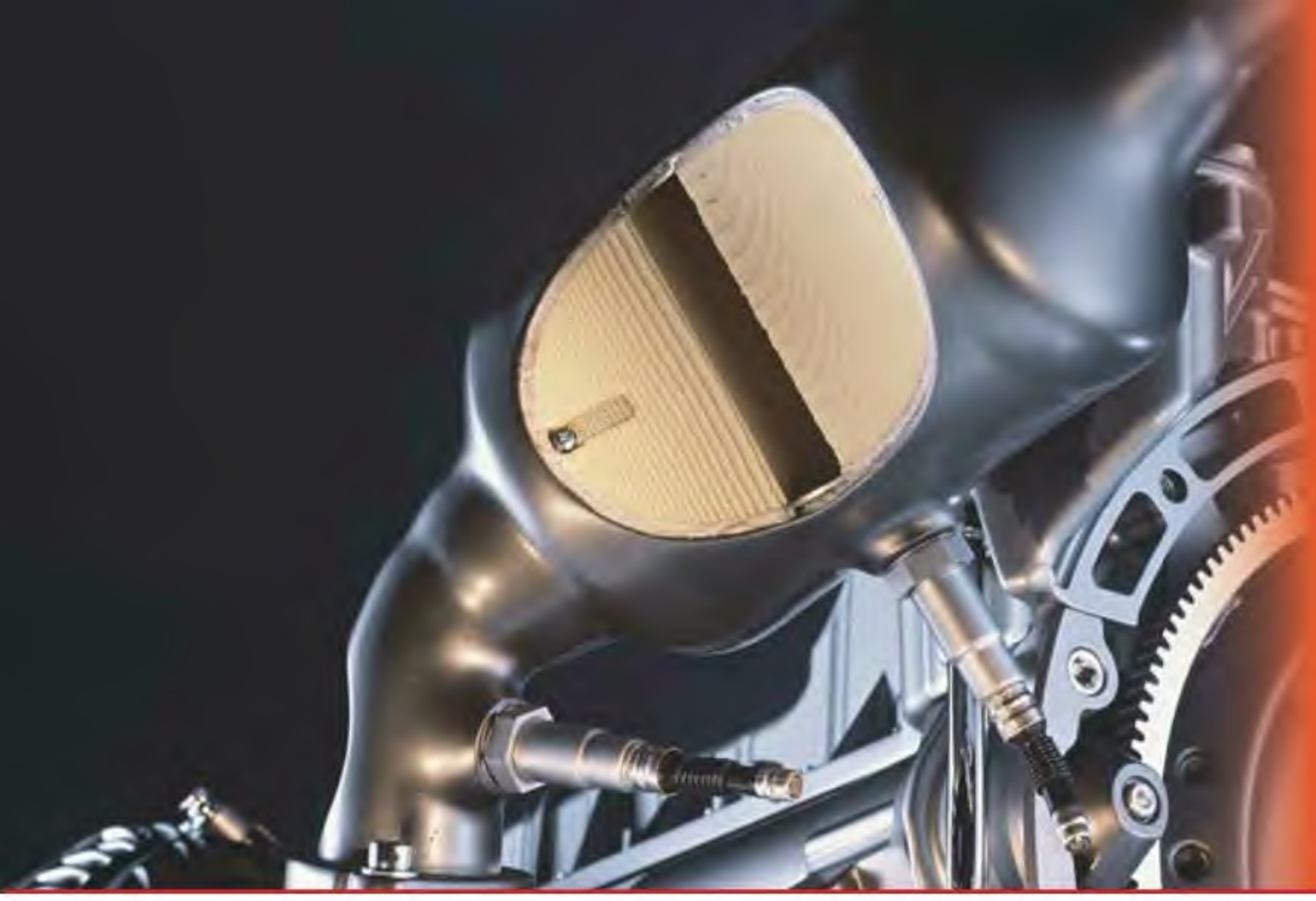
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12. Which of the following parts is *not* a component of a modern evaporative emission system?
    (A) Fuel tank air dome.
    (B) Air injection pump.
    (C) Non-vented fuel tank cap.
    (D) Rollover valve.
13. Explain the operation of the charcoal canister in an evaporative emissions control system.
14. How does an EGR system work?
15. An air injection system forces fresh air into the _____ of the engine to reduce HC and CO emissions.
16. The diverter valve keeps air from entering the exhaust system during engine deceleration, preventing backfiring. True or False?
17. What is a catalytic converter?
18. Which of the following does *not* relate to catalytic converters?
    (A) Monolith.
    (B) Dual bed.
    (C) Stores unburned fuel.
    (D) Oxidizes or burns emissions.
19. Why is a mini catalytic converter sometimes used?
20. Summarize the operation of a computer-controlled emission control system.

ASE-Type Questions

1. Each of the following is a natural cause of pollution *except*:
   (A) wind-blown dust.
   (B) volcanoes.
   (C) engine exhaust.
   (D) forest fires.
2. Strict laws that reduce air pollution are enforced by the:
   (A) EPA.
   (B) ASE.
   (C) SAE.
   (D) All of the above.
3. A nickname given to a visible cloud of airborne pollutants is:
   (A) fog.
   (B) smog.
   (C) smoke.
   (D) vapors.
4. Which of the following is *not* a type of vehicle emissions?
   (A) Particulates.
   (B) Hydrocarbons.
   (C) Photochemicals.
   (D) Carbon monoxide.
5. Positive crankcase ventilation systems are being discussed. Technician A says that automakers use open PCV systems in late-model vehicles. Technician B says that PCV systems reduce air pollution and prevent engine damage caused by blowby gas buildup. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Decreased valve overlap is used to:
   (A) reduce hydrocarbons.
   (B) reduce carbon monoxide.
   (C) increase engine smoothness.
   (D) All of the above.
7. Each of these is used to reduce the amount of air pollution produced by automobiles *except*:
   (A) catalytic converter.
   (B) exhaust gas recirculation system.
   (C) positive crankcase ventilation.
   (D) H_2O system.
8. While discussing the operation of the evaporative emissions control system, Technician A says a charcoal canister stores fuel vapors when the engine is not running. Technician B says the canister absorbs fuel vapors only when the engine is running. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Which of the following is *not* an EGR valve component?
   (A) Spring.
   (B) Plunger.
   (C) Purge line.
   (D) Vacuum diaphragm.
10. In a pulse air system, which of the following blocks airflow in one direction and allows airflow in the other direction?
    (A) Gulp valve.
    (B) Reed valve.
    (C) Check valve.
    (D) All of the above.

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Chapter 52
Emission Control System Testing, Service, and Repair

After studying this chapter, you will be able to:

- Explain the use of exhaust gas analyzers.
- Inspect and troubleshoot emission control systems.
- Perform periodic service operations on emission control systems.
- Test individual emission control components.
- Replace or repair major emission control components.
- Demonstrate and practice safe work procedures when working on emission control systems.
- Correctly answer ASE certification test questions on emission control system testing and service.

Emission control systems, like any automotive system, can malfunction. When this happens, excessive exhaust emissions and fuel vapors escape into the atmosphere. Engine performance may also suffer when engine and fuel injection system problems develop. However, in many cases, an emissions problem is not apparent to the vehicle's driver. It is very important that you, as an automotive technician, be able to correctly diagnose and repair emission control systems.

This chapter will summarize the most common tests and repairs done on today's emission control systems. It will explain how to diagnose problems using a scan tool and an exhaust gas analyzer. The chapter will then cover pinpoint tests and replacement procedures on individual parts.

Tech Tip

Studies have shown the emissions from passenger vehicles have dropped over 90% in the last 20 years. As an automotive technician, it is your job to keep cars running efficiently and without producing excessive air pollution.

Computer-Controlled Emission System Service

Computer-controlled engine and emission systems can cause a wide range of problems. The engine ECM controls the fuel injection system, EGR valve, evaporative emissions control, and other systems. Any of these systems can affect the vehicle's operation and can increase emissions.

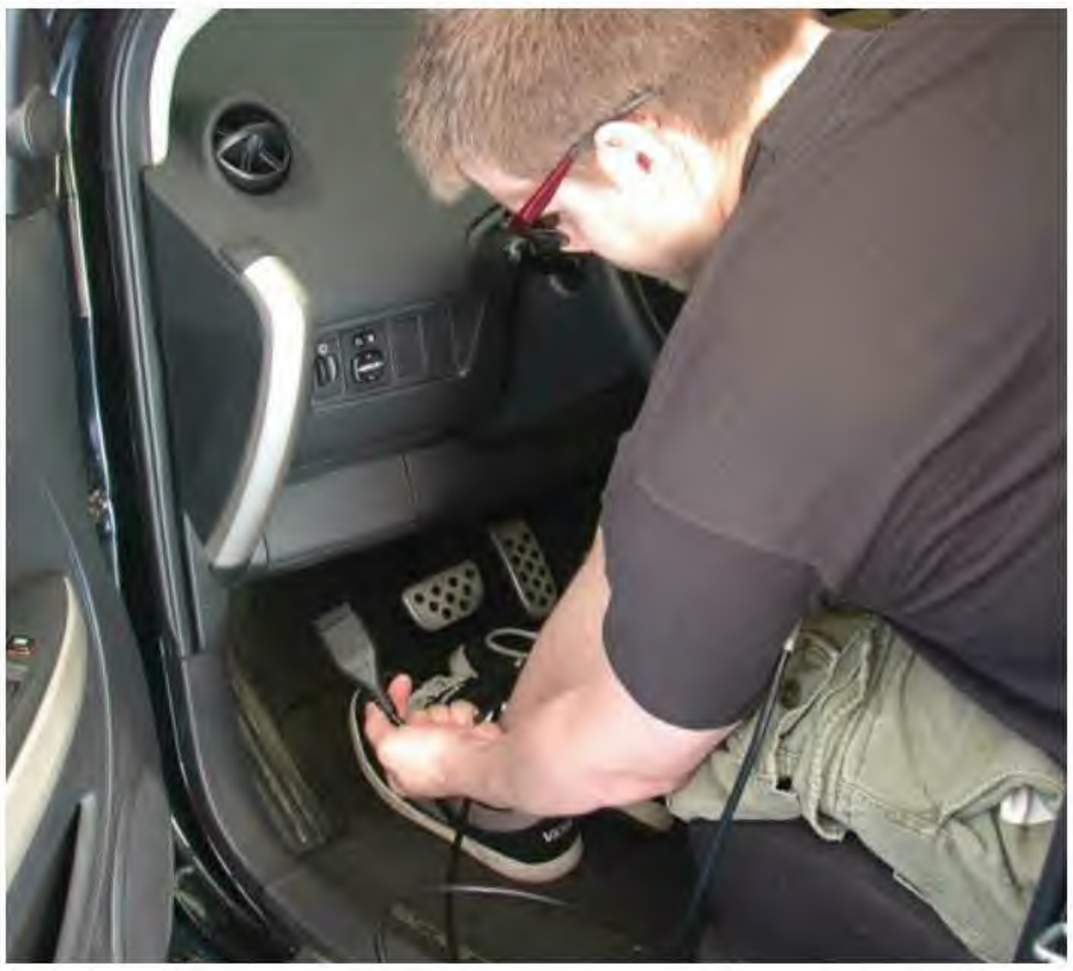
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Scanning Emission Systems

A scan tool will quickly check the general condition of monitored parts of the various emission control systems. Connect the scan tool to the vehicle's data link or diagnostic connector under the driver's side of the dash. See **Figure 52-1**.

First check for stored trouble codes and retrieve any scan tool information that might help fix the problem. If no trouble codes are set, review the live data readings for both oxygen sensors. Check for a bad O_2 sensor. Also look at the secondary oxygen sensor reading for a failed catalytic converter. Fouled oxygen sensors or a clogged catalytic converter are common problems on high mileage vehicles. The live scan tool readouts can help you find problems when a hard trouble code has not been set. Refer to **Figure 52-2**.

For example, if the scan tool indicates a constant low voltage signal from the catalyst monitor (rear oxygen sensor), you would know where to start your tests, but you would not know exactly what is wrong. You could have a defective oxygen sensor, a poor connection, or a malfunctioning catalytic converter. A trouble code from the catalyst monitor could be due to the sensor itself, its wiring, or a defective catalytic converter. Keep this in mind when scanning a vehicle's computer system. Think how the system is supposed to operate and determine whether other components could cause the abnormally high or low sensor signal.

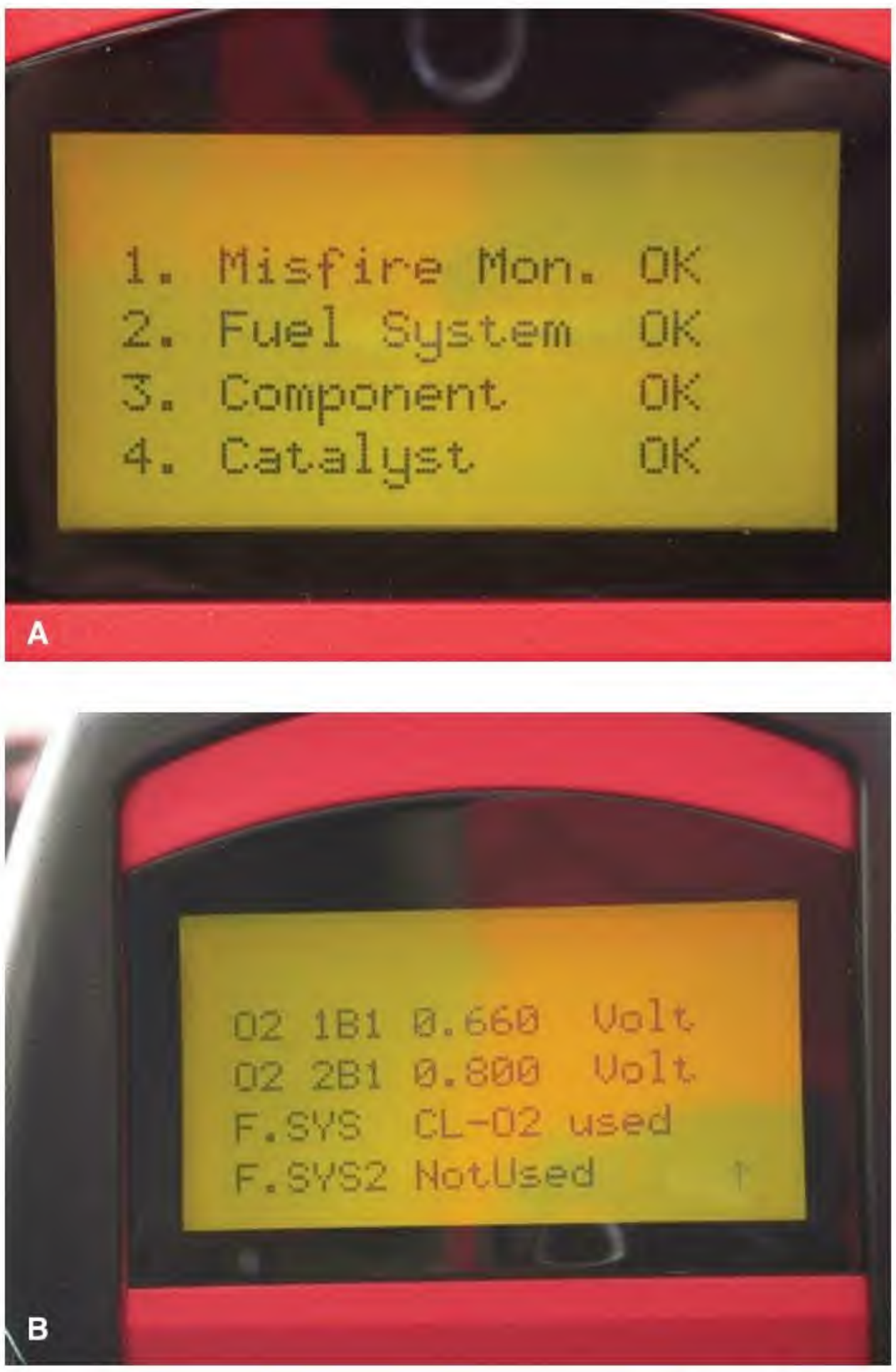


Snap-on Tool Corp.

Figure 52-1. A scan tool communicates with the vehicle's computer(s) to retrieve and explain trouble codes for most electrical devices. Locate the OBD connector under the left side of dash and plug your scan tool fully into the connector.

Emission Maintenance Reminder

The ***emission maintenance reminder*** is a circuit that automatically turns on a dash light or instrument cluster notification to indicate the need for emission control system service. After the prescribed



Snap-on Tool Corp.

Figure 52-2. Here a scan tool has done automatic tests of all sensors and actuators that can affect emissions. The scanner tests indicate whether each system is OK. A—Readouts show no engine misfiring, normal fuel system operation (fuel pressures and injection pulse widths at idle), and the normal catalytic converter operation (primary and secondary O_2 sensors test normal). B—Live readout screen on the scan tool shows actual operating voltages of the O_2 sensors.

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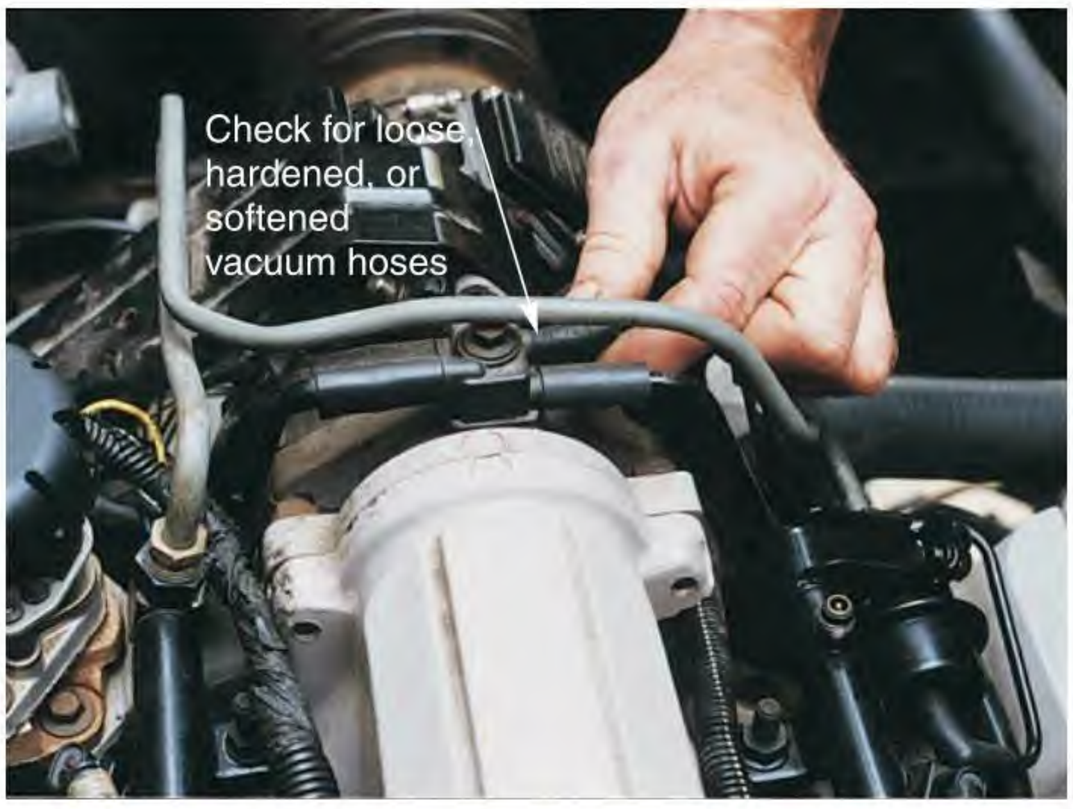
adjustments and repairs have been made, you must turn off the emission maintenance reminder. The procedure for turning off the reminder varies from one manufacturer to another. Since there are so many variations, it is best to refer to the appropriate service information for specific instructions.

Inspecting Emission Control Systems

Using information from the scan tool, you must find the source of the problem. Start out by inspecting all engine vacuum hoses and wires. A leaking vacuum hose or disconnected wire could trip a trouble code and upset the operation of the engine and emission control systems, **Figure 52-3**.

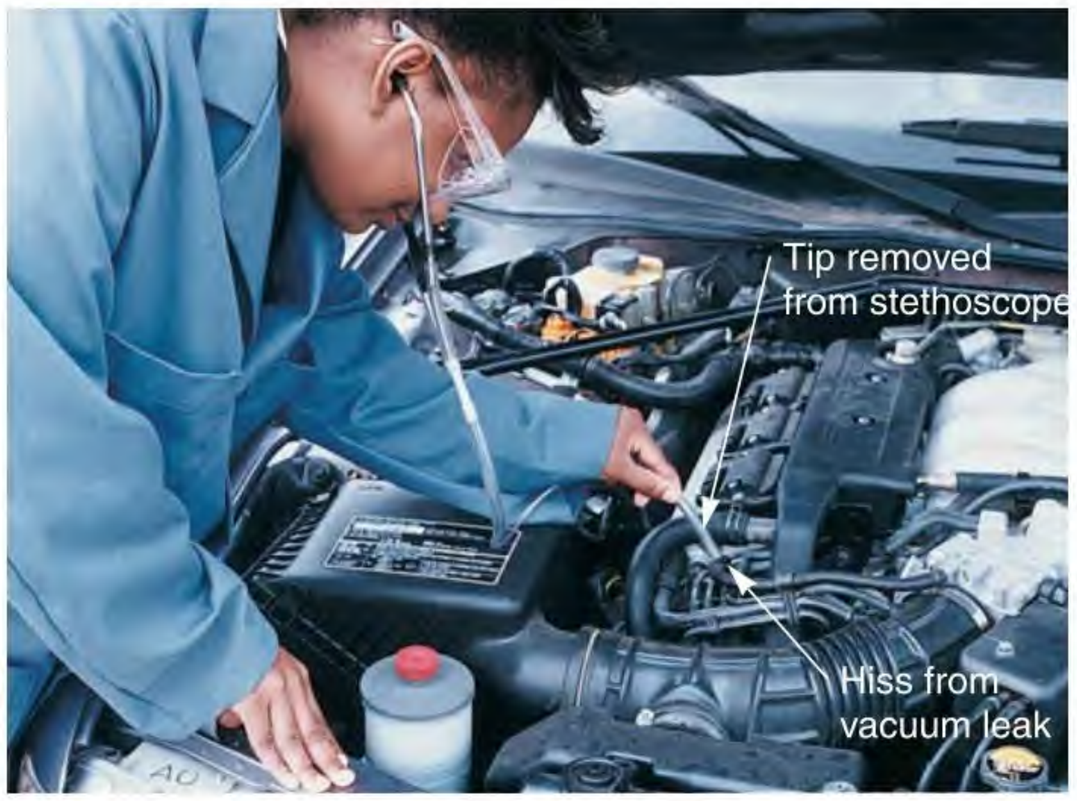
A stethoscope with the metal probe removed can be used to listen for vacuum leaks, **Figure 52-4**. A section of vacuum hose can also be used as a listening device. Place one end of the hose next to your ear. Move the other end of the hose around the engine compartment, along vacuum hoses and connections. When the hose nears a vacuum leak, you will be able to hear a loud hissing sound.

Look for evidence of disconnected wires, oil leaks onto the oxygen sensor, extremely dirty engine oil, and blowby, all of which could trip a trouble code or increase air pollution. Also, inspect the air cleaner for clogging. Check that any air pump belt is properly adjusted. Try to locate any obvious problems in the engine, fuel system, or exhaust system. If nothing is found during your inspection, each system should be checked and tested.



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Figure 52-3. Begin inspecting the emission control system by looking for disconnected vacuum hoses and wires.



Snap-on Tool Corp.

Figure 52-4. Use an automotive stethoscope with the metal tip removed to listen for vacuum leaks.

Engine Exhaust Gases

As discussed in the previous chapter, engine exhaust gases contain chemical substances that change with combustion efficiency. ***Combustion efficiency*** is the ratio of heat actually developed in the combustion process to the heat that would be released if the combustion were perfect.

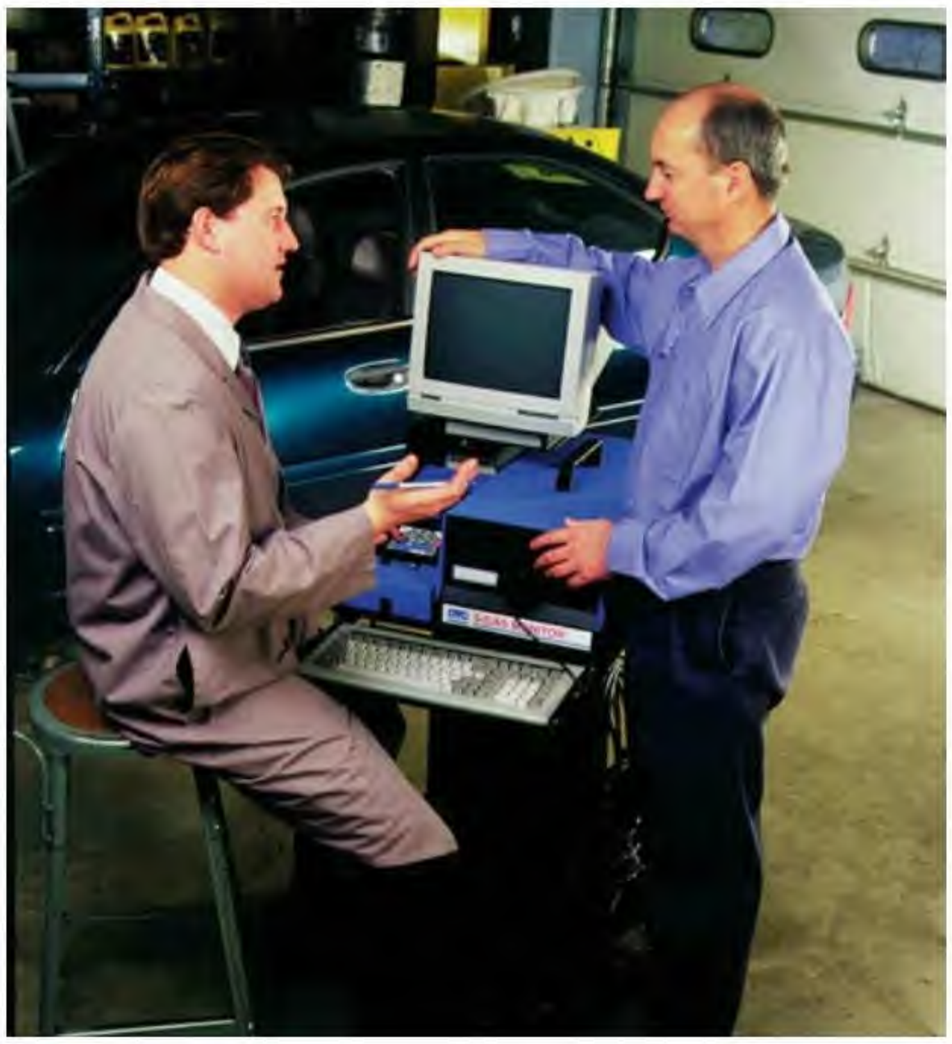
Engine exhaust gases and the various substances in them are the result of combustion. Some of these substances, such as hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NO_x), are harmful. Other by-products of combustion, such as carbon dioxide (CO_2), oxygen (O_2), and water (H_2O), are not harmful. By measuring HC, CO, O_2, CO_2, and NO_x, we can find out how efficiently the engine and emission control systems are working.

Exhaust Gas Analyzer

An ***exhaust gas analyzer*** is a test instrument that measures the chemical content of the engine's exhaust gases. See **Figure 52-5**.

With the engine running, the exhaust analyzer will sample, analyze, and indicate the amount of pollutants and other gases in the exhaust. The technician can use this information to determine the condition of the engine and other systems affecting emissions. An

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OTC

Figure 52-5. Five-gas analyzers are replacing four-gas analyzers. They can provide added information for finding emission system problems.

exhaust gas analyzer is an excellent diagnostic tool that will indicate excessive emissions caused by:

- Fuel metering problems—Fuel metering problems can make the engine run too rich (increased HC and CO_2 emissions) or too lean (increased NO_x emissions.
- Engine mechanical problems—Engine mechanical problems can cause oil to enter the cylinders, reduce compression pressure, and other things that increase emissions.
- Vacuum leaks—Vacuum leaks can bypass the airflow meter, affecting fuel metering and emissions.
- Ignition system problems—Ignition system problems can cause engine misfiring, which generates more emissions.
- PCV troubles—PCV troubles can fail to pull fumes out of the crankcase.
- Clogged air filter—A clogged air filter can restrict airflow into the engine, making it run rich.
- Faulty air injection system—A faulty air injection system can affect catalytic converter efficiency.
- Evaporative emissions control system problems—Evaporative emissions control system problems can allow raw fuel vapors to enter the atmosphere.
- Computer control system troubles—Computer control system troubles can affect any vehicle system.
- Catalytic converter condition—Catalytic converter failure can prevent the burning of fuel emissions in the exhaust system.

Types of Exhaust Gas Analyzers

There are three different kinds of exhaust gas analyzers: two-gas analyzers, four-gas analyzers, and five-gas analyzers.

A ***two-gas exhaust analyzer*** can measure the amount of hydrocarbons (HC) and carbon monoxide (CO) in a vehicle's exhaust gases. This type of analyzer has been used for a number of years. However, the two-gas analyzer cannot accurately analyze the exhaust gases from newer engines; therefore, it is being replaced by four- or five-gas analyzers.

A ***four-gas exhaust analyzer*** measures the quantity of hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), and oxygen (O_2) in an engine's exhaust.

Although carbon dioxide and oxygen are not toxic emissions, they provide useful data about the engine's operating efficiency. Because late-model engines are so clean burning, a four-gas exhaust analyzer is needed to accurately evaluate the makeup of the exhaust gases. It provides extra information for diagnosing problems and making adjustments.

A ***five-gas exhaust analyzer*** measures hydrocarbons, carbon monoxide, carbon dioxide, oxygen, and oxides of nitrogen. It is the latest and most informative type of exhaust gas analyzer. Oxides of nitrogen is a toxic pollutant that should be measured, if possible, as a means of diagnosis. Most state vehicle inspection stations use a five-gas analyzer.

Using an Exhaust Gas Analyzer

Before testing the vehicle, take it on a thorough road test. This allows the vehicle to reach the proper operating temperature. Never test a vehicle with a cold engine, since inaccurate readings will result.

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Service Procedure

To use an exhaust gas analyzer:

1. Plug the machine in and allow it to warm up as described by the manufacturer.
2. After warm-up, zero and calibrate the analyzer. Exhaust gas analyzer ***calibration*** involves zeroing the meter scales while sampling clean air (no exhaust gases present in room) with the analyzer. Newer analyzers sample a ***calibration gas*** (mixture of several gases) to adjust the meter readings for accuracy. The gas is automatically metered while the meter scales are calibrated, **Figure 52-6**. In most cases, any calibration adjustment is done by the analyzer itself automatically or when commanded by the technician. Older analyzers may have to be manually adjusted.

Warning

Never inhale exhaust gas analyzer calibration gas. The gas contains emission gases that can be harmful to your health.

3. To begin the test, install the probe in the vehicle's tailpipe. If working in an enclosed shop, slide the probe through a hole in the shop's vent hose, **Figure 52-7**.

Since exact procedures vary, always follow the operating instructions for the particular exhaust analyzer. This will ensure accurate measurements.

Warning

When using an exhaust analyzer, do not let engine exhaust fumes escape into an enclosed shop area. Engine exhaust can kill. Use the shop exhaust ventilation system to trap and remove the toxic fumes.

Older analyzers measure hydrocarbons and carbon monoxide at idle and approximately 2500 rpms. If you have a five-gas analyzer, it will also measure oxygen, oxides of nitrogen, and carbon dioxide. Compare the analyzer readings with specifications for the vehicle's model year.



OTC

Figure 52-6. Calibration gas is used to set or zero meters on four- and five-gas analyzers. One or more tanks of calibration gas is connected to the analyzer. The gas is drawn through a pickup tube while the analyzer adjusts the meters to specifications for the gas.

When testing some electronic fuel injection systems without a load, only idle readings on the exhaust analyzer will be accurate. A dynamometer must be used to load the engine to simulate actual driving conditions.

Exhaust Gas Analyzer Readings

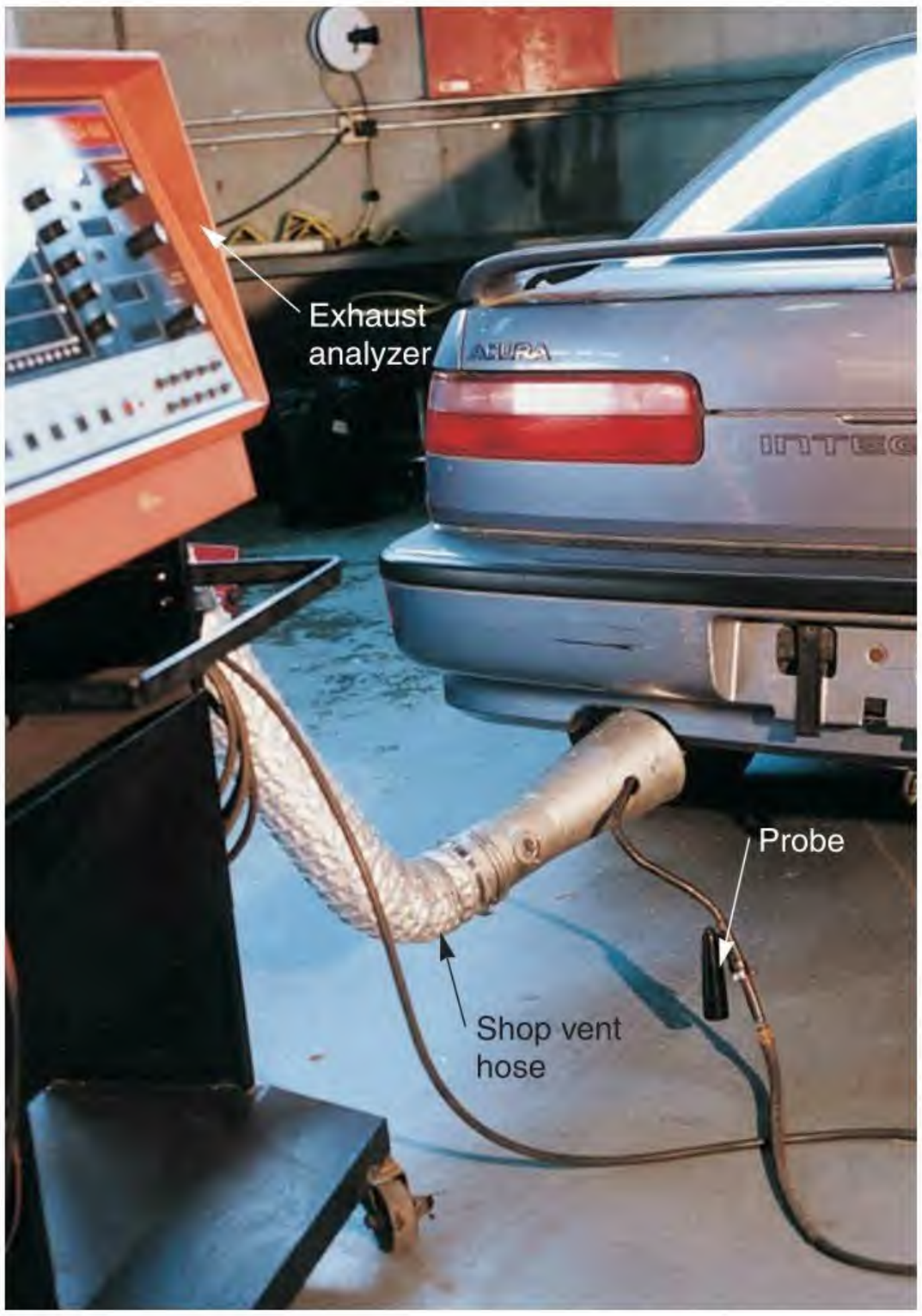
Exhaust gas analyzer readings are used to determine the chemical content of the engine's exhaust gases. Your test readings must be within state-regulated specifications for the geographic area and the year of the vehicle. Generally, new vehicles have stricter specifications and require lower analyzer readings than older vehicles.

Although most states provide emission specifications in parts per million and percentage, **Figure 52-8**, some states give emission specifications in grams per mile. When this is the case, the vehicle must be operated on a chassis dyno so that the amount of emissions produced per mile driven can be calculated.

Hydrocarbon Readings

An exhaust gas analyzer measures hydrocarbons (HC) in parts per million (ppm) by volume. For example, an analyzer reading of 10 ppm means there are 10 parts of hydrocarbons for every million parts of exhaust gas.

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Figure 52-7. Warm up the engine and calibrate the analyzer before installing the exhaust analyzer probe in the vehicle's tailpipe. The adapter on the vent hose prevents toxic vapors from entering the shop.

EXHAUST GAS DATA		
Engine speed	**RPM**	**750**
Engine temp.	°F	190
Hydrocarbons	HC	0–35 PPM
Carbon monoxide	CO	0.1–0.45%
Oxygen	O_2	0–0.35%
Carbon dioxide	CO_2	14–16%
Oxides of nitrogen	NO_x	19 PPM

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Figure 52-8. Exhaust gas analyzer readings. Note that the readings for hydrocarbons and oxides of nitrogen are given in parts per million. Carbon monoxide, oxygen, and carbon dioxide readings are given as percentages.

A vehicle that is 10–15 years old will have a relatively high hydrocarbon specification, such as 900 ppm. A newer vehicle, having stricter emission requirements, could have a 0–35 ppm hydrocarbon specification. If the exhaust analyzer reading is higher than specifications, the vehicle's hydrocarbon emissions (unburned fuel) are excessive.

Tech Tip

Always refer to the emission control sticker in the engine compartment or a service manual for emission level specifications. Values vary year by year.

A rotten egg smell from the exhaust is often an indication of the presence of unburned fuel and, therefore, excessive hydrocarbons. Higher-than-normal HC readings can be caused by one or more of the following conditions:

- Fuel system malfunction—Fuel system malfunctions include leaking fuel injector, a faulty pressure regulator, or improper fuel pressure.
- Improper ignition timing—Improper ignition timing involves computer or adjustment problems.
- Engine problems—Engine problems include blowby, worn rings, or a blown head gasket.
- Faulty emission control system—A faulty emission control system includes a bad PCV, catalytic converter, EGR valve, or evaporative control system.
- Ignition system troubles—Ignition system troubles include fouled spark plug, a faulty ignition coil, or an open spark plug wire.
- Computer control system problems—Computer control system problems include a defective input sensor, output actuator, or ECM.

CO Readings

An exhaust analyzer measures carbon monoxide (CO) in percentage by volume. For instance, a 0.1% analyzer reading would mean that 0.1% of the engine exhaust is made up of carbon monoxide. The other 99.9% consists of other substances. High carbon monoxide results from the incomplete burning of fuel caused by a lack of air (oxygen) during the combustion process.

If the exhaust analyzer reading is higher than specifications, the engine is producing too much carbon monoxide. You would need to locate and correct the cause of the problem.

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The exhaust analyzer's carbon monoxide reading is related to the air-fuel ratio. A high carbon monoxide reading would indicate an over-rich mixture (too much fuel compared to air). A low or no carbon monoxide reading would indicate a lean air-fuel mixture (too much air compared to fuel). Typical causes of high carbon monoxide readings are as follows:

- Fuel system problems—Fuel system problems include a sticking or leaking injector, leaking fuel pressure regulator, high float setting, restricted air cleaner, defective input sensor, or computer control problem.
- Emission control system troubles—Almost any emission control system problem that can upset carbon monoxide readings.
- Incorrect ignition timing—Incorrect ignition timing occurs when timing is too far advanced or retarded.

Oxides of Nitrogen Readings

A five-gas analyzer can measure oxides of nitrogen, while a four-gas analyzer cannot. Since oxides of nitrogen are toxic, some state air quality agencies have made exhaust emission measurements with a five-gas analyzer mandatory.

Typical causes of high NO_x emissions include the following:

- High combustion chamber temperatures—Problems with high combustion chamber temperatures occur when there is excessively high engine compression ratio, carbon deposits in the combustion chambers, low cooling system, blocked water jackets, stuck thermostat, etc.
- EGR system problems—EGR system problems occur when burned gases are not being injected into the intake manifold and combustion flame temperature is too high.

Carbon Dioxide Readings

Four- and five-gas exhaust analyzers measure carbon dioxide (CO_2) in percent by volume. Typically, CO_2 readings should be approximately 14.5–16% for a modern engine. CO_2 readings provide more data for checking and adjusting the air-fuel ratio.

Carbon dioxide is a by-product of combustion. It is produced when one carbon molecule combines with two oxygen molecules in the combustion chamber. Carbon dioxide is not toxic at low levels. When you breathe, for example, you exhale carbon dioxide.

Normally, oxygen and carbon dioxide levels are compared when evaluating the content of the engine exhaust. For example, if the percent of carbon dioxide exceeds the percent of oxygen, the air-fuel ratio is on the rich side of a stoichiometric (chemically correct) mixture. CO_2 is also a good indicator of possible dilution of the exhaust gas sample through an exhaust leak.

Oxygen Readings

Four- and five-gas exhaust analyzers measure oxygen (O_2) in percentage by volume. Typically, oxygen readings should be between 0% and 0.35% for modern vehicles. Oxygen is needed for the catalytic converter to burn HC and CO emissions. Without oxygen in the engine exhaust, exhaust emissions can pass through the converter and out the vehicle's tailpipe.

As detailed in Chapter 51, there are two systems that add oxygen to the engine exhaust: the air injection system and pulse air system. As air is added to the exhaust, CO and HC emissions decrease. As a result, oxygen readings can be used to check the operation of the fuel injection system, air injection system, catalytic converter, and computer.

The oxygen level in the engine exhaust sample is an accurate indicator of a vehicle's air-fuel mixture. It is also a good indicator of a possible exhaust leak, which can dilute the exhaust gas sample. When an engine is running lean, oxygen increases proportionately with the air-fuel ratio. As the air-fuel mixture becomes lean enough to cause a lean misfire (engine miss), oxygen readings rise dramatically. This provides a very accurate method of measuring lean and efficient air-fuel ratios.

If you find any exhaust gas analyzer reading to be abnormally high or low, use your knowledge of system operation to pinpoint the trouble. By knowing which emissions are affected by which engine problem or emission system trouble, you can narrow down the source of the problem to specific components. You would then need to test each component or circuit to verify your conclusions.

Tech Tip

An engine with a defective thermostat can fail an emission test. If the engine operating temperature is too high, it can affect engine combustion efficiency and the operation of the computer control systems, which will try to compensate for the overheating engine. If the engine cannot reach the proper operating temperature, the computer will not be able to go into closed loop mode. Keep these basic system malfunctions in mind when diagnosing problems.

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State Emissions Testing Programs

Many states have some form of ***emissions testing program***. These programs, often referred to as ***inspection and maintenance programs***, generally involve taking exhaust gas readings as a vehicle's engine operates at idle and at a set rpms. They may also involve checking the vehicle for the presence of a catalytic converter and a fuel inlet restrictor.

Exact test procedures vary from state to state. However, the federal government has passed laws that require stricter emission testing of vehicles in areas with air pollution problems. These tests are referred to as enhanced emissions tests.

IM 240

IM 240 is an enhanced emissions test that requires the vehicle to be operated on a dynamometer at speeds of up to 55 mph (89 kmh) for 240 seconds while exhaust gas emissions are measured. Two additional tests—the evaporative emissions system purge test and the evaporative emission system pressure test—may be required in some areas.

Evaporative Emissions System Purge Test

The ***evaporative emissions system purge test*** measures the flow of fuel vapors into the engine while performing the IM 240 test. A flow meter transducer is installed into the system purge line between the charcoal canister and the engine intake manifold fitting. A personal computer connects to the flow transducer to analyze data. The computer can then detect if there is adequate purge flow to remove fumes from the canister to draw them to the engine for burning.

Evaporative Emissions System Pressure Test

An ***evaporative emissions system pressure test*** checks the system for leaks into the atmosphere. It is performed during the IM 240 test. Pressure test equipment is connected to the evaporative emission system's vapor vent line. A computer then meters low pressure nitrogen into the system (evaporative emission system, fuel lines, fuel tank, filler neck, etc.).

When about 0.5 psi (3.4 kPa) pressure is reached, the computer closes off the system and checks for a pressure drop for two minutes. If pressure remains above recommendations, the evaporative emission system passes the pressure test. If pressure drops too much, repairs would be needed to fix the leakage.

Smoke Generator Testing

A smoke generator is a testing tool that produces smoke and injects it into any sealed system to find leaks. A smoke generator can find evaporative emission control system leaks, engine vacuum leaks, engine oil leaks, exhaust system leaks, and wind and water leaks into the passenger compartment or trunk area.

When smoke is injected into any closed system, smoke will be emitted from any leakage point in the system. See **Figure 52-9A**.

Evaporative emissions trouble codes can be set by a loose leaking fuel tank cap, leaking or cracked vacuum hoses, rusted metal evaporative lines, a cracked plastic engine intake manifold, and loose fittings. Leaks can be difficult to locate without the use of a smoke generator.

Before smoke testing, inspect for obvious problems that could cause leakage. Check service literature or TSBs on the Internet for common evaporative emission system problems specific to that make and model of vehicle. If the trouble code is for the solenoid vent valve, check it first. The valve can stick open and fail to seal the system when the engine starts.

When performing a smoke leakage test, the technician must keep a few safety rules in mind.

- The engine must be off when smoke testing.
- Do not leave the vehicle unattended when smoke testing.
- Do not bring an ignition source near the vehicle when smoke testing due to the combustibility of the smoke.
- Work in a well-ventilated area and wear eye protection.

Service Procedure

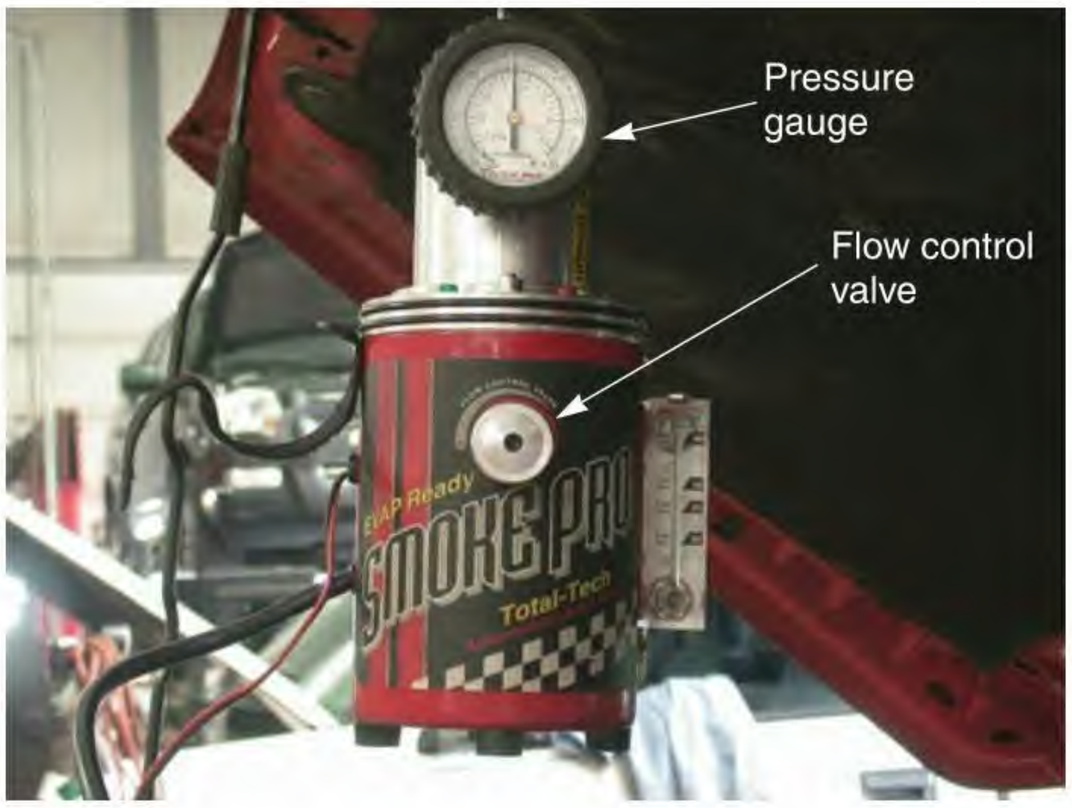
To perform a smoke leakage test on an evaporative emission control system:

1. Use your scan tool or diagnostic tablet to close the evaporative vent valve to seal the system.
2. Fill the smoke generator with the recommended test oil for generating smoke.

Tech Tip

Consult your smoke generator's manual for exact setup and operation procedures, as steps may vary.

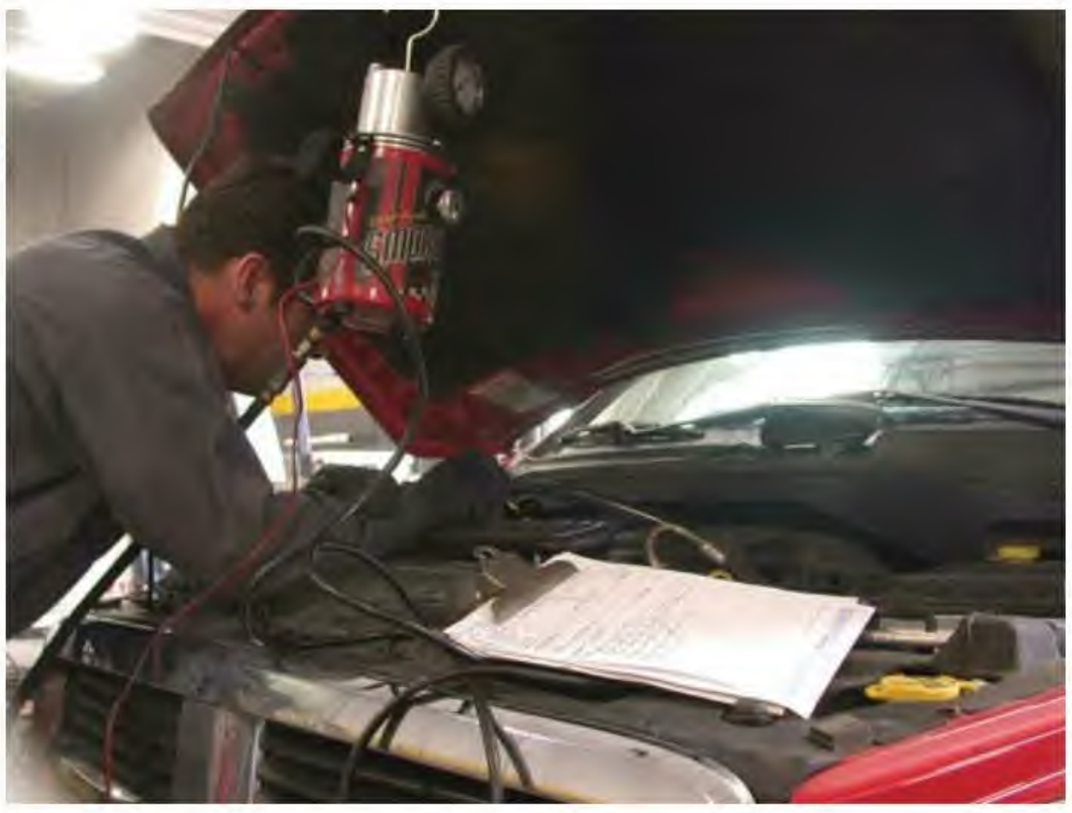
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A



B



C

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Figure 52-9. A smoke generator is used to find leakage in any sealed system of a vehicle, including the evaporative emission control system. A—Note the pressure gauge, flow gauge, and flow control valve on the smoke generator. B—Metal and plastic or foam rubber cones are provided with the system for sealing and testing various systems. This small brass cone is for connecting to vacuum lines. Large plastic or foam cones are for sealing and testing engine air intake or the exhaust system at the tailpipe. C—A technician is looking for smoke leakage near the charcoal canister in the evaporative emission control system.

3. Connect the generator to the battery and to shop air pressure.
4. Connect the generator vacuum line to the evaporative hose running to the engine intake manifold or vacuum brake booster, **Figure 52-9B**. You may have to use T-fitting if you want to test the whole system at once.
5. Seal the engine air intake duct with a large foam rubber cone or plastic bag and tape.
6. Turn the generator on so that smoke is injected into the test vacuum hose and system.
7. Adjust the smoke generator flow control valve so that the flow indicator is about halfway up on its clear plastic graduated scale.
8. Remove the gas cap until smoke comes out of the filler neck. Then reinstall and tighten the gas cap.
9. Keep injecting smoke into the system until the pressure reads maximum allowable pressure.
10. Observe the flow control meter. Any further flow into the system indicates a leak that must be located.
11. Look very closely near the gas tank, vent lines, and engine compartment for smoke. Smoke will come out any leak in the evaporative control system or other closed system. A halogen light will help you see any smoke leakage. See **Figure 52-9C**.
12. Repair the leak and smoke test the system again. You might have a cracked, leaking vacuum hose, rusted metal evaporative line, or similar problem.
13. Erase the trouble codes and test-drive the vehicle to verify your repairs.

The EPA estimates that approximately 25% of the vehicles tested will fail their emission tests. Repair costs to customers to pass the emission tests is capped at a fixed amount in most areas, usually between $100 and $500. If the capped repair amount is spent and the vehicle still does not pass, the owner will receive a waiver on further testing for a specified period of time. The emission testing facilities provide a printout of the emission fail records to help technicians repair the problem(s).

Vehicle Inspection Reports

A ***vehicle inspection report*** summarizes why a vehicle either passed or failed its state-mandated emission test. This report is given to the driver after

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the vehicle has been tested at the state-owned emission testing station. Refer to **Figure 52-10**.

The ***vehicle information section*** of the report identifies the type of motor vehicle. It lists the license plate number, VIN, year, make, model, engine type, fuel type (gas or diesel), test number, and the type of emission test needed (OBD or non-OBD).

The ***repair information section*** provides the vehicle owner with instructions for having the vehicle repaired if it fails the test. The ***inspection facility information section*** identifies the inspections facility and inspectors, as well as the date and time of the test.

The ***exhaust emission readings section*** of the test report gives readings for HC, CO, and NO_x, and OBD results, if applicable. Standard, or good, emission levels are listed along with test results. If any of the emissions levels are higher than normal (standard emission specification for that model year) or if the

Vehicle information

Repair information

Readings not performed because of trouble codes

OBD trouble code summary

Clean Air Car Check

STATE
VEHICLE INSPECTION REPORT

It is unlawful for any person to allow or participate in the preparation, duplication, sale, distribution, or use of false, counterfeit, or stolen Vehicle Inspection Reports.

Vehicle Information

License Plate	Vehicle Identification Number	Year	Make	Model	Mileage
			DODG	DAKOTA	96

GVWR	Fuel	Test Number	Inspection Type	BMV Motor Vehicle Test No.
5100	GAS	1	OBD	

Your motor vehicle emissions test result if shown below under TEST RESULT.

IF THE TEST RESULT IS:

Pass or Waiver - Present this form when registering your vehicle. Detach the lower portion for mail-in purposes.

Fail -
- After repairs or adjustments are made and the Repair Data Form found on the reverse side of this form is completed you may return for a retest. The inspection facility is not authorized to perform an emission retest without a completed Repair Data Form.
- Repairs may be covered under your warranty. Check your owner's manual or contact your dealer for details.

Inspection Facility Information

Inspection Date/Time	Station ID	Lane	Inspector ID (A)	Inspector ID (B)
03/20/02 08:32	8	1	KIMW	TOM

Exhaust Emissions Readings

	HC Hydrocarbons	CO Carbon Monoxide	NOx Oxides of Nitrogen	OBD Result
Standards:				
Readings:				
Results:				FAIL

On-Board Diagnostics (OBD) Details:

```
On Board Diagnostic Result: FAIL
  "MIL commanded on"
  Check engine light status: Commanded ON

  Diagnostic Trouble Codes: P0133,P0711
  P0133: O2 Sensor Circuit Slow Response (Bank 1 Sensor 1)
  P0711: Transmission Fluid Temperature Sensor Circuit Range/Performance
```

Gas Cap Pressure Test Result	Presence of Catalytic Converter	TEST RESULT
PASS	N/A	FAIL

If your vehicle receives a test result of FAIL or REJECT, please refer to a fail brochure before making repairs. Those with passing vehicles may present this ORIGINAL Vehicle Inspection Report Form when registering their vehicle. For mail-in registration detach the lower portion.

(Tear here to detach for mail-in registration)

BMV Portion — Use for Registration

Vehicle Make	Model	Year	License Plate	Vehicle Identification Number
DODG	DAKOTA			

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Figure 52-10. An actual vehicle inspection report for an OBD II vehicle. Since the malfunction indicator light in the dash was glowing, a test station scan tool was connected to the vehicle's diagnostic connector. This allowed the testing station to print the trouble codes on the report. No exhaust gas emissions were measured, since the vehicle had obvious emission-related problems.

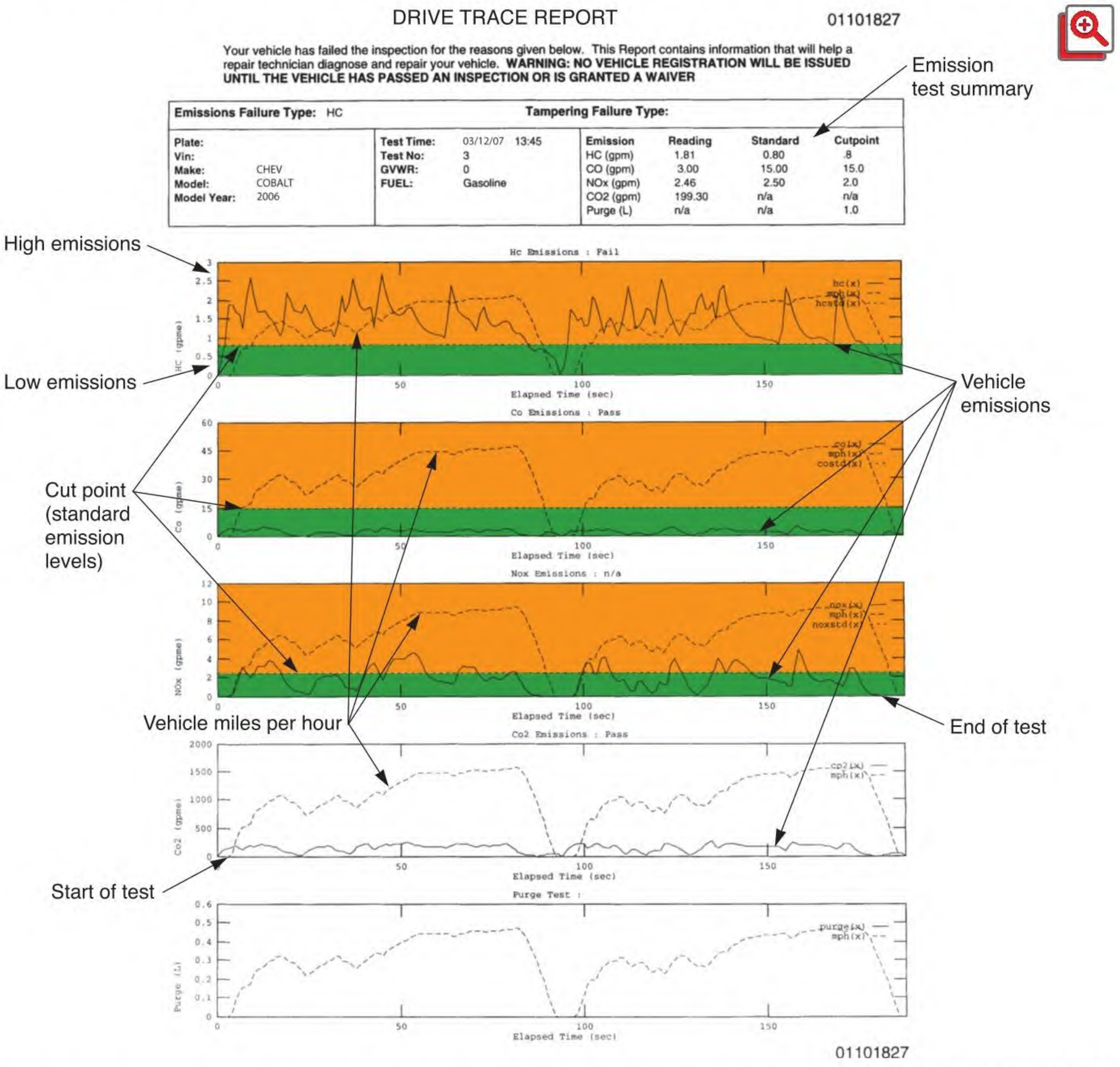
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MIL is illuminated, the vehicle fails its emission test. The vehicle must be repaired before being retested.

The OBD summary section is used to detail the results of the diagnostic system checks. With OBD II vehicles, the emission testing station will check for a glowing MIL (malfunction indicator light) in the dash. A scan tool is connected to the vehicle's diagnostic connector under the dash. If the MIL is glowing or if emission related trouble codes are found, the vehicle will fail its emission test. The inspection report will list the OBD II trouble code numbers found, along with a brief description of their possible causes.

Drive Trace Report

When testing pre-OBD II vehicles, a ***drive trace report*** is often printed out to help the technician find and repair the problems causing the increased air pollution. A drive trace report can also be printed to help the technician repair OBD II vehicles. One is shown in **Figure 52-11**.



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Figure 52-11. Each graph in this drive trace report shows how emissions were affected by vehicle speed, acceleration, and deceleration. The solid line trace is the emissions measurement. The trace with the larger dashes represents vehicle and engine speed. The straight line with smaller dashes is the emission standard cut point for that vehicle. If emissions average higher than the cut point, the vehicle fails the emission test. What emissions did this vehicle fail?

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Each ***drive trace*** is a graph showing emission levels over the time of the test. Five drive traces are normally given on each report: HC, CO, NO_x, CO_2, and purge.

The vertical scale on the left of each graph shows emission levels. The horizontal scale along the bottom of the graph is test time in seconds (usually 200–240 seconds total).

A key on the drive trace report denotes what each line on the graphs represents. A solid line, or trace, represents the actual emission level for the test vehicle. A dashed line, or trace, represents vehicle speed in mph. Emission standards are generally lower for newer vehicles.

The ***emission standard base line***, also called the ***cut point***, is the average allowable emission level for the specific model year. It is represented by a dotted line running straight across from the standard maximum allowable emission level. A base line or cut point is given for HC, CO, and NO_x, but not for CO_2 or purge traces.

Evaluating Drive Trace Reports

When evaluating a drive trace report, first note which pollution levels are higher than the maximum allowable level (cut point). To eliminate possible problem sources, also note which emission levels are normal. Note the vehicle speed (mph) at which the emission levels are the highest. Do emission levels increase more upon acceleration or deceleration?

If the vehicle failed the HC segment of the test, you would know that something is causing raw, unburned fuel to leave the tailpipe. If CO emissions are high, partially burned fuel has been detected. If NO_x emissions are high, combustion temperatures are too high, causing nitrogen oxide pollution.

Draw a straight line down through the highest emission level so you can compare what other emissions are doing at that exact point in the test. This will let you correlate what one emission level is doing compared to the others. Look at **Figure 52-12**.

You must use this information and your knowledge of engine, fuel, ignition, and emission control system operation to pinpoint possible problem sources so they can be fixed. Reasons for high emission levels were explained earlier.

Vacuum Solenoid Service

Various vacuum solenoids are used to interface emission system electronics with the devices that operate off engine vacuum. They can be used in almost all emission control systems.

When trying to find problems, you should refer to a ***vacuum hose diagram***, which shows the routing of all vacuum hoses. Just as a wiring diagram helps you trace circuit problems, a vacuum hose diagram will give useful information on finding incorrectly routed hoses, leaking or restricted hoses, and bad vacuum components. See **Figure 52-13**.

When troubleshooting vacuum solenoids, check for hard, brittle hoses that can leak and prevent normal operation of parts. If the vacuum solenoid is electrically powered, check it for voltage. Connect a voltmeter to the solenoid terminals and start the engine. Make sure you are getting voltage to the unit when needed, **Figure 52-14**.

You may also need to check that the solenoid valve opens and blocks vacuum as designed. Connect a vacuum gauge or hand pump to the vacuum connections on the unit. When the solenoid is energized and de-energized, it should switch vacuum on and off.

You can also connect a remote source of voltage to a vacuum solenoid to check its operation. When voltage is connected to the solenoid, it would switch vacuum on or off. Look at **Figure 52-15**.

PCV System Service



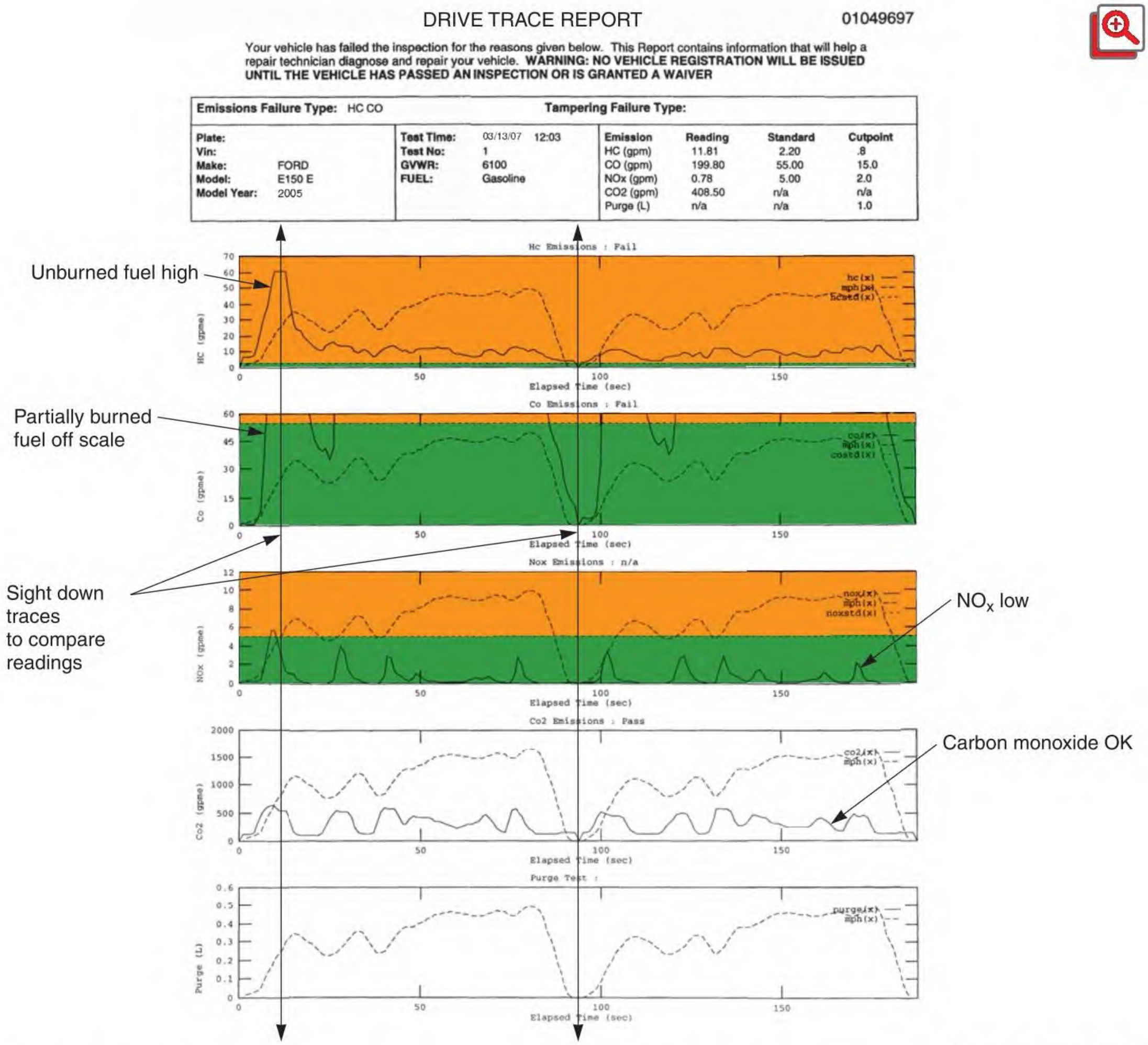
An inoperative PCV system can increase exhaust emissions. It can also cause engine sludging and wear, rough engine idle, and other problems. A leaking PCV system can cause a vacuum leak and produce a lean air-fuel mixture, causing a rough engine idle. A restricted PCV system can enrich the fuel mixture, affecting engine idle and causing the engine to surge (idle speed goes up and down) and emit black smoke.

Most auto manufacturers recommend periodic maintenance of the PCV system. Inspect the condition of the PCV hoses, grommets, fittings, and breather hoses. Replace any hose that shows signs of deterioration. Clean or replace the breather filter if needed. Also, check or replace the PCV valve. Since replacement intervals vary, always refer to the vehicle's service manual.

PCV System Testing

To quickly test a PCV valve, pull the valve out of the engine and shake it. If the PCV valve does not rattle when shaken, replace the valve. With the engine idling, place your finger over the end of the valve. With airflow stopped, you should feel suction on your finger

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Figure 52-12. Study this drive trace report. Note that both HC and CO are high. During repairs, the technician noticed blue smoke coming out of the tailpipe. The high-mileage engine was burning oil, which contaminated the catalytic converter. A new converter would temporarily reduce the emissions problem, but engine rebuild is needed for proper repair.

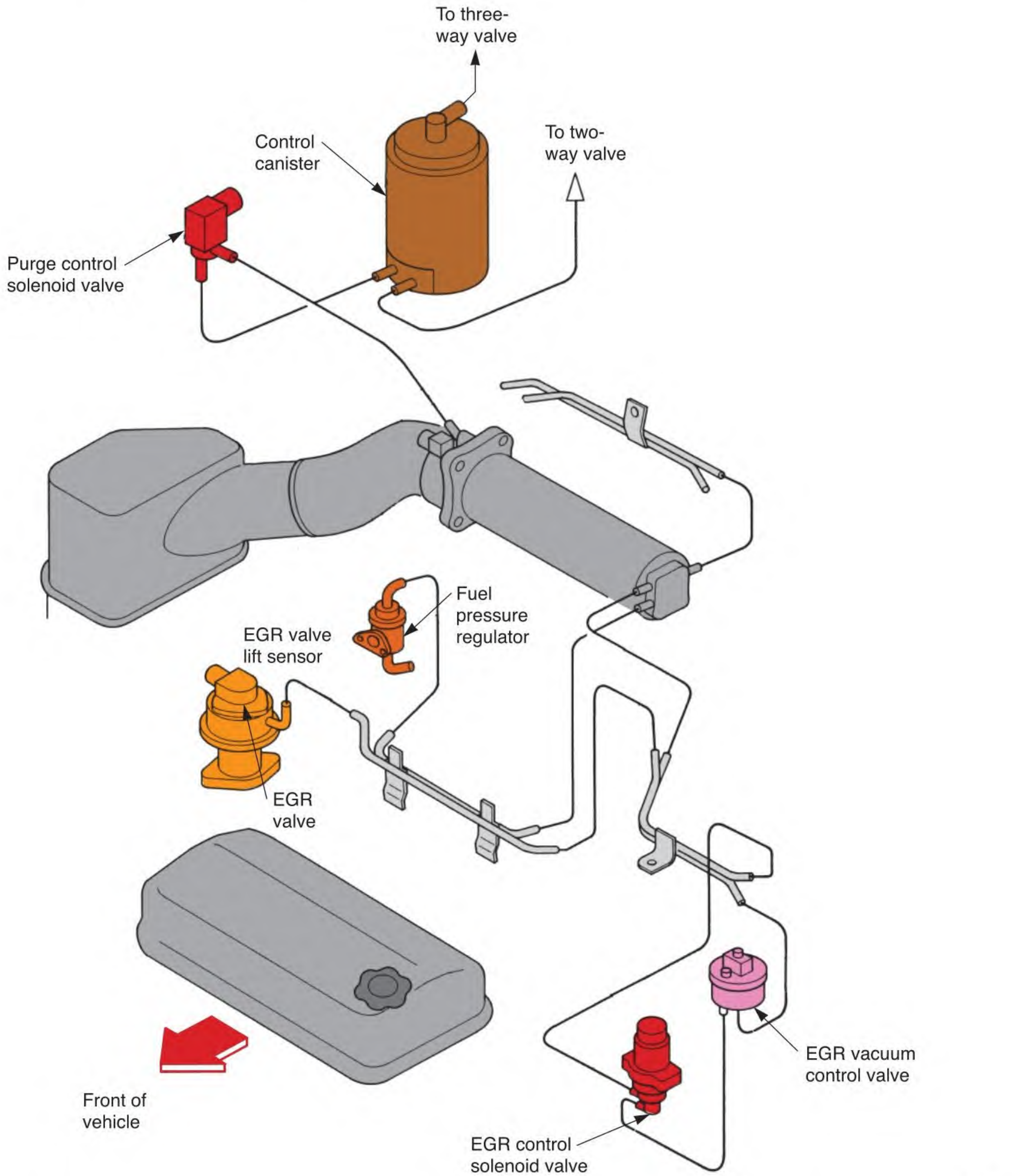
and the engine idle speed should drop about 40–80 rpms, **Figure 52-16**.

If you cannot feel vacuum, the PCV valve or hose might be plugged with sludge. If engine rpms drops more than 40–80 rpms and the engine begins to idle smoothly, the PCV valve could be stuck open.

A ***PCV valve tester*** will measure the exact amount of airflow through the system. To use a tester, make sure engine intake manifold vacuum is correct. Then, connect the tester to the engine as described in the operating instructions. Start and idle the engine. Observe the airflow rate on the tester. Replace the PCV valve if airflow is not within specified limits.

Some auto manufacturers suggest placing a piece of paper over the PCV breather opening to test the PCV system. After sealing the dipstick tube with tape, start and idle the engine. After a few minutes of operation, the piece of paper should be pulled down

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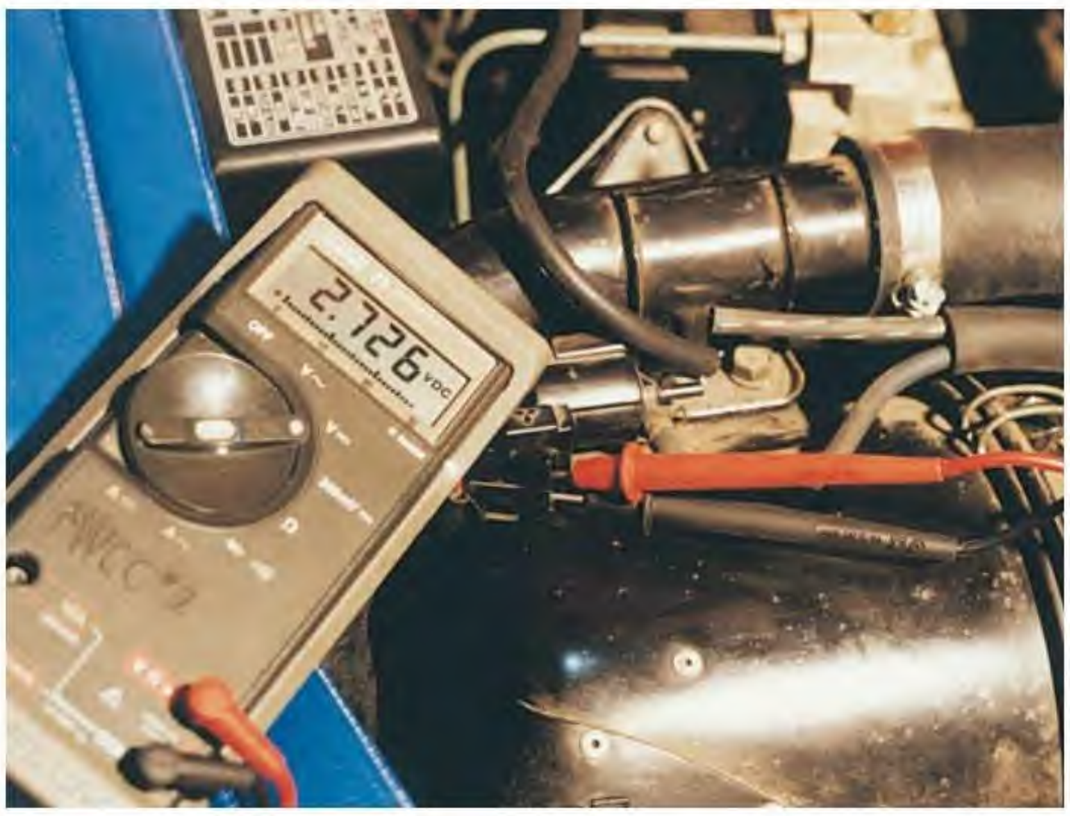
Honda

Figure 52-13. Service manual vacuum hose routing diagrams like this one are helpful if vacuum lines have been disconnected or come off. They also identify the purpose of each vacuum solenoid.

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A



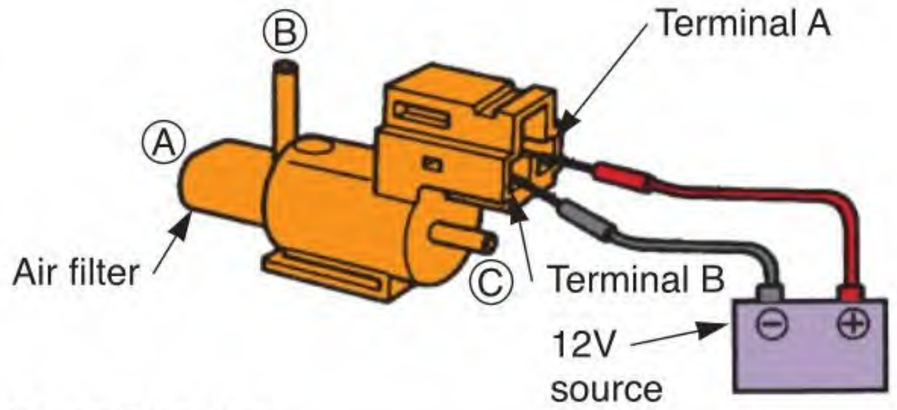
B



C

Fluke

Figure 52-14. Solenoid vacuum valves are common sources of trouble in emission control systems. A—Check the vacuum hoses for hardening, cracks, and leaks. B—Use a multimeter to check for voltage to the solenoid. If you are not getting control voltage, trace the wiring back to the ECM. C—Use a vacuum pump to check that the solenoid is turning the vacuum source on and off as designed.

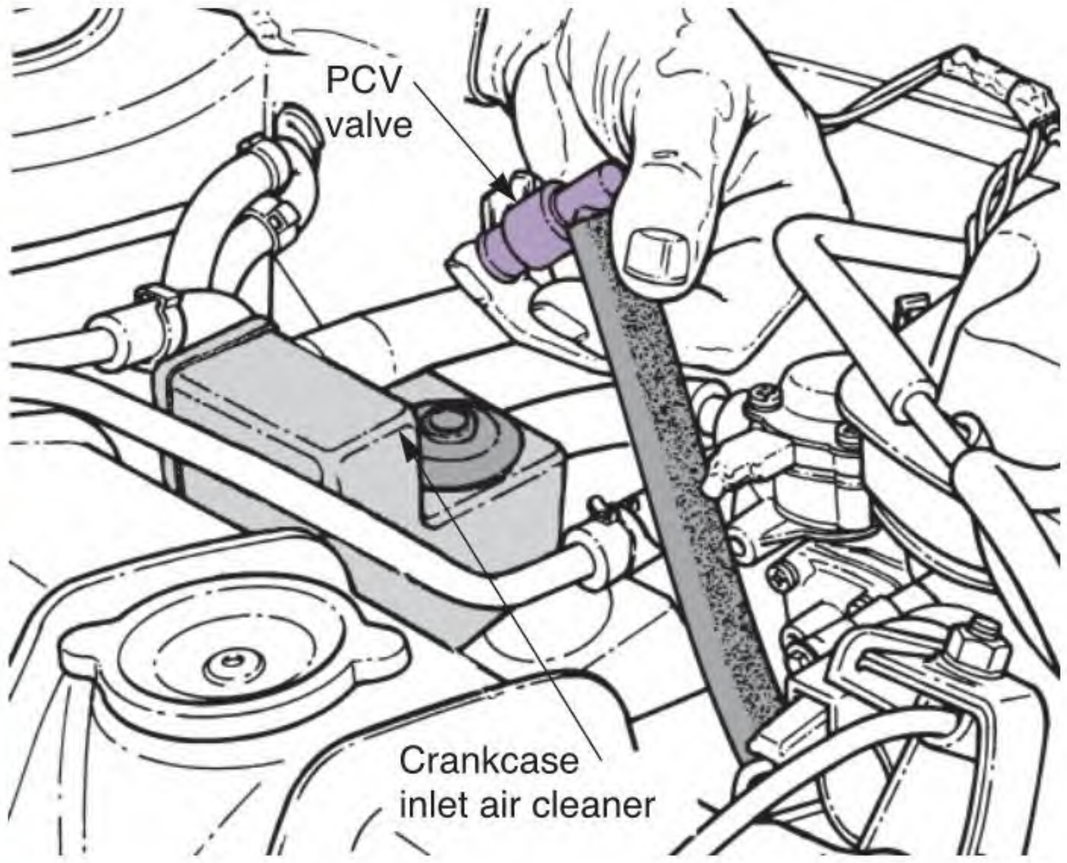


Specification

Port	Airflow
A—B	Yes
A—C	No
B—C	No

Mazda

Figure 52-15. This illustration shows how you can connect battery voltage to a vacuum solenoid to check its operation.



Chrysler

Figure 52-16. With the engine running, place your finger over the PCV valve. There should be suction present; if not, the hose may be plugged.

against the breather opening by crankcase vacuum. If suction does not develop, there is a leak in the system (ruptured gasket, cracked hose, etc.) or the system may be plugged.

A four- or five-gas exhaust analyzer can also be used to check the general condition of a PCV system. Measure and note the analyzer readings with the engine idling. Then, pull the PCV valve out of the engine, but not off the hose. Compare the readings after the PCV valve is removed.

A plugged PCV system will show up on the exhaust analyzer when oxygen and carbon monoxide

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do not change. ***Crankcase dilution*** (excessive blowby or fuel in the oil) will usually show up as an excessive (1% or more) increase in oxygen or a 1% or more decrease in carbon monoxide. This is because the excess crankcase fumes will be pulled into and burned in the engine, affecting your readings.

Evaporative Emissions System Service

A faulty evaporative emissions control system can cause fuel odors, fuel leakage, fuel tank collapse (vacuum buildup), excess pressure in the fuel tank, or a rough engine idle. These problems usually stem from a defective fuel tank pressure-vacuum cap, leaking charcoal canister valves, deteriorated hoses, or incorrect hose routing.

Maintenance on an evaporative emissions control system typically involves cleaning or replacing the filter in the charcoal canister. Service intervals for a canister filter vary. However, if the vehicle is operated on dusty roads, clean or replace the filter more often. Look at **Figure 52-17**.

Also inspect the condition of the fuel tank filler cap. Make sure the cap is installed properly and the seals are in good condition. Special testers are available for checking the opening of the pressure and vacuum valves in the cap. The cap should be tested when excessive pressure or vacuum problems are noticed.

All hoses in the evaporative emissions system should be inspected for signs of deterioration (hardening, softening, cracking). When replacing a hose, make sure you use special fuel-resistant hose. Vacuum hose can be quickly ruined by fuel vapors.

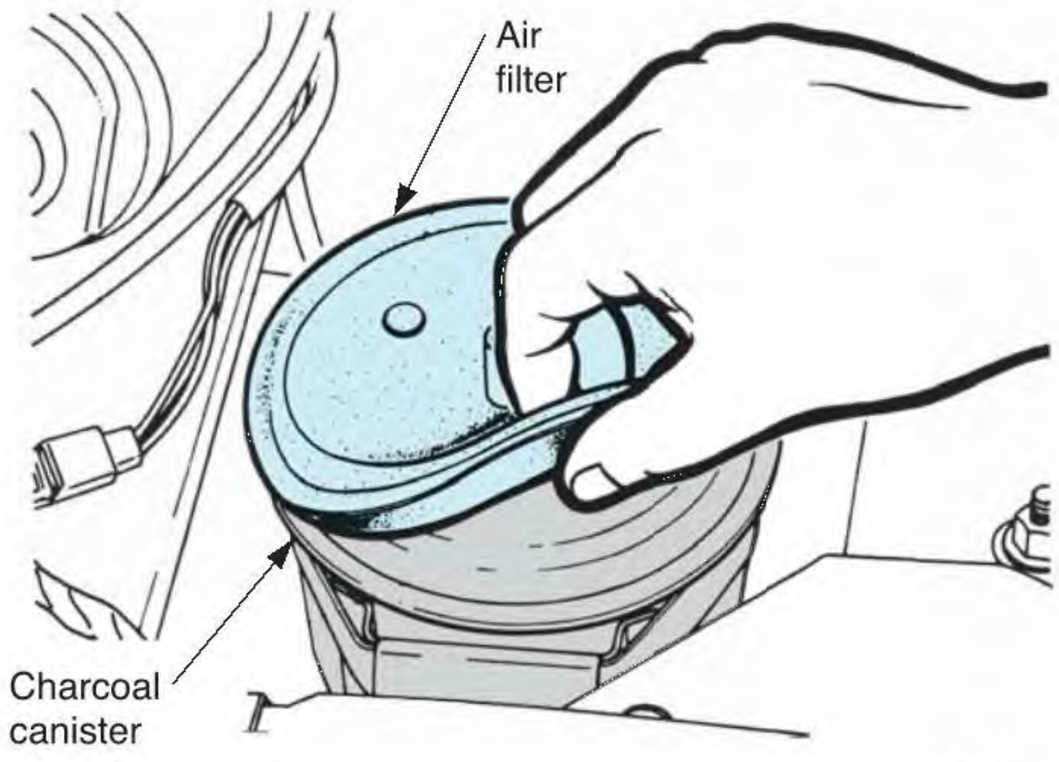
Use a hand vacuum pump to test the charcoal canister vacuum purge solenoids for diaphragm leakage. If a diaphragm will not hold a vacuum, it is ruptured and must be replaced. You can also use the vacuum gauge to check for a vacuum supply to any canister vacuum solenoid. See **Figure 52-18**.

EGR System Service

EGR system malfunctions can cause engine stalling at idle, rough idle, detonation, and poor fuel economy. If the EGR valve sticks open, it will cause a lean air-fuel mixture. The engine will run rough at idle or stall. If the EGR fails to open or the exhaust passage is clogged, higher combustion temperatures can cause abnormal combustion (detonation) and knocking.

Tech Tip

It is fairly common for small rocks to fly into the engine compartments of four-wheel-drive vehicles during off-road driving. If they are the right size, these small rocks may become lodged in the EGR valve and cause it to stick open. The engine will have a low idle, run rough, or stall. This may or may not trip a trouble code.



Chrysler

Figure 52-17. Some charcoal canisters have air filters. The filter should be removed and cleaned or replaced at periodic intervals.



Snap-on Tool Corp.

Figure 52-18. A hand vacuum pump will quickly check the operation of canister purge valves. Follow service manual directions. Make sure valves hold vacuum and are not leaking.

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Maintenance intervals for the EGR system vary with vehicle manufacturer. Refer to a service manual for exact mileage intervals. Some vehicles have a reminder light in the dash. The light will glow when EGR maintenance is needed. Also, check that the vacuum hoses in the EGR system are in good condition. They can become hardened, which can cause leakage. Also check for proper wire routing and for good electrical connections on digital EGR valves.

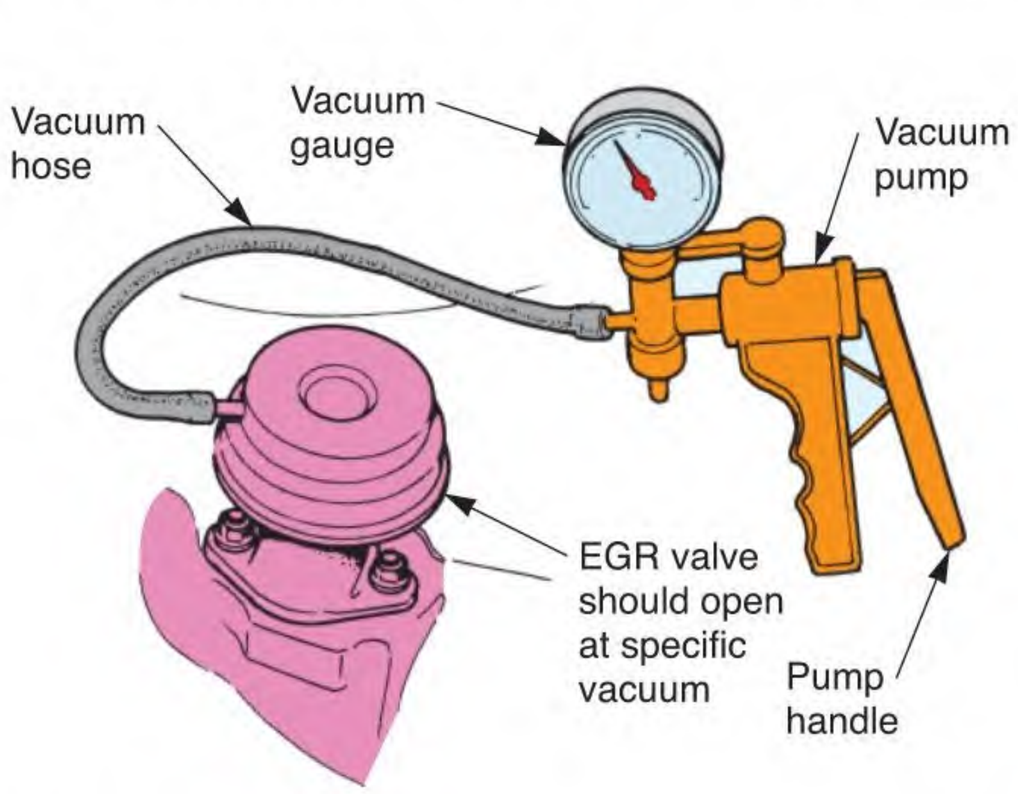
EGR System Testing (Vacuum Type)

To test a vacuum EGR system, allow the engine to warm to operating temperature. Operating the accelerator linkage by hand, increase engine speed to 2000–3000 rpms very quickly. If visible, observe the movement of the EGR valve stem. The stem should move as the engine is accelerated. If it does not move, the EGR system is not functioning.

Sometimes the EGR valve stem is not visible. You will then need to test each EGR system component separately. Follow the procedures described in a service manual.

To test the EGR valve, idle the engine. Connect a hand vacuum pump to the EGR valve. Plug the supply vacuum line to the EGR valve. When vacuum is applied to the EGR valve with the pump, the engine should begin to miss or stall. This lets you know that the EGR valve is opening and that exhaust gases are entering the intake manifold, **Figure 52-19**.

If the EGR valve operation does not affect the engine idle, remove the valve. The valve or the exhaust manifold passage could be clogged with carbon. If needed, clean the EGR valve and exhaust passage. When the EGR valve does not open and close properly, replace the valve.



Honda

Figure 52-19. With the engine idling, apply vacuum to the EGR valve. If the EGR valve is working, the engine should miss or stall.

EGR System Testing (Electronic Type)

Most problems with late-model electronic, or digital, EGR valves will trip a trouble code. You can then quickly and easily isolate most problems with a scan tool. EGR valves that provide electrical data to a computer control system require special testing procedures. Refer to a shop manual covering the specific system. Component damage could result from using an incorrect testing method.

The problem symptoms described earlier also apply to a digital EGR. If not working normally, a digital EGR can cause a rough engine idle, high oxides of nitrogen, and other problems.

To pinpoint test a digital EGR valve, connect a handheld scope to the wires going to the valve. The scope's waveform will measure the voltage applied to the EGR from the ECM and will also check the condition of the EGR windings. If you do not have voltage to the EGR, check for a bad electrical connection. There could also be an ECM problem in the control circuit to the EGR valve. See **Figure 52-20**.

If the EGR valve is not functioning properly and is determined to be faulty, replacement of the valve is required. See **Figure 52-21**.

Air Injection System Service

Air injection system problems can cause engine backfiring (loud popping sound), other noises, and increased HC and CO emissions. Remember, air injection is used to help burn any fuel that enters the exhaust manifolds and exhaust system. Without this system, the fuel could ignite all at once (backfire) with a loud bang. Insufficient air from the air injection system could also prevent the catalytic converter from functioning properly.

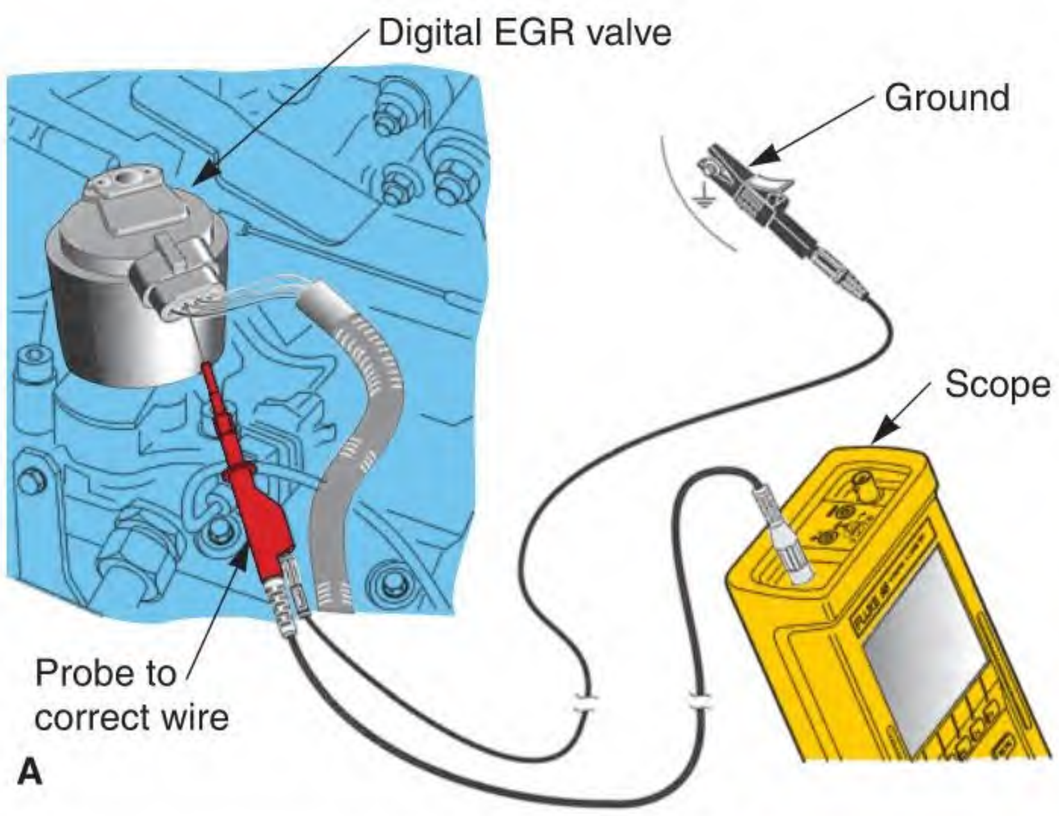
Air injection system maintenance typically includes replacing the pump inlet filter (if used), adjusting pump belt tension, and inspecting the condition of the hoses and lines.

If the pump belt or any hoses show signs of deterioration, they should be replaced. Refer to shop manual specifications for maintenance intervals.

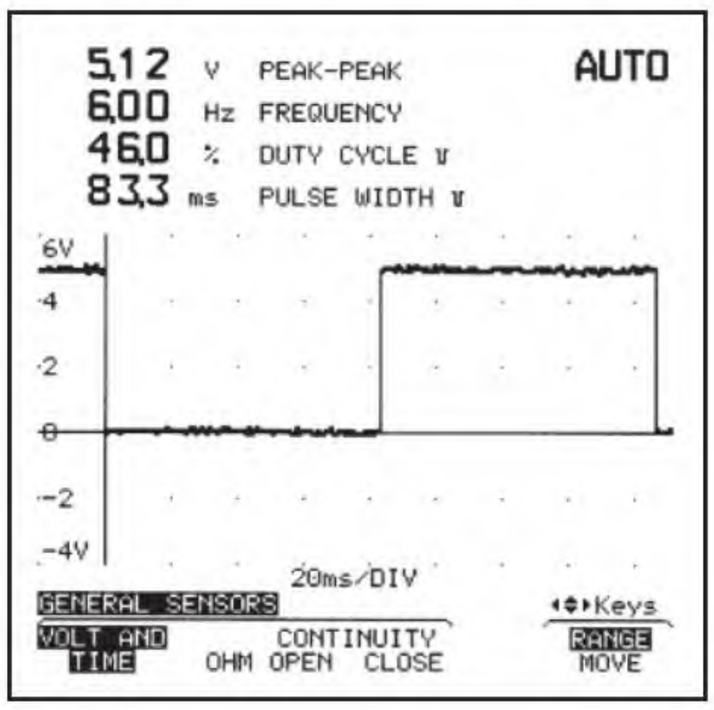
Testing Air Injection Systems

A four- or five-gas exhaust analyzer provides a quick and easy method of testing an air injection

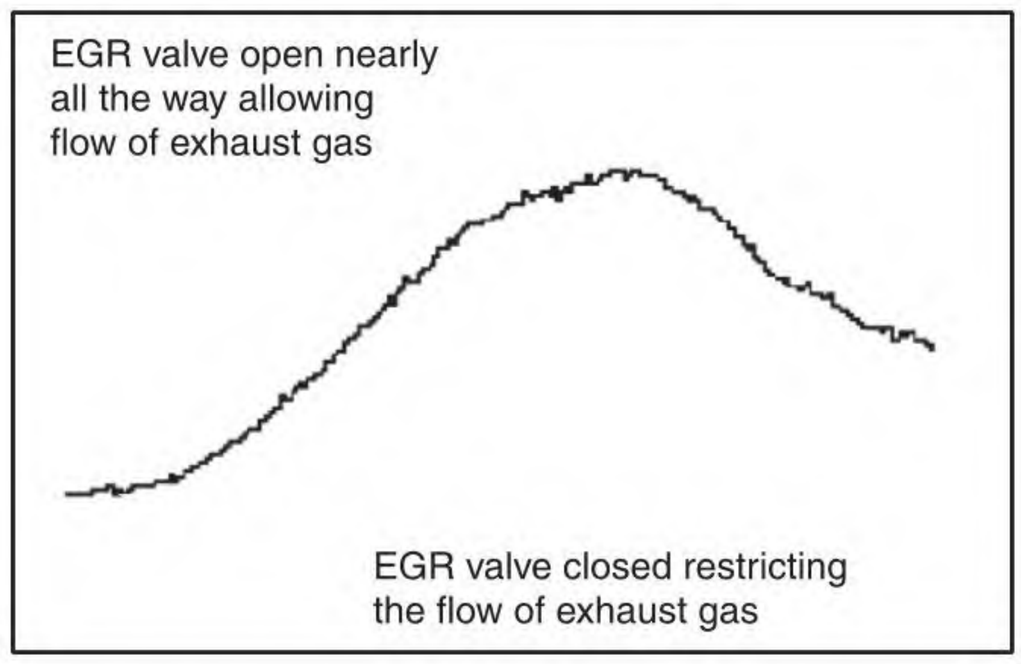
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A



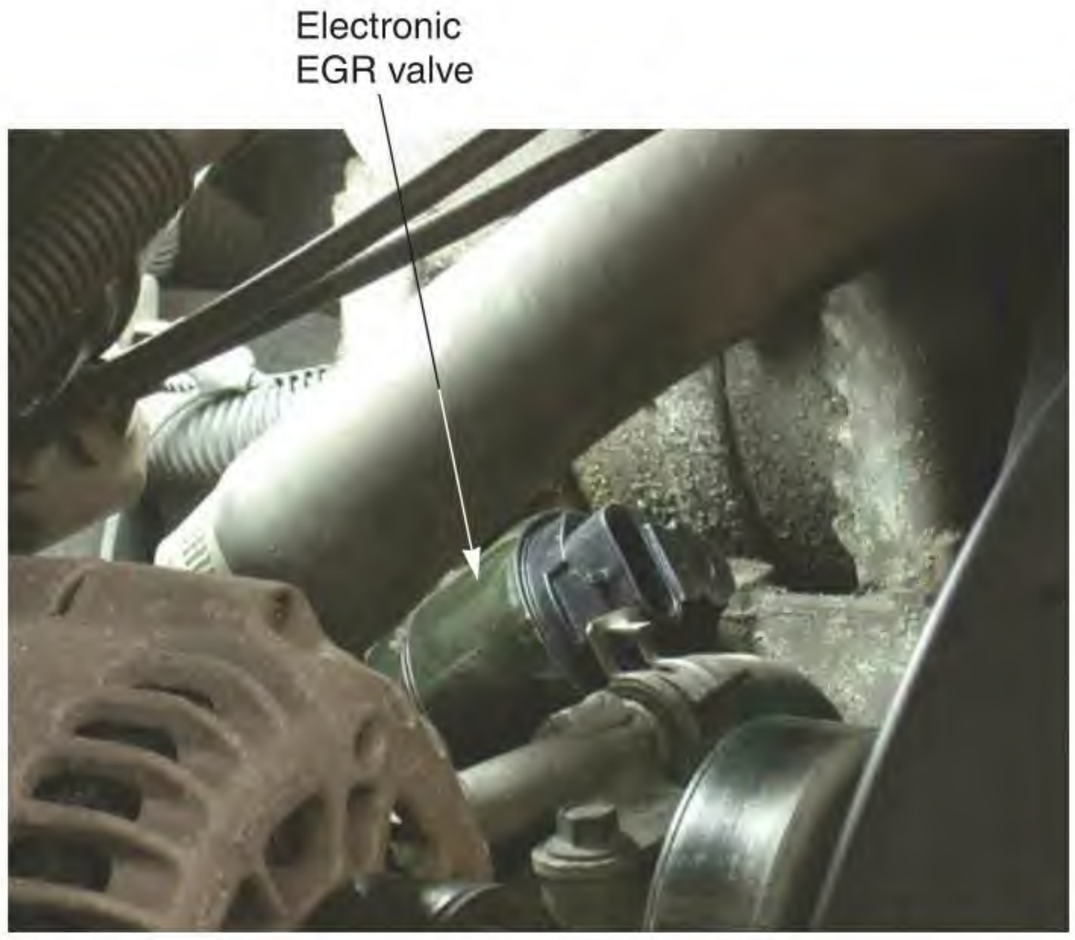
B



C

Fluke

Figure 52-20. An oscilloscope can be used to check digital EGR valves and their ECM control circuits. A—Connect the scope to ground and probe through the EGR valve connector. The service manual wiring diagram will tell you which wires to probe. B—The scope should show a normal signal going to the EGR valve. C—A scope can also be connected to read the return signal from the EGR position sensor/actuator.



A



B

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Figure 52-21. The major steps for electronic EGR valve replacement. A—EGR valves are often hidden somewhere on top of the engine. Refer to service literature if you cannot find it. Unplug the electrical connection to the EGR valve first, before unscrewing the bolts securing the EGR valve to the engine. Compare the old and new EGR valves to verify correct replacement unit. B—High temperature adhesive is often needed to hold the new EGR gasket in place during installation. Apply adhesive and the gasket and allow a few minutes of drying time. Then, reinstall the EGR valve.

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system. Run the engine at idle and record the readings. Then, disable the air injection system. Remove the air pump belt or use pliers to pinch the hoses to the air distribution manifold. Compare the exhaust analyzer readings before and after disabling the air injection system.

Without air injection, the exhaust analyzer's oxygen reading should drop approximately 2%–5%, while hydrocarbon and carbon monoxide readings should increase. This would show that the air injection system is forcing air (oxygen) into the exhaust system. If the analyzer readings do not change, the air injection system is not functioning. Test each component until the source of the problem is found.

To test the air pump, remove the output line from the pump. Use a low-pressure gauge to measure the amount of pressure developed by the pump at idle. Typically, an air pump should produce about 2–3 psi (14–21 kPa) of pressure.

If a low-pressure gauge is not available, place your finger over the line and check for pressure. Replace the pump if faulty. When testing the diverter valve or other air injection system valves, refer to a service manual. It will explain testing procedures for the specific components.

Pulse Air System Service

Many of the maintenance and testing methods discussed for an air injection system apply to the pulse air system. Inspect all hoses and lines and measure the exhaust's oxygen content with a four- or five-gas analyzer. Exhaust analyzer oxygen readings should drop when the pulse air system is disabled. If readings do not drop, check the action of the aspirator (reed) valves.

With the engine running, you should be able to feel vacuum pulses on your fingers. However, you should not feel exhaust pressure pulses trying to blow back through the valves. Replace the valves if they do not function as designed.

Catalytic Converter Service

Catalytic converter problems are commonly caused by contamination, overheating, and extended service. A clogged catalytic converter, resulting from deposits or overheating, can increase exhaust system back pressure. High back pressure decreases engine performance because gases cannot flow freely through the converter.

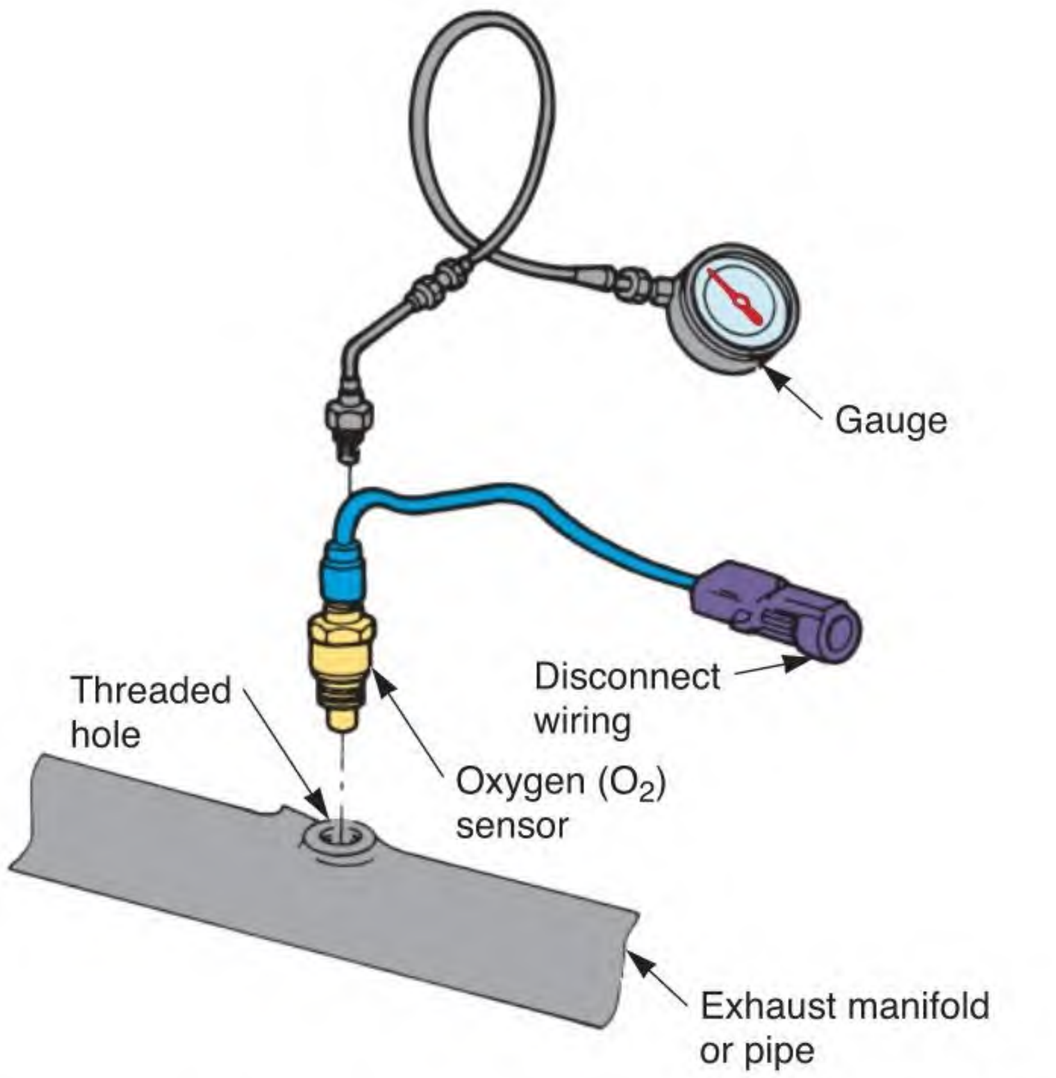
Tech Tip

A clogged catalytic converter is a fairly common problem. The increased back pressure will reduce engine power considerably. You may notice a rotten egg odor at the tailpipe. A clogged converter can also overheat, possibly causing a fire.

An ***exhaust back pressure test*** will check for a clogged catalytic converter and other system parts. Remove the front oxygen sensor and install a pressure gauge into the threaded hole, **Figure 52-22**.

Start the engine. Read the pressure gauge at idle and at higher speeds. If the pressure gauge reads too high, the converter, muffler, or an exhaust pipe is restricted. To isolate the exhaust restriction, disconnect parts one at a time. When the back pressure drops, you have found the source of the restriction.

After extended service, the catalyst in the converter can become coated with deposits. These deposits can keep the catalyst from acting on the hydrocarbons, carbon monoxide, and oxides of nitrogen. The inner



Snap-on Tool Corp.

Figure 52-22. If you suspect a clogged catalytic converter or other exhaust system obstruction, test the exhaust system's back pressure. Remove an oxygen sensor or exhaust tube on the engine before the catalytic converter. Install a pressure gauge into the sensor hole or exhaust riser tube. Start the engine and compare the pressure readings to specifications.

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baffles and shell can also deteriorate. This deterioration in a pellet-type catalytic converter can allow BB-size particles to blow out the tailpipe.

Pellet catalytic converters normally have a plug that allows replacement of the catalyst agent. The old pellets can be removed and new ones installed. If the converter housing is damaged or corroded, replace the converter. Monolithic (honeycomb) catalytic converters must be replaced when the catalyst becomes damaged or contaminated.

Tech Tip

Before condemning a catalytic converter, refer to a factory service manual. It will give added information on checking other systems before converter replacement.

Testing Catalytic Converter Efficiency

An exhaust gas analyzer can be used to check the general condition of the catalytic converter. Follow the specific directions provided with the analyzer. Warm and idle the engine. With some systems, you may need to disable the air injection or pulse air system before performing this test. Measure the oxygen and carbon monoxide at the tailpipe.

If oxygen readings are above approximately 5%, you know there is enough oxygen for the catalyst to burn the emissions. However, if the carbon monoxide readings are still above about 0.5% (other systems operating properly), then the catalytic converter is not oxidizing the emissions from the engine, and the converter or catalyst requires replacement.

Tech Tip

Your scan tool can be used to diagnose catalytic converter problems on OBD II vehicles. The catalytic converter's condition is monitored by measuring its oxygen storage capacity using two oxygen sensors—a pre-converter sensor and a post-converter sensor. Under normal conditions, the pre-converter oxygen sensor switches frequently and the post-converter sensor seldom switches. The pre-converter sensor switches more frequently because it "smells emissions", while the post-converter sensor "sniffs" cleaner gases.

Catalyst Replacement

To install new pellets in an older catalytic converter, follow service manual instructions. You must use a special vibrating tool to shake the old pellets out of a hole in the converter. Then, new pellets are installed and the service plug is replaced in the converter housing. This procedure is not used frequently, since it is faster and easier to simply replace the catalytic converter.

Warning

Remember that the operating temperature of a catalytic converter can be over 1400°F (760°C). This is enough heat to cause serious burns. Do not touch a catalytic converter until you are sure it has cooled.

Catalytic Converter Replacement

On many vehicles, the converter can be unbolted from the exhaust system. Remove the clamps that secure the converter to the exhaust pipes. Then use a muffler cutter or a chisel to cut and loosen the old converter from the exhaust pipes. Hammer blows to the converter should then free it from the vehicle.

Sometimes the catalytic converter is an integral part of the header pipe. With this design, the converter and pipe may have to be replaced together. When installing the new converter, use new gaskets and reinstall all heat shields. See **Figure 52-23**.

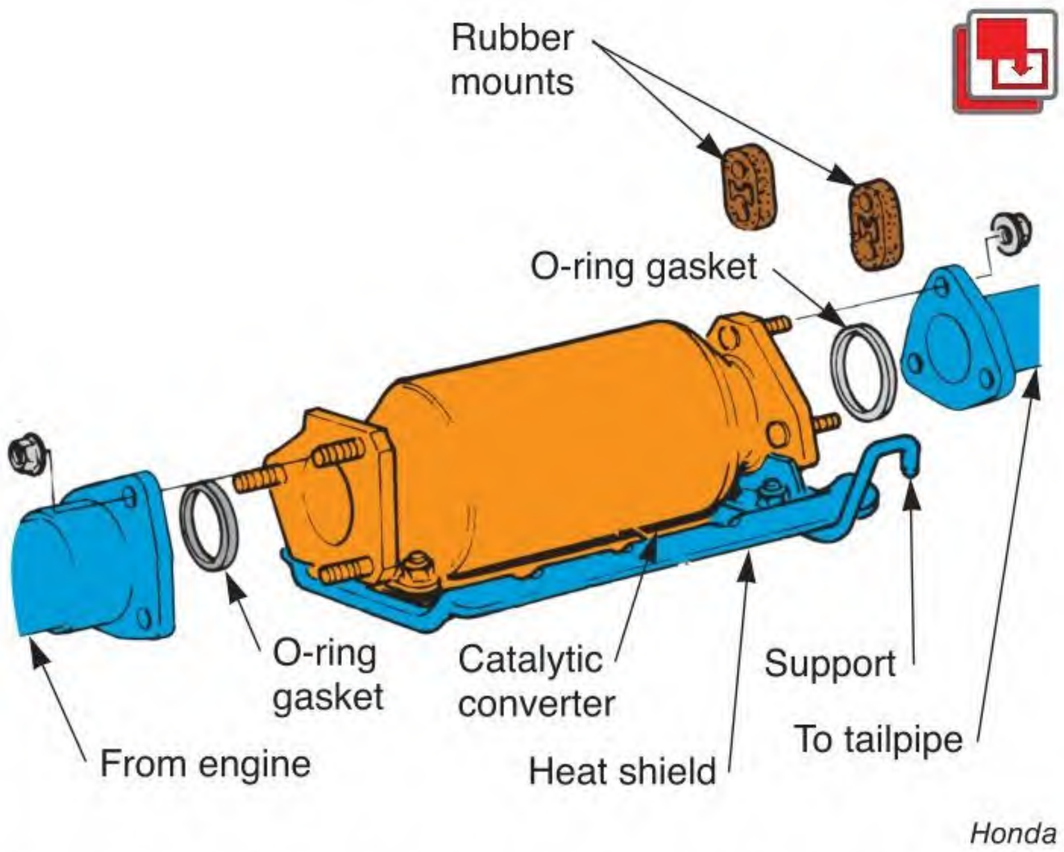
Tech Tip

After replacing a catalytic converter, turn in the old converter to be recycled. The platinum and other precious elements are very expensive and are becoming increasingly difficult to find.

Oxygen Sensor Service

After prolonged service, oxygen sensors become coated or fouled with exhaust by-products. As this happens, fuel economy and emissions may be adversely affected. If gas mileage is 10% to 15% lower

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Honda

Figure 52-23. When installing a new catalytic converter, replace all gaskets, rubber mounts, and mounting hardware. Make sure the heat shield is in place to avoid fires under the vehicle.

than normal, suspect a lazy oxygen sensor. A ***lazy O_2 sensor*** will not alter its output signal fast enough to maintain an efficient air-fuel ratio. The sensor will be slow to change its voltage or resistance with changes in exhaust content.

A bad oxygen sensor will affect engine performance and emissions. If it does not work properly, fuel metering will be too lean or too rich. A bad rear oxygen sensor (catalyst monitor) may not detect an inoperative catalytic converter.

A ***dead O_2 sensor*** has little or no resistance or voltage output change. Even when the exhaust content changes, the sensor's signal remains almost constant.

Testing Oxygen Sensors

Most O_2 sensor problems will trip a trouble code with OBD I and OBD II systems. However, there are times when an oxygen sensor will be close to, but not out of, its operating parameter and will not trip a trouble code. Even if the scan tool shows a problem with the O_2 sensor, pinpoint tests will also be needed to verify the source of the trouble.

If the scan tool readout shows that the O_2 sensor output voltage is abnormal, you might want to measure the sensor's output voltage with a multimeter. Look at **Figure 52-24**. An oscilloscope can also be used to check the signal leaving the O_2 sensor, **Figure 52-25**.

When testing a titania oxygen sensor, it may also be necessary to check the reference voltage supplied by the ECM, as well as the sensor's resistance or voltage drop. Refer to the service manual for details.

By comparing actual voltage (zirconia-type sensor) or resistance levels (titania-type sensor) to scan tool readout values and manufacturer's specifications, you can determine whether the sensor, wiring, or ECM is at fault.

If you are using a dual trace scope (scope has two test leads and can display two separate waveforms at once), you can compare the signals from the front and rear oxygen sensors on OBD II vehicles. If the voltage levels from the sensors are too similar, you may have a faulty catalytic converter, **Figure 52-26**.

If you have trouble isolating an oxygen sensor-related problem, refer to the factory service manual. It will give specific information to help find the source of the problem.

Tech Tip

Testing methods for wide-band oxygen sensors are similar to those for conventional oxygen sensors. Refer to the manufacturer's service manual for specific instructions, since testing methods may vary.

Oxygen Sensor Replacement

Service Procedure

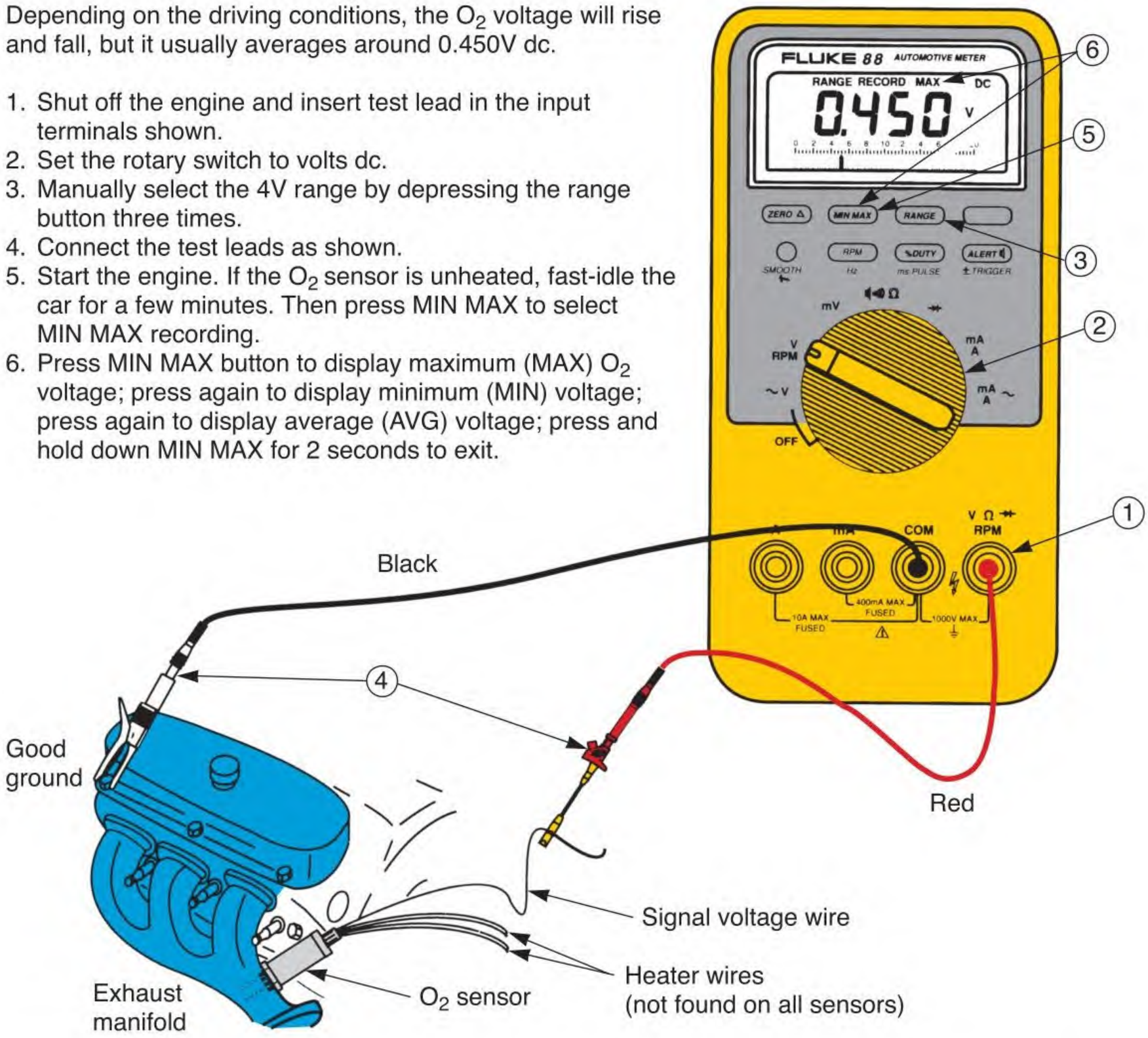
To replace an oxygen sensor:

1. Disconnect the negative battery cable.
2. Separate the sensor from the wiring harness by unplugging the connector. Never pull on the wires themselves, as damage may result, **Figure 52-27**.
3. Spray the sensor threads with a generous coat of penetrating oil.
4. Use a special sensor socket to remove the sensor from the exhaust system. Use care to avoid thread damage.
5. Inspect the sensor for signs of contamination, **Figure 52-28**.
6. Obtain and install the correct replacement oxygen sensor.
7. Start the sensor by hand.
8. Tighten the sensor with a wrench or socket. Do not overtighten and damage the sensor during installation.
9. Reconnect the wire connector and check system operation.

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Depending on the driving conditions, the O_2 voltage will rise and fall, but it usually averages around 0.450V dc.

1. Shut off the engine and insert test lead in the input terminals shown.
2. Set the rotary switch to volts dc.
3. Manually select the 4V range by depressing the range button three times.
4. Connect the test leads as shown.
5. Start the engine. If the O_2 sensor is unheated, fast-idle the car for a few minutes. Then press MIN MAX to select MIN MAX recording.
6. Press MIN MAX button to display maximum (MAX) O_2 voltage; press again to display minimum (MIN) voltage; press again to display average (AVG) voltage; press and hold down MIN MAX for 2 seconds to exit.



Fluke

Figure 52-24. If the scan tool indicates a possible oxygen sensor problem, you can use a multimeter to check the sensor's actual output voltages. This will eliminate wiring to sensor to ECM as a possible source of the weak signals from the low-voltage exhaust gas sensors.

OBD II Drive Cycle

The ***OBD II drive cycle*** is normally performed whenever the battery or ECM has been disconnected, or after diagnostic trouble codes have been erased. Additionally, some states require the drive cycle to be performed before an emissions test.

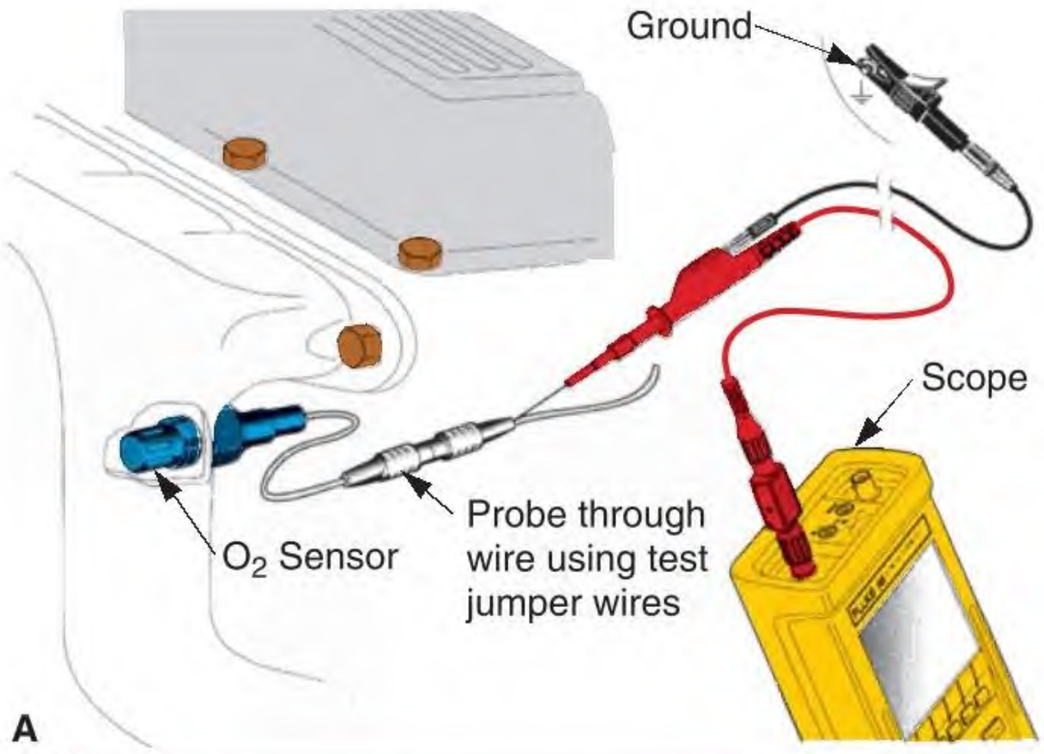
The drive cycle is designed to tell the technician whether the OBD II system is operating properly. It involves attaching a scan tool to the vehicle and driving the vehicle for a specified period of time. The drive cycle will include periods of acceleration, cruising, and deceleration.

Tech Tip

Carefully study the drive cycle procedure and scan tool operation before starting the drive cycle. You should be reasonably sure that you can complete the drive cycle from beginning to end. If the drive cycle has to be aborted for any reason, the engine must be allowed to cool, which can cause a considerable delay.

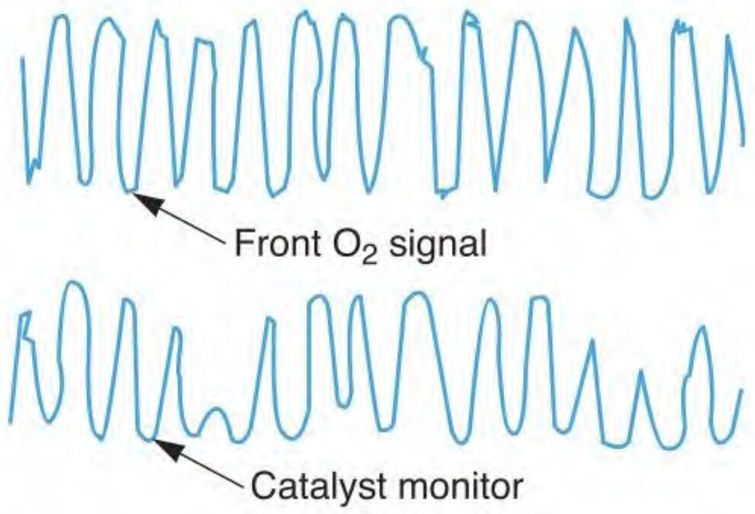
The drive cycle is different for each vehicle, so check the service manual for specific instructions. To begin the drive cycle, check that the coolant temperature is low enough to allow the ECM to start in the open loop mode. On most engines, coolant

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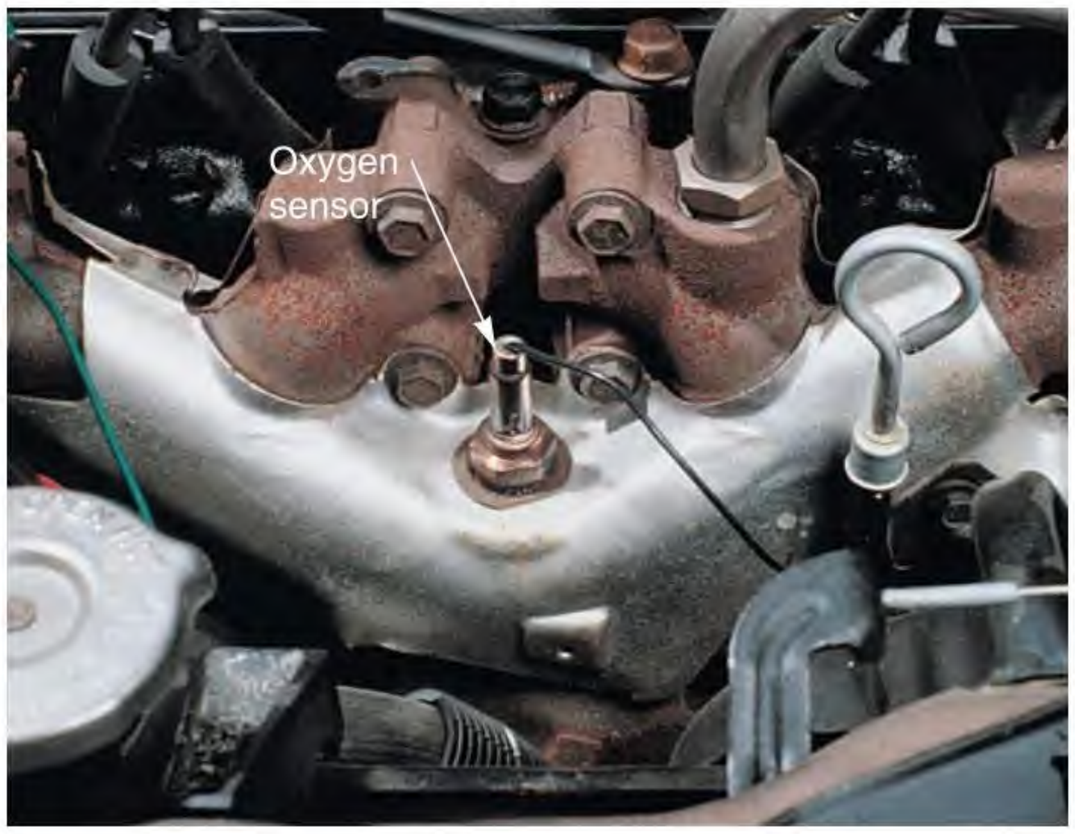
Fluke

Figure 52-25. You can use an oscilloscope to check the output signal from an oxygen sensor. A—Ground one lead and probe through the connector using jumper wires or metal pins. Do not pierce the oxygen sensor wiring; internal wiring corrosion can affect the sensor's signal strength. B—The oxygen sensor's signal output should vary up and down to adjust the engine fuel injection system. Note the millivolt readout on the scope face. C—This is a typical waveform for a zirconia O_2 sensor.



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Figure 52-26. With a dual trace scope or scan tool scope function, you can compare signals from each oxygen sensor. If the waveform from the catalyst monitor is too similar to the signal produced by the front sensor(s), the catalytic converter is not burning the remaining fuel in the exhaust and should be replaced. Investigate the engine's mechanical condition as a reason for the converter damage.



Fel-Pro

Figure 52-27. Care must be taken when disconnecting the oxygen sensor connector from the wiring harness. Connector damage could cause a sensor trouble code after you install a new sensor and result in a time-consuming "come back" repair.



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Figure 52-28. This oxygen sensor became lazy because of a coating of carbon soot caused by a fuel injector that was leaking.

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temperature should be below 120°F (49°C). Be sure to allow for variations in coolant temperature sensor calibration. In warm climates, the cooldown period can take as long as six hours. If possible, allow the vehicle to sit overnight before starting the drive cycle.

Attach the scan tool, and set the tool to record the ECM status as the engine operates. Some scan tools have a dedicated drive cycle option. A typical drive cycle will cover engine warm-up, idling, accelerating, decelerating, and cruising, in a specific order. This order must be followed as outlined in the service manual. See **Figure 52-29**. Some scan tools will prompt the technician throughout the drive cycle. After ensuring that the engine temperature is low enough to start the drive cycle, start the vehicle and complete the drive cycle sequence as outlined in the service manual.

A typical drive cycle will take from 8–15 minutes to complete, depending on the manufacturer. Depending on the portion of the cycle being performed, you may have to turn the air conditioning on and off at certain times, cruise at a steady speed, accelerate at part throttle to a specified speed, and decelerate without braking. Some state air quality programs eliminate the warm-up portion of the drive cycle, as it is impractical to allow the vehicle to cool off before testing.

Performing the drive cycle with the vehicle on a chassis dynamometer will allow the scan tool to gather readings in the shortest possible time. If the vehicle is driven on the road, it may be impossible to complete the drive cycle exactly as designed. Therefore, some scan tools can be paused when the drive cycle must be delayed. However, if the engine is shut off for any reason, the drive cycle must be restarted from the beginning.

The scan tool will indicate when the drive cycle is complete, but not whether the vehicle passed or failed. Any malfunctions will be stored as trouble codes in the scan tool. Check for stored trouble codes and make further diagnostic checks and repairs as needed. After repairs are complete, repeat the drive cycle to ensure that the vehicle is repaired.

Emission Control Information Sticker

The ***emission control information sticker***, or label, gives important engine data, evaporative emissions information, schematics, and other specifications for complying with EPA regulations. Study the information given on the label or sticker. The emission control sticker is normally located on the underside of the hood, on the radiator support, or on a valve cover.

OBD II Drive Cycle

Vehicle Status	Monitored System or Component
Cold start—coolant temperature must be less than 122°F (50° C)	N/A
Idle for 2.5 minutes in drive (automatic transmission) or neutral (manual transmission) with the air conditioning and rear defroster on	HO_2S heater, misfire, secondary air, fuel trim, EVAP purge
Turn air conditioning off and accelerate to 55 mph (90 km/h) at half throttle	Misfire, fuel trim, EVAP purge
Cruise at 55 mph for 3 minutes	Misfire, EGR, secondary air , fuel trim, HO_2S, EVAP purge
Decelerate to 20 mph without braking; clutch engaged (manual transmission)	EGR, fuel trim, EVAP purge
Accelerate to 55–60 mph (90–97 km/h) at 3/4 throttle	Misfire, fuel trim, EVAP purge
Cruise at 55–60 mph (90–97 km/h) for 5 minutes	Catalyst monitor, misfire, EGR, fuel trim, HO_2S, EVAP purge
Decelerate to a stop without braking; clutch engaged (manual transmission)	EGR, EVAP purge
End of drive cycle	N/A

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Figure 52-29. This chart shows an OBD II drive cycle for a particular vehicle. Be sure to read and understand each part of the procedure before starting a drive cycle.

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Diagnostic Case Study

Concern: Mr. Goldsmith brings in his 2012 Kia Forte to the shop. The engine has a rough idle but otherwise seems to operate normally.

Cause: Duff checks for trouble codes, but no trouble codes are set. Knowledge of emission control system operation makes Duff think that the EGR valve could be leaking. Duff passes this information on to the shop's emissions repair technician. The technician attaches a hand-operated vacuum pump to the EGR valve. The valve diaphragm shows slight leakage. The technician removes the EGR valve and inspects it. Carbon buildup is found on the EGR and inside the intake manifold passages.

Correction: The passages clogged with carbon deposits are cleaned out, and the EGR valve is replaced with a new unit. The car is tested and appears to be idling normally. The technician uses an exhaust gas analyzer to check emissions. The emissions are within acceptable limits, and the vehicle is released to the owner.

Summary

- Emission system scanning involves using a scan tool to check the condition of monitored parts of the various systems.
- The emission maintenance reminder is a circuit that automatically turns on a dash light to indicate the need for emission control system service.
- An exhaust analyzer is a testing instrument that measures the chemical content of engine exhaust gases.
- The five-gas exhaust analyzer measures HC, CO, CO_2, O_2, and NO_X.
- Exhaust gas analyzer calibration involves adjusting the needles or digital readouts to measure correctly.
- When using an exhaust analyzer, do not let engine exhaust fumes escape into an enclosed shop area.
- The evaporative system purge test measures the flow of fuel vapors into the engine while performing the IM 240 test.
- EGR system malfunctions can cause engine stalling at idle, rough engine idling, detonation (knock), and poor fuel economy.
- Air injection system problems can cause engine backfiring (loud popping sound), other noises, and increased hydrocarbon and carbon monoxide emissions.
- A clogged catalytic converter can increase exhaust system back pressure.
- With OBD II equipped vehicles, the catalytic converter's condition is monitored by measuring its oxygen storage capacity using two oxygen sensors.
- Most O_2 sensor problems will trip a trouble code with OBD I and OBD II systems. Pinpoint tests are needed to verify the source of the trouble.
- The OBD II drive cycle is designed to tell the technician whether the OBD II system is operating properly. It is normally performed whenever the battery or ECM has been disconnected, or after diagnostic trouble codes have been erased.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

calibration
calibration gas
combustion efficiency
crankcase dilution
cut point
dead O_2 sensor
drive trace
drive trace report
emission control information sticker
emission maintenance reminder
emission standard base line
emissions testing program
evaporative emissions system pressure test
evaporative emissions system purge test
exhaust back pressure test
exhaust emission readings section
exhaust gas analyzer
five-gas exhaust analyzer
four-gas exhaust analyzer
IM 240
inspection and maintenance programs
inspection facility information section

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lazy O_2 sensor
OBD II drive cycle
PCV valve tester
repair information section
two-gas exhaust analyzer
vacuum hose diagram
vehicle information section
vehicle inspection report

Activities

1. Set up an exhaust gas analyzer correctly, following the manufacturer's instructions. Demonstrate to your instructor and to the class the proper procedure for checking emission levels. If there are high emission levels, write your recommendations for service of any problems.
2. If a flat rate manual and parts catalog are available, prepare a bill for the service and repair in Activity 1. Use a labor rate suggested by your instructor.

Review Questions

Answer the following questions using the information provided in this chapter.

1. A(n) _____ is a testing instrument that measures the chemical content of the engine exhaust gases.
2. What is the difference between two-, four- and five-gas exhaust analyzers?
3. List five reasons that HC readings can be higher than normal.
4. High CO readings can be caused by fuel system problems. True or False?
5. With a five-gas exhaust analyzer, oxygen in the engine exhaust is an accurate indicator of air-fuel mixture. True or False?
6. Typically, if the levels of CO exceed the O_2 levels, the air-fuel mixture is:
   (A) lean.
   (B) rich.
   (C) stoichiometric.
   (D) None of the above.
7. How do you check the general operation of a PCV valve with your finger and with an exhaust gas analyzer?
8. If a vacuum pump is used to activate an EGR valve at idle, the engine should *not* be affected. True or False?
9. An air pump in an air injection system should produce about _____ to _____ psi or _____ to _____ kPa.
10. Describe the results of a clogged catalytic converter.
11. The operating temperature of a catalytic converter may be over _____ or _____.
12. A driver complains that a malfunction indicator light glows in the dash. Technician A says that an ohmmeter should be used to measure the resistance of the computer system oxygen sensor. Technician B says that a scan tool should be used to check for stored trouble codes. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
13. What is the purpose of the OBD II drive cycle?
14. A(n) _____ can be used to pinpoint test a digital EGR valve and check the condition of the EGR windings.
15. The emission control _____ gives important instructions, diagrams, and specifications for complying with EPA regulations.

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ASE-Type Questions

1. An exhaust gas analyzer will indicate each of the following *except*:
   (A) ignition system problems.
   (B) faulty air injection system.
   (C) stored trouble code.
   (D) engine mechanical problems.
2. Which of the following is *not* measurable by a four-gas exhaust analyzer?
   (A) Oxygen.
   (B) Hydrocarbons.
   (C) Carbon dioxide.
   (D) Oxides of nitrogen.
3. An exhaust gas analyzer measures hydrocarbons by volume in:
   (A) percentages.
   (B) parts per million.
   (C) grams per mile.
   (D) All of the above.
4. The term *stoichiometric* indicates that a fuel mixture is:
   (A) chemically correct.
   (B) too rich.
   (C) too lean.
   (D) contaminated.
5. A state emissions test drive trace indicates high NO_x levels. Which of the following could *not* be the source of the problem?
   (A) Carbon on pistons.
   (B) Low coolant level.
   (C) Clogged EGR valve.
   (D) Leaking fuel injector.
6. A faulty evaporative emissions control system can cause:
   (A) fuel odors.
   (B) fuel leakage.
   (C) rough engine idle.
   (D) All of the above.
7. EGR system service is being discussed. Technician A says that an EGR valve stuck open will cause a rich air-fuel mixture. Technician B says that a pinpoint test on a digital EGR valve means hooking the vehicle up to an exhaust gas analyzer. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. Air injection system problems can cause each of the following *except*:
   (A) engine backfiring.
   (B) increased hydrocarbon emissions.
   (C) increased carbon dioxide emissions.
   (D) increased carbon monoxide emissions.
9. Technician A says that catalytic converter problems are commonly caused by contamination. Technician B says that catalytic converter problems are often caused by extended service. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. An oxygen sensor will not alter its output signal fast enough to maintain an efficient air-fuel ratio. Technician A says the sensor is shorted. Technician B says the sensor is lazy. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Emission Control System Diagnosis		
Condition	**Possible Causes**	**Correction**
Excessive hydrocarbon reading.	1. Poor cylinder compression. 2. Leaking head gasket. 3. Ignition misfire. 4. Poor ignition timing. 5. Defective input sensor. 6. Defective output sensor. 7. Defective ECU. 8. Open EGR valve. 9. Sticking or leaking injector. 10. Improper fuel pressure. 11. Leaking fuel pressure regulator. 12. Oxygen sensor contaminated or responding to artificial lean or rich condition. 13. Improperly installed fuel filler cap.	Test components. Service or replace as necessary.
Excessive carbon monoxide reading.	1. Plugged air filter. 2. Engine carbon loaded. 3. Defective sensor. 4. Defective ECM. 5. Sticking or leaking injector. 6. Higher than normal fuel pressure. 7. Leaking fuel pressure regulator. 8. Oxygen sensor contaminated or responding to artificial lean or rich condition.	Test components. Service or replace as necessary.
Excessive hydrocarbon and carbon monoxide readings.	1. Plugged PVC valve or hose. 2. Fuel-contaminated oil. 3. Heat riser stuck open. 4. Air pump disconnected or defective. 5. Evaporative emissions canister saturated. 6. Evaporative emissions purge valve stuck open. 7. Defective throttle position sensor.	Test components. Service or replace as necessary.

(Continued)

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Emission Control System Diagnosis

Condition	Possible Causes	Correction
Excessive oxides of nitrogen.	1. Vacuum leak. 2. Leaking head gasket. 3. Engine carbon loading. 4. EGR valve not opening. 5. Injector not opening. 6. Low fuel pressure. 7. Low coolant level. 8. Defective cooling fan or fan circuit. 9. Oxygen sensor grounded or responding to an artificial rich condition. 10. Fuel contaminated with excess water.	Test components. Service or replace as necessary.
Excessively low carbon dioxide reading.	1. Exhaust system leak. 2. Defective input sensor. 3. Defective ECU. 4. Sticking or leaking injector. 5. Higher-than-normal fuel pressure. 6. Leaking fuel pressure regulator.	Test components. Service or replace as necessary.
Low oxygen reading.	1. Plugged air filter. 2. Engine carbon loaded. 3. Defective input sensor. 4. Defective ECU. 5. Sticking or leaking injector. 6. Higher-than-normal fuel pressure. 7. Leaking fuel pressure regulator. 8. Oxygen sensor contaminated or responding to artificial lean condition. 9. Defective evaporative emission system valve.	Test components. Service or replace as necessary.
High oxygen reading.	1. Vacuum leak. 2. Low fuel pressure. 3. Defective input sensor. 4. Exhaust system leak.	Test components. Service or replace as necessary.

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Section 9

Engine Troubleshooting and Performance

Chapter 53
Engine Performance and Driveability

Chapter 54
Advanced Diagnostics

Peak engine performance not only keeps the customer happy by providing maximum engine power, but it is also essential to reducing engine-related emissions.

Section 9 will describe common engine performance problems, detail their causes, and explain how each can be corrected. It explains how to use advanced diagnostic tools to find problems in the engine and related systems.

The information in this section will give you the "state-of-the-art" skills needed to succeed as an automotive technician. It will also help you pass ASE Test A6, *Electrical/Electronic Systems*, and Test A8, *Engine Performance*.



Chapter 53
Engine Performance and Driveability

After studying this chapter, you will be able to:

- List the most common engine performance problems.
- Describe the symptoms for common engine performance problems.
- Explain typical causes of engine performance problems.
- Use a systematic approach when diagnosing engine performance problems.
- Use scan tool data to find mechanical and electrical problems that adversely affect gasoline engine smoothness, efficiency, power, and emissions.
- Correctly answer ASE certification test questions on problems affecting engine performance.

An ***engine performance problem*** is any trouble that affects the power, acceleration, fuel economy, emissions (pollutants), and dependability of the vehicle. Any problem that affects the performance of the power train is often referred to as a ***driveability problem***.

Driveability problems can be caused by electronic and mechanical engine problems. Engine sensors and actuators, and their wiring can cause a wide array of engine operation problems. The ignition system, fuel system, emission control systems, or the engine itself could be keeping the engine from running optimally. This can make diagnosis very challenging. You must be able to narrow down the causes until the faulty circuit, part, or component is found, **Figure 53-1**.

This chapter reviews typical performance problems that are fully explained in other textbook chapters. This summary is needed to prepare you for the next chapters on advanced diagnostics and engine tune-up.



Ford

Figure 53-1. Engine performance problems reduce engine power, lower fuel economy, and increase emissions.

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Locating Engine Performance Problems

Use a systematic approach when trying to locate performance problems. A ***systematic approach***, or ***strategy-based diagnostics***, involves using your knowledge of automotive system theory and a logical process of elimination (sequence of events) to find the source of a problem. See **Figure 53-2**.

Think of all the possible systems and components that could upset engine operation. Then, one by one, mentally eliminate the parts or systems that could not produce the symptoms. The ***problem symptoms*** are the noticeable changes in performance to the system or part: abnormal noise, loss of power, rough idle, hesitation, etc. To troubleshoot driveability problems properly, you need to train yourself to always ask the following questions:

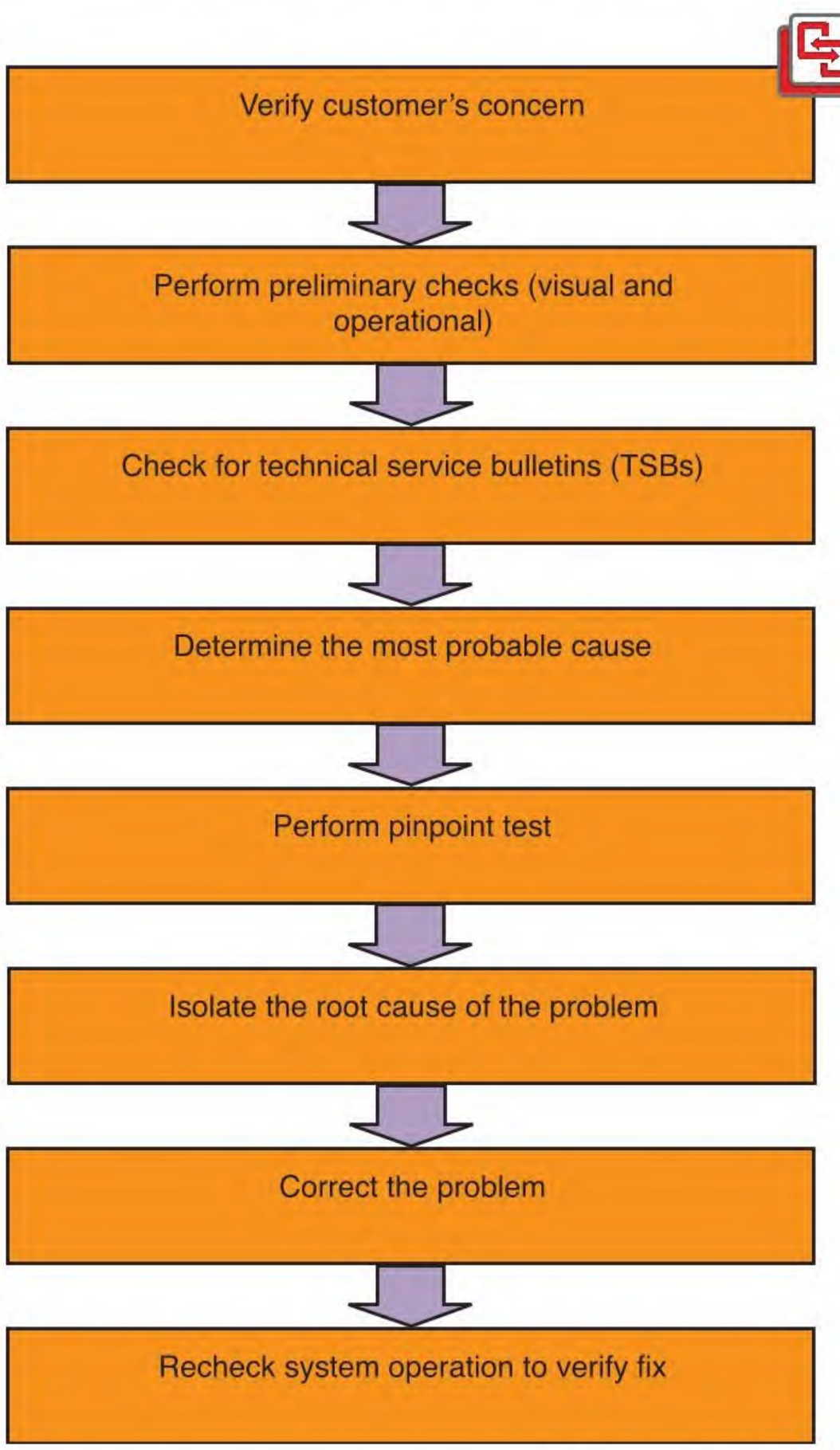
- What are the symptoms (noise, miss, smoke, etc.)?
- When do the symptoms occur (at idle, when accelerating, when engine is cold or hot, etc.)?
- What system could be producing the symptoms (ignition, fuel, engine, etc.)?
- Where is the most logical place to start testing?
- Which part is most likely to cause the symptoms?

To locate engine problems quickly, you must find the electrical component or mechanical part at fault, also referred to as the ***root cause of failure***. See **Figure 53-3**. For example, suppose a fuel-injected engine misses and emits heavy black smoke as it begins to warm up after a cold start. The heavy black smoke would tell you that too much fuel is entering the engine. Remember, blue engine smoke is burning oil, and white smoke at the engine tailpipe is steam from boiling water (engine antifreeze or normal condensation). Since the engine only runs poorly after it begins to warm up, you should realize that the problem is also temperature related.

Through simple deduction, you would probably think of the engine coolant temperature sensor. Based on readings from the coolant temperature sensor, the ECM controls the engine's fuel mixture and lengthens injector pulse width when the engine is cold to richen the mixture and avoid engine stalling at cold, idle speeds. It is possible that the temperature sensor has failed and is sending a false "cold" signal to the ECM. This is making the engine run much too rich as it begins to warm to full operating temperature. Look at **Figure 53-4**.

As you can see, logical thought will help you find the most likely problem source. In this example, too much gasoline injected into the engine was causing the engine misfiring and black exhaust smoke. However, by knowing that black smoke is partially burned fuel soot and the problem was temperature related, a good technician should be directed to the ETC sensor readings first. The technician would know that the defective coolant temperature sensor was incorrectly increasing injector pulse width because of a false signal from the defective sensor. Therefore, the temperature sensor was the root cause of engine performance failure.

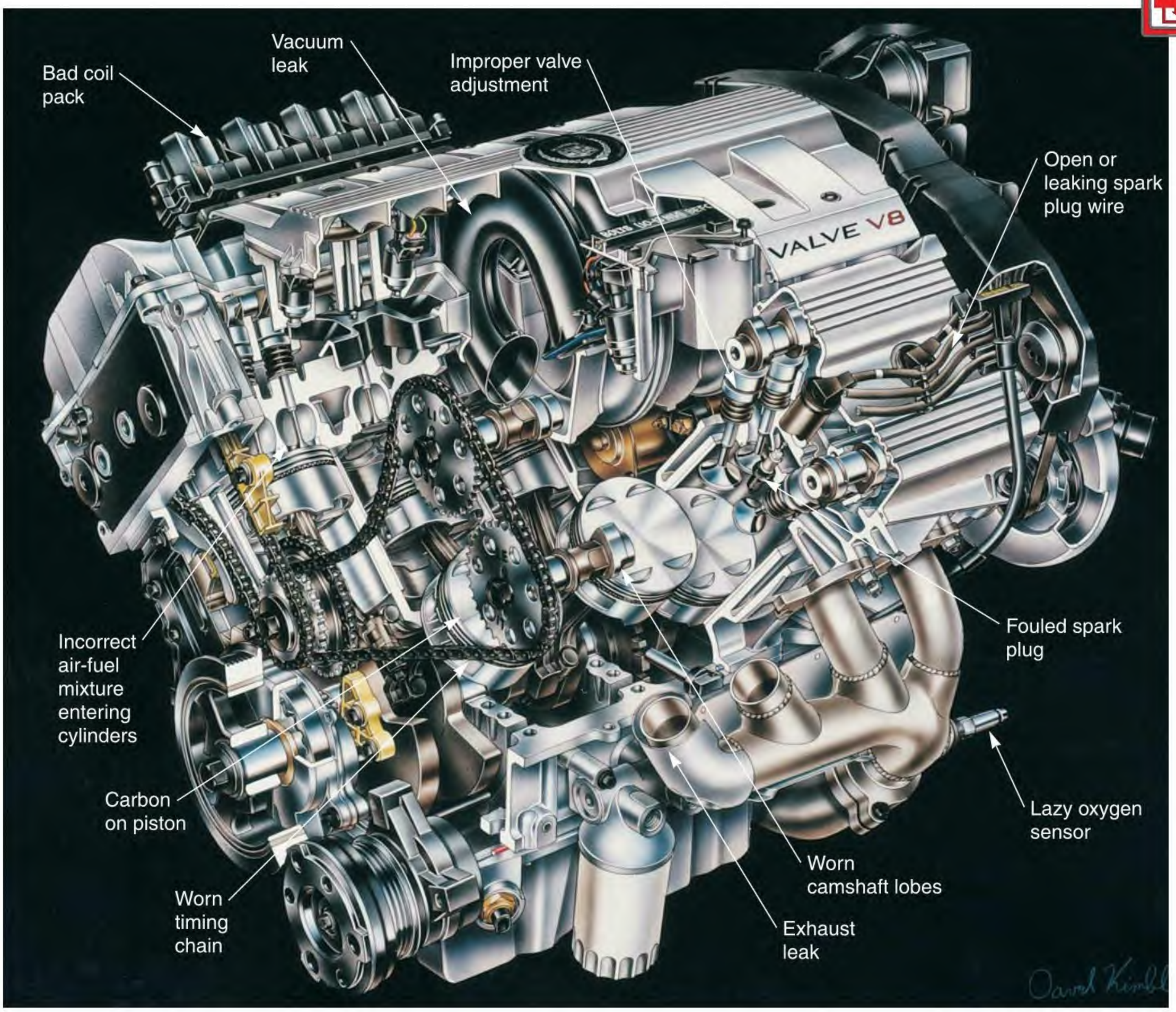
If your first idea is incorrect, rethink the problem and check the next most likely trouble source. If you approach automotive problems in a haphazard



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Figure 53-2. This chart shows the basic steps for strategy-based diagnostics. Study the chart's steps carefully.

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Figure 53-3. Note most common engine parts that will wear and someday fail after years of "good service."

manner and simply install parts without taking time to properly diagnose the problem, you will be in for a long, frustrating day.

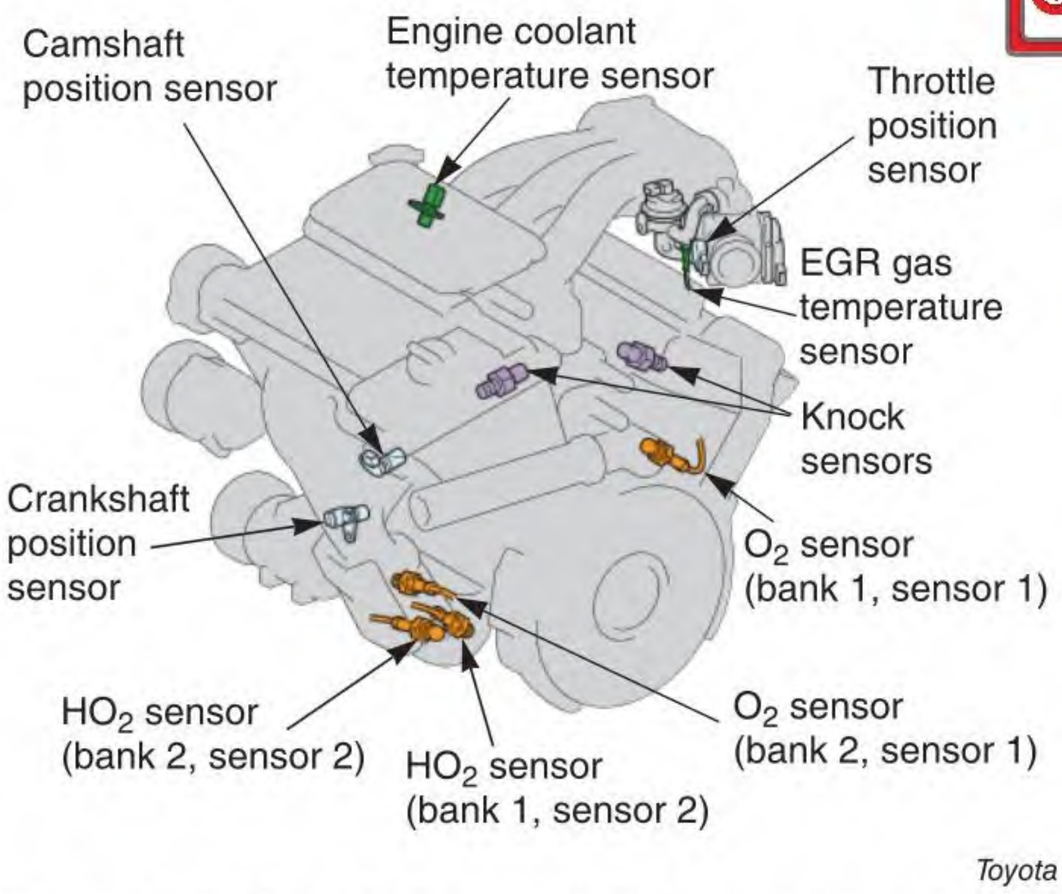
Performance Problem Troubleshooting Charts

If you have trouble locating an engine performance problem, refer to a factory diagnostic chart, or ***troubleshooting chart***. It will list problem causes and corrections. A manufacturer or automaker diagnostic chart is written for a particular make and model vehicle. This makes factory service information more accurate and detailed than general charts that cover all makes and models. Refer to **Figure 53-5**.

Technical Service Bulletins

Technical service bulletins (TSBs) explain problems that frequently occur in one make or model vehicle. They are published by the auto manufacturers and explain the symptoms of, as well as the tests and corrections for, common problems. Auto manufacturers keep records of specific problems that have been fixed in the past. If one or more problems happen regularly, they are published in service bulletins sent out to their dealerships.

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Toyota

Figure 53-4. Often, a faulty sensor is the source of an engine performance problem. If the scan tool points to just one defective sensor, replacing that sensor will often fix the performance problem.

Always obtain and read technical service bulletins. They give helpful information on fixing common problems with specific makes and models of cars and light trucks.

Other Sources of Service Information

There are several other sources of service information that can be used when a problem is difficult to locate and correct. Trade magazines often discuss common and difficult-to-locate failures. Always read these types of magazines.

By accessing the Internet, you can search for service information and review problems encountered by other technicians. You can type in information about the vehicle or problem and quickly search for additional information. Some vehicle manufacturers and part manufacturers provide service data on the Internet.

Fuel Supply System

System Troubleshooting Guide

Note: Across each row in the chart, the systems that could be sources of a symptom are ranked in the order they should be inspected starting with ①. Find the symptom in the left column, read across to the most likely source, then refer to the page listed at the top of that column. If inspection shows the system is OK, try the next most likely system ②, etc.

Symptom \ Page / Sub-system		Fuel injector	Pressure Regulator (Pressure Regulator Cut-off Solenoid Valve)	Fuel Filter	Fuel Pump	Main Relay	Contaminated Fuel
		78	84	88	89	91	*
Engine won't start				③	①	②	
Difficult to start engine when cold or hot		③	③ (When hot)	②	①		
Rough idle		①	②				③
Frequent stalling	**While warming up**	①		②			
	After warming up	①		③	②		
Poor performance	**Misfire or rough running**	①	②				③
	Fails emission test	①	②				
	Loss of power			①	③		②

* Fuel with dirt, water, or a high percentage of alcohol is considered contaminated.

Honda

Figure 53-5. This is a troubleshooting chart for the fuel supply system of one make of vehicle.

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Typical Performance Problems

It is important that you understand the most common engine performance problems. The following sections will help you use test equipment, troubleshooting charts, and service manuals during diagnosis.

No-Crank Problem

A ***no-crank problem*** occurs when the starter fails to turn the crankshaft. Turning the ignition key or pressing the engine start button produces a "click" sound. You can hear the starting motor engaging the engine flywheel gear, but the crankshaft pulleys do not rotate. The engine seems locked up. No-crank problems can be due to internal engine part failures or by starter drive-gear mechanism failures. This is true for conventional gas engines as well as hybrid power trains.

If an engine won't crank and start, first check the starter and solenoid circuits, as well as all related wiring. If the starter spins (humming noise) but the engine does not turn over (no gear noise), a gear grinding noise is made, suggesting the starter drive pinion may not be engaging with the flywheel. The engine flywheel teeth may be broken off or damaged.

If an engine mechanical problem is suspected, try to turn the engine crankshaft by hand. Use a flywheel tool or breaker bar and socket to rotate the crankshaft a little. If the engine crankshaft is locked and will not turn, the engine has internal mechanical problems. If the engine turns over easily (below crankshaft snout bolt torque) as it should, the starting mechanism is at fault and not the engine.

No-Start Problem

A ***no-start problem*** occurs when the engine cranks but fails to start. This is the most obvious performance problem. There is a defective mechanical part or electric component preventing the engine from igniting and burning its gasoline or diesel fuel. The first step in diagnosing a no-start problem is to check for a strong spark.

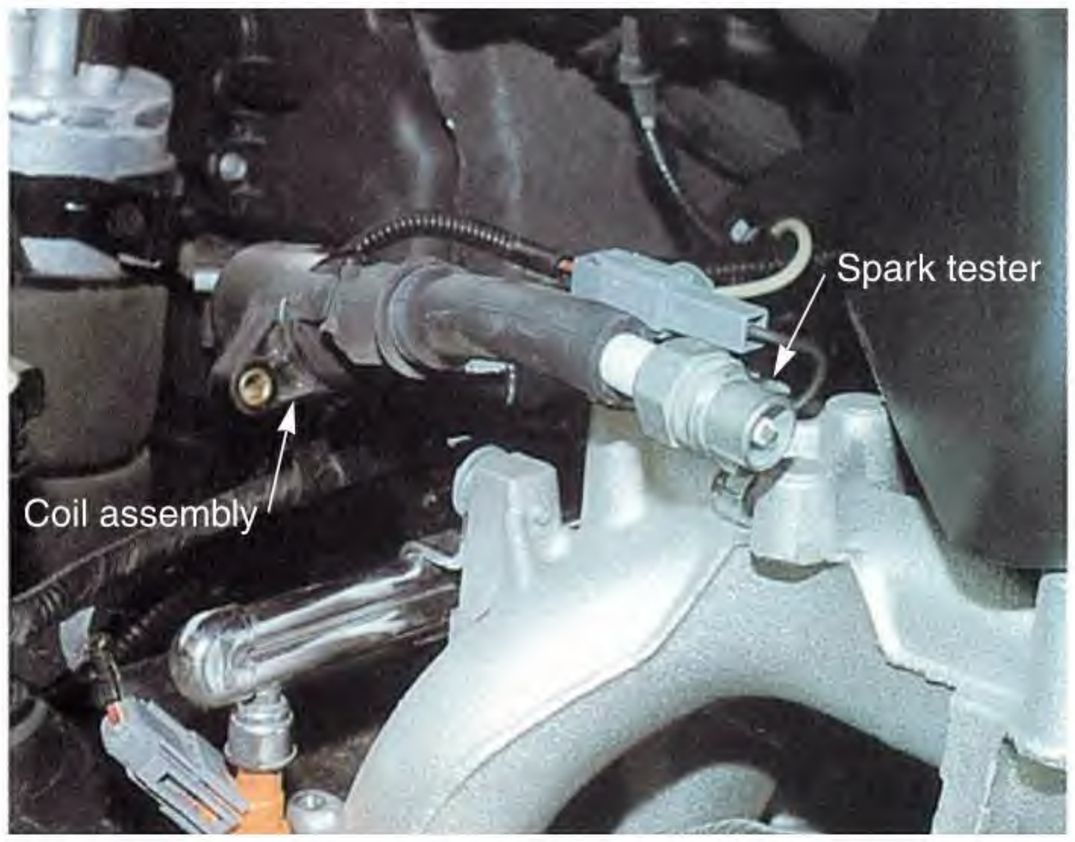
Service Procedure

To check for spark:

1. Disconnect the spark plug wire or ignition coil (direct ignition) from one of the spark plugs on top of the engine.
2. Connect your spark testing tool to the high-voltage secondary conductor or direct ignition coil secondary terminal.
3. Ground the tester black lead to bare metal on an unpainted engine bracket.
4. Have another mechanic crank the engine or fire the ignition coil with a scan tool while you watch for a bright spark inside the tester's air gap.

If the ignition system is not producing a strong spark across the air gap, the problem is in the ignition system (ignition coil, coil wire, spark plug wire, pickup coil, crankshaft sensor, ignition module, or engine ECM, but not the engine). See **Figure 53-6**.

If you have spark, check for fuel by making sure the fuel system is feeding gasoline to the engine. With direct and multiport injection, check for fuel pressure at the test fitting on the fuel rail. With throttle body fuel injection, watch the injector outlet for a spray of gasoline during engine cranking. If you do not have fuel, then something is wrong with the fuel system.



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Figure 53-6. A spark tester should be used to check the ignition system for the presence of a spark. Do not use a screwdriver to ground the ignition wire as this will expose you to high voltages.

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Also check the wiring harness going to the injectors for pulse from the ECM. Disconnect a wiring harness from one of the injectors and install a ***noid light***. If the light flashes, the ECM is sending a signal to the injectors. If the noid light does not flash, there is a problem in the computer control system, its inputs, or the wiring. Look at **Figure 53-7**.

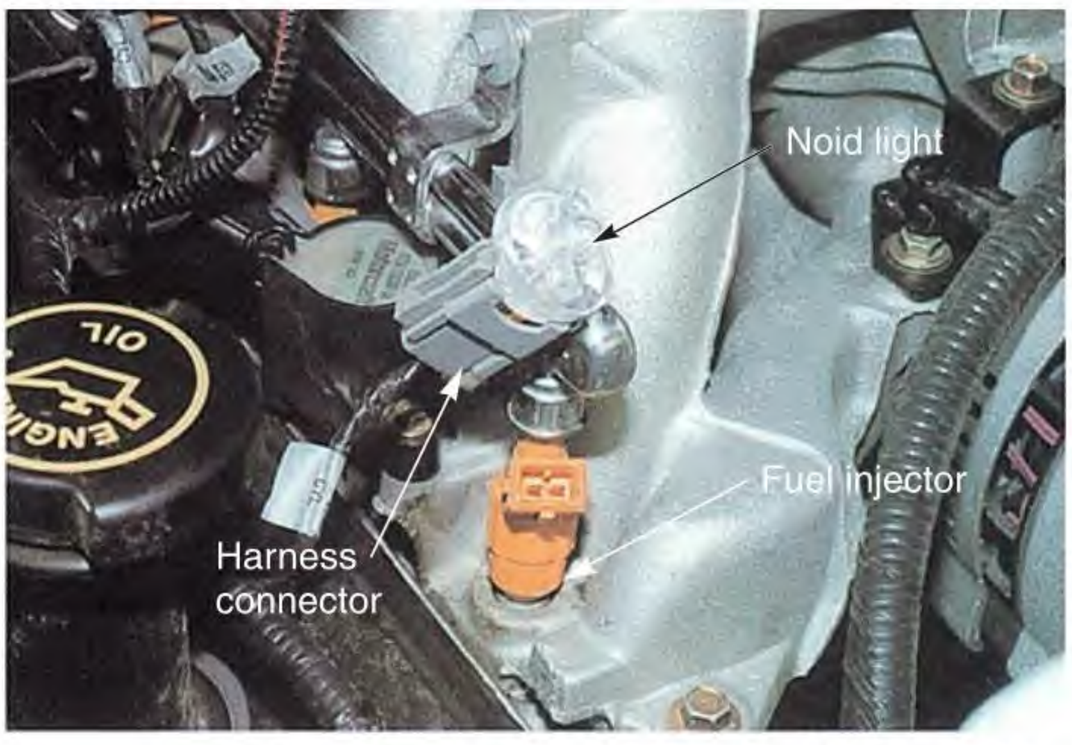
By checking for fuel and spark, you have narrowed down the cause of the problem to two major engine systems. If you don't have spark but you have fuel pressure, you might have a bad electrical relay or connection. Something is not feeding voltage to the ignition system—possibly a failed ignition coil, or fouled spark plugs not igniting the fuel mixture. If you have spark but no fuel pressure, check for fuel in the tank, clogged fuel filters, or inoperative fuel pumps. With a direct injection/ignition engine, check for both low and high fuel pressure with your scan tool live data readings.

If you have both fuel and spark, check engine compression. Excessively low compression (badly worn rings or valves) will prevent the engine from starting. A jumped timing chain or belt could also be keeping the engine from starting. With a diesel, slow cranking speed can prevent starting.

Hard Starting

Hard starting is due to the partial failure of a system and its component, part, or circuit. The 12-volt battery may be depleted. The starting motor could be dragging and not spinning the engine quickly enough. There could be a vacuum leak, an engine mechanical problem, a fuel or ignition system malfunction, a sensor problem, or a worn engine timing chain.

When hard starting is encountered, check scan tool readouts for camshaft versus crankshaft timing (stretched or worn timing chain or adjusters), MAP sensor readings to look for low vacuum at idle (burned engine intake valves), and other engine-related circuit readings.



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Figure 53-7. An injector noid light can be used to quickly check for the presence of an injector pulse from the ECM to eliminate it as a source of a no-start problem. Without current flow to the injector coils, no fuel would be sprayed into the cylinder. This could trip engine misfire or EFI diagnostic codes.

Tech Tip

As a safety feature, critical failures in anti-lock braking and HV drivetrain systems can cut 12-volt power to the engine ECM, ignition ECM, or fuel injection ECM, and hybrid ECM. Brake repairs must be made and trouble codes erased before 12-volt power is restored and drive system is operable again. If an engine cranks but will not start and the ABS warning lights in the dash are glowing, repair all brake system problems first. This will also correct the engine no-start problem. After activating a factory reset code to the ABS ECM to erase codes, the ECMs should then provide for normal engine starting and operation.

Stalling

During a ***stall***, the engine suddenly stops running, or dies. Only battery power is available. This may occur at idle, after cold starting, or after warm-up.

There are many causes of engine stalling:

- Idle or low engine speeds caused by severe engine vacuum leak (bad intake manifold gasket, or disconnected large diameter PVC vacuum hose).
- Open or loose electrical connection in the ignition system.
- Engine misfire due to fouled or eroded spark plug electrodes.
- Low fuel pressures.
- Computer glitches (ECU problems) that electronically shut off the engine.

Engine stalling at higher engine speeds is more likely due to a clogged fuel filter limiting maximum fuel flow, or thermal expansion causing electric parts to open and kill power to the ignition or fuel systems.

To isolate the cause of engine stalling, note when engine stalling occurs—at low idle speeds, after cold engine starting, as soon as the engine reaches full

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operating temperature, or only at highway cruising speeds. You can then review each sensor output signal to see if it corresponds to each engine operating condition to find the source of the engine stalling problem.

Misfiring

Engine ***misfiring*** is a performance problem resulting from one or more spark plugs failing to ignite and burn their air-fuel charges to produce normal combustion power. The dead cylinder is not producing combustion pressure, causing the crankshaft to slow down until the next cylinder fires. The crankshaft speed sensor detects this change in frequency and signals the engine ECM. The ECM then stores an engine misfire code for your scan tool.

There are four general causes of engine misfiring: engine mechanical problems, fuel system problems, ignition system problems, and intake or exhaust system problems.

- Engine Mechanical Problems—Low cylinder compression can trip an engine misfire code. Low compression will keep the spark plugs from igniting the air-fuel gas cloud in the cylinder. The engine could have damaged valves, piston rings, cylinder walls, timing chains, head gaskets, or worse. Engine mechanical problems will usually affect only one or two engine cylinders, not all of them, unless the problem is a flopping, loose timing chain.
- Fuel System Problems—Improper fuel delivery that causes an extremely lean or rich fuel mixture can prevent normal combustion and a misfire. A clogged or leaking fuel injector, improper fuel pressure, and similar problems can affect engine combustion. One bad injector will cause a misfire in only one cylinder. Improper fuel pressure could affect the misfire in any or all cylinders. A rich mixture will increase catalytic converter operating temperature and change the oxygen sensor live readings.
- Ignition System Problems—A weak electric arc at the spark plugs can prevent normal combustion. If a spark plug gap is burned too wide from extended service, it can cause a misfire code to be tripped for the affected cylinder.
- Intake or Exhaust System Problems—A restriction in the engine intake tract or exhaust system can cause poor combustion. A dirty air filter, engine intake manifold vacuum leak, or restricted catalytic converter can cause an engine to misfire in one or more cylinders. These problems can affect one or more cylinders. Keep these causes in mind when troubleshooting engine misfire problems.

OBD II Cylinder Misfire Monitoring

An engine misfire occurs when the fuel mixture fails to ignite and burn properly. The unburned fuel is pushed out of the engine and into the exhaust system. It can then damage the catalytic converter and pollute the environment.

Discussed briefly in earlier chapters, OBD II engine misfire is monitored using the engine crankshaft sensor as the primary source of data. When a cylinder fails to fire, the rate of crankshaft acceleration will drop slightly with the misfire. The crankshaft sensor and computer interpret this fluctuation in crankshaft speed as an indication of a poorly running engine.

A few OBD II systems detect misfire by electronically measuring the ionization at the spark plug electrodes. Spark duration is primarily affected by cylinder compression pressure. For example, high cylinder pressure and a wide spark plug gap tends to block or even stop electrical flow across the electrode air gap. Although high-boost turbo engines use smaller spark plug gaps, the voltage can still arc to ground through such high air pressure.

Low engine compression or a narrow air gap allows the electric arc to shoot to ground more quickly due to less resistance. Since the ECM can detect spark duration in milliseconds, on-board ECM diagnostics can check for low cylinder pressure, eroded spark plug electrodes, and even possible mechanical engine problems electronically.

Engine misfires can be grouped into two broad categories, depending on their severity. ***Type A misfires*** are severe enough to cause catalytic converter damage. This type of misfire will trip a trouble code and illuminate the MIL. If the misfire causes the catalytic converter temperature to climb to 1800°F (1000°C) or above, the ECU will prompt the MIL to blink on and off. This is the only condition that will cause the MIL to blink. If operating conditions change and the converter is no longer in danger of being damaged, the MIL will stop blinking but will remain illuminated, signaling the need for service.

Type B misfires are less severe, causing an increase in emissions but not catalytic converter damage. Type B engine misfires will not set a trouble code unless a 2% misfire rate is detected during two

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consecutive drive cycles. A misfire rate of less than 2% is acceptable because the catalytic converter can easily handle the amount of pollutants the misfire would cause.

Misfire trouble codes may indicate a problem in a single cylinder or in multiple cylinders. A ***single cylinder misfire code*** indicates that there is a problem in one cylinder. For example, code PO303 indicates that a #3 cylinder misfire is detected. You would check for problems with the ignition coil, spark plug, and injector, as well as for mechanical wear or damage, in that cylinder.

The ***random cylinder misfire code*** (PO300) indicates that a problem is occurring in all cylinders. You would know that something affecting all the cylinders is the cause. For example, an engine vacuum leak, restricted exhaust, or low fuel pressure may cause a random cylinder misfire code.

An OBD II scan tool can produce the following ***misfire data***:

- ***Misfire data values***—Misfire data values indicate something is causing an engine cylinder not to fire its fuel mixture properly. The misfire data can be recorded by the vehicle computer and stored in memory. The scan tool will retrieve this data and help you find problem sources.
- ***Misfire history***—Misfire history data indicates which cylinder was misfiring and how badly it has been misfiring.
- ***Misfire passes***—Misfire passes show how many times the cylinder has not misfired.
- ***Misfire failures***—Misfire failures indicate how many misfire tests have been recorded.
- ***Misfire rev. status***—Misfire rev. status shows accepted misfires (real misfires) and rejected misfires (false data caused by rough road or other cause).
- ***Total misfires***—Total misfires is an average number of misfires recorded during the last 200 crankshaft revolutions.
- ***Misfiring cylinder***—The primary misfiring cylinder (cylinder with the most misfires) and the secondary misfiring cylinder (cylinder with the next highest number of misfires) by cylinder number.
- ***RPM at misfire***—Shows the engine rpms when the computer detected a cylinder misfire. This is handy for further scope diagnosis since you know the engine speed when the problem occurs.
- ***Load at misfire***—The load (as a percentage) when the engine misfire happened. The engine ECM compares MAP and MAF, and TPS sensor readings to determine how much air the engine is consuming. It can also compare fuel pressure signals, injector pulse widths, and O_2 voltages for even more accurate calculations of engine load.

Other misfire data can also be produced depending on vehicle make, model, and year. Refer to the service manual for more information.

Tech Tip

Non-OBD trouble codes and data stream values pinpoint potential circuit faults and mechanical problems not mandated by vehicle emission laws. Engine system codes/data and system failure codes/data can be produced by modern on-board diagnostics systems. The retrievable repair data depends on the make, model, and year of vehicle. The amount of on-board diagnostic information available depends on the specific vehicle's ECM circuit complexity and diagnostic capabilities. Non-OBD-required repair data varies. Refer to the vehicle's service manual for more information.

Engine Load

Engine load is a percentage measurement that represents how hard an engine is working. When an engine accelerates quickly up to highway speeds at full throttle, engine load would be around 80% of maximum allowed for reciprocating assembly longevity. If a modern engine is coasting during vehicle deceleration, engine load should be 0%. Many hybrids shut the gas engine off completely any time the vehicle does not need it for propulsion.

Rough Idle

A ***rough idle*** occurs when the engine seems to vibrate on its mounts at very low rpms. An engine firing on all cylinders produces a steady, low frequency ***exhaust note*** (sound of engine exhaust gases), as all cylinders produce normal combustion on their power strokes. With a rough idle engine, the vibration of the camshaft cover is clearly noticeable. A cup of coffee would spill if rested on top of the engine when idling. Instead of a steady exhaust note (equally spaced air pressure sound waves leaving vehicle tailpipe), you

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can actually hear cylinders misfire and not make their distinctive steady state exhaust note.

With a dead cylinder not burning its fuel, you will not be able to hear normal combustion pressure blowing past the open engine exhaust valve and into the exhaust system. For example, if a six-cylinder engine has a missing cylinder, at the tailpipe you would hear five sharp pressure waves and then a single "puff" sound when no combustion gas pressure entered the exhaust from the misfiring cylinder.

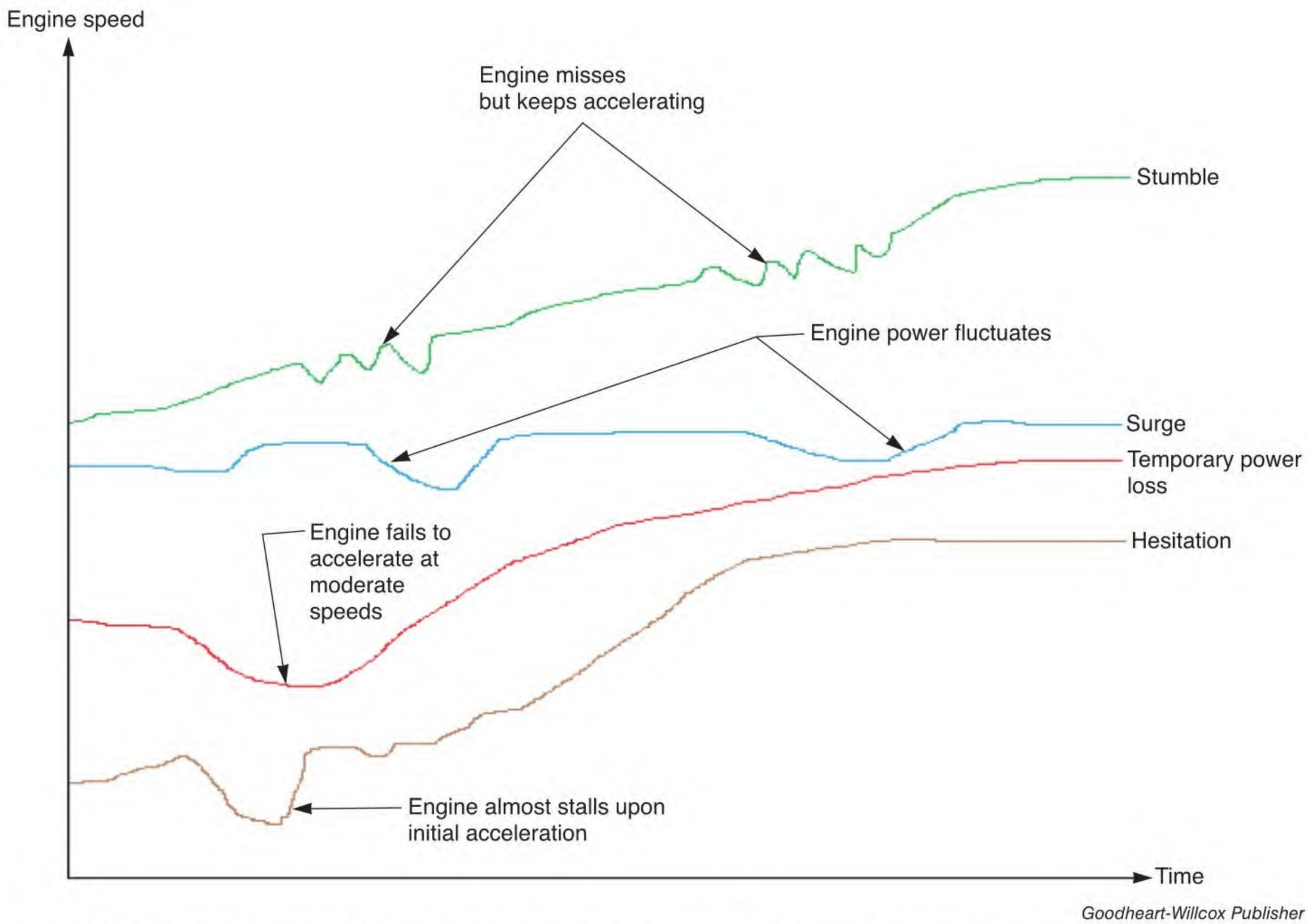
A vacuum leak is a common cause of rough idling. If a vacuum hose hardens and cracks, it will allow outside air to enter the engine intake manifold, bypassing the throttle body air inlet valve. This can cause a lean air-fuel mixture, preventing normal combustion.

Usually, an engine vacuum leak will produce a hissing sound around the top of the engine. An intake manifold vacuum leak will also make the engine run rough and increase idle rpms. If a manifold vacuum is leaking, the engine roughness will smooth out when the engine is revved up above 2500 rpms. Even a small engine intake manifold gasket leak can make the engine stall or run roughly at idle. Other causes of a rough idling engine include fouled spark plugs, bad secondary wire insulation or open high voltage conductors, a failing direct ignition coil, a lean air-fuel mixture, and similar conditions.

A section of vacuum hose can be used to locate engine vacuum leaks. Place one end of the hose next to your ear. Move the other end around the engine. When the hiss becomes very loud, you have found the leak.

Hesitation

Hesitation is a condition in which the engine does not accelerate normally when the gas pedal is pressed. The engine may almost stall and has a "flat spot" (the power does not increase normally) before developing power. The condition is similar to stumbling, **Figure 53-8**.



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Figure 53-8. This graph illustrates several engine performance problems. Study engine operation during hesitation, surge, and stumble problems.

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A hesitation is usually caused by a temporarily lean air-fuel mixture as engine speed increases. With fuel injection, a failed throttle position sensor causes a lean fuel mixture and reduced engine power as the gas pedal is depressed.

Check whether the hesitation is more pronounced with the engine cold, warm, or hot. Also determine if the engine hesitates on initial movement or during acceleration.

Stumbling

Stumbling is similar to a hesitation, but the engine repeatedly loses power and causes a jerking motion of the car on acceleration or highway cruising. When accelerating or cruising at a steady speed, a vibration can be felt as the engine misfires. When traveling down the highway, the engine may temporarily miss or stumble over and over. See **Figure 53-8**.

Stumbling is often caused by slow oxygen sensors, a "dead spot" in a throttle position sensor, engine temperature sensor failure, or any part that leans or richens the air-fuel mixture too little or too much. Stumbling can also be caused by intermittent electrical problems that erratically cut current flow to the ignition and fuel systems.

Surging

Surging is a condition in which engine power slowly fluctuates up and down with a continuous, soft jerking motion. When driving at a steady speed, the engine seems to speed up and slow down, without movement of the accelerator.

Surging is sometimes caused by an extremely lean fuel injection setting. Surging can also be caused by ignition or computer control system problems, an electronically controlled automatic transmission that is changing gears abruptly, or intermittent electrical troubles that affect engine and drivetrain systems.

Backfiring

Backfiring is caused by fuel vapors igniting and exploding in the intake manifold or the exhaust system. A loud bang or pop sound can be heard when the air-fuel mixture ignites and burns.

Backfiring can be caused by incorrect ignition timing, crossed spark plug wires, a defective ignition coil, a bad throttle position sensor, exhaust system leakage, a faulty air injection system, a computer system malfunction, or other system faults.

A mild backfire in the engine intake manifold is sometimes referred to as an ***engine cough***. Instead of a loud bang or pop, the mild backfire will sound like a rush of air or a cough. This is sometimes due to the backfire pressure wave trying to rotate the engine crankshaft backward.

Dieseling (After-Running, Run-On)

Dieseling, also called ***after-running*** or ***run-on***, occurs when the engine fails to shut off. The engine keeps firing, coughing, and producing power. The air-fuel mixture ignites spontaneously, forcing the pistons down without the spark plugs firing. Dieseling is usually caused by leaking injectors, low octane fuel, or an overheated engine.

Pinging (Spark Knock)

Pinging, or ***spark knock***, is a metallic tapping or light knocking sound that usually occurs when the engine accelerates under load. Pinging is caused by abnormal combustion (preignition or light detonation). Pinging is normally caused by low-octane fuel, advanced ignition timing, carbon buildup in combustion chambers and pistons, or engine overheating.

Vapor Lock

Vapor lock occurs when the fuel is overheated, forming air bubbles that upset the air-fuel mixture. Vapor lock can cause engine stalling, lack of power, hard starting, and no starting. Vapor lock is usually caused by too much engine heat transferring into the fuel. A fuel line may be touching a hot engine part, or the fuel return system may be plugged. You would need to locate any condition that could overheat the fuel. Vapor lock is seldom a problem with today's direct fuel injection gasoline and diesel engines.

Fuel Line Freeze

Fuel line freeze results when moisture in the fuel turns to ice. This usually occurs with diesel fuel. The ice will block fuel filters and prevent engine operation. This problem does not occur as frequently as in the past, due to the use of alcohol and other fuel additives. With diesel fuel, the overcooled fuel can form wax, which completely blocks the fuel filters.

To correct fuel line freeze, replace clogged fuel filters. You may need to place the vehicle in a warm garage until the water in the gasoline or diesel fuel

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thaws. Gas line antifreeze additives can be helpful in extreme cold climates.

Poor Fuel Economy

Poor fuel economy is a condition causing the vehicle to use too much fuel for the miles driven. Fuel economy can be calculated by comparing how far the vehicle can be driven on one gallon (3.79 L) of gasoline. The actual miles driven until the gas tank empties can then be compared to the manufacturer's estimated MPG rating. Compare actual and estimated mpg to determine if the power train has a fuel consumption problem.

Poor fuel economy can be caused by a wide range of problems. Some of these include rich air-fuel mixture, engine miss, incorrect ignition timing, worn timing chain, worn piston rings, burned valves, or leakage in the fuel system.

Lack of Engine Power

Lack of engine power, also termed a ***sluggish engine***, causes the vehicle to accelerate slowly. When the gas pedal is pressed, the engine does not have the torque or horsepower to gain speed properly. The engine may or may not misfire.

As with poor fuel economy, there are many troubles that can reduce engine power: fuel system problems, ignition system problems, emission control system problems, engine mechanical problems, etc.

Scanning Diesel Engine Problems

Diesel engines can suffer from many of the same performance problems as gasoline engines. In most cases, the visual and physical engine/system checks to diagnose these problems, as well as the problem symptoms, are similar for both types of engines. Modern diesel engines are computer controlled and can be diagnosed with a scan tool, diagnostic tablet, or laptop computer with special software—just like their gasoline counterparts.

After connecting the diagnostic tool to the diesel vehicle, the technician checks the ECM for stored trouble codes. By examining these and other engine data, the technician can find the root cause of the diesel performance issue, such as a bad injector solenoid, low fuel supply pressure, clogged fuel filter, air/vacuum leak, or similar problem.

Vacuum and Pressure Gauge Tests



A vacuum gauge measures negative air pressure (pressure lower than atmospheric pressure) produced by the engine, fuel pump, vacuum pump, and other components. It is a valuable tool for determining engine condition and testing vacuum-actuated devices.

A ***pressure gauge*** measures positive pressures (pressures higher than atmospheric pressure) produced by the engine, turbocharger, fuel pump, or other device. It can be used to check for high exhaust system back pressure (restricted converter or system), abnormal fuel pressure, incorrect turbocharger boost pressure, and other problems. You must use your knowledge of system operation, assessment of the problem symptoms, and basic pressure testing methods to isolate hard-to-find problems.

A ***vacuum-pressure gauge***, or ***vacuum gauge***, reads both negative and positive pressures. It can be used to check all the previously mentioned systems.

To use a vacuum-pressure gauge to check the engine, connect the gauge to a vacuum fitting on the intake plenum or manifold. Start the engine and note the reading on the gauge. Compare the gauge readings to normal readings. Refer to **Figure 53-9**.

To help pinpoint problems that cannot be duplicated in the shop, technicians will often mount the vacuum-pressure gauge in the passenger compartment and run a long hose to the vacuum fitting on the engine. This allows the vehicle to be driven while checking for intermittent vacuum or pressure problems. It also allows the technician to monitor engine and other system values under load. See **Figure 53-10**.

Vacuum Pump Tests

A hand vacuum pump is commonly used to check vacuum-actuated devices and vacuum diaphragms. Since vacuum diaphragms are made of rubber, which can rupture or leak, they are a common source of performance problems.

To check a vacuum-actuated device, connect the vacuum pump to the fitting. Pump the handle and see if the device will hold a vacuum. If it leaks, the diaphragm or the device should be replaced, **Figure 53-11**.

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Normal engine reading
Vacuum gauge should have reading of 18-22 inches of vacuum. The needle should remain steady.



Burned or leaky valves
Burned valve will cause pointer to drop every time burned valve opens.



Weak valve springs
Vacuum will be normal at idle but pointer will fluctuate excessively at higher speeds.



Worn valve guides
If pointer fluctuates excessively at idle but steadies at higher speeds, valves may be worn allowing air to upset fuel mixture.



Choked muffler
Vacuum will slowly drop to zero when engine speed is high.



Intake manifold air leak
If pointer is down 3–9 inches from normal at idle, throttle valve is not closing or intake gaskets are leaking.



Carburetor or fuel injection problem
A poor air-fuel mixture at idle can cause needle to slowly drift back and forth.



Sticking valves
A sticking valve will cause pointer to drop intermittently.

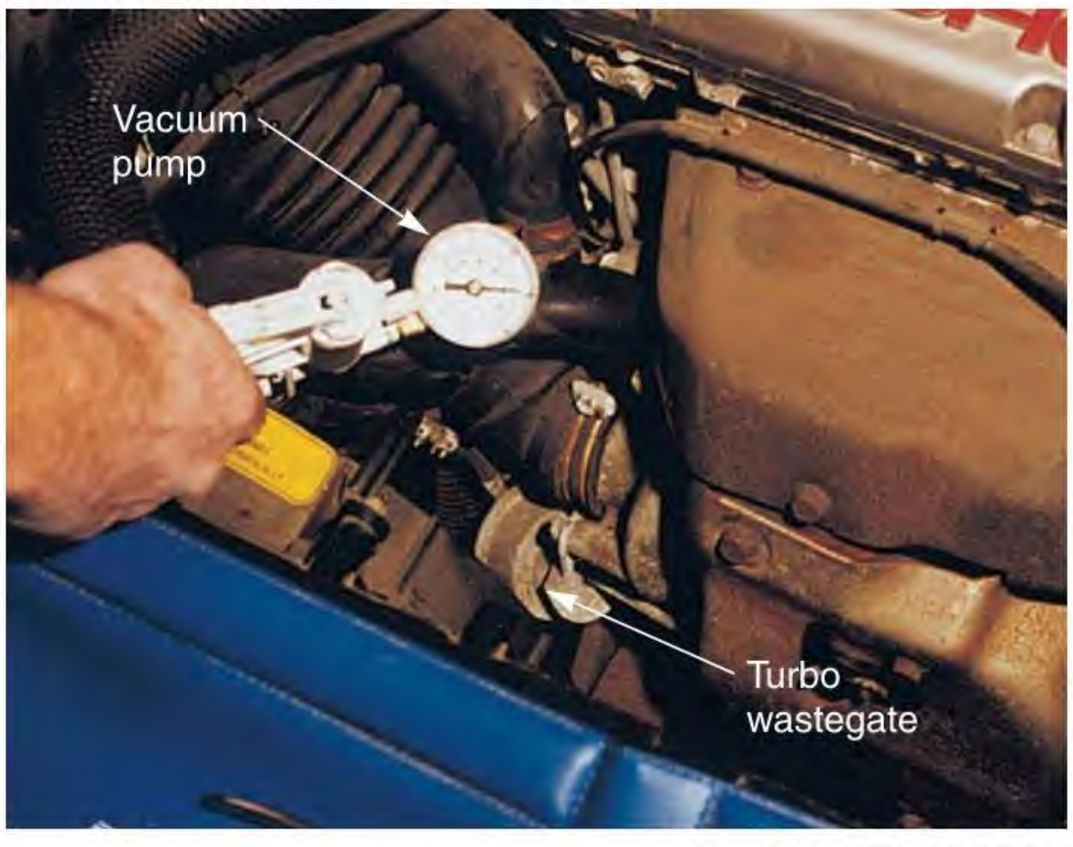
Sonco

Figure 53-9. Study typical vacuum gauge readings and the engine problems they indicate.



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Figure 53-10. Connect a long section of vacuum hose to a vacuum gauge when road testing a vehicle. Connect the hose to any vacuum fitting on the engine intake manifold. Run the hose and gauge under the hood and through the window. The vacuum gauge will display engine vacuum, turbocharger boost pressure, or supercharger boost pressure while you accelerate and decelerate the engine under full load. This will also let you double-check the accuracy of the dash boost gauge.



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Figure 53-11. Always keep vacuum diaphragms in mind as a potential source of engine performance troubles. They can rupture, leak air, and fail to move the mechanical valve normally. A vacuum pump can be used to check the condition of a vacuum diaphragm. A bad vacuum diaphragm will not hold a vacuum and your tester's needle will slowly drop to zero.

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Other Engine Performance Problems

Many other worn or damaged mechanical engine parts or failed electric components can reduce engine power and fuel economy. You would have to compare known good live data display readings on your scan tool and compare them to specifications. Live data specifications are actual electrical values (volts, amps, or ohms) that represent specific temperatures, pressures, speeds, percentages, duty cycles, frequencies, and quantities.

The manufacturer provides normal circuit values for the engine when it is turned off, and when it is running cold, hot, at idle, and at higher engine rpms. These numbers can be used to check actual circuit and sensor value variations of temperature, pressure, percentage, frequency, and other extremes. Study the engine performance data given in **Figure 53-12**.



Workplace Skills

Professionalism is a broad trait in an employee that includes everything from following orders to taking pride in good workmanship. A professional takes the time to do everything the proper way. If a technician presents himself or herself with professionalism, the customers have more confidence that their vehicles will be properly fixed. Always think, dress, and act like a professional.

	Variable factor	Influential part	Target condition	Service procedure
1	Mixture ratio	Pressure regulator	Made lean	Remove vacuum hose and apply vacuum.
			Made rich	Remove vacuum hose and apply pressure.
2	Ignition timing	Crankshaft position sensor	Advanced	Rotate distributor clockwise.
			Retarded	Rotate distributor counterclockwise.
3	Mixture ratio feedback control	Oxygen sensor	Suspended	Disconnect oxygen sensor harness connector.
		ECM	Operation check	Perform on-board diagnostic system (On-board Diagnostic Test Mode II) at 2000 rpm.
4	Idle speed	IAC valve-AAC valve	Raised	Turn idle adjusting screw counterclockwise.
			Lowered	Turn idle adjusting screw clockwise.
5	Electrical connection (Electric continuity)	Harness connectors and wires	Poor electrical connection or improper wiring	Tap or wiggle.
				Race engine rapidly. See if the torque reaction of the engine unit causes electric breaks.
6	Temperature	ECM	Cooled	Cool with an icing spray or similar device.
			Warmed	Heat with a hair drier. **[WARNING: Do not overheat the unit.]**
7	Moisture	Electric parts	Damp	Wet. **[WARNING: Do not directly pour water on components. Use a mist sprayer.]**
8	Electric loads	Load switches	Loaded	Turn on headlamps, air conditioning, rear defogger, etc.
9	Closed throttle position switch condition	ECM	ON-OFF switching	Rotate throttle position sensor body.
10	Ignition spark position	Timing light	Spark power check	Try to flash timing light for each cylinder using ignition coil adapter (SST).

Nissan

Figure 53-12. This diagnostic chart shows how different factors and parts can cause abnormal operating conditions. The technician can perform the service procedures listed to simulate intermittent problems.

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Summary

- An engine performance problem is any trouble that affects the power, fuel economy, emission output levels, and dependability of the engine.
- A systematic approach to troubleshooting, also termed strategy-based diagnostics, involves using your knowledge of automotive service and a logical process of elimination to find the source of a problem.
- Problem symptoms are the noticeable changes in performance to the system or part: abnormal noise, loss of power, rough idle, hesitation, etc.
- Engine misfiring is a performance problem resulting from one or more cylinders failing to fire.
- A vacuum leak is a common cause of rough idling. If a vacuum hose hardens and cracks, it will allow outside air to enter the intake manifold, bypassing the throttle body.
- A hesitation is a condition in which the engine does not accelerate normally when the gas pedal is pressed.
- Stumbling is similar to a hesitation, but the engine misses instead of temporarily losing power and jerking upon acceleration.
- Surging is a condition in which engine power fluctuates up and down with a continuous, soft jerking motion.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

after-running
backfiring
dieseling
driveability problem
engine cough
engine load
engine performance problem
exhaust note
fuel line freeze
hard starting
hesitation
lack of engine power
load at misfire
misfire data
misfire data values
misfire failures
misfire history
misfire passes
misfire rev. status
misfiring
misfiring cylinder
no-crank problem
noid light
no-start problem
pinging
poor fuel economy
pressure gauge
problem symptoms
random cylinder misfire code
root cause of failure
rough idle
RPM at misfire
run-on
single cylinder misfire code
sluggish engine
spark knock
stall
strategy-based diagnostics
stumbling
surging
systematic approach
technical service bulletins (TSBs)
total misfires
troubleshooting chart
type A misfires
type B misfires
vacuum gauge
vacuum-pressure gauge
vapor lock

Activities

1. Check shop manuals for a no-start diagnosis chart and demonstrate how you would troubleshoot a no-start problem on a vehicle assigned by your instructor.
2. Invite an experienced driveability technician to speak to your class about troubleshooting procedures. Prepare a list of questions that you might ask the technician. Discuss the questions with your instructor beforehand.

Review Questions

Answer the following questions using the information provided in this chapter.

1. How do you use a systematic approach to troubleshooting?
2. If you have difficulty locating an engine performance problem, refer to a factory _____, which lists problem causes and corrections.

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3. A car is towed into a shop with a no-start problem. The engine cranks but will not fire and run on its own power. The car has a throttle body, fuel injected gasoline engine. Technician A says to check for spark and fuel first. Technician B says that the spark plugs should be removed first. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. Define the term *misfiring*.
5. A vacuum leak is a common cause of rough idling. True or False?
6. A(n) _____ is a condition where the engine does not accelerate normally when the gas pedal is pressed.
7. What causes "backfiring"?
8. Define the term *dieseling*.
9. A(n) _____ or _____ is a metallic tapping or light knocking sound that usually occurs when the engine accelerates under load.
10. Vapor lock occurs when the gasoline is cooled and forms a gel, preventing fuel flow and engine operation. True or False?

ASE-Type Questions

1. Technician A says when attempting to locate an engine performance problem, you should observe the engine's exhaust smoke. Technician B says when attempting to locate an engine performance problem, you should listen for any abnormal engine noises. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. A fuel injected engine misses and emits heavy black smoke. Technician A says this problem normally indicates an emission control system malfunction. Technician B says this problem may indicate a faulty engine temperature sensor. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. An automotive engine has a no-start problem. Technician A says this condition may indicate an ignition system malfunction. Technician B says this problem may indicate a fuel system problem. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. An engine has poor fuel economy. Technician A says this problem may be the result of a leaky fuel line. Technician B says this problem may be caused by a rich air-fuel mixture. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. All of the following are common engine performance problems *except*:
   (A) hard starting.
   (B) misfiring.
   (C) oil leak.
   (D) dieseling.
6. An automotive engine won't start. Technician A says you should first look in the engine compartment for obvious signs of trouble. Technician B says an exhaust gas analyzer should be used first to diagnose the engine problem. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. A car has a hard starting problem. Technician A says the engine may have a faulty throttle position sensor. Technician B says this engine malfunction may be caused by a faulty coolant temperature sensor. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. Technician A says stalling may occur while the engine is idling. Technician B says stalling may occur after cold starting. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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9. An automotive engine has a stalling problem. Technician A says this problem may be due to a low idle speed setting. Technician B says this problem may be due to a severe engine vacuum leak. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. All of the following may cause an engine to surge *except*:
   (A) lean air-fuel mixture.
   (B) ignition system problem.
   (C) computer system malfunction.
   (D) starter solenoid problem.
11. An automobile engine has a misfire problem. Technician A says type A misfires are severe enough to cause catalytic converter damage. Technician B says that "rpm at misfire" and "load at misfire" are misfire data produced by a scan tool when connected to the OBD II diagnostic link. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
12. A vacuum leak is detected in an automotive engine. Technician A says the leak will produce a banging sound at low engine rpms. Technician B says an intake manifold vacuum leak will make the engine run rough and increase idle rpms. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
13. Technician A says engine hesitation is normally caused by a temporarily rich air-fuel mixture. Technician B says engine hesitation is usually caused by a temporarily lean air-fuel mixture. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
14. An engine is brought into the shop with a misfire problem. Technician A says to use a scan tool to find out which cylinders are misfiring. Technician B says to suspect the spark plug, ignition coil, and the high voltage conductor before checking cylinder compression. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
15. An engine is brought into the shop with a dieseling problem. Technician A says this may be caused by a high octane fuel. Technician B says this may be the result of an overheated engine. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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Chapter 54
Advanced Diagnostics

After studying this chapter, you will be able to:

- Use advanced diagnostic techniques to troubleshoot difficult problems.
- Use scan tool snapshot and datastream values to find problems not tripping trouble codes.
- Use a breakout box to measure circuit values.
- Identify electromagnetic interference (EMI).
- Use an oscilloscope on any type of analog sensor or digital sensor.
- Evaluate waveforms from scope test patterns to analyze the operation of sensors, actuators, and other electrical-electronic devices.

At one time or another, every technician encounters a vehicle problem that seems impossible to fix. The technician might replace a part that seems bad, only to find the same annoying symptoms when the attempted repair fails to fix the problem. The new part must be removed and further diagnosis completed until the real "culprit" is found. This is when advanced diagnostic techniques come in handy.

This chapter summarizes these advanced techniques, such as using advanced scan tool datastream values, heat guns, freeze spray, handheld scopes, and diagnostic laptop computers and tablets. You will learn how to read scope waveforms to troubleshoot difficult-to-locate problems with sensors, actuators, and the ECM itself. By learning how to use these tools and a few "tricks of the trade," even the most difficult problems can be located and corrected with minimal frustration. Most advanced scan tools, touch-screen diagnostic tablets, and laptop computers with special software have a scope function that can be used for advanced diagnostics. All of these diagnostic tools read voltage values through the vehicle's diagnostic connector.

Advanced Diagnostics

Strategy-based diagnostics involves using a consistent, logical procedure to narrow down possible problem sources. Basically, the procedure involves verifying the complaint, making preliminary checks, scanning for codes, reading service bulletins, performing service manual-recommended checks, repairing the problem, and rechecking system operation.

When diagnosing problems, use your knowledge of system operation to determine which part could be malfunctioning and causing the symptoms.

For example, if an engine misses and runs poorly only when cold, think of all parts or components that

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are affected by temperature. Remember the functions of the coolant temperature sensor, the intake air temperature sensor, and the fuel injectors. The operation of these components is affected by temperature. They are monitored and/or controlled by the ECM, which enriches the air-fuel mixture when the engine is cold to avoid stalling.

If the scan tool shows a diagnostic trouble code (DTC), you should check everything related to that circuit. Then perform pinpoint tests to determine whether the wiring or an electronic component is at fault.

Advanced Scan Tool Tests

In addition to retrieving stored trouble codes, modern scan tools can be used for many advanced diagnostic procedures. For example, the advanced scan tool can display live electrical circuit values with the engine running. When the engine hesitates, misfires, surges, or runs poorly, an advanced scan tool will display real-time operating values and store all data in its memory. At a future time, you can study the "live" operating values (temperatures, pressure, speeds, throttle position, boost, voltages, etc.) that occured while the vehicle was being test-driven or was running in the shop.

Scan Tool Snapshot

A scan tool ***snapshot*** is an instantaneous reading of the operating parameters that are present when a problem occurs. This feature is often used when a problem is hard to find or when intermittent troubles are present. Most scan tools can be programmed to automatically take a snapshot of operating parameters whenever a diagnostic trouble code is set. If desired, the snapshot feature can be triggered manually, allowing the use of the snapshot even when the vehicle does not generate a trouble code.

The manual capture feature requires you to monitor operating conditions and to press a button on the scan tool when the problem occurs. For example, if a car only acts up when driving at a specific highway speed, drive the vehicle at the trouble-causing speed and scan under these conditions. When the symptom occurs (engine misses), press the appropriate scan tool button to capture the operating values while the problem is happening.

After returning to the shop, look for any operating parameter that is almost out of specifications. The operating parameter may not be tripping a trouble code, but it may be affecting vehicle operation. Sometimes, two or more electrical values can be almost out of specs.

By using the information provided by the snapshot feature, you can often determine what is causing the problem. You might have two sensors ready to fail, a poor electrical connection in combination with a mechanical failure, etc.

Scan Tool Datastream Values

Scan tool datastream values are "live" electrical values measured with the vehicle running and, in some cases, being driven. They almost eliminate the need for a breakout box or pinpoint measurements of electrical values. You can read the scan tool screen to see weak values or values that are almost out of specs. If you have a performance problem but no trouble codes have been set, study the datastream values. Values that are almost out of specs may signal a problem area. Datastream values give added information for finding troublesome problems. See **Figure 54-1**.

Scan Tool Actuator Tests

Most advanced scan tools can switch computer-controlled actuators on and off. This allows the technician to verify the operation of these components. For example, a scan tool can be used to fire an ignition coil, control the idle speed motor, or disable a fuel injector. Scan tools allow you to hear vacuum solenoids and injectors clicking, servo motors buzzing, and cooling fans blowing.

Checking ECM Terminal Values

Computer terminal values can be tested at the metal pins of the ECM. A digital VOM can be used to read terminal voltage and resistance values. These readings can then be compared to known good values. The service manual will usually specify the electrical values that should be present at each terminal of the multi-pin computer or ECM connector.

Often, the readings are taken with the wiring harnesses connected to the ECM. This eliminates the need to unplug connectors when making electrical measurements.



Caution

Never connect a low-impedance (resistance) analog meter or test light to a computer. A low-impedance meter or tester could draw enough current to damage delicate electronic devices.

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Datastream Values						
For Cold Ke y On, Cold Idle, and Hot Idle: Vehicle in PARK, A/C turned OFF, no power steering load, all ACC's OFF, Brake Pedal Released. For 55 MPH Cruise: Vehicle in Drive 4, A/C turned ON, and no power steering load, compare data after driving for approximately 1 mile.						
Scan Tool Parameter	**Display Units**	**Data List**	**Cold Key ON**	**Cold Idle**	**Hot Idle**	**55 MPH Cruise**
Engine Speed	RPM	ENG 1	0	Within 80 RPM of Desired Idle	Within 80 RPM of Desired Idle	1730
Desired Idle	RPM	ENG 1	0	700 to 1200	550 to 675	720
MAF	gms-sec	ENG 1	0.0	9.8 to 11.0	5.0 to 6.0	20 to 28
TP Sensor	V/°	ENG 1	0.63/1.7	.60 mV/ 0.8°	.60 mV/ 0.8°	1.06/11.0
ECT	°C	ENG 1	80° C	–20° C to 50° C	90° C to 110° C	90° C to 110° C
IAT	°C	ENG 1	80° C	–20° C to 50° C	0° C to 90° C	0° C to 90° C
MAP	kPa/V	ENG 1	97/4.63	30 to 50 kPa 1.50 V @ 38 kPa	30 to 50 kPa 1.50 V @ 38 kPa	64/2.88
BARO	kPa/V	ENG 1	97/4.65	85 to 103 kPa	85 to 103 kPa	98/4.69
TP Angle	%/°	ENG 1	0%/0.0°	0%/0.0°	0%/0.0°	11%/8.6°
Engine Load	%	ENG 1	0%	1 to 5%	1 to 5%	13%
Engine Speed	RPM	ENG 1	0	Within 80 RPM of Desired Idle	Within 80 RPM of Desired Idle	1730
IAC Position	counts	ENG 1	160	Varies	30 to 80	100
Inj. PWM Bank 1	ms	ENG 1	0.0	3.75 to 4.50	3.20 to 3.75	5.1 ms
Inj. PWM Bank 2	ms	ENG 1	0.0	3.75 to 4.50	3.20 to 3.75	5.2 ms
HO_2S Bn 1 Sen. 1	mV	ENG 1	67	Varies	Varies	Varies
HO_2S Bn 2 Sen. 1	mV	ENG 1	111	Varies	Varies	Varies
Rich to Lean Status Bn 1 Sen. 1	Lean/Rich	ENG 1	Lean	Varies	Varies	Varies
Rich to Lean Status Bn 2 Sen. 1	Lean/Rich	ENG 1	Lean	Varies	Varies	Varies
HO_2S Bn 1 Sen. 2	mV	ENG 1	45	Varies	Varies	Varies
HO_2S Bn 1 Sen. 3	mV	ENG 1	156	Varies	600 mV or more	600 mV or more
Rich to Lean Status Bn 1 Sen. 2	Lean/Rich	ENG 1	Lean	Varies	Varies	Varies
Rich to Lean Status Bn 1 Sen. 3	Lean/Rich	ENG 1	Lean	Varies	Varies	Varies
Fuel Trim Cell	Number	ENG 1	0	16	16	5
Fuel Trim Learn	Disabled/ Enabled	ENG 1	Disabled	Disabled	Enabled	Enabled
Shrt Term FT Bn 1	%	ENG 1	0%/128	–2.0 to 2.0	–3.0 to 3.0	–6.0 to 6.0

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Figure 54-1. Scan tool datastream values can be helpful when you have performance problems but no trouble codes. Datastream values are electrical values detected by the ECM. If values from a pinpoint test do not match datastream values, suspect wiring or ECM problems.

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Using a Breakout Box

A ***breakout box*** allows you to check electrical values at specific pins on an ECM or in a wiring harness. It is one of the last tools used in diagnostics, as it is time-consuming.

The breakout box is connected in parallel with the ECM wiring harness. An inline connector is provided for plugging the test box into the wiring harness, usually at the ECM connector.

Then, a multimeter is used to touch specific terminals on the breakout box. The measured circuit values are compared to the manufacturer's specifications. If the measured values are not within specifications, you usually have a defective component or a wiring problem. For example, if a reference voltage out of the ECM is low, the ECM is bad or the wiring between the ECM and the breakout box is faulty. See **Figure 54-2**.

Isolating Electromagnetic Interference

Electromagnetic interference (EMI), or radiation interference, occurs when an induced voltage enters another system's wiring. Sources of EMI can include loose, misrouted, or unshielded spark plug wires; police and CB radios; failed alternators; ac electric drivetrain components; and aftermarket electrical accessories.

In the past, electromagnetic interference was limited to noise in the radio speakers. In late-model vehicles, EMI can cause a computer-controlled system to malfunction. For example, induced voltage from a loose ignition coil secondary conductor could enter a sensor wire. This unwanted voltage would then enter the computer as false data. Numerous computer malfunctions or false outputs could result.

To isolate the source of electromagnetic interference, try turning off or disabling circuits or devices. If, for example, removing the drive belt from the alternator corrects the problem, suspect problems inside the alternator. If the problem only occurs with the heated windshield turned on, check components within the heated windshield circuit. In hybrid electric vehicles, if symptoms only occur when driving in all-electric mode, suspect high-voltage hybrid drive components, like the power control module or motor-generator, and their electrical connections. See **Figure 54-3**.



OTC Div. of SPX Corp.

Figure 54-2. A breakout box is usually the last tool used to find performance problems. It is connected to the computer wiring harness. Then a multimeter can be used to check terminals on the breakout box for actual operating voltages, resistance, and current values. These values can be compared to known good values or to datastream values to find the cause of the problem.

Radio Interference Testing

You can use a small transistor radio to find induced voltage sources. Turn the radio on and set it on the AM band, but do not tune it to a station. If the shop is equipped with fluorescent lights, turn them off or test the vehicle outside, away from power lines and any other sources of EMI.

Move the radio around the engine compartment, hybrid drive components (if applicable), and under the dash with the engine running. If EMI noise (static) is present, a popping or cracking noise will be produced by the transistor radio. To correct an EMI problem, you must stop the source of the interference (replace leaking secondary wire, replace faulty alternator, etc.) or shield the affected system's wiring from the interference (reroute the sensor wire or wrap the wire with foil-type tape, for example).

Digital Thermometer Tests

A ***digital thermometer*** is an electronic device used to measure temperature. Measuring temperature can help you verify scan tool readouts and find hard-to-locate problems. It is handy for advanced diagnosis of various systems and components. A digital thermometer can be used to measure:

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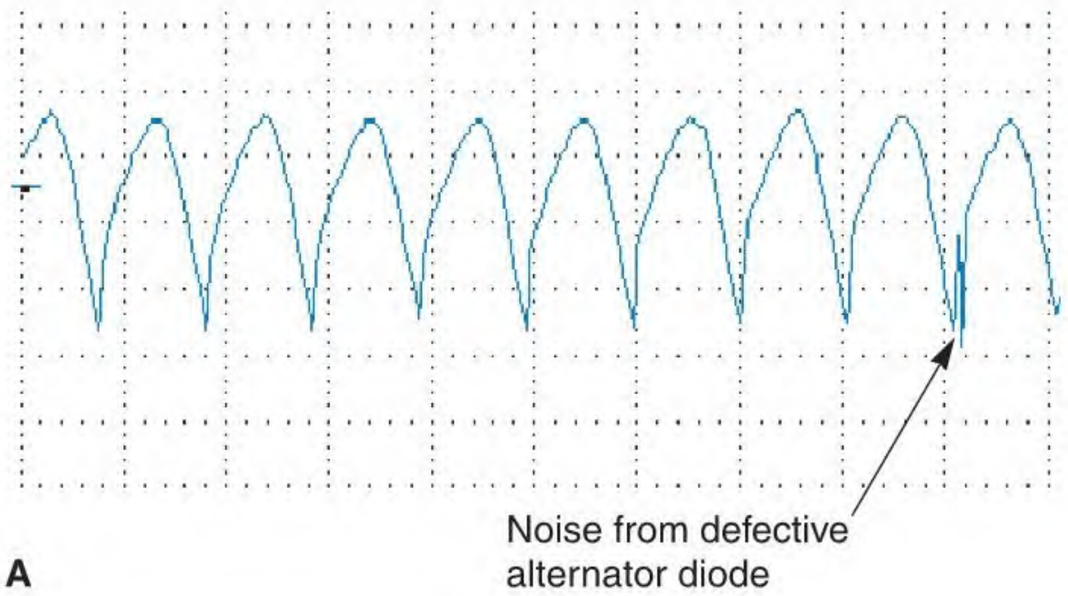


Figure 54-3. A—Electromagnetic interference can come from a variety of sources and can cause major problems. This waveform is caused by a defective alternator diode. B—This is the injector pulse waveform from the same vehicle. Note the hump pattern similar to the alternator pattern.

- Engine operating temperature.
- Exhaust manifold temperature.
- Radiator and thermostat housing temperature.
- Actual coolant temperature.
- Sensor temperature.
- Ambient room temperature.

You can test a temperature sensor while it is still in the engine by checking thermometer readings against sensor resistance when the engine is cold and again after it warms. Touch the thermometer's probe to the sensor to get a reading of its operating temperature. This will let you compare sensor temperature and resistance readings with manual specifications and datastream values on your scan tool.

Tech Tip

A laser thermometer is a handy tool when trying to find vehicle problems that do not set hard trouble codes. By aiming the laser on various parts and components, you can almost instantly measure their actual operating temperatures. You can then compare your temperature readings to the datastream values displayed on the scan tool.

Finding Temperature-Related Problems

When an engine or a hybrid electric drive performance problem occurs only at a specific temperature, suspect electronic parts first. Electronic circuits and components, especially ignition control modules, and hybrid PCMs, ECMs, and HV batteries can be affected by temperature extremes.

To check a component for problems affected by temperature, use a heat gun to warm the component or a can of freeze spray to cool the unit. If the problem occurs with the temperature change, the unit is at fault and should be replaced. See **Figure 54-4**.

Caution

Do not apply too much heat to an electronic module. Excessive heat can damage delicate electronic components. Only match the engine operating temperature of about 200°F (93°C). Use a digital or laser thermometer to monitor the temperature when heating the unit to avoid damage from overheating.

Dynamometer Testing

A ***dynamometer***, often referred to as a ***dyno***, is used to measure an engine's power output and performance. By loading the engine, the dynamometer can check engine acceleration, maximum power output, and on-the-road performance characteristics. A dyno allows the technician to put a full high-speed load on the engine, motor-generator, and driveline to test everything under highway driving conditions, **Figure 54-5**.

If you are having trouble finding a driveability problem, you might perform diagnostic tests while operating the vehicle on a dynamometer. This will let you simulate any condition that causes the problem.

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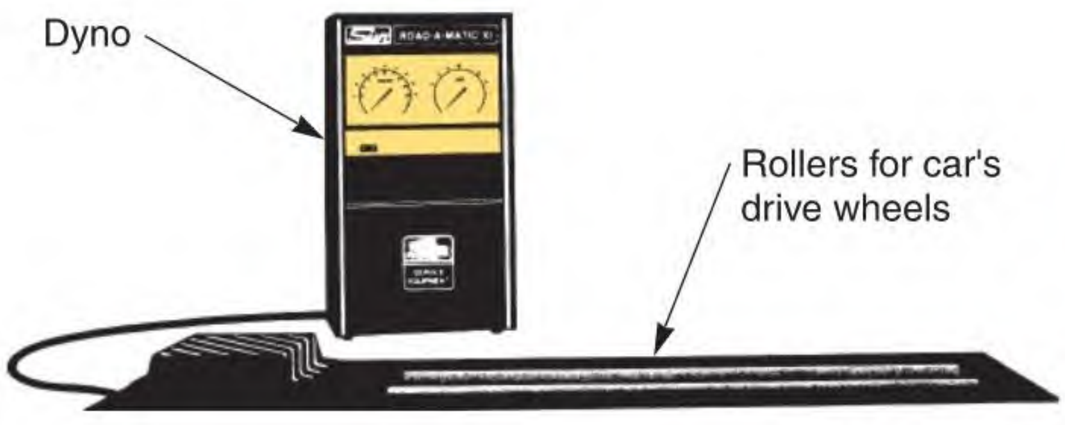
A



B

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Figure 54-4. When intermittent engine problems appear to be caused by heat, cold, or a period of engine operation, suspect the engine or ignition ECMs. A—Freeze spray directed onto the ECM may cause or solve the engine performance problem. If it does, replace the ECM. B—If the engine stops running when air from the heat gun is directed onto the ECM, you have found the problem source. Do not overheat the ECM, however, or you could damage it.



Sun Electric Corp.

Figure 54-5. A chassis dynamometer will measure engine power output under road conditions. It will also load the engine while other tests are performed.

For example, you could connect a five-gas exhaust analyzer to the tailpipe and operate the vehicle under load on the dynamometer.

You can also shift the vehicle through each gear, accelerate to the speed at which the problem occurs, walk around the vehicle to listen for abnormal noises, or connect listening devices—all while simulating driving conditions on the dyno.

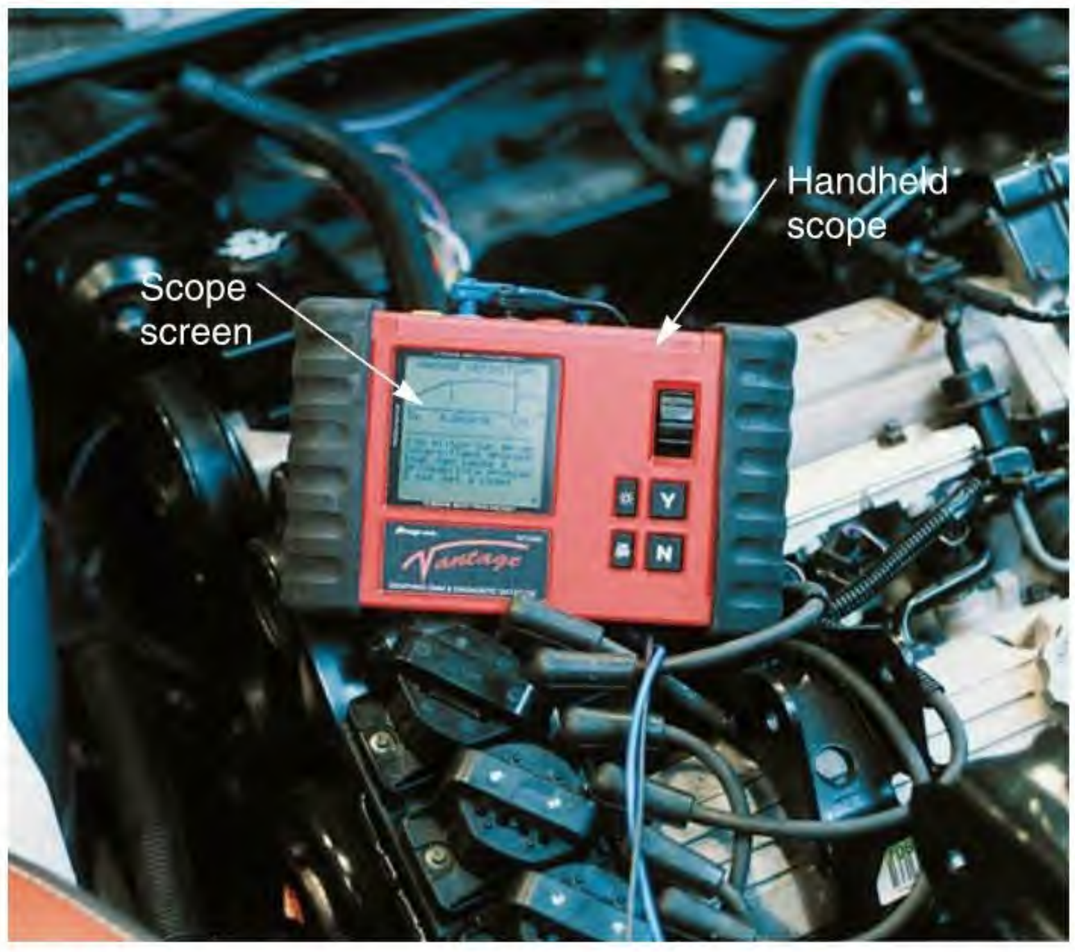
Using an Oscilloscope

An ***oscilloscope***, often called a ***scope***, is a piece of test equipment that displays voltages in relation to time. When connected to circuit voltage, the scope produces a line on a screen that moves up and down with changes in voltage. The line illustrates the various voltages present in the circuit over short periods of time.

By comparing the scope pattern (line shape or waveform) to a known good pattern, the technician can determine whether something is wrong in the circuit. Most advanced scan tools and diagnostic laptop computers and tablets have an oscilloscope function as part of their software. See **Figure 54-6**.

Reading the Scope Screen

The ***scope screen*** can give instructions, display voltages as a ***trace***, or give other values as digital displays. The oscilloscope's ability to draw a trace or



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Figure 54-6. This handheld scope will give tips for testing components and display voltage readings in relation to time.

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waveform (pattern of circuit voltages) for very short time spans makes it very useful for testing ignition, sensor, and computer system performance. You should learn to recognize good scope patterns. Then, you can easily find abnormal scope patterns that show circuit problems.

Scope voltage is shown on the scope screen along the vertical (up and down) axis, or scale. Voltage is the most commonly used value on a scope screen. Voltage values are given on the right and left borders of the screen. Scope voltage scale readings can range from microvolts to thousands of volts. As voltage increases, the trace line on the scope moves up. As voltage drops, the trace line moves down a proportionate amount.

With the controls set on kV, the numbers on the screen represent kilovolts, or thousands of volts. One kV equals 1000 volts; 5 kV equals 5000 volts; etc. If a line on the scope screen extends from 0 to 7 kV, the scope is reading 7000 volts.

If the scope is set to read 0–10 volts for checking the ECM and its sensors, a line trace five divisions tall would indicate 5 volts. Similarly, an alternating current waveform five divisions tall would be a reading of 5 volts peak-to-peak (from the top of the positive trace to the bottom of the negative trace).

Scope time is given on the horizontal scale of the scope screen in degrees, milliseconds (ms), or duty cycle.

Different time frequencies can be selected for the horizontal scale on the bottom of the scope screen. These scales are calibrated in degrees of camshaft or crankshaft rotation. Degrees may also be given as a percentage of duty cycle, for quick reference to any number of engine cylinders and sensor frequencies.

The most common scope time scale used is milliseconds, used for measuring actual time of speed, ignition, fuel injection, and other sensor signal frequencies. This makes it possible to measure how long, in milliseconds, each spark plug fires. A certain amount of time is needed to properly ignite and burn the air-fuel mixture. A major engine part failure that lowers engine compression will also shorten spark plug firing times. Electricity can flow more easily through uncompressed air in a dead cylinder with no compression.

Scope Sweep Rate

Scope sweep rate is the frequency or time division shown on the screen during each test. The sweep rate adjustment affects the horizontal, or time, measurement. The scope sweep rate must be set to match the waveform frequency to be analyzed. Sweep rate is commonly given in milliseconds.

A low scope sweep rate will compress the waveform, and too much information will be shown at once. A high sweep rate will expand the waveform, and only a small section of the complete waveform will be displayed. A slow, two-second sweep (2000 ms) might be needed to capture the signal from a TPS sensor as you open and close the engine throttle valve. A five millisecond sweep could be used to check the rapid spike voltage signals from a knock sensor hammer test.

Trial and error adjustment of sweep rate is commonly used to find the right frequency and sweep rate for each signal. The sweep rate control knob, or sweep control button, on the scope is changed until the desired number of scope sweeps or voltage patterns is displayed on the screen. Compare the scope test pattern to a known good pattern.

Ignition System Patterns

A vehicle's ignition system is designed to produce wide fluctuations in voltage. When an ignition system is functioning properly, these voltages will be within factory specifications.

A component with higher-than-normal resistance (wider-than-normal spark plug gap, for example) would be indicated on the scope as a higher-than-normal voltage trace. The high resistance to voltage arcing would produce a high voltage drop. A shorted component (oil-fouled spark plug) would have low resistance and would produce a lower-than-normal voltage trace.

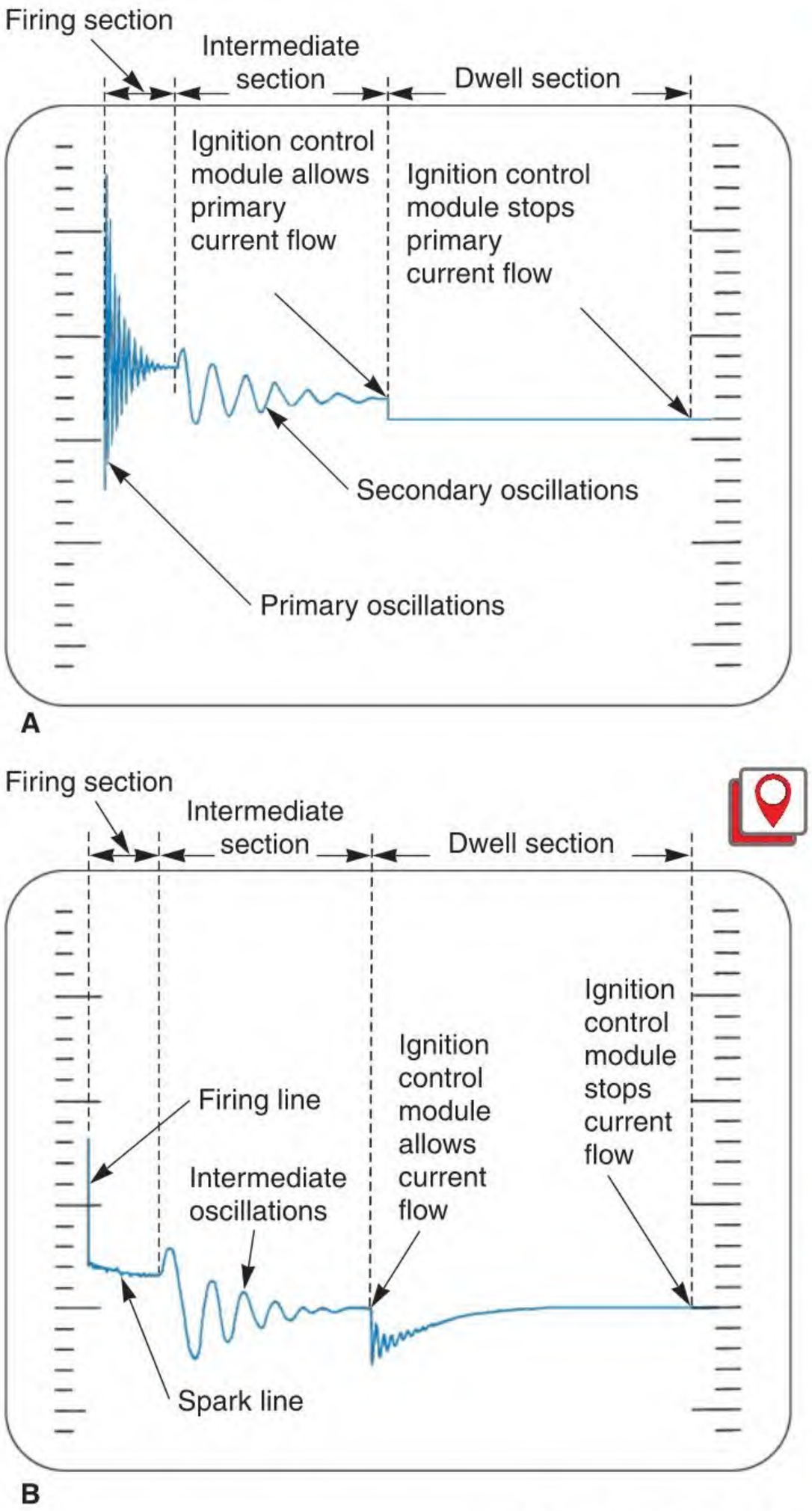
An oscilloscope's controls allow it to display either the primary (low-voltage) pattern or the secondary (high-voltage) pattern of the ignition system. The scope patterns are similar, but important differences should be understood.

To introduce the basic sections of a scope pattern, the primary and secondary patterns for one cylinder will be explained. More complex patterns for specialized tests will be covered later in this chapter.

The ***primary scope pattern*** shows the low-voltage, or primary-voltage, changes in an ignition system or ignition coil. The primary ignition pattern has three sections: firing, intermediate, and dwell. Note how the voltages change in each section of the pattern as shown in **Figure 54-7A**.

The ignition secondary circuit cannot work properly unless the primary circuit is in good condition. A problem

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Figure 54-7. A—Typical primary waveform for an ignition system. Study the various sections of the trace. B—A secondary waveform for one cylinder. The firing line is the voltage needed to fire the spark plug. The spark line is the voltage needed to maintain the spark across the plug gap. Intermediate oscillations show voltage fluctuations after the spark plug stops firing. Dwell is the amount of time primary current flows through the ignition coil.

in the primary circuit will usually affect the secondary circuit. For this reason, the secondary circuit pattern is checked more often than the primary pattern.

The ***secondary scope pattern*** shows the high voltages needed to fire the spark plugs, **Figure 54-7B**.

Secondary Firing Section

The secondary pattern starts on the left with the firing section. The ***firing section*** will pinpoint problems with the spark plugs, the plug wires, and ignition coils.

The ***firing line*** is the tall spike or line representing the amount of voltage needed to cause the electric arc to jump across the spark plug gap. It is normally the peak voltage in the ignition system.

The ***spark line*** shows the voltage used to maintain the arc across the spark plug electrodes. Once the spark is started, less voltage is needed to maintain the arc. The spark line should be almost straight, clean, and about one-fourth as high as the firing line.

Secondary Intermediate Section

The secondary pattern's ***intermediate section***, or ***coil oscillations section***, shows voltage fluctuations after the spark plug stops firing. Typically, the voltage should swing up and down four times (four waves) at low engine speeds. This section of the pattern will indicate problems with the ignition coil or coil pack.

Secondary Dwell Section

The secondary pattern's ***dwell section*** starts when the ignition module conducts primary current through the ignition coil. The ignition coil is building up a magnetic field during the dwell section. The dwell section will indicate problems with the ignition module.

Tech Tip

Some late-model ignition systems, especially with direct gasoline injection, can fire each ignition coil and spark plug approximately a thousand times per power stroke. You would have to adjust your time scale on the scope to see all or just a few of these electrical firing lines.

Scope Test Patterns

There are five scope test patterns commonly used by the technician when checking ignition system operation: primary superimposed, secondary superimposed, parade (display), raster (stacked), and expanded display (cylinder select).

The ***primary superimposed pattern*** shows the low voltages in the primary system—the ignition module and ignition coil primary windings.

Superimposed means that the patterns for all the cylinders are placed on top of one another. This makes the trace line thicker than the single cylinder pattern discussed earlier.

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Sometimes, an experienced technician will inspect the primary superimposed pattern before going to the more informative secondary pattern.

The ***secondary superimposed pattern*** is one of the most commonly used scope patterns. It places all the cylinder waveforms on top of each other, but it also shows the high voltages produced by the ignition coils. The superimposed secondary waveform allows you to quickly check the operating condition of all cylinders. Look at **Figure 54-8A**.

For example, if one spark plug is not firing properly, the waveform for that cylinder (spark plug) will not align with the others. The abnormal trace will stand out because the firing voltage is higher or lower than normal.

The secondary superimposed pattern is used to check for general problems in the ignition system. If one of the waveforms is out of place, the other scope patterns may be used to find exactly which component is causing the problem.

The ***parade pattern***, also called the ***display pattern***, lines up the waveform for each cylinder side by side across the screen. The number one cylinder is on the left. The other cylinders are displayed in firing order going to the right, **Figure 54-8B**.

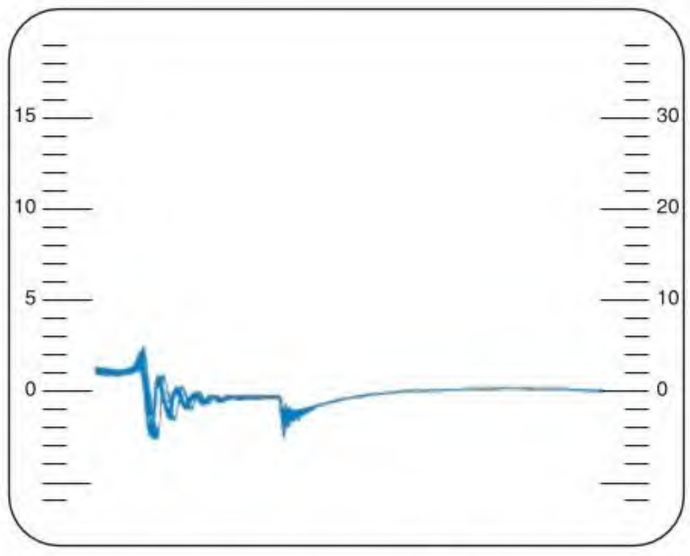
The parade pattern takes the superimposed waveforms and separates each along a horizontal axis. This makes the parade pattern useful for comparing firing voltages of each spark plug. If one or more firing lines are too tall or short, a problem is present in those cylinders.

During normal operating conditions, secondary voltages will vary from 7–25 kV or higher for modern electronic ignitions. Newer electronic ignition systems normally produce higher voltages because of the wider spark plug gaps needed to ignite lean fuel mixtures.

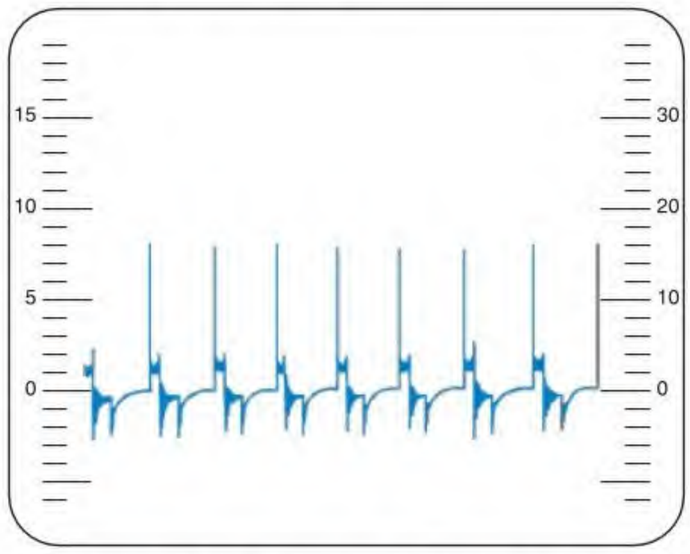
A tall firing line on the parade pattern indicates high resistance in the ignition secondary caused by an open spark plug wire, a wide spark plug gap, or a burned coil-to-plug connection. High resistance requires higher voltage output from the ignition coil.

A short firing line indicates low resistance in the ignition secondary, which may be an indication of leaking secondary insulation, oil-fouled spark plugs, carbon tracking on the coil pack, or similar problems. Low resistance requires less voltage output from the coil.

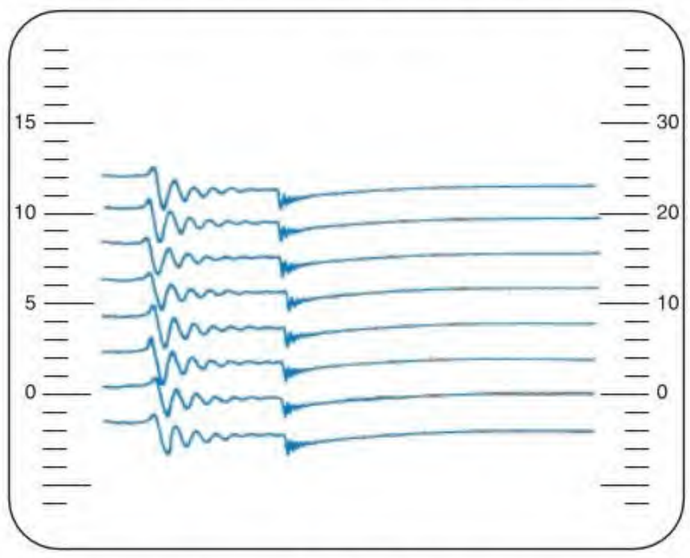
In a ***raster pattern***, or ***stacked pattern***, the voltage waveforms are placed one above the other, **Figure 54-8C**. The bottom waveform is the number one cylinder. The other cylinders are arranged in firing order from the bottom up.



A—Superimposed display has all patterns on top of each other. It checks that all patterns are uniform.



B—Parade display has cylinder patterns side by side in firing order. It is useful for comparing firing voltages. Number one cylinder is on the left, with its firing line on the right.



C—Stacked or raster has all cylinders one above the other. It is useful for comparing duration of events. Number one is on bottom. Others are in firing order.

FMC

Figure 54-8. Three basic scope test patterns. A—Superimposed. B—Parade pattern. C—Stacked or raster pattern.

The raster pattern is normally used to check timing or dwell variations between cylinders.

Some oscilloscopes have a control that allows one cylinder waveform to be displayed above the parade pattern. This arrangement is called an ***expanded display***, or ***cylinder select***. If a problem is located in

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one trace, that trace can be expanded (enlarged and moved up on screen) for closer inspection.

Tech Tip

Diagnostic laptop computers and tablets require special test leads to check coil-on-plug secondary voltages. In some vehicles, the coil must be disconnected from the spark plug so the test lead can be wired to high voltage. Some computers use an inductive pickup to measure primary voltage, which provides an accurate indication of the secondary voltage being produced. A misfire code for a specific cylinder will indicate which coil should be tested. If the coil checks out okay, suspect a fouled or extra wide spark plug gap is preventing normal combustion in that cylinder.

Reading Oscilloscope Patterns

To read a scope pattern, inspect the waveform for abnormal shapes (high or low voltages, incorrect dwell or time periods).

Since there are so many variations of ignition waveforms, refer to the scope operating manual or another reference. Locate an illustration of a good scope pattern for the particular ignition system and compare it to the test pattern. An ***analog scope pattern*** has a smooth, gradual change in voltage over time. An ac sine wave with equal size positive and negative curves above zero volts should be present.

A ***digital scope pattern*** has very short, repeating changes in voltage (from no voltage to a few volts dc positive). Depending on the scope time scale selected, an almost vertical straight line should be displayed as the signal turns on and off.

Analyzing Square and Sine Wave Signals

When analyzing a square wave, there are several things you should check.

- The ***baseline*** is the reference line, or zero volts.
- The ***rising edge***, or ***leading edge***, is where the square wave goes from zero to high voltage.
- The ***on-time***, or ***high-time***, is the portion of the square wave that stays at maximum voltage.
- The ***trailing edge***, or ***falling edge***, is the drop in voltage back to zero.
- The ***off-time***, or ***low-time***, is where the square wave stays on the baseline.
- The ***amplitude***, or ***peak-to-peak voltage***, of a square wave is determined by the horizontal distance from the baseline to the high-time.

You can inspect these sections of the waveform to determine if there is a problem. Some common problems that can affect digital or square waves include:

- Low or high resistance in the circuit or its components.
- Faulty electronic circuit.
- Circuit contaminated by moisture.

When analyzing sine waves, check the following:

- Analog peak-to-peak voltage—Is the waveform voltage strong from top to bottom?
- Analog wave shape—Is the trace normal for a known good component?
- Analog wave frequency—Is the distance between waves normal?
- Analog wave smoothness—Is there unwanted hair or static on the sine wave?

Computer System Scope Tests

An oscilloscope can be used to help you find computer system problems. When the scan tool does not find anything and you still have performance problems, you may need to check sensor and ECM signals with a scope.

Crankshaft Position Sensor Scope Testing

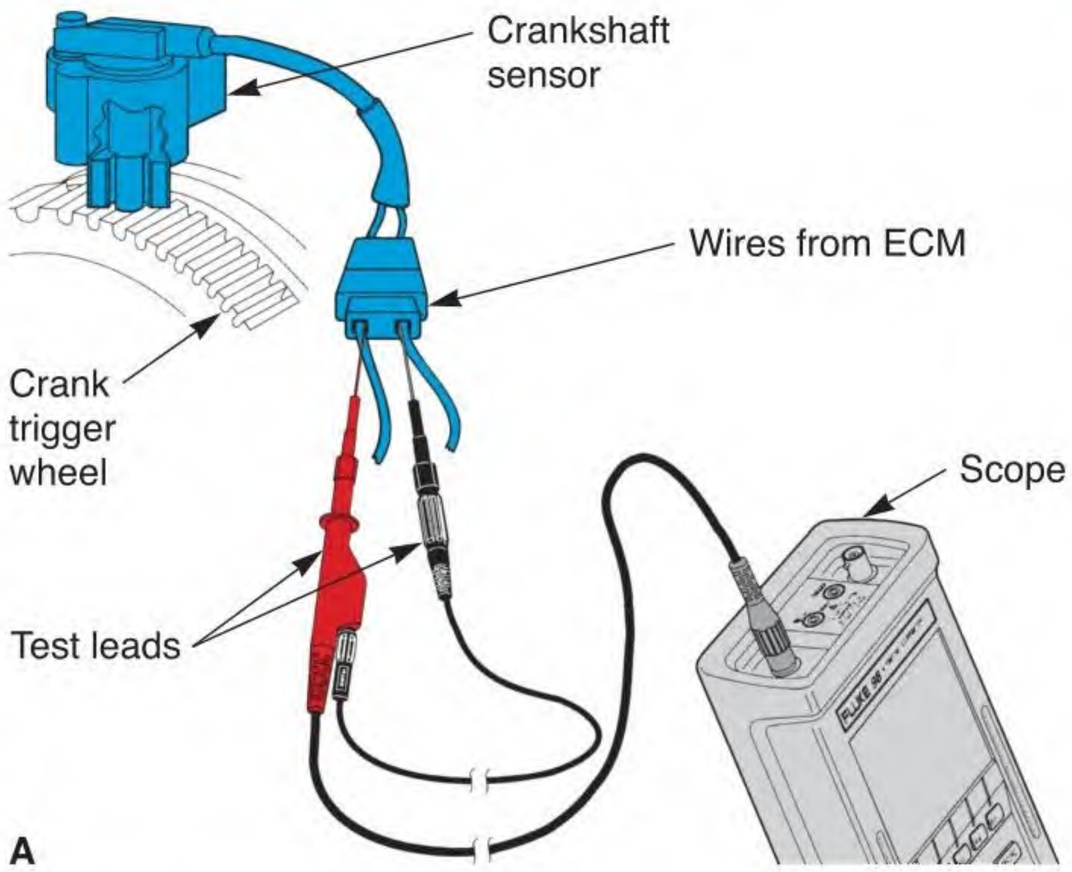
Figure 54-9 shows how to use a handheld scope to test a crankshaft position sensor (CPS). You can use the needle probe on the scope lead to check for an output signal without disconnecting wires. This scope will show both ac output and a trace for voltage signal variations. Note that this testing method would also work on engine block-mounted magnetic crankshaft position sensors.

Tech Tip

Some electrical connectors are sealed and do not allow easy probing. You may need to install a test connector or jumper wires between the two halves of the connector to probe sensor voltages.

When reading the sensor waveform, make sure the peak voltage levels are equal to each other. If one is short or missing, inspect the trigger wheel for a broken tooth. Peak-to-peak voltage levels should be within specifications.

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Figure 54-9. A scope can be used to check for proper crankshaft position sensor operation. A—Since crankshaft position sensors generate their own voltage signal, connect the scope to the terminals as specified. B—Note the resulting display. Compare the waveform to the service manual description.

As with any sensor, reference voltages, wiring, and other criteria will vary. If in doubt, always refer to the service manual for the vehicle being tested to get accurate electrical values.

Throttle Position Sensor Scope Testing

To scope test a throttle position sensor (TPS), connect the test leads to the sensor output wire and to ground. Voltage should still be fed to the sensor from the ECM. Move the throttle open and closed. The TPS waveform should show a smooth curve, without any spikes. See **Figure 54-10**.

Accelerator Pedal Sensor Scope Testing

Many new cars have a drive-by-wire electronic engine acceleration circuit. An accelerator sensor signals the engine ECM to control engine speed and power by operating the engine air throttle valve in the throttle body. Most accelerator sensors produce similar but opposite polarity signals as a fail-safe system. A dual-trace scope wired into the circuit can compare voltage outputs from the accelerator pedal. When an accelerator pedal sensor fails, the vehicle will not move (no increase in engine speed) or may only move very slowly. See **Figure 54-11**.

Manifold Absolute Pressure Sensor Scope Testing

A scope can also be used to test the operation of both analog and digital manifold absolute pressure (MAP) sensors. Accelerate the engine and note the changes in airflow signals going to the ECM. Compare the waveform signals to known good patterns. Refer to **Figure 54-12**.

An analog manifold pressure sensor signal will show a rise and fall in signal voltage as engine vacuum increases and decreases. At idle, vacuum is high and MAP sensor voltage is low. When the engine throttle valve is opened, engine vacuum drops and sensor output voltage increases to about 0.5 volts. Some waveform hair, or hash, is from pressure pulses as engine intake valves open and close at high frequency.

A digital MAP sensor is fed a 5 volt dc reference from the ECM through one wire, is grounded through a second wire, and sends a return signal to the ECM through a third wire. The digital MAP sensor varies its signal frequency with variations in engine vacuum. Low engine vacuum produces a lower frequency signal than high engine vacuum. A higher-than-normal MAP frequency signal is often due to a leaking engine vacuum hose.

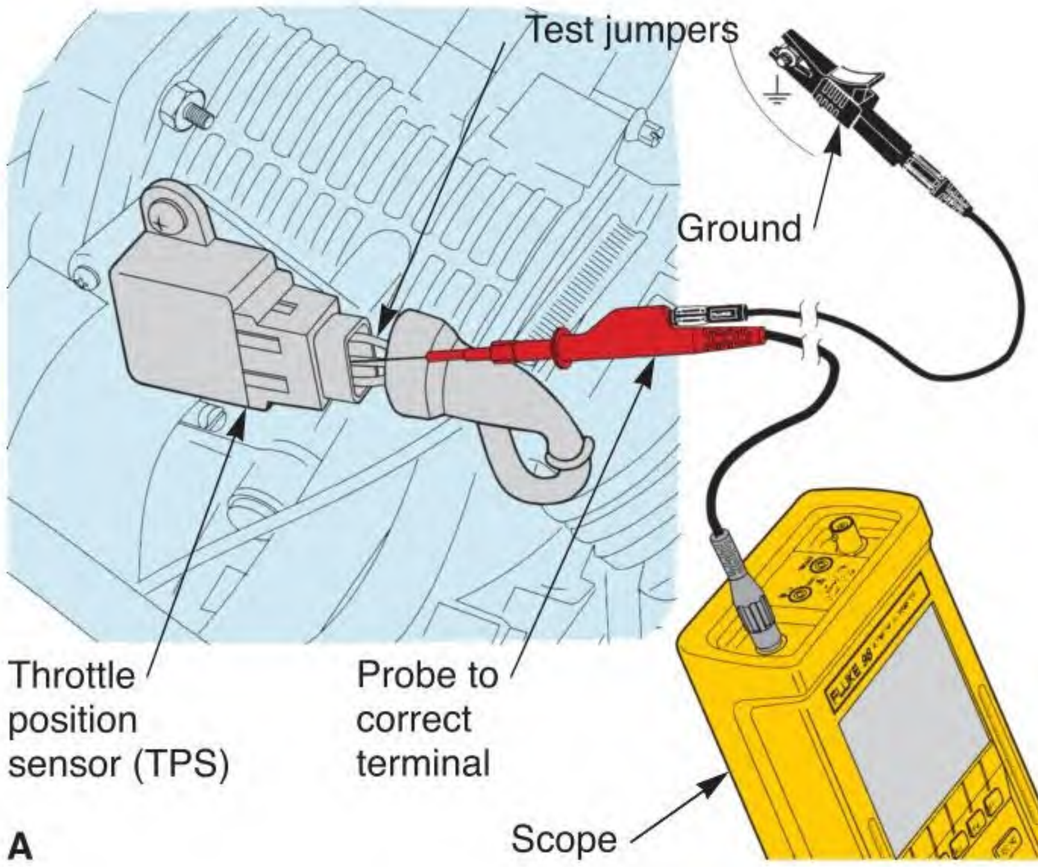
Mass Airflow Sensor Scope Testing

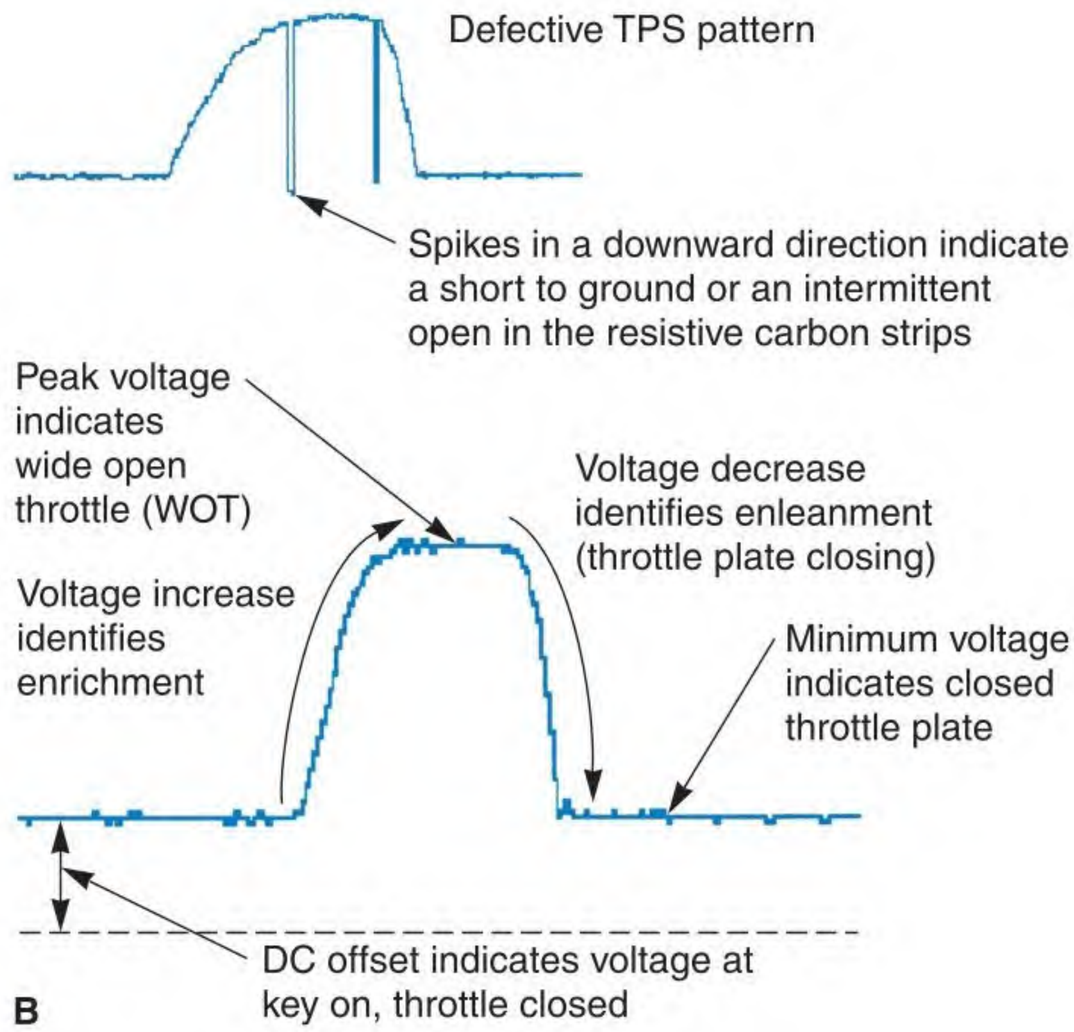
To test analog or digital mass airflow sensors using a scope, probe the connector as recommended in the service manual. Compare your scope readings to factory specifications and known good readings. See **Figure 54-13** and **Figure 54-14**.

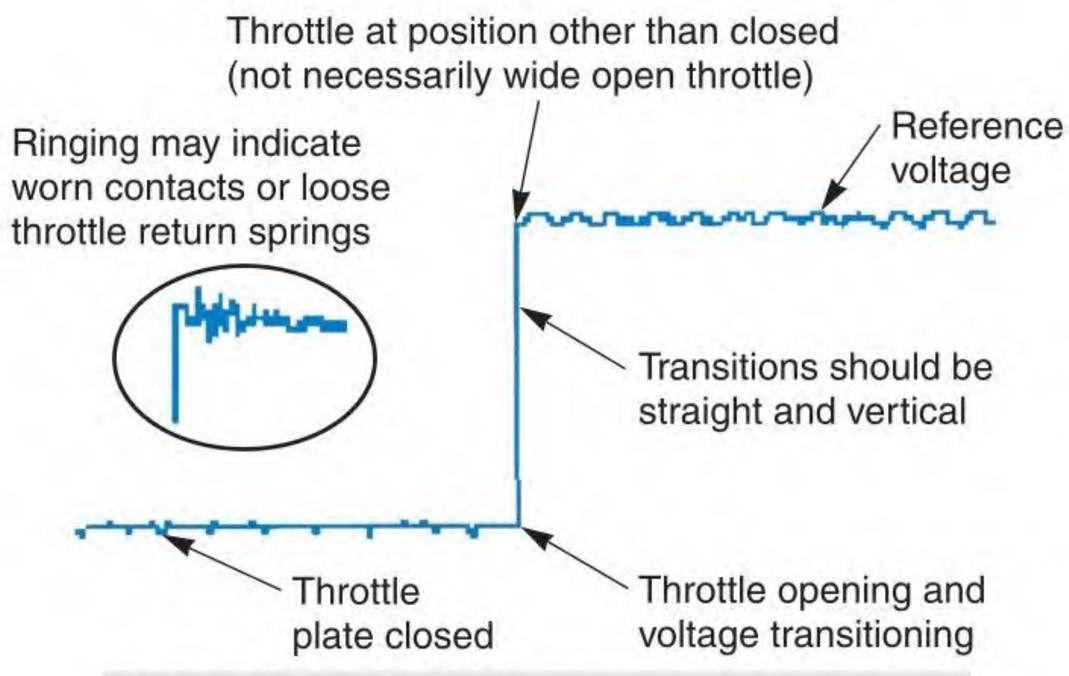
Knock Sensor Scope Testing

To test a knock sensor with a scope, connect the scope test leads to the sensor. Tap lightly on the metal bracket or cylinder block next to the sensor with a small hammer or a wrench. The metal-striking-metal shock wave should energize the knock sensor crystal to generate an ac spike or dc glitch on the normally smooth dc reference voltage signal. This is illustrated in **Figure 54-15**.

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Figure 54-10. A throttle position sensor can be checked with a scope. A—Probe through wires or use jumpers so power can be connected to sensor. B—Potentiometer, or variable-resistor, TPS should produce smooth curve as throttle is moved open and closed. Spikes indicate sensor problem. C—Switching-type TPS should produce good square wave without ringing.

Another way to check a knock sensor signal and ECM actuation signal is with your scope or scan tool live readings. Tap near the knock sensor with a metal tool while watching the readout for ignition timing. The ECM should retard ignition timing when you tap on the engine.

Tech Tip

Oscilloscopes can also be used to check injector operation in an electronic fuel injection system.

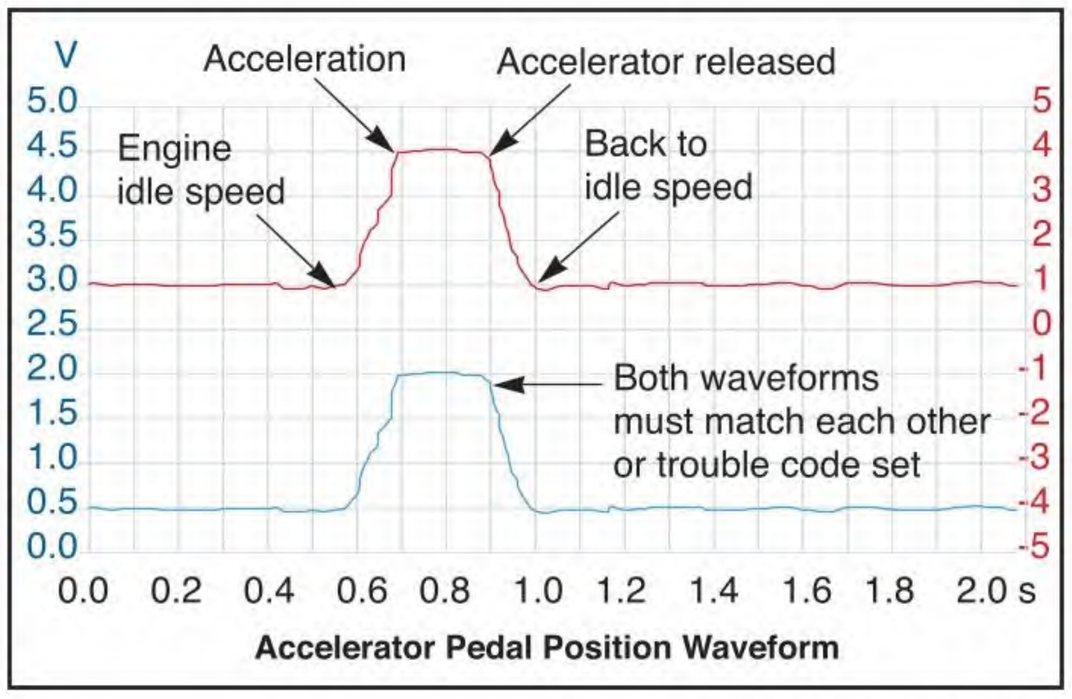
Oxygen Sensor Scope Testing

An oscilloscope can be used to check the signal produced by an oxygen sensor. To review how to do advance tests on oxygen sensors, refer to **Figure 54-16** and **Figure 54-17**.

ECM Scope Testing

A scope can be used to check the ac and dc voltages leaving an electronic control module or ECM. As discussed in previous chapters, you can measure and observe the pulses going to fuel injectors, solenoids,

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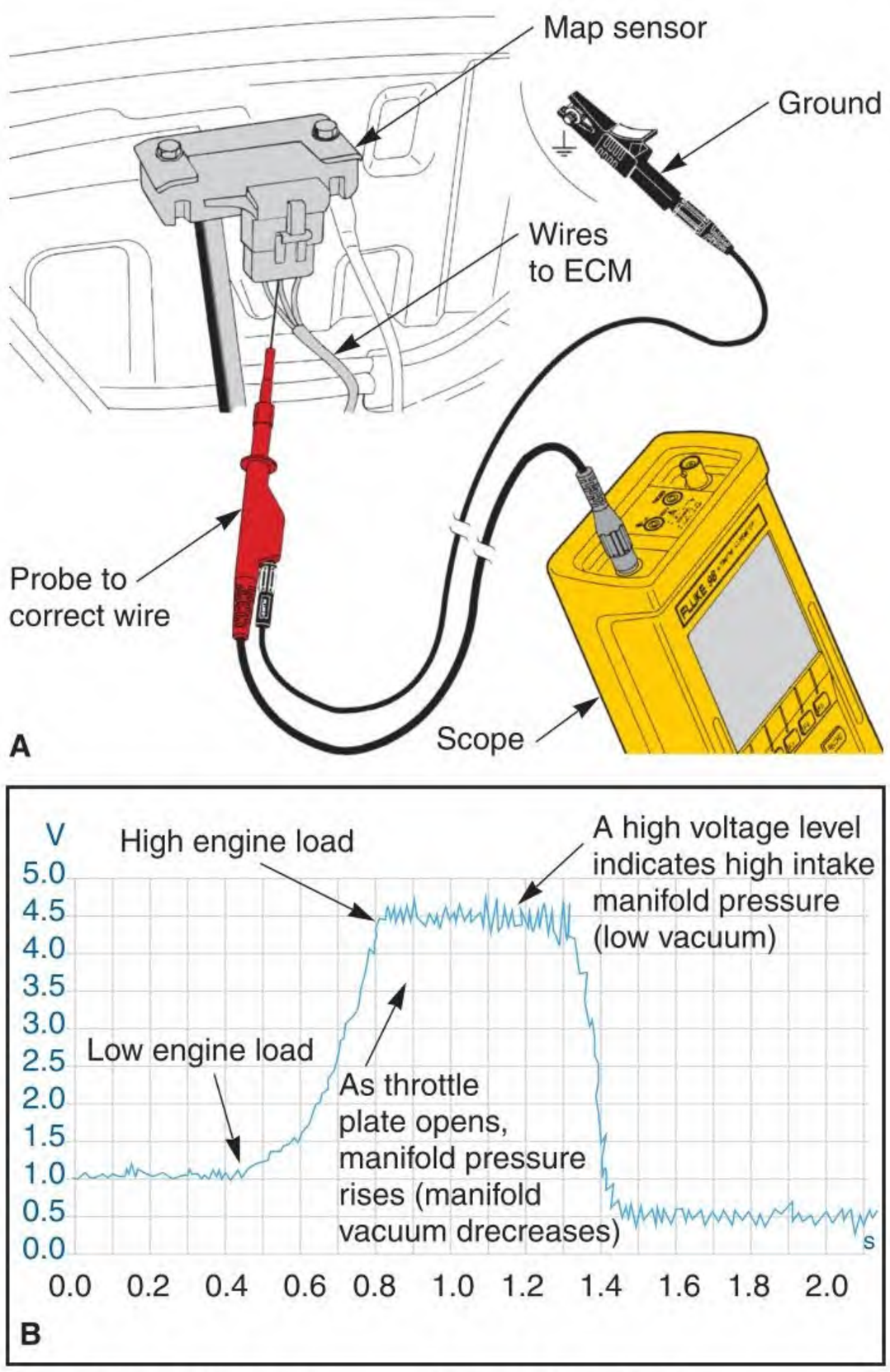
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Figure 54-11. Dual signals coming from an accelerator pedal sensor are shown. One waveform has been inverted on screen, but its polarity is actually opposite that of the other waveform. This ensures that a lightning strike, wiring short, or other trouble cannot accidentally increase engine speed uncontrollably. If the two waveforms are not exact opposites, the ECM will not increase engine throttle valve opening and engine power output.

and servo motors. You can also double-check the actual reference voltage being sent to sensors, **Figure 54-18**.

Since ECM testing varies and is complex, always refer to the service literature for detailed instructions. To test any device or component, compare the amplitude and shape of your voltage or current waveform to known correct values over time. If the ECM fails to produce a good pulse or strong reference voltage and other parts are not at fault, the engine or ECM should be replaced.

A ***reference voltage test*** involves using a multimeter to measure the actual voltages being sent out by the ECM to resistive sensors. It measures ECM reference voltages without disconnecting wires.



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Figure 54-12. A manifold absolute pressure sensor can be checked with a scope. A—Here, a scope is probing through the connector to test the MAP sensor. The other lead is grounded. B—Analog MAP sensor signal. The signal's amplitude should increase with engine speed. C—Digital MAP sensor signal. The signal's frequency should increase with engine speed.



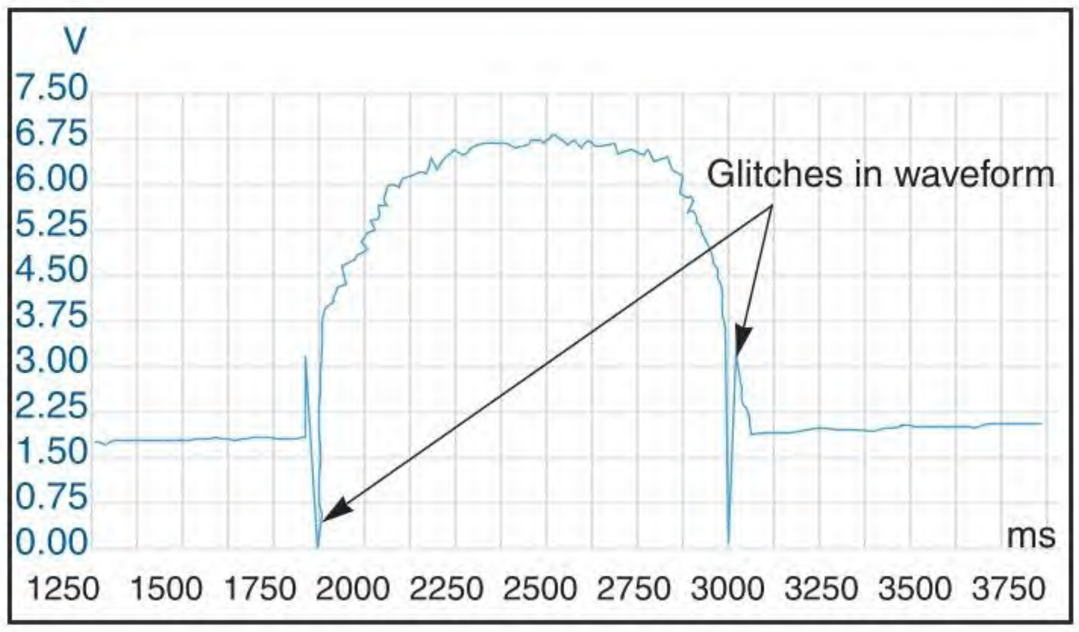
Service Procedure

To check ECM reference voltages going to resistive sensors:

1. Remove any lower plastic covers or body trim pieces that block access to the engine ECM. The ECM is usually under the dash or in a plastic housing in the engine compartment.
2. Place needle probes on the ends of your voltmeter or scope test leads. The long metal tip will let you reach the back of the ECM harness connector to measure voltages in all computer circuits.
3. Ground the black test lead on a good, bare metal (no paint) ground near the ECM.

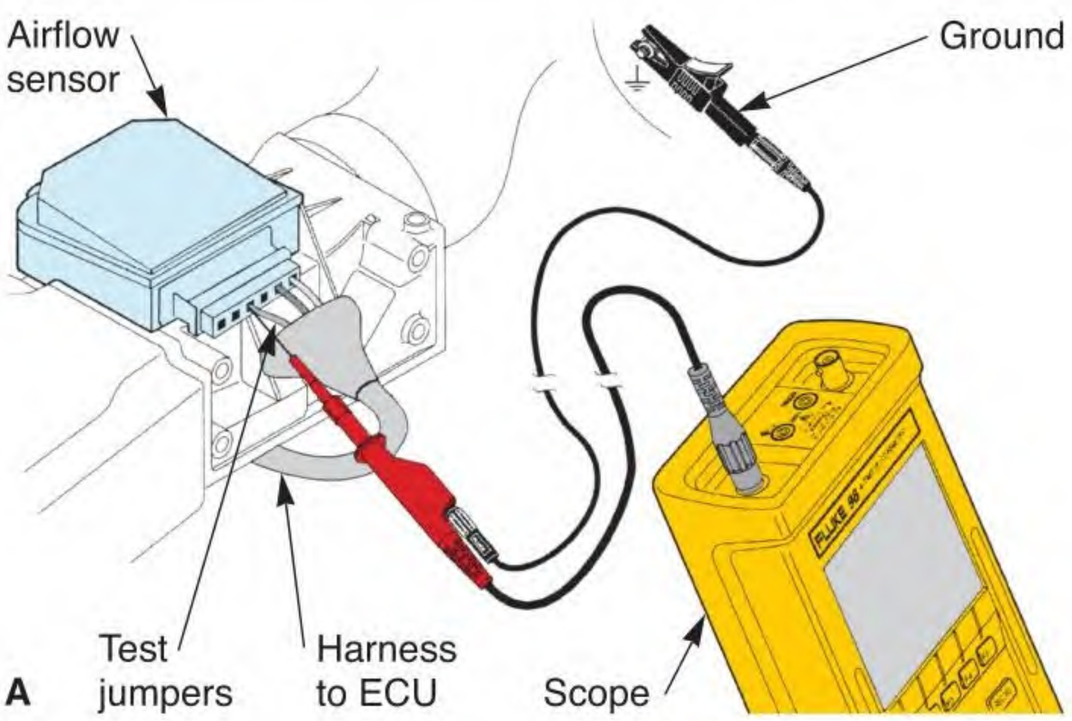
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4. Use an appropriate service manual illustration of the ECM harness connector to find the wires that should be carrying a reference voltage.
5. Turn the ignition key in the passenger compartment to *Run* so that 12 volts dc is fed to the ECM from its relay.
6. Touch the needle probe on your instrument to the correct metal wire terminal inside the ECM harness connector.
7. Note the exact reference voltage and the condition of the dc on the waveform for each circuit.



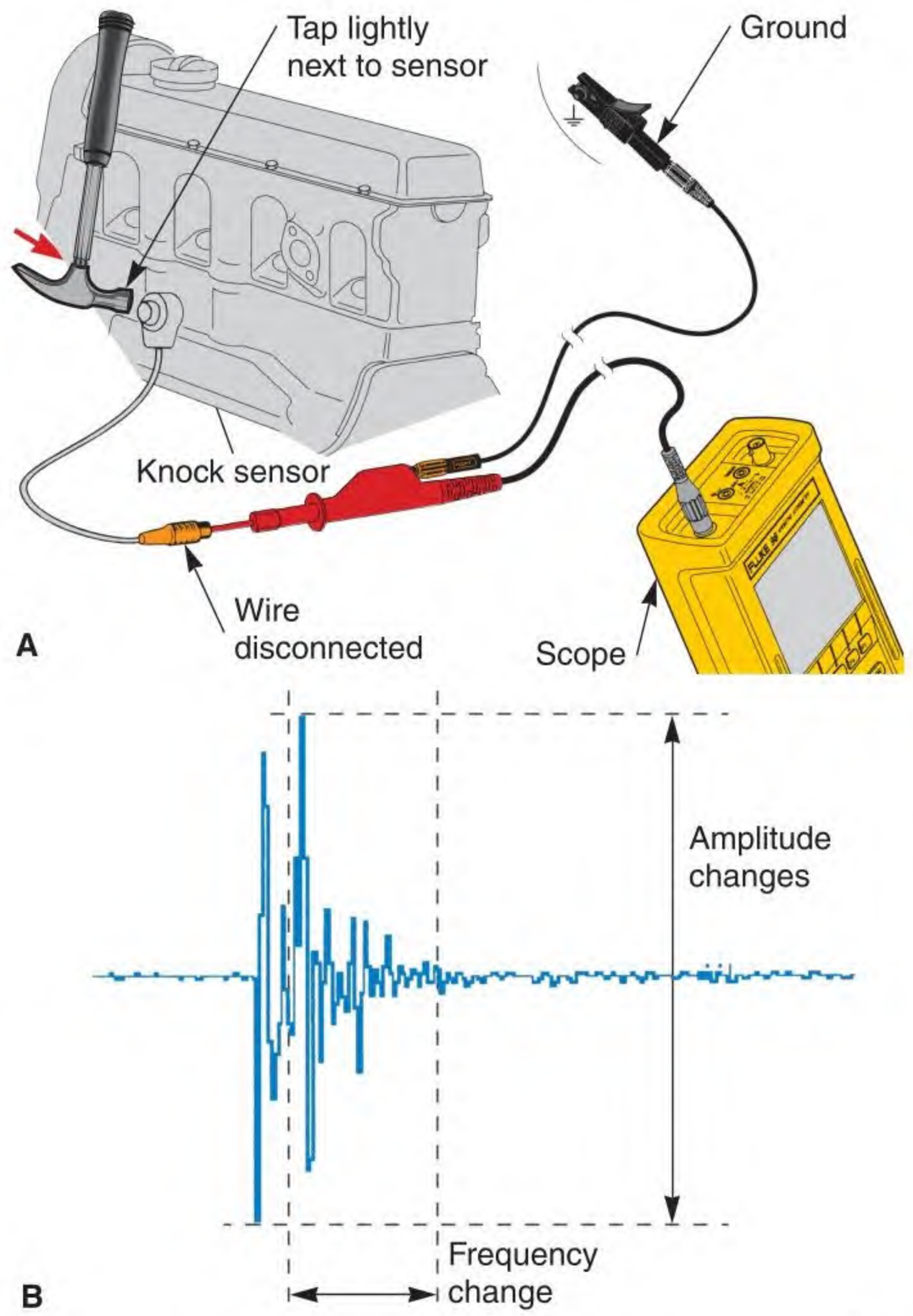
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Figure 54-14. This is a signal produced by a faulty engine airflow sensor as the throttle is opened and closed. Note the glitches from the bad spot on the variable resistor as the throttle is opened (first glitch) and then closed (second glitch) to return the engine to idle speed. This airflow sensor must be replaced to improve engine operation or efficiency.



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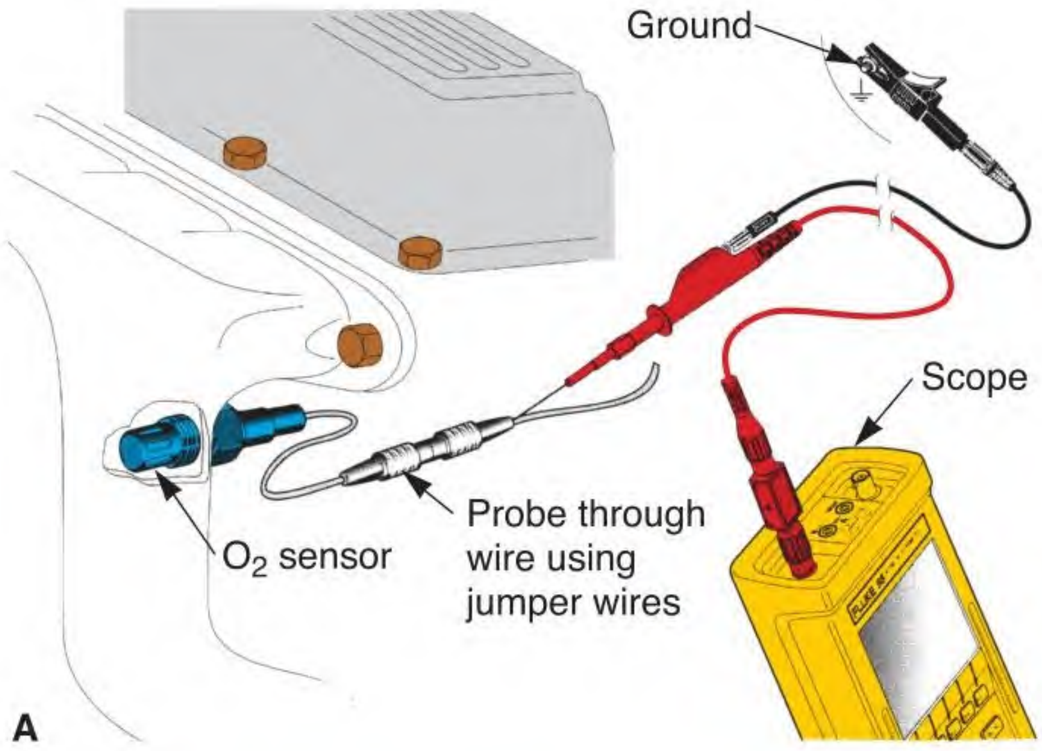
Figure 54-13. Note the basic method for testing analog and digital airflow sensors. A—Jumpers are being used to allow power to remain connected to sensor. Probe service manual recommended pins or wires. B—As flow increases, an analog airflow meter should produce more voltage. C—With a digital airflow meter, signal frequency usually increases with engine speed and airflow.

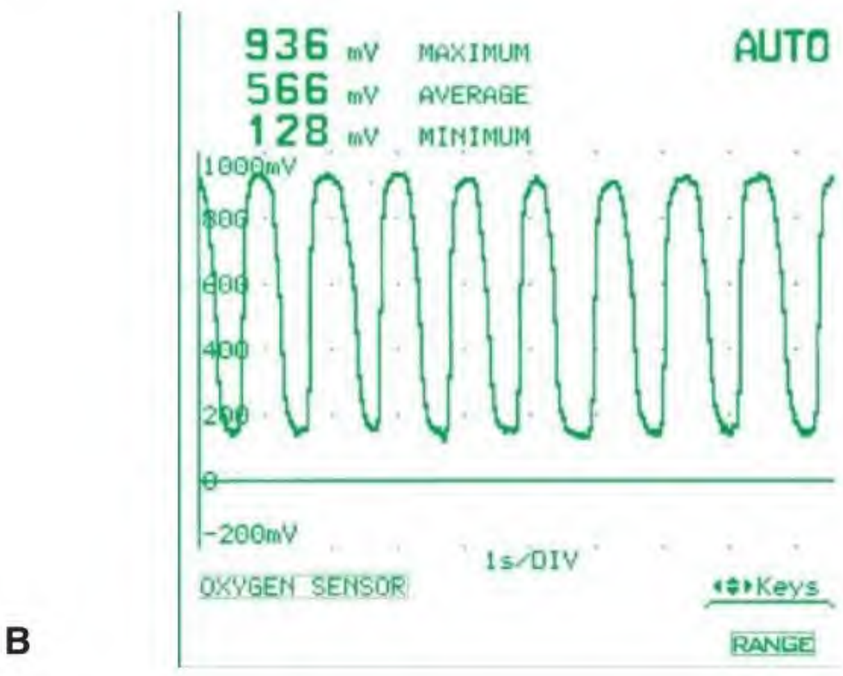


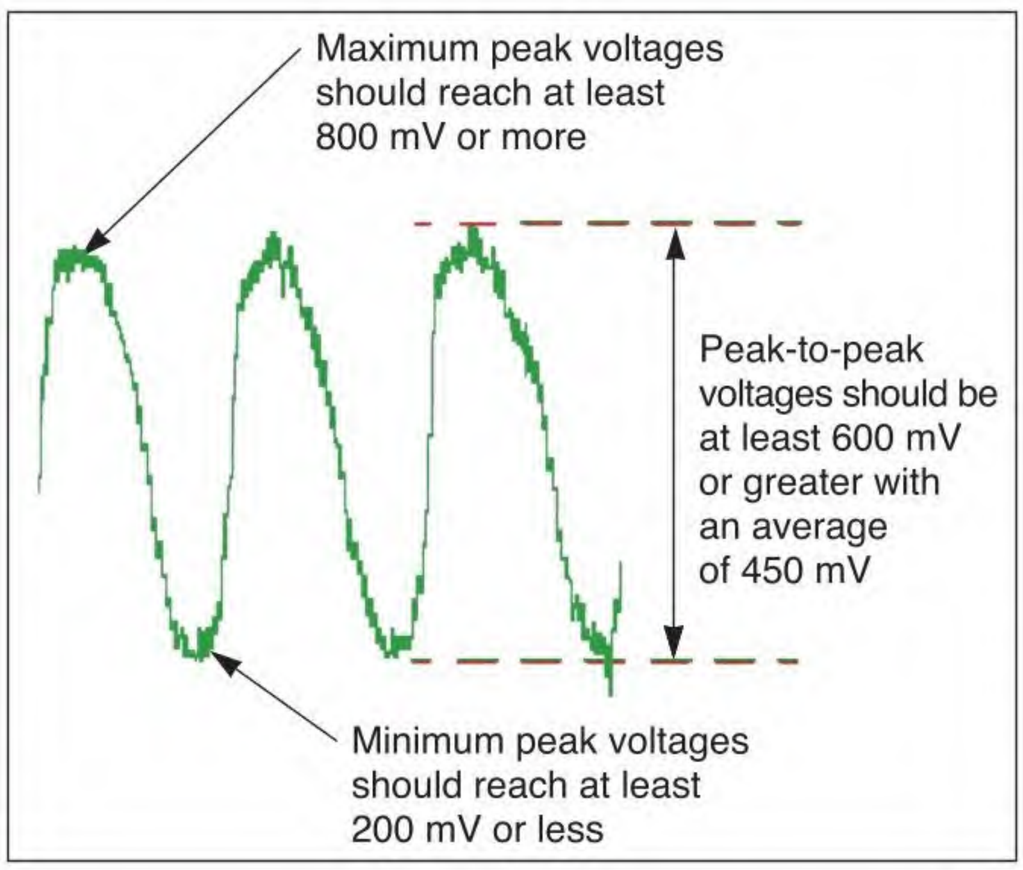
Fluke

Figure 54-15. Knock sensor signals can be analyzed with a scope. A—Connect scope lead to knock sensor and other lead to ground. Tap on engine with small hammer or wrench to produce output signal. B—Knock sensor should produce a small voltage spike when engine is tapped on.

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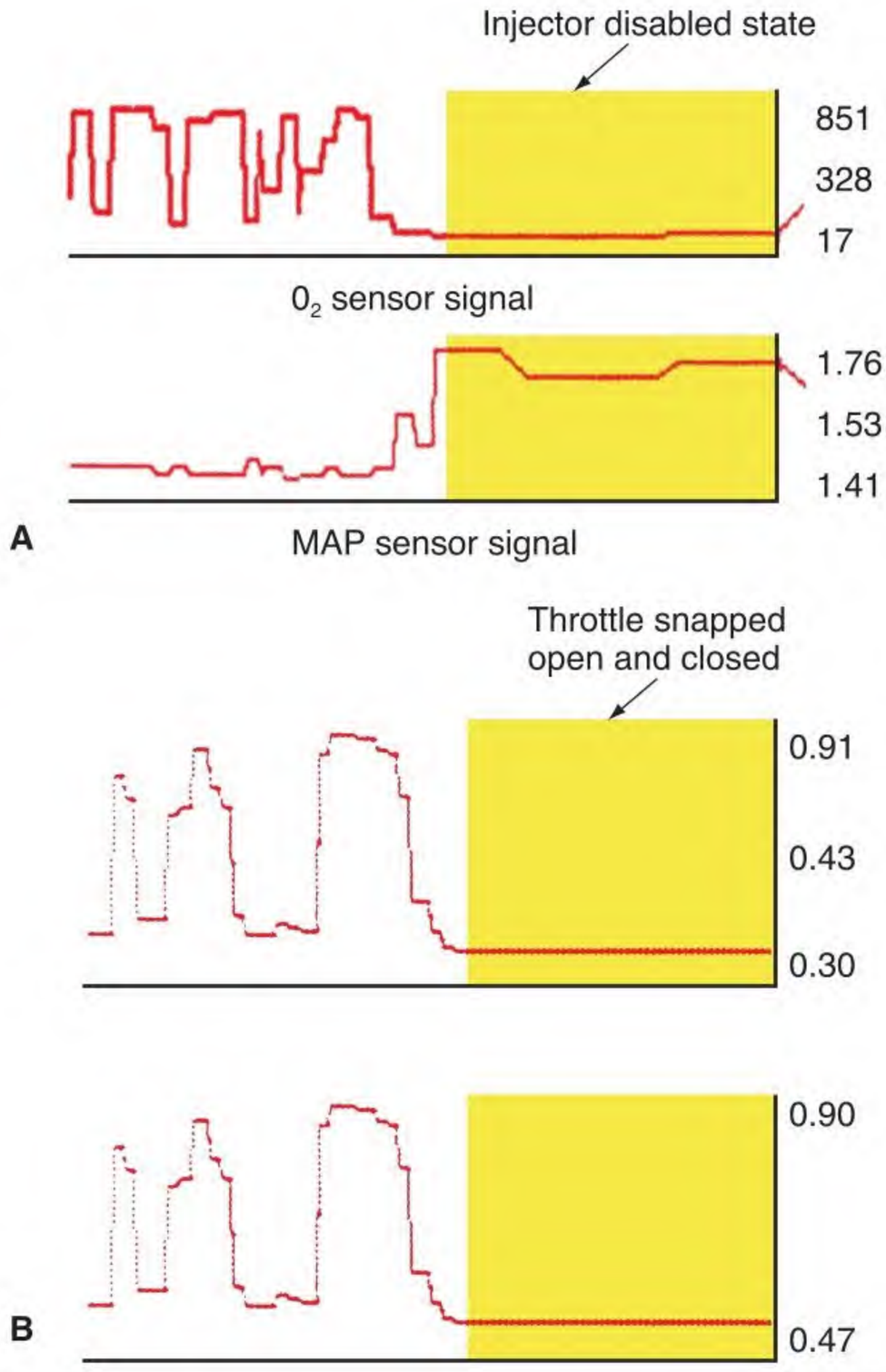






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Figure 54-16. An oscilloscope can also be used to check the output signal from an oxygen sensor when trouble is hard to find. A—Ground one lead and probe through the connector using jumper wires. Do not pierce the oxygen sensor wiring. B—The oxygen sensor's signal output should vary as shown. Also note the millivolt readout on the scope face. C—This is a typical waveform for a zirconia O_2 sensor.



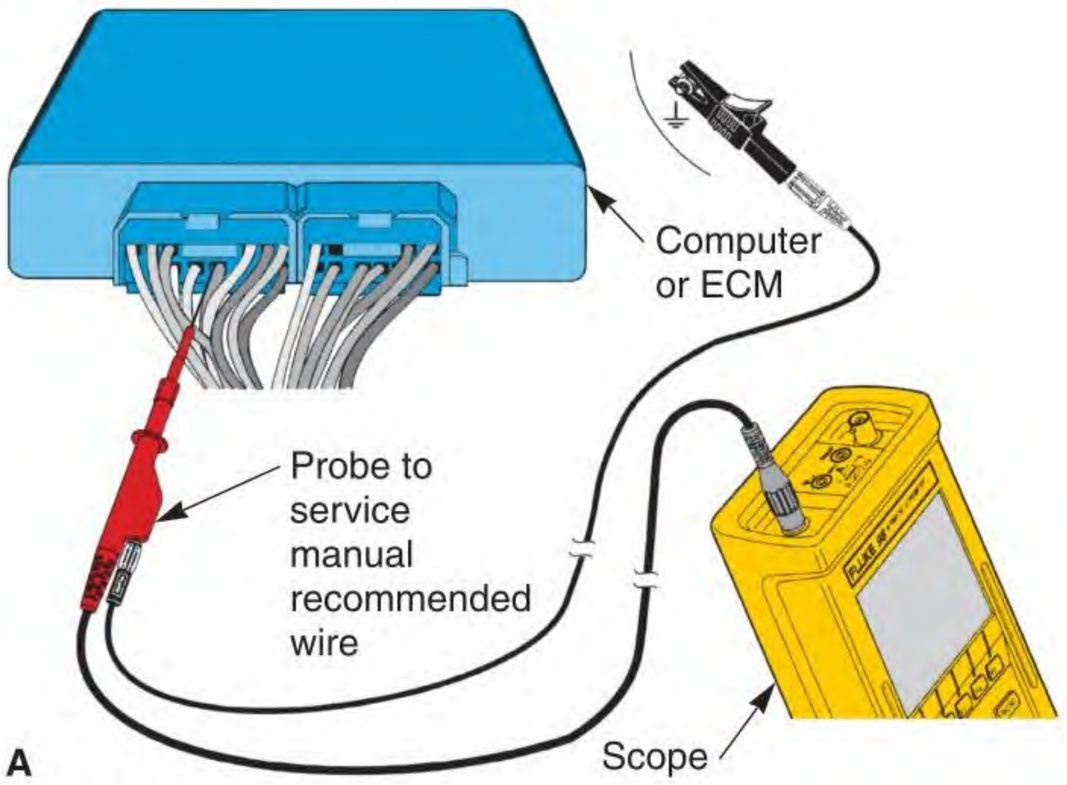
OTC/SPX Corp.

Figure 54-17. A—A dual-trace scope can be used to compare oxygen sensor and MAP sensor voltage waveforms. Both can be viewed as you shut off a fuel injector. Both waveforms should change when the fuel mixture is leaned out by turning the injector off. B—Here, waveforms for two oxygen sensors are compared with a dual-trace scope. When the throttle is snapped open, both waveforms should change at the same rate and values.

If specifications call for a reference voltage of 0.5 volt dc, your readings must be within a few tenths of a volt of the specification. A 12-volt alternator must produce smooth dc, and so must a hybrid motor generator when it starts to generate electricity to recharge the HV battery.

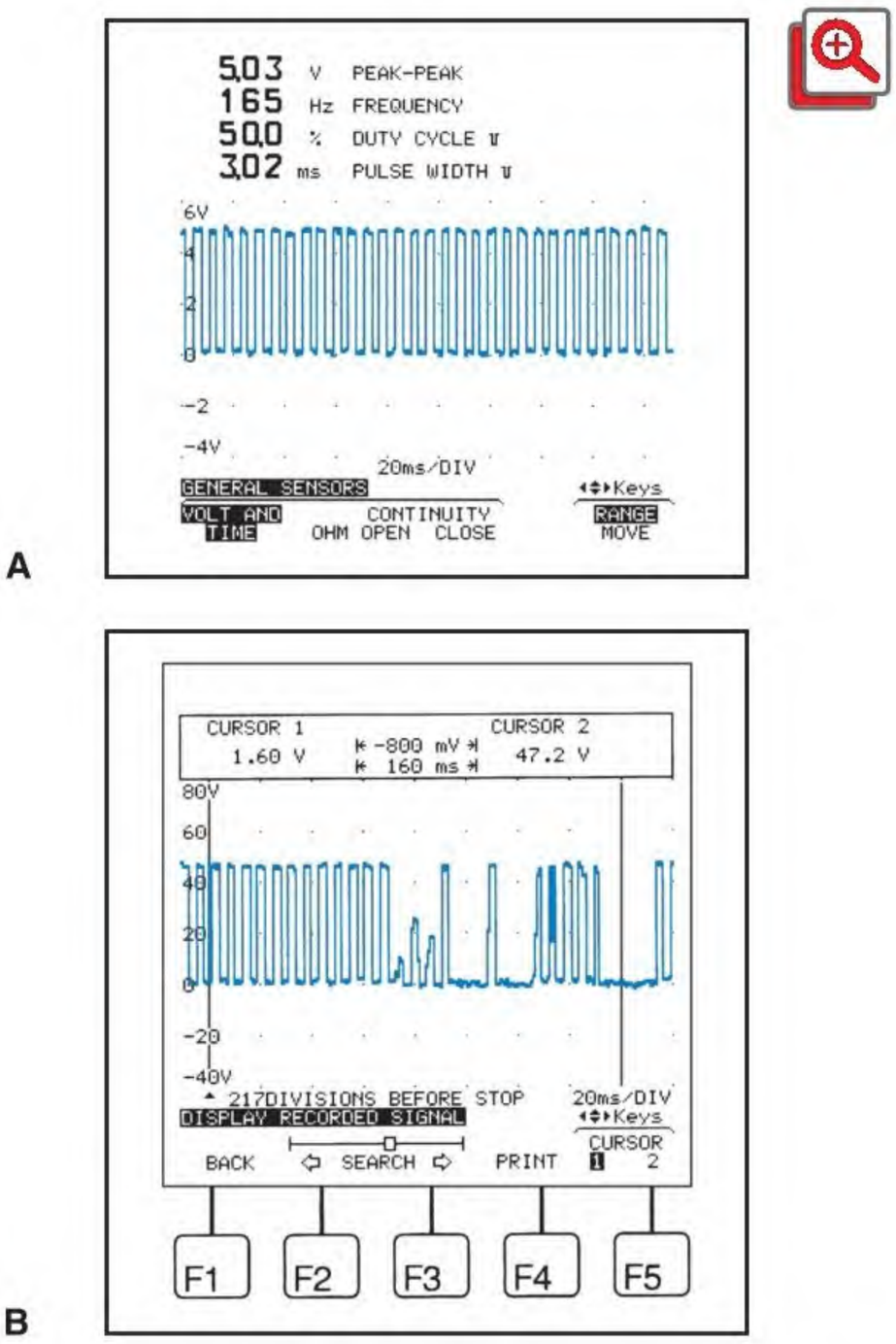
If reference voltage is low, you could have a partially shorted feed circuit, a shorted sensor, or high-resistance ground connection. If reference voltage is high or zero, there is probably a voltage regulator problem inside the ECM.

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Figure 54-18. A—A scope will check reference voltage going to sensors and the control pulses from the ECM to the actuators. Compare readings and waveforms to service manual specifications. B—Reference voltages should meet specifications and the waveforms should reflect smooth dc voltage.



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Figure 54-19. The flight record is a feature on some small handheld scopes. Connect to a suspect sensor using long test leads and place the scope on seat during test drive. A—Normal, consistent signals from a magnetic sensor. B—When the problem occurs, the scope will store a picture of the sensor signals. Note how each signal varies, possibly from intermittent open sensor coil windings or a loose mounting.

Flight Record Test

A ***flight record test*** stores the sensor or actuator waveform in the scope's memory when a problem occurs. For example, when trying to check an intermittent problem, connect the handheld scope to the sensor and test drive the vehicle. When the problem occurs, press the storage button on the scope. The scope will then store a picture of the sensor output for analysis, **Figure 54-19**.

Diagnostic Laptop Computers and Tablets

A ***diagnostic laptop computer*** or touch-screen diagnostic tablet is the most advanced tool for diagnosing difficult-to-find problems on today's vehicles. The laptop's diagnostic software combines many different diagnostic tools (scan tool, scope, etc.) into a single application that uses the computer as its interface. A wireless ***diagnostic tablet*** can retrieve trouble codes and perform tests remotely through a wireless scan tool module that the technician plugs into the vehicle's DLC. In addition to many other features, nearly all of the tests and functions described in this chapter can be performed using these powerful diagnostic instruments. Working via the shop's wired or wireless network, either tool can access a vast amount of information over the Internet, including service manuals.

For example, specific vehicle makes and models commonly have one or two difficult problems, ranging

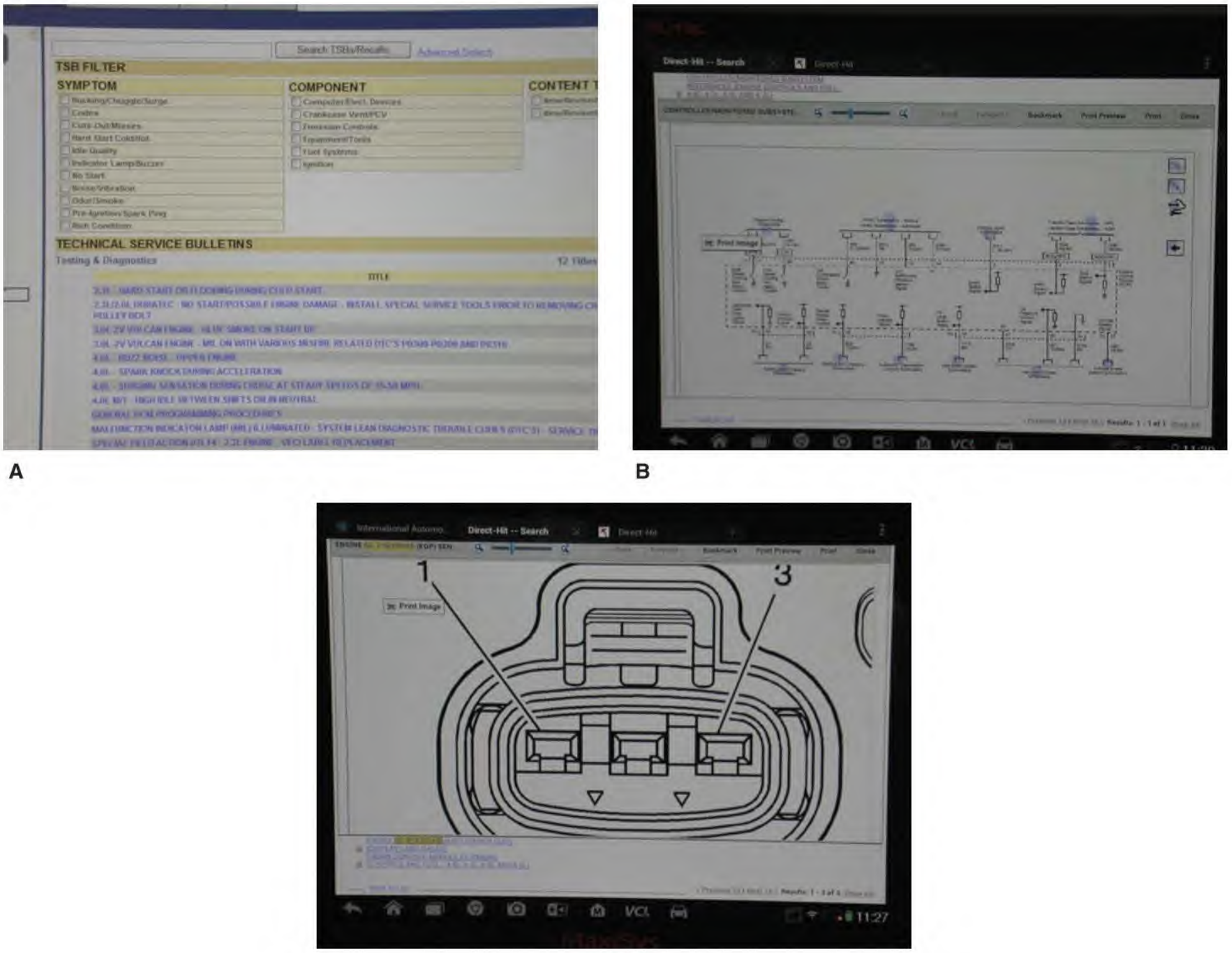
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from weak ignition coils to faulty ECMs. By inputting the make, model, and year of the vehicle into the device, along with the vehicle's symptoms or problems, the diagnostic software will list common part problems to "steer you in the right direction" for finding and fixing these difficult issues. See **Figure 54-20**. The tool's connection to the Internet makes such a convenience possible.

Ignition Load Test

An ***ignition load test***, or ***acceleration test***, measures the spark plug firing voltages when engine speed is rapidly increased. When an engine is accelerated, higher voltage is needed to fire the spark plugs. While a defective component may produce a normal scope pattern at idle, it may not operate properly under load.

To perform a load test, set the scope on parade and idle the engine between 1000 and 1200 rpms. While watching the firing lines on the scope, quickly open the injection throttle valve and release it. The firing voltage should increase, but it must not exceed certain limits.



A B C

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Figure 54-20. Laptop computers or touch-screen diagnostic tablets have replaced large engine analyzers. A scanner or diagnostic tablet can be plugged into the car's diagnostic connector to show which cylinder is misfiring. This avoids the need to connect a dozen test leads to the engine to take scope readings. If a trouble code sets for cylinder number 3, you would know to check all parts (ignition coil, spark plug, and wiring connections) that affect combustion in that cylinder. A—Laptop screen showing common symptoms and problems for specific makes and models of cars and trucks. B—Diagnostic tablet displaying a specific wiring diagram to aid in problem diagnosis. C—Tablet screen shot showing pin numbers for checking electrical values at a specific wiring harness connector.

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The highest firing line should not be more than 75% of actual coil output. Typically, voltage should not exceed 15 kV in a contact point ignition or 20 kV in an electronic ignition. The upward movement of the firing lines during the load test should be the same. If any of the firing lines are high or low, a defect is present.



Diagnostic Case Study

Concern: Mr. Farnsworth brings his pickup truck to the shop with an elusive problem. When asked to describe the problem, he says that the engine runs fine but loses all power after several minutes of driving. After the vehicle sits for about 20 minutes, it starts and runs again. Mr. Farnsworth says he has taken his truck to four different shops and none have been able to fix the problem.

Cause: Duff checks for trouble codes and finds none. He also checks for obvious problems but finds nothing. Since the vehicle must be driven for several minutes before the engine stops running, Duff suspects that engine heat may be related to the problem, especially since the ECM is located in the engine compartment on Mr. Farnsworth's vehicle. He passes the job along to one of the shop's master automobile technicians.

The technician decides to begin his diagnosis by heating the ECM to normal operating temperature to determine whether it is causing the problem. He starts the engine and lets it idle. To ensure that he does not damage the ECM by overheating it, he aims a laser thermometer on the ECM case. Next, he uses a heat gun to warm the ECM. When the ECM reaches 140°F, the engine stalls. The technician attempts to restart the vehicle without success.

Correction: The technician installs a new ECM and takes the truck for a test drive. The vehicle operates properly. Back at the shop, the technician checks the ECM temperature with the digital thermometer. The ECM temperature is 150°F and the vehicle is functioning normally. The test drive and diagnostic time are added to the customer's bill and the truck is released to the owner.

Summary

- Strategy-based diagnostics involves using a consistent, logical procedure to narrow down possible problem sources.
- Scan tool datastream values are "live" electrical values measured with the vehicle running or driving.
- A breakout box allows you to pinpoint test electrical values at specific pins on the ECM or in the computer system.
- Electromagnetic interference results from induced voltage into wires and can cause a computer to malfunction.
- Scope voltage is shown on the scope screen along the vertical (up-and-down) axis or scale.
- Scope time is given on the scope screen on the horizontal scale in degrees, milliseconds, or duty cycle.
- A primary scope pattern shows the low voltage or primary voltage changes in an ignition system.
- The secondary scope pattern shows the actual high voltages needed to fire the spark plugs.
- The term *superimposed* means that all the cylinder waveforms are placed one on top of the other.
- The parade pattern, also called the display pattern, lines up the waveform for each cylinder end-to-end across the screen.
- In a raster pattern, or stacked pattern, voltage waveforms are arranged individually one above the other, starting with the number one cylinder on the bottom of the screen.
- Some electrical connectors are sealed and do not allow easy probing. You may need to install a test connector or jumper wires between the two halves of the connector to probe sensor voltages.
- An oscilloscope can be used to check the ac and dc voltages leaving an electronic control module or ECM.
- A flight record test stores the sensor waveform in the scope memory when a problem occurs.

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Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

acceleration test
amplitude
analog scope pattern
baseline
breakout box
coil oscillations section
cylinder select
diagnostic laptop computer
diagnostic tablet
digital scope pattern
digital thermometer
display pattern
dwell section
dynamometer
dyno
electromagnetic interference (EMI)
expanded display
falling edge
firing line
firing section
flight record test
high-time
ignition load test
intermediate section
leading edge
low-time
off-time
on-time
oscilloscope
parade pattern
peak-to-peak voltage
primary scope pattern
primary superimposed pattern
raster pattern
reference voltage test
rising edge
scan tool datastream values
scope
scope screen
scope sweep rate
scope time
scope voltage
secondary scope pattern
secondary superimposed pattern
snapshot
spark line
stacked pattern
strategy-based diagnostics
trace
trailing edge

Activities

1. Study the instruction manual for a touch-screen diagnostic tablet and demonstrate how to hook it up and perform a test designated by your instructor.
2. With the oscilloscope feature selected on an advanced scan tool and the tool connected to a vehicle's DLC, point out the three sections of an ignition secondary scope pattern.
3. Interpret the trace patterns of a scope set up to test the ignition system.
4. Scope test several sensors using a laptop computer or diagnostic tablet. Make a sketch of the waveform produced by each with a written explanation of your results.

Review Questions

Answer the following questions using the information provided in this chapter.

1. Define *strategy-based diagnostics*.
2. A scan tool _____ is a record of the operating parameters present at the moment a problem occurs.
3. Electromagnetic interference can be caused by _____.
   (A) loose wires
   (B) unshielded secondary wires
   (C) aftermarket electrical accessories
   (D) All of the above.
4. A(n) _____ box allows a technician to test electrical values at specific pins on an ECM's wiring harness.
5. A(n) _____ is used to measure an engine's power output and on-the-road performance without driving the vehicle out of the shop.
6. How do you read a scope pattern?
7. Voltage is shown along the vertical axis of the scope screen. True or False?
8. A(n) _____ involves using a multimeter to measure the actual voltages being sent out by the ECM to resistive sensors.
   (A) radio interference test
   (B) dynamometer test
   (C) reference voltage test
   (D) flight record test
9. On the scope screen, _____ is given on the vertical scale and _____ is given on the horizontal scale.
10. One kV equals _____.
    (A) 100 volts
    (B) 1000 volts
    (C) 10,000 volts
    (D) None of the above.

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11. If a scope waveform is higher or taller than normal, this indicates a component with a higher-than-normal _____.
12. The _____ scope pattern shows the actual voltages needed to fire the spark plugs.
13. Sketch and explain the three major sections of an ignition system's secondary waveform scope pattern.
14. When analyzing a square wave, what six things should be checked?
15. A wireless diagnostic tablet retrieves trouble codes and performs tests remotely through a wireless scan tool module that the technician connects into the vehicle's _____.
    (A) engine cylinders
    (B) ignition electrical circuit
    (C) fuse panel
    (D) data link connector (DLC)

ASE-Type Questions

1. Technician A says that strategy-based diagnostics involves using a logical procedure to narrow down possible problem sources. Technician B says that advanced diagnostic techniques are used when conventional tests fail to pinpoint a problem. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Technician A says computer terminal values should be measured with a low-impedance meter. Technician B says computer terminal values should be measured with a digital VOM. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. A scan tool has the capability to perform each of the following tasks *except*:
   (A) display datastream values.
   (B) capture a snapshot of operating parameters.
   (C) measure exhaust emissions.
   (D) switch actuators on and off.
4. Technician A says an oscilloscope's primary pattern represents the high-voltage changes in an engine's ignition system. Technician B says an oscilloscope's primary pattern represents the low-voltage changes in an engine's ignition system. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. Technician A says a low scope sweep rate will extend the waveform, causing only a small section of the complete waveform to be displayed. Technician B says sweep rate is commonly given in minutes. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. The spark line on an oscilloscope's secondary pattern is almost straight and about one-fourth as high as the firing line. Technician A says this indicates normal ignition system operation. Technician B says this indicates an ignition system malfunction. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. Technician A says electronic components within vehicles are free from problems caused by temperature extremes. Technician B says electromagnetic interference in late-model vehicles may cause vehicle computer systems to malfunction. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. Technician A says low circuit resistance can affect a square waveform. Technician B says high circuit resistance can affect a square waveform. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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9. Technician A says that a diagnostic laptop computer or tablet can display real-time datastream values when connected to a vehicle. Technician B says a wireless diagnostic tablet can access vehicle data remotely via a module connected to the vehicle DLC and the shop's wireless Internet network. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. A vehicle is brought into the shop with fuel injector problems. Technician A says a laptop computer with diagnostic software can be used to detect certain fuel injector malfunctions. Technician B says a touch-screen diagnostic table is also capable of testing fuel injector operation. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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Section 10

Engine Service and Repair

Chapter 55
Engine Mechanical Problems

Chapter 56
Engine Removal, Disassembly, and Cleaning

Chapter 57
Short Block Rebuilding

Chapter 58
Engine Top End Rebuilding

Chapter 59
Engine Front End Service

Chapter 60
Engine Reassembly, Installation, and Break-In

Engine mechanical problems generally result from abuse or prolonged service. As an engine runs, friction slowly wears pistons, piston rings, cylinder walls, bearings, journals, valves, and other components.

This section will give you the skills needed to properly troubleshoot and rebuild automotive engines. Chapter 55 describes engine problems and summarizes repair procedures. Chapter 56 explains how to properly tear down an engine while gathering information about its condition. Chapters 57–60 detail how to measure, inspect, and assemble the parts of an engine, as well as how to install and break in an engine. The information in this section will help you pass ASE Test A1, *Engine Repair*.



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Chapter 55
Engine Mechanical Problems

After studying this chapter, you will be able to:

- Explain why proper diagnosis methods are important to engine repair.
- List common symptoms of engine mechanical problems.
- Discuss how to find abnormal engine noises.
- Summarize procedures for gasoline and diesel engine compression testing.
- Explain when and how to do a cylinder leakage text.
- Summarize common causes and corrections of engine mechanical problems.
- Perform an initial inspection, pressure tests, and electronic tests to determine the mechanical condition of major internal engine parts.
- Correctly answer ASE certification test questions on engine mechanical problems and corrections.

As an engine runs, internal friction and combustion slowly wear valves, pistons, piston rings, cylinder walls, bearings, journals, cam lobes, and other moving parts. This constant wear increases clearances between precise fitting assemblies. With enough clearance increase, worn bearings can leak oil pressure so that engine parts "hammer together" and self-destruct. Engine mechanical problems result from part wear and breakage after prolonged service (over 100,000 miles of operation) or abuse (over-revving or engine modifications).

This chapter will further explain common engine mechanical problems. It will introduce engine problem symptoms such as rod bearing knock, main bearing knock, piston double knock, valve clatter, and other abnormal engine operating conditions. You will learn what different engine knocks and noises sound like. You will also learn proven tests to find the source of any mechanical problem.

Why Is Diagnosis Important?

If a technician does not know how to properly diagnose engine problems, a great deal of time, effort, and money will be wasted. In fact, an untrained technician may unnecessarily rebuild an entire engine assembly when a minor repair would have corrected the fault.

For example, a worn or stretched timing chain can cause the engine valves to open and close at the wrong times in relation to piston movement. This could cause low compression stroke pressure in all cylinders. The engine would have low power output and low compression readings. It might also overheat and crack the engine exhaust manifolds.

The technician could incorrectly diagnose the trouble (worn timing chain) as a major engine mechanical

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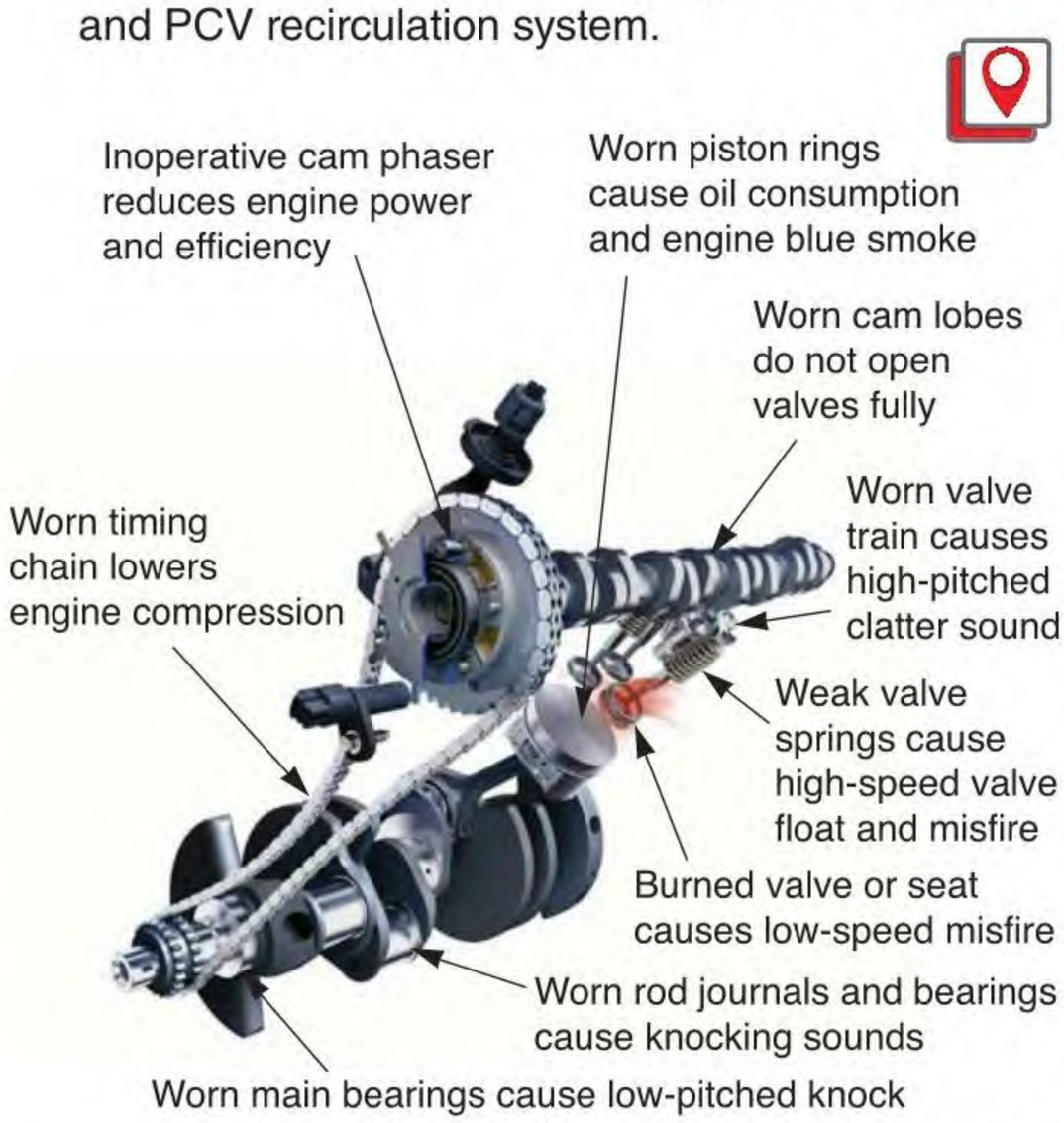
problem (worn piston rings, scored cylinders, etc.) and unnecessarily overhaul the engine. The misdiagnosis would result in the customer paying a lot more than necessary due to the technician's lack of training or knowledge.

Common Engine Mechanical Problems

Common engine mechanical problems include leaking gaskets, worn piston rings, burned and leaking valves, loose or worn engine bearings, worn timing chains, and damaged (cracked, broken, scored) engine parts. See **Figure 55-1**.

These problems can occur after extended service (high mileage), engine overheating, lack of periodic maintenance, and other types of abuse. Symptoms that result from these types of problems include the following:

- Excessive oil consumption—Due to external oil leakage (bad oil pan gasket or oil seal), or internal oil leakage (oil flowing up past piston rings and valve seals), engine oil must be added often.
- Crankcase blowby—Combustion pressure blows past the piston rings, into the engine crankcase and PCV recirculation system.



Ford

Figure 55-1. Engine mechanical problems may be related to the valve train, timing mechanism, engine gaskets, cylinder head, cylinder block pistons, connecting rods, crankshaft, or intake or exhaust manifolds.

- Abnormal engine noises—Knocking, tapping, hissing, and rumbling are audible.
- Engine smoking—Too much fuel, water, or oil burned during combustion can produce blue-gray, black, or white smoke blowing out of the tailpipe.
- Poor engine performance—Symptoms include rough idle, slow acceleration, and vibrating engine.
- Coolant in engine oil—Leaking coolant produces oil with white, milky appearance.
- Engine lockup—Lockup prevents the crankshaft from rotating.

With any of these troubles, inspect and test the engine to determine the exact problem source. You must find out what repair is needed. You can then determine whether the engine can be repaired in the vehicle or if it must be removed for more major repairs.

Engine Smoke

Engine smoke is normally noticed exiting the tailpipe when the engine speed is increased or decreased. The color of the smoke is important in diagnosing the source of the problem, as shown in **Figure 55-2**.

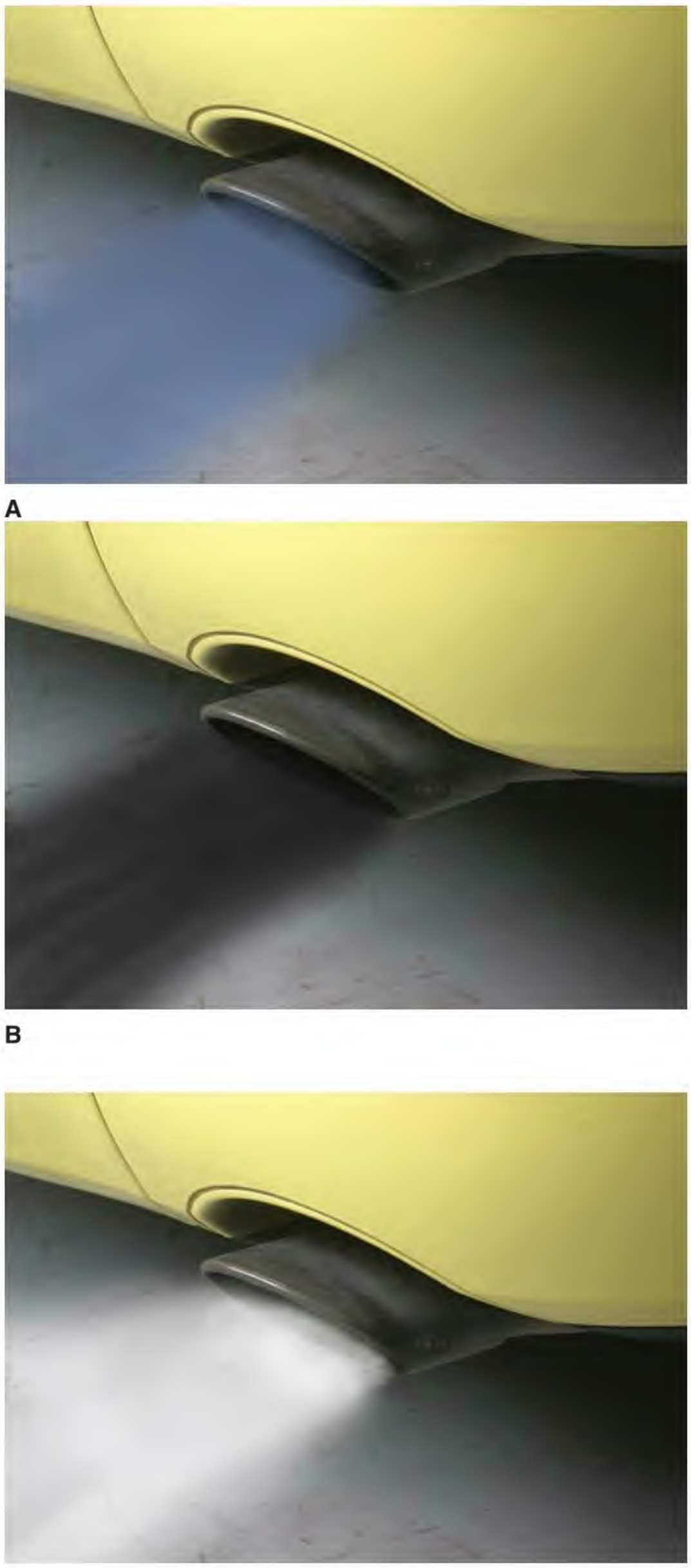
With a gasoline engine, excessive exhaust smoke may be the following colors:

- ***Blue-gray engine smoke***—Engine oil is entering combustion chambers. Smoke may be due to worn rings, worn cylinders, leaking valve stem seals, or other troubles.
- ***Black engine smoke***—Black smoke is caused by an extremely rich air-fuel mixture, not an engine mechanical problem.
- ***White engine smoke***—White smoke may be due to internal coolant leaking into the cylinders. It may also be the result of water condensation due to moisture collecting in the muffler and exhaust pipes as they warm up.

With a diesel engine, exhaust smoke may be the following colors:

- ***Blue diesel smoke***—Engine oil is entering combustion chambers and being burned. This may be due to ring, cylinder, or valve seal problems.
- ***Black diesel smoke***—There is an injection system problem, or low compression is keeping fuel from burning.
- ***White diesel smoke***—White smoke is the result of unburned fuel, a cold engine, or coolant leaking into the combustion chambers.

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A

B

C

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Figure 55-2. Engine smoke may indicate major problems. A—Blue smoke points to oil entering combustion chambers. B—Black smoke suggests a rich fuel mixture. C—White smoke, if not normal water condensation, may indicate coolant or anti-freeze leakage into cylinders and chambers.

Engine Pre-Teardown Inspection

After gathering information from the customer or service writer, start the vehicle and inspect the engine using your senses (sight, smell, hearing, touch). Look for external problems (oil leaks, vacuum leaks, part damage, contaminated oil, etc.).

If a leak is found, smell the fluid to determine if it is oil, coolant, or another type of fluid. Listen for unusual noises, which may indicate part wear or damage.

Increase engine speed while listening and watching for problems. The engine may run fine at idle but act up at higher speeds. Several engine problems can be identified through simple inspection.

Coolant in oil will show up as white or milky oil. It is caused by a mechanical problem that allows engine coolant to leak into the engine crankcase. There may be a cracked block or head, leaking head gasket, leaking intake manifold gasket (V-type engine), or similar troubles. Look at **Figure 55-3A**.



A



B

Toyota

Figure 55-3. During engine inspection, look for obvious signs of major problems. A—Check the dipstick for coolant, gasoline, or other contaminants in the oil. The condition of the oil may reflect the condition of the engine. B—Check spark plugs for oil fouling. This would point to bad piston rings, cylinder walls, or valve seals causing oil leakage into the combustion chambers.

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Oil-fouled spark plugs point to internal oil leakage into the engine combustion chambers, **Figure 55-3B**. They are an indication that the engine has worn rings, worn or scored cylinder walls, or bad valve seals. You will need to perform additional tests to find the source of the problem. Oil in the coolant is usually not an indication of engine problems. It is commonly caused by a leak in the radiator (transmission) oil cooler. However, on rare occasions, a faulty head gasket, a cracked block, or a cracked head can allow oil to seep into coolant passages, contaminating the coolant with oil.

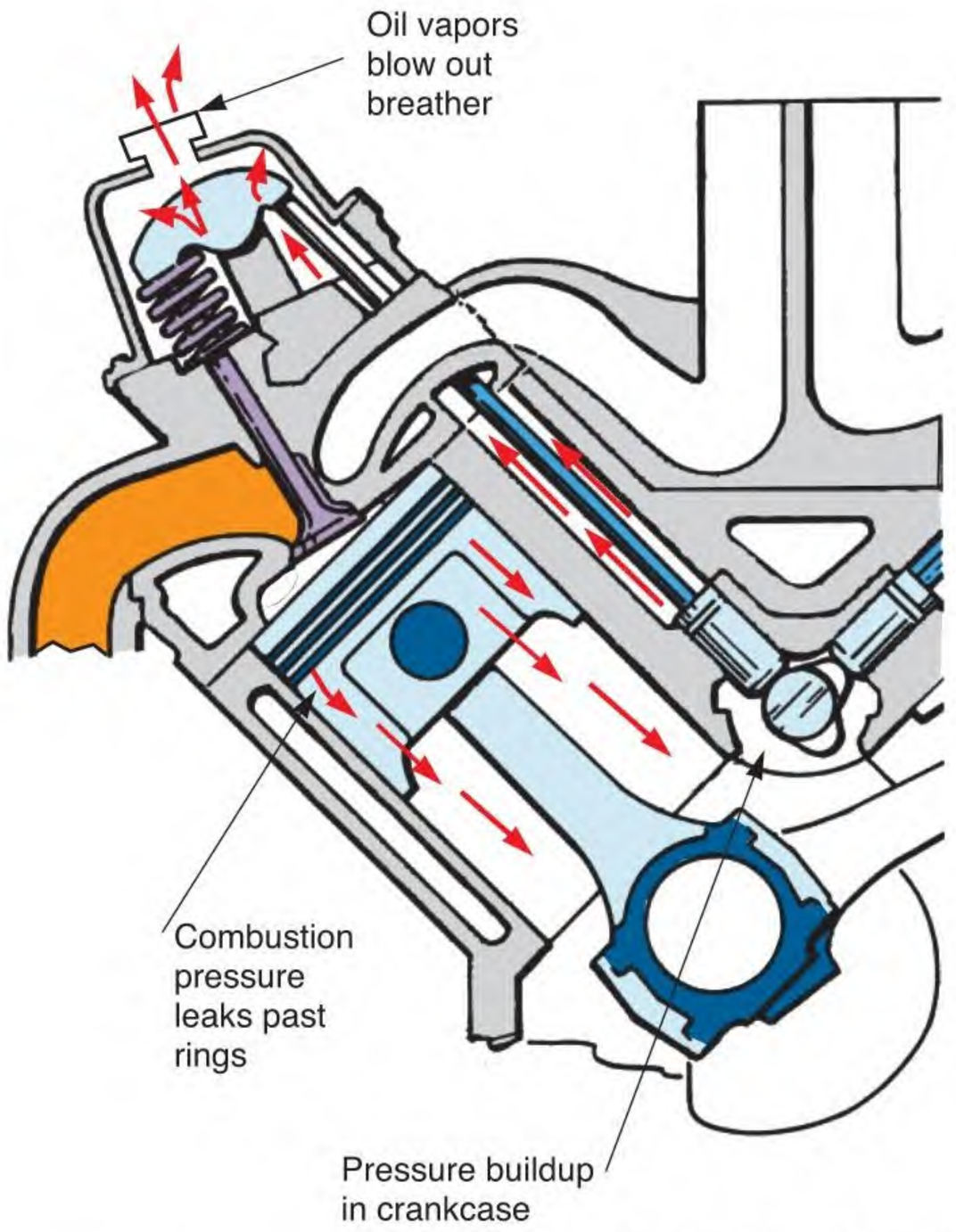
Engine oil leaks are the result of hardened or cracked gaskets, worn seals, loose fasteners, or damaged parts. To find oil leaks, clean the affected area on the outside of the engine. Then, trace the leak upward to its source. Oil will usually flow down and to the rear of the engine because of cooling fan action.

External coolant leaks will show up as a puddle of coolant under the engine. Leaks can be caused by hose problems; rusted freeze (core) plugs; or warped, worn, or damaged parts. Use a pressure tester to locate external coolant leaks.

Engine blowby occurs when combustion pressure blows past the piston rings and into the lower block and oil pan area of the engine. Pressure then flows up to the valve covers and out through the breather. Excessive blowby will show up as an oily area around the breather. With the valve cover breather removed, oil vapors may blow out when the engine speed is increased. See **Figure 55-4**.

Engine vacuum leaks show up during inspection as a hissing sound, like air leaking out of a tire. Vacuum leaks are loudest at idle and temporarily quiet down because as the engine is accelerated, manifold vacuum drops. Very rough engine idling usually accompanies a vacuum leak.

Engine exhaust leaks show up as a clicking sound around the engine. Combustion pressure will blow out the leak and make a metallic noise. A ruptured exhaust manifold gasket, warped exhaust manifold, or loose header nuts are the most common reasons for exhaust leakage. The clicking sound will tend to decrease on engine deceleration because combustion pressure is lessened as soon as the throttle is closed and fuel metering is decreased. Refer to **Figure 55-5**.



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Figure 55-4. Blowby allows combustion pressure to enter the engine crankcase past the piston rings. Pressure buildup in the lower end of the engine can cause oil mist to blow out of the breather openings (cap removed) and into the PCV system..

Abnormal Engine Noises

Abnormal engine noises (hisses, knocks, rattles, clunks, popping) may indicate part wear or damage. You must be able to quickly locate and interpret engine noises and determine what repairs are needed.

A stethoscope is a listening device. Like a doctor's stethoscope for listening to your heart, an automotive stethoscope can be used to find internal sounds in parts.

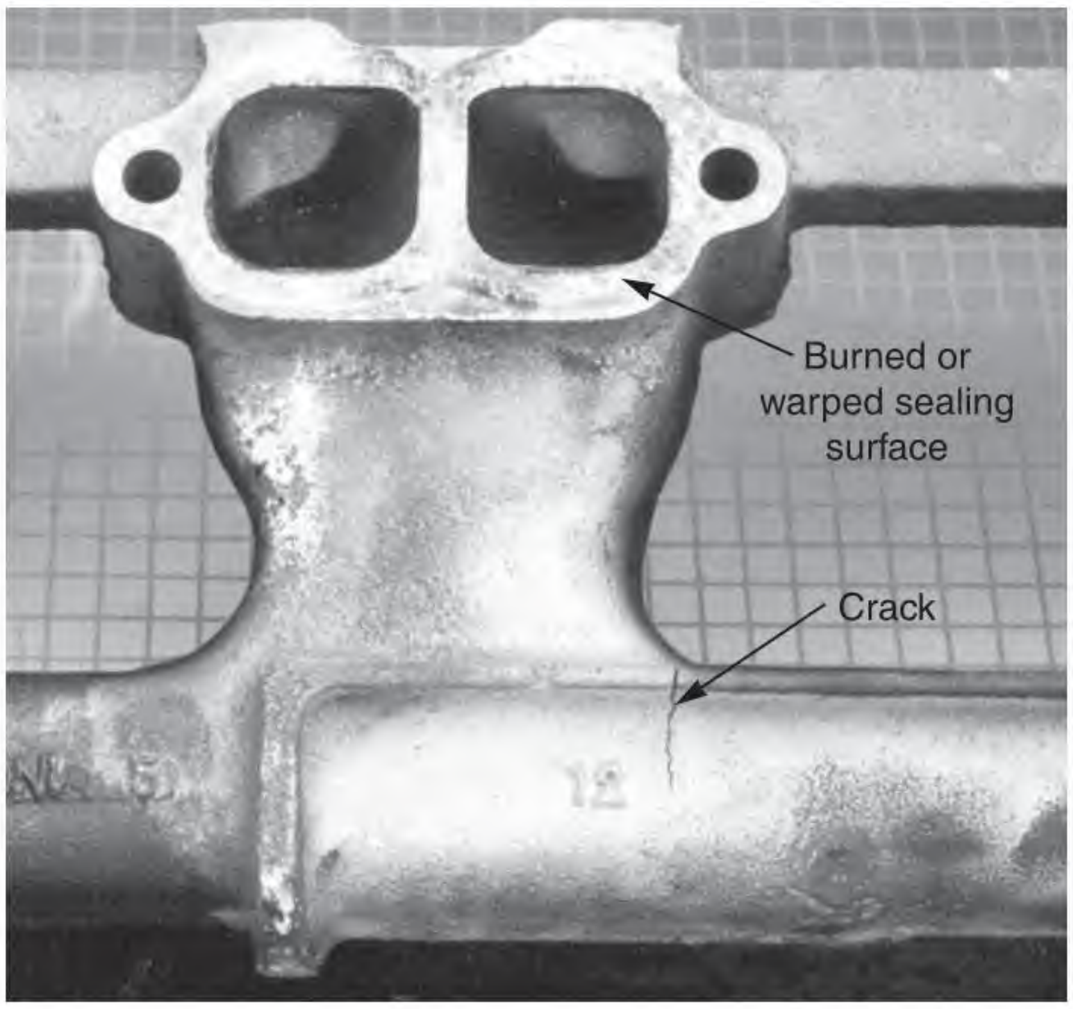
To use a stethoscope, put on the headset earpiece. Then, place the probe around the noisy area until you hear the loudest sound. If a stethoscope is not available, use a long screwdriver. Sounds will travel through the screwdriver the same way they do with a stethoscope.

A section of hose can be used to locate vacuum leaks and air pressure leaks. Place one end of the hose next to your ear. Move the other end around the engine compartment. The hiss becomes louder as the hose nears the leaking part.

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A



B

Fel-Pro

Figure 55-5. An engine exhaust leak will make a light ticking or clicking sound as high-pressure gas pulses leave the cylinder head. A—This exhaust leakage path could be easily seen after exhaust manifold removal. B—This exhaust manifold cracked from overheating because the engine ran with retarded ignition timing for an extended period of time.

Warning

When using a listening device, keep it away from the spinning engine fan or belts. Severe injury could result if the stethoscope, screwdriver, or hose hits and is pulled into the fan or belts!

Testing Engine Mechanical Conditions

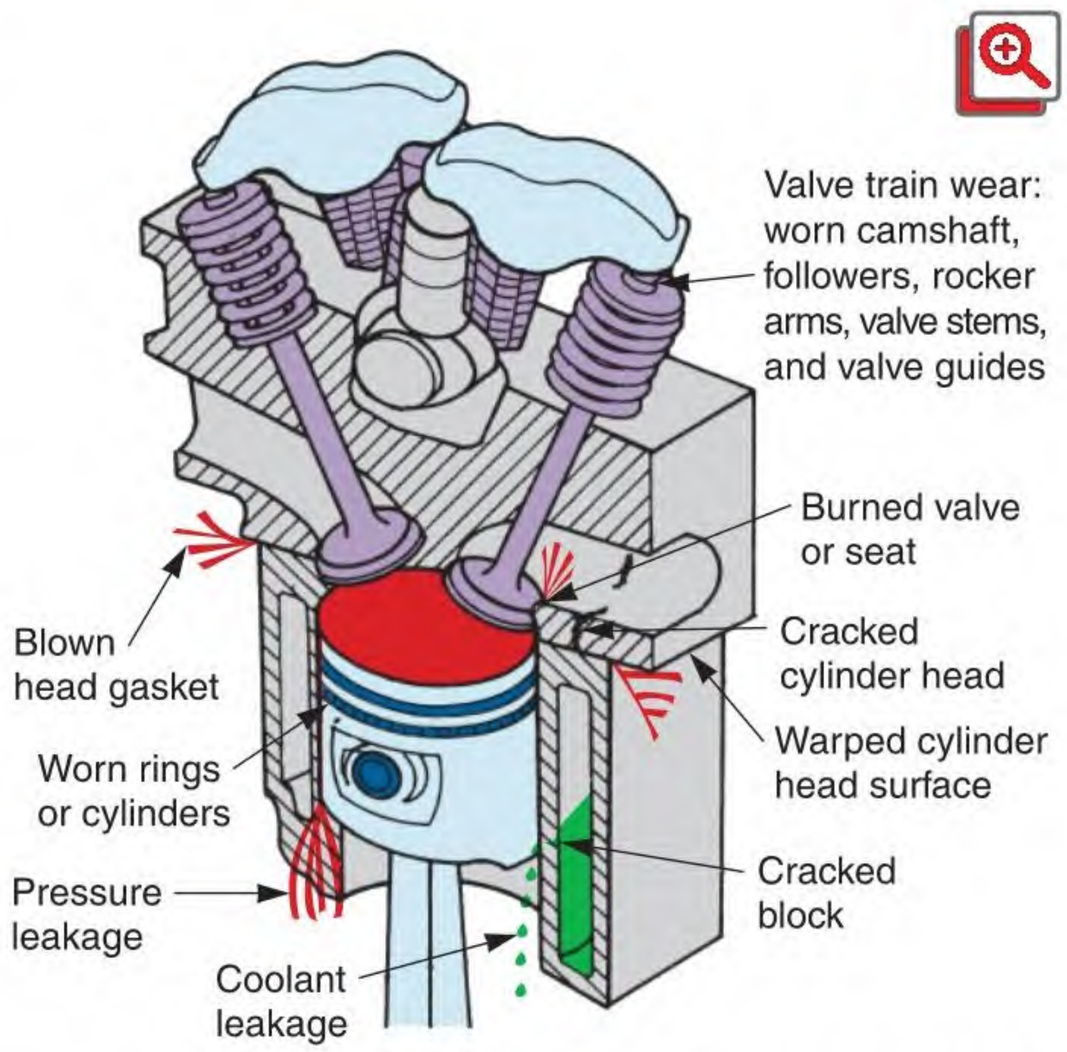
There are many electronic and pressure/vacuum gauges you can use to find the source of major engine failures. Perform the tests in the order discussed, since each test gathers more information about the possible engine problem.

Cranking Balance Test

Modern scan tools, laptops, or diagnostic tablets can perform a ***cranking balance test*** to check the engine's mechanical condition. This test looks for cylinders with low compression. Low compression may be due to burned engine valves, worn piston rings, or other engine mechanical problems. See **Figure 55-6**.

The advanced diagnostic device monitors the amount of current drawn by the starter motor through a complete crankshaft rotation. As each cylinder goes through its compression stroke, a little more starter current draw is needed to rotate the crankshaft.

Lower peak current draw during any compression stroke shows low compression in that cylinder. A low current draw or low display line for any cylinder indicates the starter is not being loaded enough by the compression stroke.



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Figure 55-6. Note the typical reasons for combustion pressure leakage.

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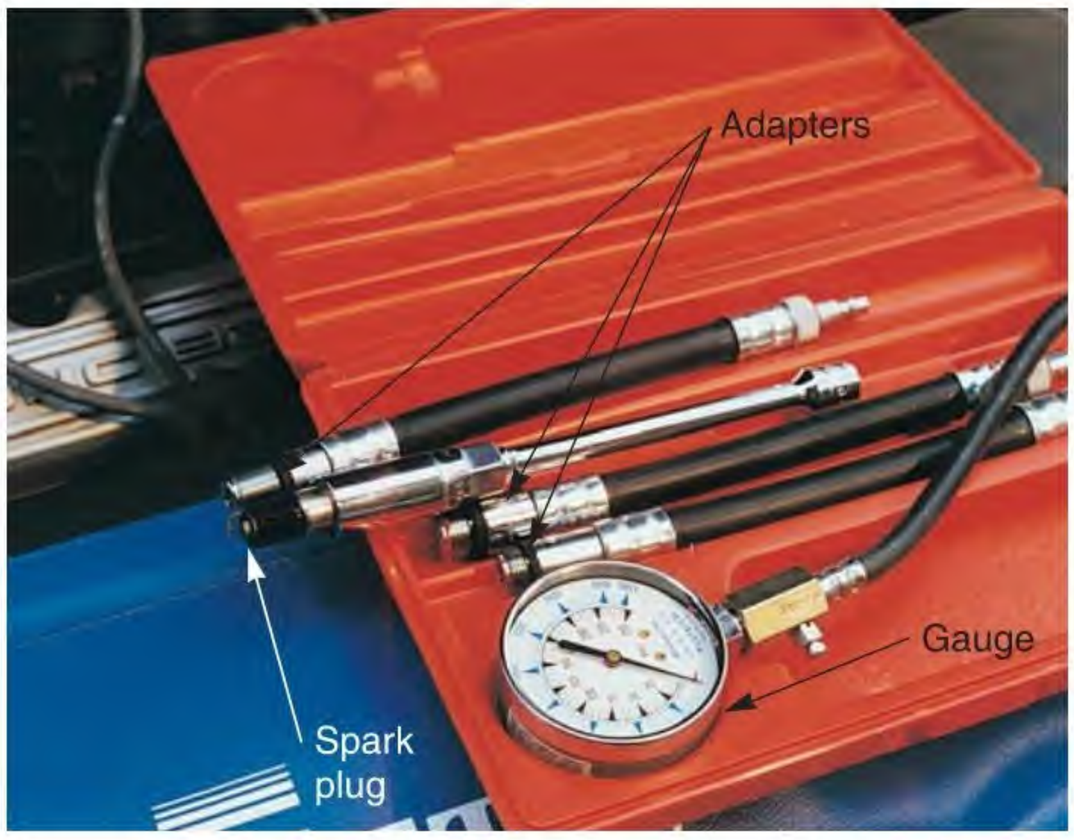
Compression Test

A ***compression test*** is used to determine compression stroke pressure. This is a common method of determining engine mechanical condition. It should be done anytime symptoms point to cylinder pressure leakage. An extremely rough idle, popping noise from the air inlet or exhaust, excessive blue smoke, or blowby are all reasons to consider a compression test.

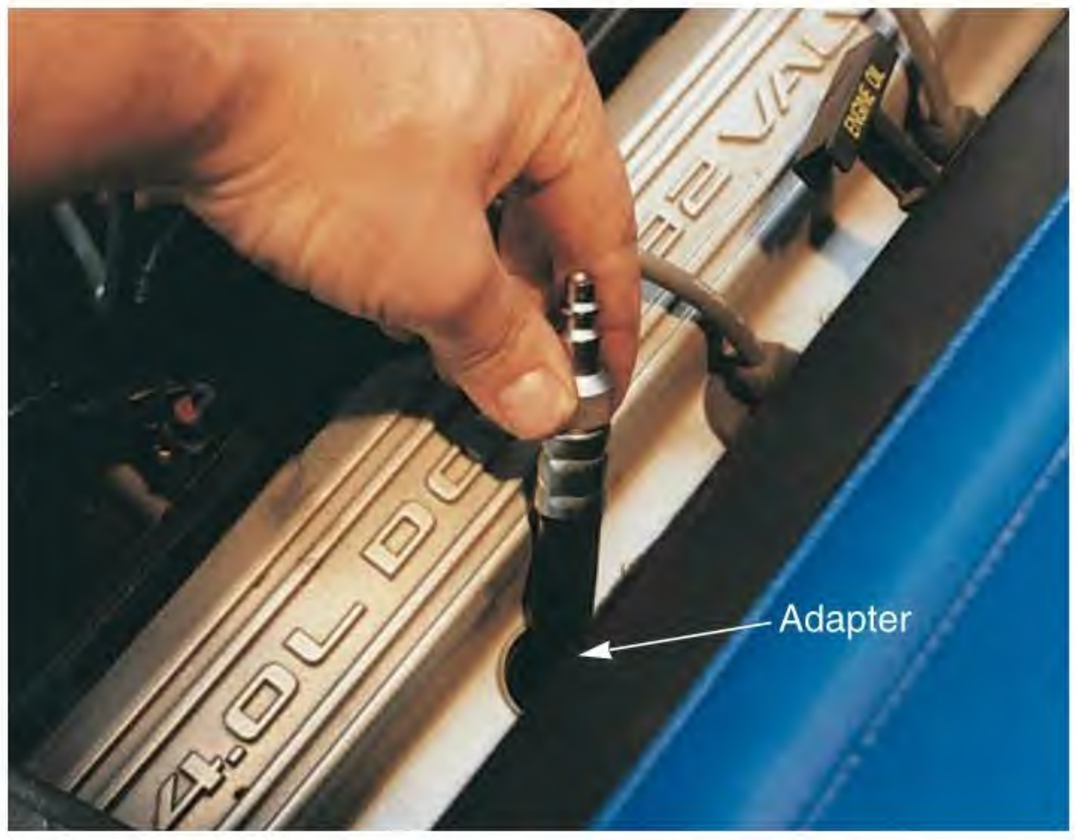
Tech Tip

A compression test is often performed to verify low compression after a cranking balance test indicates trouble.

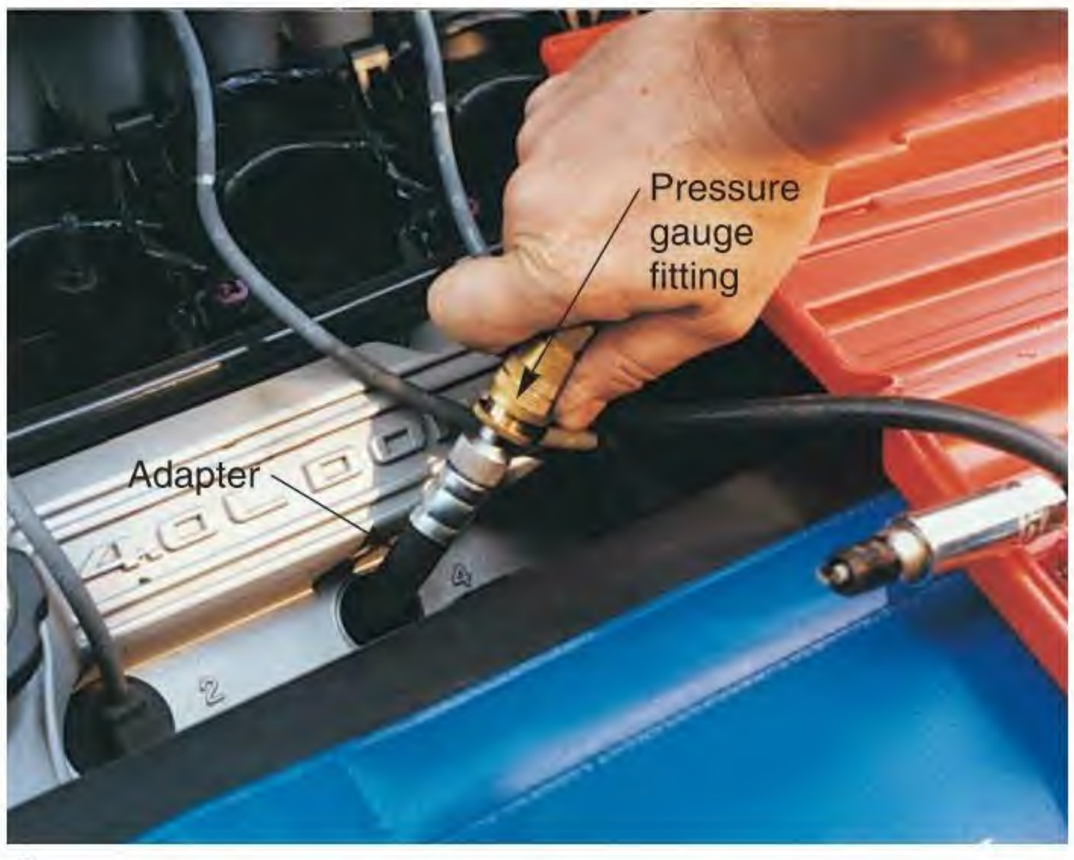
A ***compression gauge*** is used to measure compression stroke pressure during this test. If gauge pressure is lower than normal, pressure is leaking out of the engine combustion chamber. Refer to **Figure 55-7**.



A



B



C



D

Snap-on Tool Corp.

Figure 55-7. Study the major steps for doing a compression test. A—Select the correct adapter to match spark plug thread size. Remove all spark plugs. B—Screw the compression test hose adapter into the spark plug hole. C—Install a pressure gauge onto the adapter by pulling back on the sleeve and pushing down on the gauge. D—Crank the engine until the pressure gauge reading levels off at maximum. Repeat on other cylinders.

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A compression test is frequently performed during a tune-up. If the engine fails the compression test, mechanical repairs must be made before the tune-up because it is impossible to tune an engine that is not mechanically sound.

Several problems can cause ***low engine compression***:

- Burned valve(s).
- Burned valve seat.
- Physical engine damage, such as a hole in a piston, broken valve, and so on.
- Blown head gasket.
- Worn rings or cylinders.
- Broken valve spring.
- Insufficient valve clearance.
- Jumped timing chain or belt.

Compression Test—Gasoline Engine

Service Procedure

To perform a compression test on a gasoline engine:

1. Remove all of the spark plugs so that the engine will crank easily.
2. Block open the throttle plates to prevent a restriction of airflow into the engine.
3. Disable the ignition system to prevent sparks from arcing out of the disconnected spark plug wires or direct coils.

Caution

Some electronic ignition systems may be damaged if operated with an open (max resistance) secondary high-voltage circuit. Usually, the primary wire connector going to the ignition coil or coil pack can be removed to disable high-voltage output. On older engines, ground the secondary coil wire to avoid electric arcs shooting out of the disconnected high-tension conductors.

4. Disable the fuel injection system so that gasoline will not spray into the engine during cranking. This could be very dangerous if fuel vapors ignited during the compression test. Unplug the primary 12-volt wires to the injectors or remove the fuel pump fuse. Check service data for specific directions.
5. Screw the compression gauge into one of the spark plug holes. Hand tighten the fitting into the threaded spark plug hole.
6. Crank the engine, allowing the crankshaft to rotate for about six compression strokes. The needle on the compression gauge will move up a little on each compression stroke.
7. Write down the gauge readings for each cylinder and compare the readings to specifications.

Gasoline engine compression readings should be around 125 psi (860 kPa) for a turbocharged engine with an 8:1 compression ratio. Compression test readings can go as high as 200 psi (1400 kPa) on an engine with 12:1 compression. Readings should be within 5–15% of each other.

Look for cylinder pressure variations during an engine compression check. If some cylinders have normal pressure and one or two have low readings, engine performance will be reduced. The engine will have a rough idle and lack power.

If all of the cylinders have low pressure readings, the engine may run smoothly but lack power and gas mileage. If a camshaft is out of time with the crankshaft (due to a worn timing chain, for example), compression pressure will be lowered in all cylinders.

Two adjacent cylinders with low pressure readings might point to a blown head gasket with a rupture between the two cylinders. A blown head gasket will sometimes produce a louder-than-normal puffing noise from the spark plug or glow plug holes with the compression gauge removed. One end of an engine can sometimes run hotter and fail more often than middle cylinders due to uneven coolant flow. Also, if the low cylinder is at the back of the engine, the camshaft may be broken.

Compression Test—Diesel Engine

A diesel engine compression test is similar to a gasoline engine compression test. However, a compression gauge intended for use on a gasoline engine must never be used on a diesel engine. The gauge can be damaged by the high compression stroke pressure. A diesel compression gauge must read up to approximately 600 psi (4200 kPa).

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Service Procedure

To perform a compression test on a diesel engine:

1. Remove either the injectors or the glow plugs. Refer to a service manual for instructions (most suggest glow plug removal).
2. Install the compression gauge in the recommended hole.
3. Disconnect the fuel shut-off solenoid to disable the injection pump.
4. Crank the engine about six compression strokes and note the highest reading on the gauge.

Diesel engine compression readings will average 275–400 psi (1900–2750 kPa), depending on the engine design and compression ratio.

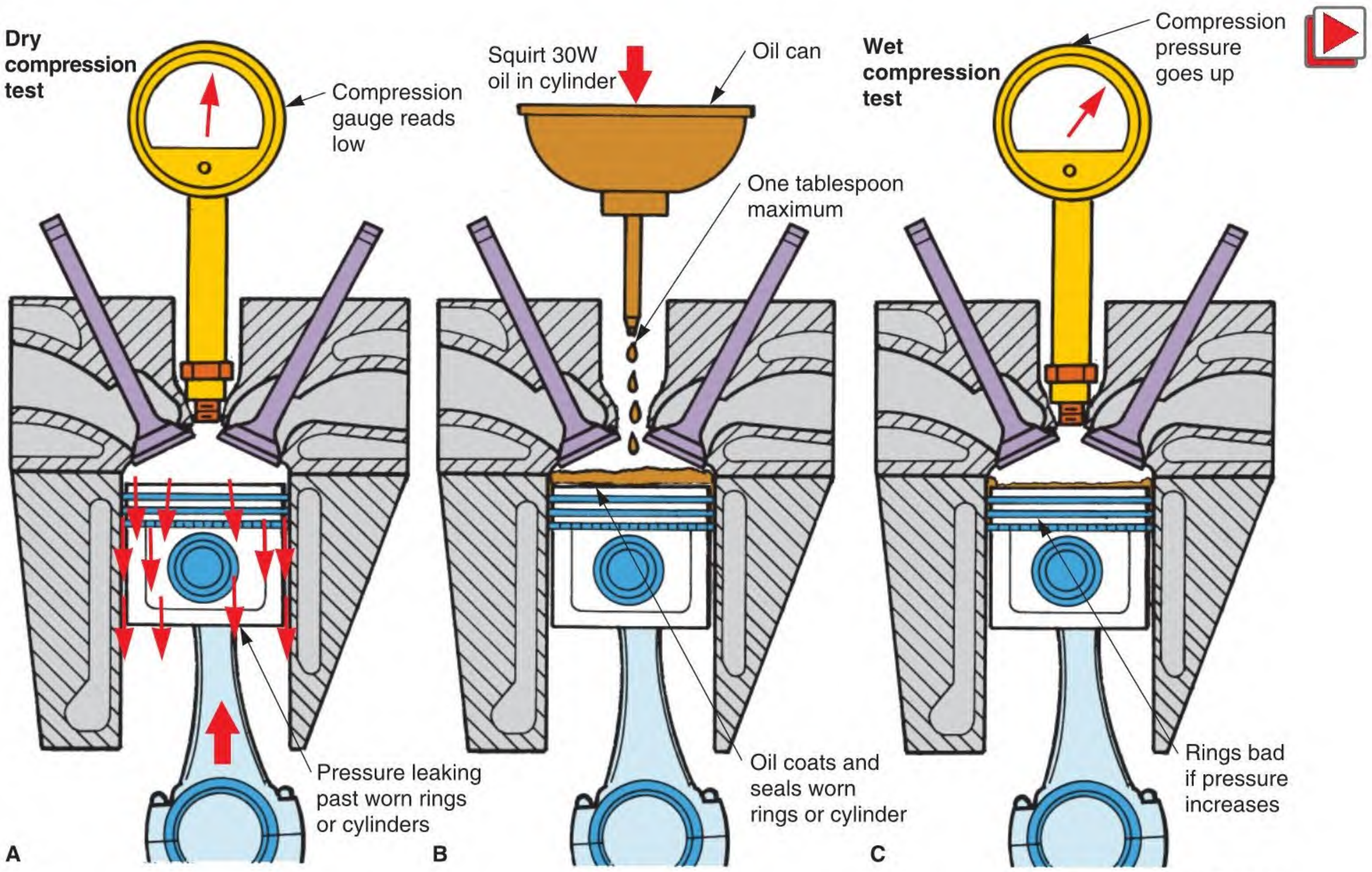
Tech Tip

During a compression test, the cranking speed must be up to specifications, about 200 rpms minimum. The engine should also be warm for accurate test results. Charge the 12-volt battery if cranking rpms are too low.

Wet Compression Test

A ***wet compression test*** should be performed in any cylinder that has a compression test reading below specifications. The test will help you determine which engine parts are causing the problem. See **Figure 55-8**.

To conduct a wet compression test, squirt a tablespoon of SAE 30 engine oil into the cylinder having the



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Figure 55-8. Study the steps for a wet compression test using motor oil to seal the piston rings. A—Complete a conventional, dry compression test with a pressure gauge. Record all readings and compare to specifications. B—If compression is low, squirt a tablespoon of oil into the cylinder to temporarily seal rings. C—Measure compression pressure again. A higher pressure reading indicates that the cylinder may have bad rings or is a worn cylinder. The same pressure reading would indicate a burned valve or blown head gasket.

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low pressure reading. Do not squirt too much oil into the cylinder during a wet compression test, or a false reading will result. With excessive oil in the cylinder, compression readings will go up even if the piston rings and cylinders are not in good condition. Oil, like any liquid, will not compress. It will take up space in the cylinder, raising the compression ratio and gauge readings.

After placing a small amount of oil in the cylinder, install the compression gauge. Recheck the cylinder pressure using the procedure for a standard (dry) compression test. If the compression gauge reading increases with oil in the cylinder, the piston rings and cylinders may be worn and leaking pressure. The oil temporarily coated and sealed the bad compression rings to increase compression pressure.

If the pressure reading remains the same with oil in the cylinder, the engine valves or head gasket may be leaking. The engine oil will seal the rings but will not seal a burned valve or blown head gasket. In this way, a wet compression test will help diagnose low-compression problems.



Caution

Some manufacturers warn against performing a wet compression test on a diesel engine. If too much oil is squirted into the cylinder, hydraulic lock and part damage could result because the oil cannot be compressed in the small cylinder volume.

Dynamic Engine Compression Test

A ***dynamic engine compression test***, also termed a ***running engine compression test***, measures cylinder pressures with a test gauge while the engine is idling. It is sometimes done after a conventional plug-out, cranking, or static compression test. When no engine problems and low compression problem cylinders are found, a dynamic compression test is performed to find intake air and exhaust system problems affecting engine performance.



Service Procedure

To perform a dynamic compression test on an engine:

1. Run the engine until it reaches full operating temperature, if possible. This will heat-expand all engine parts to reach proper part clearances and also warm the motor oil to normal high temperature operating viscosity.
2. Pull all spark plugs and complete a normal (static) compression test. This will test and eliminate piston ring blowby; burned, leaking valves; holes in pistons; scored cylinder walls; and other major mechanical wear or damage as possible causes.
3. If you find cylinders with low compression during a plug-out compression test, an engine running engine compression test will not be necessary.
4. Complete a running engine compression test if you suspect a clogged engine intake or exhaust tract. Engine air intake or exhaust system blockage from damaged parts could be upsetting engine performance.
5. Install all but one spark plug back into the engine cylinder heads. Many technicians like to leave out the front, number 1 spark plug since it is usually easier to remove and install than the rear plug.
6. Ground the cylinder's ignition coil secondary terminal to the engine to prevent ICM or electronic module damage.
7. Disable the electronic fuel injector for the engine cylinder to be tested. Disconnect the injector coil winding by pulling off its plastic harness connector.
8. Install a compression gauge in the open spark plug hole.
9. Start and idle the engine. Observe the gauge pressure reading every five or six compression strokes.
10. Open the tool's Schrader valve to "zero" the gauge until you get a consistent reading for five or six "puffs," or gauge needle deflections. Each time the pressure gauge reading increases, it indicates another high-speed compression stroke.
11. Write down the average pressure gauge reading after a few engine compression strokes with the engine running.
12. Rapidly open the throttle valve lever on the engine throttle body. Increase engine speed to about 3000 rpms and then snap the throttle closed. This will make high cylinder vacuum gulp air to increase compression stroke pressure even more. If there are no air or exhaust restrictions, compression gauge readings should increase.

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Engine running compression pressure at idle should be 50–75 psi (about half cranking compression). Snap throttle compression should be about 80% of cranking compression.

If your snap throttle reading is low (less than 50% of cranking compression), look for a clogged air filter, carbon buildup on intake valves and valve ports, worn camshaft lobes, valves not opening fully, and inoperative variable runner intake manifolds. Breakage of the internal intake manifold flaps or ducts can restrict airflow into the engine to lower engine compression and performance.

If engine running compression readings are high, something is blocking engine exhaust flow. You could have a rusted, stopped-up muffler or pipe, or a burned, clogged catalytic converter.

Cylinder Leakage Test

A ***cylinder leakage test*** measures air leakage out of the engine combustion chamber. It is an accurate way of finding the specific trouble source. Shop air is used to pressurize the cylinder, and a pressure gauge is used to measure the actual percentage of cylinder leakage.

The gauge-valve unit is installed in a spark plug or glow plug hole. Shop air pressure is connected to the gauge-valve line. The crankshaft must be rotated so the cylinder being tested has its piston at TDC on the compression stroke (both valves closed).

To begin testing, adjust the air pressure so that the gauge reads zero leakage when the test hose is disconnected or shut off. Then, allow air to enter the cylinder. The pressure gauge should drop. The amount of pressure drop depends on how well the rings, valves, head gasket, etc., seal pressure inside the cylinder.

If the pressure gauge shows a pressure drop of 10% or less, the engine is in fair condition. A higher percentage of pressure drop indicates excess leakage and a mechanical engine problem.

To find the source of leakage, listen for a hissing sound at the intake manifold inlet, exhaust pipe, and valve cover breather. Depending on where you hear leakage, the problem(s) could include the following:

- **Hiss at the intake manifold inlet**—A leaking or damaged intake valve, an intake valve adjusted too tight, or a broken intake valve spring may be at fault.
- **Hiss at the tailpipe**—The problem may be a bent or burned exhaust valve, an exhaust valve adjusted too tight, or a broken exhaust valve spring.
- **Hiss at the valve cover breather**—Worn piston rings, worn cylinder walls, a blown head gasket, or a burned piston may be the cause.
- **Hiss around the outside of head**—This could mean a blown head gasket, a warped head or block deck, or cracked head or block.
- **Hiss from an adjacent spark plug hole**—A blown head gasket, cracked head, or cracked block may be the problem.

Tech Tip

During a cylinder leakage test, make sure you have the piston at TDC on the compression stroke. If piston is not at TDC, a valve could be open and cause false indications.

Vacuum Test

A vacuum gauge can be used to perform a ***vacuum test***, which measures intake manifold vacuum and indicates engine condition.

Service Procedure

To perform a vacuum test:

1. Connect the vacuum gauge to an intake manifold vacuum fitting.
2. Warm the engine.
3. Run the engine at the correct idle speed and read the vacuum gauge. Vacuum should be steady and within specifications, about 15″–17″ Hg (40 cm/Hg to 45 cm/Hg).

A burned valve, late ignition timing, worn timing chain or belt, restricted exhaust system, etc., will show up as abnormal vacuum gauge readings. Refer to the service manual and textbook index for more information on engine vacuum testing.

Cylinder Balance Test

A ***cylinder balance test***, also called a ***power balance test***, measures the power output from each of the engine's cylinders. As each cylinder is disabled by the scan tool, laptop, or tablet, the tachometer

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should indicate an rpm drop. During a cylinder balance test, all cylinders should have the same percentage of rpms drop (within 5%). If a disabled cylinder does not produce an adequate amount of rpms drop, the cylinder is not firing properly.



Caution

Never short a cylinder in a running vehicle with a catalytic converter for more than 15 seconds; converter overheating damage could result.

If the rpms drop in one or more cylinders is below normal, a problem common to those cylinders is indicated. The cylinders could have low compression (burned valve, blown head gasket, or worn piston rings), a lean mixture (vacuum leak, faulty fuel injector, or computer malfunction), or other problems.



Tech Tip

Many late-model engines will automatically raise engine idle speed when a cylinder is disabled for testing. When doing a cylinder balance test, disable the idle speed control solenoid or motor so engine speed drops when a good cylinder is disabled.

Deciding What Type of Engine Repair Is Needed

After performing all the necessary inspections and tests, decide what part or parts must be repaired or replaced to correct the engine mechanical problem. Evaluate all data from your pre-teardown diagnosis. If you still cannot determine the exact problem, the engine may have to be partially disassembled for further inspection.

Evaluating Engine Mechanical Problems

Before you can properly repair engine problems, you must be able to do the following:

- Explain the function of each engine part.
- Describe the construction of each engine part.
- Explain the cause of engine problems.
- Describe the symptoms of major engine problems.
- Select appropriate methods to pinpoint specific problems.
- Know which parts must be removed for certain repairs.
- Know whether the engine must be removed from the vehicle before the repair can be made.

Engine Gasket Problems

A blown head gasket can cause a wide range of problems, including overheating, missing, coolant or oil leakage, engine smoking, and burned mating surfaces on the cylinder head or block. Quite often, a blown head gasket will be indicated by a compression test. Two adjacent cylinders, usually the two center ones, will each have low pressure.

A leaking intake manifold gasket often results in a vacuum leak, which may cause rough idle. To check for an intake gasket leak, squirt oil along the edge of the gasket. The oil may temporarily seal the leak, in which case the intake gasket has ruptured. A low vacuum gauge reading can also indicate an intake manifold gasket leak.

A leaking exhaust manifold gasket is indicated by a clicking sound. As combustion gases blow into the manifold and out of the bad gasket, a metallic-like rap is produced.

A leaking cam cover, leaking front cover, or leaking oil pan gasket will allow crankcase motor oil to drip from under the engine. An oil leak will increase oil consumption. If the leak is severe, it could empty the oil pan and cause major engine bearing damage.

Part warpage is a condition in which the sealing surfaces on a part are not flat. It is a common cause of gasket failure. Always check for warpage when servicing a bad gasket.

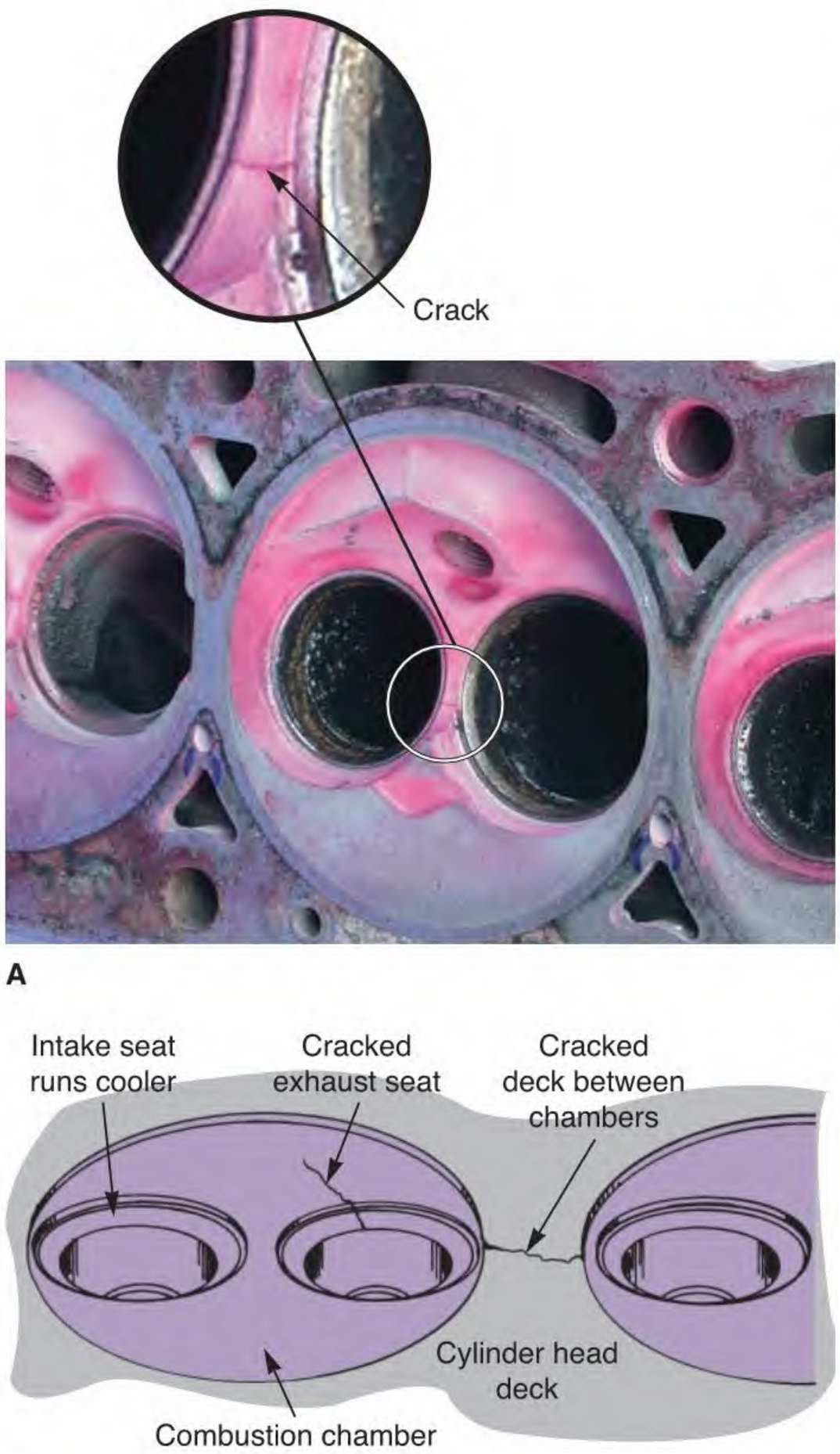
Cylinder Head Problems

A warped cylinder head has been overheated and is no longer true. Usually, the deck will warp and cause head gasket leakage. Coolant may leak into the engine oil, producing a milky substance. This is more of a problem with aluminum cylinder heads than with cast iron cylinder heads.

A cracked cylinder head may also result from engine overheating. Unequal heat expansion will break the head casting, usually near an exhaust port or on the deck between adjacent cylinders. Engine coolant that is weak in antifreeze can also freeze in cold weather and crack a cylinder head.

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A cracked head can leak coolant or combustion pressure. Coolant leakage can enter the combustion chamber or run down into the oil pan. Pressure leakage will allow combustion gases to enter the cooling system. Coolant on a spark plug, milky oil, white exhaust smoke, and overheating are symptoms of a cracked head. A cracked head must be removed and welded, or replaced. Look at **Figure 55-9**.



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Figure 55-9. Study how cracks can form in a cylinder head, usually from engine overheating and part overexpansion. A—This cylinder head had a crack between valve seats and had to be replaced. B—Locations of cylinder head cracks are shown. These cracks can be very small and difficult to see.

Valve Train Problems

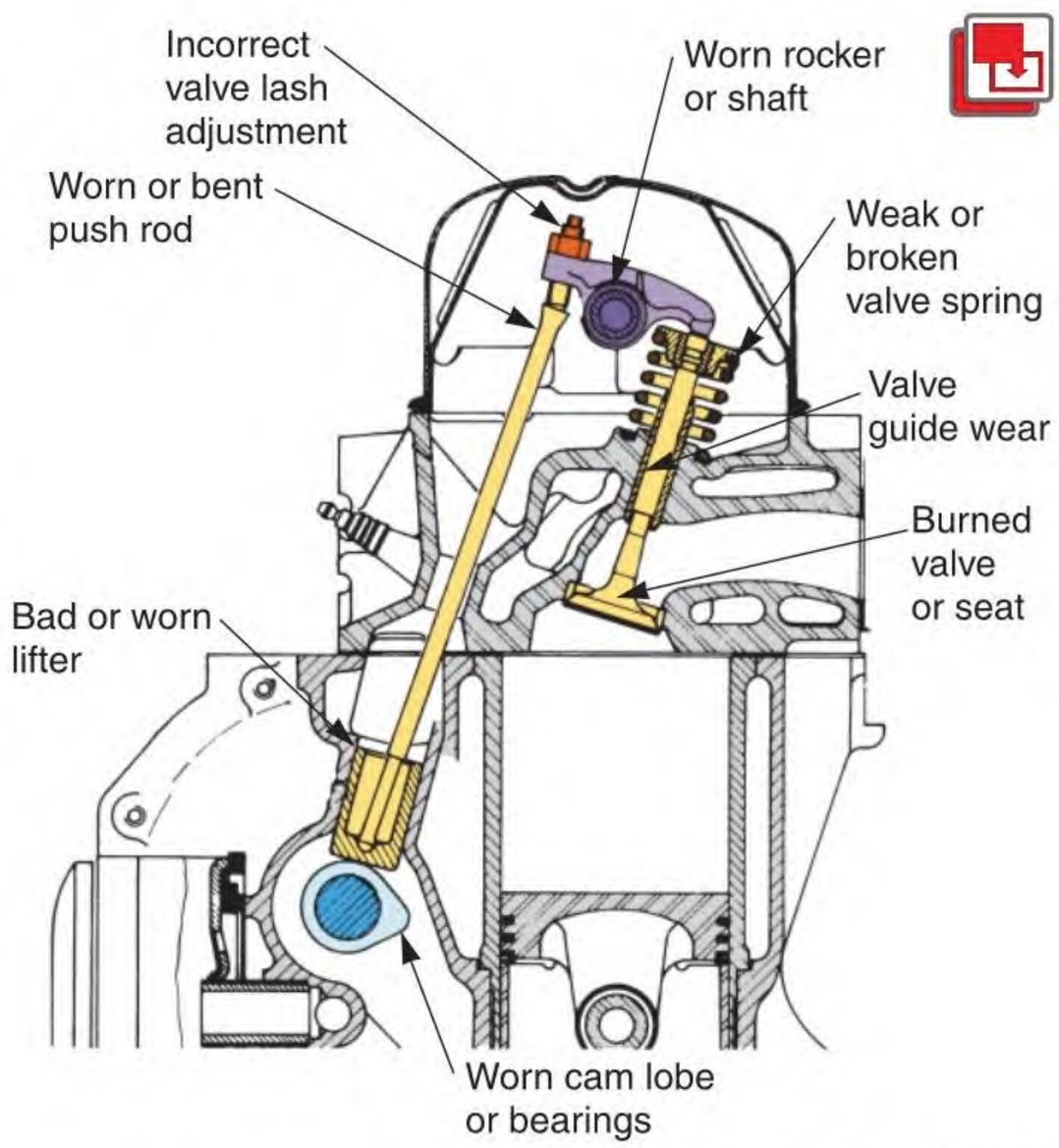
A bad engine valve train is a common cause of mechanical problems in an engine. Valve train problems can cause engine noise; power loss; missing; rough idling; and even piston, cylinder, and head damage. Friction is high between valve train parts, and most of the parts are lubricated by splash oiling. Wear can occur between parts after extended service or from lack of maintenance. Look at **Figure 55-10**.

Valve Problems

Valves open and close millions of times during the life of an engine. They must do this while sealing the tremendous heat of combustion. After extended service, various valve problems can develop. See **Figure 55-11**. You must be able to diagnose and locate intake and exhaust valve failures efficiently.

A burned valve has had a portion of the valve margin and face burned away from the high heat of combustion. Pressure can leak past the burned valve, reducing power in that cylinder. The engine will miss or run rough, especially at idle.

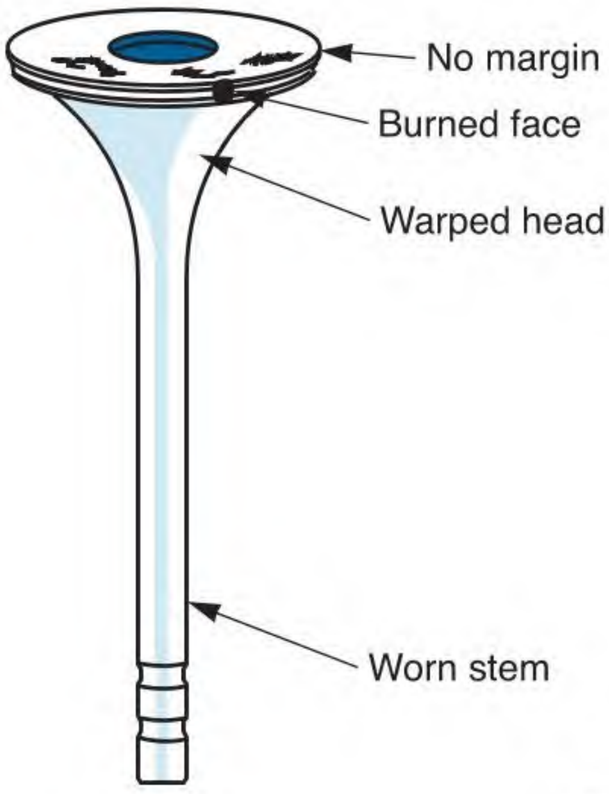
With a burned valve, you may be able to hear a puffing sound as pressure blows past the valve. There may be a popping or puffing sound at the throttle body



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Figure 55-10. Study these typical valve train problems.

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Sioux Tools

Figure 55-11. Note common problems that can develop with an engine valve. A burned valve face will usually set an engine misfire code. The resulting low compression stroke pressure will keep the fuel and air mixture from igniting and burning. A worn valve stem will let the valve wiggle sideways in the head, causing excess oil to be drawn into the port.

(bad intake valve) or exhaust system tailpipe (burned exhaust valve). To fix a burned valve, you must remove the cylinder head from the engine.

Valve face erosion is the wearing away of the face where it contacts the seat in the cylinder head. This is a common problem when unleaded fuel is used in an older engine that was designed for leaded fuel.

A bent valve is one in which the head of the valve is not perpendicular to the valve stem. It may result from over-revving of the engine, which may allow the piston to hit the valve head. A bent valve may also result from a timing belt problem on an interference engine.

A cracked valve often results from engine overheating. A chipped valve is normally due to mechanical damage or a defective valve.

A ***sharp valve margin*** (inadequate margin) is caused by valve face wear due to friction or from metal removal from valve grinding. A valve must have a margin between the valve head and face to withstand the high temperatures of engine operation. Normally, valve margin thickness is most important on the exhaust valves, since they are exposed to higher operating temperatures than the intake valves. See **Figure 55-12**.



Burned Valve



Eroded Valve Face



Bent Valve (right)



Cracked Valve



Chipped Valve



Sharp Valve Margin

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Figure 55-12. Study the types of wear and damage common on used engine valves.

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Valve stem wear results from friction between the stem and the valve guide in the cylinder head. Normally, only a small amount of oil enters the guide, which makes stem wear common. Valve stem problems are easy to overlook. Always inspect the stem, keeper grooves, and tip closely. Refer to **Figure 55-13A**.

Severe stem or guide wear can produce a light rapping or tapping sound. The valve can flop sideways when acted on by the rocker arm or valve spring. Head removal and valve replacement are needed to correct worn valve guides and stems.

In addition to wear along the length of the valve stem, check the keeper grooves for wear or damage. Also, if the chamfer on the stem tip is too small or missing, the tip is badly worn. Refer to **Figure 55-13B**.

Valve stem breakage is a severe failure that usually occurs when the piston hits the valve head. This will bend and break off the valve head at the stem. A broken valve spring, weak valve spring, missing keepers, etc., can cause this problem.

When the valve head breaks off, it will usually be hit by the piston and forced up into the cylinder head. Piston and head damage normally results.

Valve stem scoring results when the stem has been overheated and scarred by severe friction. The rough surface of the scored valve stem will accelerate valve guide wear.

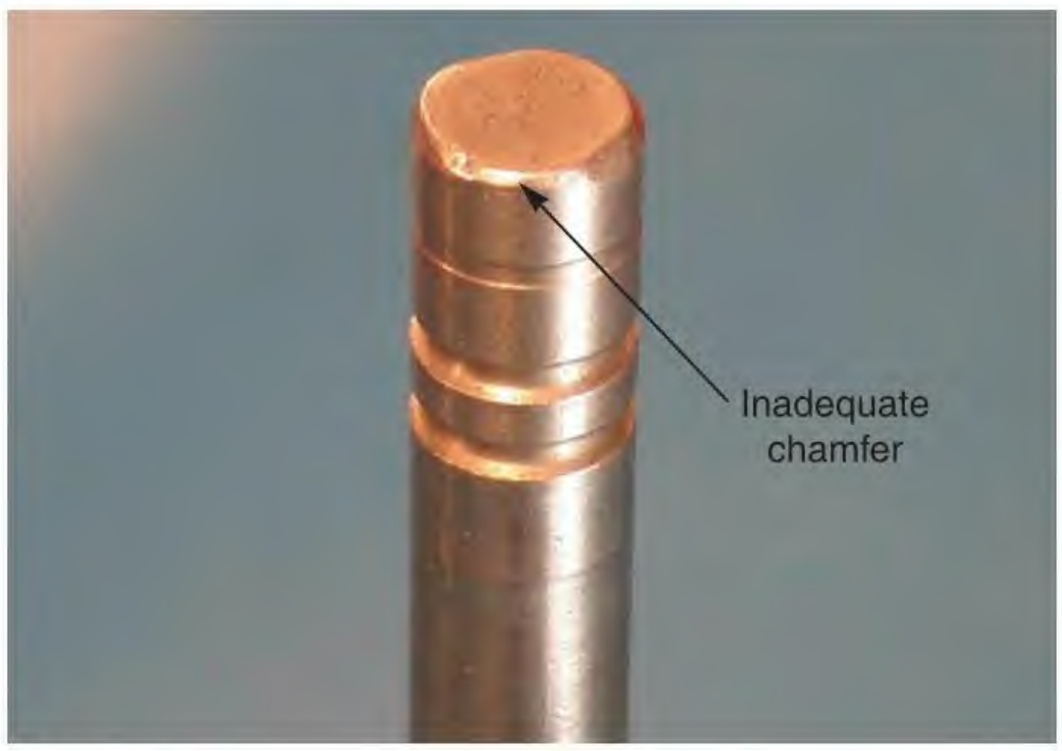
Valve guide wear produces the same symptoms as valve stem wear. The valve will be free to shift sideways in the guide. Oil can be drawn down through the excess clearance and burned in the combustion chamber. See **Figure 55-14.** Worn valve guides will make an engine smoke on startup. A tapping noise can also result from valve guide wear.

A ***dropped valve guide*** has broken free from its press-fit in the head, allowing the guide to fall down around the head of the valve. It can wedge the valve open and cause severe part damage. This problem is more common on aluminum heads.

A bad valve stem seal has hardened or broken from extended service or engine overheating. The synthetic rubber seals are no longer soft and pliable.



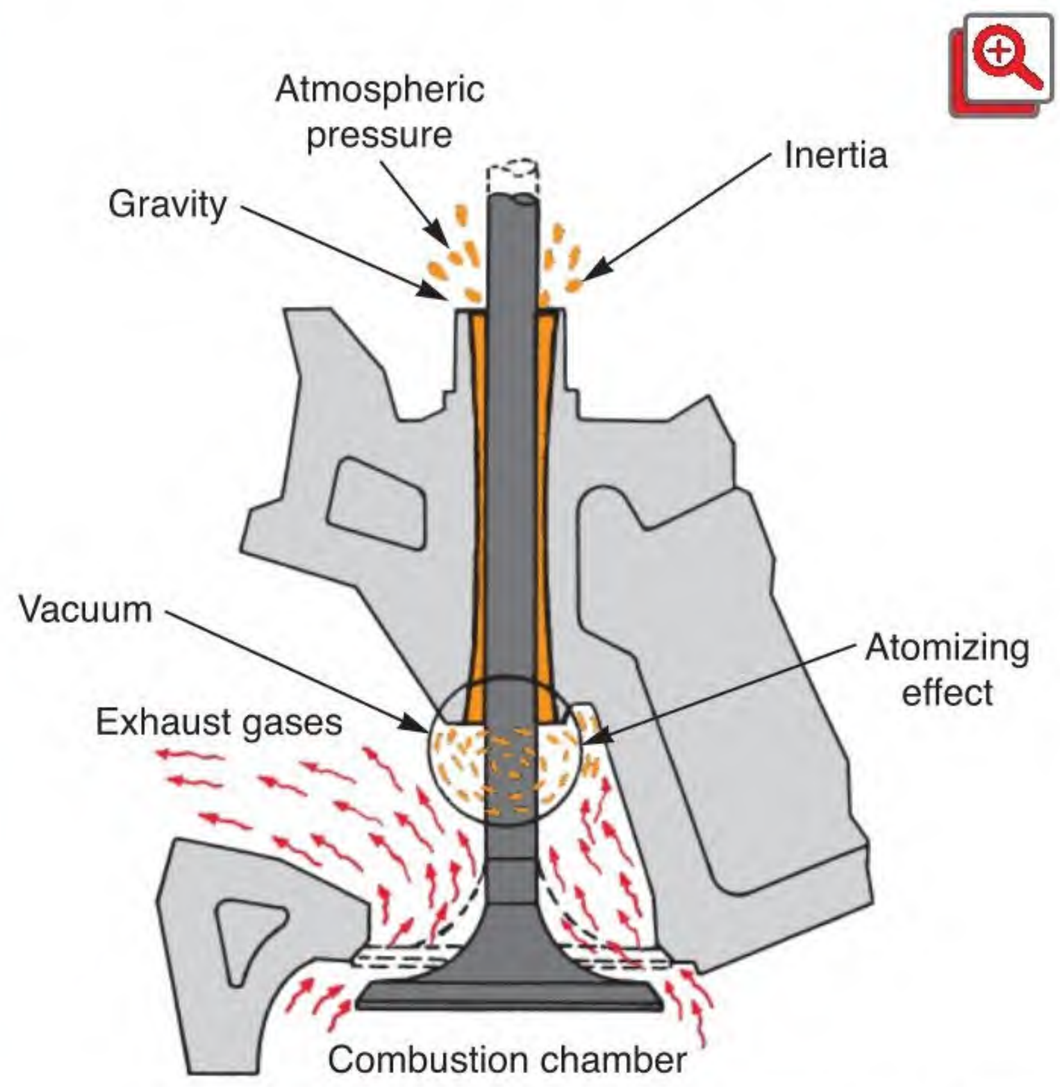
A



B

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Figure 55-13. Study engine valve stem problems. A—Inspect the stem tip and keeper grooves closely for wear and damage. B—The valve stem chamfer has been worn off, making the valve stem too short for proper valve clearance adjustment.



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Figure 55-14. Worn valve guides and bad valve stem seals are common engine problems. Oil can drain down out of the head and into combustion chambers in a few hours. Then, when the engine is first started, it will burn this oil and emit blue exhaust smoke for only a few seconds.

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With severe failure, a seal can disintegrate and fall down into the oil pan. Look at **Figure 55-15**.

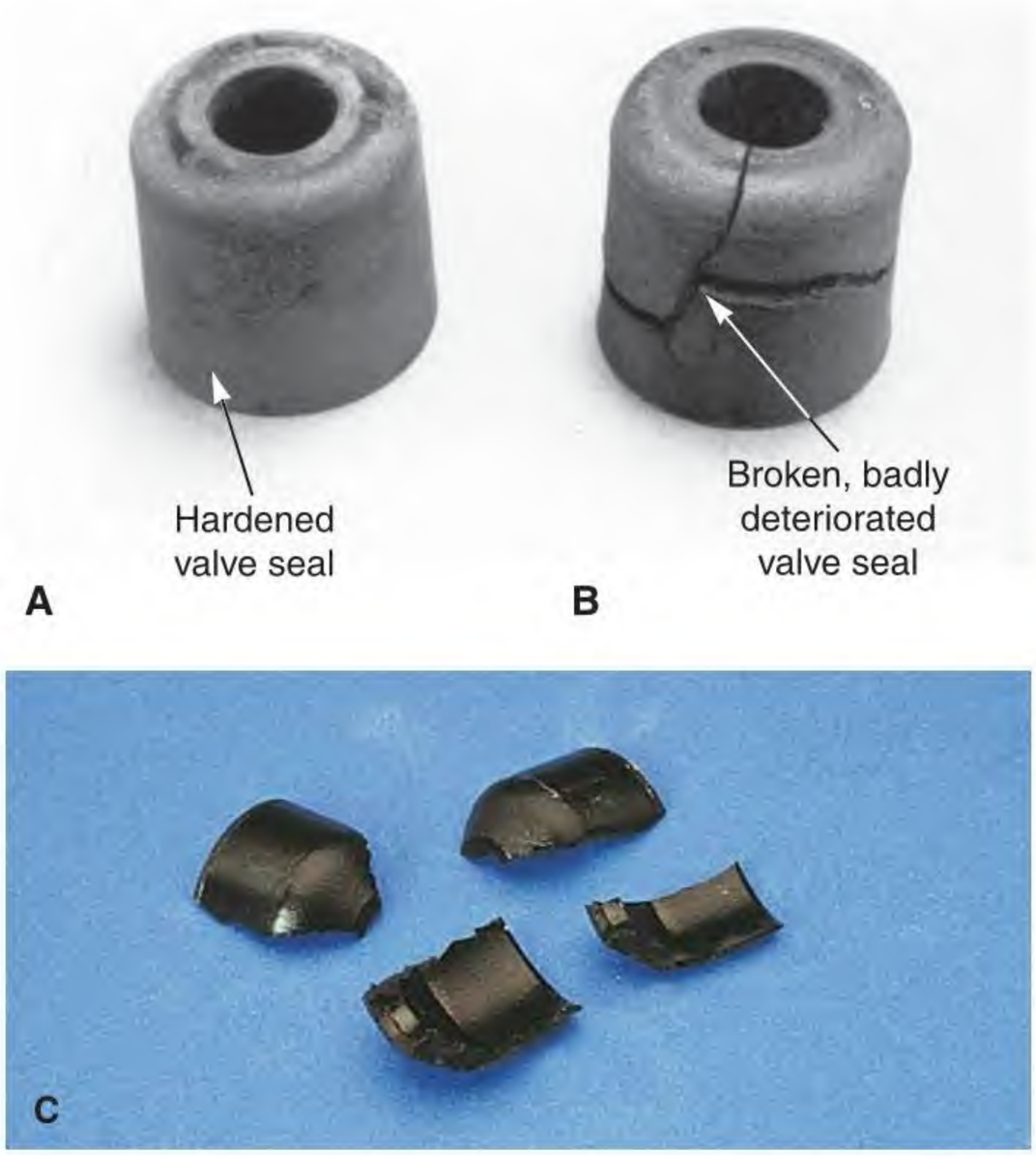
Bad valve stem seals will make the engine emit blue smoke from the tailpipe, especially right after engine start-up. Oil drips down past the seal and into the guides when the engine is not running. Then, on start-up, the oil is drawn into the cylinders and burned.

Valve stem seals can usually be replaced without removing the cylinder head. Air pressure is used to hold the valves closed. Then, a special tool is used to compress the valve spring. The keepers, springs, and seals can then be removed for service.

A ***stuck valve***, or ***frozen valve***, results when the valve stem rusts or corrodes and locks in the valve guide. This can happen when the engine sits in storage for an extended period.

A stuck valve can sometimes be fixed by squirting rust penetrant around the top of the valve guide. If this fails to correct the problem, remove the cylinder head for service.

If a valve is hit by a piston due to over-revving of the engine or a weak or broken valve spring, the valve can stick and lock in its guide. The valve will hang open and fail to close with normal spring action.



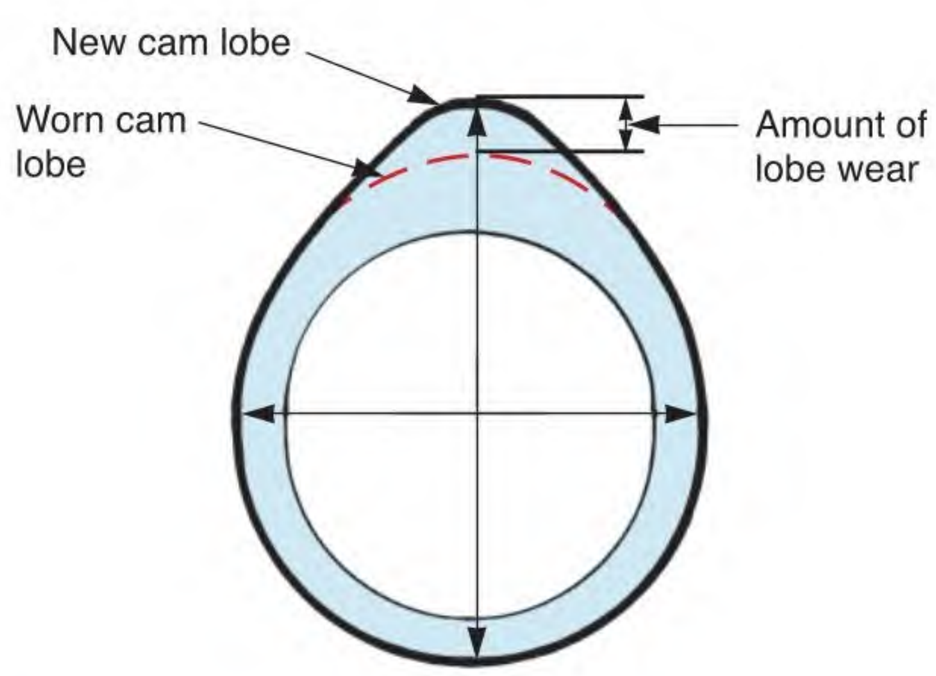
Fel-Pro

Figure 55-15. Bad valve stem seals. A—This valve stem seal looks fine, but it is hard and brittle and cannot stop motor oil flow into the valve guide. B—Cracked valve seals can break and fall into the bottom of the cylinder head or inside valve spring. C—This seal has broken up into pieces, which could block oil passages and cause oil starvation damage to other parts.

Camshaft Problems

There are several potential camshaft problems. These include lobe wear, journal wear, camshaft breakage, and camshaft drive failure.

Camshaft lobe wear is a condition where friction from the lifter or follower has worn off some of the camshaft lobe. Look at **Figure 55-16**. This usually happens in a high-mileage engine or one that has not had oil changes at the recommended intervals.



A



B

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Figure 55-16. The camshaft and lifters wear after prolonged service. A—A worn camshaft lobe will open valves less, reducing engine power and efficiency. If a cam lobe is worn enough, its valve may not open at all. B—This worn cam lobe's rough surface is due to the lifter wearing into the lobe. The customer did not change engine oil for more than 25,000 miles! The dirty oil acted as a grinding compound on all moving parts in the engine.

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Valve train clatter, reduced valve lift, and poor engine performance will result from excess lobe wear. To check for major lobe wear, remove the valve cover and watch the rocker arms or valve springs. A badly worn lobe will not open the valve normally. To check for minor lobe wear, you must measure the rocker arm motion with a dial indicator.

Camshaft journal wear and camshaft bearing wear will increase part clearance and can reduce engine oil pressure. Again, this normally only happens after extended service or operating the engine with dirty oil.

Camshaft thrust surface wear can allow the camshaft to move too far forward and rearward in the engine. This can sometimes produce a light, slow knocking sound, timing chain or gear problems, and increased lifter and lobe wear.

A broken camshaft will prevent some of the valves from operating. The lobes on one end of the broken camshaft will not rotate and open their valves. Severe performance problems or valve damage can result. Removal of a valve cover will let you check valve train and camshaft action. Camshaft breakage is not very common, but should be considered if several cylinders are dead.

Hydraulic Lifter or Tappet Problems

Hydraulic lifter or tappet problems can produce valve train noise or a light tapping sound from inside the valve cover. A new lifter has a convex (crowned or humped) bottom, which makes it rotate in the lifter bore during engine operation. High mileage can wear off this crown and accelerate camshaft lobe wear. Look at **Figure 55-17**.

External lifter wear results in the bottom of the lifter becoming concave (sunk in) due to friction between the lifter and camshaft lobe. This can increase the valve train clearance. Engine disassembly is needed to verify external lifter wear.

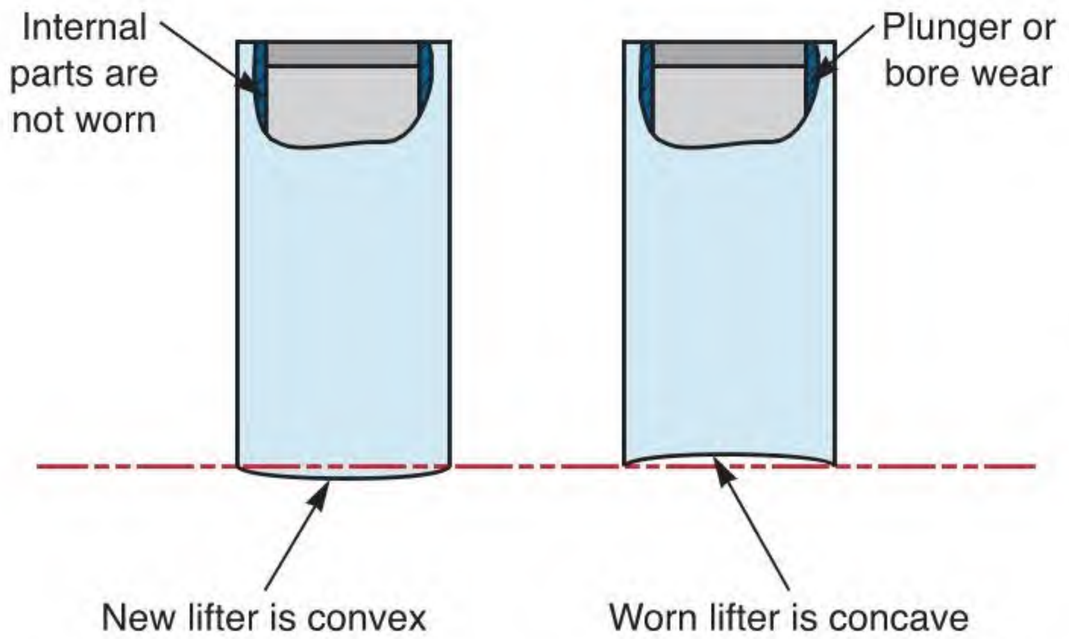
Internal lifter wear on a hydraulic lifter can prevent the lifter from pumping to take up valve train clearance. Look at **Figure 55-18**. The excess clearance can cause the rocker arm to clatter as it strikes the valve stem tip. The noise will be near the top of the engine. With the engine idling and the valve cover removed, push down on the push rod end of the rocker arm. This should increase the valve train noise. If not, the lifter for that valve is bad.

Low engine oil pressure and contaminated or dirty oil can cause hydraulic lifter clatter. Check the oil level and oil pressure before condemning the lifter or lifters. Roller lifters also have needle bearings and a roller that can wear and fail. Lifter removal and close inspection is needed to find problems with the roller or needle bearings. Look at **Figure 55-19**.

Rocker Arm Problems

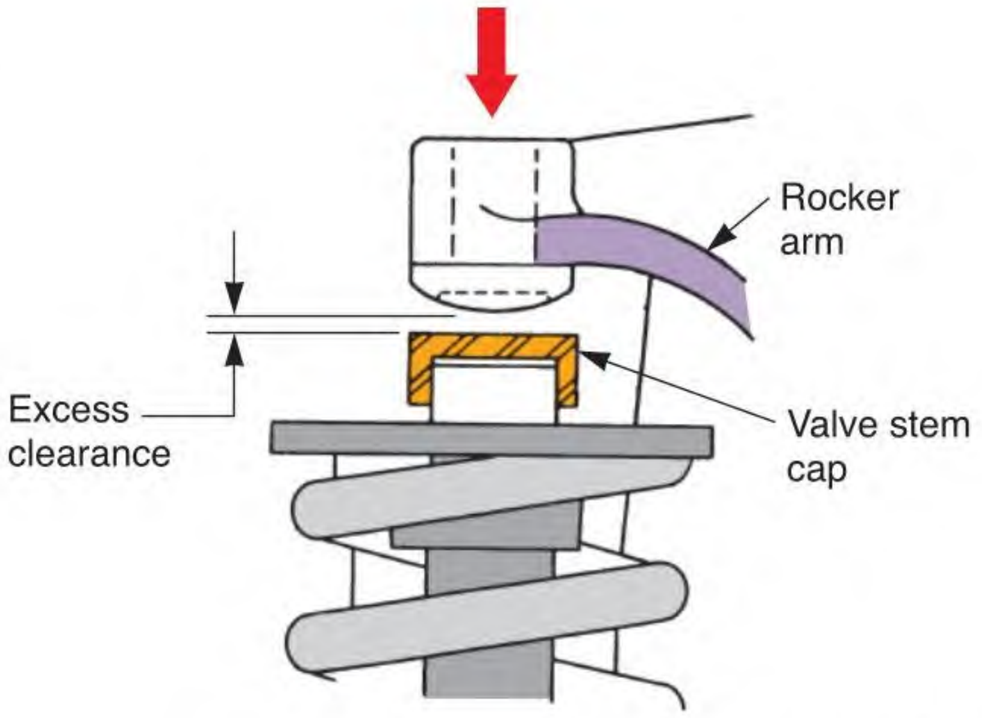
Rocker shaft wear results from friction between the shaft and the rocker arm. This can happen because of inadequate lubrication, dirty oil, or high mileage. The clearance between the rocker arm and shaft will increase, which can cause valve train clatter. The bottom of the shaft is more prone to wear than the top of the shaft.

Rocker arm wear can occur on the inside diameter of the rocker arm or where it contacts the valve or push



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Figure 55-17. A new lifter or follower is crowned so it rotates on the cam lobe. A badly worn lifter will be cupped from friction and wear by the cam lobe.



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Figure 55-18. Excess clearance in a valve train can produce a clattering or clacking sound from under the valve cover. The loose rocker will clack loudly as it strikes the valve stem tip or cap.

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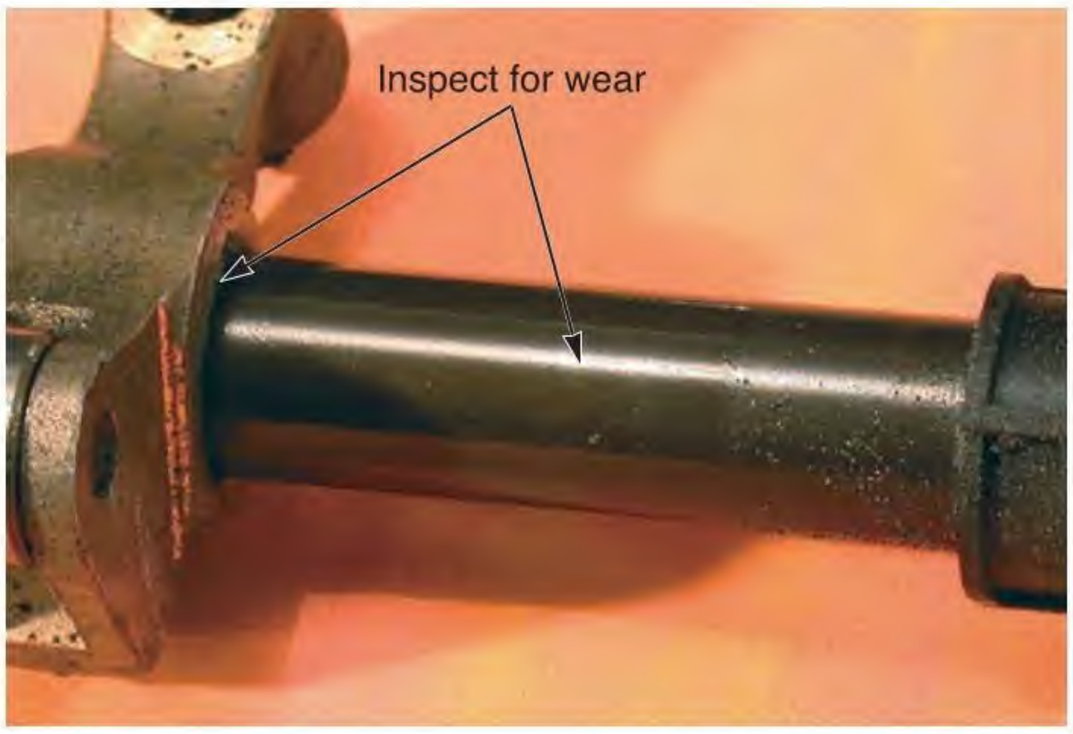
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Figure 55-19. A roller lifter must not be worn at the roller assembly or where the push rod contacts the top of the lifter.

rod, **Figures 55-20A** and **B**. This can make the lifter plunger move too far out and result in a light valve train tapping noise. With an overhead camshaft engine, the rocker can wear at its contact point with the camshaft. Inspection is needed to verify rocker wear problems.

Rocker stand wear is a common problem when the stand is made of aluminum. The stand will wear where it rubs on the rocker arm, causing valve train noise. See **Figure 55-20C**.

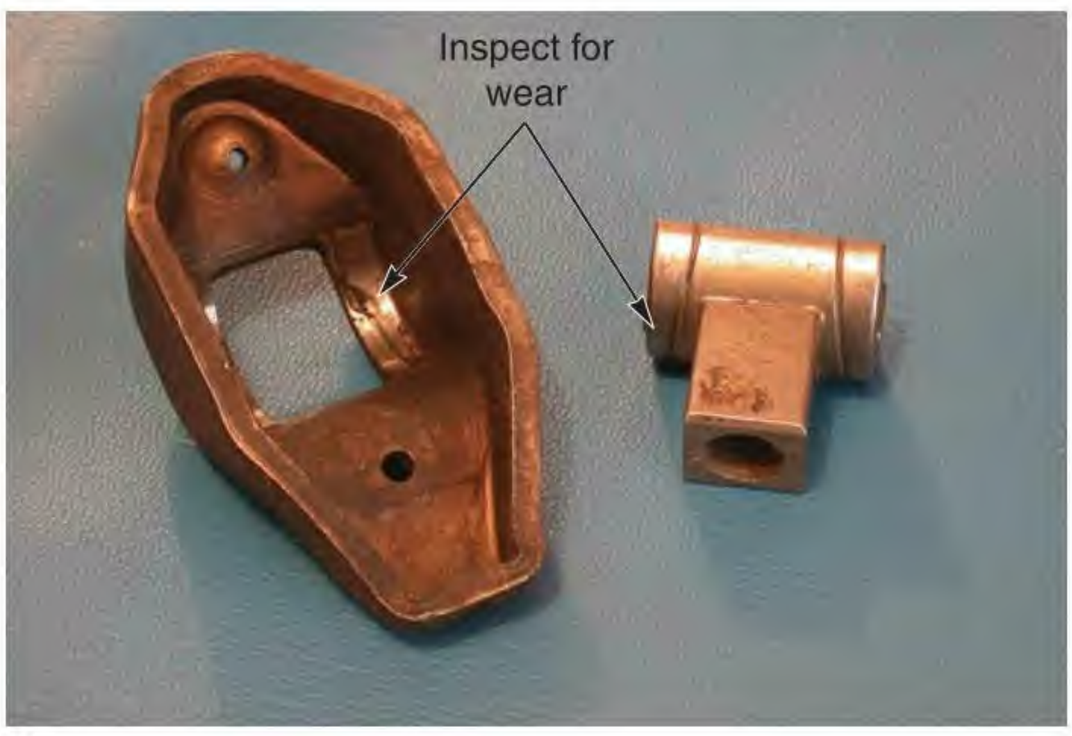
Rocker arm or stand breakage can occur if the valve strikes the piston from over-revving, or if the valve is stuck in the head after the engine has been unused for a period of time and the valve stem becomes rusted. A rusted valve stem can prevent proper valve action and cause a severe engine miss. See **Figure 55-20D**.



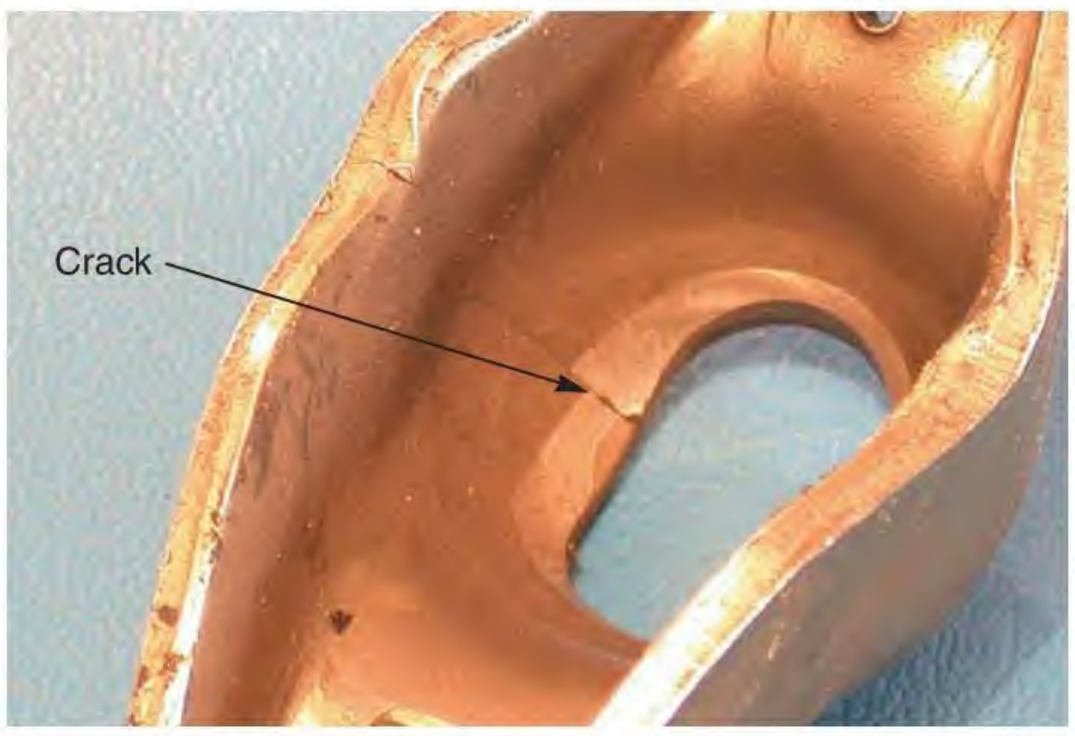
A



B



C



D

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Figure 55-20. Valve train clatter and wear are common problems with older high-mileage engines. A—If the engine uses a rocker shaft, inspect and measure it for wear under the rocker arms. B—Tips of rocker arms can also break or wear. Note that this rocker arm has a swivel head for making good valve stem contact. C—Aluminum parts will wear more than steel parts. If a pedestal is worn enough, the hydraulic lifter cannot take up valve clearance, resulting in valve clatter. D—Close inspection found this cracked steel rocker arm.

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Valve Spring Problems

Valve float is a condition in which weakened valve springs or excessive engine speed causes the valves to remain partially open. This problem usually occurs at higher engine speeds. The engine may begin to miss, pop, or backfire as the valves float. Excess valve-to-rocker clearance may cause valve train noise.

Valve springs weaken after prolonged use. They lose some of their tension. As a result, the springs become too weak to close the valves properly. A broken valve spring will frequently let the valve hang partially open or even be hit by the piston head, which can result in a bent valve.

Inspection is often needed to verify a broken valve spring. See **Figure 55-21.** The cylinder with a broken valve spring may pass a compression test.

Valve springs can be replaced without cylinder head removal. As with valve stem seal replacement, air pressure and a special tool will permit spring replacement.

Tech Tip

If a hydraulic lifter sticks in a position that is too high and the valve does not fully close, symptoms similar to those produced by valve float may be noticeable.

Push Rod Problems

A bent push rod is not straight and may be cracked, leading to oil pressure reduction. See **Figure 55-22**. This damage may be caused by a stuck valve, spring bind, spring breakage, piston hitting the valve, or other type of mechanical problem. If severely bent, the push rod can fall out of the rocker arm pocket. This will stop valve action, and severe missing and tapping will result. Replace bent push rods; do not straighten them.

A broken push rod usually has the small ball on the end broken off. This will cause loud valve train noise and usually push rod disengagement from the rocker arm. Loss of all oil pressure can result if a lifter pops out of the cylinder block due to a missing push rod.

A clogged push rod has the internal oil hole restricted or blocked with hardened oil and sludge deposits. The tip of the push rod can also become mushroomed, which restricts oil flow. This will speed



A



B



C

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Figure 55-21. A broken valve spring can cause major engine mechanical damage. A—When an old, reused valve spring snapped from internally generated heat (rapid collapsing and expanding of spring tension) and high engine rpms, the valve dropped down into the cylinder. B—The dropped valve was hit by the upward moving piston, cracking the piston head and snapping the valve head off the valve stem. C—The broken valve stem punctured the piston head on the next compression stroke. The engine started missing, smoking, and knocking very loudly.

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Figure 55-22. This push rod was badly bent and cracked. This failure resulted from over-revving the engine.

rocker arm wear because of reduced lubrication. Always check or clean the hole in push rods during an overhaul or valve job.

Timing Mechanism Problems

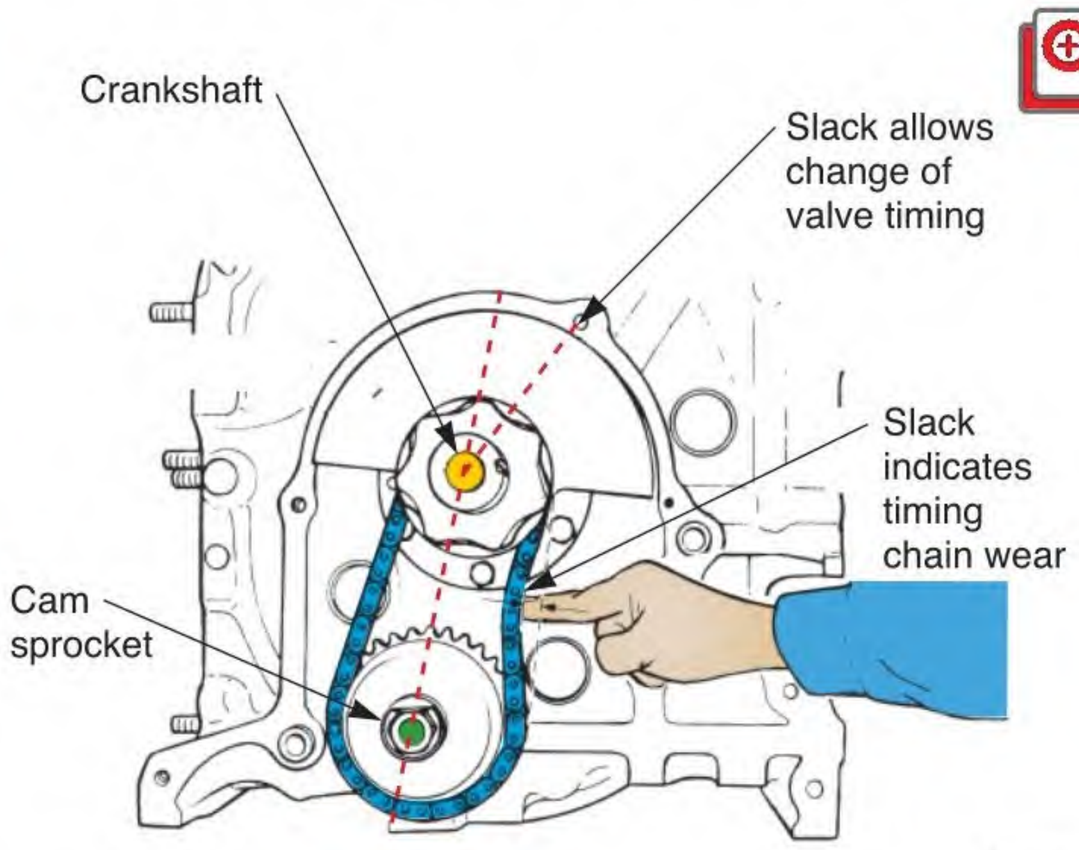
Timing mechanism problems can affect how the camshaft rotates in relation to the crankshaft to open the valves at the correct times. These problems involve the condition of the timing belt, timing chain, or timing gears.

Timing sprocket problems are common when the sprocket has plastic teeth. The plastic teeth can break off and cause timing chain slack. The broken teeth can also allow the timing chain to jump over teeth, which upsets valve timing. Severe performance problems and even valve damage can result because the valves open at the wrong times.

Timing gear problems are not very common, but can happen after extended service or breakage of other parts. The most common problem is broken gear teeth. Broken timing gear teeth can cause a loud knocking noise from inside the front cover. If enough teeth break off, the timing gears can jump and the valves will open incorrectly or the gears may lock up.

Timing chain problems can upset valve timing, reducing compression stroke pressure and engine power. Wear can cause slack between the crankshaft sprocket and camshaft sprocket. Then, the camshaft and valves are no longer in time with the crankshaft and pistons. Refer to **Figure 55-23**.

To check for a worn timing chain, rotate the crankshaft back and forth while watching the rocker arms, camshaft, or distributor rotor. If you can turn the crankshaft several degrees without rocker arm or camshaft movement, the timing chain is worn and must be replaced.



Mazda

Figure 55-23. The camshaft can rotate out of time with the crankshaft due to timing chain wear. Valves do not open when they should, reducing engine power and efficiency.

Excessive wear on the timing sprocket teeth also indicates a worn timing chain. A compression test would show lowered compression in all cylinders. Incorrect valve timing and a worn chain affect all cylinders equally. Erratic timing mark motion when using a timing light during a tune-up could also be due to a worn timing chain.

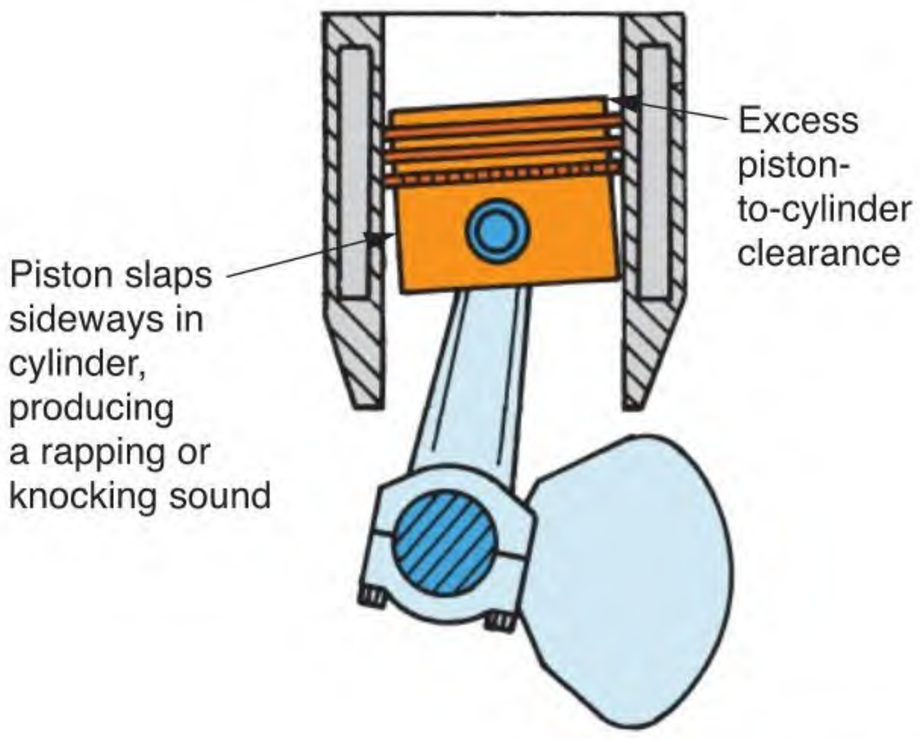
A worn timing belt will usually break, jump off its sprockets, or skip over a few sprocket teeth. Severe performance problems or valve damage can result. With some engine designs, the pistons can move up into the open valves, bending or breaking the valves.

Cylinder Block Problems

Cylinder block problems include cracks, surface warpage, worn cylinders, mineral deposits in coolant passages, and misaligned main bores. Since the block is a large casting of iron or aluminum, it suffers from the same troubles as a cylinder head: cracks, water leaks, wear to cylinder walls, and damage from part breakage. Cylinder problems are major and require engine removal so the block can be bored or replaced. Deck and cylinder wall warpage from overheating can cause head gasket leakage and oil consumption due to ring blowby. Look at **Figure 55-24**.

A worn cylinder bore has a larger-than-spec cylinder wall diameter and a ring ridge in the unworn top of the cylinders. A block ***ring ridge*** is a small lip or metal

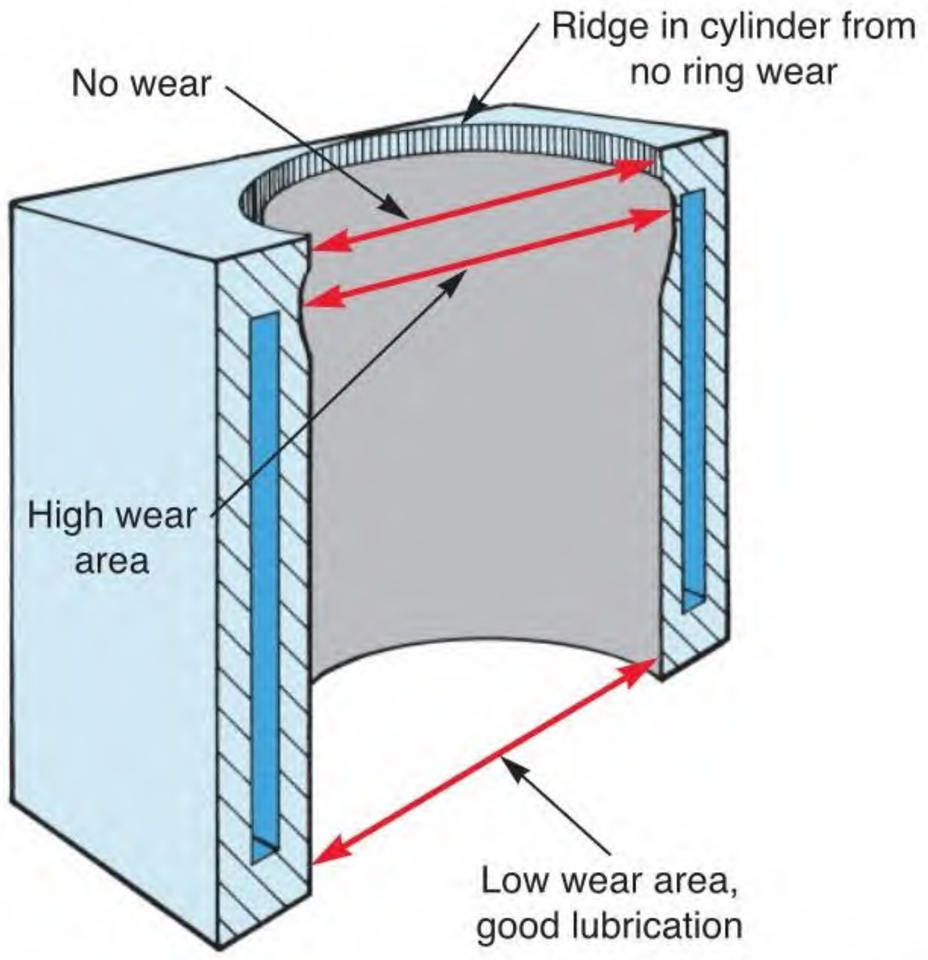
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Figure 55-24. A worn cylinder wall or piston skirt can let the piston flop back and forth, producing a knocking sound and oil consumption.

ridge formed at the tops of cylinder walls where the rings do not wear away metal. Refer to **Figure 55-25**. The steel piston rings slide up and down on their cylinder walls millions of times during the service life of an engine. This back-and-forth motion generates friction that slowly wears away the contact surfaces of the rings and cylinder walls. Since the piston rings do not rub at the very top of the cylinder walls, ring ridges or



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Figure 55-25. Note the typical wear pattern in a high-mileage engine block. Less oil at top of cylinder will make the rings and cylinder wear more at the top than at the bottom of the cylinder wall.

metal lips are formed at the top of cylinders. Because there is more splash-oiling at the bottom of cylinder walls and less at the top, the piston ring-to-cylinder contact surfaces will wear much more during reciprocating movement from TDC to BDC. As the piston rings and block cylinder walls wear, excess crankcase motor oil can enter the combustion chambers and be burned, emitting blue exhaust particulates.

A ring ridge is an obvious sign of cylinder block wear. As you will learn, piston ring ridges formed by the badly worn engine block cylinders must be machined flush before the piston is removed. The old piston rings would catch and break if this metal cylinder wall lip is not machined down flush with the worn area.

Cylinder block mineral deposits in the coolant passages can cause engine overheating. Lime can build up on the inner walls in the block and heads. This can restrict coolant flow and cause localized hot spots in old, high-mileage engines.

Cylinder block crankcase warpage will throw the main bearing bores out of alignment. Engine crankcase main bore warpage can result from severe engine overheating or engine main bearing failure. A warped main bearing girdle will crush the main bearing inserts and lock the crankshaft so that it will not rotate freely. The block must be line-bored to correct this problem, **Figure 55-26.**

A cracked cylinder block can have fractures in the cylinder walls, deck surface(s), lifter gallery, and so on. Casting cracks are often caused by engine coolant overheating, casting heat over-expansion, and block breakage from impacts for broken connecting rods and piston fragments. A lack of antifreeze in the winter can also cause ice formation inside the engine. Ice expansion can easily fracture water jackets in the cylinder block and cylinder heads.

Over-revving an engine above the "red line" (factory maximum engine rpms recommended on the dash tachometer) can easily break off piston skirts, snap off connecting rods, or pound out rod and main bearings. Engine abuse is a common cause of catastrophic engine mechanical failures. Look at the engine parts in **Figure 55-27**.

Tech Tip

Remember to quickly read or inspect a spark plug tip and front O_2 sensor tip to help diagnose engine mechanical problems (oil consumption, rich or lean fuel mixture, etc.). For example, worn piston

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rings will not seal on a scored, scratched cylinder wall. If oil control piston rings are also badly worn, severe engine oil burning will result. To quickly verify if the engine is burning oil, remove and read the engine spark plugs and exhaust gas sensors. The tips of each will be oil-fouled or covered with black soot. Show the customer the evidence to verify your oil consumption and high air pollution concerns. Inform the shop manager or customer of your findings so that the engine can be rebuilt or repaired to run more efficiently.

Connecting Rod Problems

A bent connecting rod is a condition where the rod is no longer straight when measured from pin centerline to rod bearing centerline. A bent connecting rod often results from high detonation pressure in a cylinder, piston failure and breakage, a valve breaking off, nitrous oxide injection, or excessive engine rpms. Refer to **Figure 55-28**.

A slightly bent engine rod will load one side of the rod bearing and cause the piston to cock at an angle in the cylinder. A bent connecting rod is usually not discovered until engine disassembly. Uneven wear on the piston skirt or rod bearing insert is an indication of a bent connecting rod. Machine shop fixtures are available for measuring rod straightness.

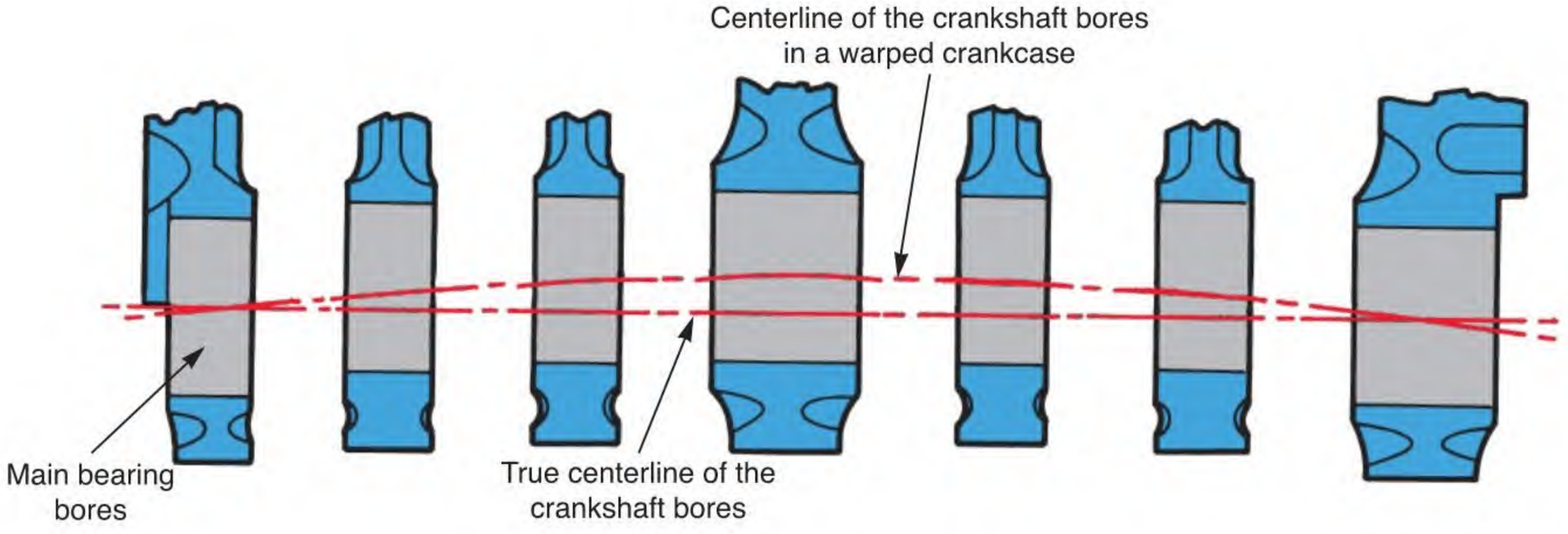
A broken connecting rod has suffered a complete fracture and failure of the I-beam or rod bolts, separating the rod cap from the piston. Rod breakage can result from excessive engine speed, running an engine with loose, worn rod bearings, loss of oil pressure, and improper assembly procedures.

When a connecting rod breaks, severe engine damage usually results. The spinning crankshaft can slam into the disengaged rod, crushing the rod into the side of the cylinder block. The piston can also fly upward and smash into the bottom of the cylinder head, causing head and valve damage. Normally, complete engine rebuilding is needed to repair a broken connecting rod.

Connecting rod bore problems result from extended service, rod bearing failure, oil pump problems, and other causes. The big end of the connecting rod can become out-of-round and can no longer hold the rod bearing in place. Always inspect closely for rod bore problems during engine rebuilding. Marks on the bearing bore indicate unwanted rod bearing movement in the torqued rod. This indicates that the entire connecting rod should be rebuilt by a machine shop or replaced.

Piston Problems

Piston problems are major and include skirt breakage, crown failure, and worn ring grooves. Piston failure normally results in high oil consumption, blue engine smoking, and sometimes engine knock due to excess piston clearances.



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Figure 55-26. Cylinder block crankcase warpage will move main bearings out of alignment with crankshaft main journals. If the block is not machined straight and true, main bore misalignment would cause the crankshaft to lock up when new bearings with less clearance are installed.

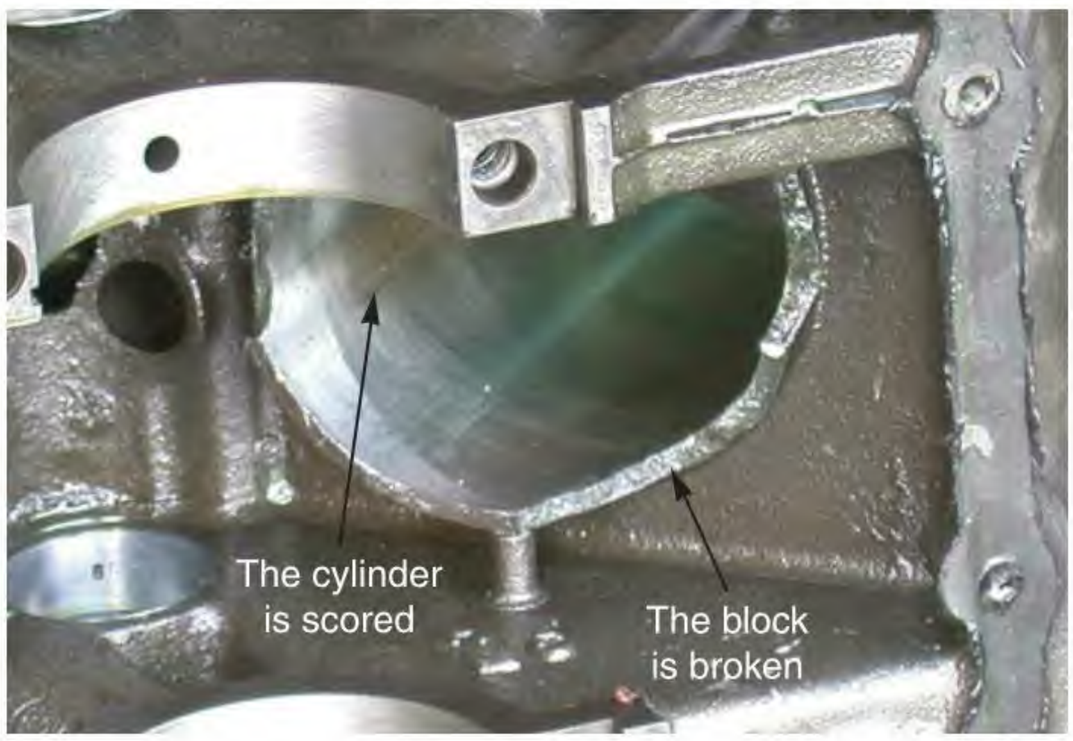
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A



B



C

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Figure 55-27. Study what can happen if an engine is operated with a badly worn rod bearing. A—A worn rod bearing and excess bearing clearance allowed this piston to slide up too far at TDC and hit the cylinder head. B—High engine rpms on a badly worn rod bearing caused the connecting rod to snap in two. The force of the rod hitting the crankshaft journal at TDC and BDC during the change in piston and rod direction of travel caused the rod cap and bolts to be hammered off the I-beam. C—After the connecting rod snapped in half, the spinning crankshaft crushed the rod into the sides of the cylinder block, damaging the cylinder wall.

Burned Piston

A burned piston is often a result of prolonged pre-ignition damage or almost instant detonation damage. Abnormal combustion, excessive pressure, and heat melt the piston and blow a hole in the crown or area around the ring grooves. The engine may smoke or knock, have excessive blowby, misfire, or exhibit other symptoms. See **Figure 55-29**.

A compression test or cylinder leakage test may indicate a burned piston. Engine disassembly is usually needed to verify the problem. However, if the cylinder wall is not damaged, the repair can be completed without removing the engine from the vehicle.

Melted aluminum deposits on a spark plug point to a melted or partially burned piston. Also, when the spark plug tip is damaged from detonation, you need to correct the cause of detonation and, in turn, possibly prevent piston damage.

Worn Piston Rings and Cylinders

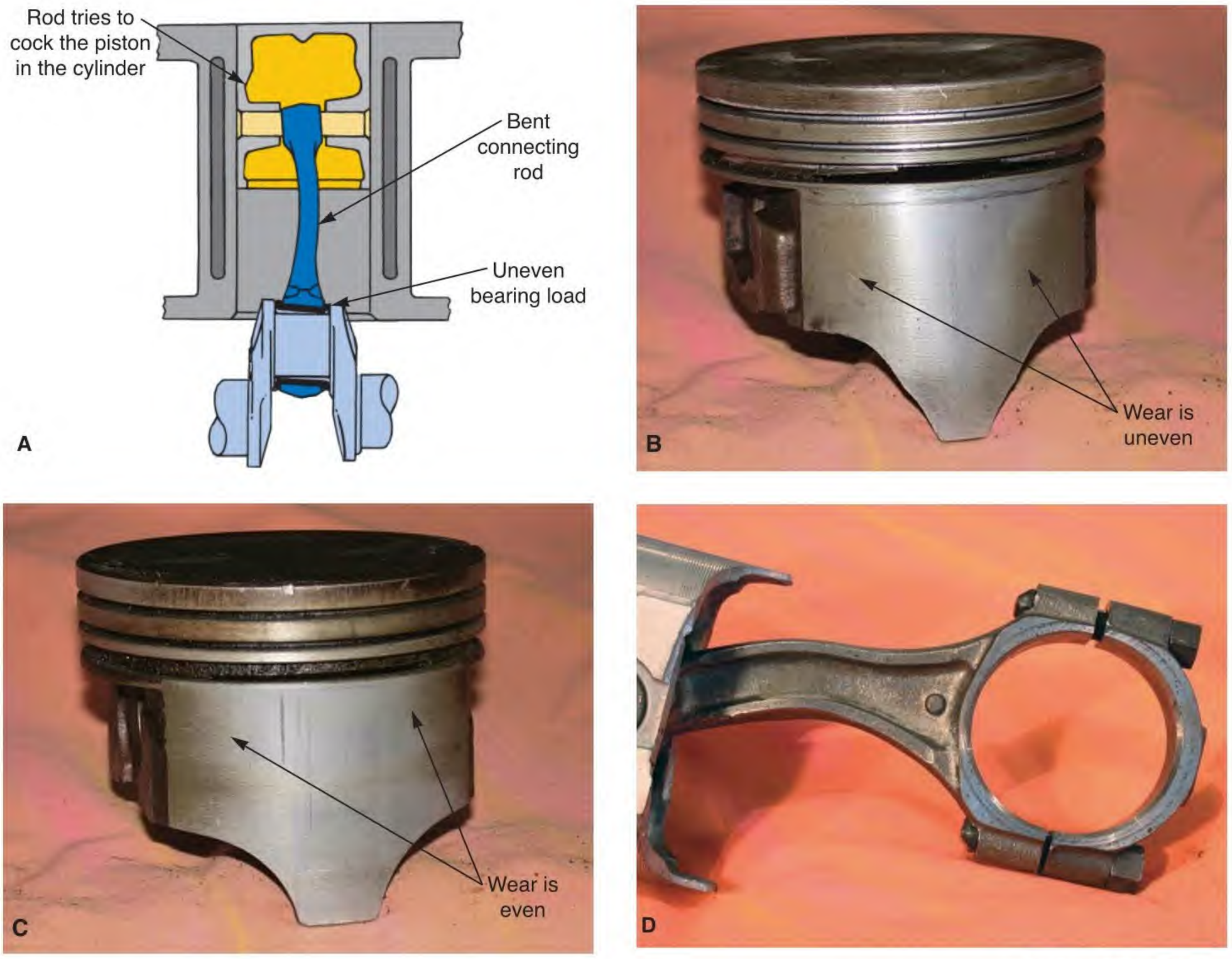
Worn piston rings or worn cylinders result in blowby, blue-gray engine smoke, low engine power, spark plug fouling, and other problems caused by poor ring sealing. To check for ring and cylinder problems, increase engine speed while watching the tailpipe and valve cover breather opening. If blue-gray smoke pours out of the tailpipe with the engine under load, the oil rings and cylinders usually need service. If excessive oil vapors and air blows out of the valve cover breather, blowby is entering the crankcase. Piston, compression and oil ring, or cylinder problems are indicated. Worn ring grooves can also cause oil consumption. Look at **Figures 55-30** and **55-31**.

If the engine cylinders are found to be worn after engine disassembly, the engine must be removed from the vehicle. The block must be sent to a machine shop for boring or ***sleeving***. If just the rings are found to be worn, but not the cylinders, the engine may be rebuilt while still installed in the vehicle. Check the service manual for details.

Piston Breakage

The most common type of ***piston breakage*** is a broken skirt. The piston then flops sideways in its cylinder and causes major cylinder damage. The affected cylinder will lose compression, burn oil, and make a knocking sound. Skirt breakage can result from too much piston-to-cylinder clearance, over-revving, or inadequate lubrication. Look at **Figure 55-32**.

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Figure 55-28. A bent connecting rod can be difficult to locate. The only symptom may be slightly lower than normal compression test pressure in that cylinder. A—A bent connecting rod loads one side of the piston skirt and rod bearing. B—Uneven piston wear pattern resulted from a bent connecting rod. C—This is a normal wear pattern. The wear is even on both sides of the piston skirt. D—After removal from the engine, the bent connecting rod was obvious. The car owner had installed an aftermarket nitrous oxide injection system. Using nitrous oxide injection is like aiming a "flamethrower" at your pistons. Nitrous injection has destroyed thousands of good engines not designed to handle an added 500 horsepower.

Piston Knock

Piston knock, or ***piston slap***, is a loud metallic knocking sound produced when the piston flops back and forth inside its cylinder. It is caused by piston skirt or cylinder wear, excessive piston-to-cylinder clearance, or mechanical damage. Piston slap is normally louder when the engine is cold. It tends to quiet down as the engine warms to operating temperature. As the aluminum piston heats up and expands, the clearance is reduced and the piston knock is reduced.

Piston Pin Knock

Piston pin knock occurs when too much clearance exists between the piston pin and piston pin bore or connecting rod bushing. Excessive clearance allows the pin to hammer against the rod or piston as the piston changes direction in the cylinder. Piston pin knock is usually indicated by a double knock. A double knock is two rapid knocks and then a short pause.

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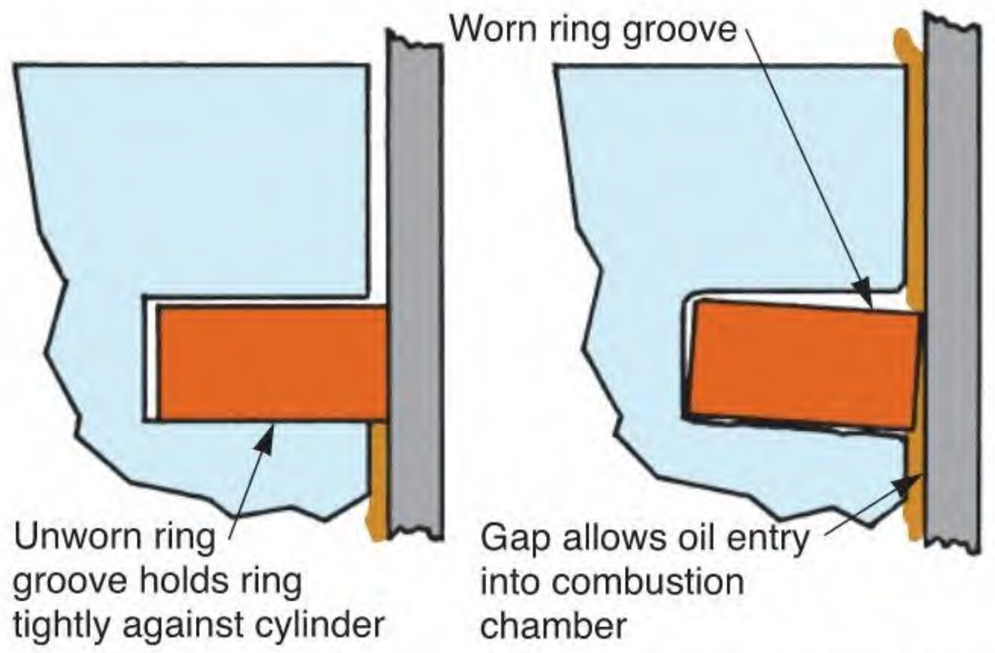


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Figure 55-29. A burned piston usually results from prolonged detonation. Symptoms are low cylinder compression, combustion blowby out of the engine breather or PCV system, blue smoke blowing out the exhaust pipe under engine load, and very rough idling. Several trouble codes (most often misfire codes and oxygen sensor codes) will be set with a burned or holed piston.

Crankshaft and Bearing Problems

The crankshaft and its bearings must withstand extreme loads and friction during engine operation. The slightest mistake during assembly, a lubrication problem, or driver abuse can lead to bearing or crankshaft troubles.



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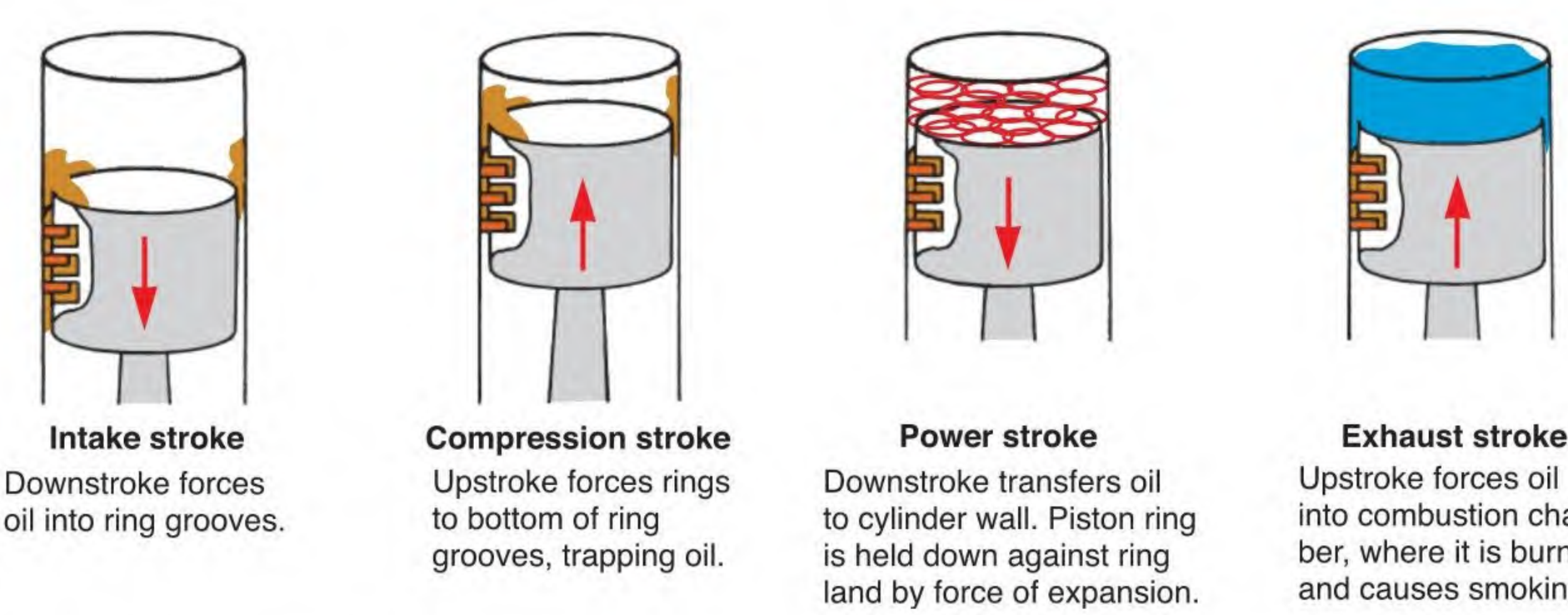
Figure 55-31. Worn ring grooves can allow rings to tip on the cylinder wall, causing oil consumption.

Rod Bearing Knock

Connecting rod bearing knock is caused by wear and excessive bearing-to-crankshaft clearance. It is indicated by a light, regular, rapping noise with the engine floating. ***Engine floating*** is a constant engine speed above idle. Rod bearing knock is loudest after engine warm-up. Oil is thicker in a cold engine, which tends to cushion and quiet rod knock.

To locate a bad rod bearing, short out or disconnect each spark plug wire one at a time. The loose, knocking rod bearing may quiet down or change pitch when the corresponding spark plug is disabled.

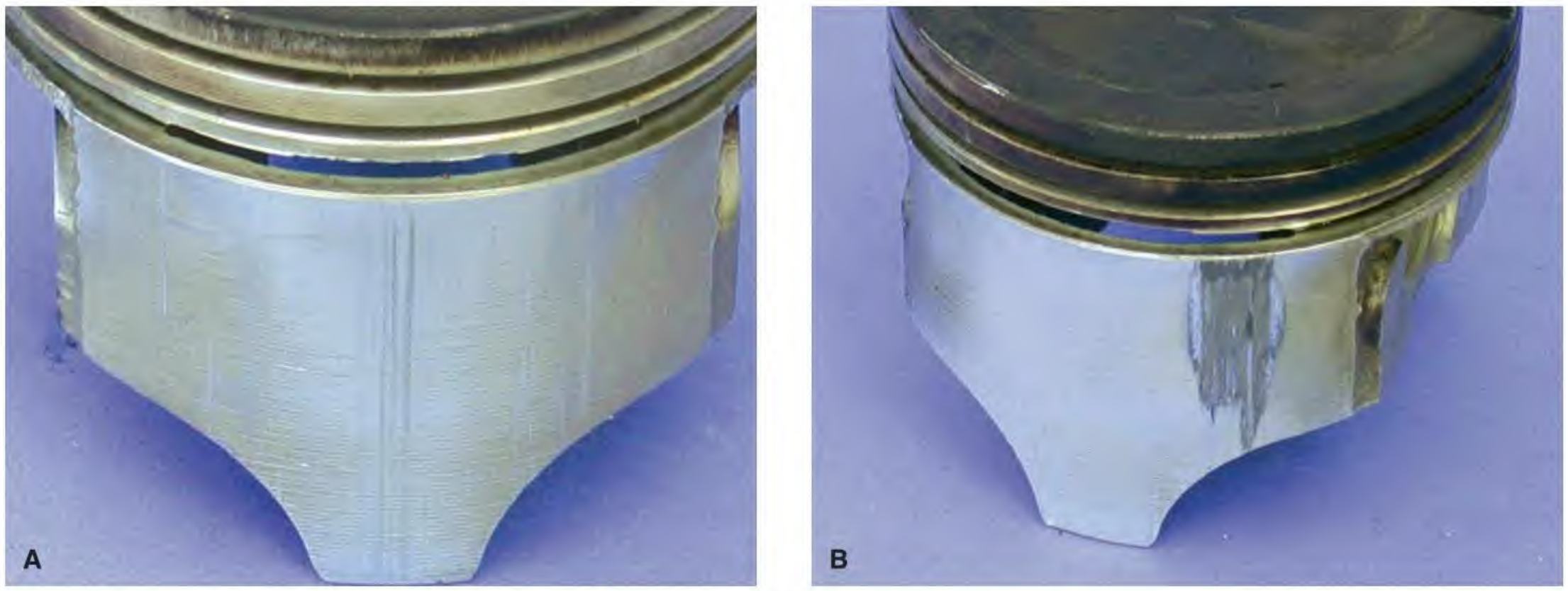
With some engines, excessive rod bearing clearance can result in the piston head striking the cylinder head. This will make a loud knocking sound, similar to a failed piston.



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Figure 55-30. Study how oil is pulled up into the combustion chamber on the intake stroke and then burned as blue smoke on the power stroke.

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Figure 55-32. Study the types of problems found on used pistons. A—This piston skirt shows normal wear for a high-mileage engine. B—This piston skirt suffered scoring when the engine overheated. C—Foreign matter is embedded in this piston skirt. When the engine was operated with low oil, the bearings eroded and that material was circulated through the engine. D—Piston ring lands were cracked when a valve broke and dropped onto the top of the piston with the engine idling.

Spun Rod Bearing

A ***spun rod bearing*** is a bearing that has been hammered out flat and then rotated inside of the connecting rod bore. It will make a sound similar to a rod bearing knock, but much louder. When a rod bearing spins, it will normally damage the rod and crankshaft journal. A slight rod bearing knock often precedes total rod bearing failure.

Main Bearing Knock

Main bearing knock is similar to rod bearing knock, but the sound is slightly deeper or duller. It is usually more pronounced when the engine is pulling or lugging under a load. Bearing wear, and possibly journal wear, is allowing the crankshaft to move up and down inside the cylinder block.

Main bearing wear will usually reduce oil pressure significantly. To verify main bearing noise, remove the oil pan. Pressure test the lubrication system. Excessive oil flow out of one or more of the main bearings implies too much bearing clearance. If a pressure tester is not available, remove and inspect each of the main bearings. If a bearing is worn but the crankshaft is not, bearing insert replacement should correct the problem.

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Worn Main Bearings

Worn main bearings are too thin, which allows too much clearance between the crankshaft and bore. This excess clearance can allow the crankshaft to shift up and down in the block with load changes. A thin layer of metal has been worn off the bearing face. Refer to **Figure 55-33**.

Excess Crankshaft Endplay

Excess crankshaft endplay is caused by a worn main thrust bearing. Thrust bearing wear can produce a deep knock, usually when the clutch on a manual transmission is applied and released. With an automatic transmission, the endplay problem may only show up as a single thud or knock on acceleration or deceleration.

With severe thrust bearing wear, you can sometimes verify bearing failure by watching the front crankshaft pulley with the engine running. When you accelerate and decelerate the engine, the crankshaft may "float" forward and rearward in the block. With the engine off, you can also pry back and forth on the crankshaft damper with a large pry bar to verify excess main thrust bearing wear.

A knock occurring with clutch or torque converter action could also be caused by loose flywheel bolts or other drivetrain problems. Check out all possible causes before beginning repairs.

Flywheel Problems

Flywheel problems include loose bolts, failure of the ring gear teeth, friction surface scoring, warpage, and so on. A loose flywheel can make a knocking sound similar to main bearing knock. The teeth on the flywheel ring gear can wear or break off and cause starter engagement troubles. Keep these problems in mind during diagnosis.

Crankshaft Vibration Damper Problems

Crankshaft vibration damper problems include physical damage such as a deteriorated rubber ring, seal journal wear, or slipped or sheared key. See **Figure 55-34**. Engine vibration can result from a damaged vibration damper. Oil leakage can occur if the seal surface is worn or scored. If the outer metal ring slips on its rubber mount, the timing marks can be out of position. This can cause confusion when trying to set ignition timing.

Engine Mount Problems

Broken engine mounts allow the engine to move excessively in the vehicle chassis with engine torque. This movement can cause damage to external parts in the engine compartment, such as the radiator, valve cover, and intake manifold. With enough engine and transmission movement, the alternator or air filter can hit the hood, or wires and hoses can bind and snap.

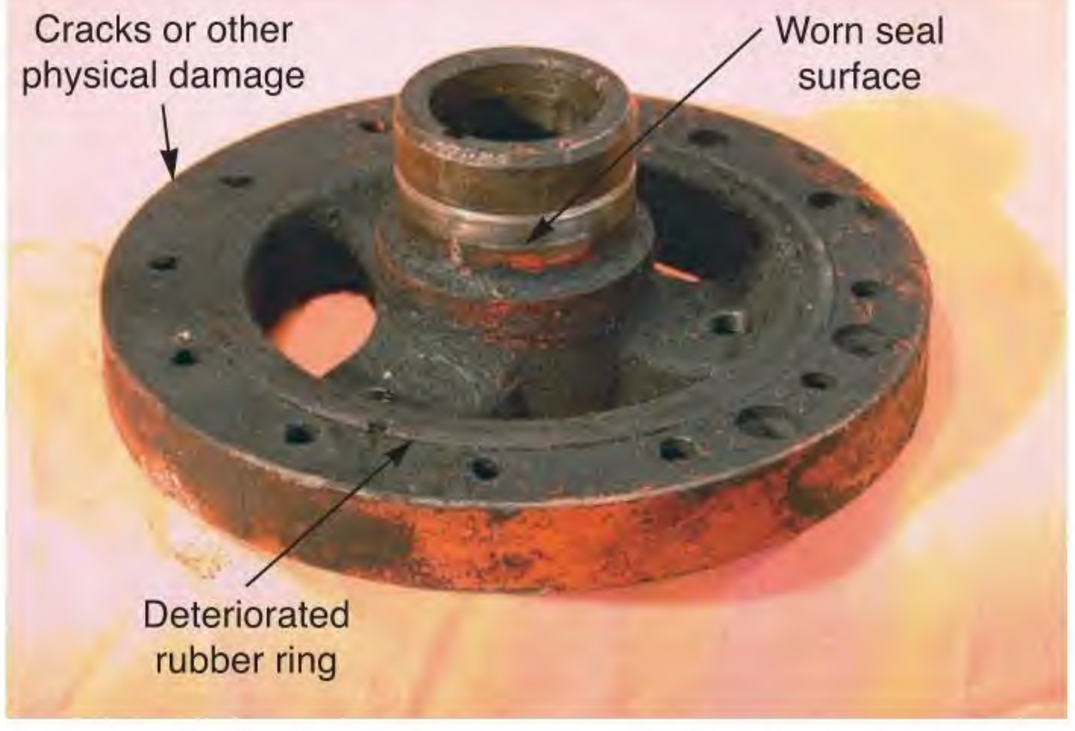
Checking Engine Mounts

To check for broken engine mounts, open the hood. Engage the parking brake and place the trans-



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Figure 55-33. Main bearing wear will lower oil pressure considerably and can cause knocking under load. This is a badly worn main thrust bearing. The lips on the side of the main thrust bearing limit forward and rearward movement of the crankshaft.



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Figure 55-34. Keep vibration damper troubles in mind during engine service. If a steel damper ring were to come off a rubber ring, it could fly into the radiator and fan, damaging them.

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mission in drive or in gear. While holding down on the brake pedal, slowly increase engine speed or release the clutch pedal. This will twist the engine, causing it to move excessively if the mounts are broken.

A safer method is to place a piece of wood and a hydraulic jack under the oil pan and try to lift up on the engine. If the mounts are broken, you will be able to see the mount separate and the engine rise up. Check carefully because broken rubber engine mounts are hard to see.

Inspect fluid filled engine mounts for leakage and replace them if ruptured. See **Figure 55-35**.

Intake and Exhaust Manifold Problems

An exhaust manifold problem is usually a cracked or warped manifold. Engine exhaust heat can crack an exhaust manifold, allowing leakage and exhaust noise. Heat can also warp a manifold, allowing it to leak next to the cylinder head mating surface.

Intake manifold problems are not very common because the manifold is not exposed to as much heat as other parts. However, an intake manifold can sometimes warp and cause a vacuum leak. Also, passage plugs can loosen or fall out, allowing vacuum or coolant leakage.



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Figure 55-35. A broken or deteriorated engine mount allows the engine to move excessively in the engine compartment. The broken mount may not be noticed during visual inspection. Load the engine and drivetrain while checking for engine movement on the mounts.

Diagnostic Case Study

Concern: Mr. Glenn brings in his 2010 Kia because of an engine knock. When asked about the knock, he says the sound gets louder the longer the vehicle is driven.

Cause: Duff allows the engine to cool before starting it. A faint knock can be heard when the engine is first revved up. As the engine warms, the knock gets louder. Duff suspects worn connecting rod bearings since cold, thick oil dampened the knock sound in the engine. He turns the repair over to the shop's specialized engine repair technician.

The technician unplugs the fuel injector wiring connectors one at a time while listening for the knock to go away or get quieter. When he pulls the connector from the injector for cylinder number five, the knock gets much lighter. The technician then removes the oil pan and the connecting rod bearing cap in the number five cylinder. The rod bearing is badly worn, and the crankshaft journal is damaged.

Correction: The engine is removed from the vehicle. Since the engine has low mileage, only a partial engine rebuild is required. The crankshaft is sent out to be ground. The connecting rod in the number five cylinder is replaced. New bearings, rings, seals, and gaskets are installed. The engine is reassembled and reinstalled in the vehicle. The newly rebuilt engine bottom end produces no unusual noises and has good oil pressure, so the vehicle is released to the owner.

Summary

- If a technician does not know how to properly diagnose (locate) engine problems, a great deal of time, effort, and money will be wasted.
- After gathering information from the customer or service writer, inspect the engine using your senses (sight, smell, hearing, and touch).
- Coolant in oil will show up as white or milky oil.
- Oil-fouled spark plugs indicate internal oil leakage into the engine combustion chambers.
- Engine blowby occurs when combustion pressure blows past the piston rings into the lower block and oil pan area of the engine.

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- Abnormal engine noises (hisses, knocks, rattles, clunks, and popping) may indicate part wear or damage.
- A compression test is one of the most common methods of determining engine mechanical condition.
- A wet compression test should be completed if cylinder pressure reads below specifications. It will help you determine what engine parts are causing the problem.
- The compression gauge reading for a good cylinder will increase evenly to specifications. The gauge readings should not vary by more than about 10% from one cylinder to another.
- Valve train problems can cause engine missing, oil consumption, blue-gray exhaust smoke, light tapping sounds from the upper area of the engine, rough idling, overall performance problems, and even cylinder and piston damage.
- A worn timing chain will upset valve timing, reducing compression stroke pressure and engine power.
- Worn rocker arms can cause valve clatter (light tapping noise) by upsetting valve clearance.
- A blown head gasket can cause a wide range of problems: overheating, missing, coolant or oil leakage, engine smoking, and even head or block damage (burned mating surfaces).
- Piston knock or slap is a loud metallic knocking sound produced when the piston flops back and forth inside its cylinder.
- Worn piston rings or cylinders result in blowby, blue-gray engine smoke, low engine power, spark plug fouling, and other problems caused by poor ring sealing.
- Connecting rod bearing knock is caused by wear and excessive rod bearing-to-crankshaft clearance.
- Main bearing knock is similar to rod bearing knock but is slightly deeper or duller in pitch.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

black diesel smoke
black engine smoke
blue diesel smoke
blue-gray engine smoke
compression gauge
compression test
connecting rod bearing knock
cranking balance test
crankshaft vibration damper
cylinder balance test
cylinder leakage test
diesel engine compression readings
dropped valve guide
dynamic engine compression test
engine blowby
engine exhaust leaks
engine floating
engine oil leaks
engine smoke
engine vacuum leaks
excess crankshaft endplay
external coolant leaks
external lifter wear
frozen valve
gasoline engine compression readings
internal lifter wear
low engine compression
main bearing knock
part warpage
piston breakage
piston knock
piston pin knock
piston slap
power balance test
ring ridge
running engine compression test
sharp valve margin
sleeving
spun rod bearings
stuck valve
vacuum test
valve float
wet compression test
white diesel smoke
white engine smoke

Activities

1. Demonstrate the steps for making a dry compression test on a gasoline engine. Compare your readings to specifications.
2. Make a poster listing the probable causes of blue-gray, black, and white exhaust emissions.

Review Questions

Answer the following questions using the information provided in this chapter.

1. List seven symptoms of engine mechanical problems.
2. With a gasoline engine, blue-gray smoke indicates:
   (A) rich fuel mixture.
   (B) coolant leakage into combustion chambers.
   (C) oil leakage into combustion chambers.
   (D) lean fuel mixture.

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3. Oil-fouled spark plugs are an indication of worn _____, worn or scored _____, or bad _____.
4. A section of vacuum hose can be used to find engine vacuum leaks. True or False?
5. Low cylinder compression *cannot* be caused by:
   (A) worn camshaft bearings.
   (B) blown head gasket.
   (C) burned valve.
   (D) worn piston rings.
6. What are typical gasoline engine and diesel engine compression readings?
7. Why is a wet compression test helpful?
8. A leaking intake manifold gasket can cause a(n) _____ leak, with resulting _____ idle.
9. What are the problems resulting from camshaft lobe wear?
10. Define the term *valve float*.
11. How can you tell if an engine has a worn timing chain?
12. Explain the symptoms of piston pin knock.
13. Why is piston slap loudest with the engine cold?
14. What are the symptoms of worn piston rings and cylinders?

ASE-Type Questions

1. Technician A says a leaking gasket is a common engine mechanical problem. Technician B says a burned valve is a common engine mechanical problem. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Which of the following is a common cause of engine mechanical problems?
   (A) Engine overheating.
   (B) Lack of periodic maintenance.
   (C) High engine mileage.
   (D) All of the above.
3. The oil in an automotive engine has a white, milky appearance. Technician A says this indicates engine coolant is probably leaking into the engine. Technician B says this indicates transmission fluid is probably leaking into the engine. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. Technician A says when inspecting an engine for mechanical troubles, you should look for engine oil leaks. Technician B says when inspecting an engine for mechanical troubles, you should look for vacuum leaks. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. Blue-gray smoke is coming out of an automobile's exhaust. Technician A says this condition normally indicates water in the engine's oil supply. Technician B says this condition normally indicates internal engine mechanical problems. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Black smoke is coming out of a gasoline engine's tailpipe. Technician A says this normally indicates an engine mechanical problem. Technician B says this condition normally indicates a fuel system problem. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. White exhaust smoke is coming out of a gasoline engine's tailpipe. Technician A says white exhaust smoke may indicate an internal coolant leak into the engine's cylinders. Technician B says white exhaust smoke may be due to water condensation on a cool day. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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8. An automobile equipped with a diesel engine is brought into the shop. The customer says there is blue smoke coming out of the engine's exhaust. Technician A says this problem may be due to worn engine cylinders. Technician B says this problem may be due to worn valve seals. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. An engine is brought into the shop with oil-fouled spark plugs. Technician A says this problem is probably caused by an ignition system malfunction. Technician B says this problem is probably caused by internal oil leakage into the engine's combustion chambers. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. Oil is present in an automobile engine's coolant. Technician A says this problem is normally the result of worn valve seals. Technician B says this problem is usually caused by a leak in the radiator transmission oil cooler. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
11. An automobile's engine is producing "crankcase blowby." Technician A says the solution to this problem is simple valve adjustment. Technician B says one of the possible causes of blowby is a burned piston or worn piston rings and cylinders. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
12. Technician A says engine vacuum leaks are normally loudest at highway speeds. Technician B says engine vacuum leaks are normally loudest during engine cranking. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
13. An automobile is brought into the shop. A compression test on the engine indicates low compression stroke pressure in all the engine's cylinders. Technician A says a complete engine overhaul is required to repair this problem. Technician B says before overhauling the engine, you should look for other mechanical problems that would affect engine compression. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
14. Technician A says a gasoline engine compression gauge can be used to perform a compression test on a diesel engine. Technician B says a gasoline engine compression gauge should not be used to perform a diesel engine compression test. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
15. All of the following are caused by a blown head gasket *except:*
   (A) overheating.
   (B) head damage.
   (C) excess valve clearance.
   (D) coolant leaks.
16. Diesel engine compression readings should average approximately:
   (A) 125–175 psi.
   (B) 180–200 psi.
   (C) 150–175 psi.
   (D) 275–400 psi.
17. Valve train problems can cause all of the following *except:*
   (A) engine power loss.
   (B) rough idle.
   (C) crankshaft damage.
   (D) engine missing.
18. Technician A says that leaking valve stem seals will cause the engine to emit blue smoke after initial starting. Technician B says that the cylinder head must generally be removed to replace the valve stem seals. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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19. Technician A says that valve float can be caused by hydraulic lifter problems. Technician B says that valve float can be the result of weak valve springs. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
20. Technician A says that a leaking intake manifold gasket can cause a vacuum leak. Technician B says that a high vacuum gauge reading indicates a blown head gasket. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
21. Technician A says that piston slap is generally loudest when the engine is warm. Technician B says that piston slap is caused by excessive piston skirt wear. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
22. Technician A says that rod knock is a light, regular rapping noise that occurs when the engine is accelerating. Technician B says that rod knock is loudest when the engine is cold. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
23. Technician A says that main bearing knock is duller in pitch than rod bearing knock. Technician B says that main bearing wear will significantly reduce oil pressure. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
24. Excess crankshaft endplay is caused by:
    (A) worn rod journals.
    (B) worn crank throws.
    (C) worn thrust bearings.
    (D) worn connecting rods.

Compression Test Results

Condition	Possible Causes
All cylinders at normal pressure (no more than 10% difference between cylinders).	None. Engine is in good condition.
All cylinders low (more than 20% below specifications).	1. Burned valve or valve seat. 2. Blown head gasket. 3. Worn rings or cylinder. 4. Maladjusted valves. 5. Jumped timing chain or belt. 6. Physical engine damage.
One or more cylinders low (more than 20% below specifications).	1. Burned valve or valve seat. 2. Damage or wear on affected cylinder(s).
Two adjacent cylinders low (more than 20% below specifications).	1. Blown head gasket. 2. Cracked block or head.
One or more cylinders high (more than 20% above specifications).	1. Carbon buildup in cylinder.

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Cylinder Leakage Test Results	
Condition	**Possible Causes**
No air escapes.	Normal condition. No leakage.
Air escapes from carburetor or throttle body.	1. Intake valve damaged or not properly seated. 2. Valve train mistimed. Possible jumped timing belt or chain. 3. Broken or damaged valve train component.
Air escapes from tailpipe.	1. Exhaust valve damaged or not seated properly. 2. Valve train mistimed. 3. Broken or damaged valve train part.
Air escapes from dipstick tube or oil fill opening.	1. Worn piston rings. 2. Worn cylinder walls. 3. Damaged piston. 4. Blown head gasket.
Air escapes from adjacent cylinder.	1. Blown head gasket. 2. Cracked head or block.
Air bubbles in radiator coolant.	1. Blown head gasket. 2. Cracked head or block.
Air heard around outside of cylinder.	1. Cracked or warped head or block. 2. Blown head gasket.

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Chapter 56
Engine Removal, Disassembly, and Cleaning

After studying this chapter, you will be able to:

- Understand and apply the information contained in a vehicle identification number (VIN).
- Determine if engine removal is needed to make specific engine repairs.
- Summarize the steps in preparing for engine removal.
- Describe how to keep wires, lines, and parts organized during engine removal and teardown.
- Summarize how to attach and use engine lifting devices.
- Explain the major steps for engine disassembly.
- List various methods for cleaning engine parts.
- Correctly answer ASE certification test questions on engine removal, disassembly, and cleaning procedures.

In previous chapters, you learned about engine design, part construction, performance problems, engine mechanical failures, and engine troubleshooting. This chapter expands your knowledge of engine service by giving the most important or typical steps for engine removal, disassembly (teardown), and cleaning. Keep in mind that exact steps for disassembly vary from engine to engine. However, there are many general procedures that apply to all makes and models of engines.

Engine Identification

The type of engine to be serviced must be identified when ordering parts. There are several ways of identifying an engine:

- Knowledge of specific engine make from work experience.
- Studying engine construction to determine if it is OHC, turbocharged, etc.
- Using the vehicle identification number (VIN) to identify how original engine was installed in the vehicle.
- Using casting numbers to find original make, model, and year of the cylinder heads and cylinder block in the engine assembly.
- Measurement after disassembly to determine size of engine parts, such as bearings, pistons, rings, etc.

Identify Engine Type

By simply looking at the engine, you can determine:

- How many cylinders it has.
- The cylinder arrangement, such as V-type, inline, or opposed.

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- If the fuel system is multiport or throttle body injection.
- If it has a longitudinal engine (mounted with the crankshaft in a line from front to rear) or a transverse engine (mounted with the crankshaft in a line from side to side).
- If accessories, such as air conditioning and power steering, are installed.
- Other facts, such as engine turbocharging or supercharging.

Using this type of information along with the year, make, model, and VIN of the vehicle, a parts person can find out what engine is installed in the vehicle and order the correct parts.

Vehicle Identification Number

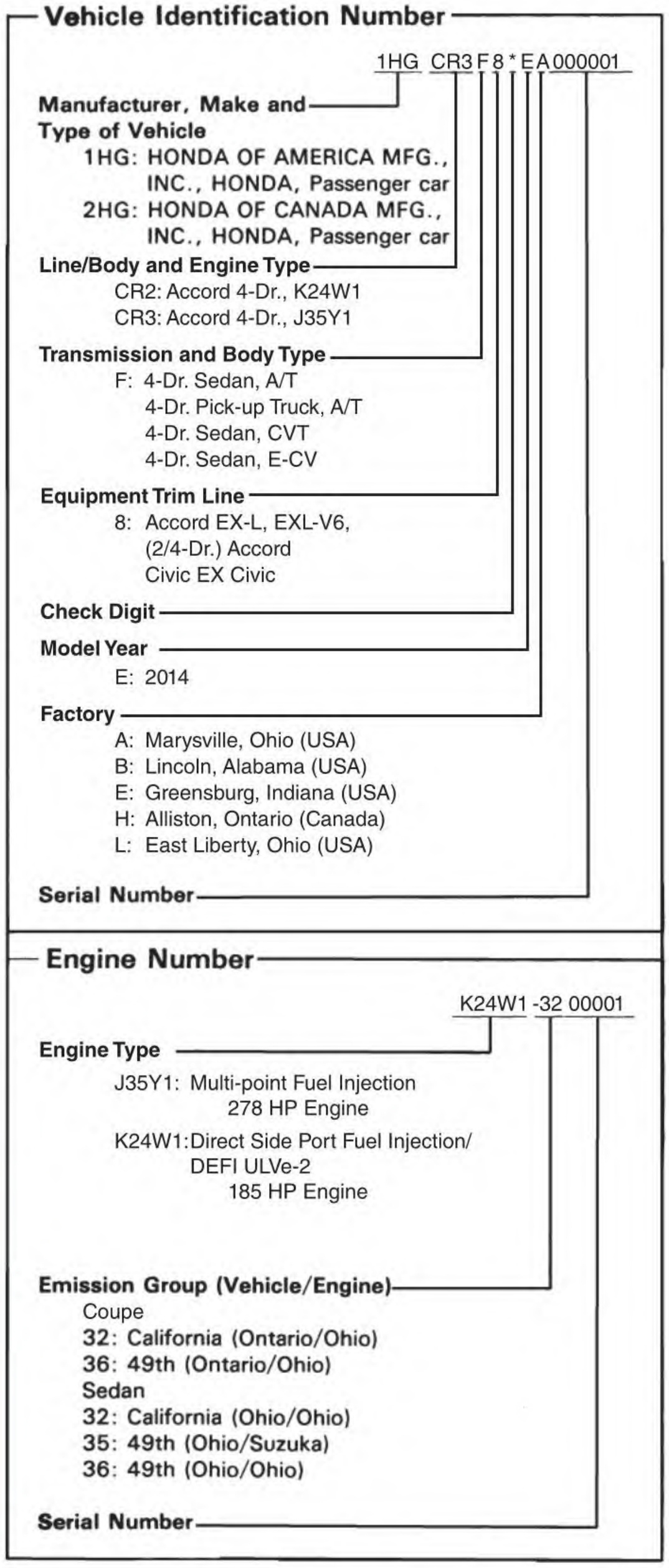
The ***vehicle identification number (VIN)*** is a unique number identifying the vehicle and some of the equipment installed on the vehicle. Contained within the VIN may be codes for the engine type and size, transmission type, differential type, body style, optional equipment, and so on.

The VIN may be located in one or more of several different locations. Service literature will help you locate and decipher the VIN. On late-model vehicles, the VIN is normally located in the top-left area of the dash and is visible through the windshield, **Figure 56-1**. By comparing the letters and numbers in the VIN to service literature, you can find out what engine was installed in the vehicle at the factory. Refer to **Figure 56-2**.



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Figure 56-1. The VIN can be found on the top-left area of the dash or inside the door opening.



Honda

Figure 56-2. Study how to read a VIN.

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Tech Tip

Before ordering parts, make sure the vehicle has its original engine. If the engine has been changed, the VIN may not match the engine and you could order the wrong parts.

Casting Numbers

Casting numbers are numbers formed into parts during manufacturing. They can be found on major components, such as the block, camshaft, and heads. These numbers can be used to find out information when ordering parts. Books or charts are available at auto parts stores that decode casting numbers. The manufacturer's webpage as well as other online sites may also contain helpful information.

Part Measurement

Part measurement is another way of finding out which engine you are working on. You can measure cylinder bore, valve sizes, head port sizes, piston diameter, and so on. This will help you and the parts person determine the block, head, and engine type.

Tech Tip

Before giving a quote and beginning engine removal, confirm that engine rebuild parts are available. Some foreign automakers require you to purchase a whole new engine and do not sell rebuild parts. In this case, the only other option is to locate and purchase a used engine from a salvage yard.

Is Engine Removal Necessary?

Many engine repairs can be made with the engine block in the chassis. Repairs limited to the cylinder head, valve train, and other external parts are commonly in-vehicle operations, that is, the engine remains in place. Engines must be removed when the cylinder block or crankshaft is badly damaged. Study **Figure 56-3**.

Whether or not the engine must be removed for a repair often depends on the year, make, and model of the vehicle. For example, one make of vehicle might require engine removal simply to replace a damaged oil pan because access to parts is hampered by the body or chassis. On the other hand, a different make of vehicle may have unobstructed access to the oil pan, allowing for quick and easy in-vehicle oil pan removal. This design may also permit in-vehicle replacement of piston rings, oil pump, bearings, and other major components. Generally, full-size cars and light trucks provide easier access to, and removal of, external engine parts. Therefore, they are likely to allow more in-vehicle engine repairs.



Riverdale Auto Repair

Figure 56-3. Many engine repairs can be done with the engine block still in chassis. Here, cylinder heads have been removed for a complete cylinder head rebuild or valve job.

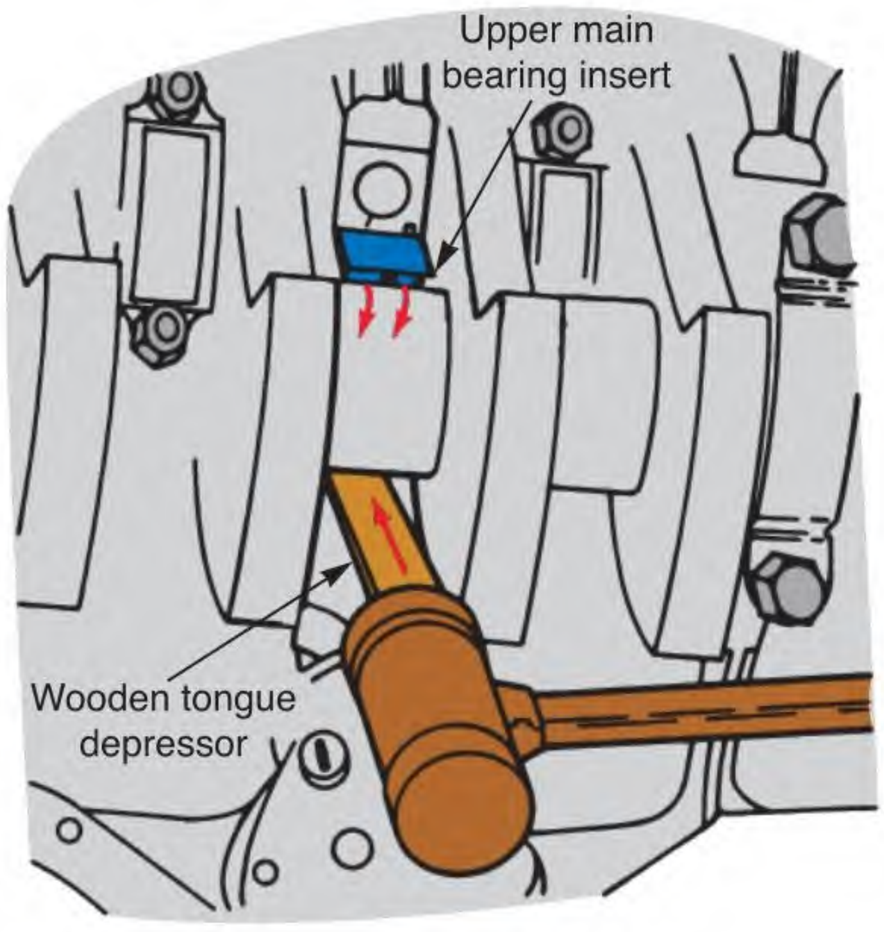
When unsure if the engine must be removed for a repair, refer to the service manual. It provides directions for the vehicle and engine on which you are working.

A few engine repairs that can be done with the engine block still installed in the vehicle include:

- Valve job—This involves reconditioning the valve faces, seats, and other valve train or cylinder head parts. Normally, the intake manifold, exhaust manifold(s), and cylinder head(s) can be removed with the short block bolted in the chassis.
- Valve seal and valve spring replacement—These components can usually be replaced without removing the cylinder heads from the engine or the valves from the cylinder heads. Shop air pressure is injected into the cylinders to hold the valves closed. Then, a small valve spring compressor is used to compress the springs, allowing for removal and replacement of the keepers, retainers, springs, and seals.

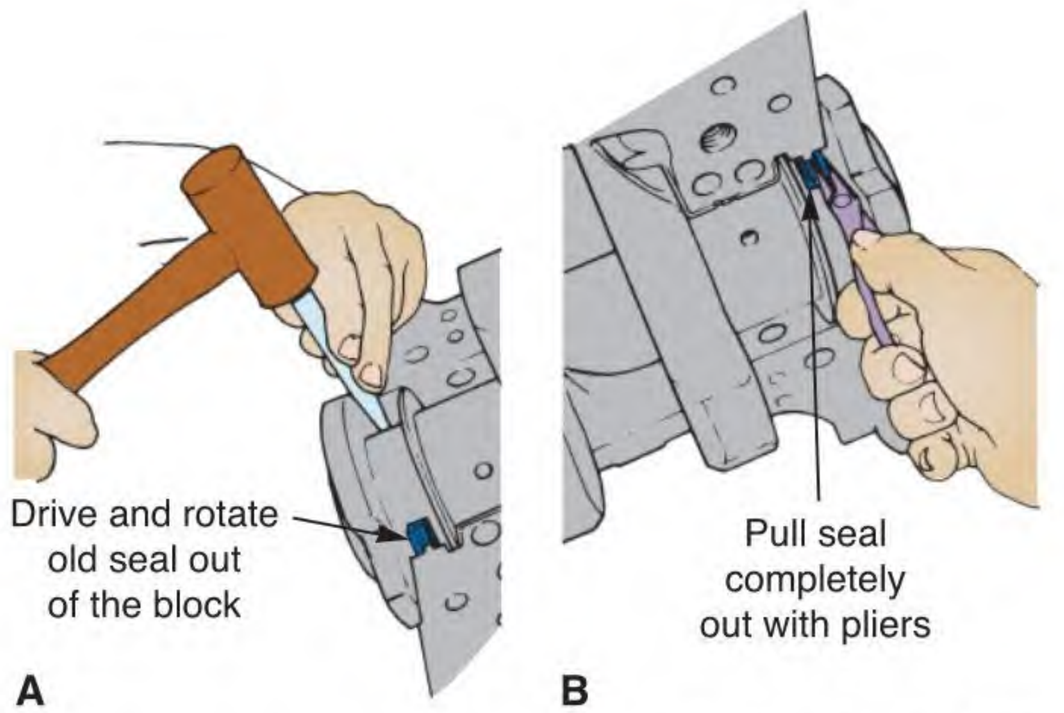
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- Oil pump replacement—However, if the oil pan cannot be removed by simply raising the engine off the motor mounts, engine removal is required.
- Main bearing replacement—Engine main bearings can sometimes be replaced with the block in the vehicle. After removing the oil pan, unbolt and remove the main caps to expose the main bearing inserts. Fit the correct size bearing inserts into the main caps. To remove the upper main bearing inserts, push them around the crankshaft with a thin blade screwdriver, wooden tongue depressor, or shim. Pushing on the edge of the bearing rotates the upper bearing out, **Figure 56-4**. A special cotter pin–type tool that fits into a crankshaft oil hole can also be used. By pulling on a breaker bar on the crankshaft snout bolt, the cotter pin-type tool will spin and rotate the bearing out from between the block and crankshaft main journal.
- Rear main oil seal replacement—This is an in-vehicle operation if the oil seal is a two-piece seal and the oil pan can be removed without removing the engine. The top half of a two-piece neoprene oil seal can be pushed out of the block with a small screwdriver. The bottom half of a two-piece seal fits in the main cap, **Figure 56-5**.
- Piston service—If the block is in good condition, pistons can sometimes be serviced without removing the engine block from the vehicle. For example, a bad piston pin may make a double knock. Determine which one is knocking by using a stethoscope. Then, pull the oil pan and the cylinder head on the correct side of the block. Remove the rod cap for that piston and push the piston out. Replace the piston and pin. Then, reassemble the engine. This would save time over pulling the engine out of the vehicle. However, it is normally more efficient to remove the engine for piston service. In-vehicle piston service is normally only appropriate on a low-mileage engine, such as one that is under warranty.



Renault

Figure 56-4. It may be possible to replace rod and main bearings without removing the engine from vehicle. A wooden tongue depressor, popsicle stick, or wooden shim can be used to rotate old upper bearing insert out of the block.



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Figure 56-5. A two-piece rear main oil seal can often be replaced without removing engine from vehicle. Modern one-piece rear crankshaft oil seal would require engine or transmission removal. A—Driving upper half of a neoprene seal out with a driver. B—Use pliers to pull seal out of block.

- External engine part service—External engine parts include exhaust manifolds, intake manifolds, cam covers, valve covers, front cover, and so on. These can normally be serviced without engine removal. When servicing exhaust manifolds, it may help to unbolt the engine or motor mounts and lift the engine with a floor jack.

Engine repairs that normally require engine removal include:

- Cylinder block service—Seldom can repairs be done to the cylinder block casting unless it is removed and disassembled. Honing and cylinder sleeve replacement can be done in-house if equipped with proper tools and equipment. Many auto shops send out the block to a machine shop.
- Crankshaft service—If wear or damage to the crankshaft is excessive, you need to pull the engine out of the vehicle for repairs. However, if only the crankshaft

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and bearings need service (no rod or piston damage), the engine top end assembly can remain in place during crankshaft replacement. You do not have to remove the cylinder heads, valve covers, rods, and other engine components. This saves you hours of work and also saves the customer money from unnecessary labor costs. Refer to **Figure 56-6**.

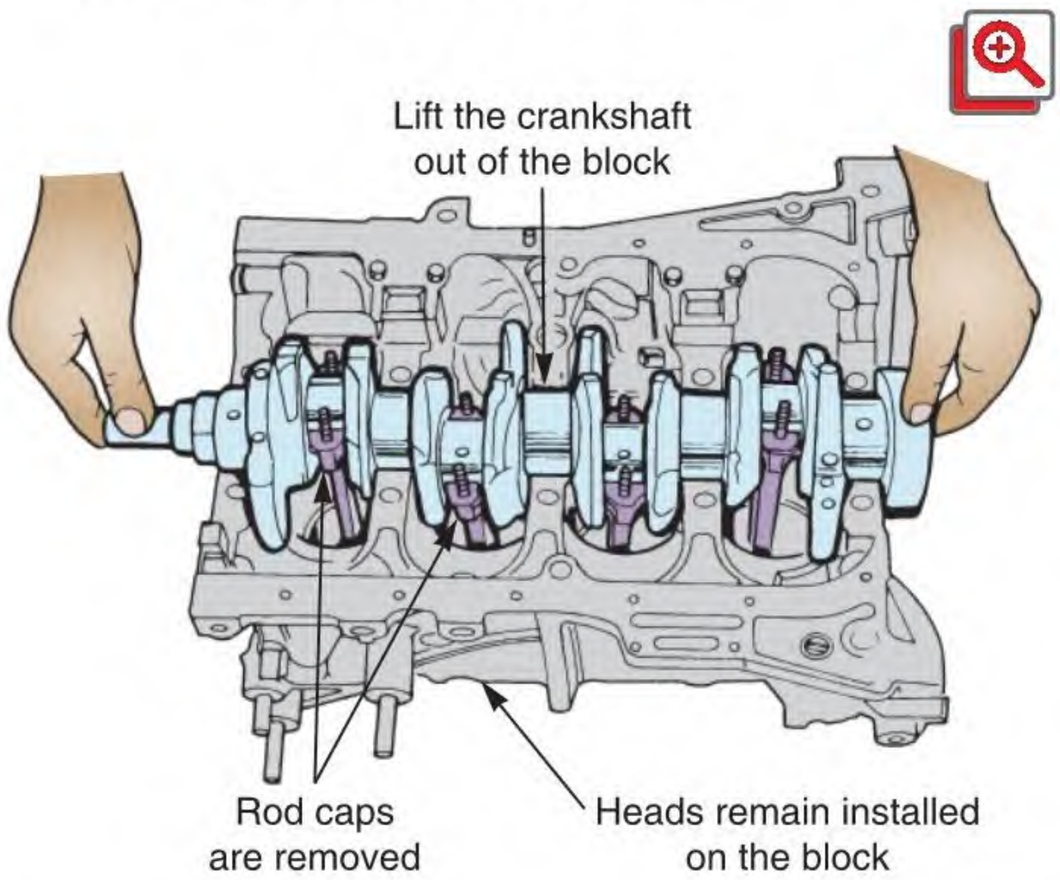
- Cylinder repair—Wear or damage to the cylinder walls requires complete engine removal for cylinder machining and replacement.

Remember that there are exceptions to almost any rule. Machines are available for in-vehicle turning of crankshaft journals, but these machines are not common. In addition, some engines must be lifted halfway out of the vehicle just to change spark plugs. This makes it important for you to refer to the service manual when in doubt.

Engine Overhaul

The terms ***engine overhaul*** and ***engine rebuild*** are understood to mean a process that includes:

- Completely disassembling the engine (heads, block, cam drive, manifolds, etc.).
- Cleaning, inspecting, and measuring critical parts, such as the crankshaft, cylinder walls, valves, and cylinder heads.
- Replacing worn bottom end parts, such as the main bearings, rod bearings, crankshaft seals, piston rings, pistons, and gaskets.
- Replacing worn top end parts in cylinder heads, such as valves, valve seals, valve guides, valve springs, and sometimes other valve train parts.
- Replacing or repairing worn camshaft drive assembly parts, such as camshafts, cam phasers, timing chains, chain guides, timing belts, timing gears, front crankshaft seal, and front cover.
- Machining worn or warped engine castings and forgings, including cylinder block, crankshaft, camshaft, and cylinder heads.
- Reassembling the engine using proper sealants, methods, and torque specifications.



Honda

Figure 56-6. If rods are not damaged, you can replace a bad crankshaft without removing the cylinder heads and manifolds. However, if the rods, pistons, or cylinders are damaged, complete engine removal and teardown would be required.

Parts Replaced or Reconditioned

Basically, the following parts are replaced or reconditioned during a major engine overhaul:

- Piston rings and worn or damaged pistons.
- Connecting rod, main (crankshaft), and camshaft bearings.
- Oil pump.
- Timing belt, chain, or gears.
- Core plugs.
- Camshaft(s) and worn lifters.
- Valve train components, especially worn valve springs.
- Valve guides and seats.
- All gaskets and seals.
- Other parts that are not within specifications.

In addition, as you will learn later, sometimes the block must be bored and oversize pistons installed. You may need to have the crankshaft turned and install undersize main and rod bearings. Camshaft bearings could be worn and lowering oil pressure, which means they need to be replaced.

In-Vehicle Engine Overhaul

An ***in-vehicle engine overhaul*** can only be done when cylinder and crankshaft wear are within specifications and the oil pan and heads can be easily removed with the engine installed in the vehicle. The general condition of the crankshaft can be determined by measuring oil pressure, listening for bearing knock, and/or inspection.

Generally, remove the top end from the engine. Check cylinder wear to make sure the cylinders will take new rings without boring. Remove the oil pan

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and rod caps. Drive the pistons out of the top of the block. Hone and clean the cylinders. Replace the main bearings. Then, reinstall the pistons and rods with new rings and rod bearings. Install the new oil pump, reconditioned heads, and other engine parts.

Tech Tip

An in-vehicle engine overhaul is only cost- and time-efficient when there is a large engine compartment and plenty of room to work under the engine. A light truck is a good example. In most cases, it is just as easy to remove the engine for major service.

Preparing for Engine Removal

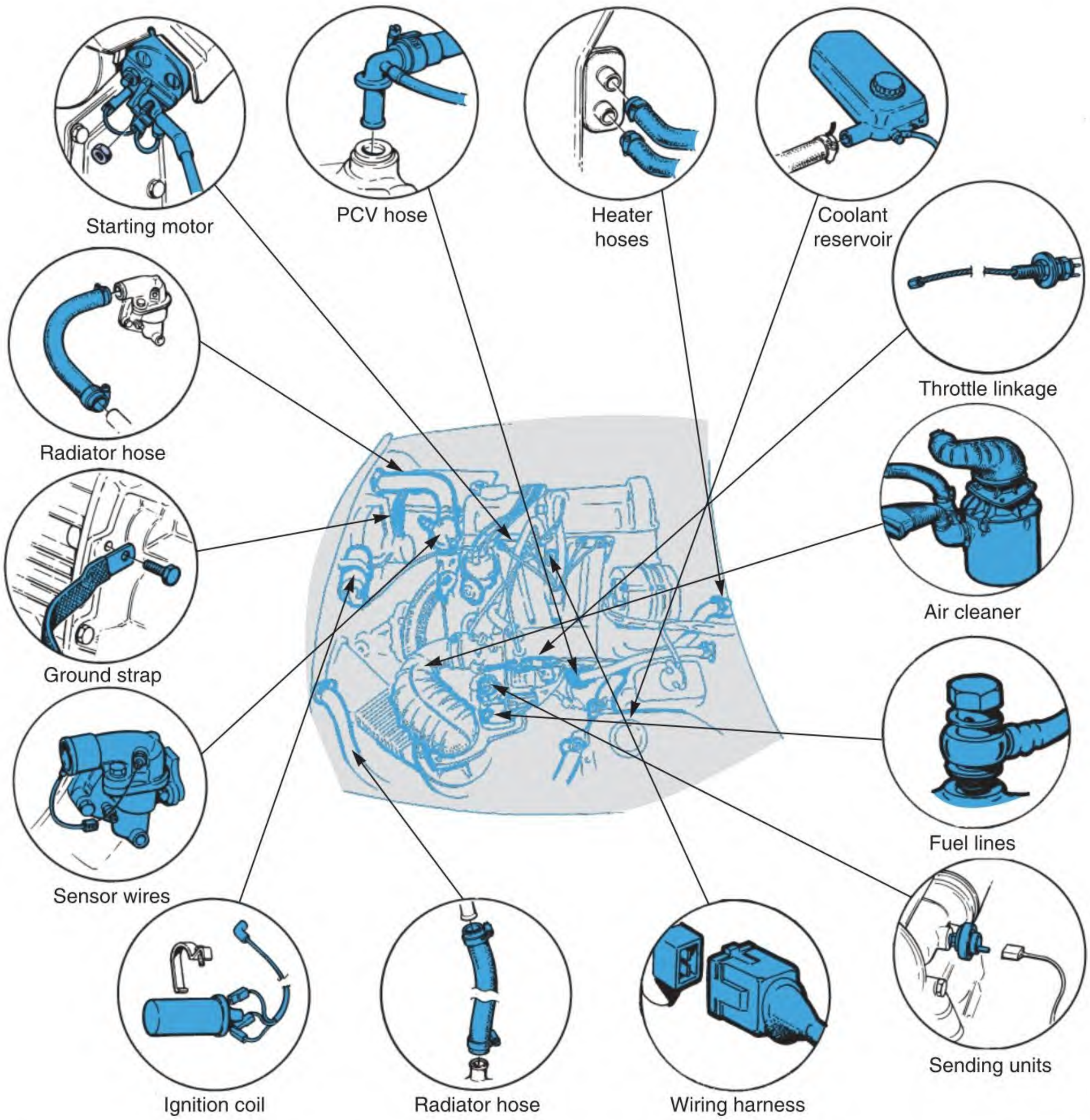
To prepare for engine removal, most technicians disconnect everything under the engine first. This includes the motor mounts, bell housing bolts, torque converter bolts, exhaust system, and so on. See **Figure 56-7**.

The parts under the engine are disconnected first so that oil, fuel, and coolant are not leaking out from the disassembled top end while working under the engine. Also, you can still turn the engine over using the starter to rotate the torque converter and remove its bolts. Next, disconnect the starter and drain the fluids. Finally, disconnect everything on top of the engine that prevents engine removal. This includes the air cleaner, throttle linkage, wiring harness connections, and vacuum hoses. See **Figure 56-8**.

Subaru, Honda, Peugeot

Figure 56-7. Most technicians begin engine removal under the vehicle. A—Remove any shrouds, shields, or covers that are in the way. B—Unbolt the bell housing if the transmission or transaxle is to remain in the vehicle. C—Unbolt the torque converter if the transmission is to stay in the vehicle. D—Unbolt the engine motor mounts. E—Unbolt and remove the exhaust manifold or header pipe. F—Drain the coolant and oil.

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Saab

Figure 56-8. Remove all brackets, hoses, wires, and components that will prevent removal of engine from vehicle. Study some of the items that might have to be removed for engine removal.

Service Procedure

Basically, use the following steps to get the engine ready for removal. Depending on whether the vehicle is rear- or front-wheel drive, you may need to modify this procedure.

1. Park the vehicle so there is plenty of space on both sides and in front of the vehicle.
2. Place the vehicle on jack stands. Disconnect or remove everything under the vehicle that prevents engine removal. The exhaust system can be rusted and the manifold or header pipes can be difficult to unbolt. Use rust penetrant and a six-point socket if the bolts or nuts are hard to remove.

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Warning

When an engine is on a stand, move it very slowly because the small caster wheels can catch and tip the engine off the stand. If anyone is in the engine's path when it falls, their legs and feet can be crushed severely.

3. Drain and collect the engine oil and coolant.
4. Lower the vehicle and place covers over the fenders to protect the paint.
5. Scribe lines around the hood hinges to aid realignment. Then, have someone help you remove the hood. Store the hood in a safe place where it cannot be scratched or damaged.
6. Disconnect the battery, negative terminal first, to prevent electrical shorts. Remove the battery if it is in the way. On a hybrid, disable the electric drive.

Warning

Make sure the 12-volt battery or HV battery is disconnected from all electric circuits. If you were to hit and pinch a 12-volt "hot wire" with the heavy engine, you could short the wire and start an electrical fire. If a high-voltage hybrid accidentally touches the engine on an orange power cable conductor to the HV battery pack voltage, a large welding arc flash or repeated shorts will badly burn metal parts at the short circuit. You could also be burned by shorting a hybrid battery cable to ground.

7. Disconnect or remove the components on the top of the engine. Keep all fasteners in a separate container.
8. Unplug all electrical wires between the engine and chassis. If needed, use masking tape to label or identify the wires. This will simplify reconnection of dozens of wires during engine installation, **Figure 56-9**.
9. Remove all coolant, fuel, and vacuum hoses or lines that prevent engine removal. Label as needed, especially vacuum lines. On vehicles with an electric fuel pump, you may need to bleed off fuel pressure before disconnecting the fuel lines.
10. Do not disconnect any power steering or air conditioning lines unless absolutely needed. Usually, the power steering pump or air conditioning compressor can be unbolted and placed on one side of the engine compartment. If you must remove air conditioning lines, the refrigerant must be properly recovered.
11. Remove the radiator, fan, and other accessories in front of the engine. Do not hit or drop the radiator.
12. Remove any other part that prevents engine removal. Check behind the engine for hidden ground wires, dipstick tubes, and so on.
13. Unbolt the motor mounts holding the engine in the vehicle. Today's engines usually use two or three engine mounts. There may also be a damper strut between the engine and shock tower to keep the engine from rotating on its mounts under high power or load conditions.

If it is not a hybrid HV starting system, you will have to remove the 12-volt starting motor to remove the engine from the vehicle. This is illustrated in **Figure 56-10**.

Keep fasteners organized in several different containers. For instance, keep all of the bolts and nuts from the front of the engine in one container. Keep engine top end and bottom end fasteners separate in two additional containers. This will speed reassembly.

Removing Transmission with Engine

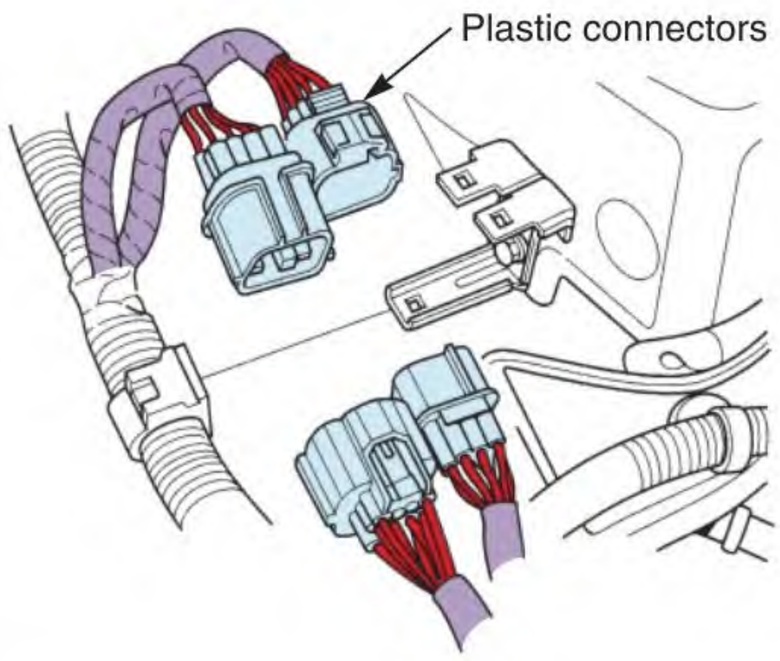
Some front-wheel drive vehicles require that the engine and transaxle be removed as a single unit. Check the service manual for details.

You may want to drain the fluid from the transmission or transaxle if it is to be removed. On rear-wheel-drive vehicles, the drive shaft, transmission and clutch linkage, speedometer cable, rear motor mount, and other parts must also be removed. On a transaxle, the axle shafts must be disconnected.

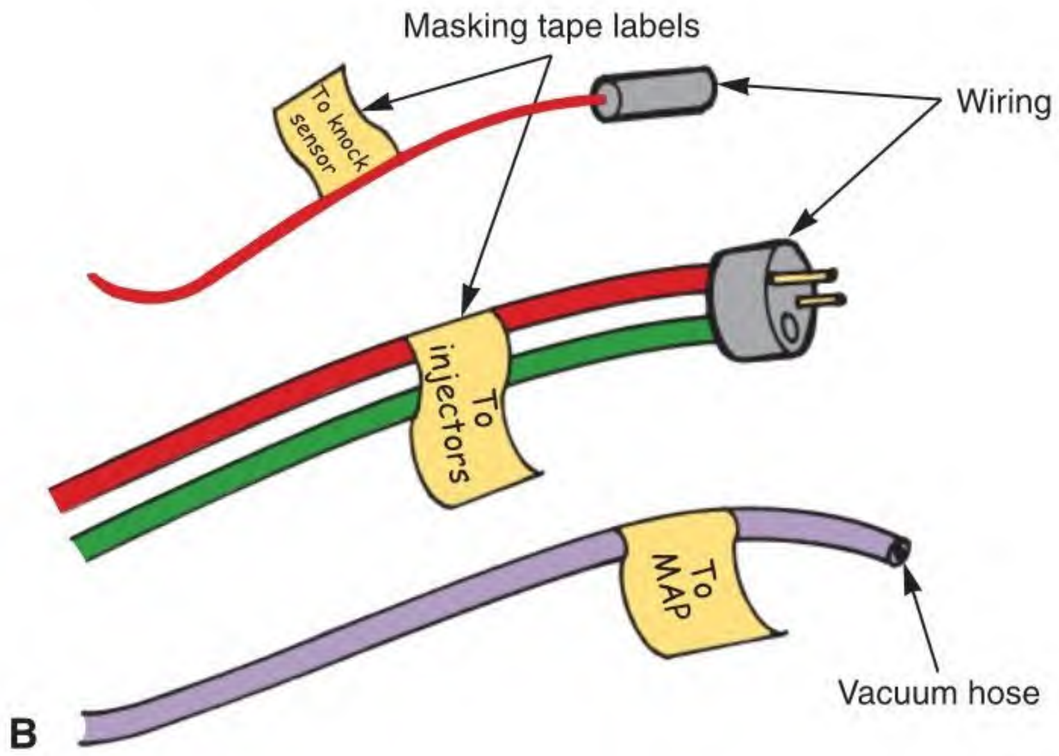
Tech Tip

Keep your work area clean. Coolant and engine oil will usually drip onto the shop floor during engine removal. To prevent an accident, wipe up spills as soon as they occur. A clean work area also helps present a professional image to the customer.

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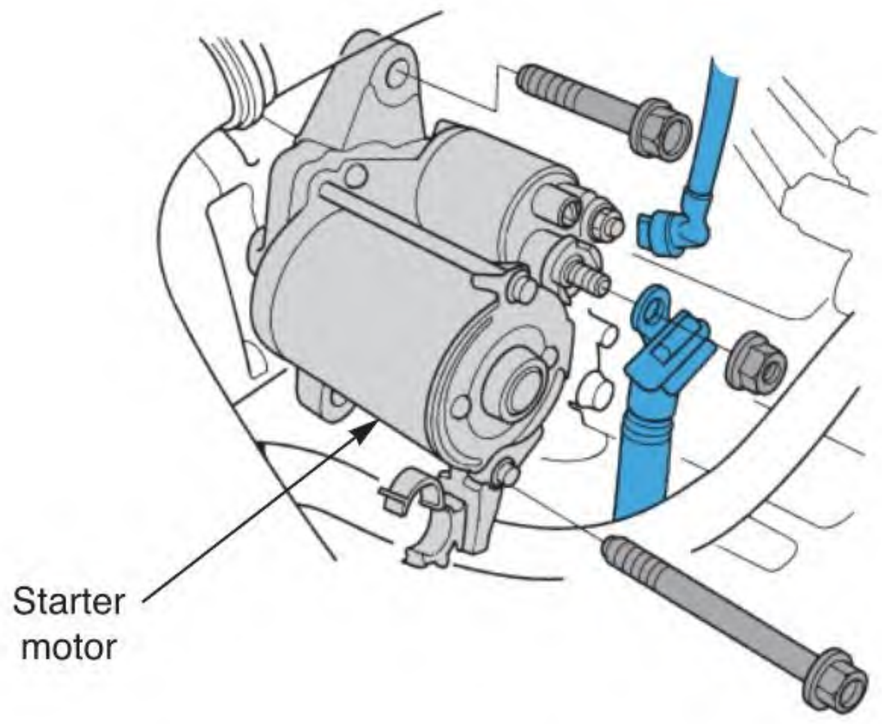
A



B

Honda

Figure 56-9. Here are a few tips to follow when disconnecting all wire connectors going to an engine before extraction from the frame or unibody. A—Be careful not to break plastic connectors when disconnecting wire harnesses from the engine. B—Masking tape can be made into labels for hoses and wires.



Acura

Figure 56-10. Disconnect the starter since it often bolts to bell housing next to the flywheel ring gear. You may need to remove the starter to provide clearance for lifting engine out of the vehicle.

Engine Removal

Before attempting removal of the engine, double-check everything to be sure nothing remains to be disconnected or removed. Always perform the following checks before starting the removal process.

- Look behind and under the engine for hidden wires or ground straps. Damage to the wiring harness can be very time-consuming to repair or replace.
- Make sure all bell housing bolts are removed. Some are difficult to see when covered with road grime.
- If the transmission is to remain in the vehicle, check all torque converter bolts to make sure they have been removed.
- Make sure all fuel lines have been bled down, disconnected, and then plugged to keep debris out of the fuel system.
- Check that the motor mounts are unbolted from the frame or crossmember.
- Make sure your floor jack or holding bar is supporting the full weight of the transmission, transaxle, or hybrid motor-generator assembly.

Warning

An engine weighs several hundred pounds. Be very careful when lifting and moving an engine. Serious injury could result if an engine were to fall off a crane or stand. Be sure all necessary precautions are observed.

Installing Lifting Fixture or Chain

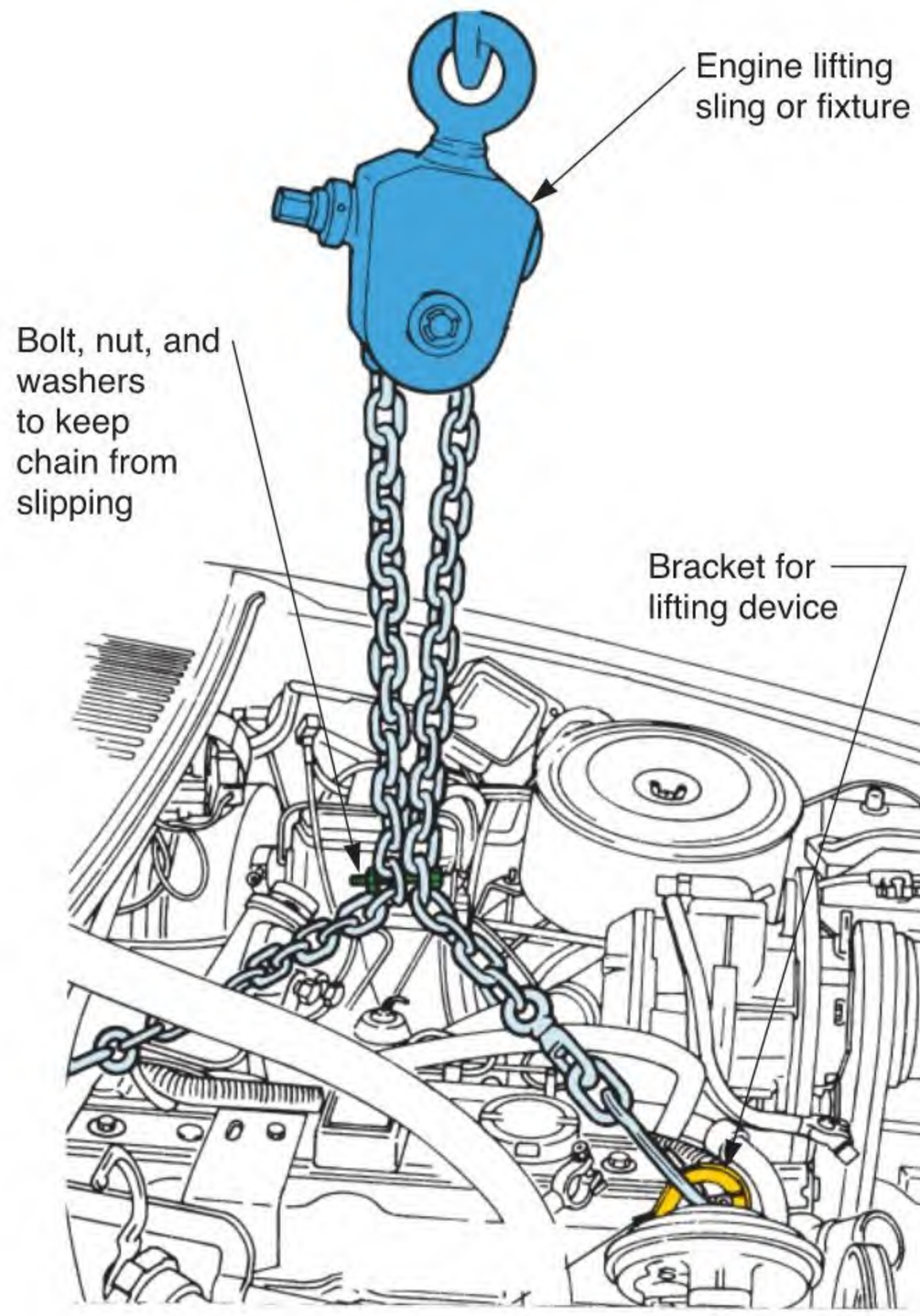
Position the ***lifting fixture*** or chain at the manufacturer's recommended lifting points on the engine. Sometimes, lift points are designed into the engine,

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often as brackets bolted to the block. Bolt the lifting fixture or chain to the engine. Use washers as needed to ensure the bolts do not pull out of the chain or lifting fixture. Refer to **Figure 56-11**.

Make sure the attaching bolts are the correct diameter for the hole in which they are installed. Also, the bolts must be fully seated and a proper length. They must thread into the hole a distance equal to at least 1 1/2 times the diameter of the bolt. This is illustrated in **Figure 56-12**.

Generally, position the fixture or chain so that it will raise the engine in a level manner, or slightly tilted down at the rear if needed. If one lifting point is at the right-front of the cylinder head, the other should be on the left-rear of the head. Use common sense and follow the manufacturer's instructions. Refer to **Figure 56-13**.



Ford

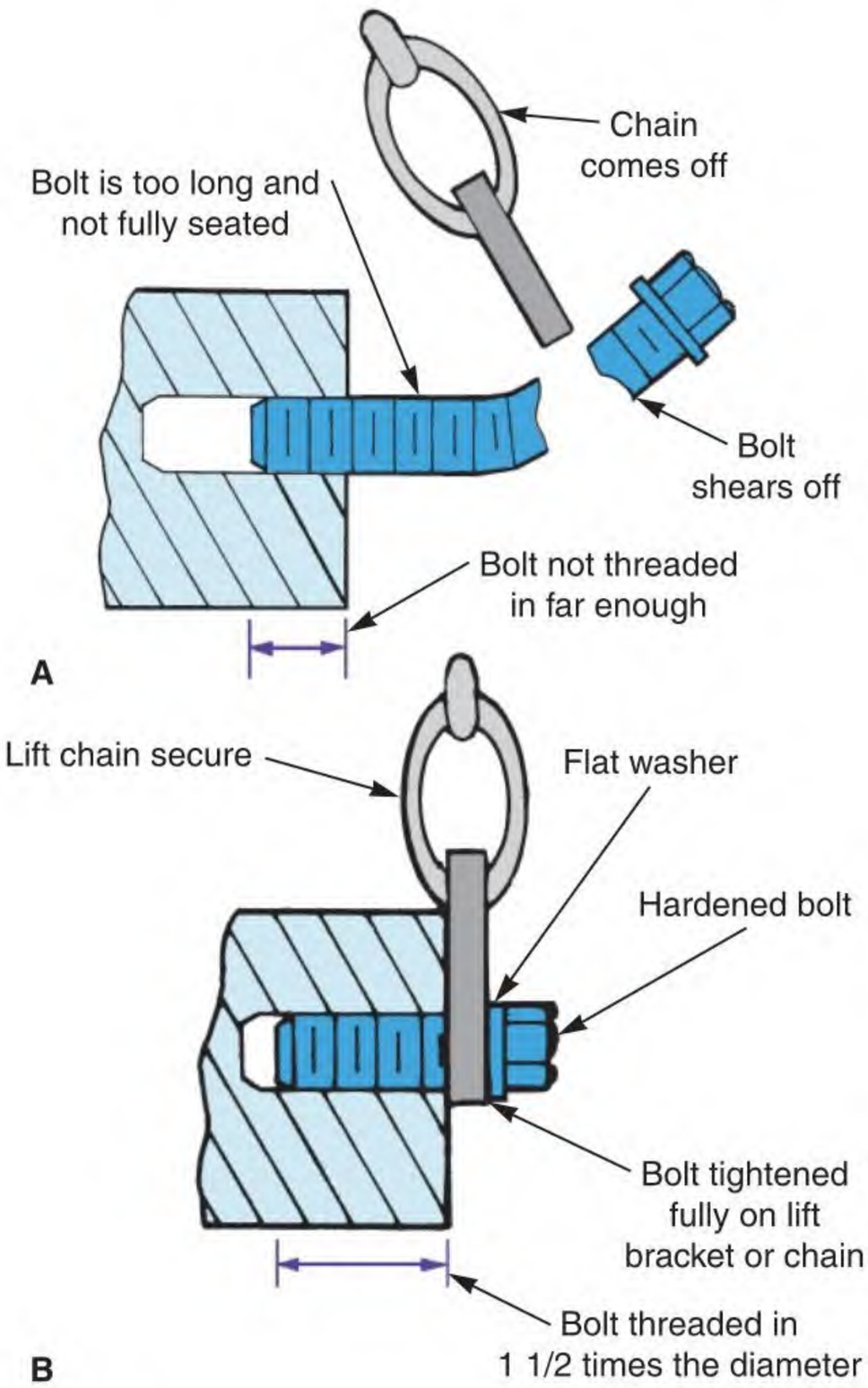
Figure 56-11. Make sure the lifting chain or fixture is attached properly. Note how this engine has brackets for engine removal. If the chain is attached with bolts, make sure the bolts are strong enough and fully threaded into holes.

Caution

Avoid damaging the motor mounts during engine removal. Some motor mounts are liquid-filled units or computer-controlled, hydraulic units to reduce engine noise. The computer can alter the stiffness of the mounts by using solenoid valves that control hydraulic flow in the mounts. If you damage any of these mounts, it can be an expensive mistake.

Lifting Engine from Vehicle

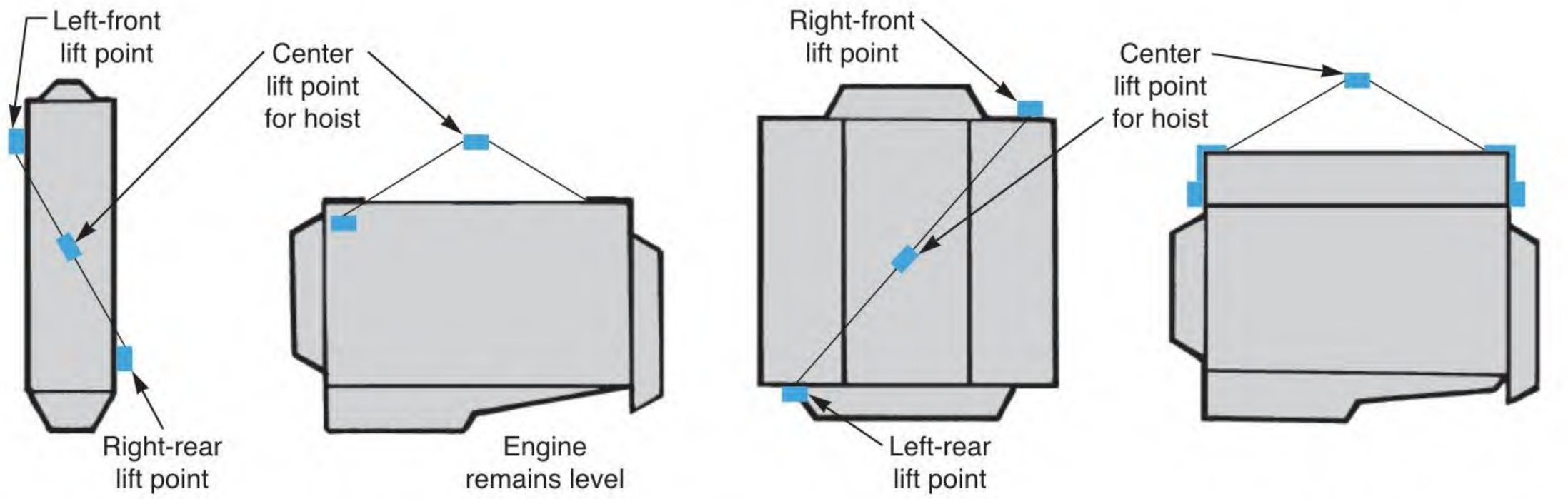
Make sure the ***crane boom*** or ***engine hoist*** is centered over the engine. Then, attach the crane or hoist to the lifting fixture or chain. Place a floor jack



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Figure 56-12. Make sure the bolts used to fasten the lift chain to the engine are long enough and properly tightened. A—If the bolt extends too far from the hole, it can bend and break. B—A correctly installed bolt.

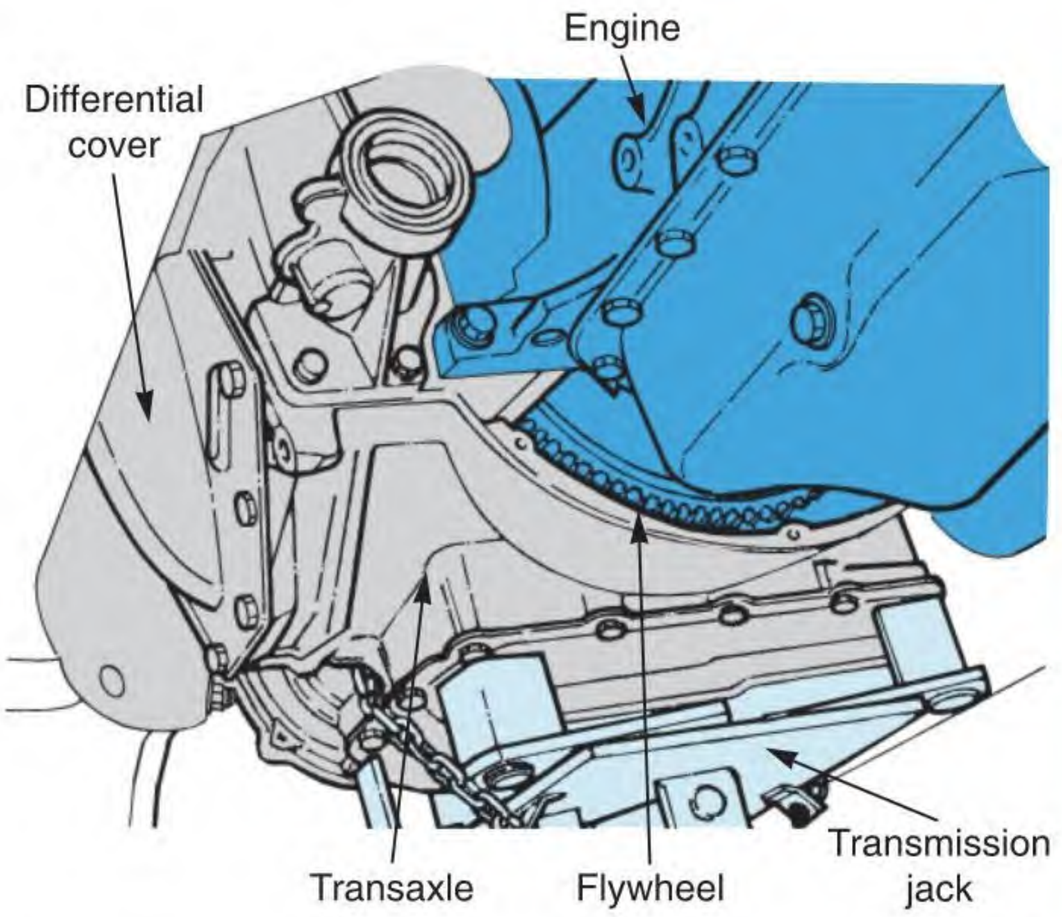
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Figure 56-13. Lift points should be on opposite sides and ends of the engine.

under the transmission if needed. If the transmission is to stay in the vehicle, support it. Do not let a transmission or transaxle hang unsupported after engine removal. This could damage the mounts, drive shaft, drive axles, and other parts, **Figure 56-14**.



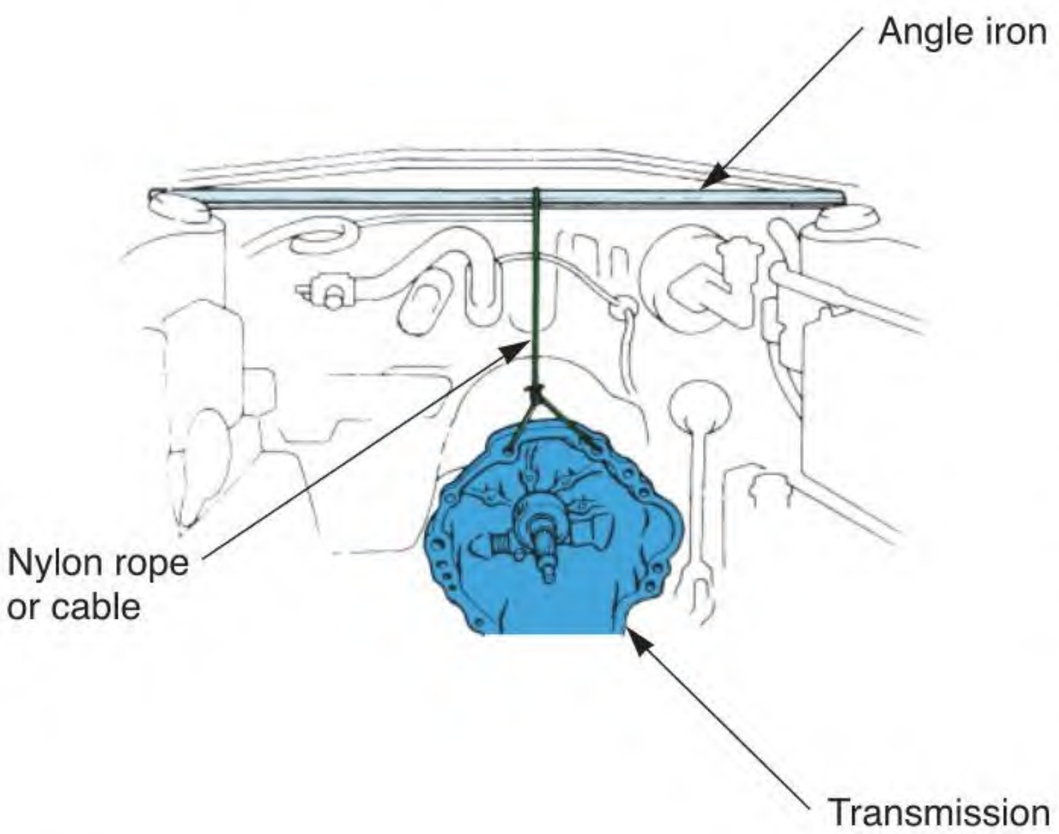
Chrysler

Figure 56-14. If the transmission/transaxle is to stay in the vehicle, support it. Do not let it hang unsupported.

Service Procedure

1. Raise the engine slowly about an inch or two.
2. Use a large pry bar to separate the engine alignment dowel pins from the transmission, transaxle, or hybrid motor-generator assembly. This will separate the engine crankshaft or flywheel from the clutch, torque converter, or electric driveline. Look at **Figure 56-15**.
3. Pump the crane handle a few times, and then recheck the engine to double-check that everything is disconnected between the chassis and engine. Make sure the engine is not hitting the firewall, fender aprons, brake master cylinder, evaporator or heat core box, radiator support, steering column, etc. Do not let the engine catch on air conditioning refrigerant lines, wiring harnesses, and especially high-power hybrid power cables.
4. If you are using an adjustable lifting fixture on the engine, turn its handle to tilt the engine. This will add body/frame clearance as the large assembly is slowly raised out of the engine compartment.
5. When the engine is high enough to clear the radiator support, roll the crane and engine straight out and away from the vehicle. With a stationary engine hoist, roll the vehicle out from under the engine.
6. As soon as you can, lower the engine to the ground or mount it on an engine stand. See **Figure 56-16**.

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Toyota

Figure 56-15. If the transmission is not removed, it must be supported. Note the use of an angle iron holding fixture and rope to hold up on transmission, protecting the rear rubber mount from breakage.



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Figure 56-16. This technician has checked to make sure the engine is secured to the stand. The lifting chain can now be removed.

Warning

Never work on an engine that is held up by a crane or hoist. The engine could shift and fall, causing serious injury or damaging the engine. Also, keep your hands and feet out from under the engine when raising or lowering the crane or hoist.

Lowering Engine from Vehicle

In some vehicles, the engine and transaxle are removed from underneath the vehicle. With some vans, the engine can be removed through the large door in the side of the body.

Most rear- and mid-engine sports cars and some minivans require you to raise the vehicle on a lift or place it on jack stands. A large floor jack is then used to lower the engine and electric drive out the bottom of the chassis.

Many new vehicle designs require you to only remove a few large subframe cradle bolts for engine removal. You can then quickly lower the whole power train (engine, transaxle, drive axles, and rear suspension) all at once. This allows for all power train assemblies to be serviced and repaired more easily while they are on your tool cart. Check manufacturer service instructions for details on engine removal.

Separating Engine and Transmission/ Transaxle

If you pulled the engine and transmission/transaxle together, you will need to separate the transmission from the engine. Rest the assembly on the shop floor. Place blocks of wood under the engine, or leave the hoist and chain attached to the engine, to keep it from flipping over while sitting on the ground. Also, make sure the transmission/transaxle is sufficiently supported.

With an automatic transmission or transaxle, remove the bolts between the engine and bell housing. Check closely all the way around the engine because some can be hard to find. Remove the starter motor (if still attached) and any other parts preventing transmission removal. Some technicians prefer to leave the torque converter bolted to the flywheel. Others unbolt the converter so it will come out with the transmission. To separate the assembly, lift up on the transmission/transaxle, wiggle the unit, and gently pull it off of the engine.

With a manual transmission or transaxle, first unbolt the transmission. Then, remove the bell housing, clutch, and flywheel. Finally, separate the assembly by gently pulling the transmission/transaxle off of the engine.

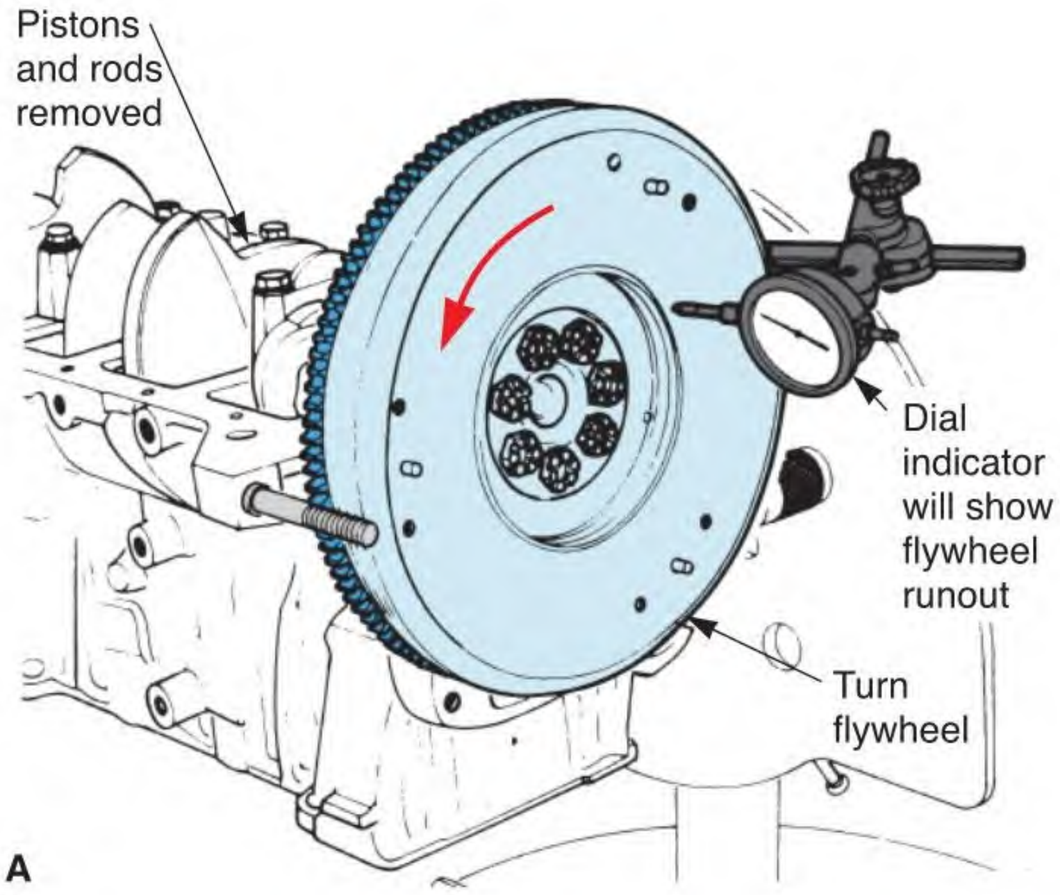
Inspect the flywheel for problems. Check its friction surface for heat checking and cracks. Use a dial indicator to check the flywheel surface for runout, which indicates warpage. Then, if needed, use a flywheel holding tool to keep the crankshaft from turning as you loosen and remove the flywheel bolts, **Figures 56-17A** and **56-17B**.

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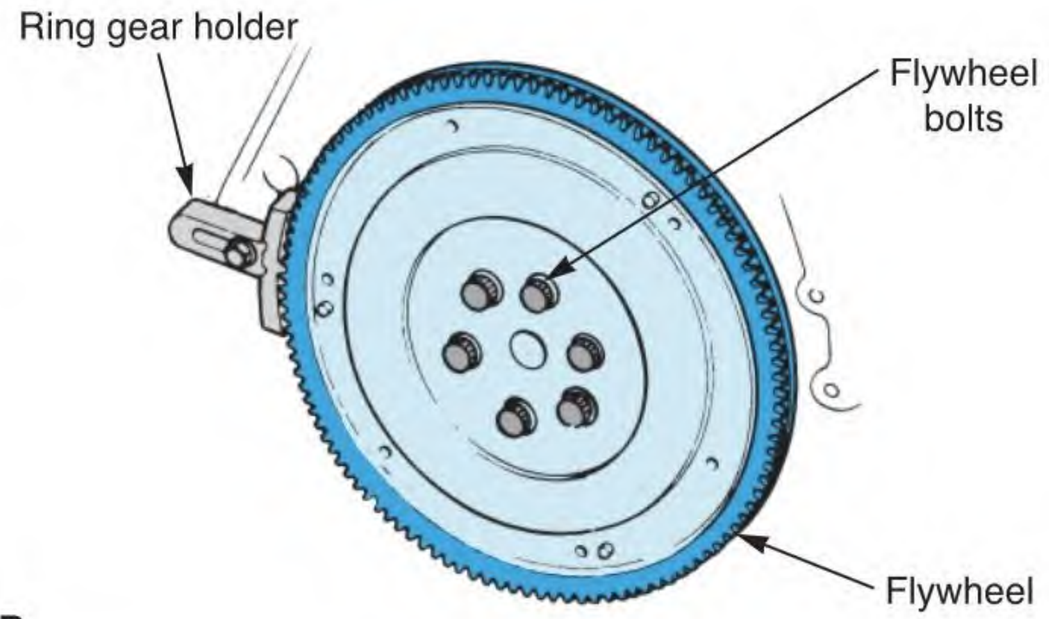
You should also check the flywheel teeth for damage. If any of the teeth are broken or ground off, install a new ring gear on the flywheel. You do not want to rebuild the engine and have the starter motor grinding on a bad ring gear. Use heat from a torch to enlarge the ring gear so it can be driven off with a flat nose punch and hammer. Study **Figures 56-17C** and **56-17D**.

Warning

The clutch friction disc on a manual transmission may contain asbestos or similar heat-resistant material, which can cause cancer. Wear appropriate respiratory protection. Do not blow clutch dust off of parts with a blowgun. Always use appropriate dust containment and removal procedures.



A



B



C



D

Honda

Figure 56-17. Before mounting an engine on a stand, you should remove the flywheel. A—To check for flywheel runout, mount a dial indicator on the friction surface and rotate the crankshaft snout bolt with a breaker bar. Needle deflection equals runout. B—To remove frozen flywheel bolts, you may want to use a holding fixture like this one. C—The friction surface on this flywheel is badly worn and heat checked (small cracks). D—Always check a used flywheel for worn teeth. If they are worn, the starting motor may grind.

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Placing Engine On Engine Stand

Most ***engine stands*** have a removable, rotating plate to which the engine is bolted. It is usually easier to bolt the engine to this plate first while the plate is not attached to the stand.

Service Procedure

There are usually four adjustable arms on the engine stand plate.

1. Remove the engine mounting fixture (plate) from the engine stand.
2. Place the plate on the back of the engine and adjust the arms to align with the bell housing bolt holes. The arms should be evenly spaced.
3. Bolt the arms to the engine using Grade 8 bolts, but only hand tighten at this point.
4. Move the plate and adjustable arms so that the plate's pivot point (collar) is roughly at the engine's center of gravity, which is usually just above the crankshaft.
5. Tighten the bolts in the adjustable arms.
6. Use the hoist to raise the engine to approximately the height of the engine stand.
7. Move the stand into position by the mounting fixture.
8. Slowly raise or lower the engine until the collar on the mounting plate aligns with the pivot hole in the stand.
9. Insert the collar into the hole and lock it into place; most stands have a locking pin or bolt(s).
10. Slowly lower the crane boom until there is no tension on the lifting chain. See **Figure 56-18**.
11. Once you are certain the engine is securely attached to the engine stand, you can remove the lifting chain.

Warning

Be very careful when releasing the tension on the lifting chain. If the engine is not secure or not balanced and centered, the engine and stand may shift, flip, or fall, causing severe injury.



OTC Div. of SPX Corp.

Figure 56-18. An engine stand makes engine repair less strenuous on your back. The engine can be rotated into different positions. Also note the catch pan for dripping oil and coolant.

Engine Disassembly

With the engine bolted to an engine stand, you are ready to begin disassembly, or teardown. ***Teardown*** is the basic disassembly of the engine. Engine teardown methods vary somewhat from engine to engine. However, general procedures are similar and apply to all engines. The following sections provide a general guide.

Go slowly and inspect each part for signs of trouble as it is removed. Look for wear, cracks, damage, seal leakage, or gasket leakage. Remember, if you overlook even one problem, the rebuilt engine may fail in service. All of your work could be for nothing, and your employer may have to assume the responsibility of fixing the vehicle again.

Start engine disassembly by removing the exhaust manifolds, cam covers, sensors, and other parts on the tops and sides of the engine. Although any sequence might work, try to work your way around the engine so that you can separate bolts and parts according to their location in the engine (top, side, or bottom).

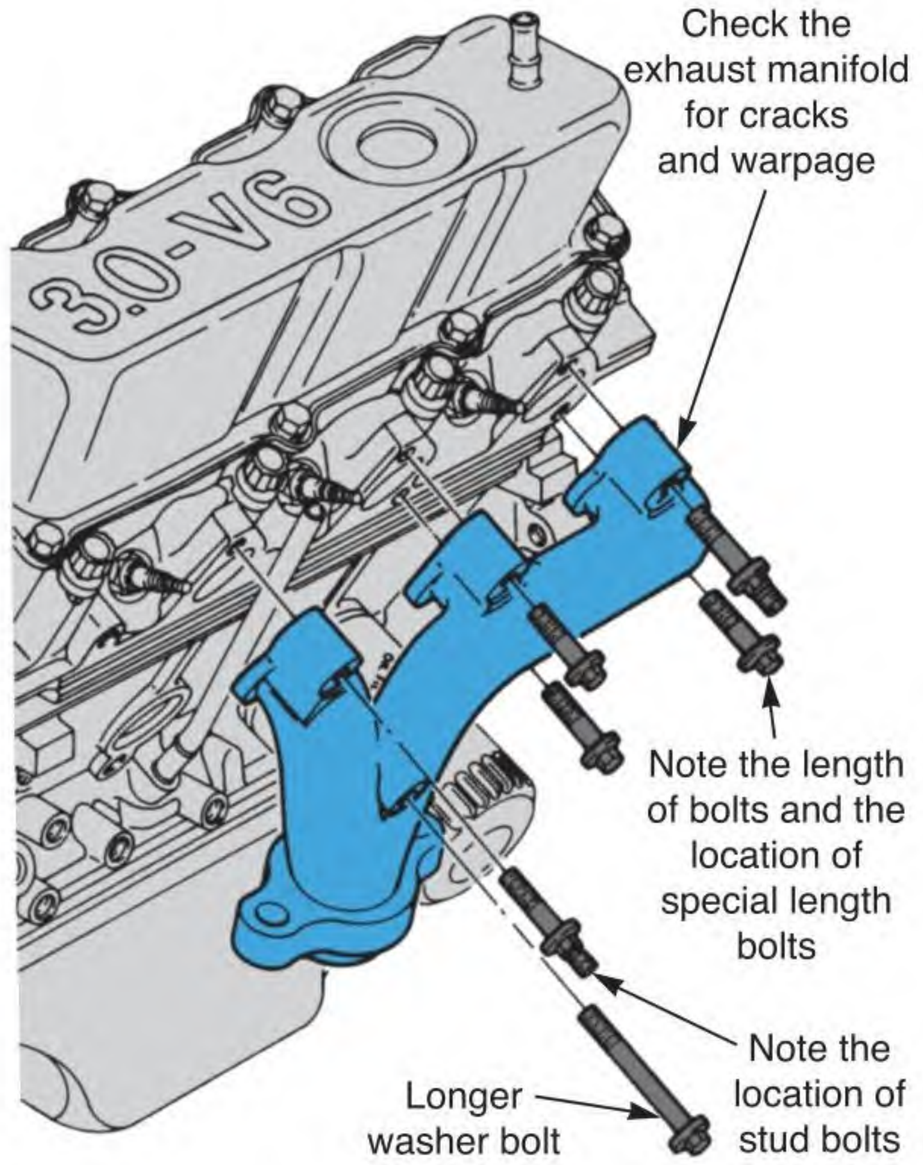
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Tech Tip

Never throw all of your bolts and parts into one big pile. Keep them separated by assembly—top end, short block, front cam drive, external parts and sensors, etc. Organization during engine teardown will help save time during engine reassembly. Why waste even one minute looking for a special-length bolt in a huge pile of mixed parts?

Engine Top End Disassembly

The engine top end generally includes the valve train, cylinder head, and related components. The top end is normally disassembled second, after the front end.



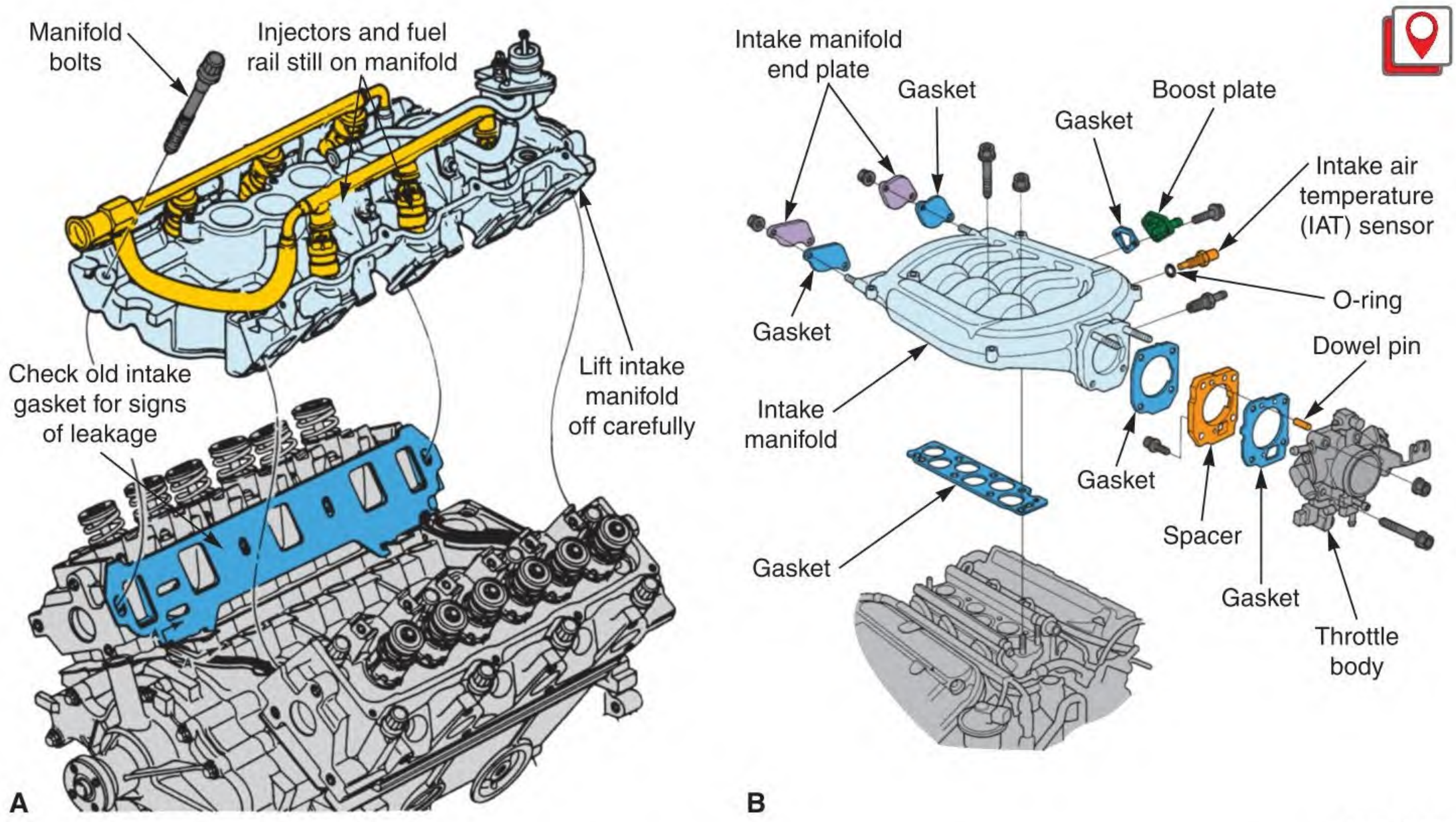
Ford

Figure 56-19. When removing the exhaust manifold, note odd bolt lengths and the location of stud bolts. They must be reinstalled in the same holes.

Service Procedure

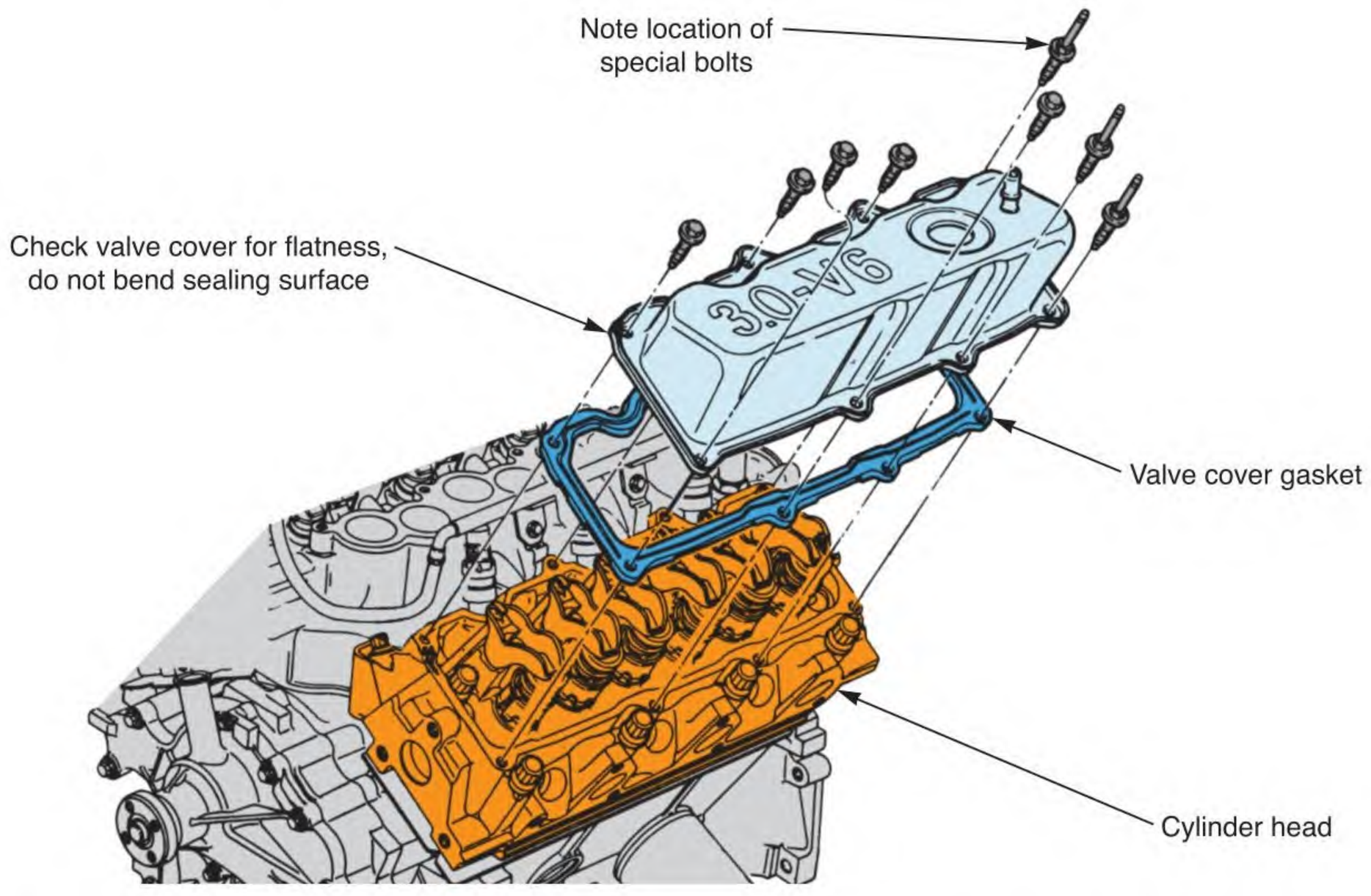
1. Remove all external engine parts, such as the fuel rail, throttle body unit, spark plug wires, coil(s), and so on. Take off all parts that could be damaged or that prevent removal of the cylinder head(s).
2. Remove the exhaust manifold(s). Note the location of any stud bolts. They must be replaced in the same hole. Brackets, such as the alternator bracket, or other devices mount to these studs, **Figure 56-19**.
3. Remove the intake manifold. With V-type, push rod engines, you may need to remove the valve train components before the intake manifold. In some designs, the push rods pass through the bottom of the intake. See **Figure 56-20**.
4. Unbolt the valve or camshaft cover(s), **Figure 56-21**. If light prying is needed, be careful not to damage the mating surfaces. Light taps with a rubber mallet may also free a cover. Be careful not to crack or damage the cover. Take extra care if the cover is plastic.
5. Remove the rocker arm assemblies. If the engine has rocker shafts, loosen the fasteners using a gradual sequence. This will prevent the end fasteners from being bent by valve spring tension.
6. If the lifters, push rods, and rocker arms are to be reused, keep them in exact order by using an organizing tray. Wear patterns and select-fit parts require that most components be installed in their original locations.
7. Remove the timing belt or chain so the head can be removed, **Figure 56-22**.
8. Loosen and remove the cylinder head bolts. Most technicians use an air impact or a breaker bar and six-point socket to loosen the bolts. On a V-type or opposed engine, use number or letter punches to mark the heads as right and left.
9. Frequently, the cylinder head is stuck to the block. To free the head, insert a breaker bar in one of the ports and pry up. Avoid prying on mating surfaces. Some heads have an unmachined notch on the deck that allows for prying without damaging the sealing surfaces.
10. Inspect the head gasket and deck surfaces for signs of leakage. Also, look for oil in the combustion chambers. This may indicate a seal or ring problem.

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Ford, Honda

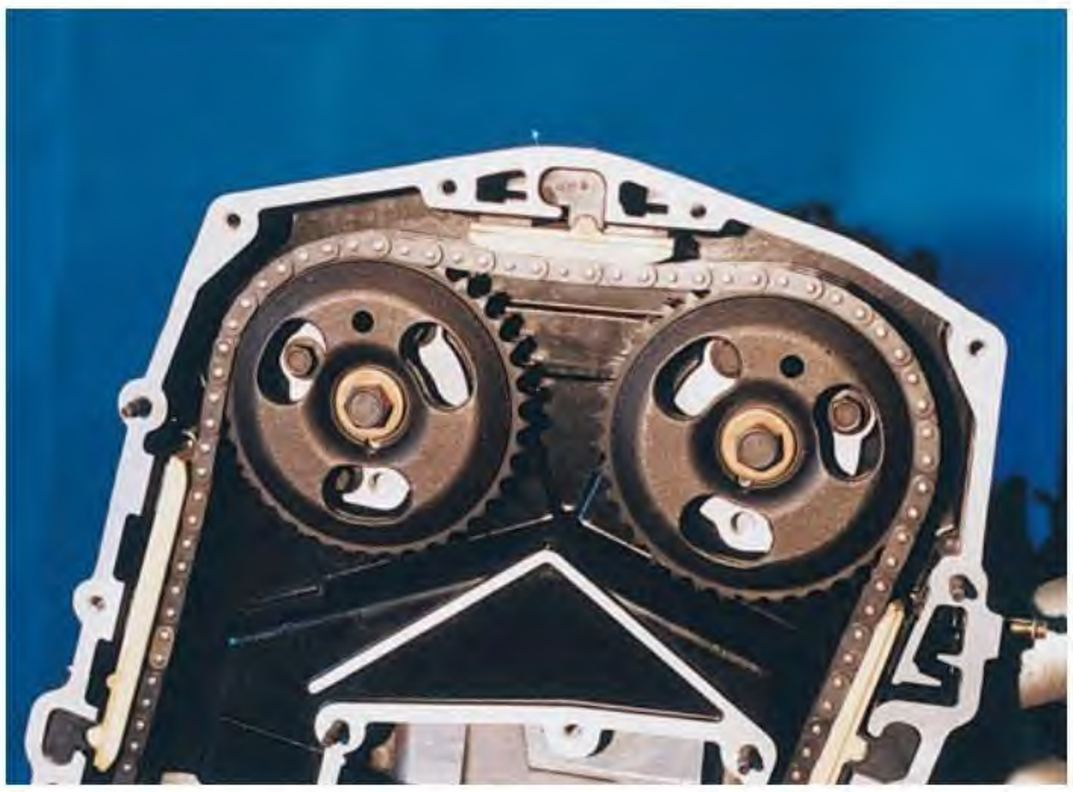
Figure 56-20. The way to remove an intake manifold depends on the type of engine. A—The intake manifold can be removed with injectors and fuel rail attached. B—This two-piece intake manifold requires you to remove the upper plenum to gain access to the lower half of the intake manifold and the injectors.



Ford

Figure 56-21. First, remove the cylinder head bolts. Free the head by inserting a breaker bar into a port and prying up.

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Figure 56-22. If you have never worked on the specific engine design, remove parts slowly while studying how they fit together. For example, you may want to align timing marks before removing the timing belt or chain. This will let you become familiar with how the cams are timed with the crank.

Caution

Do not unbolt an aluminum cylinder head when it is hot. This could cause head warpage. Allow the head to cool before loosening the bolts.

Engine Front End Disassembly

The engine front end should be disassembled first, especially with OHC engines. Engine front end disassembly is simple if a few basic rules and service manual instructions are followed.

Service Procedure

1. Remove the water pump and any other parts in front of the engine front cover. If the engine has a timing belt, remove the timing belt cover. Mark the direction of rotation on the belt. Then, loosen the tensioner and slip off the belt.
2. The vibration damper is commonly press-fit onto the crankshaft. A vibration damper puller ("wheel puller") is normally needed to remove the vibration damper.
3. If specified by the service manual, remove the front oil seal at this point.
4. Unbolt and remove the engine front cover. If prying is necessary, do it lightly while tapping with a rubber or plastic hammer. Do not bend the cover or mar the mating surfaces.
5. Remove the oil slinger and timing mechanism. Usually, the timing gears or sprockets will slide off with light taps from a brass or plastic hammer. If not, use a gear puller.
6. If the oil pump or other components are in the front cover, remove them and inspect for wear.

Caution

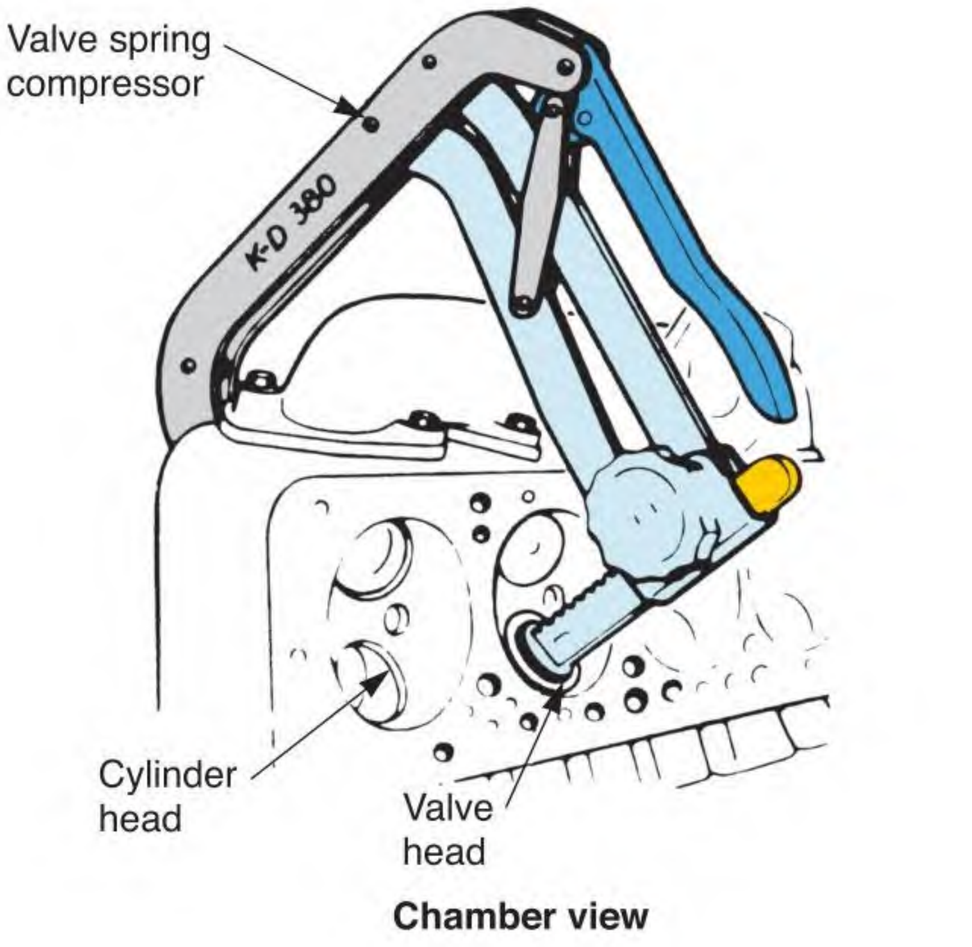
Do not attempt to rotate the crankshaft or camshaft with the timing mechanism removed and the cylinder head(s) still in place. The engine may be an interference engine, in which case the pistons could slide up and contact the valves. As a result, the valve stems may be bent or the pistons damaged.

Cylinder Head Disassembly

Disassembly procedures for cylinder heads can vary, especially between overhead valve and overhead camshaft engines. However, keep the following rules in mind during cylinder head teardown:

- Inspect for signs of trouble before disassembly. Look for oil-fouled combustion chambers, which may indicate bad rings, valve seals, or valve guides. Inspect for a blown head gasket, signs of coolant leakage, rust, and cracks. Close inspection may find other troubles.
- Use a valve spring compressor to remove the valve keepers, retainers, and valve springs. Before compressing the springs, strike the valve retainers, not the valve tips, with a brass hammer. This will free the valve retainers from the keepers and allow the compressor to squeeze the springs. Look at **Figure 56-23** and **Figure 56-24**.
- A special valve spring compressor is needed for some overhead camshaft cylinder heads. It reaches down inside the tappet bore to compress the springs.

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K-D Tools and Honda

Figure 56-23. To disassemble a cylinder head, use a valve spring compressor. One end of the tool fits on the valve head. The other end fits over the valve spring retainer. Hold the tool straight and firm on the valve spring while compressing it to keep the tool from slipping off violently.

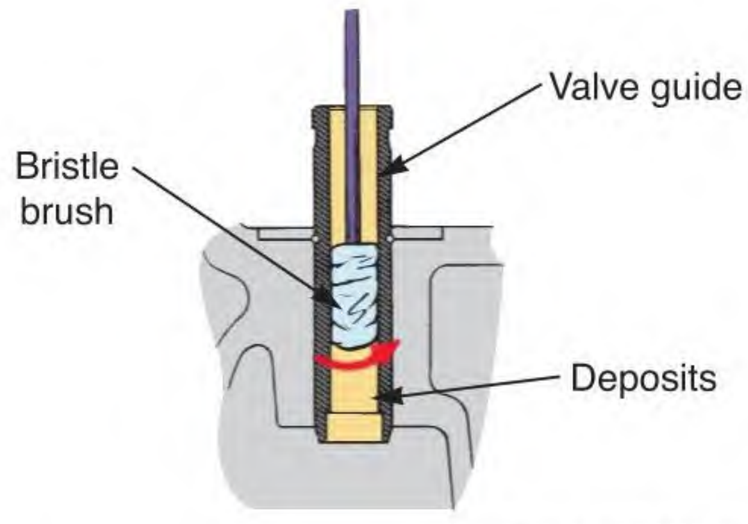
- Before removing the valves, check their tips for ***mushrooming***. This is a condition where the tips have been hammered larger by the action of the rocker arms. If mushrooming exists, file a chamfer on the valve tips. Never try to drive mushroomed valves out of the head. This can score or split the valve guides or crack the head.



Fel-Pro

Figure 56-24. With the spring compressed, the keepers can be lifted from their grooves. Release the compressor and remove the valve assembly from the head.

- Remove any other parts that prevent head service.
- Keep all parts organized. During reassembly, it is best to return reused parts to their same locations in the engine. Parts can be select-fit from the factory and their sizes may be matched for more accurate clearances.
- Clean carbon from the valve guides so they can be measured accurately for wear. See **Figure 56-25**.



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Figure 56-25. Note how a small bristle brush can be used to clean the inside of a valve guide. Use an electric drill to spin the brush while moving it up and down. Do not let the brush come completely out of the valve guide.

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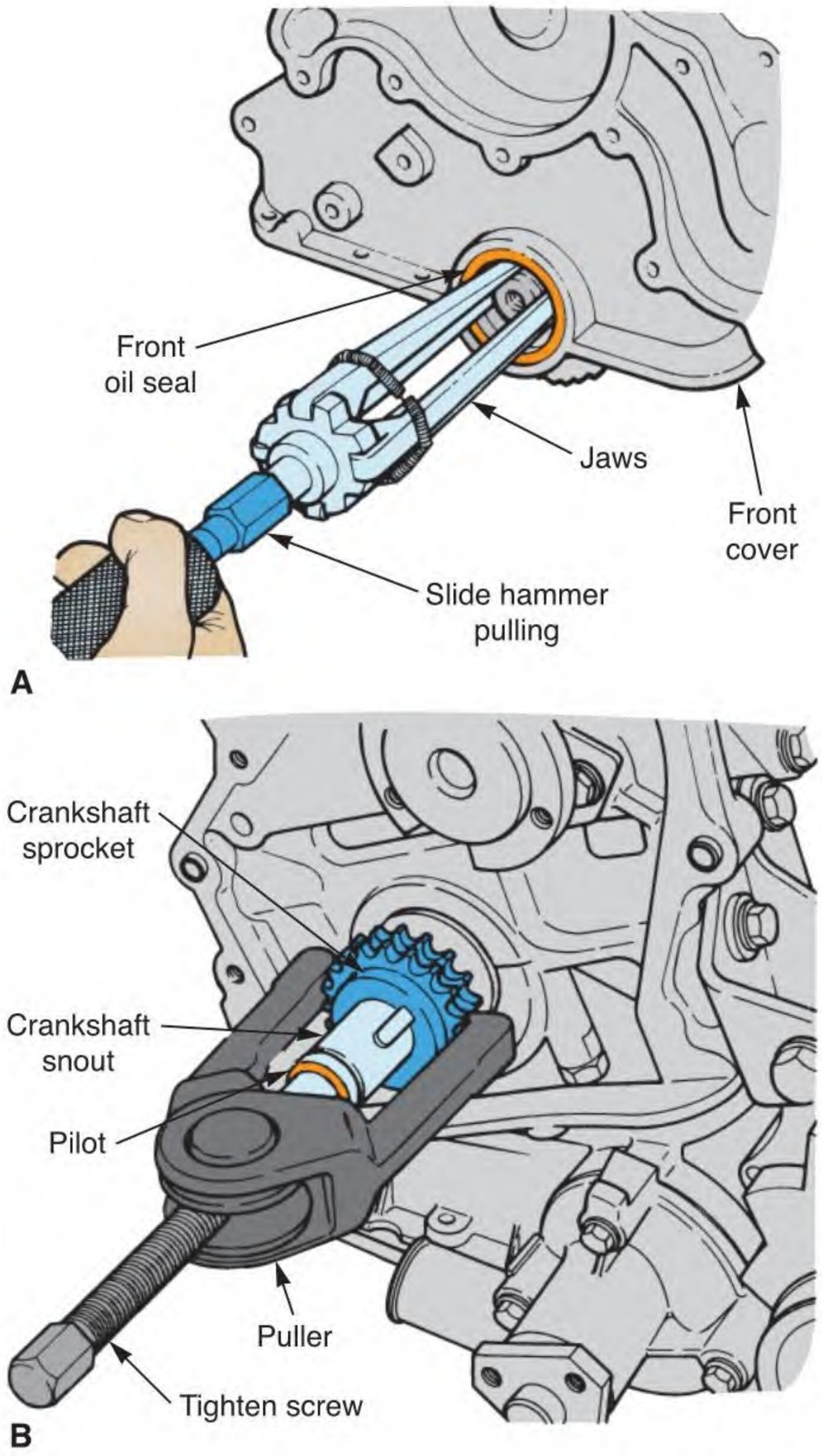
Engine Bottom End Disassembly

After top end and front end disassembly, you are ready to take the bottom end apart. The bottom end includes the pistons, connecting rods, crankshaft, and related bearings. In addition, some modern engines are equipped with balance shafts that are driven by the crankshaft. These shafts are normally located in the block or below the crankshaft, depending on the engine design. Balance shafts are normally removed during engine disassembly.



Service Procedure

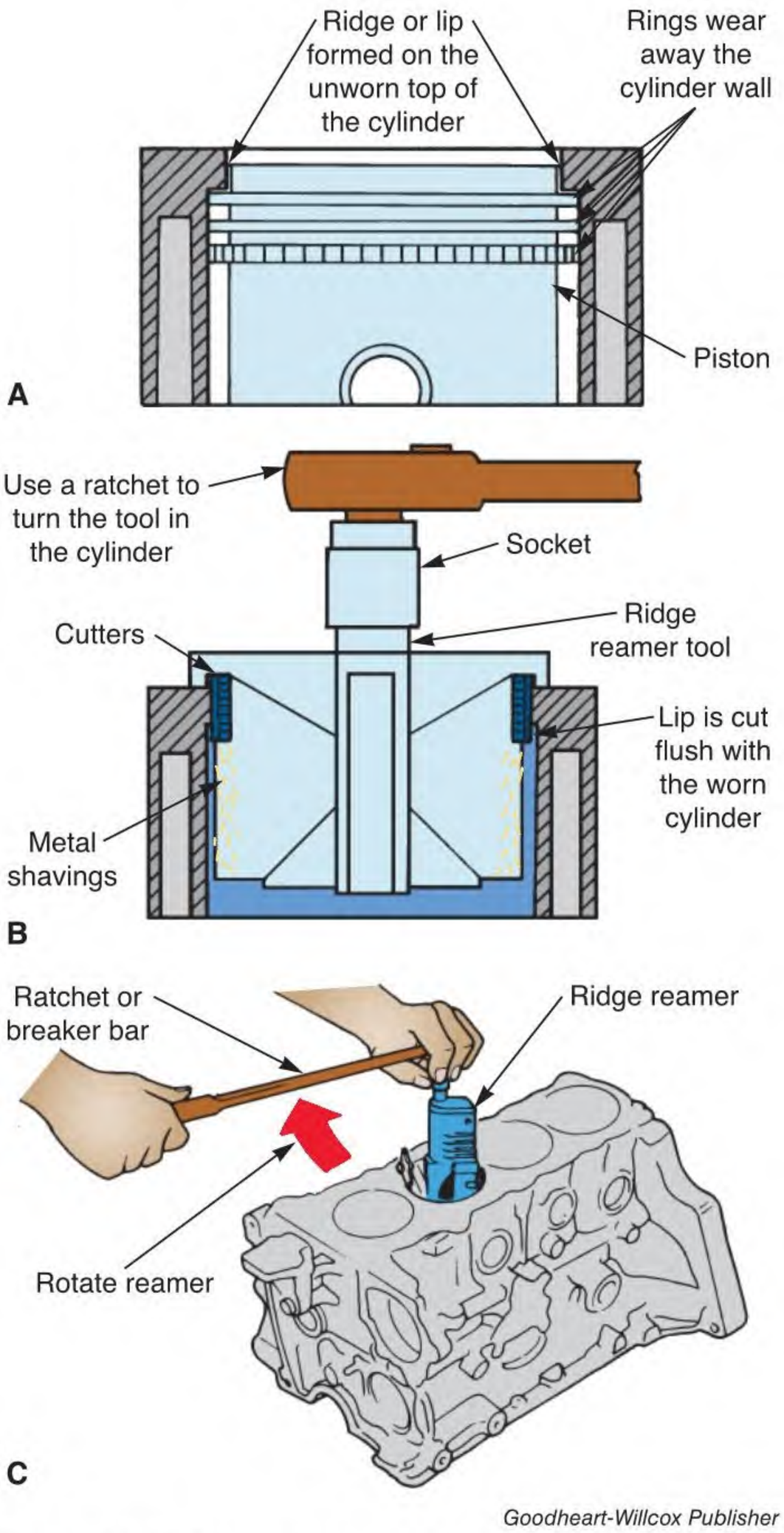
1. Unbolt and remove the oil pan and oil pump. Inspect the bottom of the pan for debris. Metal chips or plastic bits may help you diagnose engine problems. Aluminum chips may be from broken piston skirts, black rubber bits from deteriorated valve seals, plastic or fiber from broken timing gear teeth, or metal bits from failed engine bearings.
2. Remove the crankshaft drive gear or sprocket using a puller. A puller may also be needed to remove the rear main oil seal from the block, **Figure 56-26**.
3. Inspect the cylinders for signs of excess wear. Use your fingernail to feel for a lip or ridge at the top of the cylinder wall. This ridge is formed because the piston rings do not wear the cylinder wall to the top of the cylinder.
4. Use a ridge reamer to cut away the ridge. Use a wrench to rotate the reamer and cut away the metal lip. Cut until the lip is flush with the rest of the cylinder wall. This prevents damage to the piston during removal, **Figure 56-27**.
5. Use compressed air to blow the metal shavings out of the cylinder after ridge reaming to prevent cylinder or piston scoring.
6. Remove the oil pan and oil pickup tube, as shown in **Figure 56-28**.
7. Unbolt one of the connecting rod caps. Then, use a wooden hammer handle or wooden rod to tap the piston and rod out of the cylinder. Be careful not to drop the piston and rod assembly, **Figure 56-29**.
8. As soon as the piston is out, replace the rod cap. Also, check the piston head and connecting rod for identification markings. The piston will usually have an arrow pointing to the front of the engine. The connecting rod and rod cap should have numbers matching the cylinder number. If not, use a punch set to mark the rod and cap. If needed, mark the piston heads with arrows or numbers.
9. Remove the other piston and rod assemblies in the same way, one at a time. Reinstall each cap on its rod. Mark the rods, caps, and pistons as needed, **Figure 56-30**.



Ford, Chrysler

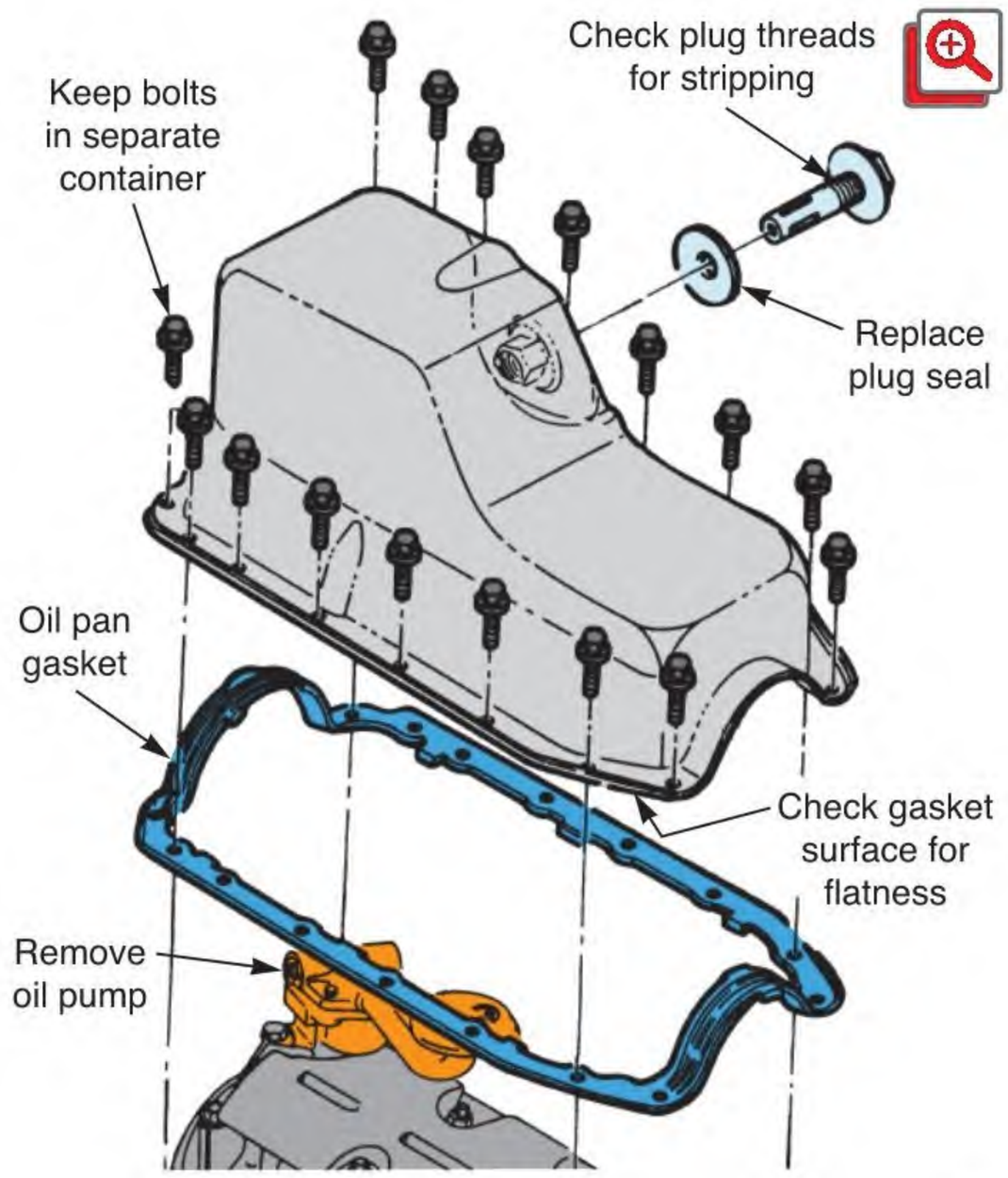
Figure 56-26. Note how some front crank sprockets and oil seals must be removed. A—A slide hammer puller is being used to remove front oil seal from front cover. B—A puller is being used to remove timing sprocket from crankshaft snout.

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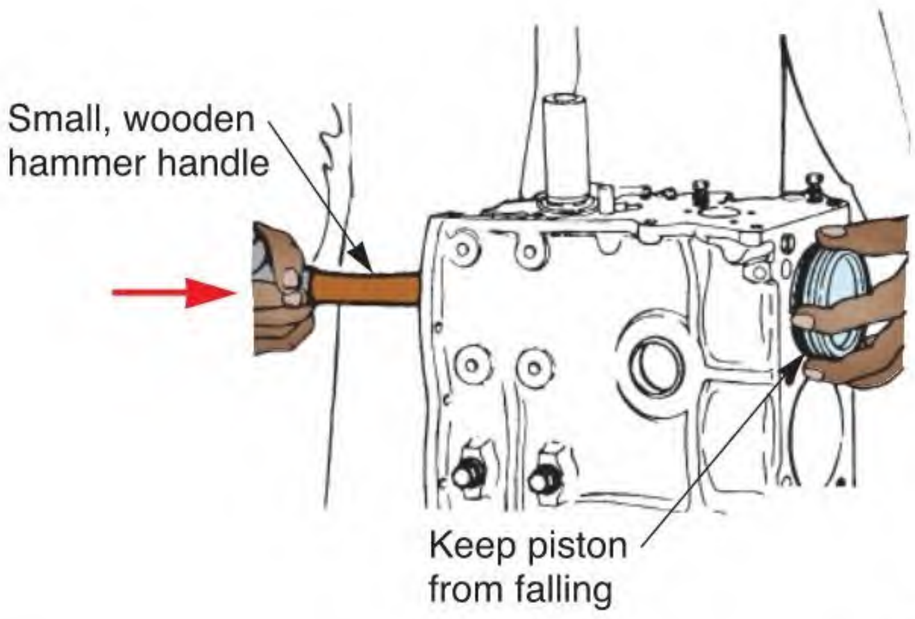
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Figure 56-27. Study how to machine off metal lips in cylinders of badly worn engine block. A—A ridge may be formed at the top of the cylinder where the rings do not wear. B—A ridge reamer is used to remove the ridge. C—Turn the reamer until the ridge is removed flush with the cylinder wall.



Ford

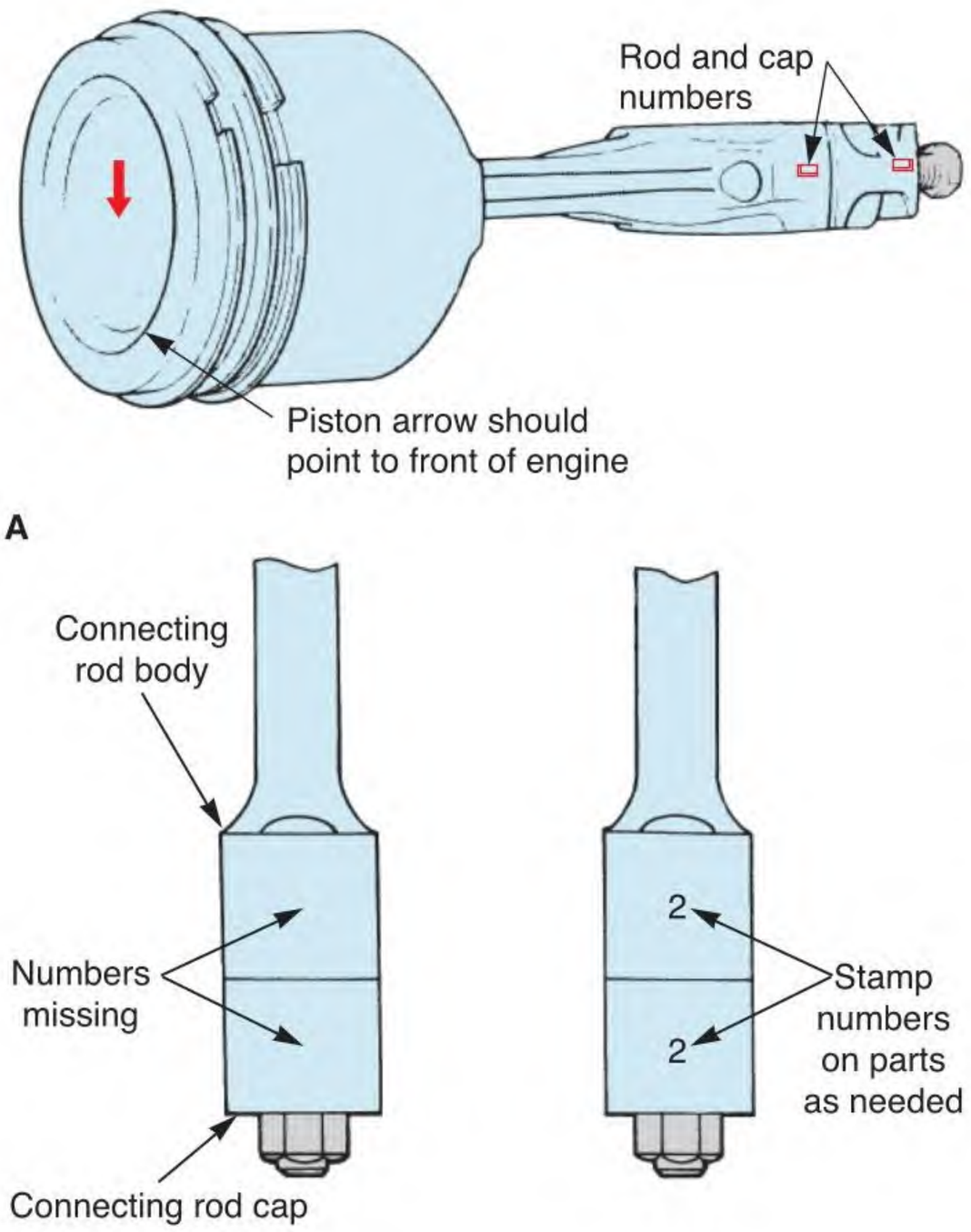
Figure 56-28. Turn the engine over on the engine stand and remove the oil pan and oil pump.



Nissan

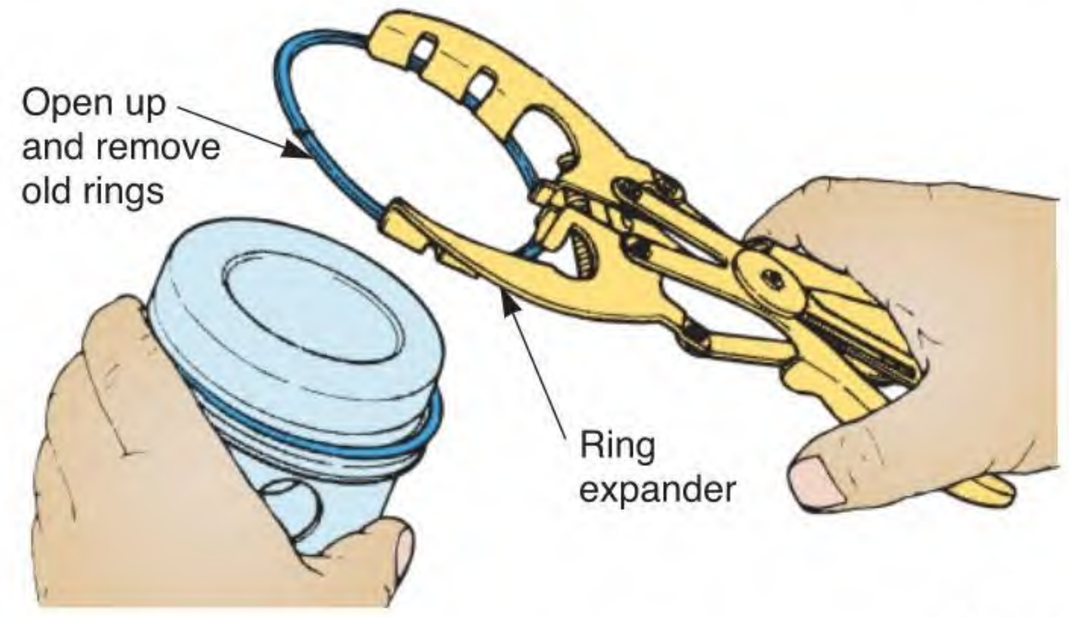
Figure 56-29. To remove pistons, unbolt rod cap. Use a wooden hammer handle to carefully tap assembly out of the block.

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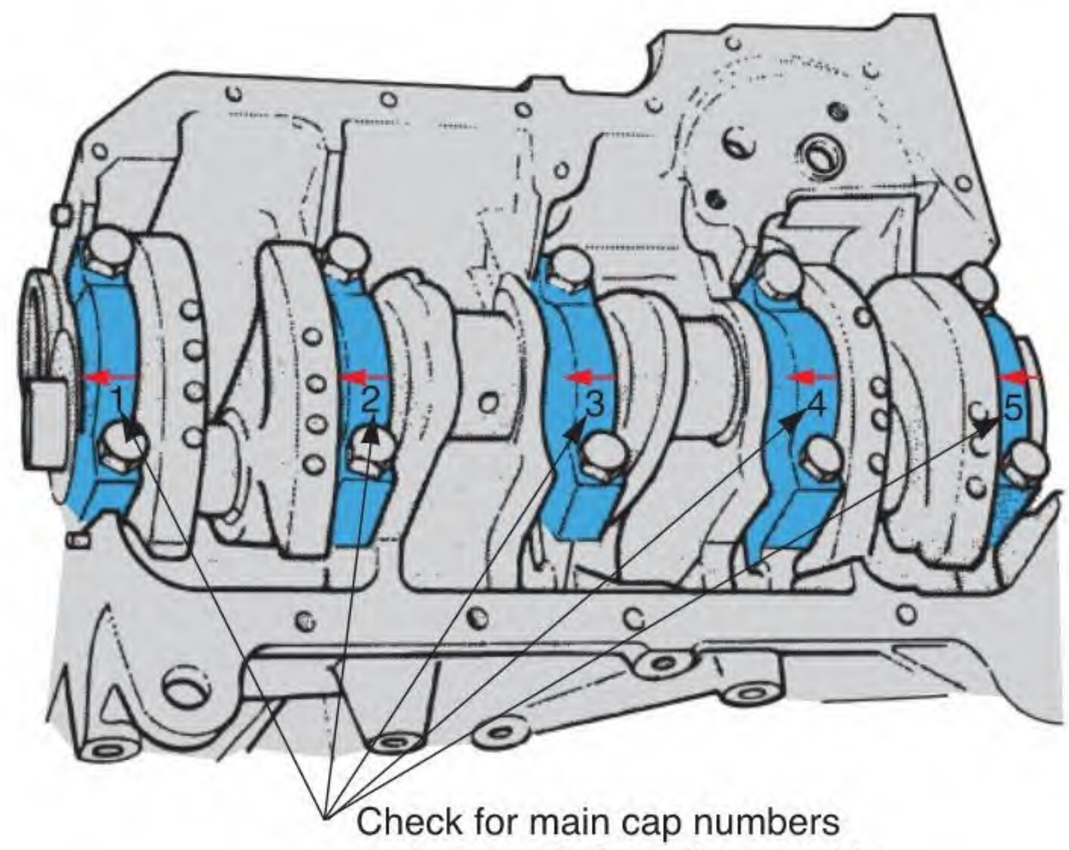
Chrysler

Figure 56-30. As soon as you slide the piston and rod assembly out of its cylinder, check the piston head and rod caps for orientation markings. A—The top of the piston must indicate top or front of piston head. Most piston pins are offset to one side of the piston to avoid piston slap or cold piston knock with the skirt wear. If there is not an identifying mark on the piston, mark the piston heads with permanent marker or sharp scribe. B—Also check for the connecting rod number and matching cap number stamped into the steel. If you mix up two rod caps on their rod beams, the engine crankshaft will usually lock up during reassembly or the vehicle could suffer major rod and bearing damage very quickly.



Chrysler

Figure 56-31. Although piston rings can be removed by hand, using a ring expander will minimize the chance of damaging the rings and piston. Piston rings are brittle and can be easily broken. Therefore, you should wear safety glasses or goggles when using a ring expander. Expand each ring just enough to remove it from the piston. After the rings have been removed, inspect the piston for groove wear and piston ring land damage. If the piston is going to be reused, make sure carbon is removed from the inside of all ring grooves.



Chrysler

Figure 56-32. Before removing block main caps, make sure they are identified with arrows or numbers. Number caps and add arrows in permanent marker or with a punch set, if needed. If main caps are mixed up, block main bore will be misaligned and crankshaft will lock up.

10. Remove all of the old piston rings from the pistons. Spiral the rings off with your fingers or use a ring expander, **Figure 56-31**.
11. Before removing the main bearing caps, check to see that they are numbered. Normally, numbers and arrows are cast on each cap. Number one cap is at the front of the engine. If they are not marked, use a punch set to mark the main caps. See **Figure 56-32**.
12. Remove the main cap bolts. To remove each cap, pull the main cap bolts out about halfway and wiggle them back and forth while pulling up on the main cap.
13. Lift the crankshaft carefully out of the block. It is heavy; be careful not to hit and nick the

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journals. Place the crankshaft in a location where it cannot be damaged.

14. To remove the balance shaft, begin by removing any retainers holding the shaft in the engine. Then, slide the shaft out. In some cases, it may be necessary to use a slide hammer to remove the shaft.
15. If the engine is old or it is going to be hot tanked, pry out the core plugs from the head and block. Core plugs rust out and leak after prolonged service. Since the engine is disassembled, it is a good time to replace them.
16. If the block must be sent to a machine shop for boring and hot tank cleaning, make sure all external hardware is removed. This includes rubber motor mounts, oil and coolant temperature sending units, sensors, actuators, and so on.

Caution

Do not do anything to dent or mar the connecting rods. The I-beam portion of the rod is especially sensitive to damage. For example, never clamp the rod in unprotected vise jaws. The dent or indentation in the metal could cause a stress point. This can lead to cracking and breakage of the rod during engine operation. When marking the rods, only mark on the side of the cap and rod body.

Cleaning Engine Parts

Parts can be very dirty. For example, valves and combustion chambers can be coated with carbon; the valve covers, lifter valley, and bottom of the intake manifold can have sludge buildup; and most parts will have an oil film.

After you have removed all of the parts from the engine block and cylinder head(s), everything should be cleaned. Different cleaning techniques are needed, depending on part construction and type of material.

Closer part inspection can be done during and after part cleaning. Some problems are difficult to see when a part is covered with oil, grease, gasket material, or carbon deposits.

Scrape Off Old Gaskets and Hard Deposits

Begin cleaning the engine by scraping off all old gasket material and hard deposits. Scrape off the gaskets for the valve covers, head, front cover, intake manifold, oil pan, and other components. Also, scrape off as much sludge and carbon as you can.

When cleaning aluminum parts, use a dull scraper and work gently. The soft, light metal is easily nicked and abraded. This could lead to gasket leakage or failure when the engine is returned to service. Refer to **Figure 56-33**.

Warning

When using a gasket scraper, push away from your body; do not pull toward your body. Even a dull scraper can cause serious cuts.

Cleaning Threads

Most technicians clean, or "chase," threads during a major engine rebuild. Rust and scale can collect inside threaded holes. This can prevent the bolts from threading in smoothly. In turn, the tightening of the bolt can be altered and the parts may not be properly clamped together. Leakage or part failure may result.

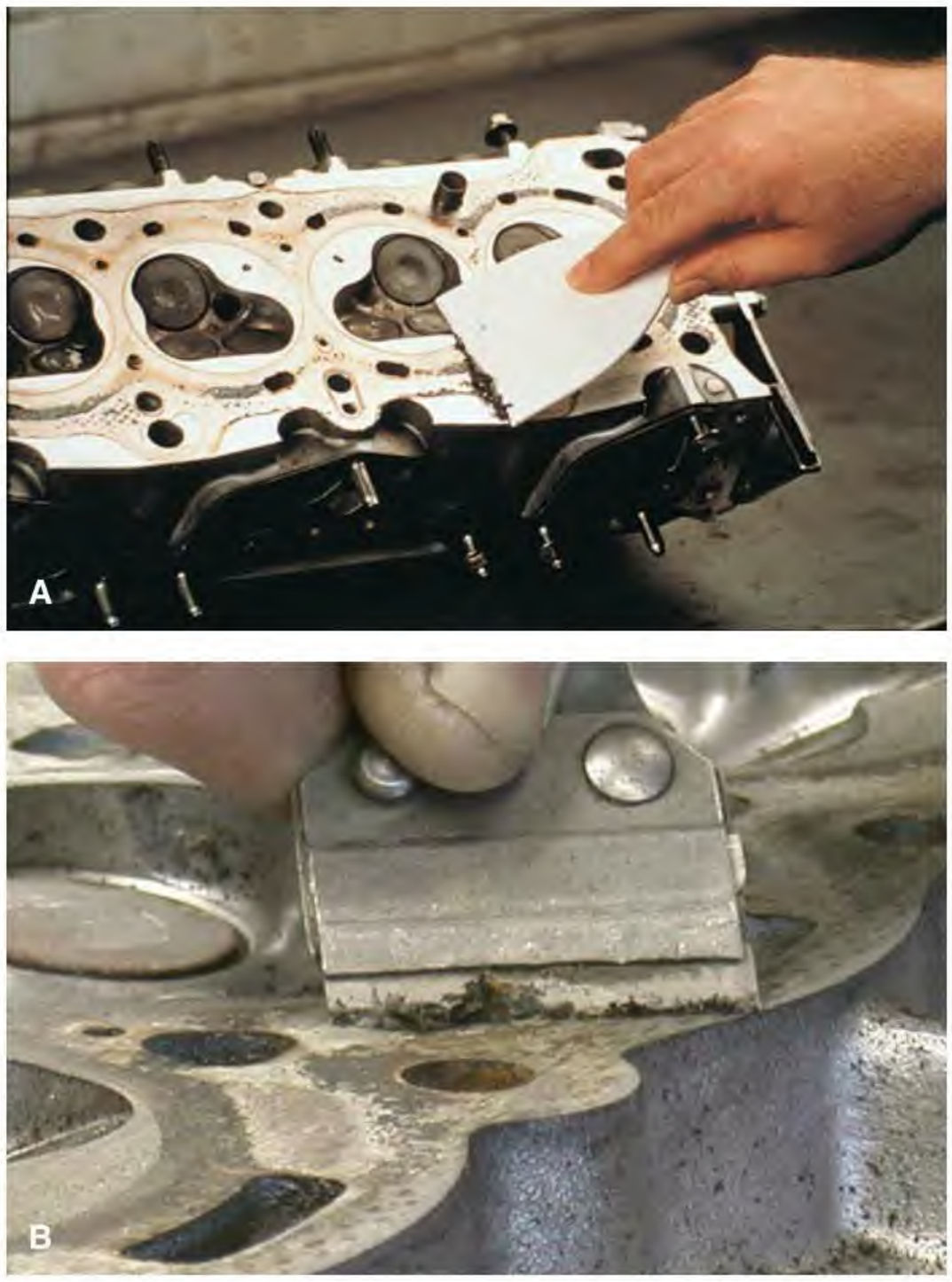
A ***thread chaser***, not a tap, should be run down through all critical bolt holes to clean the threads. Use a speed handle to lightly run the chaser down through bolt holes. Do not tighten the chaser, just run it down lightly to the bottom of each hole. This is shown in **Figure 56-34**.

Power Cleaning Tools

A ***scuff pad*** mounted in an air drill or similar tool can cut through and lift off gasket material and silicone. Yet, the pad is too soft to easily damage metal surfaces. Move the tool back and forth along the gasket material until the material is removed, **Figure 56-35**.

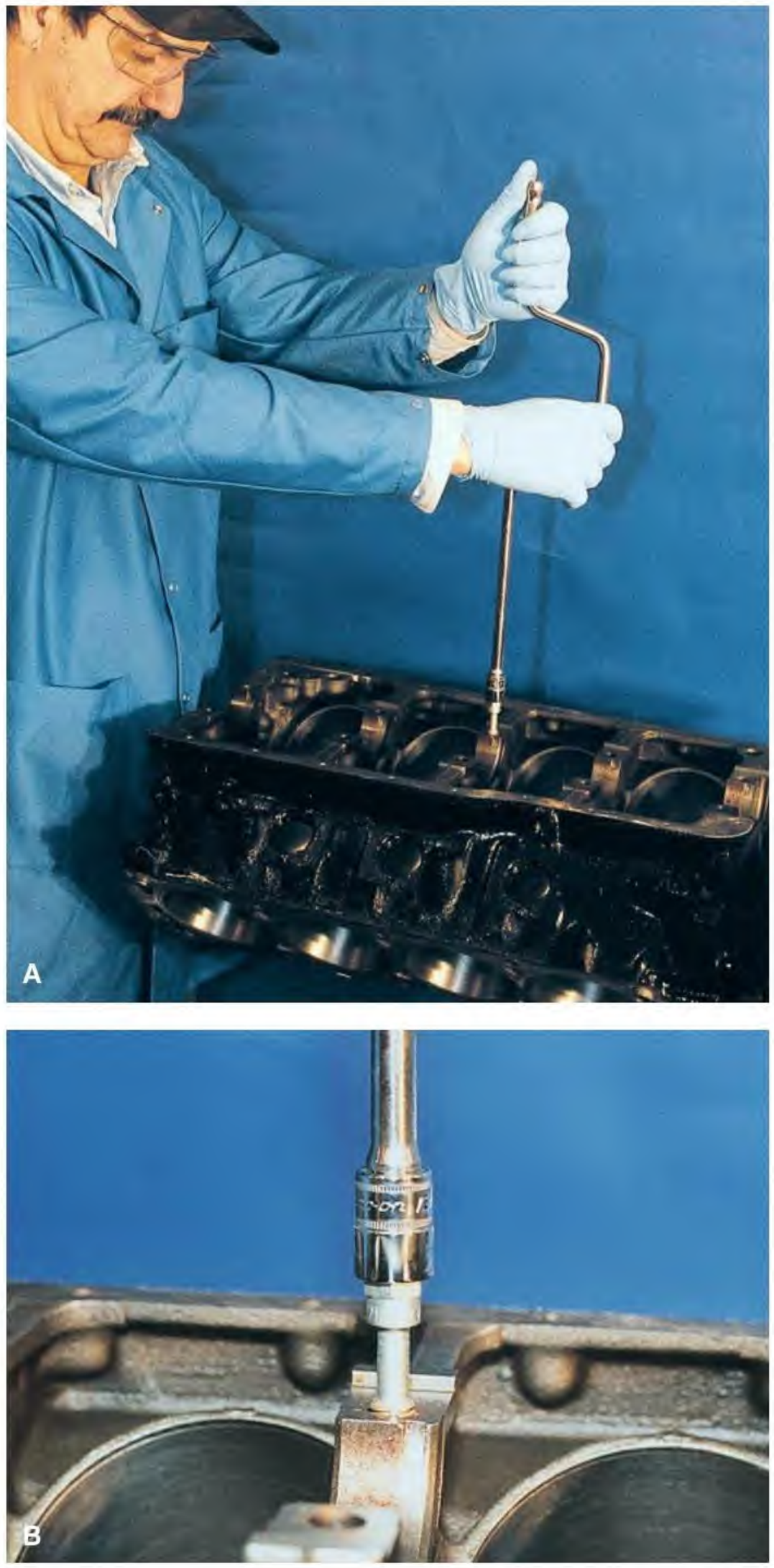
A ***power brush***, or stiff rotary brush, mounted in a drill can be used to remove hard carbon deposits. It is especially handy inside hard-to-reach areas, such as combustion chambers. See **Figure 56-36**. Move the tool over the carbon deposit until the deposit is removed. Often, it may be easiest to start at the edge of the deposit, rather than in the middle. A small power

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Fel-Pro, Ford

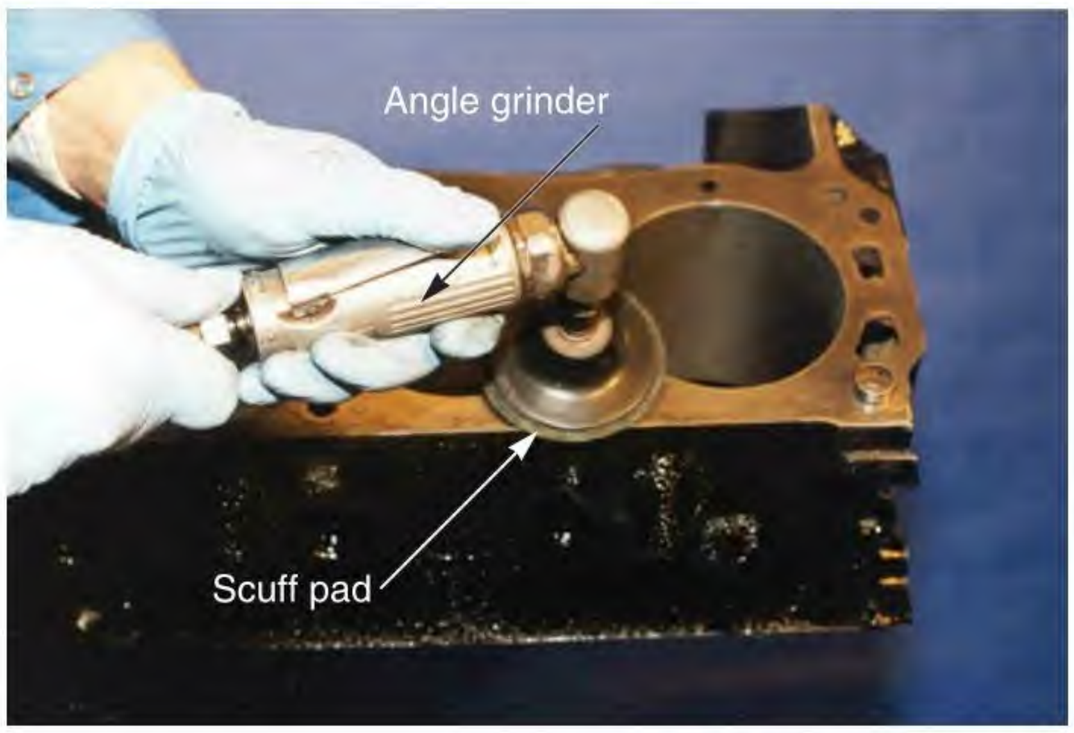
Figure 56-33. Study common methods used by professional technicians to quickly remove gasket and sealant material from engine parts, without part damage. A—Use a scraper to remove gasket material and chunks of adhesive from sealing surfaces. Be careful not to nick and gouge aluminum surfaces. If rubber rings are used instead of a gasket, pull them out of their grooves and discard them. B—Use a single-edge razor blade to remove stubborn gasket materials. This is often done around oil and coolant pages in the cylinder head. C—As a final step, block sand flat sealing surfaces to remove remaining gasket materials.



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Figure 56-34. During a major engine rebuild, run a thread chaser (not a tap) through all threaded bolt holes. A—Hand start the chaser through a couple of threads. Attach a speed handle to the thread chaser so you can quickly run the tool to the bottom of the threaded holes in parts. B—Bottom the thread chaser into its hole lightly, then spin the tool back out of threaded hole with the speed handle. Never use a power tool with a thread chaser because it can snap the tool off in the bottom of threaded holes.

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Figure 56-35. When using a scuff wheel on aluminum parts, scuff very lightly on the gasket material. Do not scuff bare aluminum too much or you might abrade, indent, and damage the part's sealing surface.



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Figure 56-36. A wire brush on an air drill is ideal for removing carbon deposits inside combustion chambers. Steel bristles will abrade hard carbon on irregular surface contours without causing cylinder head damage.

brush can be used to clean out valve guides. However, use a power brush carefully on aluminum parts.

A ***wire wheel*** is also used to remove carbon deposits, usually off of valves. However, other small parts can be cleaned with a wire wheel, such as brackets. Use an appropriate coarseness of wheel. For small or delicate parts, you may need to use a fine wheel. Heavier parts may be able to withstand an aggressive, coarse wheel. This may speed up the cleaning process. Large parts, such as the cylinder head, are too large to hold against the wheel.

Warning

Always wear eye protection when cleaning parts with power tools. When using a wire wheel mounted in a grinder, make sure the tool rest and guards are in place. Never operate power tools without the proper safety devices in place. Wear a full-face shield when using a bench grinder or wire wheel.

Cleaning Solvents

After scraping off the gaskets, various chemical cleaners (cleaning solvents) are used to remove hard-to-reach or stubborn deposits. For example, sometimes gaskets can be very difficult to scrape off. A ***spray-on gasket solvent*** can be used to soften the gasket, **Figure 56-37**. After spraying, let the chemical



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Figure 56-37. Chemical gasket removers will chemically dissolve the sealer and gasket material so gasket can be scraped off easily.

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work for a few minutes. Then, scrape off the softened gasket with a scraper.

Warning

Never use gasoline as a cleaning solvent. The slightest spark or flame could ignite the fumes, causing a deadly fire!

Cold Tank

Most auto shops have a ***cold cleaning tank*** or machine for removing oil and grease from parts. It will not remove hard carbon or mineral deposits. It has a pump and filter that circulates clean, mild naphtha solvent out of a spout. To clean parts, place them in the work area of the tank. Then, direct the stream of solvent onto the part while scrubbing the part with a soft bristle brush, **Figure 56-38**.

Decarbonizing cleaner ("carb cleaner dip tank") is another type of "cold soaking." This cleaner is a very powerful chemical that can remove carbon, paint, gum, and most other deposits. It is, however, an expensive solvent and not commonly used unless necessary. Parts are typically placed in a basket that is lowered into a tank containing the cleaner. The parts are allowed to soak in the cleaner for a couple of hours. Then, the parts are removed and rinsed.



Snap-on Tools

Figure 56-38. After removing all old gaskets, sealant, and seals, wash all engine parts in a cold solvent or mineral spirits (naphtha). Cold solvent will remove oil and grease remaining on engine parts. Wear eye protection, rubber or plastic gloves, and a respirator. Blow parts dry with a blowgun before taking them out of solvent tank.

Cold solvent is cool to the touch and not as flammable as gasoline. However, it is a fraction of crude oil and can be harmful if proper safety precautions are not followed. When using a cold solvent tank, wear a cartridge respirator, rubber gloves, and a rubber or plastic apron. Part cleaning solvents can be harmful if absorbed into your skin, inhaled, or ignited.

Hot Tank

A ***hot tank*** is used to aggressively remove mineral deposits, hard carbon deposits, oil, grease, and even paint. In a complete engine rebuild, the cylinder head(s) and block are usually hot tanked, or "boiled out." Other parts, such as valve covers or oil pans, may also be hot tanked. Most automotive machine shops have a hot tank. See **Figure 56-39**.

Aluminum engine parts can be etched and damaged by the powerful acidic solvents in some hot tanks. Hot solvent tanks can be filled with chemicals of different strengths, or caustic levels. Stronger hot tank solvents can etch aluminum engine parts. When



Miller Engineering

Figure 56-39. Large, hot tank cleaning machines using a caustic steam to clean parts are found in automotive machine shops. A complete block can be lowered and cleaned, removing hard carbon and mineral deposits in water jackets.

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hot tanking aluminum heads, blocks, manifolds, and similar castings, make sure the solvent is formulated for use on aluminum.

Caution

Before hot tank or oven cleaning, all non-metal parts (sensors, harness clips, hoses, etc.) must be removed to avoid being damaged. However, these parts can often remain in place when cleaning by hand in a cold solvent tank.

Heat Cleaning Ovens

Automotive machine shops may use a heat-cleaning oven in place of a hot tank to clean engine parts. A ***heat cleaning oven***, also termed a ***burn-off oven***, is designed to remove organic materials such as oil, grease, paint, varnish, and plastic from metal engine parts without the use of chemicals. Superheated air is circulated over the parts to burn off the organic material. The part temperature is raised just high enough to remove deposits without affecting the metal in the part.

Heat cleaning ovens eliminate the disposal and liability problems associated with acid or chemical cleaning. Modern ovens are designed to operate while producing minimal emissions.

When placing parts in a heat-cleaning oven, stack and space the parts so that air can circulate between them. Do not stack large castings flat on top of each other or surfaces may not get hot enough to be cleaned. Make sure the oven temperature and timer are set correctly for the type of metal being cleaned. Most parts can be cleaned in a couple of hours. Refer to the equipment manufacturer's instructions for details.

After heat cleaning in an oven, engine parts are often shot peened or media blasted to remove ash and soot. The engine parts can then be washed in a cold solvent tank and blown dry with an air nozzle.

Warning

When removing parts from an oven, wear leather gloves and a shop apron. Be careful not to get burned by the hot parts.

Media Blasting

Media blasting can remove paint, carbon, and other dry deposits from parts. Cylinder heads, intake manifolds, valve covers, etc., can be cleaned and readied for painting with media blasting. However, the parts must be free of oil and sludge to prevent clogging the machine.

Be careful when media blasting aluminum parts. Only use enough blast action to clean off deposits. Too much blasting can erode and etch the aluminum and ruin the part.

Carbon-coated piston heads are very hard to clean. Media blasting can quickly remove these deposits, but careful use is required. Only clean the heads of the piston, not the skirt. The media can quickly erode the skirt and ruin the piston.

Tech Tip

Make sure you are using the correct media for the application. Various types of media are available for different applications.

Air Blowgun

Using an ***air blowgun*** is normally the last step in cleaning parts. Use it to blow off small bits of dirt, solvent, water, and other debris. Be sure to blow out bolt holes, coolant passages, and oil passages. When done with this step, there should be no dirt, debris, or deposits on or in the engine and its parts.

Warning

Use extreme care when using an air blowgun. Wear eye protection. Never aim the gun at your body or other individuals. If air is forced through your skin and into your bloodstream, a blood clot may result that could cause death!

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Summary

- The vehicle identification number (VIN) is a unique number identifying the vehicle and some of the equipment installed on the vehicle. Contained within the VIN may be codes for the engine type and size, transmission type, differential type, body style, and optional equipment.
- Many engine repairs can be done with the engine block still bolted to the chassis. These repairs include valve jobs, valve spring replacements, oil pump replacements, main bearing replacements, piston service, and external engine part service.
- Engine repairs that normally require engine removal include cylinder block service, crankshaft service, and cylinder repair.
- An engine overhaul involves complete disassembly of the engine assembly; cleaning, inspection, and measurement of critical parts; replacement of worn bottom end parts and top engine parts in cylinder heads; replacement or repair of worn camshaft drive assembly parts; machining of worn or warped engine casting and forgings; and reassembly of the engine.
- An in-vehicle engine overhaul can only be done when cylinder and crankshaft wear are within specifications and the oil pan and heads can be easily removed with the engine installed in the vehicle.
- To prepare for engine removal, most technicians disconnect everything under the engine first. The parts under the engine are disconnected first so that oil, fuel, and coolant are not leaking out from the disassembled top end while working under the engine.
- Position the lifting fixture or chain at the manufacturer's recommended lifting points on the engine. Make sure the attaching bolts are the correct diameter for the hole in which they are installed. Also, the bolts must be fully seated and a proper length. They must thread into the hole a distance equal to at least 1 1/2 times the diameter of the bolt.
- Make sure the crane boom or engine hoist is centered over the engine. Then, attach the crane or hoist to the lifting fixture or chain. Place a floor jack under the transmission if needed.
- If you pulled the engine and transmission/transaxle together, you will need to separate the transmission from the engine.
- Most engine stands have a removable, rotating plate to which the engine is bolted. It is usually easier to bolt the engine to this plate first while the plate is not attached to the stand.
- Teardown is the basic disassembly of the engine.
- The engine top end generally includes the valve train, cylinder head, and related components. The top end is normally disassembled second, after the front end.
- The engine front end should be disassembled first, especially with OHC engines.
- After top end and front end disassembly, you are ready to take the bottom end apart. The bottom end includes the pistons, connecting rods, crankshaft, and related bearings.
- After you have removed all of the parts from the engine block and cylinder head(s), everything should be cleaned. Different cleaning techniques are needed depending on part construction and type of material.
- Always wear eye protection when cleaning parts with power tools.
- Never use gasoline as a cleaning solvent. The slightest spark or flame could ignite the fumes, causing a deadly fire!
- A hot tank is used to aggressively remove mineral deposits, hard carbon deposits, oil, grease, and even paint.
- Automotive machine shops may use a heat cleaning oven in place of a hot tank to clean engine parts.
- Media blasting can remove paint, carbon, and other dry deposits from parts. Cylinder heads, intake manifolds, valve covers, etc., can be cleaned and readied for painting with media blasting.

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Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

air blowgun
burn-off oven
casting numbers
cold cleaning tank
crane boom
decarbonizing cleaner
engine hoist
engine overhaul
engine rebuild
engine stands
heat cleaning oven
hot tank
in-vehicle engine overhaul
lifting fixture
media blasting
mushrooming
power brush
scuff pad
spray-on gasket solvent
teardown
thread chaser
vehicle identification number (VIN)
wire wheel

Review Questions

Answer the following questions using the information provided in this chapter.

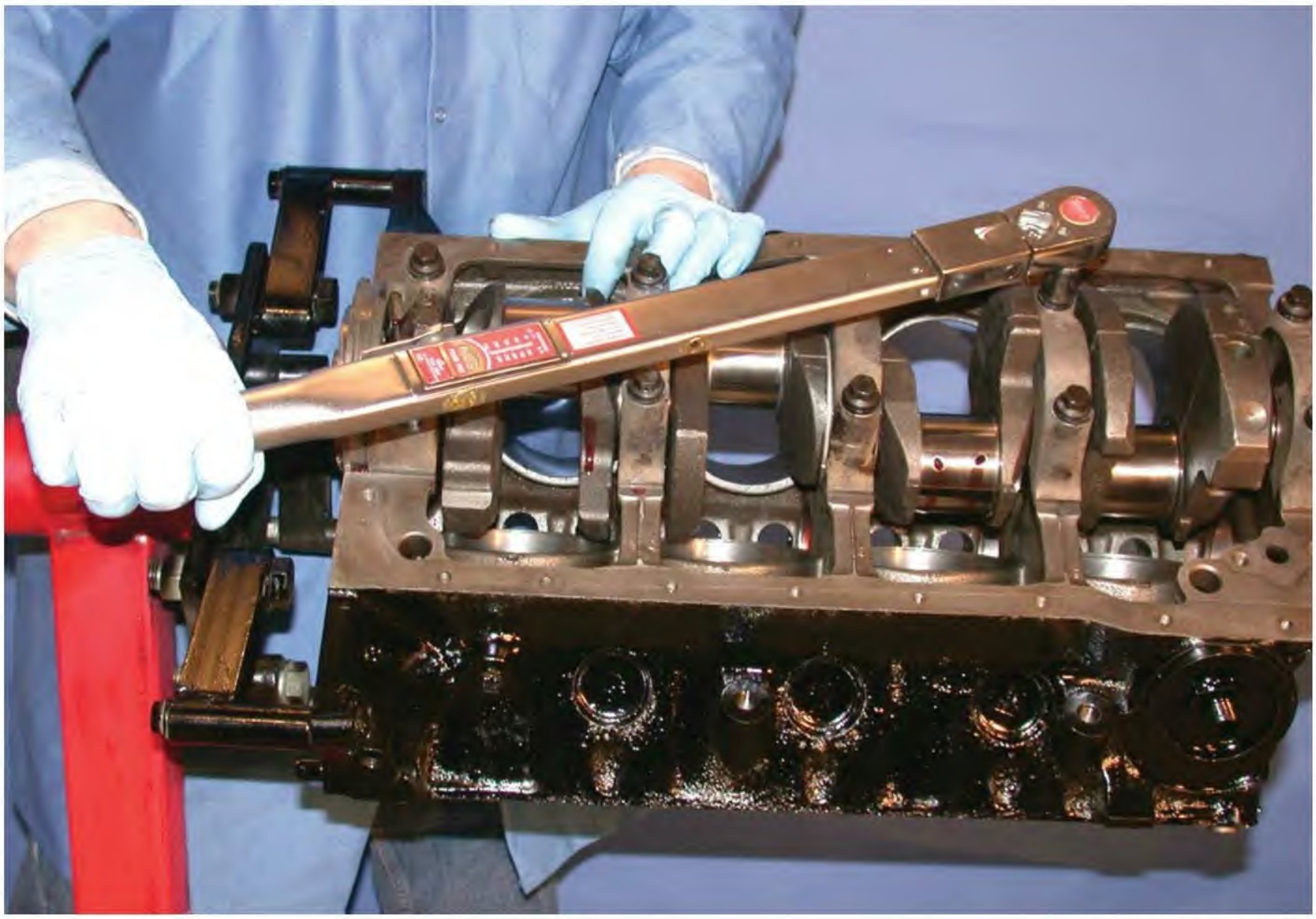
1. Which of the following may be coded in the VIN?
   (A) Engine type.
   (B) Body style.
   (C) Transmission type.
   (D) All of the above.
2. Define *casting number*.
3. Repairs to the cylinder head and valve train normally require engine removal. True or False?
4. The year, make, and model of the vehicle often determine whether or not the engine must be removed for a repair. True or False?
5. Define *engine overhaul*.
6. When preparing to remove an engine from a vehicle, why are the components underneath the engine usually disconnected first?
7. Why should you label wires and vacuum hoses when they are disconnected?
8. Do not disconnect _____ or _____ lines unless absolutely necessary.
9. List six things to double-check right before lifting an engine out of its chassis.
10. When lifting an engine from a vehicle, make sure the _____ _____ is centered over the engine.
11. When servicing a vehicle with a manual transmission, the _____ should be checked for problems.
    (A) flywheel
    (B) torque converter
    (C) clutch apply piston
    (D) None of the above.
12. Which of the following statements does *not* apply to proper engine disassembly methods?
    (A) Separate parts and bolts by assembly.
    (B) Inspect gasket for leakage.
    (C) Remove exhaust manifolds, cam covers, and sensors.
    (D) All of the above apply to proper disassembly methods.
13. Why should most parts be returned to their original locations in an engine?
14. A(n) _____ is sometimes needed to remove a vibration damper, seal, or crankshaft sprocket.
15. Why should you never drive out a valve that has a mushroomed tip?
16. A(n) _____ _____ tool is used when the cylinders show signs of excess wear. It will remove a lip at the top of the cylinders.
17. When cleaning threads, use a(n) _____ _____, not a tap.
18. Which parts are typically cleaned in a hot tank?
19. A wire wheel is commonly used to remove carbon from valves. True or False?
20. Decarbonizing cleaner ("carb cleaner dip tank") is another type of _____ _____.

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ASE-Type Questions

1. Technician A says that the VIN may be located on the front of the engine. Technician B says that the VIN may be located on the upper-left corner of the firewall. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Technician A says that the VIN can be used to identify the engine type. Technician B says that a VIN can be used to identify the transmission type. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. Tests find a burned engine valve. The engine is not smoking and has good oil pressure. Technician A says that this should be an in-vehicle operation; the block can remain bolted to the chassis. Technician B says that the engine must be removed from the vehicle to service the valves. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. All of the following operations can be performed with the engine still installed in the vehicle *except:*
   (A) valve job.
   (B) intake manifold replacement.
   (C) hot tank cleaning of the block.
   (D) valve seal removal and replacement.
5. Technician A says that an engine's timing belt should be replaced during a major engine rebuild. Technician B says that an engine's cylinder head(s) should be inspected and reconditioned as needed during a major engine rebuild. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Technician A says that when preparing to remove the engine from a vehicle, you do not need to disconnect the vehicle's battery. Technician B says that when preparing to remove the engine from a vehicle, you should remove the automobile's radiator. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. Technician A says that a transmission or transaxle should hang unsupported after engine removal. Technician B says that on some vehicles, the engine is removed from below by raising the vehicle and lowering the engine out from under the frame. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. Technician A says that repeated use of media blasting on aluminum parts is the best cleaning method to remove difficult buildup. Technician B says that gasoline is safe to use as a solvent for part cleaning. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Teardown on an OHC engine commonly begins with _____ disassembly.
   (A) front end
   (B) top end
   (C) bottom end
   (D) Any of the above.
10. An engine block has deep ridges in its cylinders. Technician A says that a brush hone should be used to recondition the cylinders. Technician B says that the block should be sent to a machine shop to have the cylinders bored. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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This technician is torquing the main bearing cap bolts to specifications during short block reassembly.

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Chapter 57
Short Block Rebuilding and Machining

After studying this chapter, you will be able to:

- Locate cracks in the cylinder block and crankshaft.
- Check for main bearing bore wear.
- Measure deck warpage.
- Check for cylinder taper and out-of-round.
- Determine piston-to-cylinder clearance.
- Hone a cylinder.
- Describe the steps in boring a cylinder oversize.
- Summarize camshaft bearing installation.
- Install core plugs.
- Measure crankshaft journal taper, out-of-round, and cheek width.
- Describe crankshaft turning.
- Identify undersize bearings.
- Measure bearing clearance.
- Properly assemble a short block.
- Describe the steps in engine balancing.
- Correctly answer ASE certification test questions on engine removal, disassembly, and cleaning procedures.

You learned about engine problems, diagnosis, teardown, and part cleaning in earlier chapters. This chapter summarizes the complete overhaul of an engine short block. You will learn how to prep a block; inspect and measure part dimensions; and install the main bearings, crankshaft, pistons, rings, rods, piston pins, rod bearings, and camshaft bearings.

Remember, the slightest mistake during short block reassembly can result in engine failure. One improperly tightened rod bolt, a mixed up rod cap, one wrong part clearance, or other seemingly minor mistake can be catastrophic. The engine may experience a major mechanical failure as soon as you start and run the engine. One minor mistake can cost you or your shop thousands of dollars when you have to rebuild the engine again for free.

An ***engine overhaul*** involves the service and repair of the engine's bottom end, top end, and front end assemblies. All the internal parts are measured, inspected, machined, or replaced as needed to return all internal part clearances (bearings, rings, pistons, etc.) back to standard specifications.

Cylinder Block Service

Cylinder block service typically includes:

- Inspection for cracks, excess wear, scored cylinders, and other block damage.
- Checking for main bore and deck warpage; having the block machined if needed.
- Measuring cylinder wear; having the block bored or sleeved if cylinders are worn beyond specifications.
- Honing or deglazing cylinders to prepare cylinder walls for new rings.

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- Installing camshaft and balancer shaft bearings and checking for oil hole alignments in bearings and block.
- Final cleaning of the cylinder block before assembly of internal parts.

As you will learn, most engine repair tasks can be done in the average automotive repair shop. However, milling and boring operations usually require the help of a machine shop.

Inspecting the Cylinder Block

Begin short block service by closely inspecting the block for problems. Look for the kind of troubles illustrated in **Figure 57-1**. Inspect the cylinder block closely to make sure it can be reused and has no major problems. In particular, check the cylinder walls for scoring, heavy wear, cracks, and so on. Check the top of each cylinder for wear. If there is a large ridge at the top of a cylinder, cylinder wall wear is severe and block boring, sleeving, or replacement is required.

Using a shop light, closely inspect the surface of each cylinder wall. Rub your fingernail around in the cylinder. This will help you feel and locate problems. Also, inspect the crankshaft main bores for signs of bearing movement, a spun bearing, or other damage in the crankcase area.

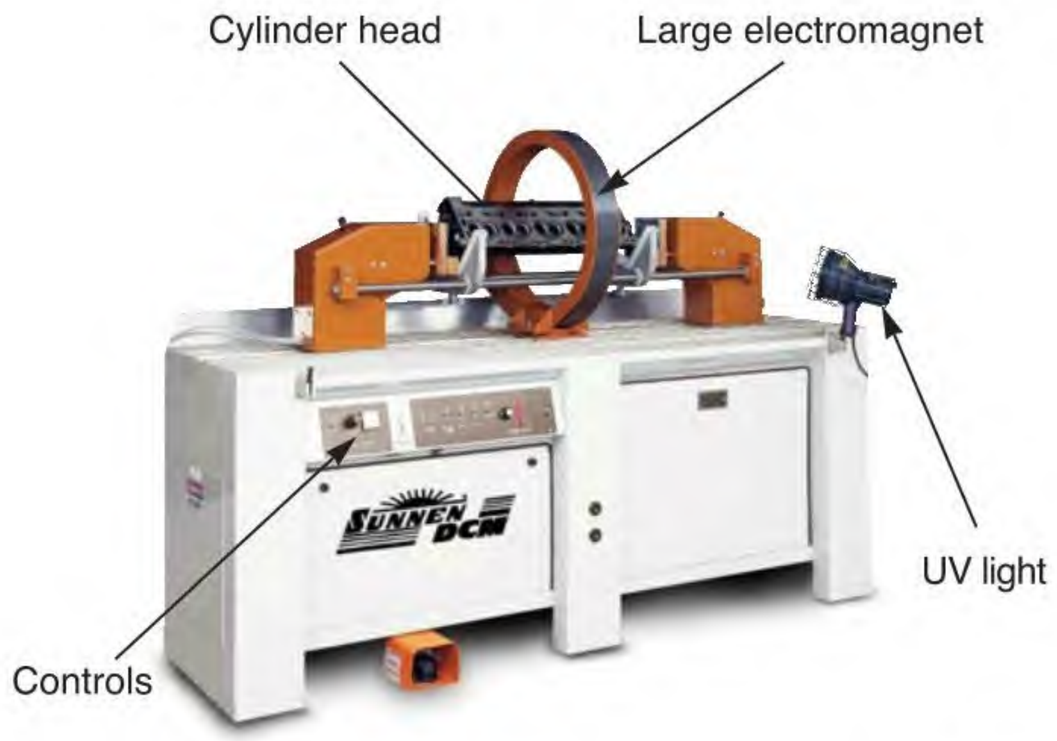


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Figure 57-1. Close inspection of cylinder walls will indicate the general condition of cylinder blocks. A—Use your fingernail to feel for cracks and scoring. B—Closely inspect the cylinder walls for these kinds of trouble.

Finding Cracks in the Block

If symptoms such as coolant in the oil or overheating point to possible cracks in the block, you should magnaflux a cast iron block or use dye penetrant on an aluminum block. ***Magnafluxing*** involves using a magnet and a ferrous (iron) powder to highlight cracks and pores in cast iron blocks. A large electromagnet surrounds the part with a magnetic field to aid crack detection, **Figure 57-2**. Smaller, handheld units are also available.



Sunnen

Figure 57-2. This is a magnetic particle inspection, or magnaflux, machine. Parts are mounted in the machine and a large electromagnet ring is moved over them as iron powder is spread onto the parts. The powder is attracted to, and highlights, any crack.

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Service Procedure

To magnaflux an iron cylinder block:

1. Place the magnet over the area to be tested for cracks.
2. Spread the metal powder over the block.
3. A break, void, or crack in the block metal sets up a magnetic field that pulls the powder to the crack or flaw. This will make the powder collect and show in the flaw. The light-colored powder will highlight the crack or pore so it is easy to detect, **Figure 57-3**.

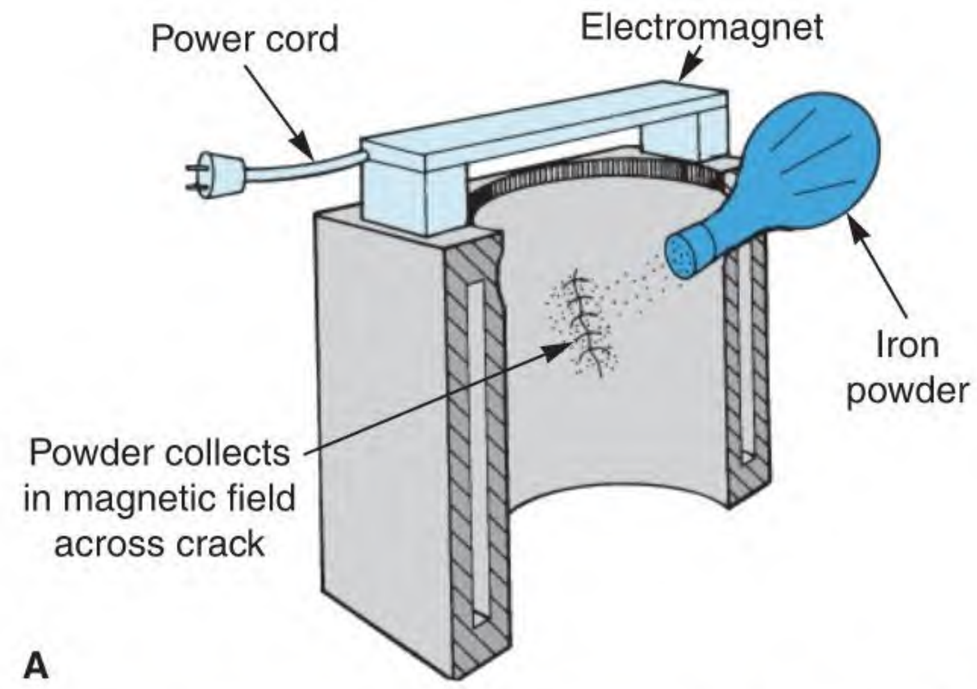
Service Procedure

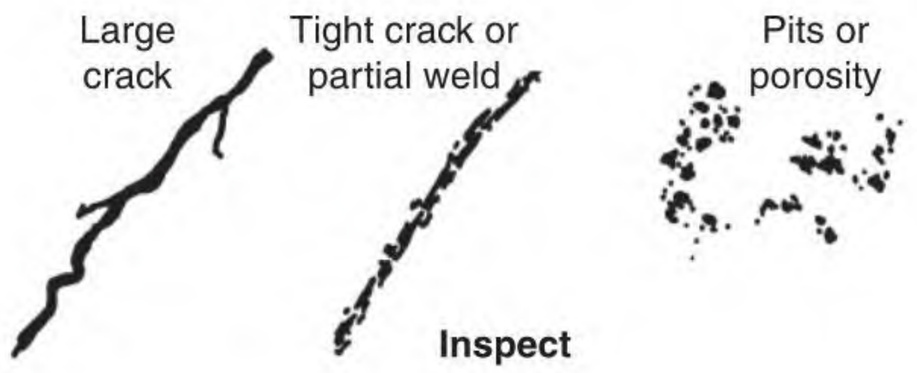
To use dye penetrant to check an aluminum block:

1. Spray the special dye over the cylinder block surface in question.
2. The dye will collect inside any crack in the cylinder block.
3. Spread or spray the powder-like developer over the penetrant.
4. The developer makes the penetrant turn red if it has collected in any crack or casting flaw(s) in the block.

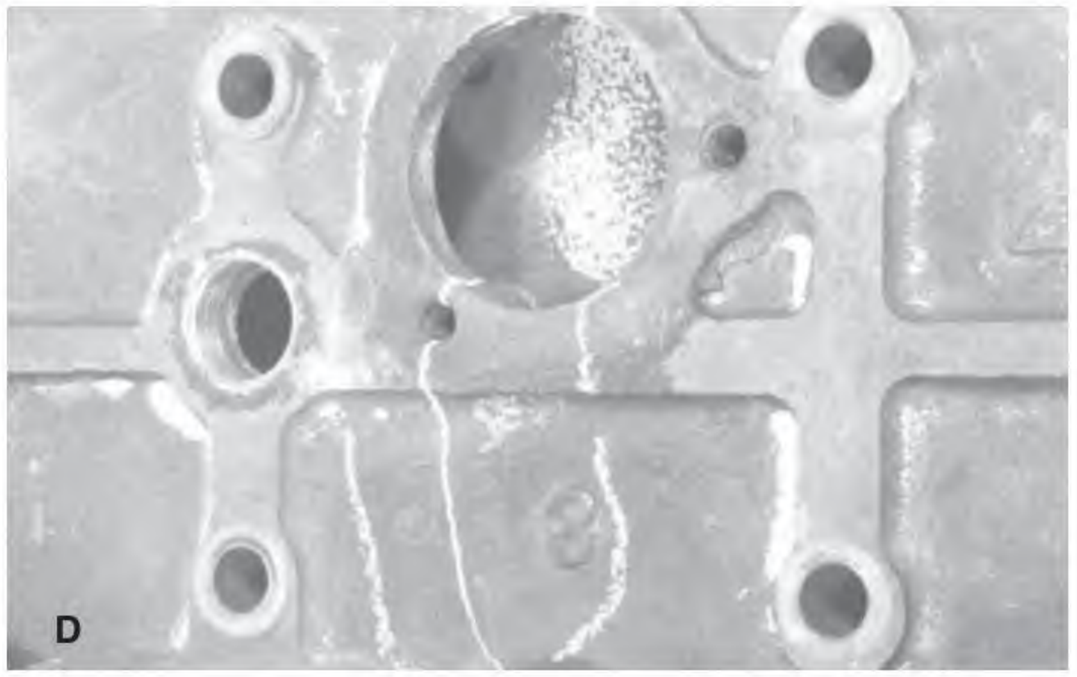
Since aluminum is a nonferrous metal, magnafluxing cannot be used to check for cracks and pores in aluminum blocks. ***Dye penetrant*** is commonly used to find cracks and casting imperfections in aluminum cylinder blocks.

Fluorescent penetrant is similar to dye penetrant, but it requires an ultraviolet (black) light to illuminate the penetrant in the cracks. When the chemical is sprayed over the part, it collects in any crack. When









K-line; Magnaflux Corp.

Figure 57-3. Study basic steps for finding cracks in steel and iron parts. A—Magnafluxing equipment is used to locate a crack in a cylinder. B—The pattern of iron particles indicates the type of problem. C—A cracked block caused by part breakage. D—Cracks in a block caused by freezing of weak coolant.

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the part is placed under a black light, the chemical concentrated in the crack glows.

Pressure testing involves filling the coolant or oil passages in the block with air pressure to find cracks or flaws. All openings to passages in the cylinder block are sealed using rubber expander plugs or gaskets. Sheets of rubber are bolted over the deck surface with metal plates. This makes the inside of the block airtight. An air hose is connected to the coolant or oil passages and the block is lowered into a large tank of water. Air bubbles will be released from any crack or pore, indicating where the problem is located.

Repairing Block Cracks

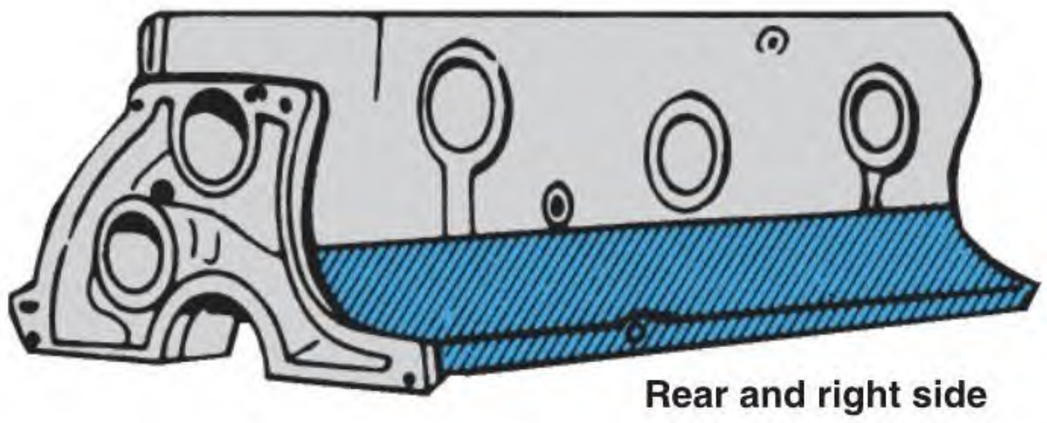
Block repairs are usually done by a specialized machine shop that has the equipment and skills needed to weld large castings. Cracks and pores in a cylinder block can be corrected by:

- Installing a sleeve in a cylinder if the crack is in the cylinder wall area.
- Welding the crack or pore. Cast iron is welded with a Ni (high nickel) rod after heating in a furnace. An aluminum block is welded with a GMAW welder and aluminum rod.
- Plugging, which involves drilling series of holes along crack and threading in repair plugs.
- Using special epoxy or metallic plastic to seal pores in certain areas of block. Epoxy should not be used on cracks, however. See **Figure 57-4**.

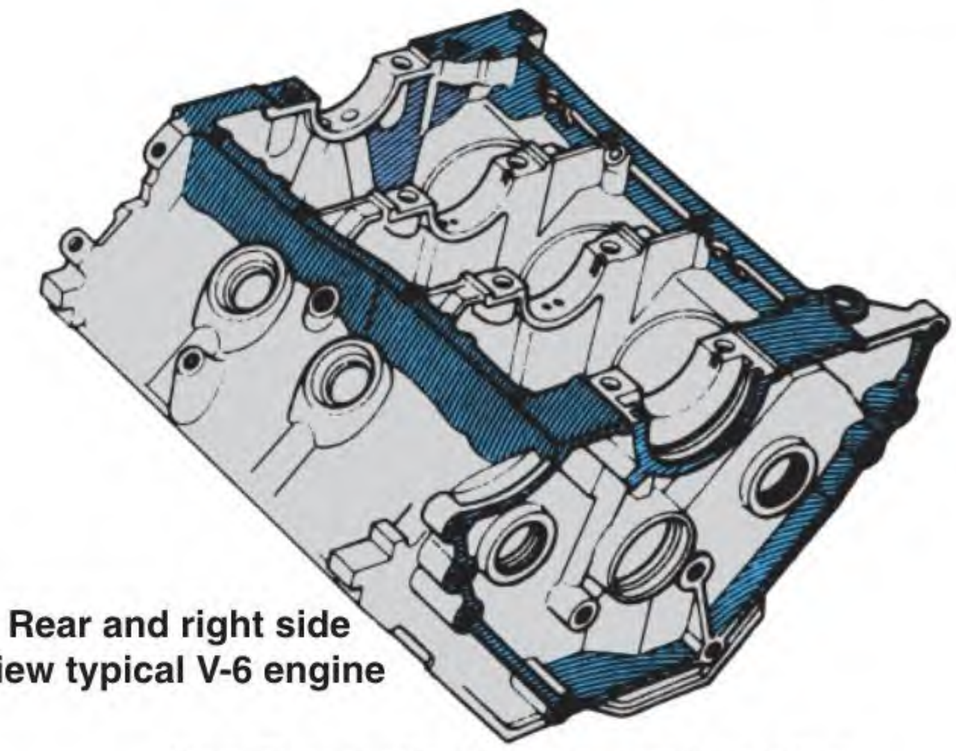
If the cracks and pores cannot be repaired, the block must be replaced. The block may also be replaced if the cost of repairing the crack is higher than that of a replacement block.

Checking Main Bearing Bores

After overheating or repeated heating and cooling, the main bearing bores in the cylinder block can warp or twist. This will affect main bearing insert alignment and crankshaft fit in the block. Under severe cases of main bearing bore misalignment, the crankshaft can lock up when the main caps are torqued with the new bearing installed. Always check for bore misalignment after main bearing failure.



Rear and right side



Rear and right side view typical V-6 engine

Note: The metallic plastic must not be applied around bolt hole bores in the cylinder block.

Ford

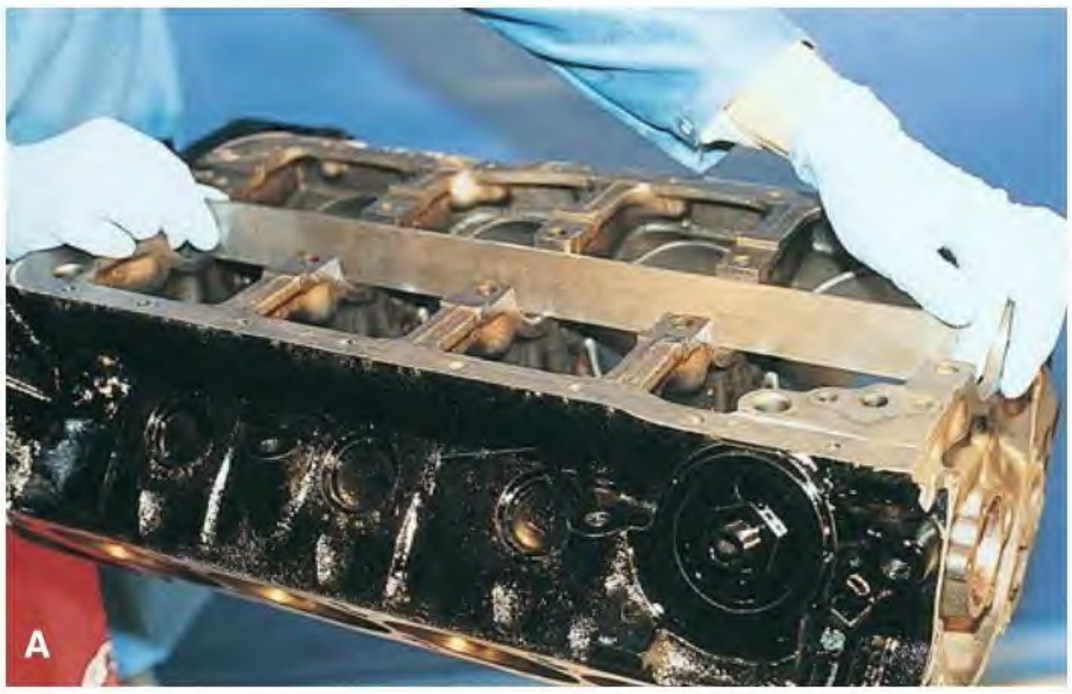
Figure 57-4. Casting flaws or pores can sometimes be repaired with special epoxy or plastic. This service manual illustration shows the areas of the block that can be sealed with two-part epoxy.

Service Procedure

To check for misalignment:

1. Lay a straightedge on the main bores with the main bearing inserts removed, **Figure 57-5**.
2. Try to slide a 0.0015" (0.038 mm) feeler gauge, or use the factory recommended size, under the straightedge.
3. If the blade fits between the straightedge and the main bore, the main bearing bores are misaligned.
4. Check for warpage at the bottom of each main bore and on each side near the main cap parting surface.

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Federal Mogul

Figure 57-5. Note how to determine if cylinder block's main bore is warped out of alignment. A— To check main bearing bore alignment, place a straightedge into the main bore of the cylinder block. B—Try to fit a 0.0015″ feeler gauge between the straightedge and block bore. If it fits, the block should be line bored by a machine shop.

Line Boring the Block

A machine shop will have a boring or honing bar for machining the bore back into alignment. Block ***line boring***, using a machine tool cutter, or ***line honing***, using rigid stones, can be used to straighten or true misaligned main bearing bores. A block should be line bored when misalignment is beyond factory specifications or a main bearing has "spun" and damaged the block. Study **Figure 57-6**.

Service Procedure

To line bore a machine block:

1. Machine the main cap mounting surfaces. When the caps are installed on the block, the main bore will be smaller in diameter and slightly out of round. This allows the block's main bore to be machined back to the original diameter.
2. Mount the cylinder block on the line boring machine so that its main bore is aligned with the boring bar.
3. Install the caps on the block and torque the fasteners to specifications.
4. Adjust the cutter bit or hone on the line boring machine to the correct bore diameter for the engine.
5. Engage the large drive head, which spins the boring bar or hone. Move the bar or hone through the main bores.
6. Verify the bore diameter with an inside micrometer or a telescoping gauge and outside micrometer.

Measuring Cylinder Block Deck Warpage

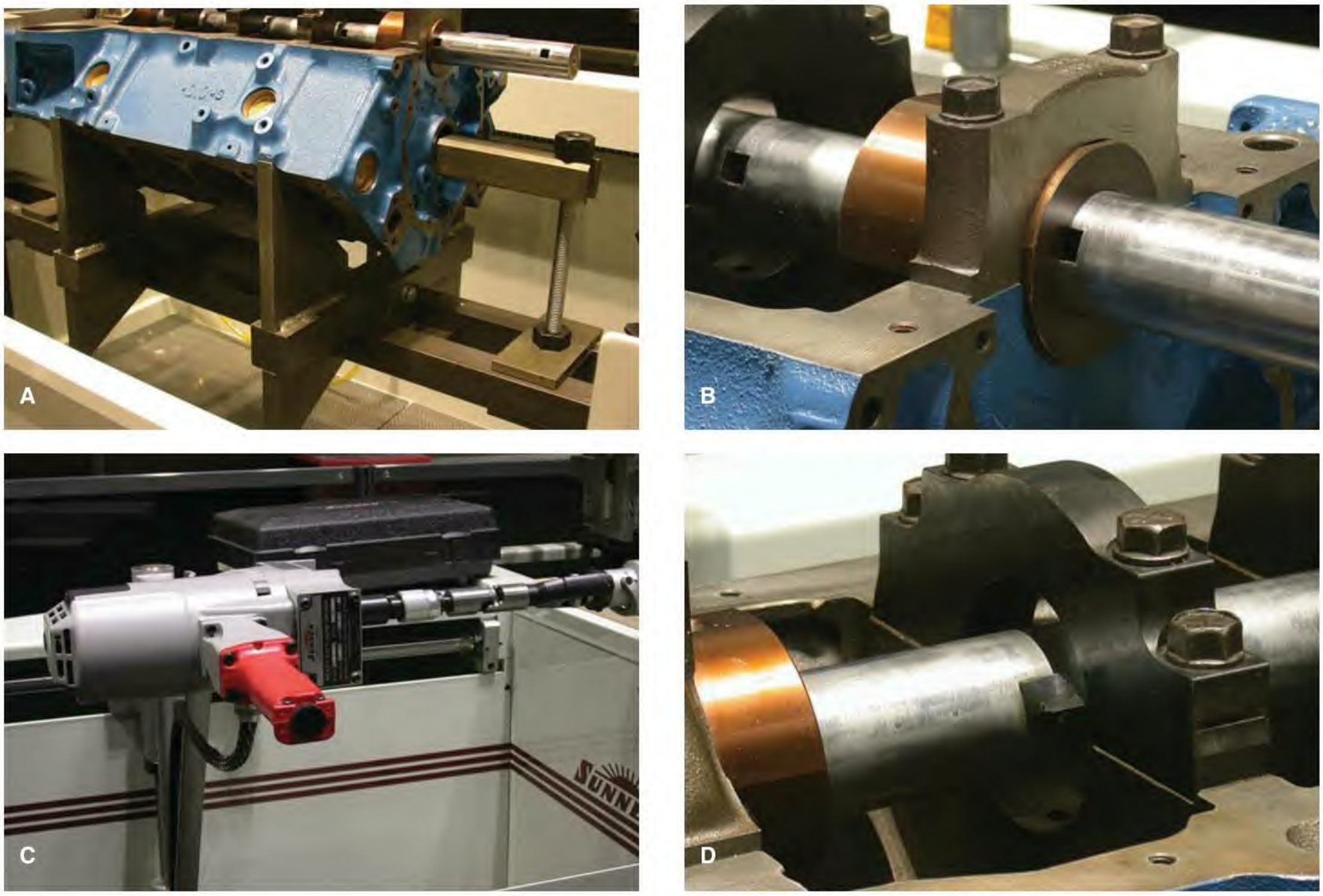
Cylinder block deck warpage often results from engine overheating, especially with thin-wall blocks. Aluminum blocks are especially prone to warpage. ***Deck warpage*** is measured with a straightedge and feeler gauge on the head gasket sealing surface(s) of the block. It should be checked, particularly when the old head gasket was blown and leaking.

Service Procedure

The following are steps to check a block deck for warpage:

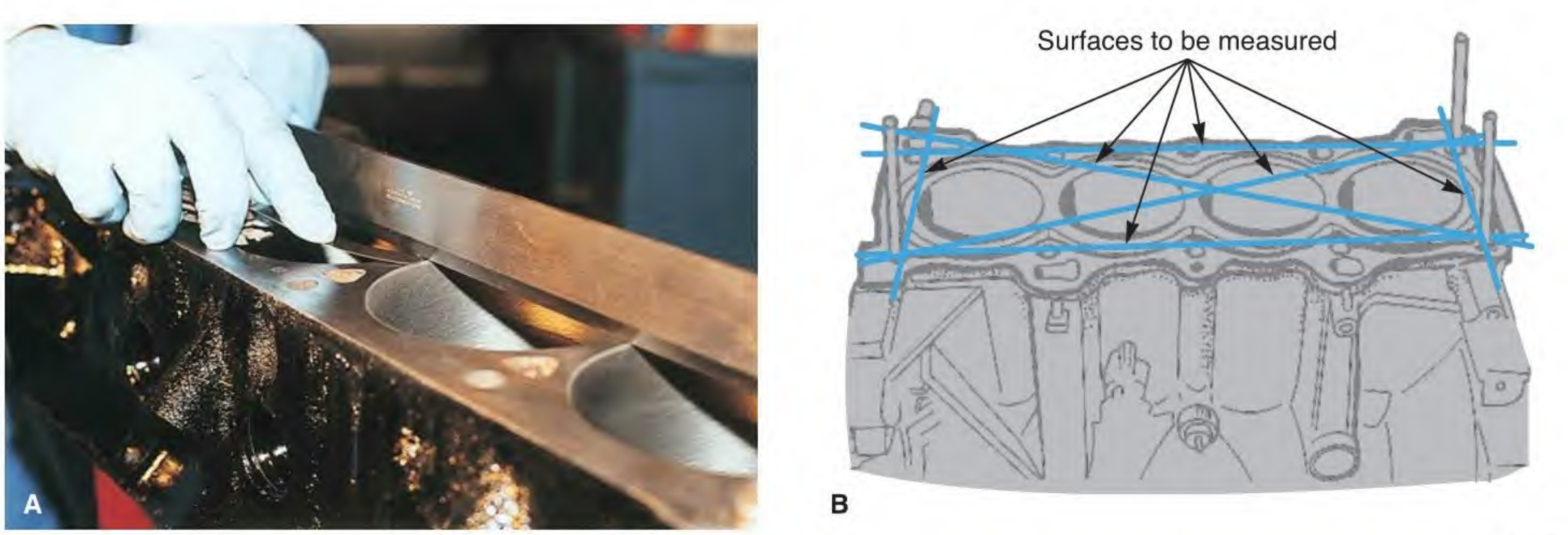
1. Lay a straightedge on the clean block deck surface, **Figure 57-7**.
2. Try to slip feeler gauges of different thickness between the block and straightedge.
3. The thickest blade that fits shows the deck warpage.
4. Check in different locations on the cylinder block deck.

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Sunnen

Figure 57-6. Note the basic procedure for line boring a cylinder block. A—The cylinder block is mounted in the line boring machine. B—Main caps are installed and the cap bolts are torqued to specifications. C—The large drive head spins the boring bar as the bar passes through the main bores. D—The cutter bit must be adjusted to the correct bore diameter.



Honda

Figure 57-7. Study steps for measuring warpage of cylinder block deck surface. A—To check for deck warpage, place a straightedge on the deck and try to slide a feeler gauge between block and straightedge. B—Check for warpage at these locations.

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If beyond specifications, generally about 0.003″ to 0.005″ (0.08 mm to 0.13 mm), replace the block or send it to a machine shop for decking. ***Decking*** a block involves surface milling the cylinder head mounting surfaces until they are parallel and equidistant from the main bore. This is also called "squaring" the block. See **Figure 57-8**.

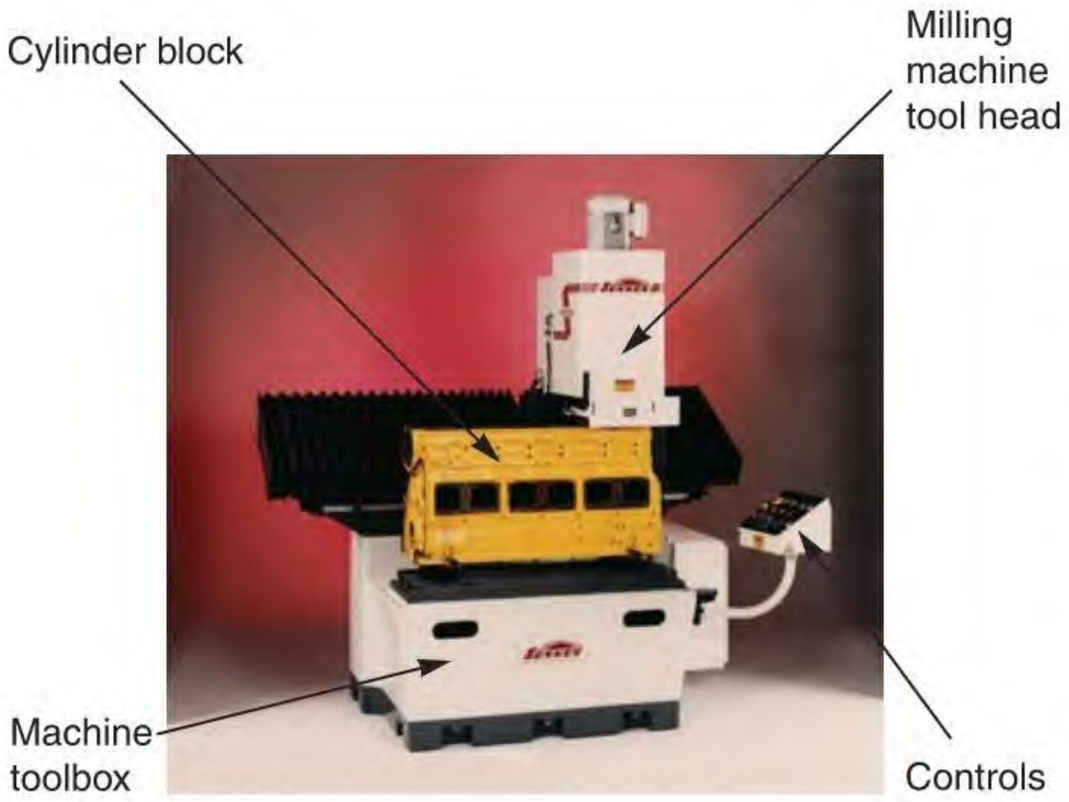
Measuring Cylinder Diameter

Before measuring cylinder wear, you should check the cylinder bore diameter. It is possible that the block was bored previously and the cylinders are not the original-specification diameter.

Service Procedure

To check cylinder diameter:

1. Check the service manual for the standard (original) bore specification.
2. Use a dial bore gauge, inside micrometer, or telescoping gauge and outside micrometer to measure the cylinder diameter at its widest point near the top of the cylinder.
3. Measure the cylinder diameter at the bottom of the cylinder in an unworn section.
4. Compare your measurements to specifications.



Sunnen

Figure 57-8. This is a machine shop milling machine being used to true the block deck.

As an example, you measure the cylinder bore near the bottom in an area of the cylinder where the rings do not wear and determine the diameter to be 4.010″. However, the standard specification calls for a 4.000″ cylinder diameter. From this, you can determine that the cylinder has been bored 0.010″ oversize. This would allow you to order the right size piston rings, know correct overbore limits, etc.

Cylinder Wear

A worn cylinder is not round, or "true." It is wider across its thrust surface. In addition, it is normally larger in diameter near the top than at the bottom. This is illustrated in **Figure 57-9**.

Cylinder taper is the difference in the diameter from the top to the bottom of the cylinder measured on the piston ring contact surface of the cylinder wall. It is caused by less oil lubricating the top of the cylinder wall. More oil splashes off of the crankshaft and onto the lower area of the cylinder wall. As a result, the top of the cylinder wears more than the bottom, producing a taper.

Cylinder out-of-round is a difference in cylinder wall diameter when measured front-to-rear and side-to-side in the block. Piston thrust action normally makes the cylinders wear more at a right angle to the centerline of the crankshaft and piston pin.

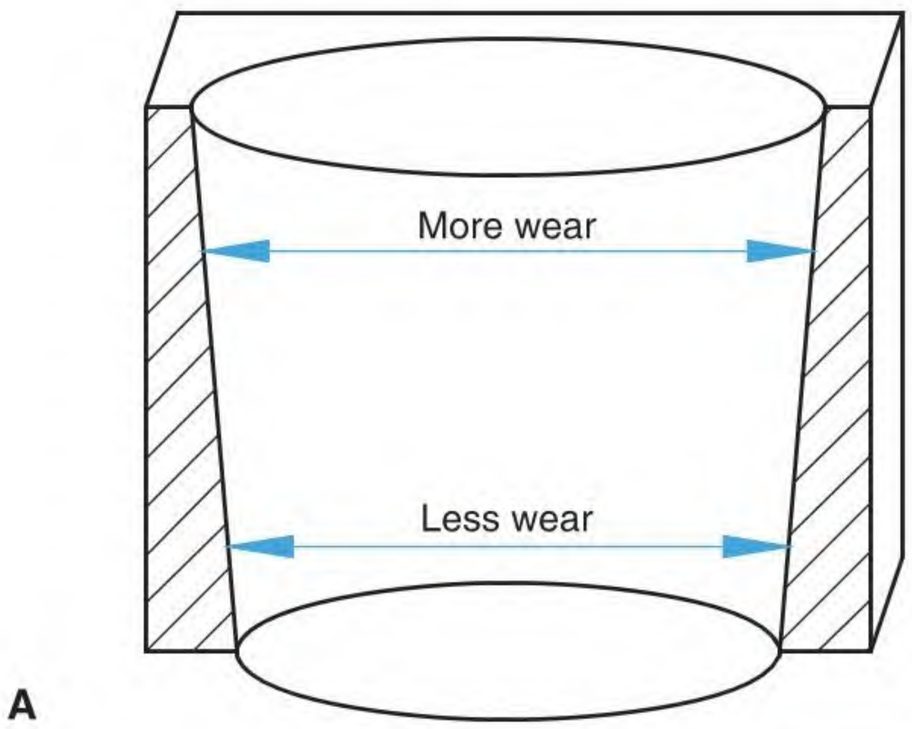
If new rings are installed in an out-of-round cylinder, blowby will result. There will be a gap where the round ring does not contact the worn cylinder. Pressure and oil can leak past this gap, resulting in oil consumption and blue exhaust smoke.

In a tapered cylinder, the piston rings expand and contract every time the piston slides up and down in the cylinder. At high engine speeds, the rings may fail to stay in contact with the cylinder. A loss of power, blowby, and oil consumption can result. New rings installed in a tapered cylinder will quickly wear or break. Cylinder taper must be removed during an engine rebuild.

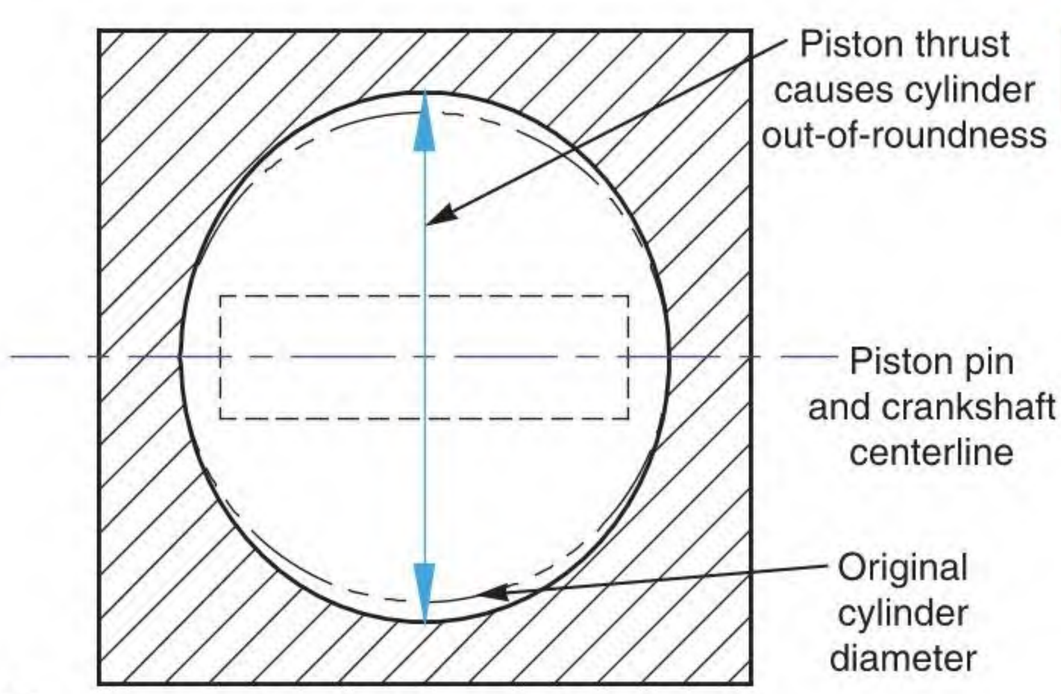
Measuring Cylinder Wear

If the cylinder is not badly scratched, scored, or otherwise damaged, you must measure cylinder wear to ensure that the new rings will seal properly. New, round rings cannot seal in worn, out-of-round or tapered cylinders. Also, cylinder and piston diameter measurements will let you determine piston-to-cylinder clearance.

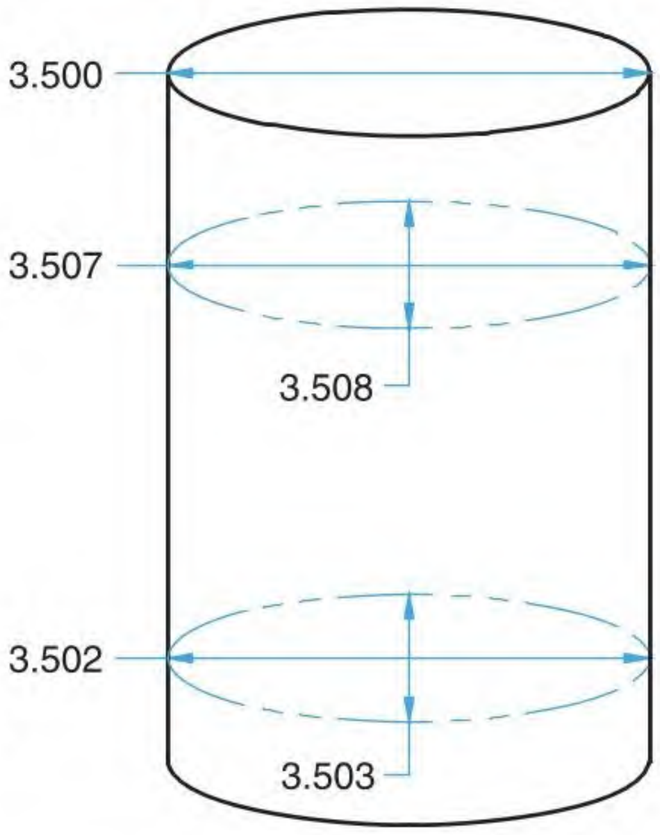
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A



B



C

Example cylinder Wear calculation

Cylinder diameter	Parallel to crankshaft	Perpendicular to crankshaft
At top	3.507″	3.508″
At bottom	3.502″	3.503″
Specification	3.500″	3.500″

Cylinder taper = maximum top diameter – maximum bottom diameter
= 3.508″ – 3.503″
= .005″

Cylinder out-of-round = maximum top diameter – minimum top diameter
= 3.508″ – 3.507″
= .001″

Cylinder wear = maximum cylinder diameter – specification diameter
= 3.508″ – 3.500″
= .008″

D

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Figure 57-9. Study the basic steps for measuring cylinder wall wear. A—The cylinder will wear more at top than bottom, resulting in taper. B—The cylinder will also wear more on the piston thrust surface, resulting in out-of-round. C—Measure the cylinder in these locations and write down your readings. D—Calculation of cylinder wear based on the measurements shown in C.

Piston-to-cylinder clearance can be found by measuring cylinder diameter and piston diameter. The difference between these two measurements is the piston clearance. See **Figure 57-10**.

A dial bore gauge can be used to quickly and precisely measure cylinder taper and out-of-round. Look at **Figure 57-11**.

Service Procedure

To measure cylinder taper and out-of-round:

1. Use an outside micrometer to adjust the dial bore gauge to the specification diameter.
2. Slide the bore gauge up and down in the cylinder.
3. The maximum dial indicator movement equals the cylinder taper. If the top of the cylinder is worn beyond specifications, no other measurements need to be taken and the cylinder must be machined.
4. To determine out-of-round, check the indicator movement with the gauge measuring parallel and perpendicular to the crankshaft centerline.

A large inside micrometer, or a telescoping gauge and outside micrometer, can also be used to measure cylinder dimensions. This method is slightly more time-consuming, however. Refer to Chapter 2 for more information on measuring tools.

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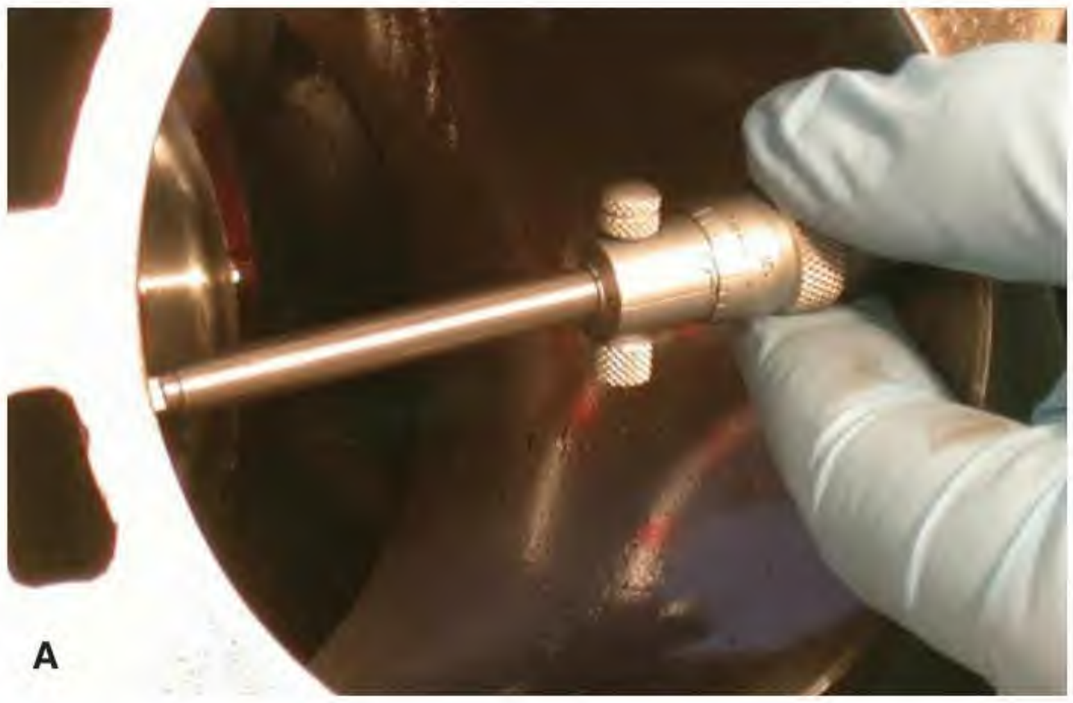
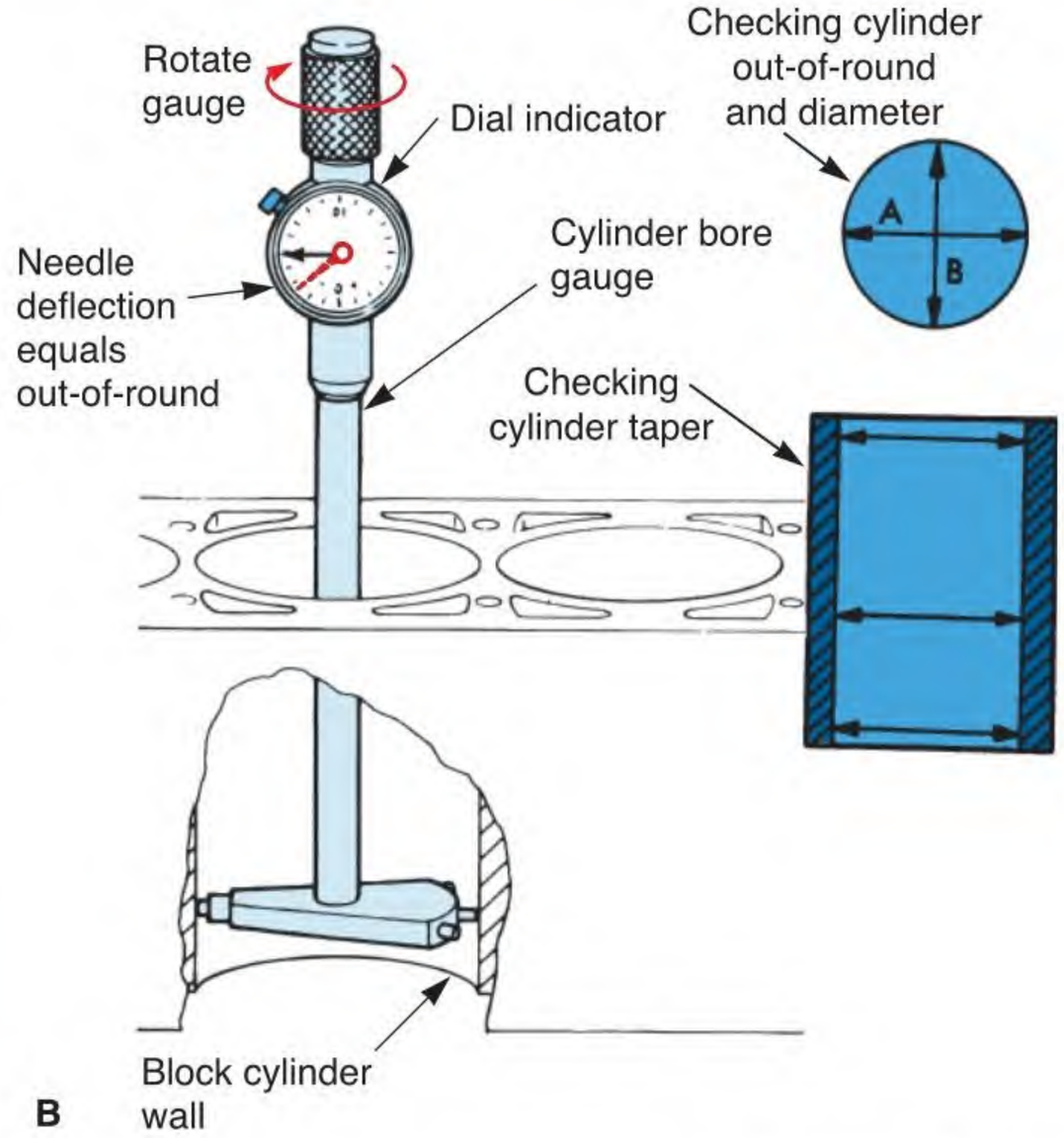




Figure 57-10. Study how to calculate piston-to-cylinder clearance. A—Use an inside micrometer to measure the cylinder diameter. B—Use an outside micrometer to measure across the piston skirt to find the piston diameter. Subtract this from the cylinder diameter to find the piston clearance.





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Figure 57-11. A dial bore gauge can be used to check cylinder wear. A—Slide the dial bore gauge up and down in the cylinder to read taper. B—Rotate the gauge around the cylinder to read out-of-round. Cylinder wear is the difference between the specification and the actual readings. Note the locations for cylinder wear measurement.

Tech Tip

Write down your cylinder measurements carefully and accurately. The slightest mistake in math could be critical to the long life and success of your engine rebuild.

Cylinder Wear Limits

Generally, cylinder boring, sleeving, or block replacement is needed when:

- Cylinder out-of-round is more than 0.005″ (0.13 mm).
- Cylinder taper is more than 0.008″ (0.20 mm).
- The maximum cylinder diameter stated by the engine manufacturer has been exceeded. This limit is typically 0.010″ (0.25 mm) over the bore specification.

Always refer to the specifications for the engine on which you are working and follow those values to calculate amount of engine part wear.

If the cylinders are worn beyond the maximum allowable limit according to factory specifications, you will have to bore, sleeve, or replace the cylinder block.

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If the block is bored oversize, all cylinders must be increased in diameter. All new oversize pistons would have to be ordered to fit the enlarged cylinders.

To save the customer money, only one sleeve need be installed if just one cylinder sustained damage to its wall surface. If the other cylinder walls are in good condition with only minor wear, only one new piston and the cylinder sleeve will repair the block damage.

Cylinder Honing and Deglazing

Cylinder honing, also called ***deglazing***, is used to remove the smooth surface polished into the cylinder walls and provide a lightly roughened or textured surface for ring seating and sealing. Honing must also be done to smooth the rough cylinder wall surface after cylinder boring. Most ring manufacturers recommend deglazing or honing with specific grit-cutting stones before new ring installation.

The pockets or valleys in the hone marks or scratches hold oil to prevent ring scoring. The peaks or high points in the honed metal surface contact the piston rings. They quickly wear down from ring friction so that the ring can match the shape of the cylinder wall.

A cylinder hone produces a precisely textured, crosshatched pattern on the cylinder wall to aid ring seating and sealing. Tiny scratches resulting from the action of the hone cause the initial ring and cylinder wall break-in wear. This makes the ring fit in the cylinder after only a few minutes of engine operation.

Hone Grit Selection

If the cylinder surface is too coarse, ring and cylinder scoring may result. If the cylinder wall surface is too smooth, the rings may not seal properly and lead to oil consumption. Therefore, it is important to select a hone with the correct grit. Generally, softer ring coatings require a coarser stone and surface texture. Harder ring coatings require a finer stone and surface texture.

Surface smoothness is measured in ***microns***, or millionths of an inch. Special testers are available that can be passed over a surface to measure root mean square (RMS), which is a measurement of surface smoothness. Cylinder smoothness or RMS should be matched to the type of piston ring. Stone coarseness is measured in grit. The higher the number, the finer the stone. Always use the honing stone recommended by the manufacturer.

Remember these rules:

- Use 220-grit stones to produce a textured 25–30 RMS surface texture for cast iron rings operating on cast iron cylinder walls.
- Use 280-grit stones to produce a medium 20–25 RMS surface for chrome rings (hard) operating on cast iron cylinder walls.
- Use 320-grit stones to produce a very fine 10–15 RMS surface for moly rings (very hard) operating on cast iron cylinder walls.
- Use 150-grit, aluminum oxide stones to lightly hone and clean up nickel-ceramic cylinder walls, or cylinder walls with a similar coating. Finish hone the coated cylinder wall with 500-grit, diamond stones.



Caution

If the incorrect honing procedure or piston ring type is used in an engine, the new piston rings may not seal properly. Oil consumption, blowby, and engine smoking can result.

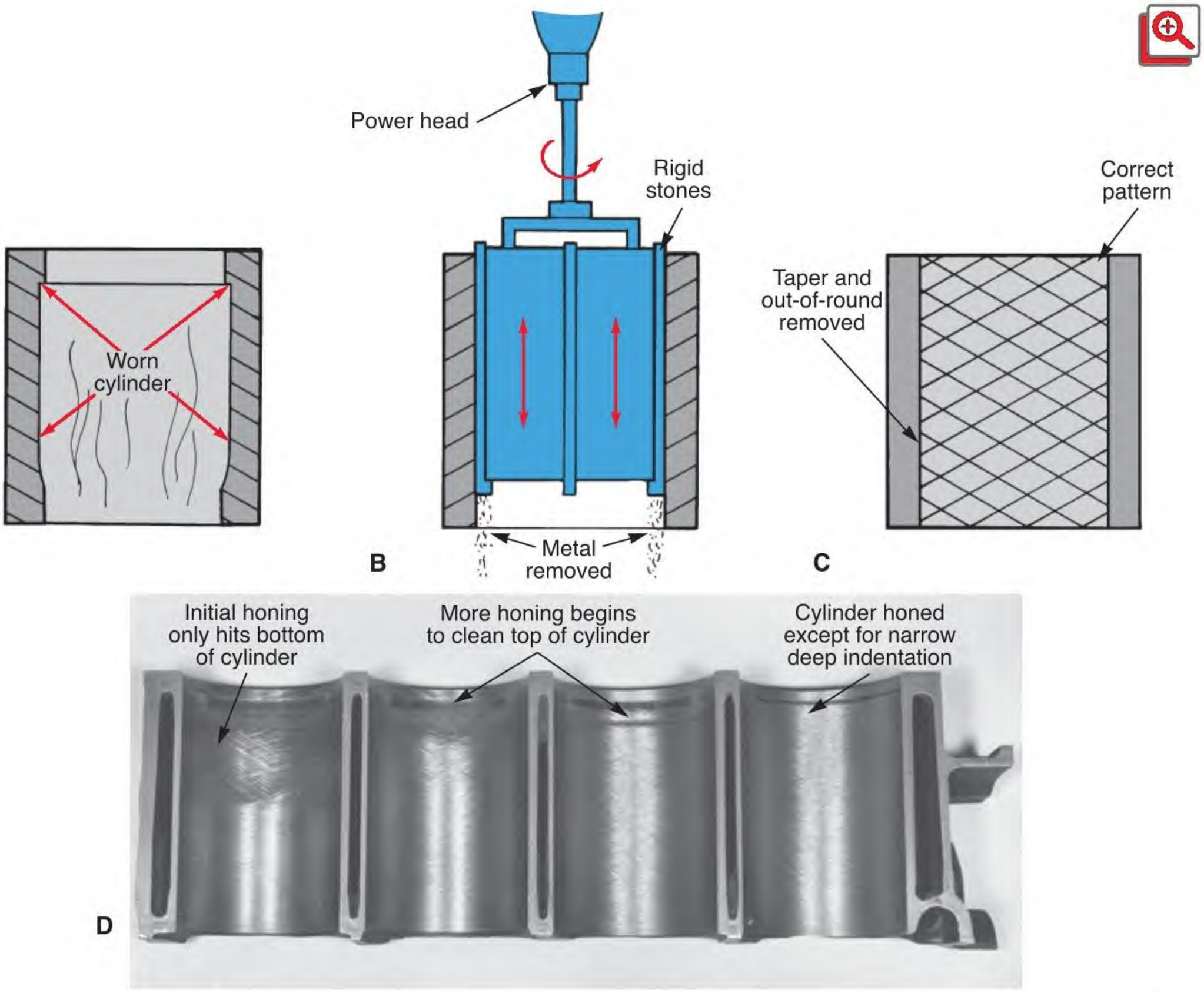
Using a Power Hone

A ***power hone*** is a machine shop tool that sizes and finishes the cylinder walls in an engine block. A rigid power hone can be used instead of a boring bar to remove cylinder taper and out-of-round. It can remove smaller amounts of metal to clean up a worn or slightly scored cylinder wall. This makes the cylinder equal in size at all points. See **Figure 57-12**.

Modern power hones are computer controlled. The machinist can enter specifications for hone speed, feed, diameter, and so on. Some machines have a display that shows the amount of taper, out-of-round, and diameter of cylinder. This allows the machinist to know how much more material must be removed to recondition the cylinder.

Typically, power honing is used when less than 0.030″ (0.76 mm) of material must be removed from the cylinder walls. If more material must be removed, as when sleeving a cylinder, the cylinder is bored instead of power honed. Generally, standard rings and pistons can be used when a power hone is used to enlarge a cylinder by a maximum of 0.008″ (0.20 mm). Most new standard piston ring sets will seal in a cylinder that is 0.010″ oversize. This will save you from having to bore the cylinder 0.010″ larger and install oversize pistons and rings.

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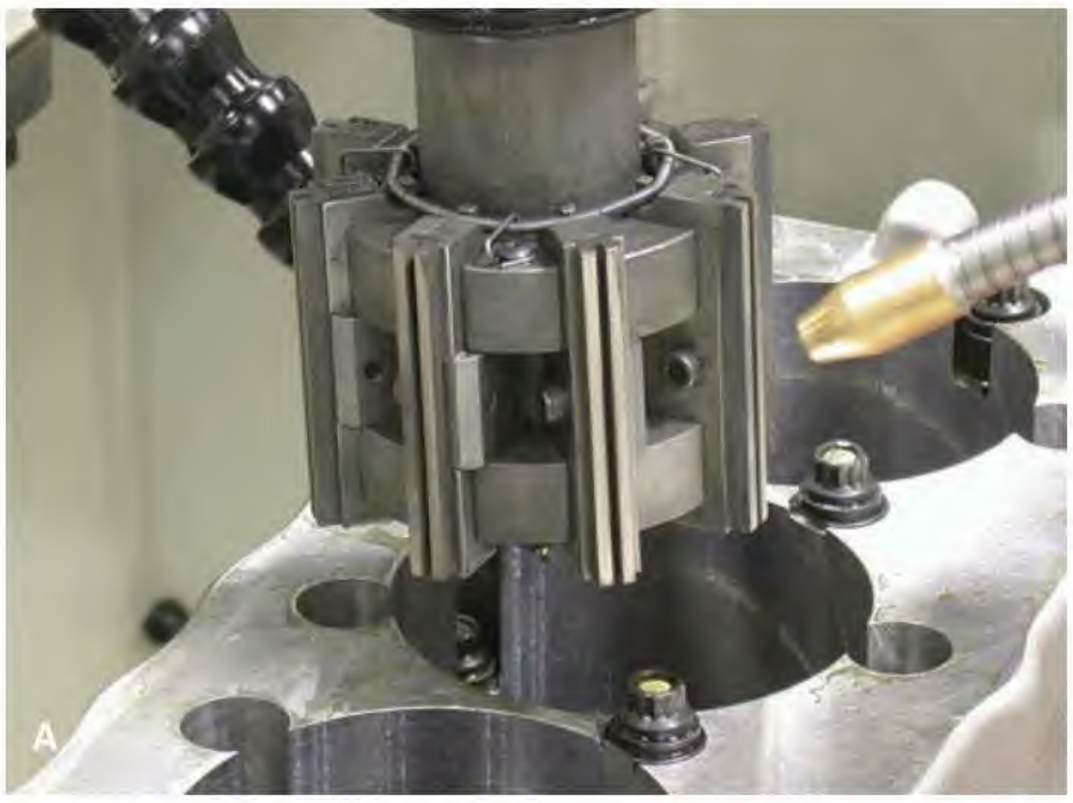
Figure 57-12. Study how to correct minor cylinder wall problems with power honing. A—This cylinder has minor scratches and a small ring ridge. B—The power hone spins rigid stones inside the cylinder. C—After honing, taper and out-of-round are removed and the cylinder wall has the correct crosshatch pattern. D—Note the stages of power honing. The small, dark ring at the top of the finished cylinder is only 0.001″ deep and will not affect ring sealing.

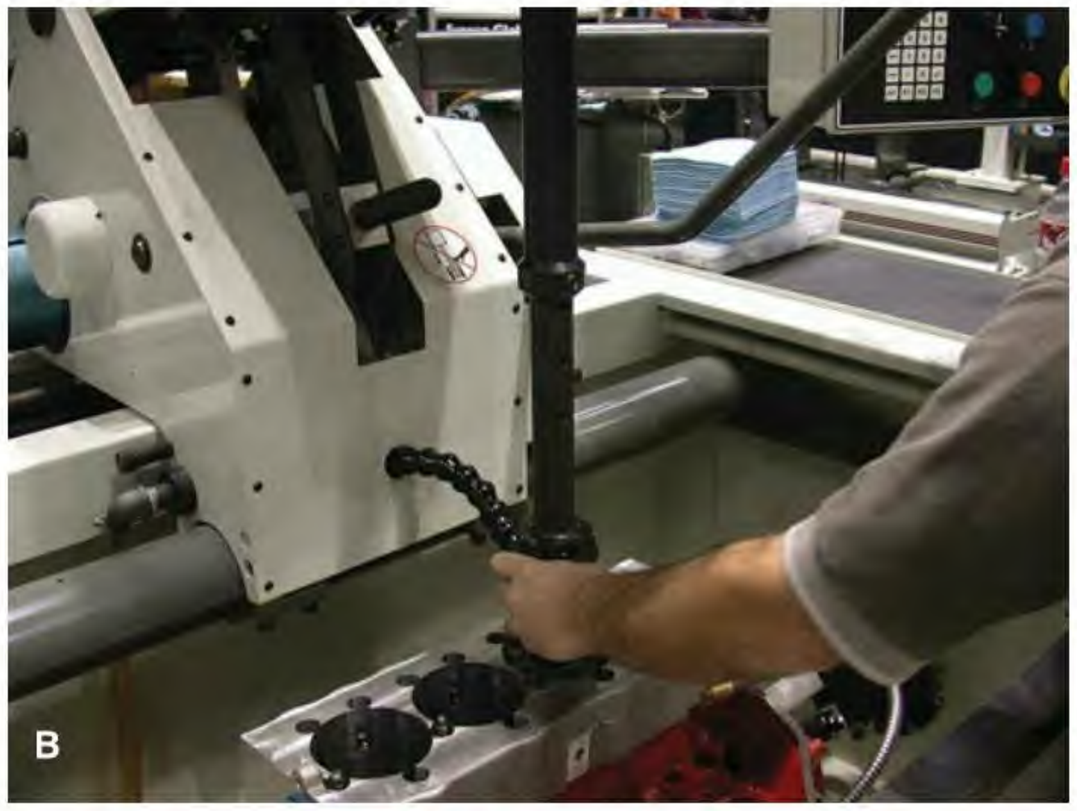
Plateau honing involves using extra fine stones to final size the cylinder dimensions and final smooth the surface finish. This step removes the "peaks" produced by the previous honing steps. It also produces the desired crosshatch pattern in the cylinder walls to speed piston ring seating and sealing during engine break-in.

A ***deck plate*** is a rigid metal cap bolted onto the block deck surface when power honing or boring. When torqued down, the deck plate stresses the block as if a cylinder head is installed. If you bore or power hone a cylinder without a deck plate, the cylinders can become out-of-round or tapered when the cylinder head is torqued in place. A deck plate avoids this potential problem when rebuilding an engine. Refer to **Figure 57-13**.

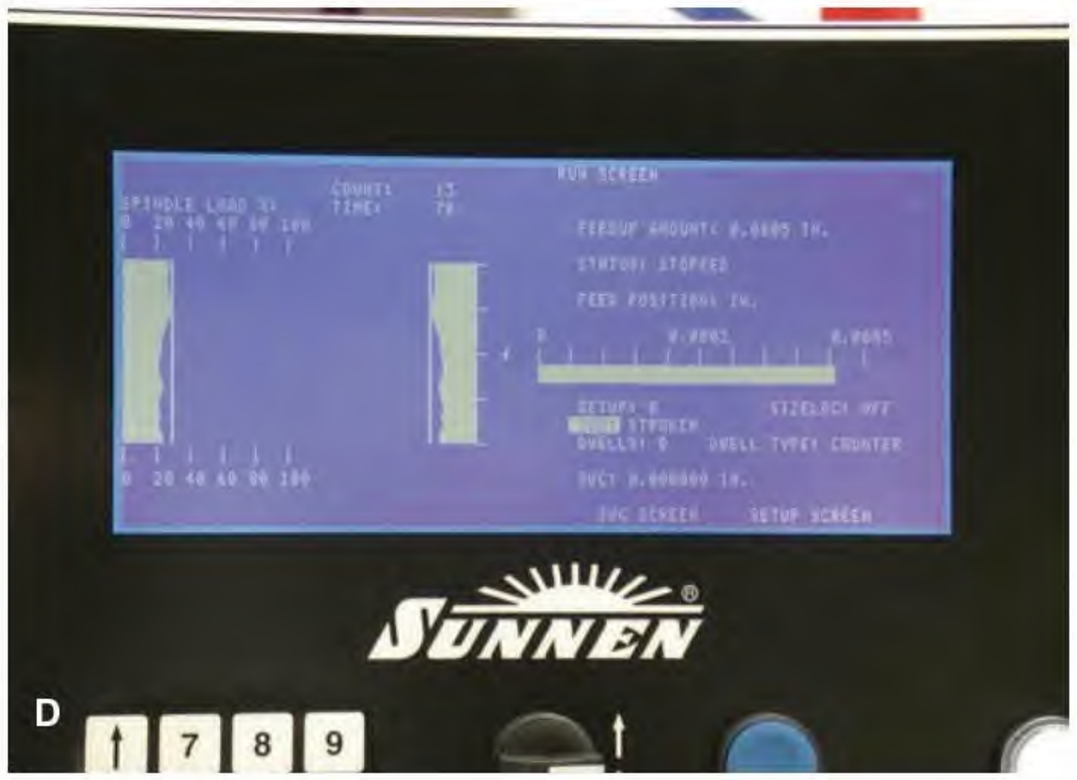
Basically, a series of rotating stones (a hone) is passed through the cylinder block bores until the final diameter and finish are achieved. Generally, the first hone used is a very coarse, 80-grit, diamond stone set. These coarse stones can rapidly remove large amounts of metal. The second power hone used is a 180-grit, semi-finish stone set. This provides initial smoothing. Finally, a 220-grit, finish stone set is used. This smoothes the cylinder walls even more and also final sizes the cylinder diameter.

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Figure 57-13. Study the major steps for using a power hone. A—The first set of stones is very coarse for rapid removal of metal. B—The machinist is centering the power hone over the cylinder bore. Note the use of a deck plate on top of the engine. C—The power hone in action. D—This display shows the amount of taper and out-of-round, and the diameter of the cylinder, so the machinist knows how much more material must be removed.

Tech Tip

For new rings to seal, the most critical cylinder characteristic is roundness. The next most critical characteristic is taper. Round rings must have a round cylinder to prevent blowby. Rings can still seal a slightly oversize cylinder wall as long as the cylinder is round and untapered.

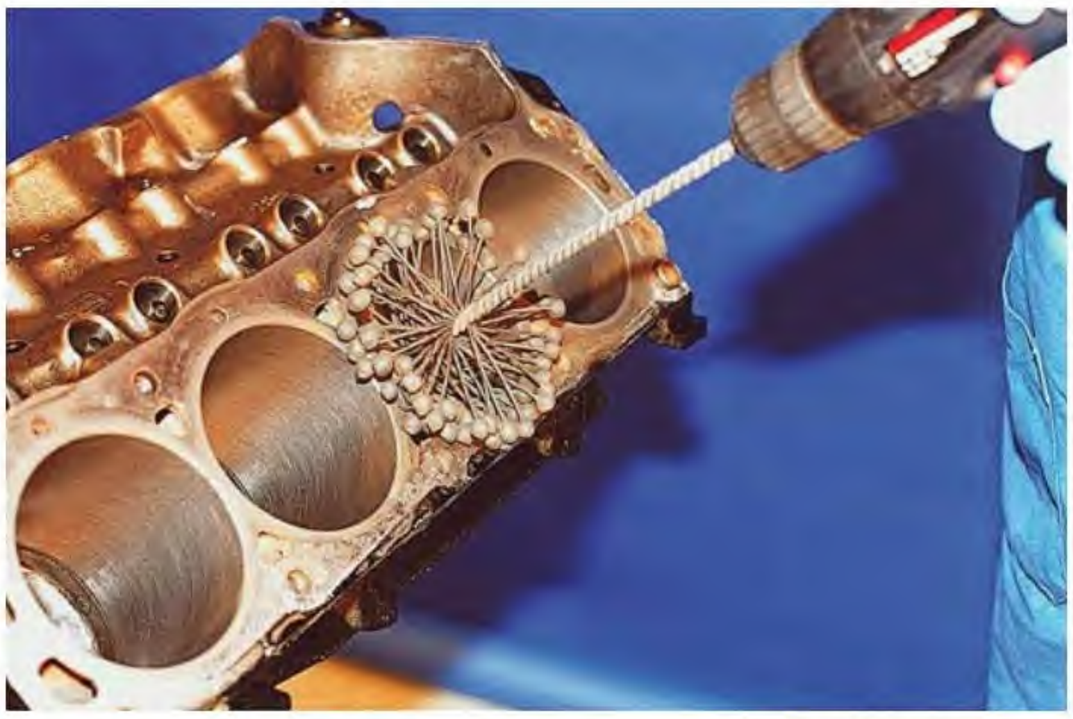
Using a Flex Hone

To hone a cylinder using a flex hone, follow the equipment manufacturer's instructions. Install the hone in a large, low-speed electric drill, **Figure 57-14**. Compress the stones (squeeze inward) and slide them into the cylinder. Be careful not to scratch the cylinder. Turn on the electric drill and move the spinning hone up and down in the cylinder.

Move the hone up and down in the cylinder fast enough to produce a 50° to 60° crosshatch pattern. This is illustrated in **Figure 57-15**. Moving the hone up and down faster or slower will change the pattern. It is usually acceptable if a small band in the cylinder under the ring ridge fails to polish up when honing. This will have little effect on ring sealing.

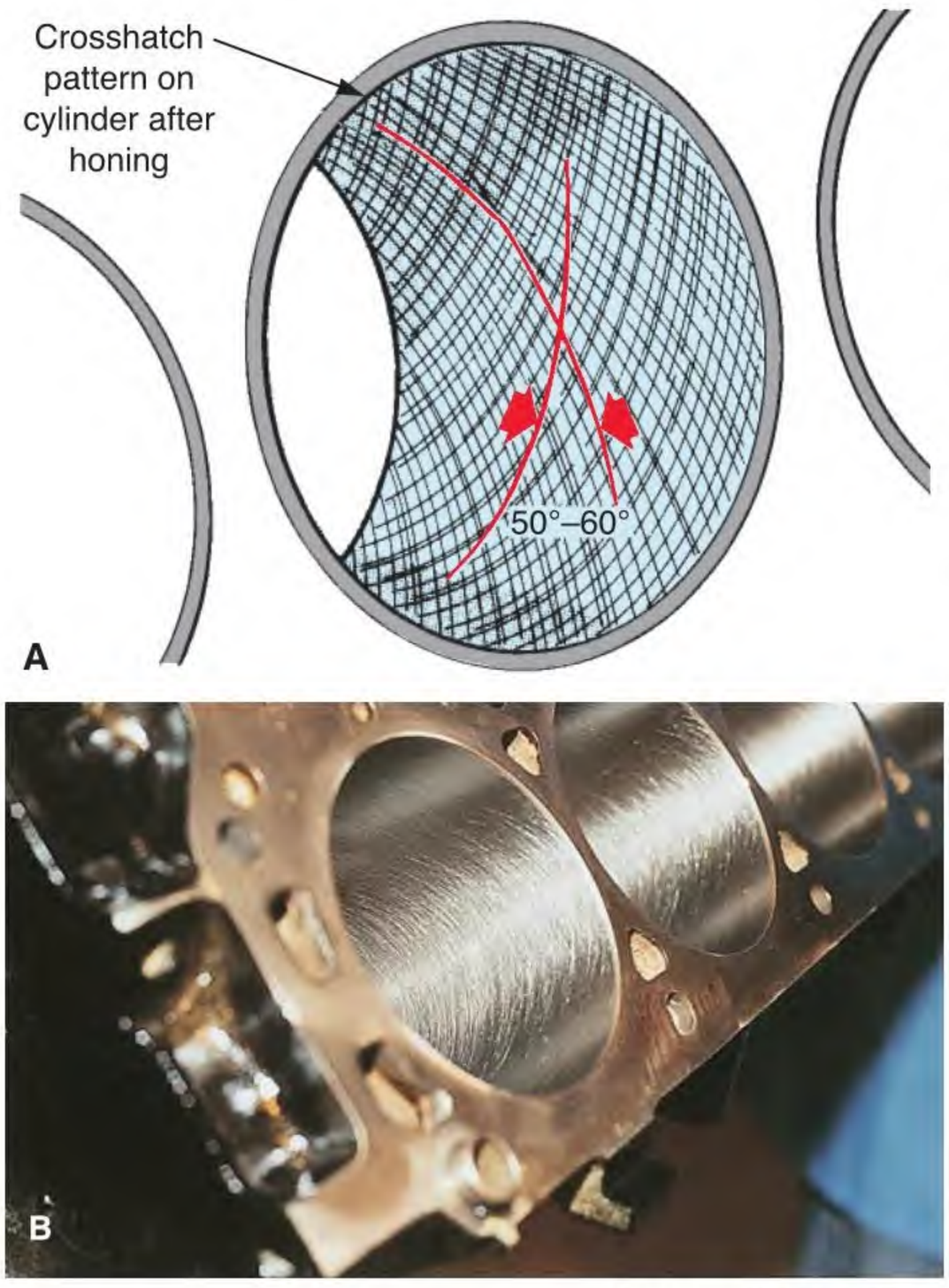
If the cylinder has not been bored or power-honed true, hone more at the bottom of the cylinder. This will remove taper and enlarge the bottom slightly to make

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Figure 57-14. A flex hone leaves the proper texture on the cylinder walls to aid ring break-in and sealing. It removes little material and should be lubricated during use. Be careful not to pull the spinning hone too far out of the cylinder.



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Figure 57-15. Make sure you move hone up and down at right speed to produce a crosshatch pattern on cylinder walls. A—When honing, try to produce a 50° to 60° crosshatch pattern. B—The crosshatch pattern is clearly visible on these finished cylinders.

the cylinder equal in diameter at the top and bottom. Hone at the bottom for a few seconds and then move up and down to produce the 50° to 60° crosshatch.

Warning

Make sure you do not pull the hone too far out of the cylinder while the hone is spinning. The hone could break and bits of stone may fly out.

Block Boring

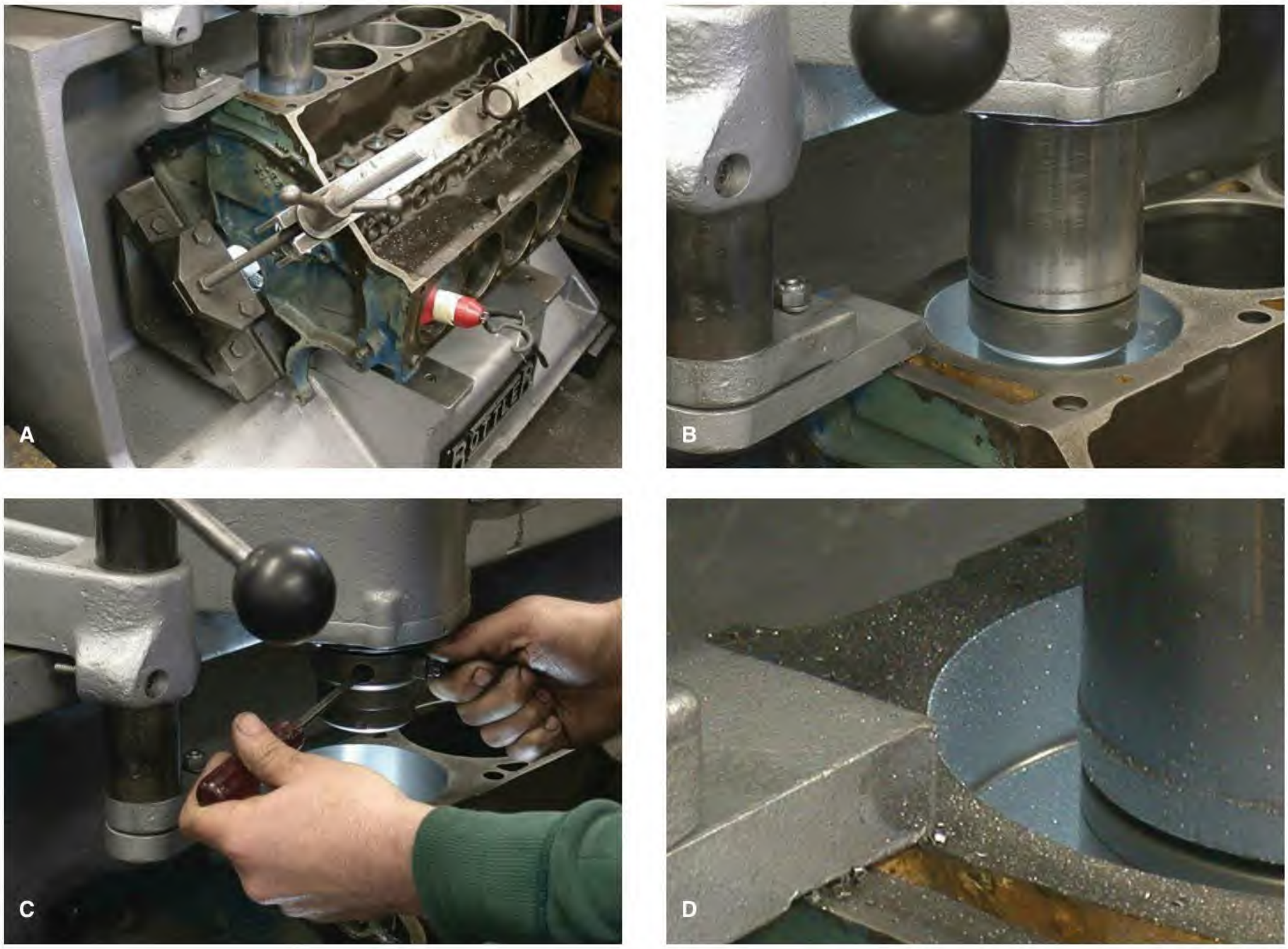
Block boring is needed to correct excess cylinder wall wear, scoring, or scratching. Boring will true the cylinder walls so the rings and pistons fit properly, **Figure 57-16**. It is also done when installing a repair sleeve. Boring oversize and installing new pistons and rings will make the engine like new. The new pistons and rings operate on a freshly machined cylinder surface, providing excellent ring sealing and service life.

The trend in industry is to use a honing machine to bore engine block cylinders when sleeving is not required; in other words, when the cylinder can be overbored within factory bore limits. However, when more material must be removed to sleeve cylinders, a boring bar is used instead of a honing machine. The cutter bit in a boring bar can cut more deeply and quickly than honing stones.

Boring is needed when your measurements show cylinder wear is beyond specifications. If power honing will not clean up the cylinder, more material must be removed. This process is called boring and can be done with a boring bar or a power hone. If taper is more than 0.012″ and out-of-round is more than 0.005″, boring is also needed. After boring, oversize pistons and rings must be installed. Unless a sleeve is to be installed, all cylinders are bored to the same oversize.

A ***boring bar*** is a machine shop tool that will cut a thin layer of metal out of the cylinders. The cylinder block must first be mounted, squared on the boring bar, and centered on the table. This will allow the boring bar to pass down through existing bores properly. When turned on and engaged, the boring bar rotates while being automatically fed down into the cylinder. The cutter tip on the boring bar removes metal from the cylinder wall. This will correct cylinder wear, out-of-round, or taper problems or allow for the installation of a repair sleeve. The maximum limit on each pass is generally 0.060″.

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VanSenus Auto

Figure 57-16. Study the major steps for boring a block with a large machine tool. A—The cylinder block must first be mounted and squared up on the boring bar. B—When turned on and engaged, the boring bar rotates while being automatically fed down into the cylinder. C—The machinist is adjusting the cutter to make a second cut. D—The second cut is being made. Notice the metal shavings generated as metal is removed.

Multiple passes are needed for larger oversizes, such as when a sleeve is being installed.

Caution

Always use a reputable machine shop. Your rebuild work is only as good as the machine work done on the parts. Always verify measurements on any machined part before assembly.

Overbore Sizes

Normally, a block is bored in increments of 0.010″ (0.25 mm). This depends on whether piston oversizes are available in standard or metric sizes. You must make sure what size of oversize pistons are available and overbore the block accordingly. Many shops order the oversize pistons, measure them, and then bore the block to perfectly match the size of the new oversize pistons. This ensures precise piston-to-cylinder clearance.

Depending on the amount of wear, the block cylinders may be bored 0.010″, 0.020″, 0.030″, 0.040″, 0.050″, or 0.060″ oversize; larger on thick-wall castings. Most shops bore cylinders either 0.030″ or 0.060″ oversize because these piston oversizes are the most readily available.

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When oversize pistons come in metric dimensions, the cylinders need to be bored either 0.25 mm, 0.50 mm, 0.75 mm, 1.0 mm, or 1.5 mm oversize. These overbore sizes match the sizes of metric pistons available to replace the stock diameter pistons.

Overbore Limit

The ***overbore limit*** is the maximum amount that a block should be bored oversize without resulting in cylinder walls that are too thin. It is a specification given by the engine manufacturer. In the past, blocks could be bored as much as 0.120″ (1.5 mm) oversize. However, many of the lightweight, thin-wall castings found in today's engines can only be bored 0.020″ (0.25 mm) oversize.

The overbore limit depends on the thickness of the cylinder walls. If too thin after boring, the cylinder wall could crack from the pressure of combustion. Always check the overbore limit of the specific block before recommending an overbore diameter. The machine shop should also be able to determine the overbore limit.

Tech Tip

Boring increases engine compression slightly. This can be critical with some engines, especially high-compression, turbocharged, and supercharged engines.

Oversize Pistons and Rings

Oversize pistons and rings are required to fit a cylinder block that has had its cylinders bored oversize. The pistons must be purchased to match cylinder oversize. If the block is bored 0.030″ oversize, then you would have to order 0.030″ oversize pistons and rings. The proper clearances are manufactured into the oversize pistons.

Caution

Make sure the correct piston oversize is available before having the block bored. If 0.020″ oversize pistons are not available, you do not want to bore the block oversize to that diameter. Many shops will not bore a block until after obtaining the new, oversize pistons. This ensures that the new pistons will properly fit the new cylinder bore dimensions. Special pistons can be ordered and machined, but these can cost several times as much as off-the-shelf pistons.

Cylinder Sleeving

Cylinder sleeving involves machining or boring a cylinder oversize and pressing in a cylinder liner. Sleeving is needed, for example, after part breakage has severely gouged, nicked, chipped, or cracked the cylinder wall. If the damage is too deep to be cleaned up with power honing or boring, sleeving is a way to salvage the block.

Sleeving also allows a cylinder to be restored to its original diameter. If the existing piston is not damaged, it can be reused. For example, if only one piston and cylinder are damaged in a low-mileage block, all of the other pistons and cylinders may be good and usable. In this case, sleeving would salvage the block and save the customer money on the repair. Sleeving can also be used if one or more cylinders require boring but the customer wants to retain the stock cylinder diameter.

Sleeve installation is a machine shop operation. If you have an aluminum block with cast iron sleeves, sleeve replacement is simple. The machine shop can drive out the old sleeve and press in a new one. Boring is not needed. This can be done for a badly damaged cylinder, for example when a rod breaks and hits the cylinder wall.

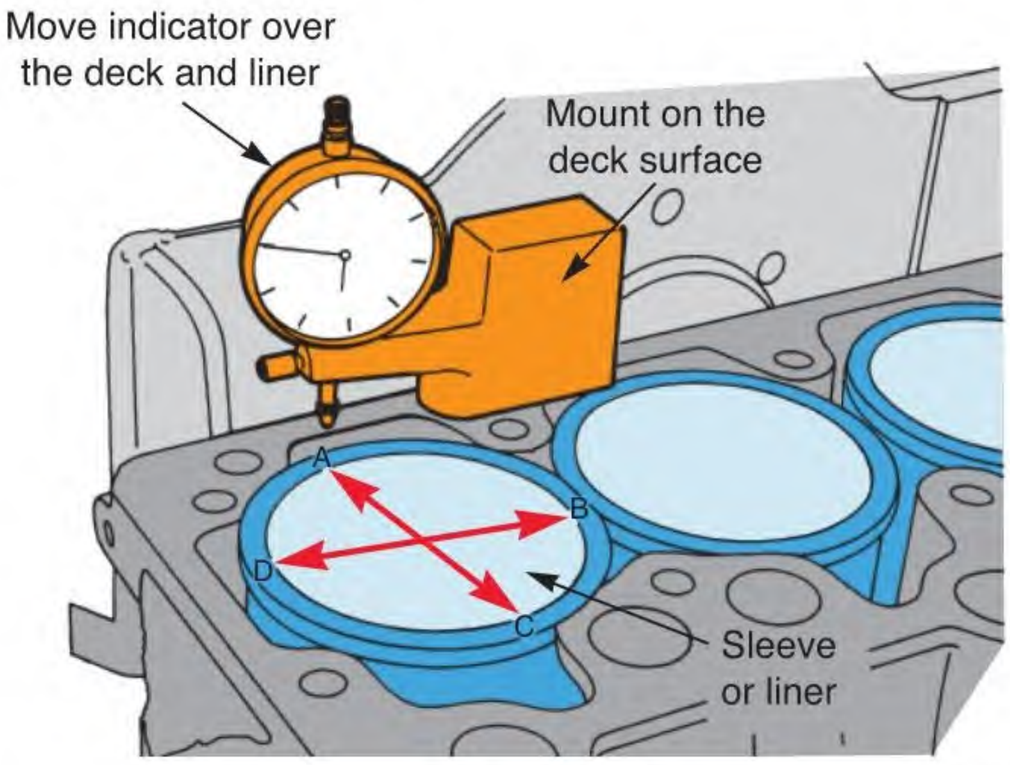
Sleeving a cast iron block is more complex. The old cylinder must be bored oversize to a diameter slightly smaller than the outside diameter of the sleeve. The sleeve is then pressed into the block. Finally, the sleeve is bored to the correct cylinder diameter using a power hone or boring bar.

Sleeve protrusion or ***liner protrusion*** is the distance that the sleeve sticks up above the block deck. Sleeve protrusion is needed to seal combustion pressure at the head gasket. If the sleeve is even or slightly below the deck surface, the hot combustion flame can blow past the cylinder sleeve into the coolant or oil, between cylinders, or out of the engine. A few thousandths of an inch (hundredths of a millimeter) sleeve protrusion will ensure the combustion chamber seals properly while still allowing the compressible head gasket to seal coolant and oil passages. Look at **Figure 57-17**.

Cleaning Cylinder Walls

After boring, sleeving, and honing, it is very important to clean the engine to remove all bits of stone and metal from inside the engine. If not removed, this material, or grit, will act like grinding compound circulating through the engine. It can wear bearings, rings, and other vital engine parts.

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Renault

Figure 57-17. Checking sleeve protrusion is critical to proper sealing of water, oil, and pressure by the head gasket.

A pressure washer is the most efficient way of cleaning a cylinder block. The high-pressure soap and water will blow all grit out of the cylinders and crankcase. After pressure washing, blow the block dry and wipe the cylinders down with motor oil. See **Figure 57-18**.



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Figure 57-18. Blow the block dry after washing. Wear eye protection and rubber gloves while blowing into all bolt holes, passages, and machined surfaces to clean them.

If a pressure washer is not available, hand wash the cylinders with warm, soapy water. See **Figure 57-19**. A soft-bristle brush, not a wire brush, will quickly loosen grit inside the hone marks. A clean rag and the detergent will then lift grit out of the hone marks. Keep rinsing the rag out and washing the cylinders until the rag comes out clean. After the rag comes out clean, wash the cylinders one more time. Then, blow the block dry.

Next, place new motor oil on a clean shop towel. Wipe the cylinder down thoroughly with the oil-soaked towel. The heavy oil will pick up any remaining grit embedded in the cylinder honing marks. Refer to **Figure 57-20**. Wipe the cylinders down until the rag comes out clean.

After cleaning, recheck the cylinder for scoring or scratches. If light honing did not remove all of the vertical scratches in the cylinder, cylinder boring or sleeving may be needed.

Check all threads in the block for damage and cleanliness. Clean all threads. Repair any damaged threads.

Caution

Before engine reassembly, double-check to make sure the block is in an acceptable condition. Remember, the block is the foundation of the engine rebuild. If the block has problems, you are building on an unstable foundation that will fail.

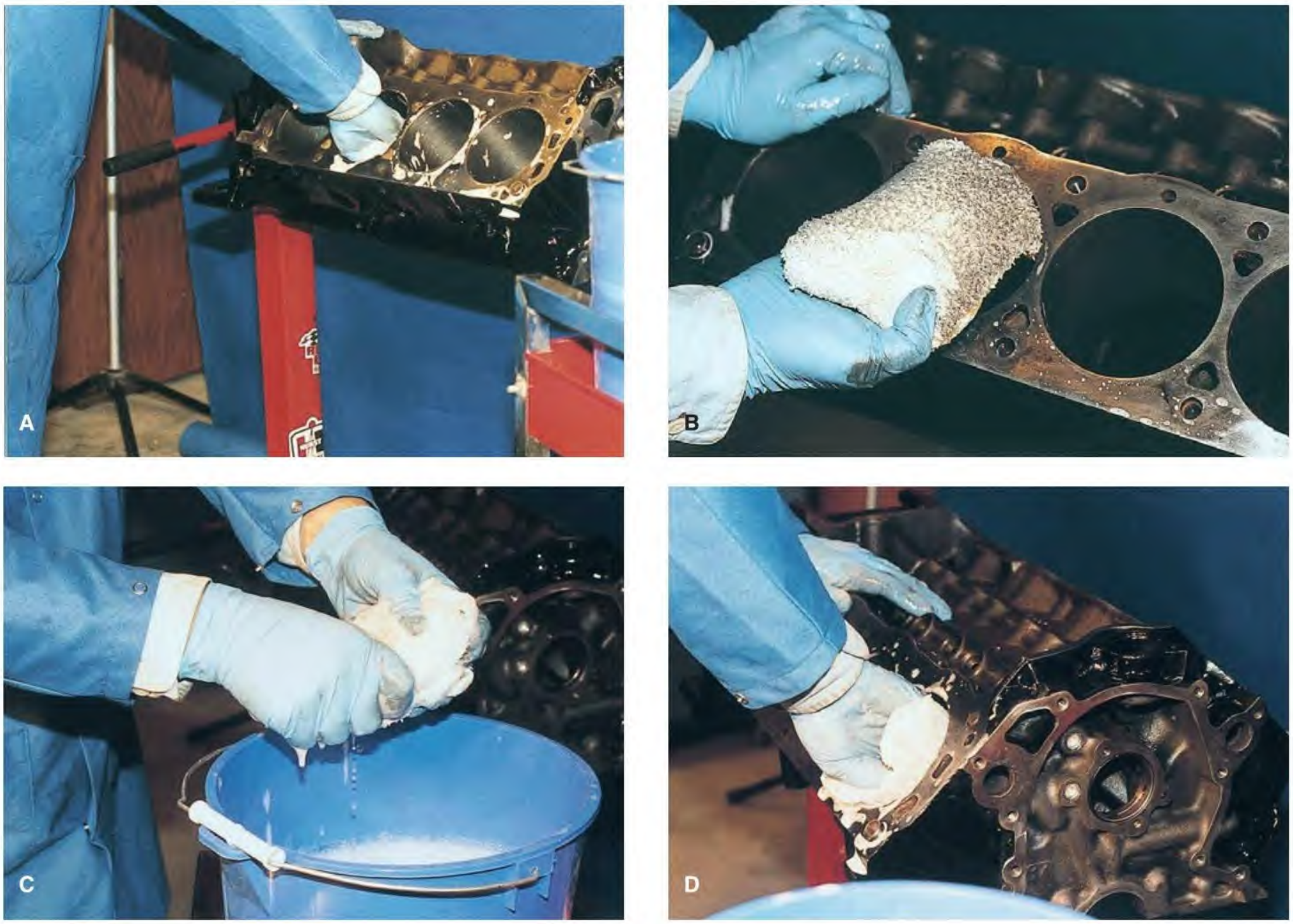
Camshaft and Balancer Bearing Installation

New camshaft and balancer shaft bearings should be installed during major engine service. Worn camshaft bearings are common and can lower engine oil pressure. The camshaft bearings on an OHC engine may be split bearings, similar to a main or connecting rod bearing. However, in cam-in-block engines, the camshaft bearings are a one-piece design and pressed into the block.

Many technicians have the machine shop install camshaft bearings. However, some technicians have the special drivers needed to press the camshaft bearings into and out of the block.

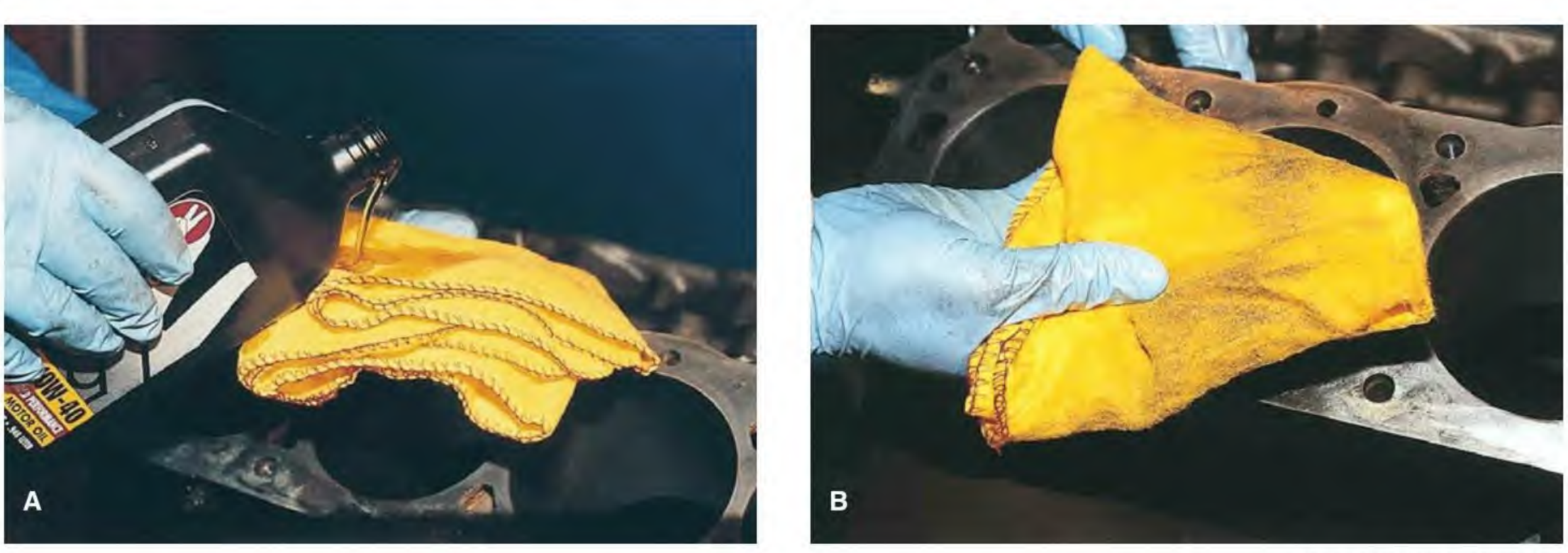
It is critical for the oil holes in the block to line up with the oil holes in the bearings. If the holes do not

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Figure 57-19. Cylinder block cleaning is critical to engine service life. All honing grit must be removed to avoid rapid piston ring and bearing wear from abrasive stone particles remaining in block. A—If a pressure washer is not available, wash the cylinders with warm, soapy water. B—A clean rag and the detergent will lift grit out of the hone marks. C—Keep rinsing the rag out and washing the cylinders until the rag comes out clean. D—After the rag comes out clean, wash the cylinders one more time.



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Figure 57-20. Motor oil will pull more grit out of cylinder crosshatch marks than soap and water. A—After washing and drying the block, pour clean motor oil on a folded shop towel. B—Wipe the cylinders with the oil-soaked rag. Note how the oil pulls more grit out of the hone marks.

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align, severe valve train wear and damage can result from lack of lubrication. See **Figure 57-21**.

Core Plug Installation

Core plugs are installed over water jackets and oil gallery openings in the outside of the cylinder block. Unless the engine is a relatively new, low-mileage engine, new core plugs are installed during a major engine rebuild.

The old core plugs must be popped out and new ones driven in. A full-shank screwdriver or pointed pry bar can be driven through the center of the core plug. The old plug can then be pried out. Be careful not to scratch or damage the plug sealing surface in the block with your prying tool.

Before installing a new core plug, sand the block core plug opening with sandpaper or emery cloth to remove rust or debris from the sealing surface. Apply recommended sealer to the outside of the core plug and drive it in. Use a correct diameter driver and light hammer blows. Some technicians like to "stake" oil core plugs in place. Use a dull chisel or punch to place a couple indentations in the block so that the core plug cannot be forced out by oil or coolant pressure. This is shown in **Figure 57-22**.

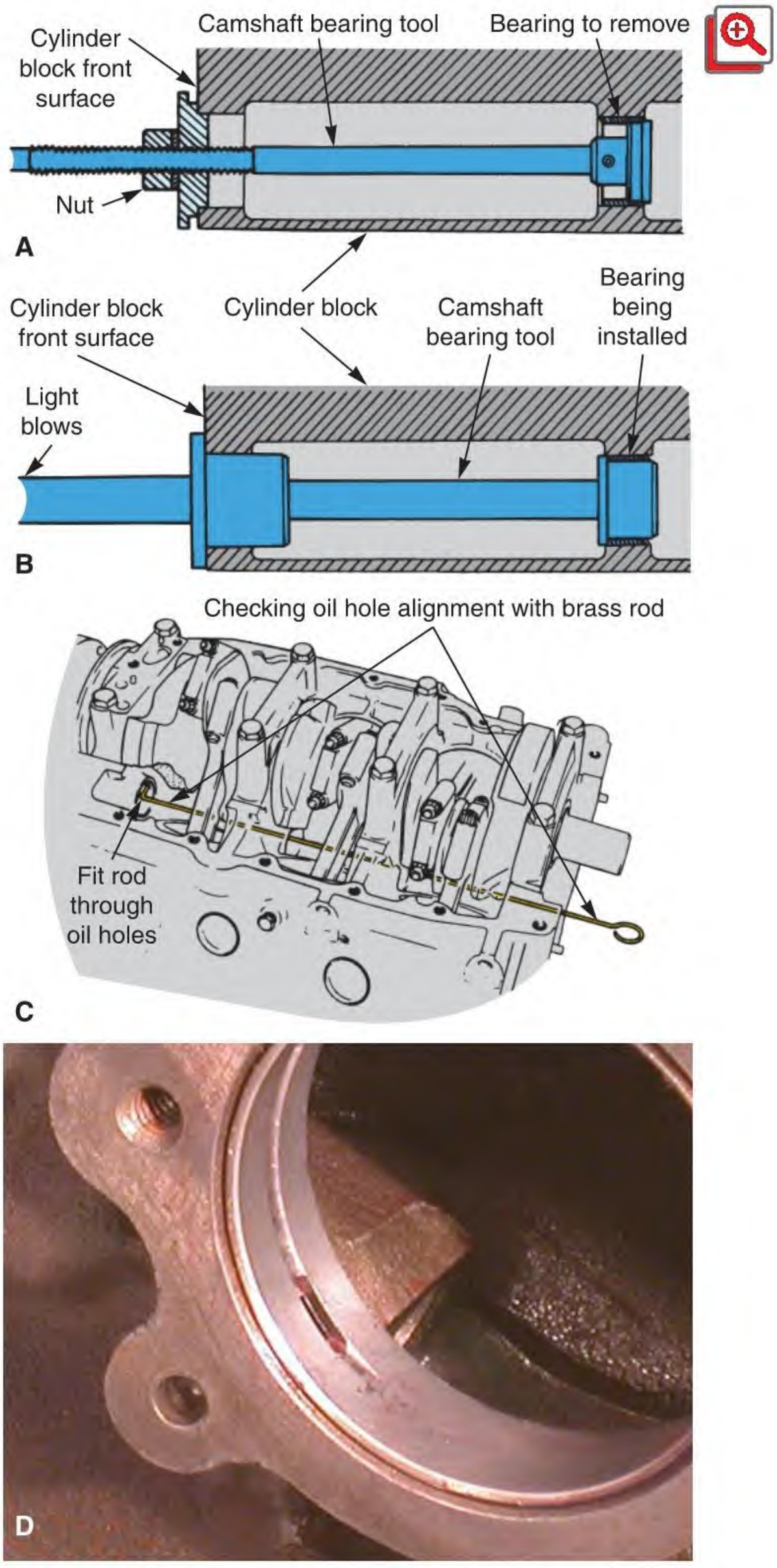
Tech Tip

Some core plugs are threaded. These are often found in high-performance engines. You may need to apply rust penetrant to the plugs and allow it to soak in before removing the plugs.

Crankshaft Service

Crankshaft service involves cleaning the crankshaft, measuring crankshaft journal wear, checking crankshaft straightness, checking for cracks, and proper installation. Quite often, the crankshaft will be in good condition and can be reinstalled without machining.

Crankshaft journals can be worn or damaged in service. In a high-mileage engine, normal wear can cause the journal dimensions to be out of specifications. If a bad oil pump has not been providing normal engine oil pressure or if the customer has not changed the oil at regular intervals, crankshaft journal wear can be high even in a low-mileage engine.



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Figure 57-21. Note how to properly install cam bearings inside a cylinder block. A—The proper driver is being used to pull the old camshaft bearings out of the block. B—The proper driver is being used to push the new camshaft bearings into place. C—Make sure the oil holes in the camshaft bearings align with the oil holes in the block or severe valve train damage can result. D—Here, you can see the oil hole in the bearing aligns with the oil hole in the block.

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Figure 57-22. These core plug openings have been staked so the plugs cannot be forced out by oil or coolant pressure.

Unusually high crankshaft wear can also be caused by operating the engine at high engine speeds or otherwise "abused." Connecting rod or rod bearing failure can also badly damage crankshaft journals.

If you take measurements and find the crankshaft journals are worn or damaged beyond specifications, the crankshaft must be rebuilt or replaced. Crankshaft rebuilding involves welding material to the journals so they are larger than the correct size and then turning (machining) them to fit the rod and main bearing inserts.

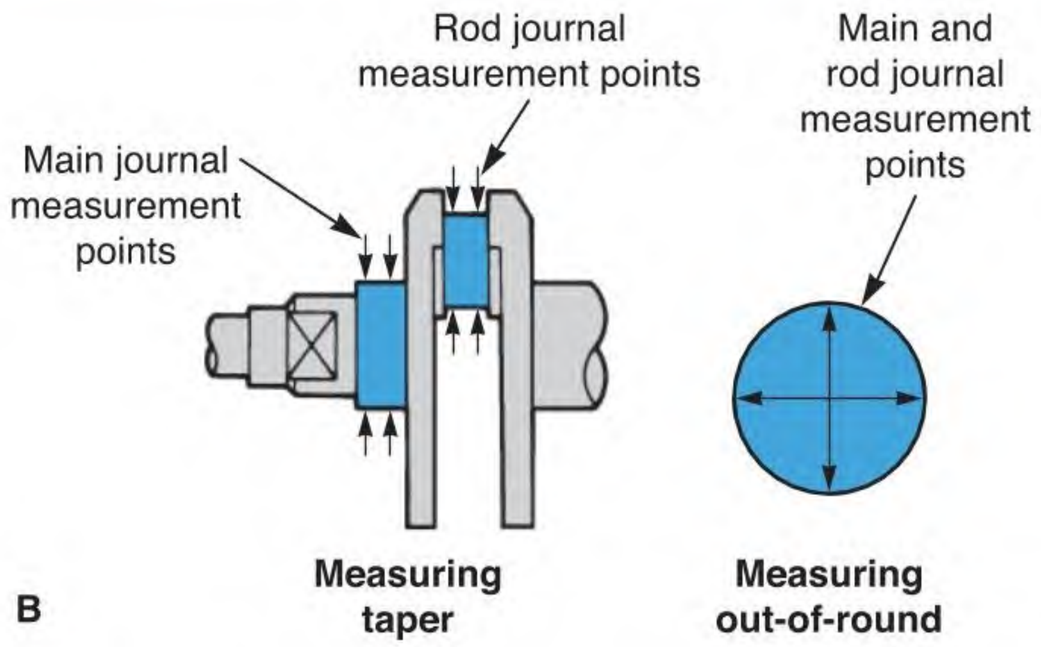
Before inspection, make sure the crankshaft is clean. Use compressed air to blow out all oil passages. Then, look at each connecting rod and main journal surface closely. Look for scratching, scoring, and any signs of wear. The slightest nick or groove is very serious. Fine crocus cloth can be used to polish off minor burrs or marks on journals. Polish around the journal, not across it.

Measuring Journal Taper, Out-of-Round, and Cheek Width

If one end of a crankshaft journal is worn more than the other, the journal is tapered. To measure journal taper, use an outside micrometer. Measure both ends of each journal, **Figure 57-23**. Any difference between the two ends indicates taper. Taper beyond recommended limits must be fixed by having the crankshaft turned.

When you measure for journal taper, also measure journal out-of-round. Out-of-round occurs when the journal is worn unevenly around its circumference.





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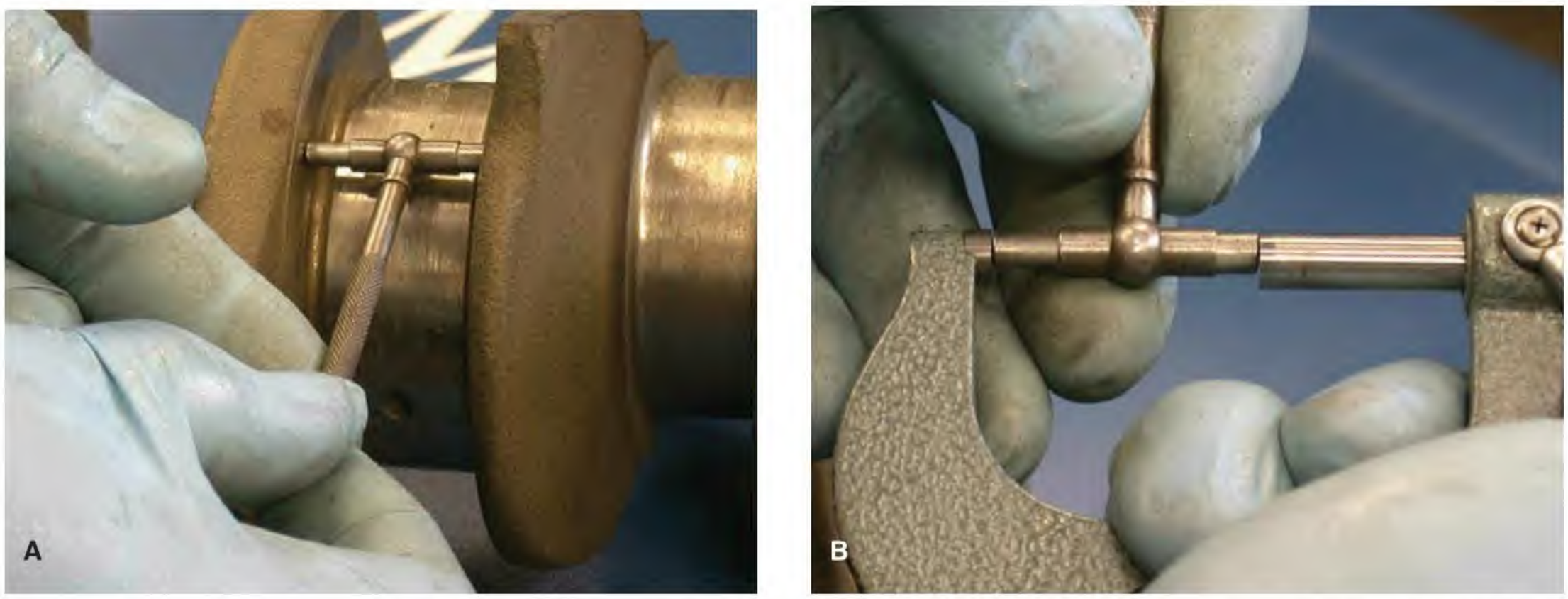
Figure 57-23. Study steps to properly measure crankshaft journal wear. A—Measure every journal to make sure none are worn more than others. B— Measure crankshaft and main journals at these locations. This will check for journal taper and out-of-round.

Measure the journal diameter at two points around its circumference. The difference between the diameters indicates out-of-round. If not within specification limits, send the crankshaft to a machine shop for turning or repair.

Generally, crankshaft journal taper and journal out-of-round must not exceed 0.0005″ to 0.001″ (0.013 mm to 0.025 mm). However, always follow manufacturer specifications. If worn more, you should have the crankshaft turned undersize. Check service manual specifications for the exact make and model engine. Also, check to see what type and size of oversize bearings are available.

Use a telescoping gauge and micrometer to measure the crankshaft cheek width. See **Figure 57-24**.

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Figure 57-24. A—Use a telescoping gauge to measure crankshaft cheek width. B—A micrometer is then used to measure the telescoping gauge. By measuring the crankshaft cheek width and connecting rod width, you can calculate rod side clearance.

Later, after measuring the rod width(s), you can subtract the rod width(s) from the crankshaft cheek width to determine rod side clearance.

Checking for a Cracked Crankshaft

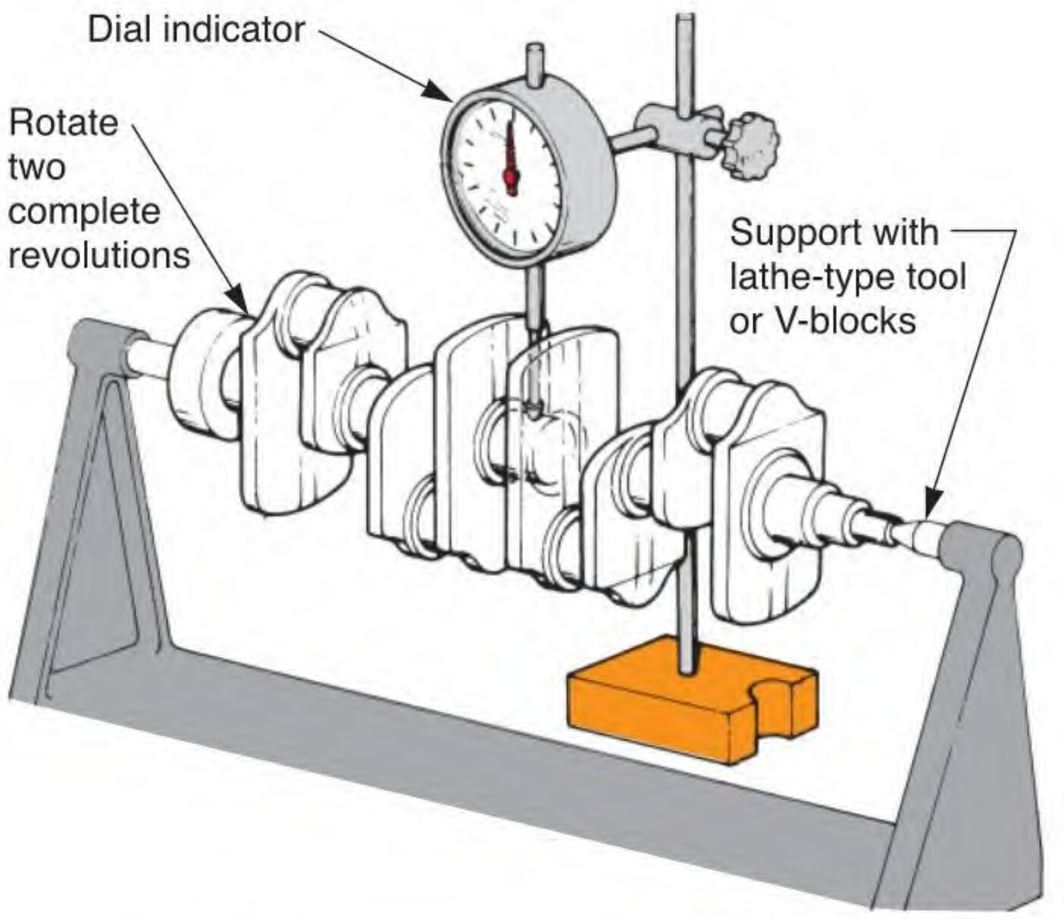
A cracked crankshaft can result from part breakage, vibration damper failure, flywheel failure, or driver abuse. Cracks can be hard to find on a crankshaft because they may be very small. However, if cracks are not located and the crankshaft is reinstalled, it may break during service.

Magnafluxing is used to locate cracks in a crankshaft. This is basically the same as locating cracks in a cast iron cylinder block, as discussed earlier. Sprinkle the metal powder over the crankshaft. The magnetic field will make the powder collect in any crack. Cracks usually form in a crankshaft on the side of the journals. If the crankshaft shows even the smallest crack, replace the crankshaft.

Checking Crankshaft Straightness

A bent crankshaft can ruin new main bearings or cause the engine to lock up when the main caps are tightened. To measure crankshaft straightness, mount the crankshaft on V-blocks or in a lathe, **Figure 57-25**. The crankshaft can also be placed in the block main bearings with all main caps installed except the center main cap. Then, mount a dial indicator against the center main journal.

Slowly turn the crankshaft while watching the indicator. Indicator movement equals the crankshaft runout,



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Figure 57-25. Measure crankshaft runout in a lathe or on V-blocks. Indicator needle movement equals runout, indicating worn or bent crankshaft.

or bend. If runout is not within specification limits, about 0.001″ (0.025 mm), replace the crankshaft or have it straightened and turned by a machine shop.

Crankshaft Turning

Crankshaft turning involves grinding the rod and main journals smaller in diameter to fix journal wear or damage. The worn crankshaft can also be repaired by

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welding additional material onto the journals and then grinding the journals to original specifications. Both of these operations are done by a machine shop.

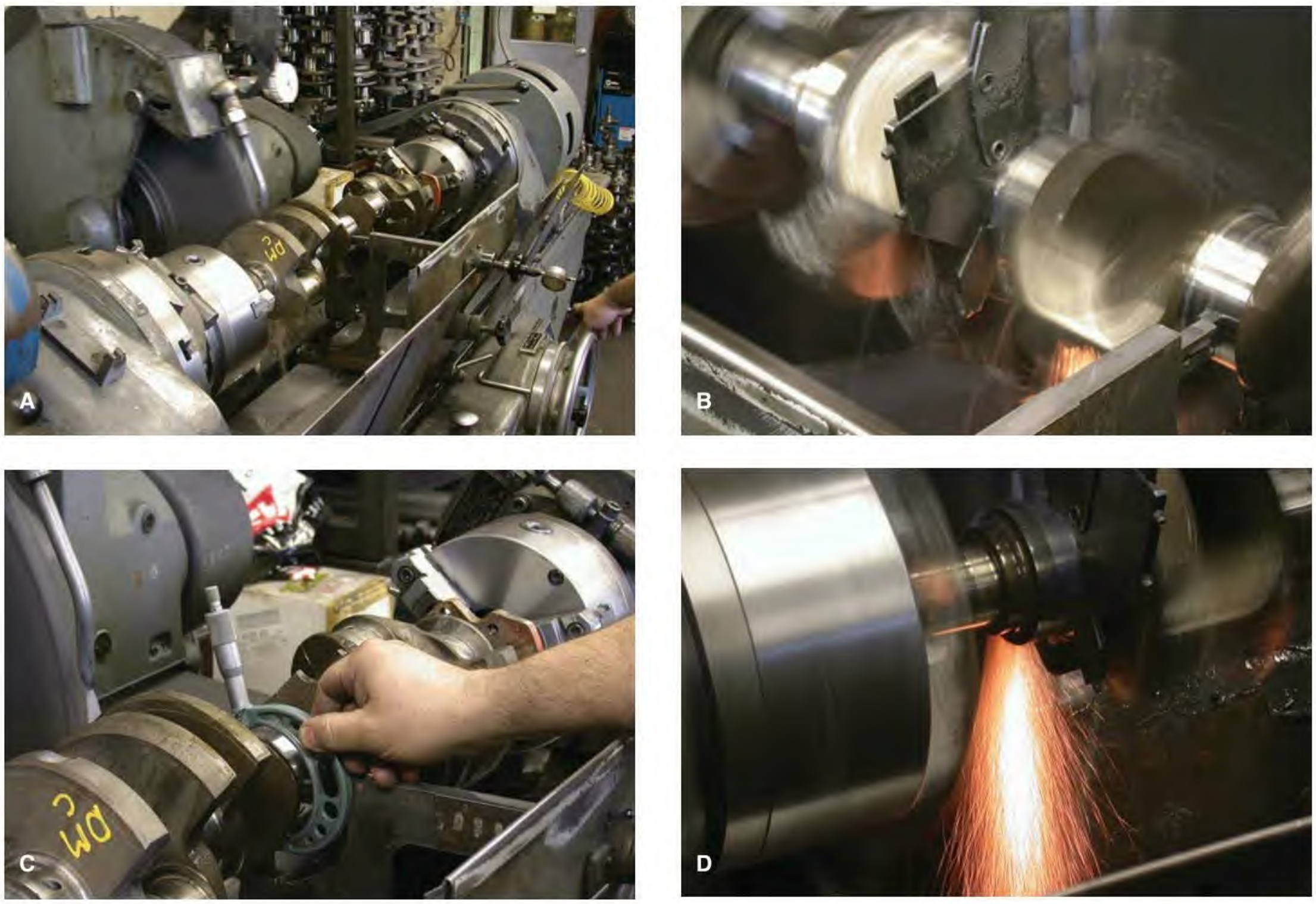
A crankshaft is mounted in a crankshaft grinding machine for turning. This machine has a large-diameter grinding stone that can resurface the crankshaft main and rod journals to precise diameters.

Service Procedure

To machine, or turn, a crankshaft, refer to factory instructions for specific crank grinding machine:

1. Mount the crankshaft so that its centerline aligns with the machine's chucks. Use dial indicators to make sure the crankshaft is centered in the chucks.
2. Engage the machine, which rotates the crankshaft and the grinding wheel.
3. Slowly move the grinding wheel the proper amount into and across each journal.
4. Turn off the machine. Use a micrometer to check the journal diameters.
5. Continue grinding as needed until the crankshaft journal is turned to the correct diameter. See **Figure 57-26**.

Undersize bearings must be used with a crankshaft that has been turned. Since the journals have a smaller diameter, the bearings must be thicker to provide the correct bearing-to-journal fit.



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Figure 57-26. Note the major steps for turning a crankshaft. A—The crankshaft is mounted in the grinding machine. B—The crankshaft spins as the grinding wheel is slowly moved into and across each journal. C—As material is removed, a micrometer is used to check the journal diameter. D—This close-up shows the grinding wheel in action.

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Undersize Bearing Markings

Always look at the old crankshaft bearings to determine whether they are undersize. Undersize bearings may be used on rebuilt engines or even in a few new engines. If the crankshaft is not turned and the connecting rod and main bores are not bored, standard size bearings are used when the crankshaft is reinstalled.

Inspect the back of the old bearings for an undersize number, **Figure 57-27**. The number stamped on the bearing back denotes bearing undersize. For example, .010 stamped on the bearing indicates that the bearing is 0.010″ undersize. A letter code can also be used to give bearing undersize. Do not confuse metric undersize markings with US customary undersize markings.

Some engines that have metric dimensions have letters or bars stamped on the block and crankshaft to denote bearing sizes, **Figure 57-28**. You can use these markings and the service manual chart to find which oversize or undersize bearings are in the engine. If the markings on the block are dirty and cannot be read, clean them with a solvent or detergent. Do not damage the markings with a wire brush, scuff wheel, or scraper or you may not be able to read them.

Cleaning the Crankshaft

The crankshaft must be perfectly clean before installation into the block. This is especially critical if the crankshaft has been ground. Debris such as metal shavings and stone grit may be inside the oil passages. Also, metal bits from failed bearings can collect inside the crankshaft. If not removed, this material can flow out and onto the new bearings during engine operation, where it will act as an abrasive. Bearing damage and failure can result.

Debris can collect inside the hollow crankshaft. The inside of the crankshaft must be cleaned to prevent bearing damage on engine operation. Remove any core or gallery plugs in the crankshaft as shown in **Figure 57-29**.

Wash the crankshaft carefully in solvent. Then, use compressed air to blow out all passages and dry off the journals. Reinstall the core or gallery plugs. Finally, wipe the journals down with an oil-soaked rag.

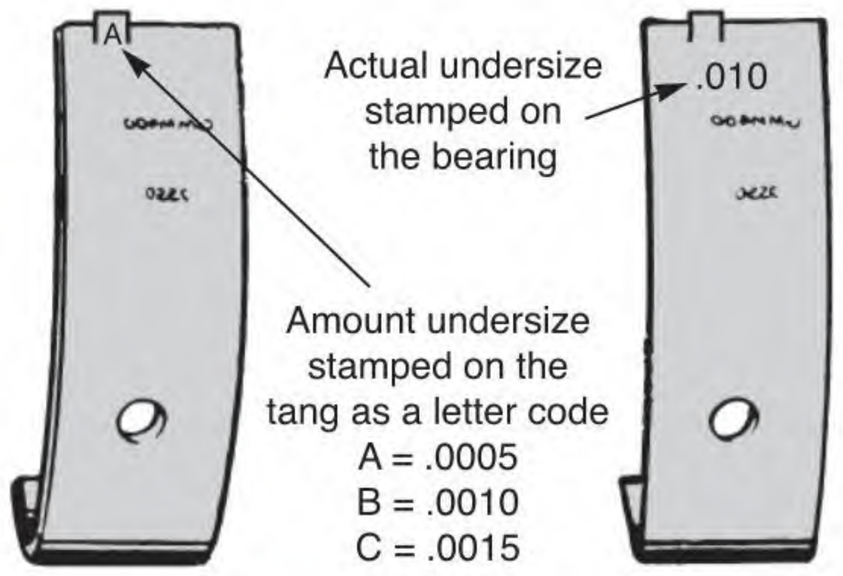
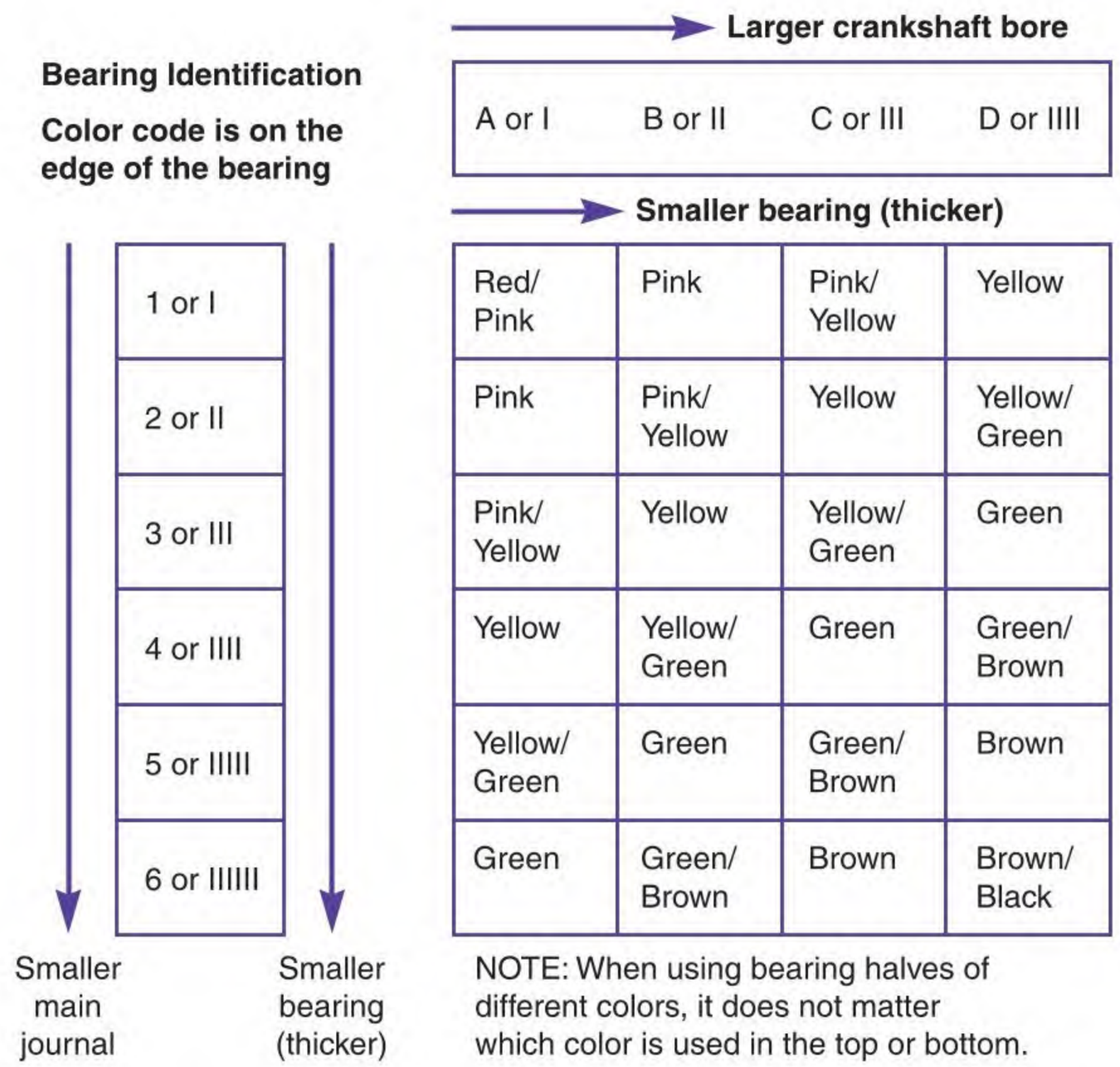


Figure 57-27. Note how undersized bearings are denoted on backs of bearings. A—Bearing undersize is marked on the back of the bearing. B—This close-up shows the bearing undersize marking on the back of a main bearing. This bearing is undersize by 0.020″.

Caution

Freshly overhauled engines have been ruined when technicians failed to remove crankshaft core or gallery plugs and clean the oil passages inside the crankshaft.

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Honda

Figure 57-28. This engine has letters and numbers (or bars) to denote bearing sizes. The crankshaft and cylinder block are both marked.

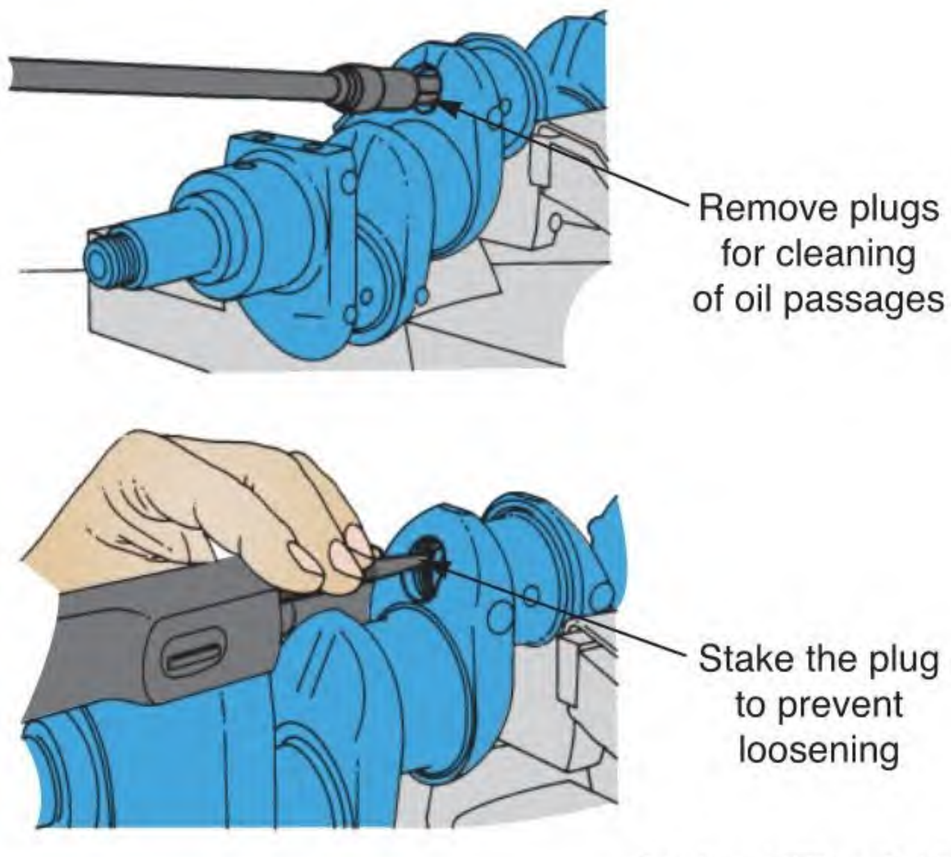
Installing the Rear Main Oil Seal

The ***rear main oil seal*** prevents oil from leaking out of the engine past the crankshaft spinning in the rear main bearing. There are two basic types of rear main oil seals: two-piece synthetic rubber (neoprene) seal and one-piece synthetic rubber seal. Each requires a different installation technique.

Two-Piece Seal

A two-piece neoprene rear seal is very easy to remove and install. Use a small screwdriver to remove the old seal from the cap and block; do not scratch the surfaces. The sealing lip on the rear main seal must

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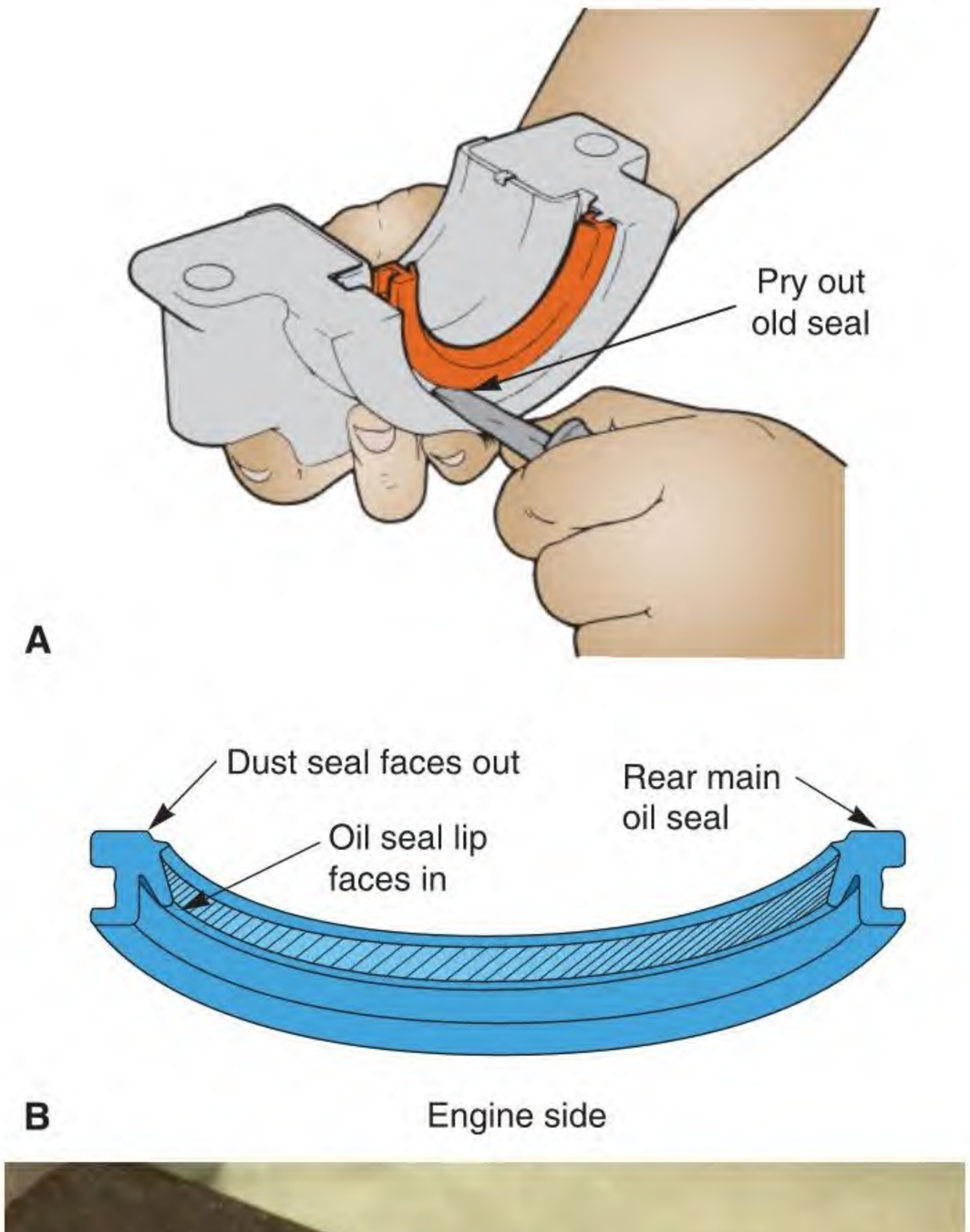
Figure 57-29. After grinding, make sure you remove any plugs and clean the inside of the crankshaft. When installing plugs, stake them in place to prevent them from loosening.

point toward the inside of the engine. Look at the new seal closely to identify the sealing lip and make sure it faces the inside of the block when installed. If installed backward, oil will pour out of the seal when the engine is first started. Lubricate the sealing lip with motor oil, but keep the back of the seal clean and dry. Some manufacturers recommend sealant on the outside of the rear main seals. Finally, press each half of the seal into place in the block and rear main cap. See **Figure 57-30**.

If additional side seals are provided for the cap, follow the instructions with the gasket set. Sealer may be recommended for the main cap side seals.

Tech Tip

Silicone sealer or anaerobic sealer is commonly recommended on the rear main cap to prevent oil leakage. The sealer keeps oil from seeping between the main cap and block mating surfaces. Check the manual to see which type of sealant to use.



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Figure 57-30. Note how to remove and install a two-piece neoprene rear main oil seal. A—Use small screwdriver to pop out the old seal. B—Look at the new seal closely to identify the sealing lip. It must face the inside of the block when installed. C—Once the seal is installed, verify that the sealing lip points to the inside of the engine.

One-Piece Seal

A one-piece neoprene seal is usually removed and installed after the rear main cap has been bolted to the block. Pry out the old seal without scratching the block. Lubricate the inside diameter of the seal with an engine assembly lube. If recommended, coat the outside diameter with an approved sealer.

A special seal-installing tool is required to install a one-piece seal. Use the correct diameter driving tool to force the new seal into position in the block rear

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main bore. See **Figure 57-31**. After installation, make sure the seal is square and undamaged. Also double-check that the seal is properly oriented with the seal lip facing inward.

Tech Tip

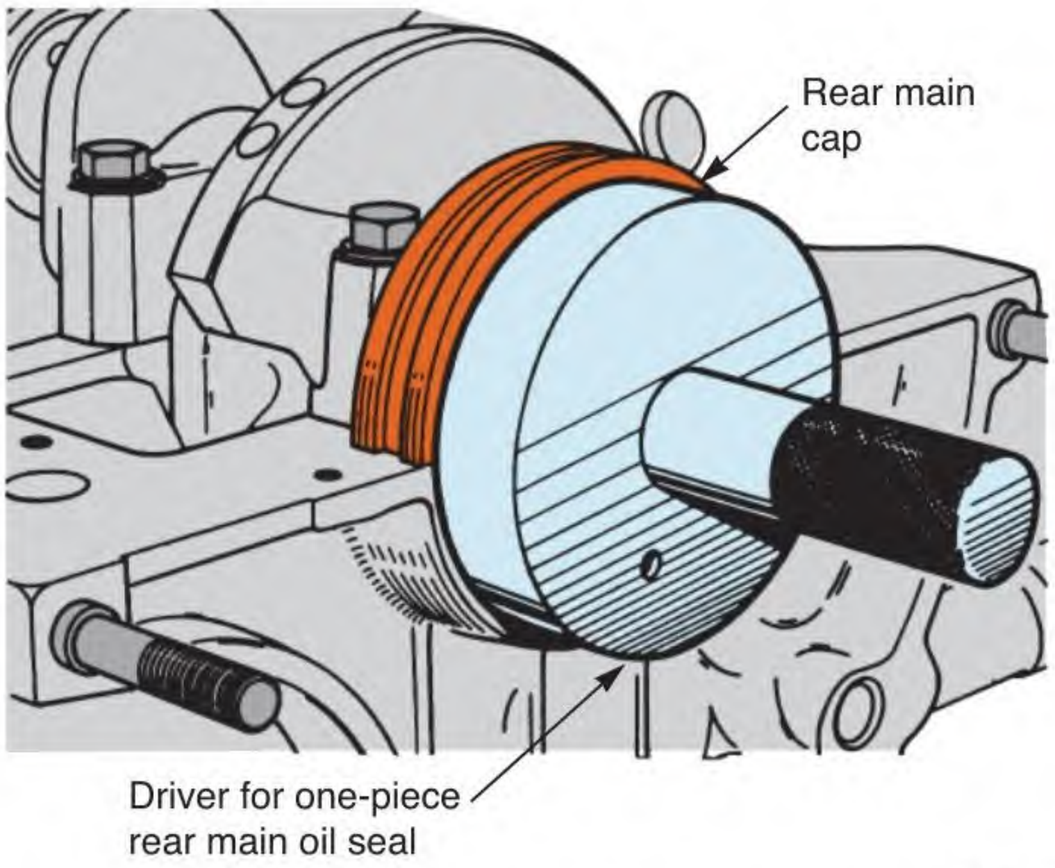
A rope-type seal was used as a rear main seal in the past. New neoprene seals should be installed in place of the rope-type seals.

Main Bearing and Crankshaft Installation

With the block and crankshaft prepped, you are ready to install the main bearings and crankshaft. Make sure you have the correct size main bearings to go with the crankshaft.

Installing the Main Bearings

Before installing the main bearings and crankshaft, carefully clean the cylinder block main bores, main cap mounting surfaces, and crankshaft journals one last time. Use compressed air to blow out the bolt holes, oil holes, and bearing mounting surfaces. Then, using solvent and a clean, dry rag, wipe the main bores free of any dust or oil. Also clean the crankshaft in a similar manner. See **Figure 57-32**.



Renault

Figure 57-31. This one-piece, neoprene rear main oil seal is being installed with a driver. This type of seal is usually installed after the crankshaft is in place. Light hammer blows on the driver are used to push the seal squarely into place.

Service Procedure

To install main bearings in the cylinder block:

1. Verify the bearing sizes marked on the box with that stamped on the back of the bearings.
2. With everything clean and dry, press the new main bearings down into place without touching the front of the bearing inserts, **Figure 57-33**.
3. The top of each bearing half should be almost flush with block on both sides.
4. The bearing tab fits into a notch in the main bore.
5. Make sure the oil holes in the bearings line up with oil holes in the cylinder block.
6. Snap the other bearing halves into the main caps.
7. Check that the main thrust bearing is located properly.

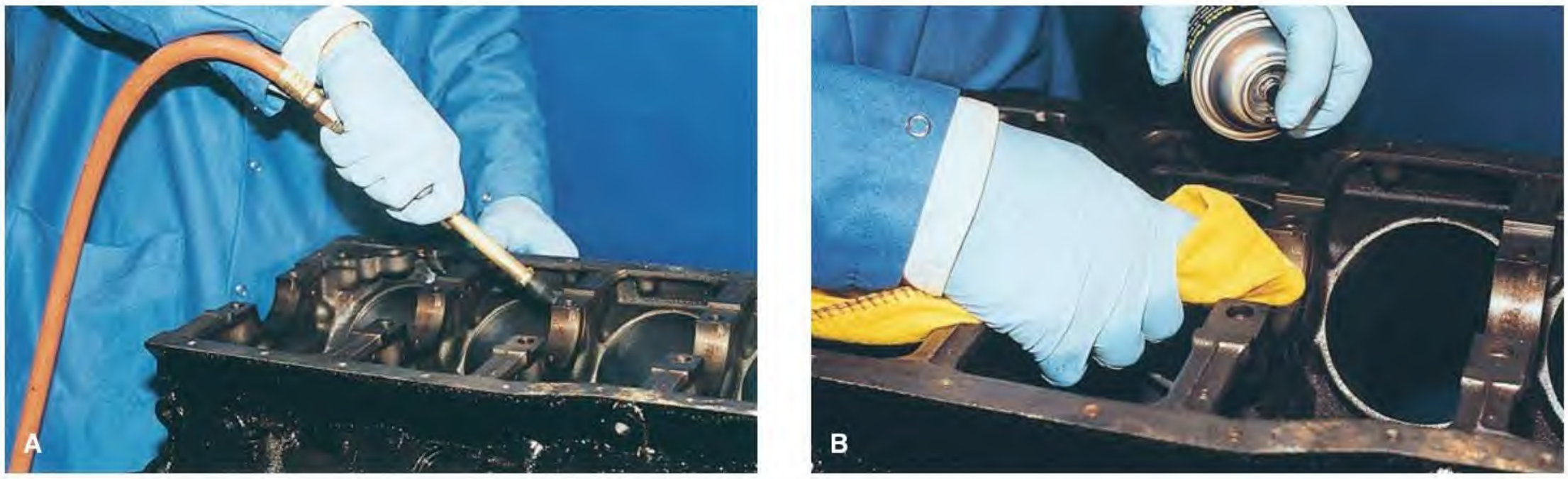
Caution

Never oil the bearing bores or the backs of bearings. This could decrease bearing clearance and make the bearings spin in their bores when the engine is started.

Installing the Crankshaft

With the main bearings and rear main seal installed (two-piece type), coat the bearing faces and rear seal lip with assembly lube, heavy engine oil, or white grease. Spread the lube over the entire surface of the bearing half. Then, carefully lower the crankshaft straight down into the main bearings. Be careful not to damage the bearings or journals by bumping or hitting them. Refer to **Figure 57-34**.

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Figure 57-32. Before installing the main bearings and crankshaft, carefully clean the main bores, main cap mounting surfaces, and crankshaft journals. A—Use compressed air to blow the parts clean. B—Wipe off the main bores with solvent and a clean shop towel. C—Use compressed air to blow out all bolt holes, especially if threads have been chased clean. D—Use a clean shop towel and solvent to wipe the crankshaft journals.



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Figure 57-33. With everything clean and dry, press the new main bearings down into place. The top of each bearing should be almost flush on both sides.

Checking Main Bearing Clearance

Plastigage™ is used to check the oil clearance between the crankshaft journal and main bearing. Place a small bead of Plastigage on the crankshaft. Be careful not to deform the bead.

Install and torque the main bearing cap. Then, remove the main cap. Compare the smashed Plastigage to the paper scale, **Figure 57-35**. If clearance is not correct, check bearing sizes and crankshaft journal measurements.

An average main bearing clearance is 0.001″ to 0.002″ (0.025 mm to 0.05 mm). However, check the service manual for the exact specification. Some technicians only check one main bearing clearance; others check all of the bearing clearances.

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Figure 57-34. Lubricate bearings thoroughly before installing heavy crankshaft on precision bearing inserts. A—Apply bearing assembly lube to all of the main bearing inserts. B—Spread bearing lube over surface of main bearings. C—Slowly lower the crankshaft straight down into the main bearings without damaging the bearings or journals.

Torquing the Main Caps

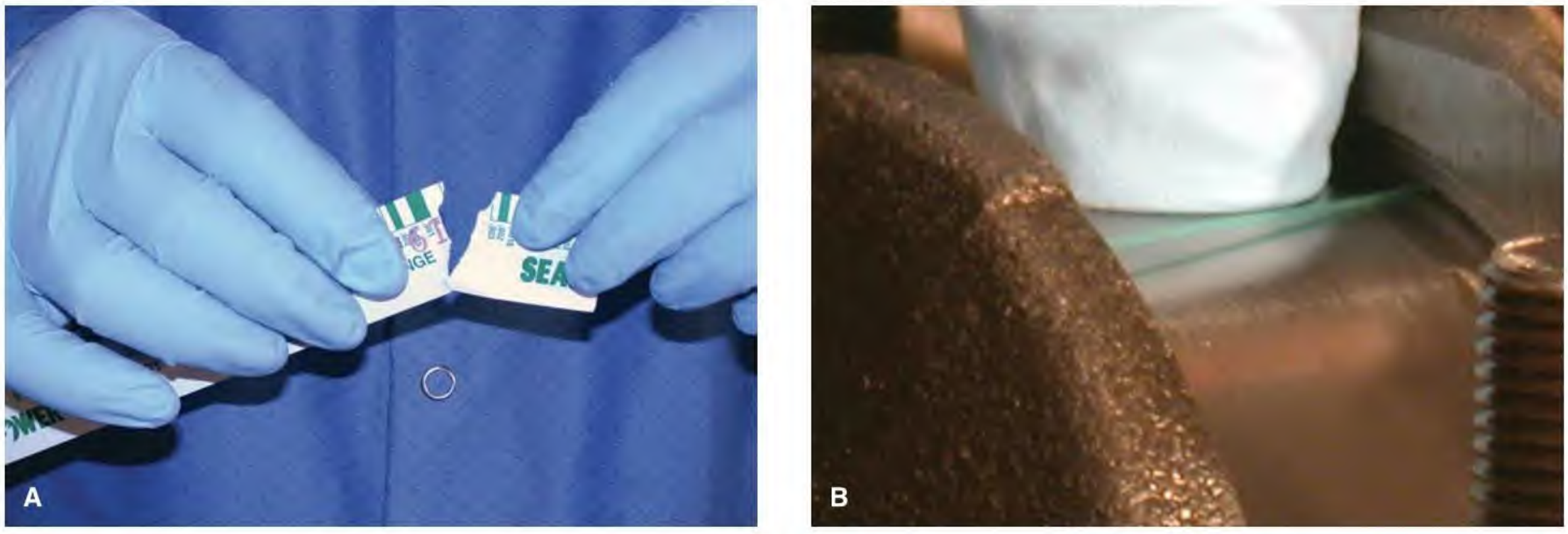
Once main bearing clearance has been verified, the main caps can be installed and torqued to specifications.

Service Procedure

To install and torque the main caps:

1. Coat the face of each bearing insert in the main caps with assembly lube.
2. Place each main cap into the block. Check main cap numbers and arrows to be sure they are positioned correctly. Each cap must be facing the right direction and in its original location. When installing the rear main cap, double-check the rear main oil seal. Make sure the sealing lip is pointing toward the inside of the engine. Remember to place sealer on the rear cap if specified, **Figure 57-36**.
3. Lubricate the bolt threads with the factory-recommended type of lubricant. The viscosity of the thread lubricant can affect bolt torque, **Figure 57-37**. Never squirt oil down into the bolt holes. This may cause hydraulic lock and prevent normal bolt tightening or cause the block to crack.
4. Look up the torque specifications for the main bearing cap bolts in the service manual.
5. Tap on each cap with a soft-faced mallet to make sure they are fully seated into the block.
6. Use a torque wrench to tighten the bolts to about one-half of the full torque. Use an even pull on the wrench. Torque each cap in the sequence recommended in the service manual, **Figure 57-38**. This will pull each cap down squarely.
7. Tighten each bolt to three-fourths of the full torque in the manufacturer's recommended sequence.
8. Tighten each bolt to the full torque in the proper sequence. Repeat the torque sequence at full torque at least one more time to ensure proper torque.
9. After torquing all the main cap bolts, make sure the crankshaft will turn freely. Install the front snout bolt and turn the crankshaft by hand with a wrench or breaker bar. See **Figure 57-39**. If the crankshaft does not rotate easily, something is wrong. Remove the main caps and check the bearing sizes, look for debris in the bearings, and verify measurements and clearances.

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Figure 57-35. Plastigage is used to accurately measure clearance of installed engine bearings. A—Tear off short piece of the Plastigage; it is inside the paper wrapper. Be careful not to squeeze the Plastigage inside the wrapper. B—Remove the Plastigage from the paper and place it across the crankshaft journal. C—Install and torque the cap and bearing down onto the Plastigage. D—Remove the cap and compare the paper scale with the width of the crushed Plastigage.

Torque-to-Yield

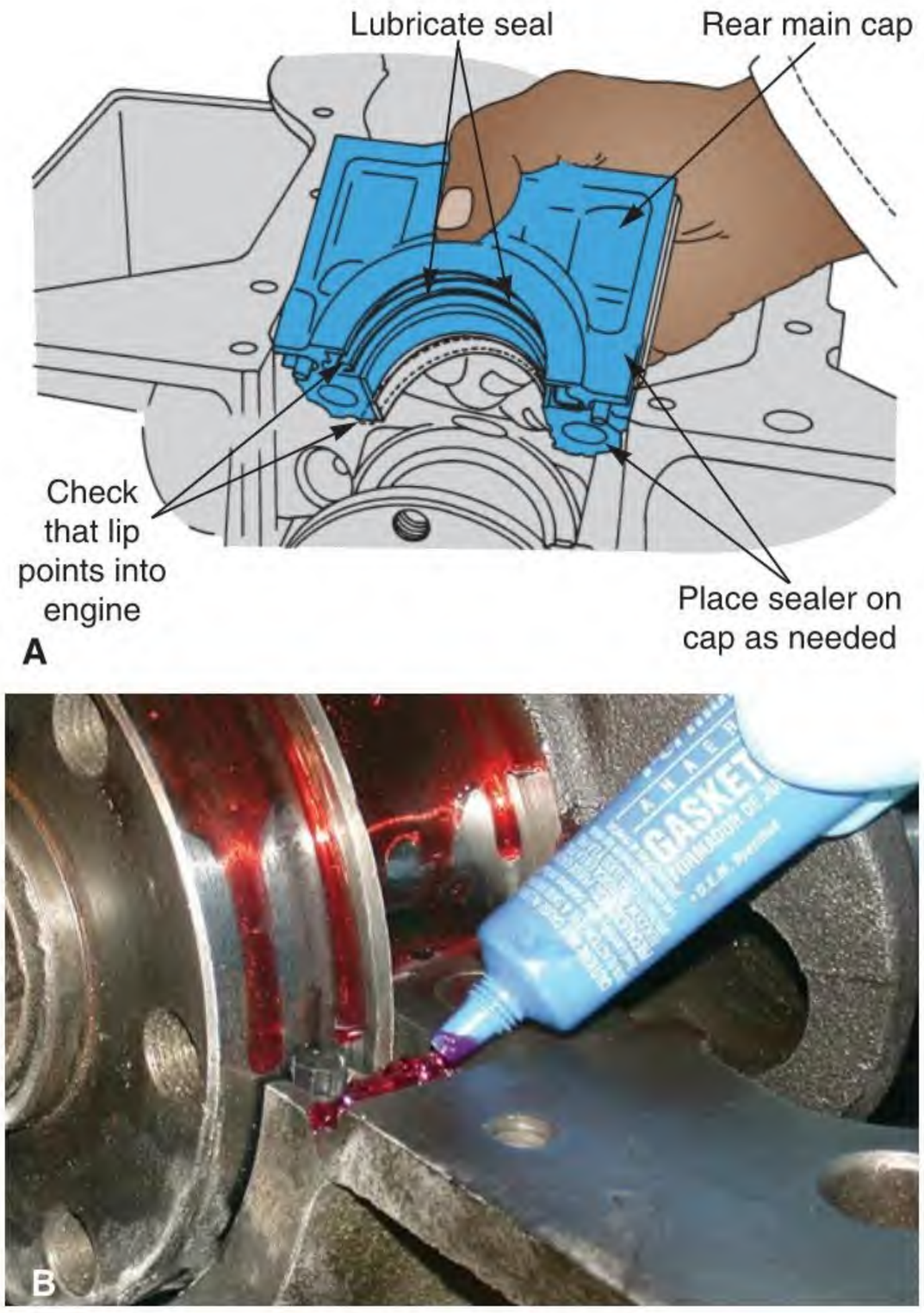
Most late-model engines have ***torque-to-yield specifications***. To properly tighten bolts with a torque-to-yield specification, first tighten each bolt to a specified torque. For tightening main caps, use the procedure described in the previous section. Then, you must turn the bolt a specified number of degrees beyond the torque point. This stretches and preloads the fastener.

A dial gauge, or degree wheel, is installed between the socket and wrench to measure the number of degrees. The small arm on the degree tool must be placed against the cap or other stationary part. Then, you must zero the degree gauge by turning the dial to read zero. Finally, turn the bolt an additional number of degrees. Use the torque sequence or pattern specified in the service manual. See **Figure 57-40**.

Checking Crankshaft Endplay

Crankshaft endplay is the amount of front-to-rear movement of the crankshaft in the block. It is controlled by the clearance between the main thrust bearing and the crankshaft cheeks, thrust surface, or journal width.

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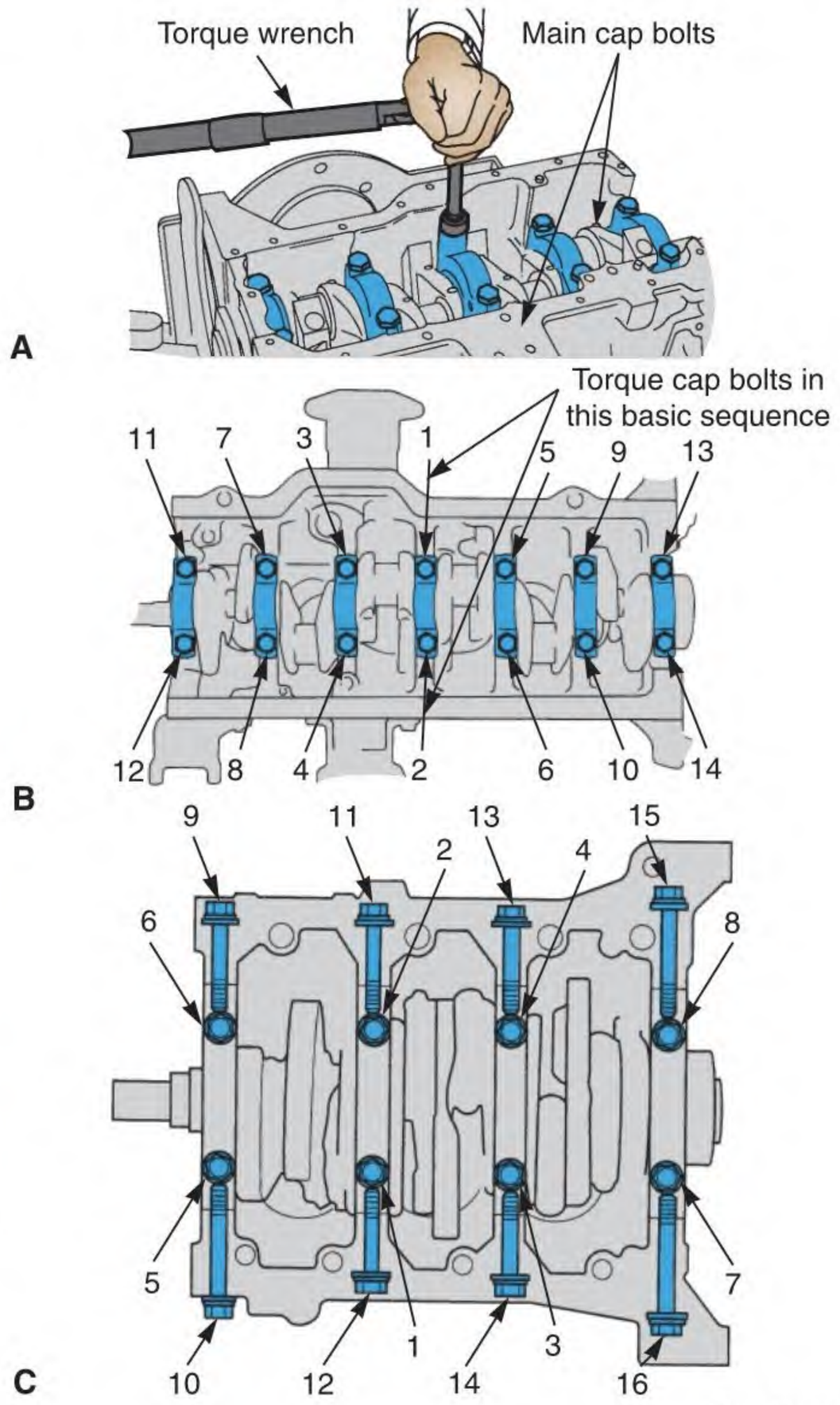
Peugeot

Figure 57-36. To avoid rear main oil seal leaks, follow engine manufacturer instructions. A—When installing the rear main cap, double-check that the rear main oil seal is installed in the correct orientation. B—With a two-piece rear oil seal, you must apply sealer to the ends of the rear main seal to avoid oil leakage out of the main cap-to-block mating surfaces.



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Figure 57-37. Before installing main bearing bolts, lubricate the bolt threads with the factory-recommended lubricant.



Ford; Honda

Figure 57-38. Note proper sequence and torque values for tightening main cap bolts. A—Torque each bolt a little at a time up to the full torque specification. B—Torque each cap in sequence as shown in the service manual. C—Note the torque sequence recommended for this engine with cross-bolt main caps.



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Figure 57-39. After torquing all of the main caps, make sure the crankshaft turns freely.

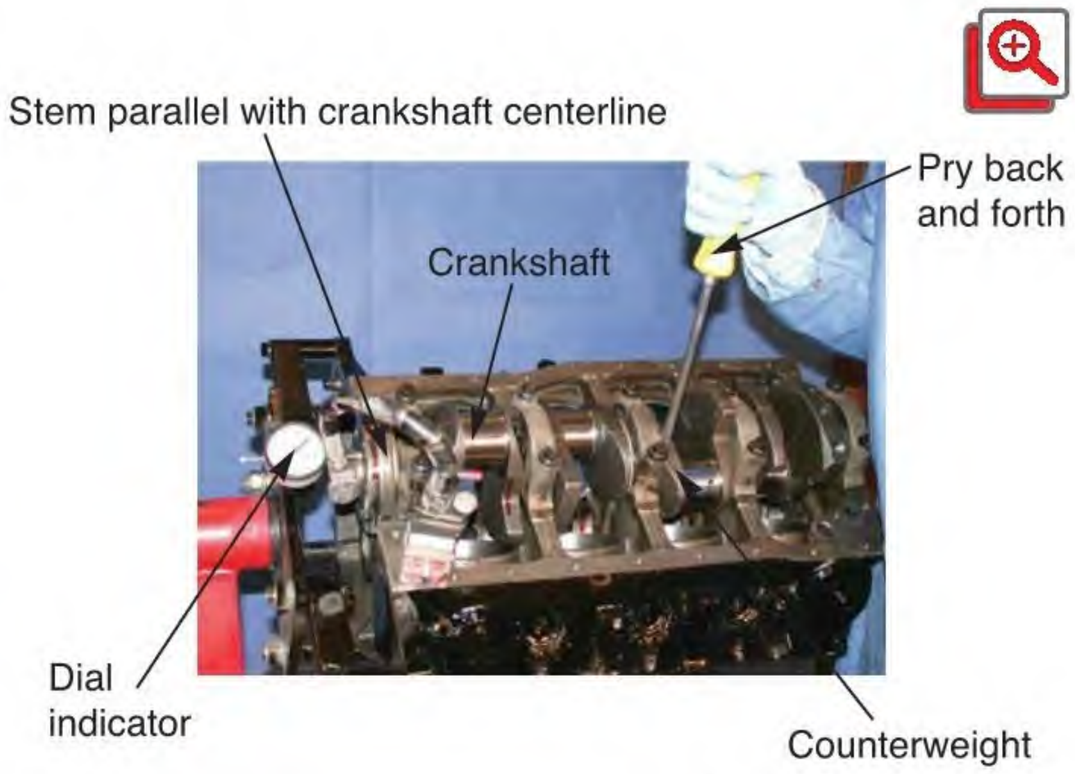
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Figure 57-40. Study how to correctly tighten torque-to-yield fasteners. A—First, torque the main cap bolts to factory specifications. Use the recommended torque sequence. B—Next, install the degree wheel onto the wrench. Position the stop against a stationary part and zero the degree wheel. Tighten the bolt the specified number of additional degrees.



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Figure 57-41. When measuring crankshaft endplay, make sure the indicator plunger stem is parallel to the crankshaft centerline. Then pry back and forth on a crankshaft counterweight while reading the indicator.

If not within specifications, usually about 0.006″ (0.15 mm), check the main thrust bearing and the width of the crankshaft journal thrust surfaces. You may have the wrong main thrust bearing or the crankshaft thrust surface may have been incorrectly machined.

Replacing the Pilot Bearing

Service Procedure

If the vehicle has a manual transmission or transaxle, you should replace the pilot bearing in the rear of the crankshaft when rebuilding an engine. This bearing supports the end of the transmission input shaft. If worn, clutch and transmission problems can develop.

1. To remove the pilot bearing, fill the cavity in the crankshaft and pilot bearing with heavy grease.
2. Use an old input shaft or driver of the correct diameter to drive out the old pilot bearing. As the driver is forced into the grease, the grease will transfer the force to the back of the pilot bearing. This pushes the bearing out of the crankshaft.
3. Select the proper driver to install the new pilot bearing, as shown in **Figure 57-42**.

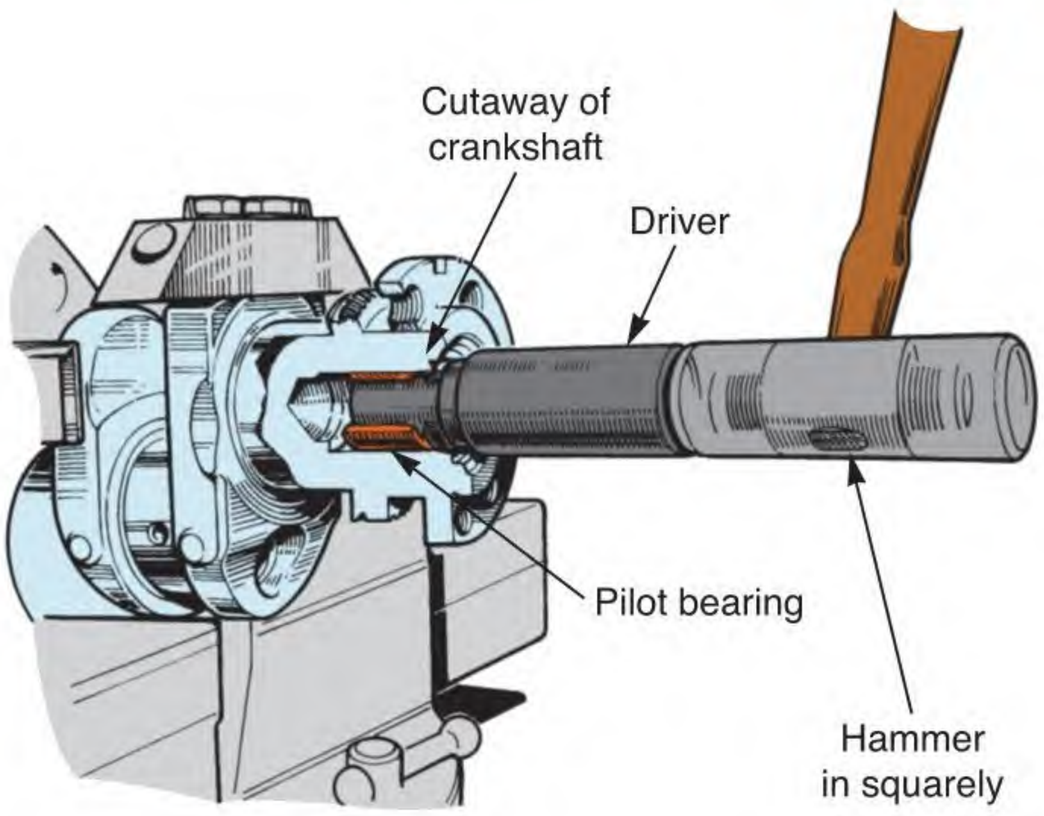
Service Procedure

To measure crankshaft and main thrust bearing clearance:

1. Mount a dial indicator on the block. Position the dial indicator against the crankshaft so that the indicator stem is parallel with the crankshaft centerline. Zero the indicator.
2. Pry back and forth on a counterweight with a small pry bar. See **Figure 57-41**.
3. The maximum movement of the indicator needle is the crankshaft endplay.
4. Compare your measurements to specifications.

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4. Drive the pilot squarely into the crankshaft. Be careful not to damage the inside diameter of the bearing.
5. After the pilot bearing is installed, place a small amount of grease inside the cavity.



Renault

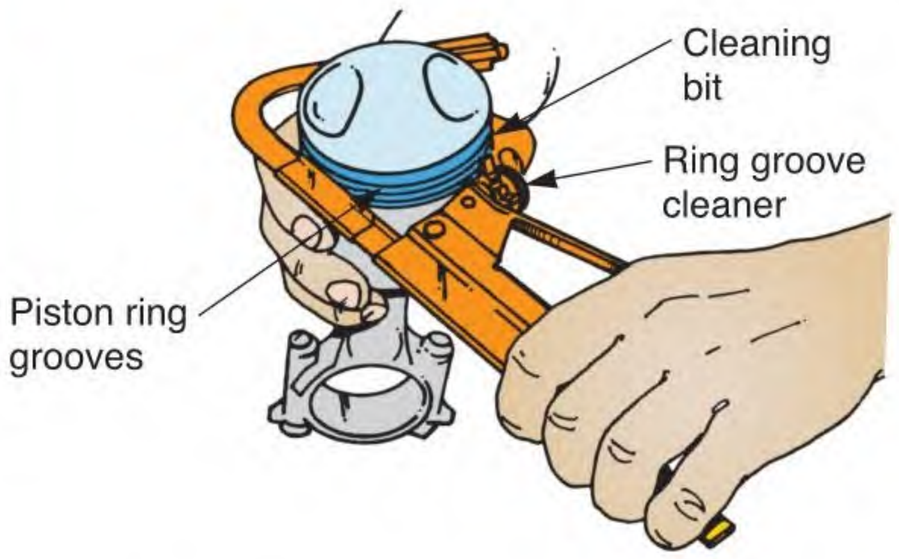
Figure 57-42. Installing a new pilot bearing. A metal driver will allow you to drive in the new crankshaft pilot bearing until it is fully seated.

Piston Service

Pistons are primarily made of aluminum, which is very prone to wear and damage. It is very critical that each piston be thoroughly checked. Look for cracked or collapsed skirts, worn ring grooves, cracked ring lands, pin bore wear, or other problems. You must find any trouble that could affect piston performance and engine service life. Discard any damaged or badly worn pistons.

Cleaning Piston Ring Grooves

Use a ring groove cleaner to remove any carbon deposits from the piston grooves. All hard deposits must be removed from inside the piston ring grooves. If not removed, the carbon deposits could force the new rings out against the cylinder walls when the piston heats up and expands. This could score the rings and cylinder walls. It could also cause enough friction to heat the rings enough so they melt and weld to the cylinder wall, causing the engine to seize (lock up). See **Figure 57-43**.

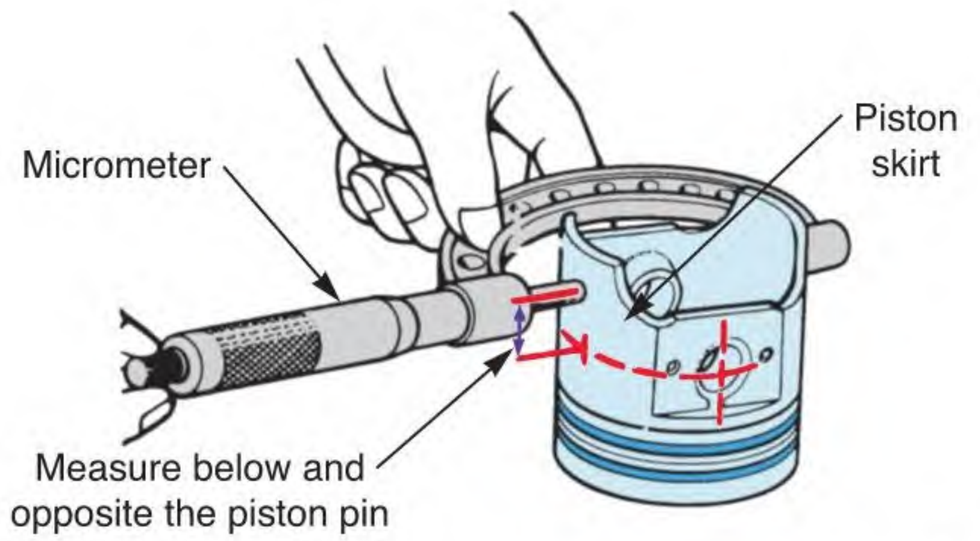


Lisle Tools

Figure 57-43. Always use a ring groove cleaner to scrape carbon from the piston grooves. If the grooves are not cleaned, new rings can be forced out against the cylinder wall, scoring the rings and the cylinder walls as soon as the engine starts.

Measuring Piston Wear

Piston wear is the amount of decrease in the piston diameter due to friction. Piston size (diameter) is usually measured on the skirts, just below the piston pin hole. Study **Figure 57-44**.



Toyota

Figure 57-44. Piston wear is usually measured on the piston skirt just below the piston pin.

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Service Procedure

To measure piston wear:

1. Measure perpendicular to the piston pin. A large outside micrometer is used to measure the piston diameter.
2. Adjust the micrometer for a slight drag as it is pulled over the piston.
3. Subtract the reading from the specification for piston diameter to find the piston wear.
4. If the wear is more than that allowed by specifications, usually 0.005″ (0.13 mm), replace or knurl the piston(s).
5. Most engine manufacturers specify that measurements are to be made just below the piston pin, perpendicular to the pin. However, some engine manufacturers require measurement even (aligned) with the pin hole. Other manufacturers require measurement lower on the skirt.
6. If you measure in the wrong location, your piston diameter reading will be inaccurate. If in doubt, check the service manual for directions on properly measuring piston wear.

Measuring Piston Clearance

Piston clearance is the distance between the side of the piston and the cylinder wall. To find piston clearance, subtract the piston diameter measurement from the cylinder diameter measurement. The difference is the piston clearance. Piston clearance is usually 0.001″ to 0.003″ (0.025 mm to 0.08 mm). Since specifications vary, always refer to the service manual.

Another way of measuring piston clearance is with a feeler gauge strip. A long, flat feeler gauge strip is placed on the piston skirt. Then, the gauge and piston are pushed into a cylinder. A spring scale is used to pull the feeler gauge strip out of the cylinder. When the spring scale reading equals specifications, the size of the feeler gauge equals piston clearance.

When piston-to-cylinder clearance is excessive, it must be corrected. This can be done by one of the following methods.

- Install a new standard size piston, providing cylinder is not worn beyond specifications.
- Bore all of the cylinders and purchase oversize pistons.
- Sleeve the cylinder.
- Knurl the piston.

Measuring Piston Ring Gap

Piston ring gap is the clearance between the ends of a ring when it is installed in the cylinder. This gap is very important. If the gap is too small, the ring could lock up or score the cylinder when it heats up and expands. If the ring gap is too large, ring tension against the cylinder wall may be low, causing oil blowby.

Service Procedure

To measure piston ring gap:

1. Compress a compression ring and place it in a cylinder (not installed on a piston).
2. Push the ring to the bottom of normal ring travel with the head of a piston. This will square the ring in the cylinder and locate it at the smallest cylinder diameter, **Figure 57-45A**.
3. Measure the ring gap with a flat feeler gauge. See **Figure 57-45B**.
4. Compare your measurement to specifications.

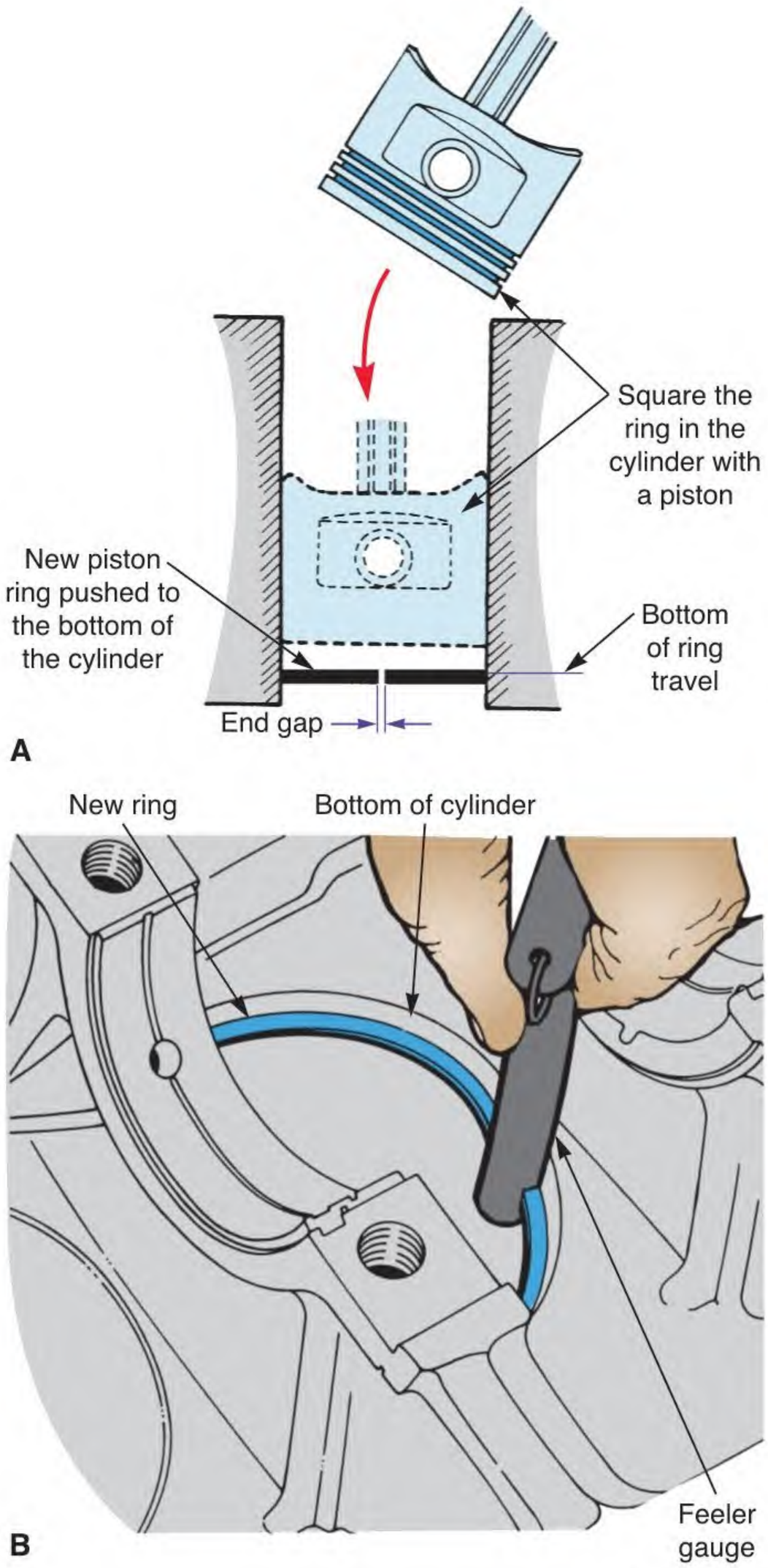
If not correct, usually between 0.010″ to 0.020″ (0.25 mm to 0.50 mm), you may have the wrong piston ring set or the cylinder dimensions may be off.

Some manufacturers allow ring filing to increase the piston ring gap. ***Ring filing*** involves using a special, thin grinding wheel to remove metal from the ends of a ring. However, some manufacturers do not allow this practice. Check the service manual before filing a ring.

Checking Ring Groove Depth

To check ***ring groove depth***, fit a new compression ring into the piston groove, as shown in **Figure 57-46**. Make sure the ring will fit below the surface of the piston. This helps ensure you have the correct ring set. If the ring groove is not deep enough, the rings may be forced out against the cylinder walls when the piston heats up and expands. Part damage could result.

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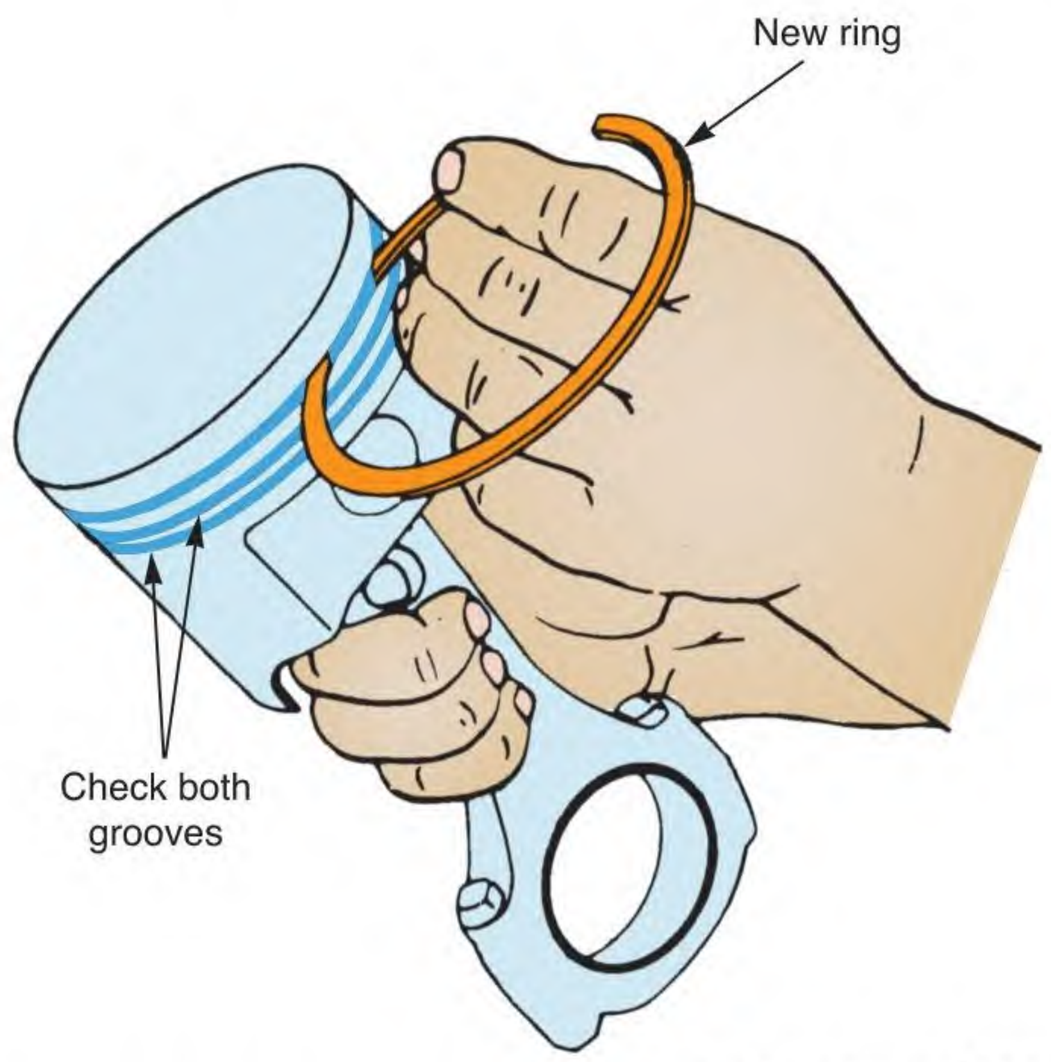


Toyota, Chrysler

Figure 57-45. This is how you properly measure piston ring gap in a cylinder. A—Use a piston to push the new ring to the bottom of the ring travel in the cylinder. B—Use a feeler gauge to check ring gap.

Piston Pin Service

Depending on the type and make of engine, the piston pin may either be free floating or press fit. A ***free-floating piston pin*** will turn in both the rod and piston. A ***press-fit piston pin*** is force fitted into either the rod or piston. Other setups have been manufactured, but are not common.



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Figure 57-46. To check ring groove depth, install the ring into the groove and make sure the ring goes below the surface of the piston.

Piston Pin Clearance

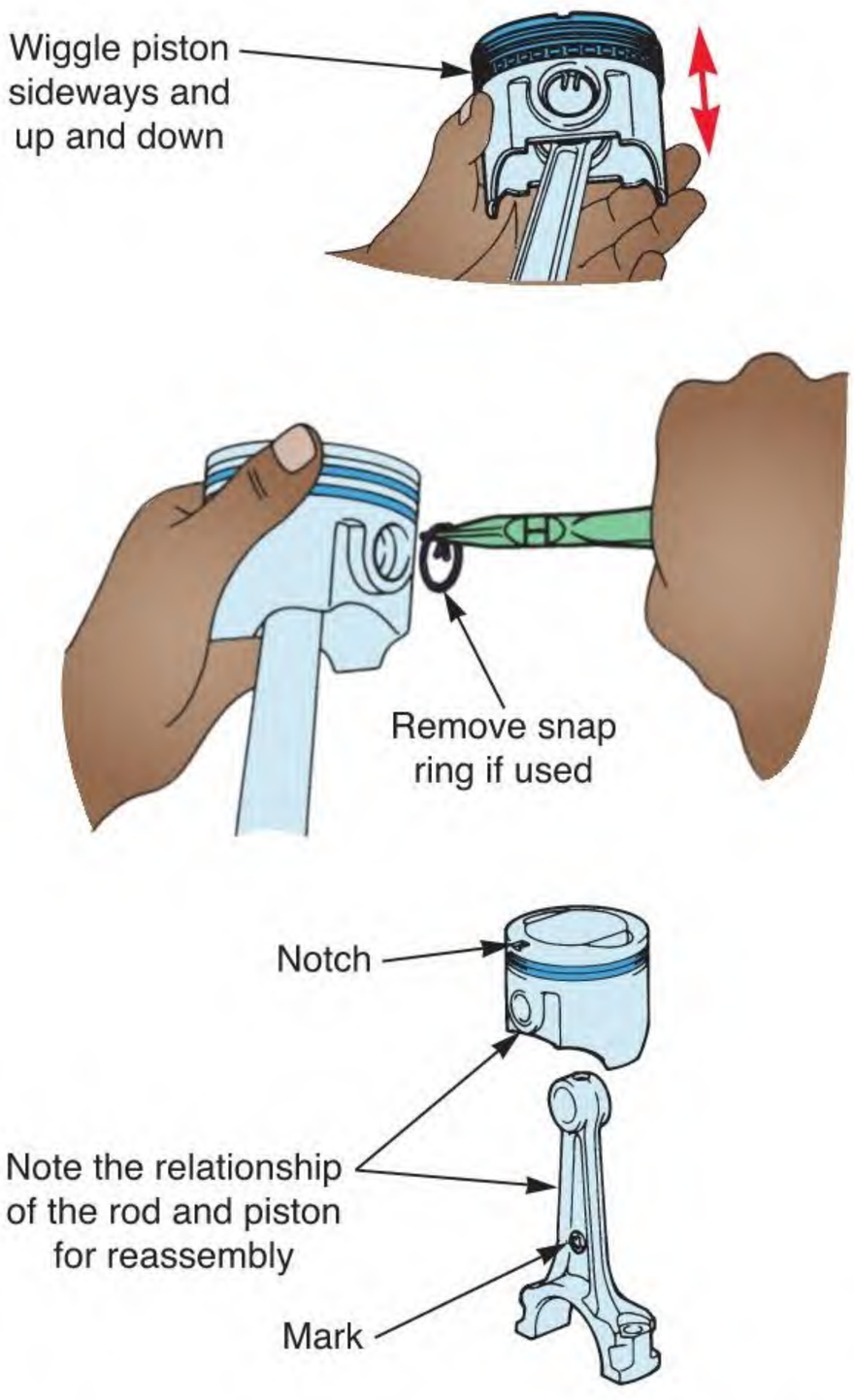
During piston and rod service, check the pin clearance on both free-floating and press-fit pins. To check for excessive piston pin clearance, lightly clamp the connecting rod I-beam in a vise. Use vise caps to protect the rod. Try to move the piston up and down and sideways against normal pin movement, **Figure 57-47A**.

If play can be detected, the pin, rod bushing, or piston pin bore is worn. After the pin is removed, a small telescoping gauge and outside micrometer should be used to measure the piston pin bore and piston pin. Then, you can determine exact part wear and clearances.

Free-Floating Pin Service

To remove a free-floating piston pin from the piston, use snap ring pliers to compress and lift out the snap rings on each end of the pin, **Figure 57-47B**. Then, push the pin out of the piston by hand. A brass drift and light hammer blows may be needed. Make sure the piston and rod are marked and kept organized, **Figure 57-47C**.

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Toyota

Figure 57-47. Study basic piston pin service. A—Checking for a loose piston pin. B—Removing a free-floating piston pin. C—Make note of how the piston is installed on the rod.

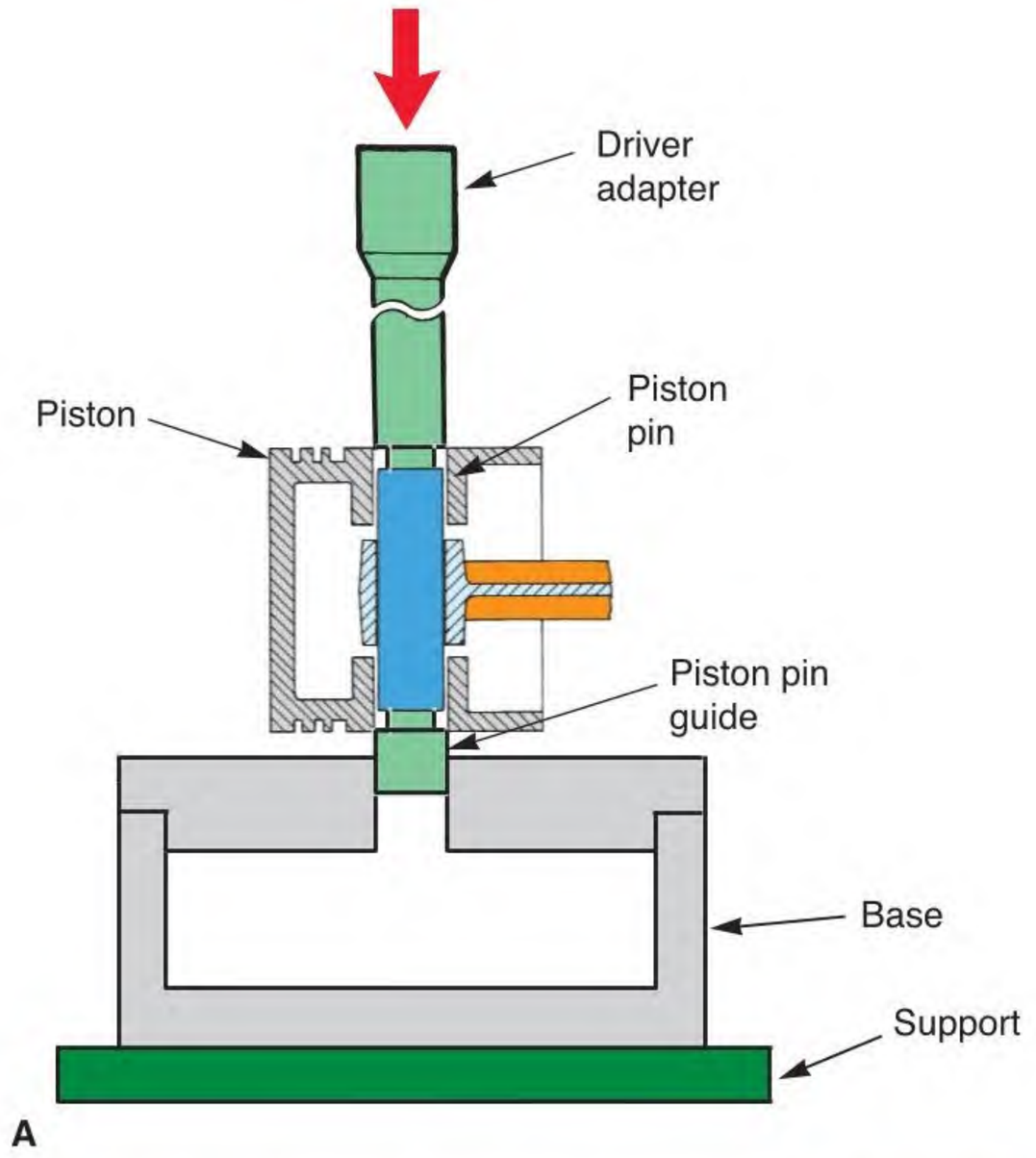
To reassemble, insert the connecting rod into the piston. Make sure the piston is facing in the right direction in relation to the connecting rod. Normally, a piston will have some form of marking on its head indicating the front of the engine. The connecting rod may have one edge of the big end bore chamfered. This faces the outside of the journal on V-type engines. The rod may also have an oil spray hole or rod numbers that must face in only one direction. If needed, check the vehicle's shop manual for directions.

After the rod and piston are assembled in the correct orientation, insert the piston pin. Then, install the snap rings to secure the pin. Double-check that the snap rings are fully seated in their grooves.

Pressed-In Pin Service

A hydraulic press is normally used to remove a pressed-in piston pin from the piston and rod, as shown in **Figure 57-48**. Mount the piston in a proper holding fixture to avoid part damage. Select a driver that is slightly smaller than piston pin bore. With the piston assembly mounted and the driver installed, slowly lower the ram onto the piston assembly. The piston pin should slide out of the rod and piston bore.

You can use a hydraulic press in a similar manner to reassemble the pin. You can also use heat to fit the





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Figure 57-48. A hydraulic press is normally used to remove a pressed-in piston pin. A—This cutaway shows how a holding fixture and hydraulic press are used to drive out a pressed-in piston pin. B—This technician is removing a pressed-in piston pin.

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pin in the piston. Basically, the rod small end is heated to make the pin bore slightly larger. Then, the cool pin can be easily inserted. Before inserting the pin, make sure the rod and piston are assembled in the correct orientation, as described in the previous section.

Figure 57-49 shows how to use an electric rod heater to properly assemble a pressed-in piston pin. Turn on the electric heating element and allow it to warm up. Place the rod small end into the heating element. Allow enough time to heat the rod and enlarge the pin bore. Then, remove the rod from the heater, insert it into the piston, and quickly push the piston pin through the piston and rod. Use the small hand-operated driver to push the piston pin into the piston and rod. The rod must be centered on the pin before it cools. When the rod cools and shrinks, it will lock the pin in place. This, in effect, creates a press fit.

Warning

When using a hydraulic press, wear eye protection and make sure the piston is mounted properly. Also, when using a rod heater, take the necessary precautions to avoid burns.

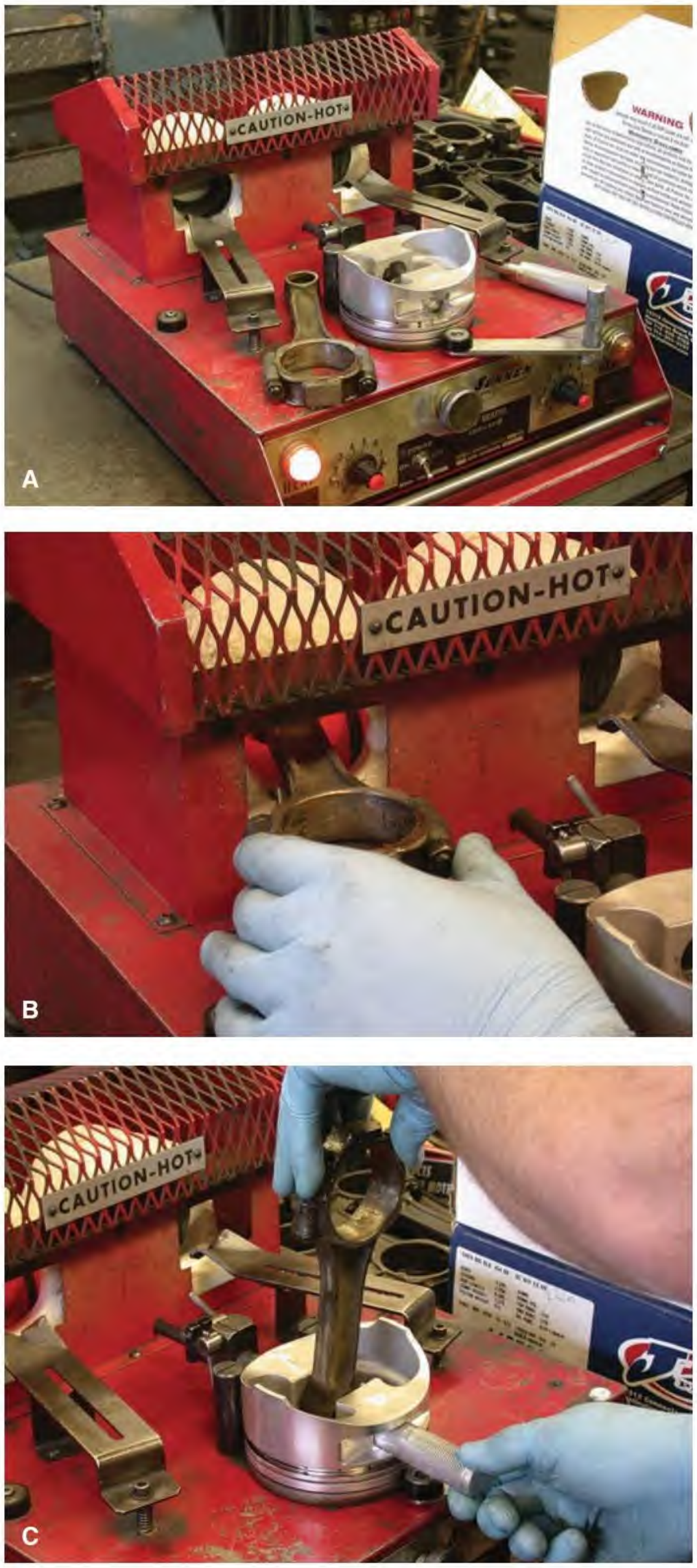
Measuring Piston Pin Wear and Clearance

To determine piston pin wear, measure the diameter of the pin with an outside micrometer. Measure in the middle and at both ends of the pin (floating types only). Look at **Figure 57-50**. Then, compare the diameter to specifications. The difference between the measured diameter and the specification is the amount of wear. If worn too much, replace the piston pins.

To find piston pin clearance with a floating pin, you must measure the diameter of the pin bore in the piston, **Figure 57-51**. By subtracting pin diameter from piston pin hole diameter, you can calculate piston pin clearance.

A typical piston pin clearance is only 0.0001″ to 0.0003″ (0.003 mm to 0.008 mm). This specification is in ten-thousandths of an inch, not thousandths (thousandths of a millimeter, not hundredths). Keep this in mind while calculating piston pin wear, piston bore wear, and rod small end wear; measure accurately.

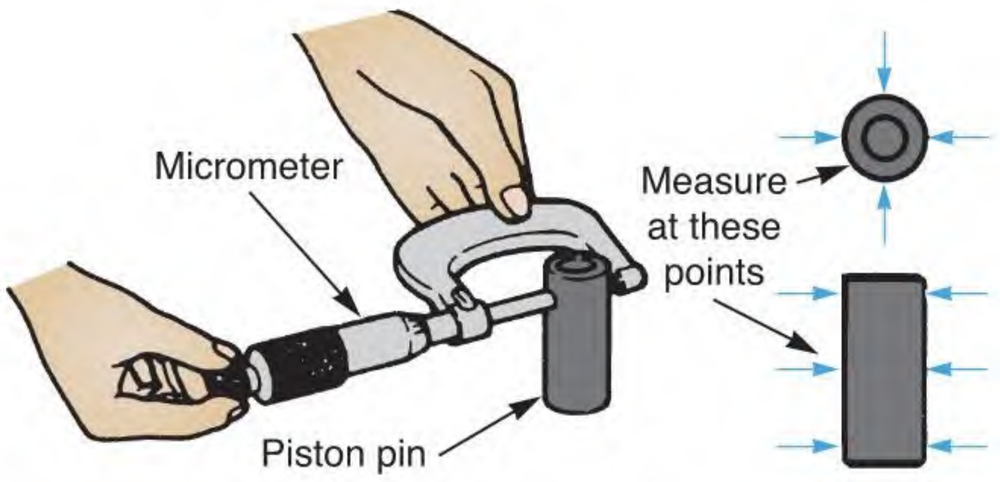
When the pin is worn, it should be replaced. If the pin bore is larger than specifications, replace the



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Figure 57-49. Study the major steps for using a rod heater to press fit a piston pin. A—Turn on the heating element and allow it to warm up. B—Place the rod small end into the heating element. C—When the rod small end is heated enough, fit it into the piston and use the hand-operated driver to push the piston pin into the piston and rod.

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Figure 57-50. Measure the piston pin in the locations shown to determine wear.



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Figure 57-51. Use a telescoping gauge and micrometer to measure the diameter of the piston pin bore. Then, subtract the piston pin diameter from the bore diameter to calculate piston pin clearance.

piston or rod. The pin bore may also be reamed larger. Oversize piston pins can then be used. Pin bore reaming is usually done by a machine shop.

Tech Tip

Oversize piston pins may be available (0.0015″ to 0.003″ or metric oversize). They can be used in reamed pistons and rods to correct wear.

Connecting Rod Service

Connecting rods are subjected to tremendous force during engine operation. As a result, they can wear, bend, or even break. The old piston and bearing inserts will indicate the condition of the connecting rod. If any piston or bearing wear abnormalities are found, there may be a problem with the connecting rod.

For example, if one side of a bearing is worn, that connecting rod may be bent. If the back of a bearing insert has marks on it, that rod big end may be distorted, allowing the bearing insert to shift inside the rod.

Rod Small End Service

Measure the rod small end with a telescoping gauge and a micrometer, **Figure 57-52A**. Make at least two measurements at 90° to each other. Then, compare the measurement to specifications. If worn beyond specifications, have a machine shop replace the rod bushing, **Figures 57-52B** and **57-52C**. After installation, the bushing must be reamed so the pin is fitted in the rod for proper clearance.

Rod Big End Service

To check the connecting rod big end for problems, remove the bearing inserts and bolt the rod cap to the rod. Torque the fastener to specifications without bending or damaging the rod. Then, use a telescoping gauge and micrometer to measure the rod bore diameter, **Figure 57-53**. Take two measurements on each edge at 90° to each other.

The difference in diameter between bore edges is rod big end taper. Any difference in the cross diameters on a single edge is rod big end out-of-round. If taper or out-of-round are greater than specifications, have a machine shop rebuild the rod or purchase a new rod.

Checking Rod Straightness

To determine if a rod is bent, a special rod alignment fixture is needed. See **Figure 57-54**. It can be used to check whether the rod small end and big end are perfectly parallel. Use the operating instructions provided with the particular fixture or send the rods to a machine shop. Replace any bent rods.

Rebuilding Connecting Rods

Connecting rods can be rebuilt by most machine shops. This should be done when inspection or measurement shows major problems. Sometimes, only one rod needs to be rebuilt, as when a bearing spins and damages

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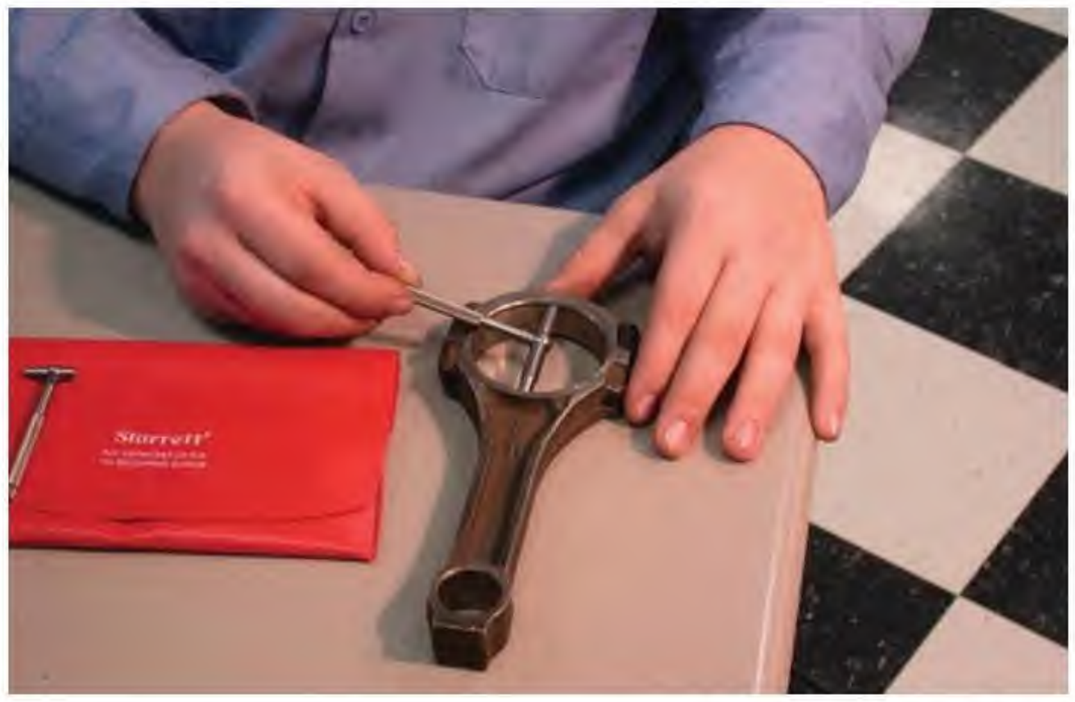


Toyota

Figure 57-52. Note basic rod small end service. A—Use a telescoping gauge and micrometer to measure the rod small end diameter, which can be used to calculate wear. B—Using a press to push out the old bushing. C—When driving in the new bushing, make sure any oil holes align.

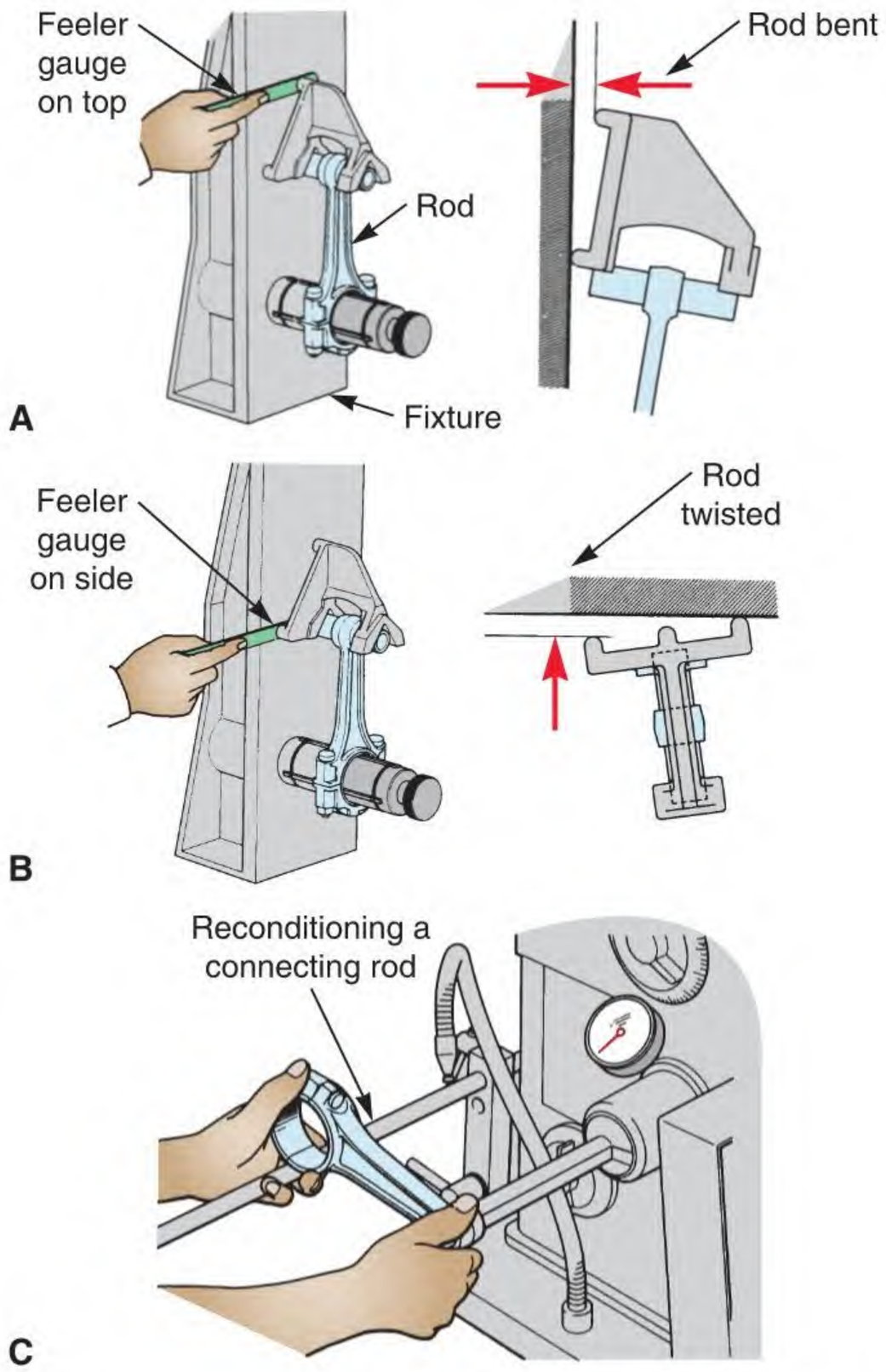
the rod big end bore. In a high-mileage engine, all of the connecting rods may require rebuilding. The following operations are done when a connecting rod is rebuilt.

- Machine the big end bore diameter to specifications.
- Replace the small end bushing.
- Check rod bore alignment and re-machine rod to straighten it.
- Install new connecting rod bolts, if needed.



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Figure 57-53. Use a telescoping gauge and micrometer to measure the diameter of the rod big end bore.



Toyota

Figure 57-54. Note use of a special rod alignment fixture. A—Checking for a bent rod. B—Checking for rod twist. C—Honing the rod small end bore.

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Installing Piston Rings

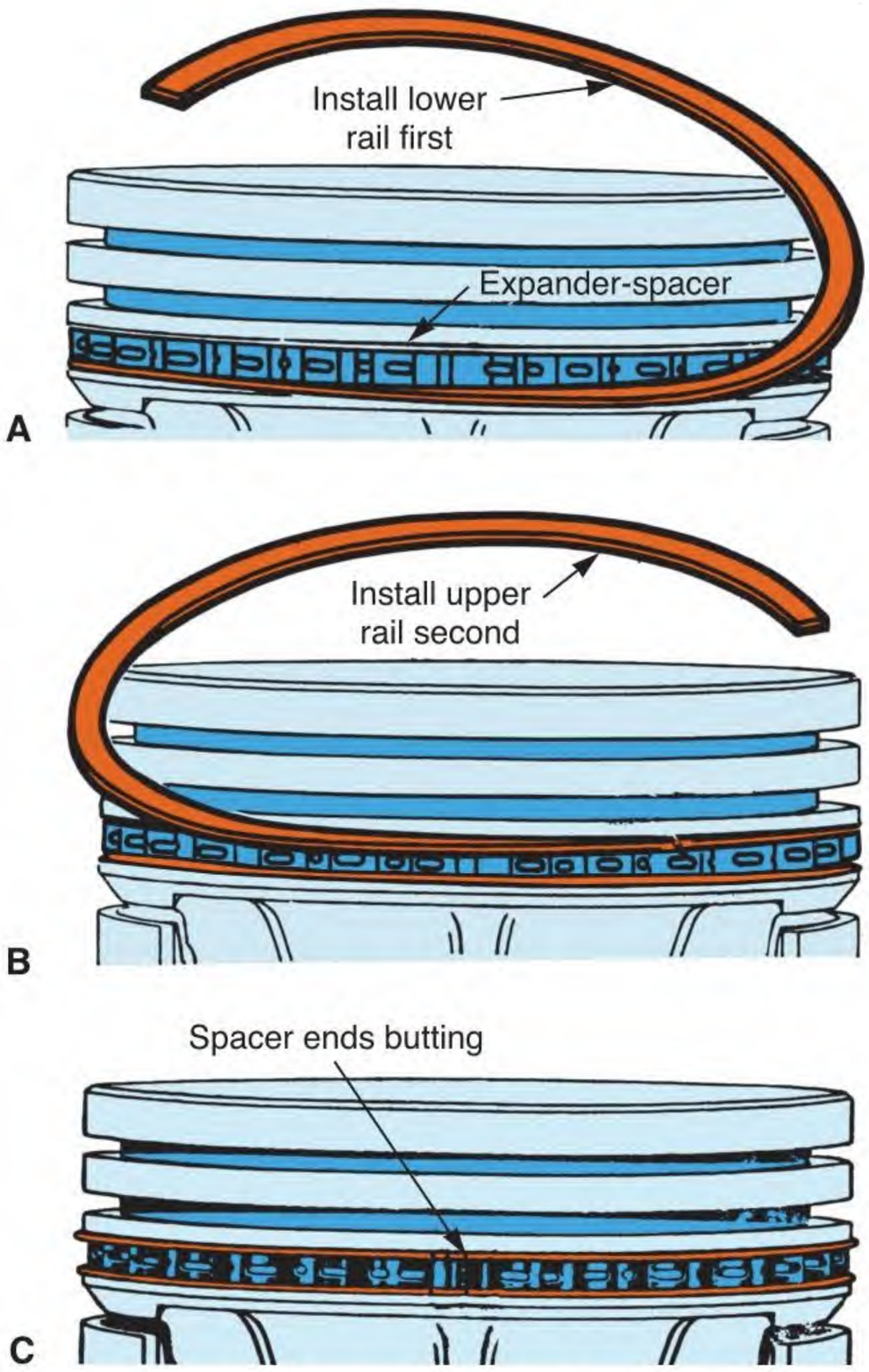
With the cylinders, pistons, and connecting rods all in proper working condition and the piston, rod, and piston pin assembled, you are ready to install the new piston rings on the pistons. Make sure you checked ring gap in the block as explained earlier.

Installing Oil Rings

Service Procedure

Install the steel oil ring first, which consists of two rails and one expander-spacer. To hold the piston, lightly clamp the rod in a vise. Use wooden blocks or brass or lead vise caps to prevent rod damage. The bottom of the piston should touch the top of the vise to keep the piston from swiveling.

1. Wrap the expander-spacer around its groove. Butt the ends together.
2. Insert one end of one oil ring rail in the groove under the expander-spacer.
3. In a spiral manner, carefully work the ring into the groove around the piston, **Figure 57-55**.
4. Insert one end of the second oil ring rail in the ring groove above the expander-spacer.
5. Work the ring into the groove by feeding it down into the spacer and piston ring groove.
6. Double-check that the expander-spacer is not overlapped. Its ends must butt together.
7. Make sure the oil ring assembly will rotate on the piston. There should be a moderate drag as the oil ring assembly is turned.
8. Rotate one of the oil ring rails so that its ring gap is almost aligned with the end of the piston pin. Rotate the other rail so that its gap is at the opposite end of the pin. If the oil ring gaps align, oil can blow through the gaps.



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Figure 57-55. Study how to properly install the oil ring onto the piston. A—Install the expander-spacer; make sure the ends are butted. Then, install the lower rail. B—Install the top rail. C—Double-check that expander-spacer ends are not overlapped.

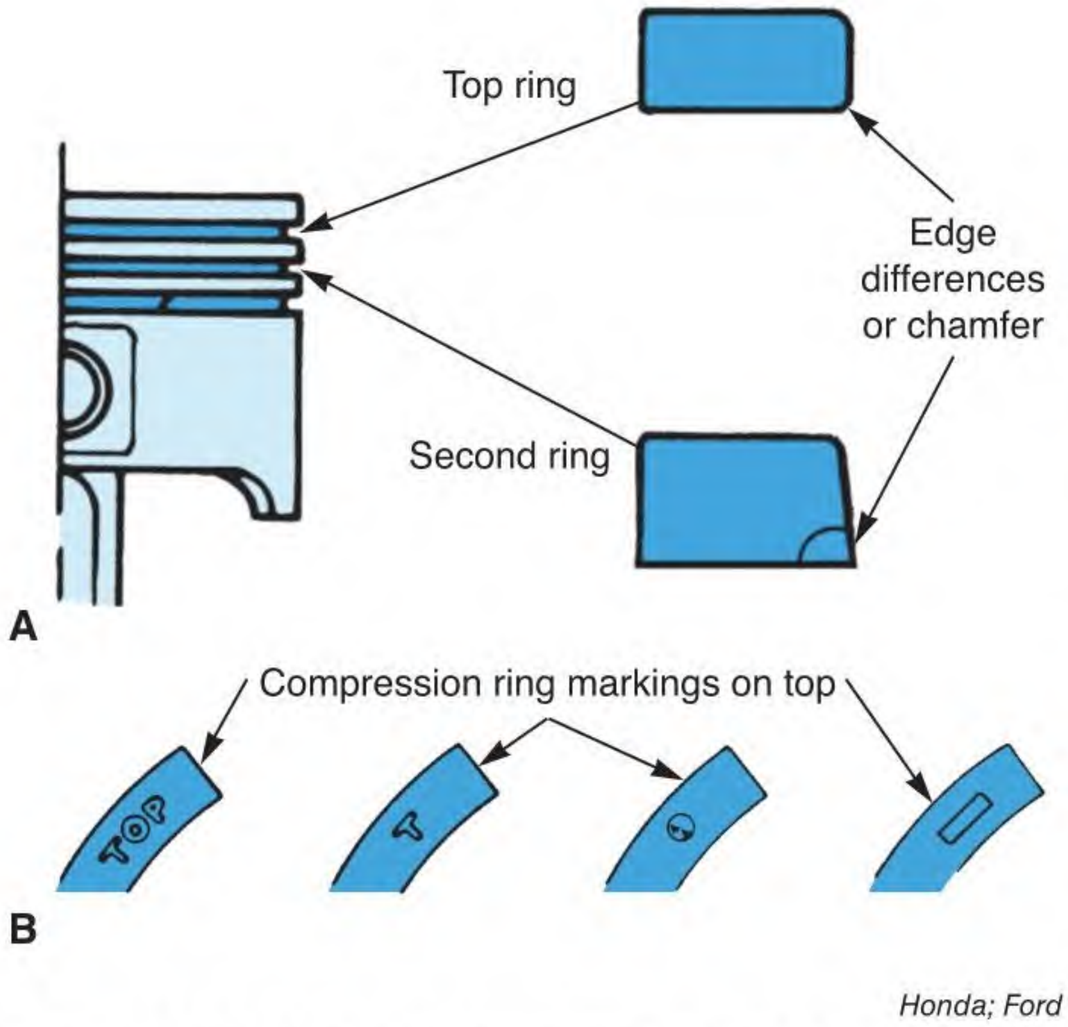
Installing Compression Rings

Read the instructions supplied with the new piston ring set. There are usually hints on proper ring installation. The shape of compression rings can vary. The shape is designed to help hold the ring against the cylinder wall for a proper seal.

Most compression rings have a top and a bottom. If installed upside down, ring failure or pressure or oil leakage may result. Ring markings are usually provided to show how compression rings should be installed. The markings show the top of each ring and which ring goes into the top or second piston groove. Refer to **Figure 57-56**.

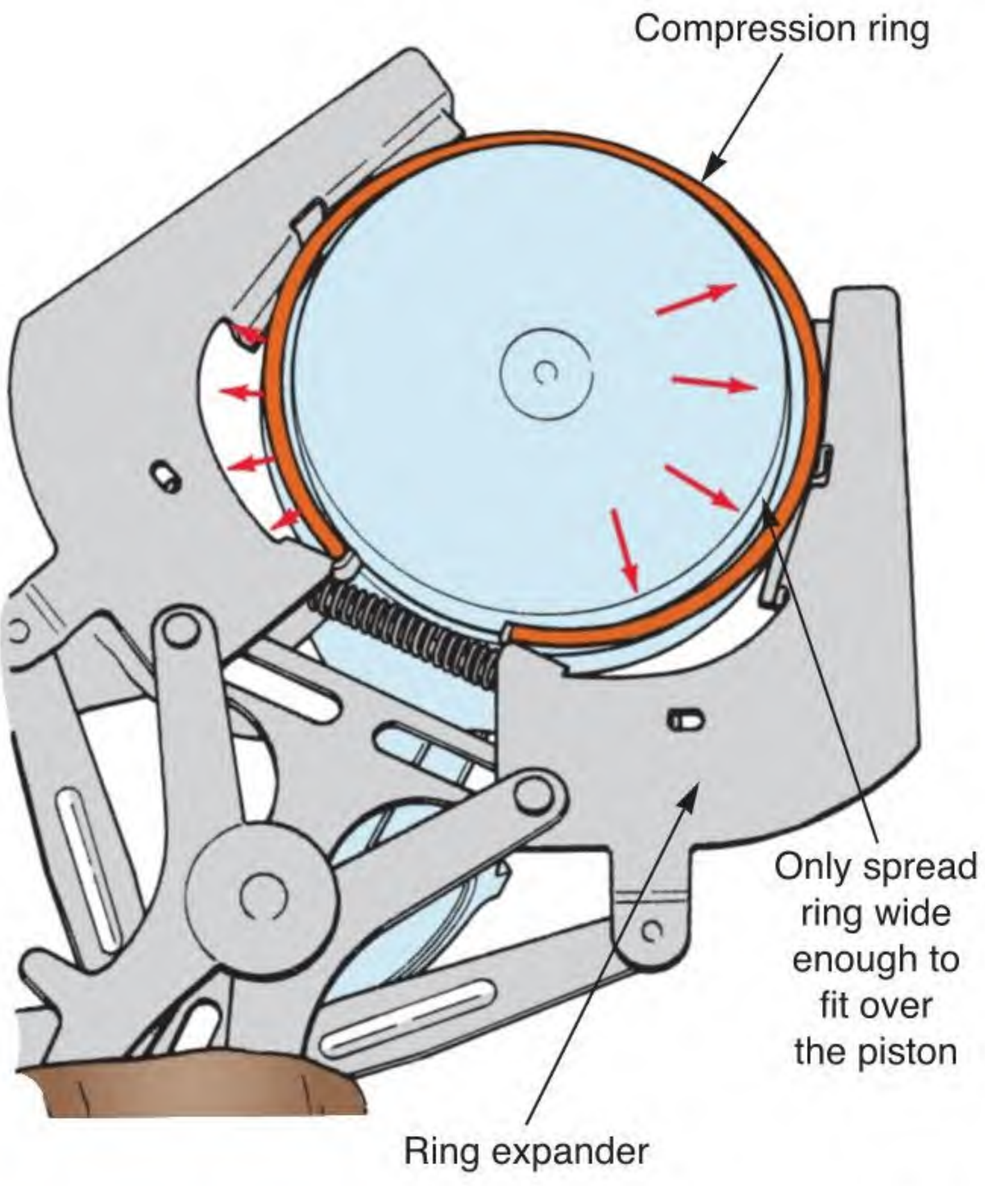
Using a piston ring expander, slip the compression rings into their grooves. A ***ring expander*** is a special tool for spreading and installing rings. See **Figure 57-57**. If a ring expander is not available, carefully use your fingers. Without overexpanding the rings, carefully insert each compression ring into the ring grooves.

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Honda; Ford

Figure 57-56. Study ring shapes and markings. A—Examples of different compression ring shapes. B—Marks indicate the top of the compression ring, if applicable.



Chrysler

Figure 57-57. If available, use a ring expander to install rings. This tool will help avoid compression ring breakage.

Caution

Compression rings are made of very brittle cast iron. They will easily break if expanded or twisted too much.

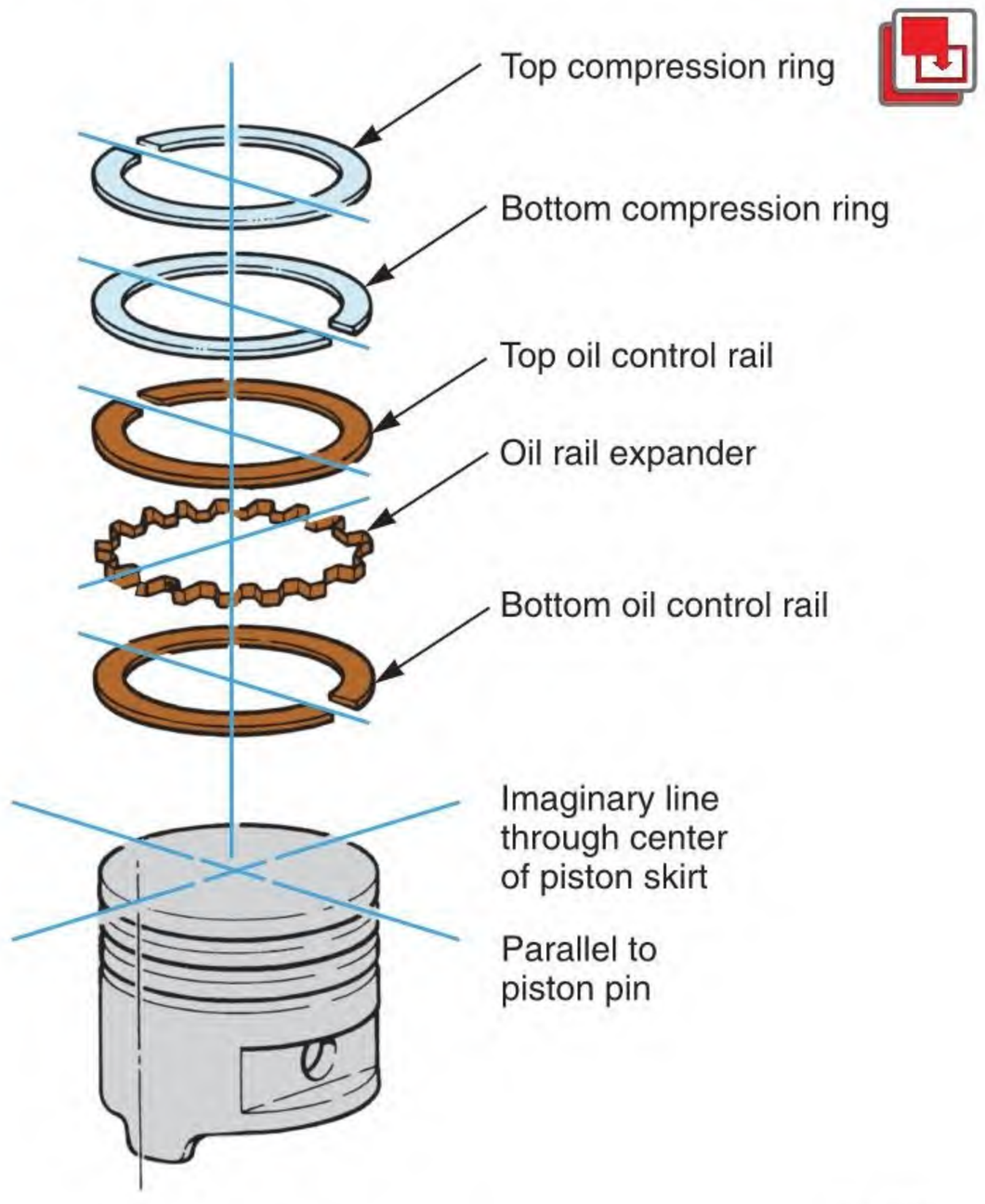
Piston Ring Gap Spacing

A specific piston ring gap spacing is normally recommended. This is to reduce blowby and ring wear. Study **Figure 57-58**.

Try to position each gap directly opposite the one next to it. This provides maximum distance between each gap for minimum pressure leakage. The gaps should also be close to the piston pin hole, but not in line with it. Being next to the pin hole reduces ring wear because the gap is not on a major thrust surface.

Measuring Piston Ring Side Clearance

Piston ring side clearance is the space between the side of a compression ring and the piston groove.



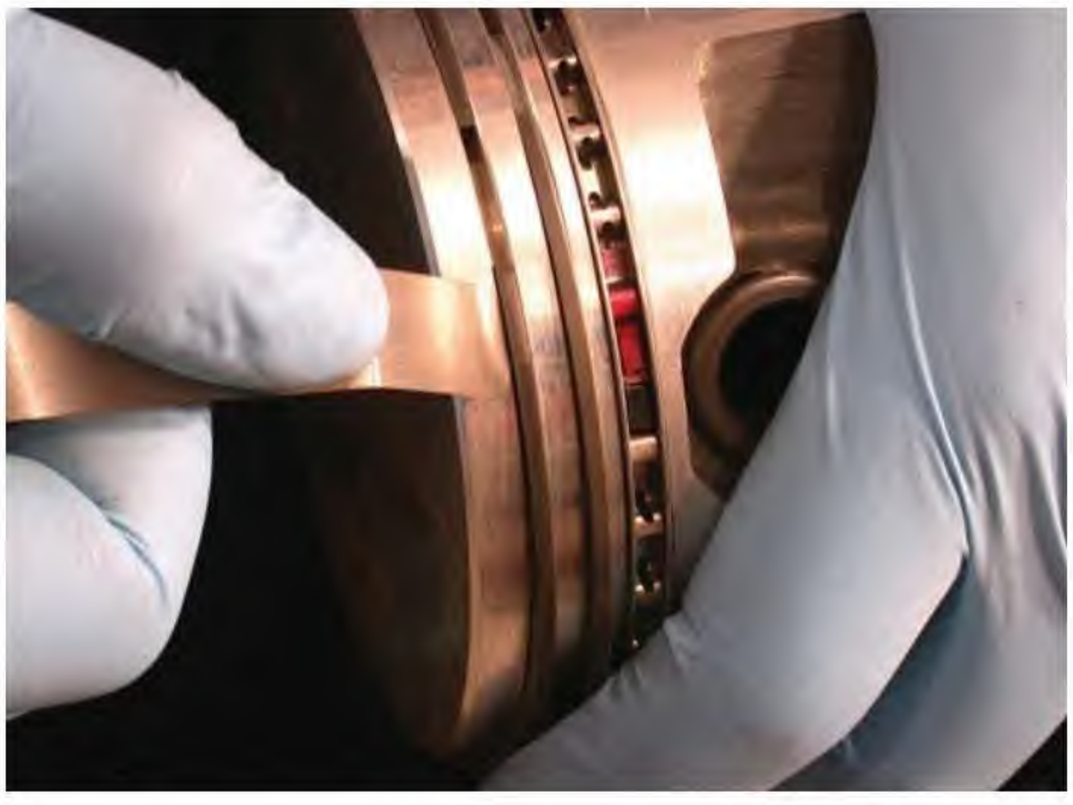
Chrysler

Figure 57-58. Space piston ring gaps away from each other as shown. Compression ring gaps should be spaced 180° apart to minimize blowby through the gaps.

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Ring groove wear tends to increase this clearance. If this clearance is too large, the ring will not be held square against the cylinder wall. Oil consumption and smoking can result.

To measure ring side clearance, install the new piston ring in its groove. Then, slide a feeler gauge between the ring and groove, **Figure 57-59**. The largest feeler gauge that fits between the ring and groove indicates the ring side clearance. The top ring groove is usually checked because it is exposed to more combustion heat and wear than the second groove. If the groove is too wide, replace the pistons.



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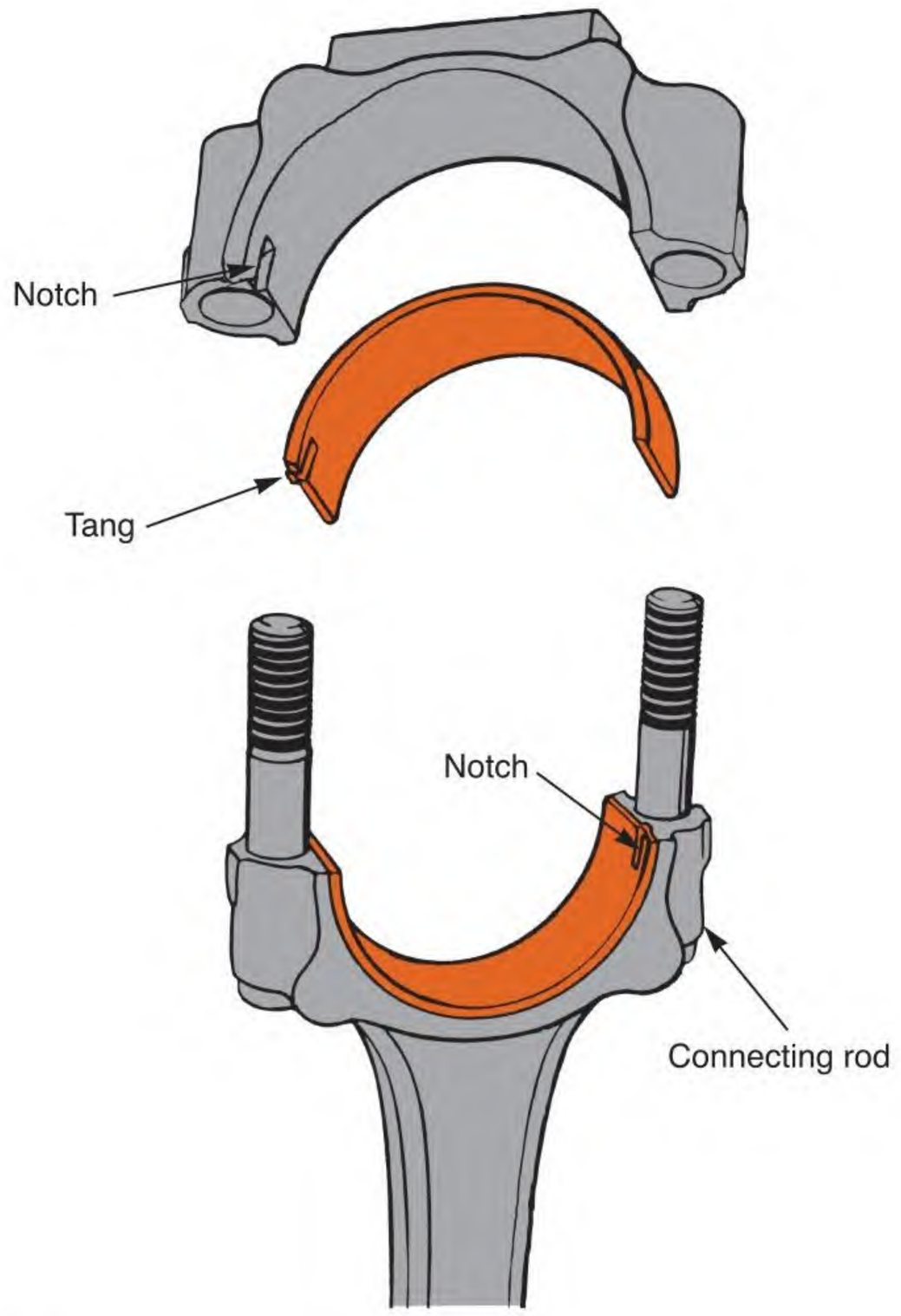
Figure 57-59. Measure ring side clearance as shown. The thickest feeler gauge that fits between the ring and groove indicates piston ring clearance in its groove.

Installing the Piston and Rod Assembly

To install the piston and rod assembly into the engine, first fit the rod bearing inserts into the connecting rod beam, **Figure 57-60**. Fit the other half of the bearing insert into the connecting rod cap. The rod bores and backs of the bearing inserts must be perfectly clean and dry (not oiled). Make sure the tang on each bearing insert fits down into the notch in the rod and rod cap.

You should also double-check the connecting rod bolts. Make sure the threads are in perfect shape. Also, make sure the bolts are fully seated in the rod body, if applicable.

To prevent part damage during initial engine start-up, you must lubricate all moving parts on the piston



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Figure 57-60. Proper rod bearing installation is critical. A—Fit clean, dry rod bearings into the connecting rod body and cap. Make sure bearing is square in the bore. B—Make sure the tang on the bearing insert is fully down into its notch in the rod and cap.

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and rod assemblies. Apply heavy oil or assembly lube to the piston rings, piston skirts, piston pin, and faces of the rod bearings. Oil is applied on the piston rings and skirts because they can heat up quickly on initial start-up if not prelubricated. Some technicians like to dip the head of the piston and new rings into a container of clean engine oil. Double-check that the ring gaps are still spaced properly. Make sure the face of the rod bearing is coated with assembly lube, **Figure 57-61**.

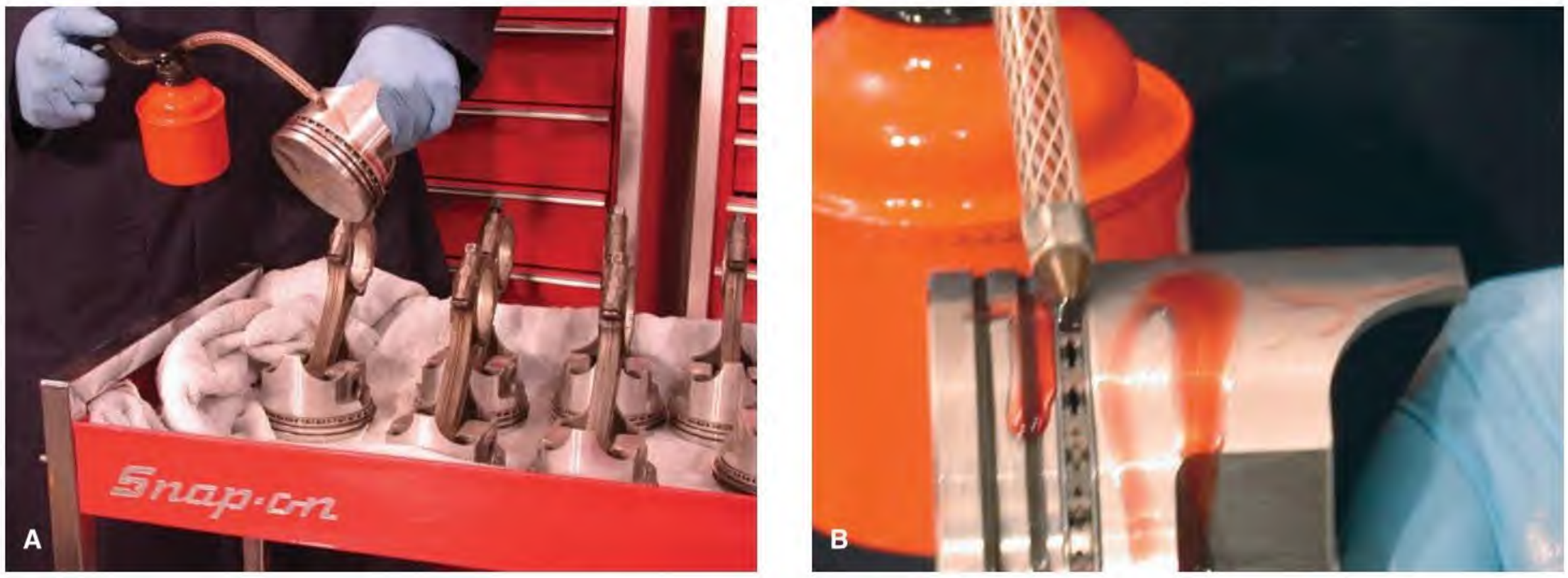
Clamp a ring compressor around the rings, as in **Figure 57-62**. While tightening the compressor, hold the compressor square on the piston. The small dents or indentations around the edge of the compressor should face the bottom of the piston. The piston and rod assembly is now ready to install into the block.

Protecting the Crankshaft

Slide special rod bolt covers over the connecting rod bolts. Plastic or rubber hoses can be used if covers are not available. This will prevent the rod bolts from scratching the crankshaft journals.

Installing Piston and Rod in Block

Turn the crankshaft until the corresponding rod journal is at or close to BDC. Double-check the markings on rod and piston. Make sure the rod is facing the right direction and that the cap number matches the rod number. Also, check that the piston notch or arrow is facing the front of the engine. For example, the number one rod normally goes in the number one cylinder with the piston marking to the front. Check the service manual if in doubt.



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Figure 57-61. Lubricate all moving parts to prevent part damage during initial engine start-up. A—Oil piston skirts. B—Lubricate piston rings. C—Oil piston pin. Slide the rod back and forth in the piston as you lubricate the pin. D—Apply oil to rod bearing faces.

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Figure 57-62. Install a ring compressor properly or rings will pop out of the tool during piston installation. A—Select the correct diameter ring compressor to fit over the piston and rings. B—Make sure the arrow on the ring compressor faces down. C—Tighten the ring compressor enough to compress the rings.

Place the piston and rod into its cylinder, **Figure 57-63A**. The ring compressor should be square against the block deck. While guiding the rod bolts over the crankshaft with one hand, tap the piston down into the engine, **Figure 57-63B**. A soft wooden or plastic hammer handle will not mark or damage the head of the piston. Keep tapping on the piston until the rod bearing makes full contact with the crankshaft journal. Look at **Figure 57-63C**.

If a piston ring pops out of the compressor, do not try to force the piston down into the cylinder. This would break or damage the piston rings or piston. Instead, loosen the ring compressor and start over.

Double-check that the piston and rod are facing in the right direction. The rod number should match the cylinder number.

Checking Rod Bearing Clearance

To measure connecting rod bearing clearance, use Plastigage. Place a bead of Plastigage across the crankshaft rod journal. Assemble the rod cap and bolts. When installing a connecting rod cap, make sure the rod and cap numbers are the same. If the rod is numbered with a 5, then the cap should also have 5 stamped on it. Mixing up rod caps can damage the bearings or crankshaft. Then, torque the rod cap bolts, as described in the next section.

Next, remove the cap and compare the smashed Plastigage to the paper scale. The width of the smashed Plastigage determines the bearing clearance. See **Figure 57-64**. Typical rod bearing clearance is about 0.0015″ (0.038 mm). This would equal a 1.5 reading on the Plastigage paper scale.

Torquing Connecting Rods

It is very important for you to properly torque each rod nut or bolt to specifications. Connecting rod bolts are the most-stressed fasteners in an engine. At high engine speeds, rod bolts must withstand thousands of pounds of force as the rod changes direction. If a rod bolt or nut is overtightened, the rod bolt could snap off during engine operation. If a rod is under-tightened, the bolts could stretch under load, allowing the bearing to spin or hammer against the crankshaft. Severe block, crankshaft, piston, and cylinder head damage could result in either case.

After checking the bearing clearance, lubricate the rod bearing and the crankshaft journal. Then install the rod cap. See **Figure 57-65**. Make sure the cap numbers match the rod number. Also, make sure the tangs on the bearing face in the right direction.

If the bolts are used, place locking compound on the threads. If nuts are used, make sure they face in the right direction. The shiny side of reused rod nuts must face down. Then, tighten the bolts or nuts hand tight. Make sure the cap is properly seated on the rod and journal.

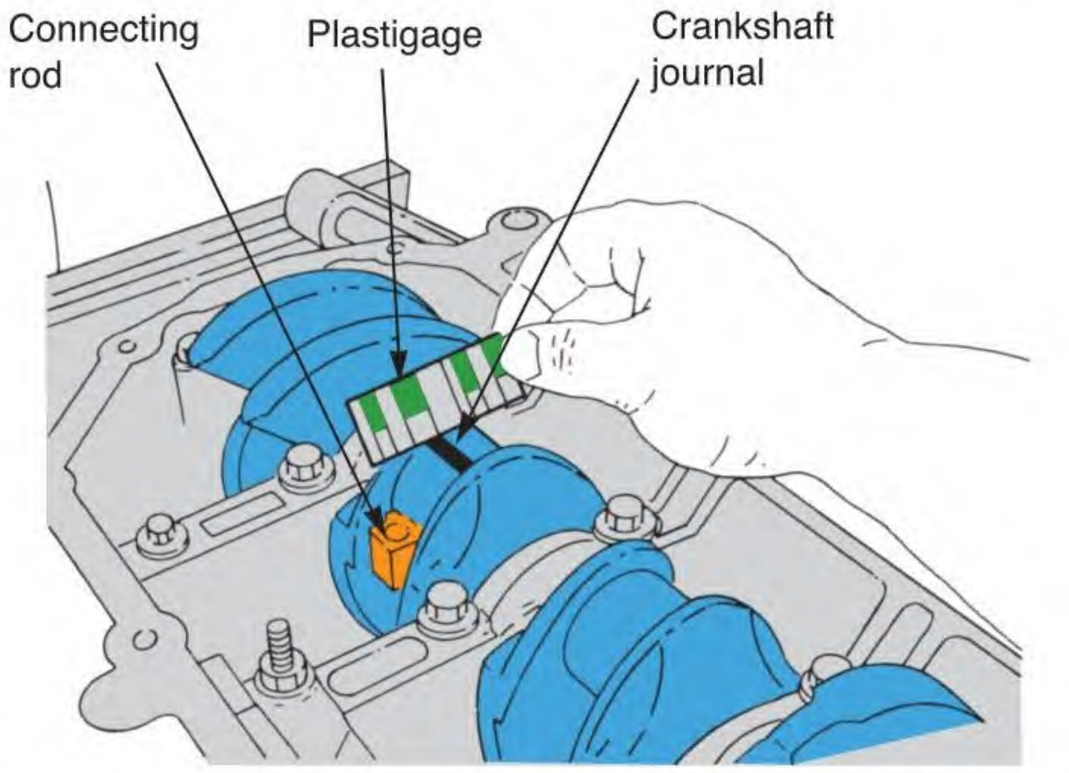
Using a torque wrench, tighten each connecting rod fastener a little at a time. First, tighten all rod fasteners to about 1/2 of the specified torque. Then, tighten all rod fasteners to about 3/4 of the specified torque. Next, fully torque all connecting rod fasteners. Finally, retorque all rod fasteners at full torque, **Figure 57-66A**. This procedure will pull the rod cap down squarely and securely on the connecting rod body.

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Figure 57-63. Study the steps for piston/rod assembly installation. Installing the piston and rod assembly. A—Slowly slide the piston and rod down into the block. The arrow on the piston must face the front of the engine. B—Use a hammer handle to tap the piston and rod down into the block. C—While tapping the piston down, guide the connecting rod over the crankshaft journal.



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Figure 57-64. Measure at least one rod bearing clearance to check crankshaft and bearing specifications. Place a piece of Plastigage on the journal, install the cap, and torque the bolts. After removing the cap, compare the paper scale with the smashed Plastigage.

Tech Tip

Always refer to the service manual when assembling an engine. Torque specifications, clearances, torque-to-yield, and other procedures can vary with engine design.

The engines in many late-model vehicles have torque-to-yield specifications for the rod bolts. The process for tightening these bolts was discussed earlier in this chapter. First, tighten the rod fastener to the specified torque. Then, install the degree gauge on the wrench and tighten each rod fastener an additional number of degrees. See **Figure 57-66B**.

Tech Tip

Some electronic torque wrenches have a torque-to-yield function. After being used to tighten the fastener to the specified torque, the wrench can be read in degrees of rotation, so a torque-to-yield degree wheel is not needed.

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Figure 57-65. Carefully install the engine connecting rod caps. A—Apply heavy oil or assembly lube to the face of the rod bearing insert. B—Lubricate the crankshaft journals with motor oil. C—Fit the rod cap down fully into place on the connecting rod body.





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Figure 57-66. A—Tighten the rod bolts to factory torque specifications. B—If the fastener has a torque-to-yield specification, use a degree wheel to tighten it the specified number of degrees after the fastener is torqued.

Checking Rod Side Clearance

Connecting rod side clearance is the distance between the side of the connecting rod and the cheek of the crankshaft journal or side of the other rod. To measure rod side clearance, insert different size feeler gauge blades into the gap between the rod and the crankshaft, as in **Figure 57-67**. The largest feeler blade that slides between the rod indicates side clearance.

Compare your measurements to specifications. Connecting rod side clearance specifications vary from 0.005″ to 0.020″ (0.13 mm to 0.50 mm). If not within specifications, the crankshaft thrust journal or connecting rod width is incorrect. The engine must be disassembled and the crankshaft replaced or welded and reground to correct the rod side clearance problem.



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Figure 57-67. To measure connecting rod side clearance, use a flat feeler gauge. The largest blade that fits indicates the clearance.

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Engine Balancing

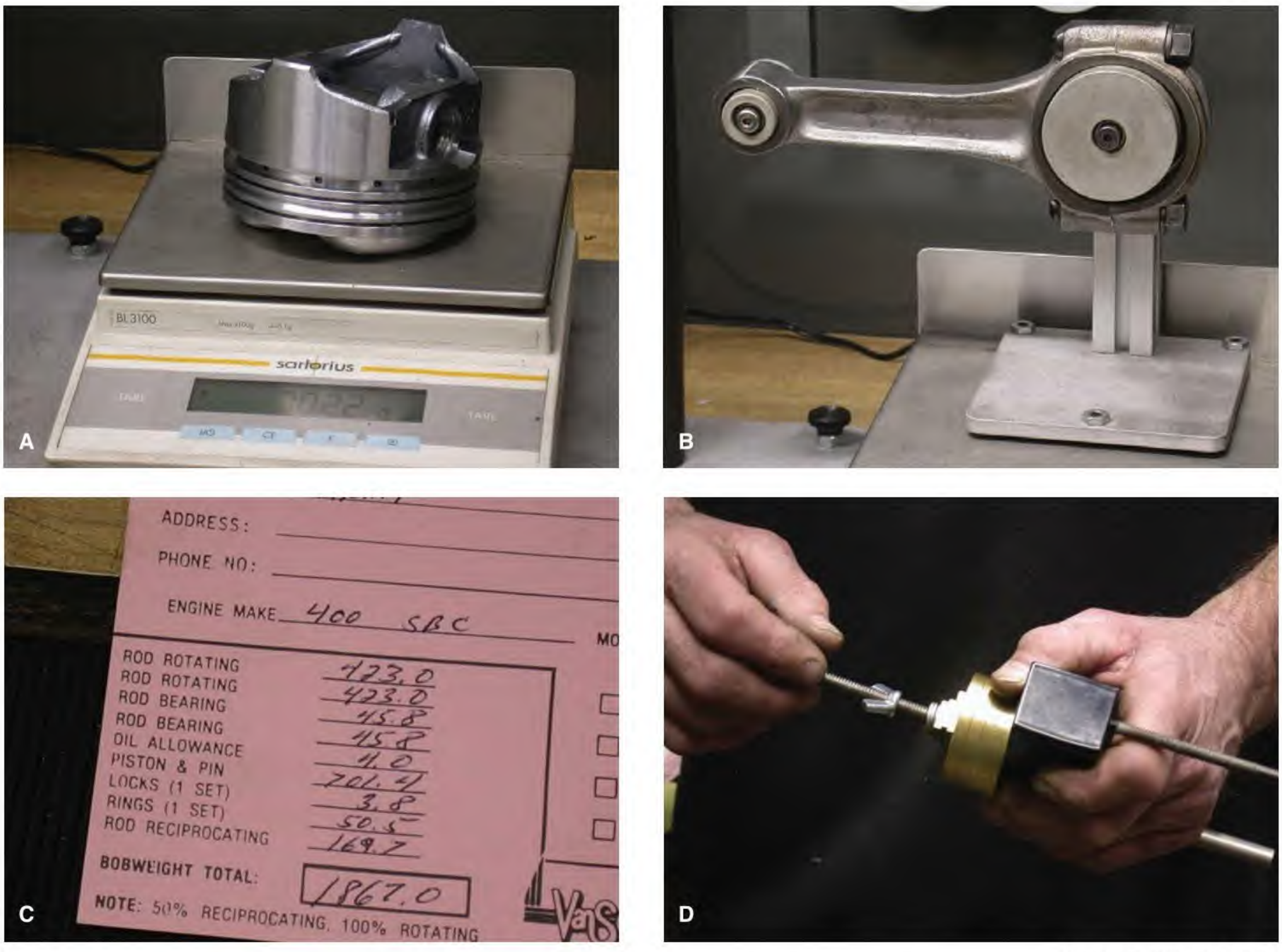
Engine balancing, or ***crankshaft balancing***, is needed when the weight of the pistons, connecting rods, or crankshaft is altered by installing new parts of a different weight. For example, if new, oversize pistons are installed and they weigh more than the old, standard pistons, engine (crankshaft) balancing may be required. If the engine is not balanced, severe engine vibration would result and the engine may be damaged. Most large, automotive machine shops have engine balancing equipment.

The first step in balancing an engine is to weigh each piston and record its weight. See **Figure 57-68A**. All pistons should weigh the same. Material must be removed from heavier pistons to make all pistons the same weight. If needed, metal is machined off the bottom of the piston pin boss.

Next, weigh each connecting rod assembly and record its weight. The weight of each rod assembly must be the same. All rod big ends and small ends should also be equal in weight. See **Figure 57-68B**. You can machine pads on each end of the rods to equalize their weights as needed.

The weight of the piston and rod assembly is called the ***reciprocating weight***. To replicate this weight as the crankshaft is being balanced, ***bob weights*** are installed on the crankshaft. The calculated reciprocating weight must account for all weight, including bearings, rings, and oil. See **Figure 57-68C**.

After you have calculated the correct bob weights, assemble the bob weights. See **Figure 57-68D**.



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Figure 57-68. Study the major steps for balancing an engine. A—Weigh the new piston and record its weight. B—Weigh the rod and record your readings. This device measures the big end and small end separately. C—Calculate the reciprocating weight and calculate the needed bob weight. D—Assemble the bob weights to match the calculated weight.

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Double-check the bob weights on a scale. Then, mount the bob weights on the crankshaft. Also, mount the vibration damper and flywheel on the crankshaft.

Next, mount the crankshaft assembly in the engine balancing machine. Using the balancing machine controls, spin the crankshaft at the speed required. The balancing machine readout indicates where and how much weight needs to be removed from or added to the crankshaft counterweights. Metal is added to a counterweight by welding and removed by drilling.

Tech Tip

Proper engine balance is very critical with today's small-displacement, high-rpm engines. Keep engine balancing in mind when making major engine modifications.

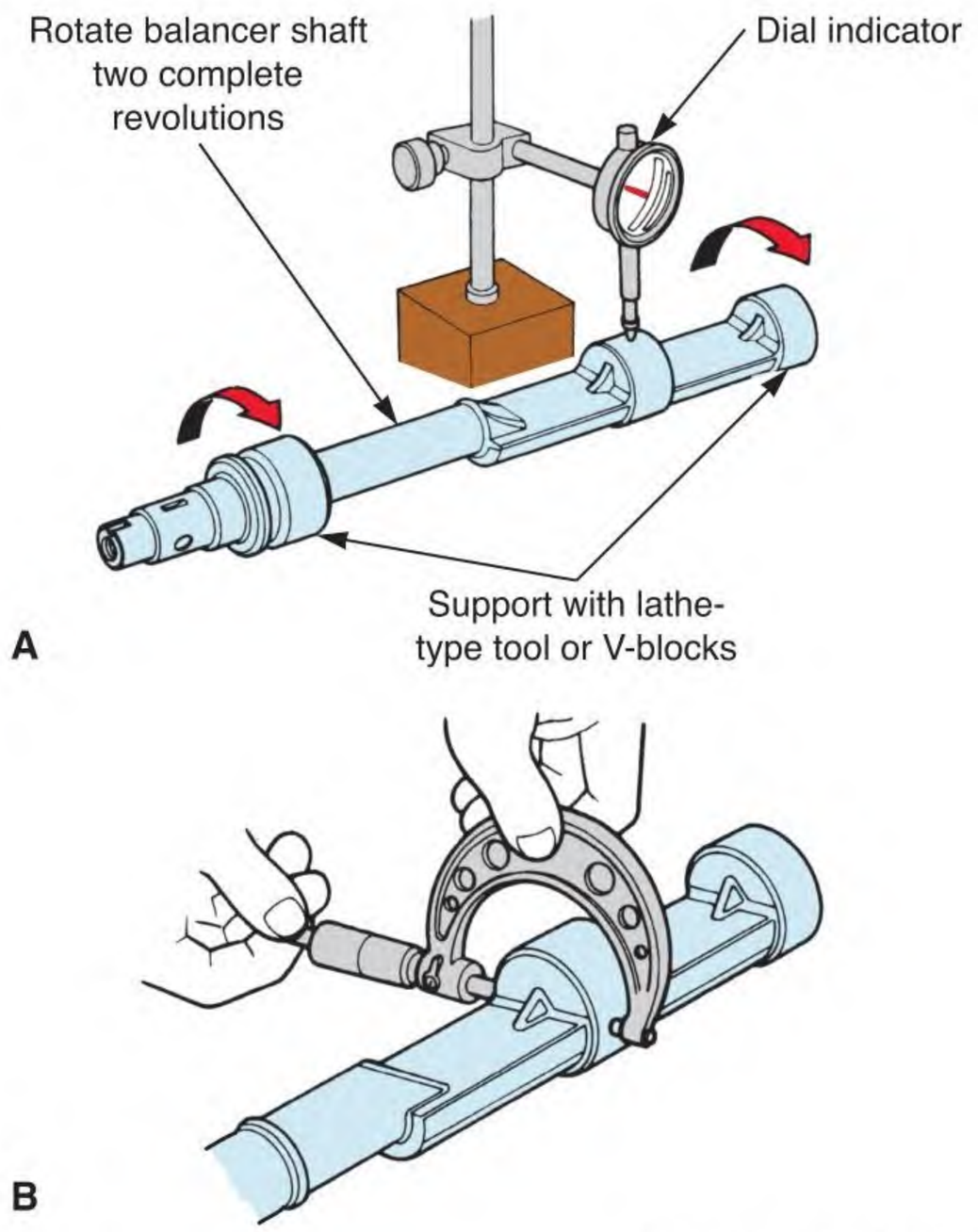
Balancer Shaft Service

Balancer shaft service involves the same basic procedures as crankshaft service. You must measure shaft runout, journal wear, and bearing clearance. Also, inspect the shaft for nicks, burrs, and wear. Often, special tools are needed to service the balancer shaft. Check the service manual for specific service procedures.

Use a dial indicator to check for excessive runout, which indicates a bent balancer shaft. See **Figure 57-69**. Mount the shaft on V-blocks. Place the indicator tip on the journals. Rotate the shaft and read the indicator. Replace the balancer shaft if the runout exceeds specifications. The balancer shaft and bearings should be replaced as a set if damaged or worn.

Use a micrometer to determine balancer shaft wear. Measure the diameter of the balancer shaft. Then, subtract the diameter from the specification for original diameter. The difference is the wear. Compare the wear to the amount allowed by specifications.

Also, inspect the balancer shaft bearings for wear. A hole gauge is often used to measure the balancer shaft bearing diameters.



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Figure 57-69. Note how to check a balancer shaft for warpage or journal wear. A—Measuring balancer shaft runout. B—Measuring the diameter of the balancer shaft journals.

Summary

- Inspect the cylinder block closely for problems before assembly. Magnafluxing is a quick way of finding cracks in cast iron blocks. Dye or fluorescent penetrant will find cracks in aluminum blocks. Cracked blocks can sometimes be repaired by welding, special epoxy, plugging, and sleeving.
- Main bore alignment and deck warpage are checked with a straightedge and feeler gauge. Machining is needed to correct misalignment or warpage of the block.
- Cylinder wear is best checked with a dial bore gauge. However, an inside micrometer or a telescoping gauge and outside micrometer can also be used. Check for cylinder out-of-round, taper, and diameter.

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- Cylinder honing is needed on used cylinders or cylinders that have been bored oversize. Honing produces the correct surface texture for proper ring break-in. Power honing will help remove cylinder taper and out-of-round. Flex or brush honing simply prepares the cylinder surface. A finer grit stone is needed when hard chrome or moly piston rings will be installed. Do not pull a spinning hone too far out of the cylinder or tool breakage can result.
- A block should be bored when cylinder wear is beyond specifications. A machine shop can bore the block cylinders oversize. Then, oversize pistons must be installed. The overbore limit depends on the manufacturer; check specifications. Cylinder sleeving can be done to repair a badly worn or damaged cylinder wall. The sleeve can be installed so that the same size piston will fit.
- Always clean the block carefully after boring or honing. You must remove all grit so that it cannot circulate through the engine during operation. Use a pressure washer or hand wash the block with soap and water. Wipe the block down with an oil-soaked rag to remove the last of the grit.
- Measure the crankshaft journals for wear. Check for general diameter, taper, and out-of-round. Also, check the crankshaft for cracks. If worn too much, have a machine shop grind the crankshaft journals undersize. Then, undersize bearings must be installed. Bearing undersize is usually stamped on the back of the bearing inserts.
- Make sure you install the rear main oil seal correctly. The sealing lip must face inside the engine. Use the proper driver to install a one-piece rear seal to prevent seal damage.
- Never oil the back of engine bearings. They should be installed clean and dry. Check oil hole alignment. Coat the bearing faces with heavy engine oil or assembly lube. Check bearing clearance with Plastigage. Torque main and rod bearing caps to specifications. Start out at about 1/2 torque and work up to full torque. Recheck final torque at least once. If the specification is torque-to-yield, turn each fastener the specified number of degrees past the torque specification.
- Clean piston ring grooves of carbon with a ring groove cleaner or broken ring. Measure the piston diameter with an outside micrometer. Usually, measure just below the piston pin on the skirt. Piston wear is found by subtracting the measured diameter from the specification for diameter. Piston clearance is found by subtracting the piston diameter from the cylinder diameter. Clearance must not be too large or piston slap can result.
- Measure piston pins and their connecting rod bores. Make sure the dimensions are within specifications. Replace parts or have the rods rebuilt if needed.
- Check the piston ring gap by sliding the ring to the bottom of the cylinder bore with a piston. Then, use a feeler gauge to check the end gap. If the gap is too small, file the ring ends until within specifications, if allowed by the manufacturer.
- Install the oil ring on the piston first. Make sure the expander-spacer ends butt together and do not overlap. Use your fingers or a ring expander to install the compression rings. Space the end gaps away from each other and slightly to one side of the piston pin ends.
- Ring side clearance is checked between the compression ring and its groove. Slide the correct size feeler gauge in next to the ring. If the groove is too wide, replace the pistons.
- Use a ring compressor to install the piston and rod into the block. Cover the rod bolts to protect the crankshaft. Then, tap the piston down into the block with a hammer handle. Torque rod and main cap bolts properly. Check rod side clearance with a feeler gauge.
- Engine balancing may be needed if components are altered or changed. The reciprocating weight is the weight of the piston, rod, bearings, and oil. The counterweight on the crankshaft must balance this weight to prevent engine vibration.

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Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

block boring
bob weights
boring bar
connecting rod side clearance
crankshaft balancing
crankshaft endplay
crankshaft service
crankshaft turning
cylinder honing
cylinder out-of-round
cylinder sleeving
cylinder taper
deck plate
deck warpage
decking
deglazing
dye penetrant
engine balancing
engine overhaul
fluorescent penetrant
free-floating piston pin
line boring
line honing
liner protrusion
magnafluxing
microns
overbore limit
piston clearance
piston ring gap
piston ring side clearance
piston wear
piston-to-cylinder clearance
plateau honing
power hone
press-fit piston pin
pressure testing
rear main oil seal
reciprocating weight
ring expander
ring filing
ring groove depth
sleeve protrusion
torque-to-yield specifications

Review Questions

Answer the following questions using the information provided in this chapter.

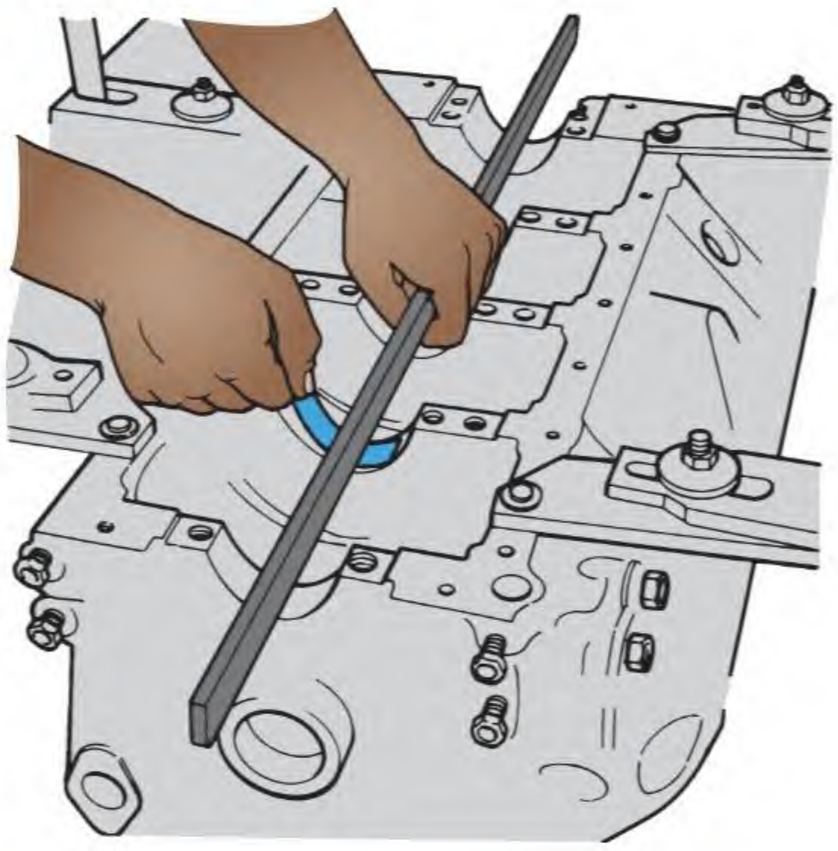
1. When _____, a ferrous powder and magnet are used to find cracks in iron and steel parts.
2. Explain three ways to repair cracks in blocks.
3. How do you check main bore alignment?
4. How do you measure cylinder taper and out-of-round?
5. Generally, a block should be bored if cylinder out-of-round is more than _____ inch or taper is more than _____ inch.
6. What is the purpose of deglazing a cylinder?
7. Define *plateau honing*.
8. What purpose does a deck plate serve?
9. Cylinders are normally bored oversize in increments of _____.
10. The _____ is the maximum amount that a block should be bored oversize.
11. Define *cylinder sleeving*.
12. Why is it important to clean the engine after honing or boring?
13. How do you measure crankshaft main and rod journal wear (taper and out-of-round)?
14. Which direction must the lip on the rear main oil seal point?
15. Check main bearing clearance with _____.
    (A) a flat feeler gauge
    (B) a dial indicator
    (C) Plastigage
    (D) a micrometer
16. Describe *torque-to-yield*.
17. How do you measure piston wear?
18. To find piston clearance, subtract the _____ from the _____.
19. Why are the piston ring gaps spaced apart from each other?
20. How do you check rod bearing clearance?

ASE-Type Questions

1. Technician A says that checking for main bore and deck warpage is a typical procedure performed during short block service. Technician B says that cylinder head milling is a common procedure performed during short block service. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
2. Which of the following problems should you look for when inspecting a cylinder block?
    (A) Cylinder ring ridge.
    (B) Cylinder scoring.
    (C) Cracked cylinder.
    (D) All of the above.

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3. Technician A says that a short block should be line bored when misalignment is over approximately 0.0015″ (0.038 mm). Technician B says that a short block should be line bored when misalignment is over approximately 0.0001″ (0.003 mm). Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. Technician A says that the illustration shows how to check for main bore misalignment. Technician B says that the illustration shows how to use Plasti-gage™ to check for bearing clearance. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.



5. Technician A says that block deck warpage is measured with a straightedge and feeler gauge. Technician B says that cylinder wear is measured with an inside micrometer and dial indicator. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Cylinder taper is the difference in cylinder diameter when measured _____.
   (A) from front-to-rear and side-to-side
   (B) at the top and bottom
   (C) at the ridge
   (D) on the deck
7. A cast iron, V-6 block is almost new and has very low mileage. However, a piston skirt broke off and scored one cylinder. All of the other pistons and cylinders are in good condition. Technician A says to bore the block oversize and install six new, oversize pistons to correct the cylinder damage. Technician B says to sleeve the damaged cylinder and buy a new piston. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. Technician A says you should torque each main bolt to about 1/2 torque in sequence, then to 3/4 torque, and finally to full torque. Then, torque each bolt once more at full torque. Technician B says to torque the first rod bolt to full torque and then the other rod bolt to full torque, and then check torque one more time. Who is right?
   (A) Technician A.
   (B) Technician B.
   (C) Both A and B.
   (D) Neither A nor B.
9. Technician A says that 0.030″ (0.75 mm) is a common oversize to which machine shops bore cylinders. Technician B says that 0.060″ (1.5 mm) is a common oversize to which machine shops bore cylinders. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. Technician A says that block decking reduces engine compression. Technician B says that block boring increases engine compression. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
11. Technician A says that an engine's compression rings are usually made of steel. Technician B says that an engine's oil ring is normally made of cast iron. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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As you disassemble a cylinder, keep the parts organized so they can be reinstalled in the same locations in head.

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Chapter 58
Engine Top End Rebuilding

After studying this chapter, you will be able to:

- Check a cylinder head for cracks, warpage, and other problems.
- Summarize cylinder head machining operations.
- Measure valve guide and valve stem wear.
- Knurl, ream, or replace valve guides.
- Recondition valve seats.
- Replace valve seats.
- Recondition valves.
- Test, shim, and install valve springs.
- Properly install valve stem seals.
- Reassemble a head.
- Measure camshaft lobe and journal wear, camshaft endplay, and camshaft bearing clearance.
- Service rocker arms and rocker arm shafts.
- Service push rods and lifters.

The cylinder head and head gasket have to seal tremendous combustion pressure in the top of the cylinder block. They must also control airflow into the cylinders and exhaust flow out of the combustion chambers thousands of times per minute. With the tremendous heat and pressure of combustion, this is a difficult task. After prolonged service, cylinder heads can warp from overheating, engine valves and valve seats can wear, and valve train parts can also fail. As a result of engine top end wear, engine compression pressure, engine performance, and exhaust emissions can suffer. Study **Figure 58-1**.

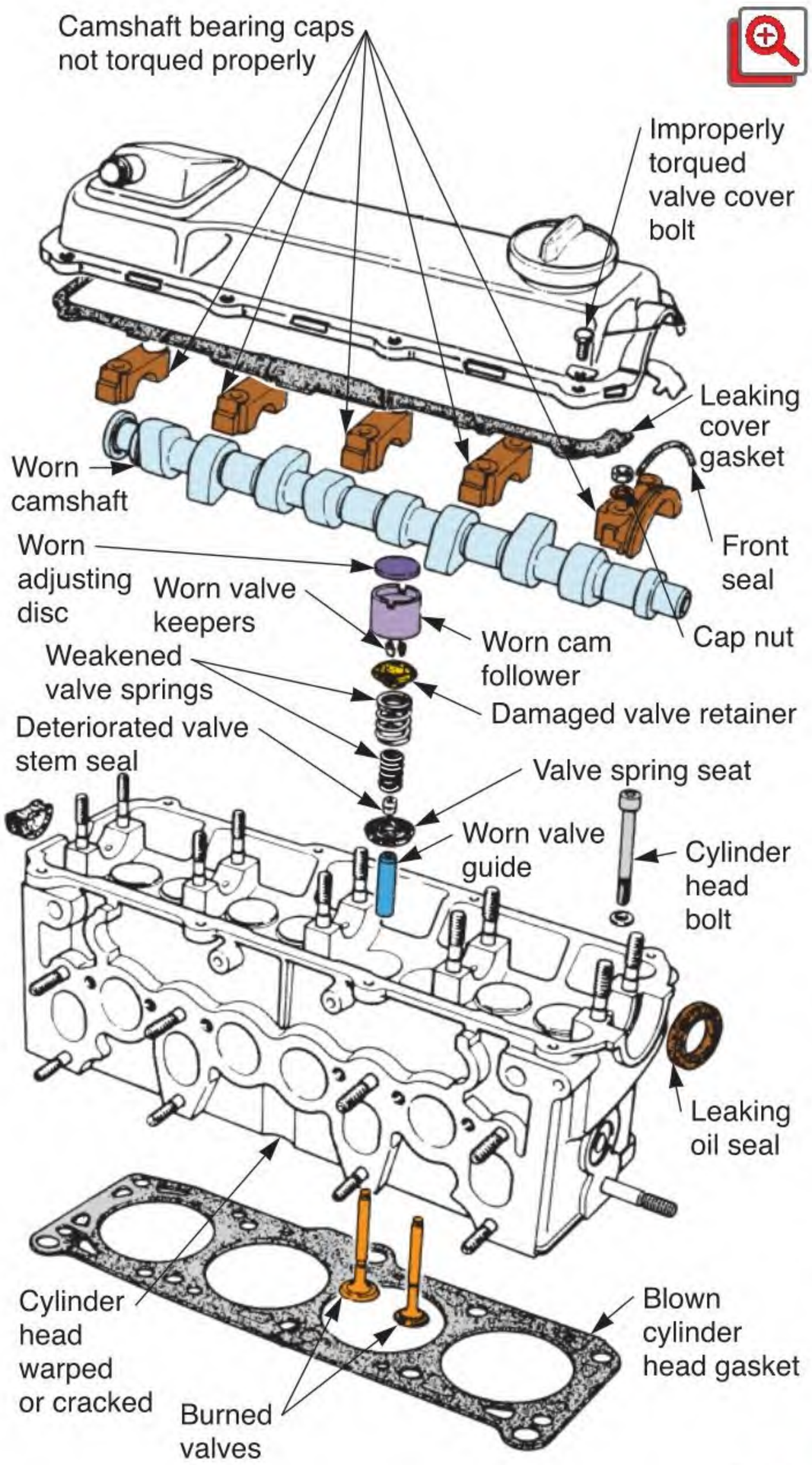
Cylinder Head Problems

With the cylinder head disassembled, inspect it closely for problems. Mount the head on a stand and check for cracks, burned seats, burned deck surface (especially between combustion chambers), cracked valve guides, and other problems. Keep in mind that if any trouble is not found, your repair could fail in service. See **Figure 58-2**.

Cylinder Head Warpage

A head that is warped has become slightly curved from overheating. ***Head warpage*** is more common with thin-cast heads, especially aluminum heads. A warped head can lead to head gasket failure due to uneven clamping pressure on the gasket. This can cause coolant leakage into the cylinder and lubrication system, compression loss, and other troubles. Before checking for warpage, all of the gasket material must first be cleaned off the head deck surface.

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Chrysler

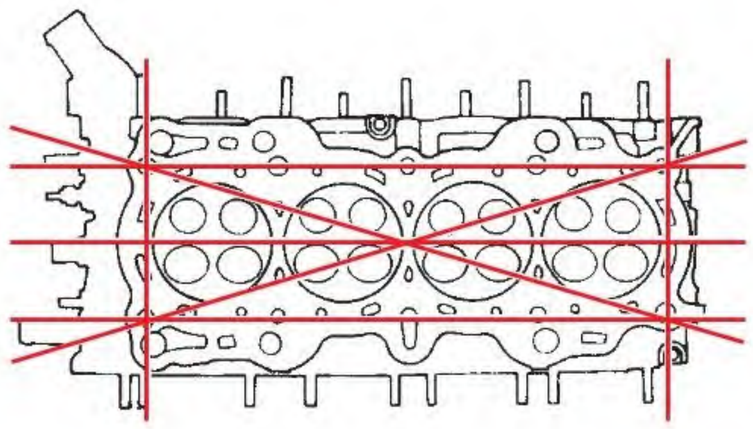
Figure 58-1. Typical parts of an engine's top end assembly are shown.

The most common location for warpage is between the two center combustion chambers. Head warpage should generally not exceed about 0.003″ to 0.005″ (0.08 mm to 0.13 mm). You can also check the exhaust and intake manifold mounting surfaces for warpage in this manner.

On the cylinder head from an overhead camshaft engine, you should also use the straightedge and feeler gauge to check the camshaft bore, **Figure 58-3**. Place the straightedge in the bore and try to slip feeler gauge blades under it. If warped beyond specifications, over approximately 0.001″ (0.03 mm), have a machine shop line bore the camshaft bores.



A



B

Fel-Pro and Honda

Figure 58-2. Study steps for measuring cylinder head surface warpage. Head warpage is a common problem with today's thin, lightweight, aluminum cylinder heads. A—Position a straightedge on the cylinder head. The thickness of the feeler gauge that fits under the straightedge equals head warpage. B—Check across the head at the angles shown. If warpage exceeds specifications, mill or replace the head.

Service Procedure

To check for cylinder head warpage:

1. Peel off the old gasket by hand using a gasket scraper or putty knife.
2. Use a single-edge razor blade to remove the last bits of the gasket. Be careful not to scratch the surface of an aluminum head.
3. Remove residue from the head deck surface. A good way to do this is to use a hand sanding board with 180 to 220 grit sandpaper. Block sanding the head surface with medium grit sandpaper removes gasket residue and levels any minor surface imperfections.
4. Lay a straightedge across the cylinder head deck.

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5. Try to slip different feeler gauge blade thicknesses under the straightedge.
6. The thickest blade that fits under the straightedge indicates the head warpage.
7. Check warpage in different positions across the head surfaces.

Cylinder Head Milling

Cylinder head milling is a machine shop operation where a thin layer of metal is cut or machined off the head gasket (deck) surface of the cylinder head. It is done to correct head warpage. Study **Figure 58-4**.

Service Procedure

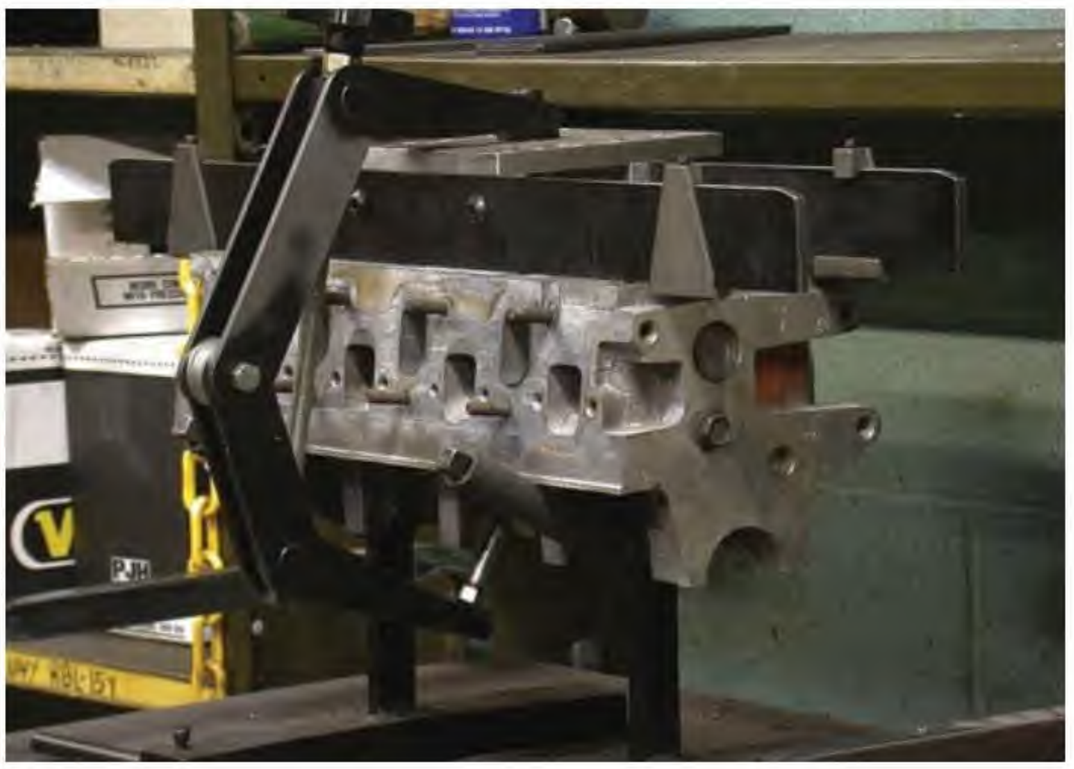
To mill or resurface a cylinder head:

1. Mount the head in a machine tool fixture so the fixture sits squarely on the cylinder head deck surface.
2. Place the fixture-head assembly on the mill table. By first mounting the head in a fixture, it is easier and quicker to get the head squared up on the mill table.
3. Clamp the cylinder head to the mill table.
4. Remove the fixture.



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Figure 58-3. A technician is checking the camshaft bore for warpage.



A



B



C

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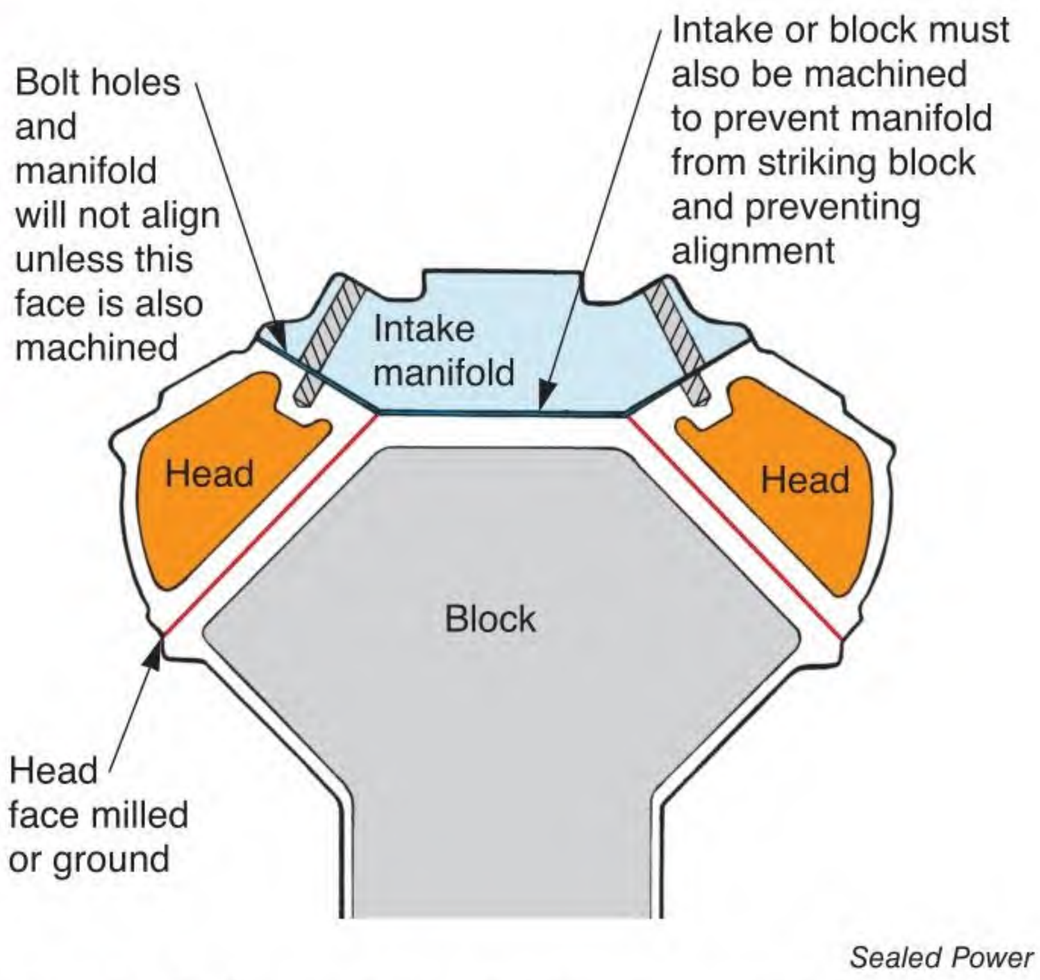
Figure 58-4. Note the major steps for milling a cylinder head. A—The cylinder head is mounted in the holding fixture so it is square on the mill table. B—A dial indicator can be used to double-check that the head is mounted properly on the mill. C—The head is being machined.

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5. Use a dial indicator to double-check that the head is properly mounted. The head should be level and square on the mill table.
6. Adjust the milling machine for the depth of cut.
7. Turn the mill on and engage the feed. The cutter is automatically fed across the cylinder head surface.

Only remove enough material to correct warpage. Milling increases the engine's compression ratio and can affect valve train geometry. Excessive milling can also affect alignment of the manifold on V-type engines. On a V-type engine, the intake manifold must also be milled if an excess amount of metal is removed from the cylinder head. Refer to **Figure 58-5**.

With a diesel engine, cylinder head milling is very critical. A diesel engine compression ratio is so high that any milling can reduce clearance volume and increase compression pressures beyond acceptable limits. Some diesel engine cylinder heads are case hardened and cannot be milled. They must be replaced when warped. Check manufacturer directions when in doubt.



Sealed Power

Figure 58-5. If excessive head milling is required on a V-type engine, you may also need to mill the intake manifold or the block. Check the service manual for details.

Cracked Cylinder Head

A cracked cylinder head can result from engine overheating or physical damage from other broken parts. Usually, a crack occurs at an exhaust seat or between chambers, allowing coolant or pressure leakage. This can lead to further engine overheating, coolant in the oil, and other symptoms. The procedure for checking for cracks in a cylinder head is basically the same as checking for cracks in a cylinder block.

Magnafluxing is a common way of finding cracks in cast iron cylinder heads. An electromagnet is placed on the head where a crack might be located. Then, a squeeze bulb is used to spread fine iron powder over the head. A crack will set up a disruption in the magnetic field that then attracts the powder. The powder collects in the crack and makes it visible. Refer to **Figure 58-6**.

Magnafluxing does not work with nonferrous materials, such as aluminum. ***Dye penetrant*** or ***fluorescent penetrant*** can be used to find cracks in aluminum cylinder heads. You must follow manufacturer instructions, since procedures vary. Refer to **Figure 58-7**.

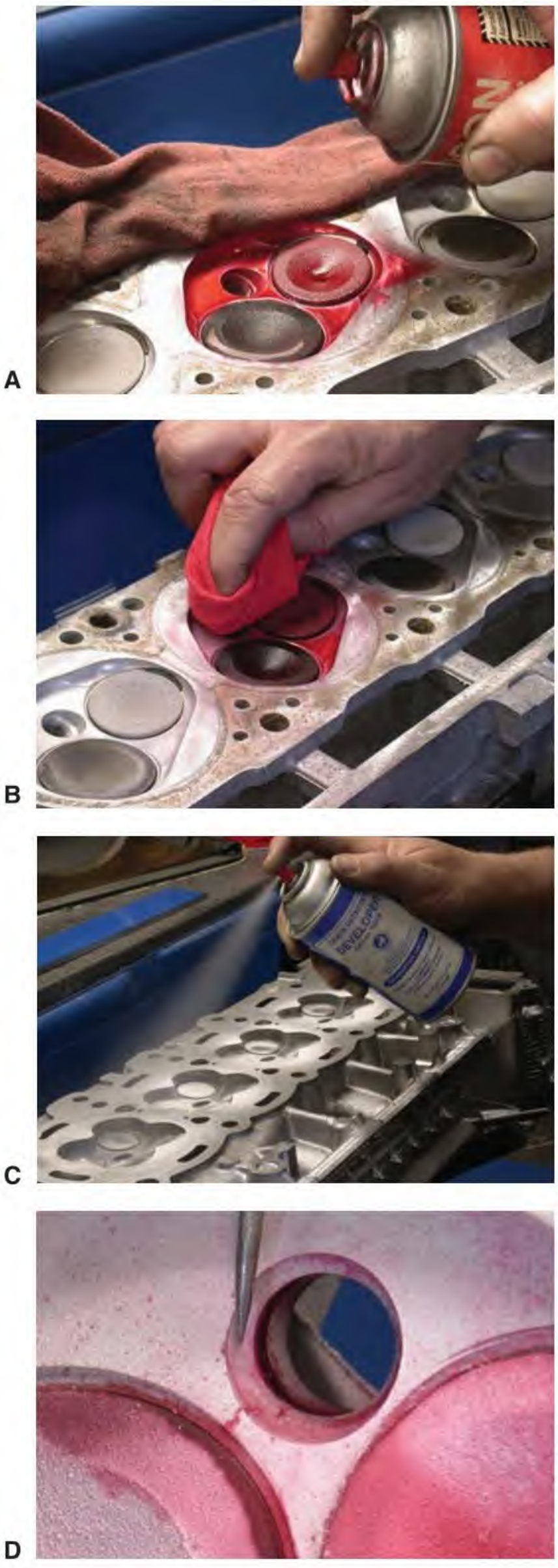


A B C

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Figure 58-6. Magnafluxing a cylinder head. A—The electromagnet is placed over the combustion chamber and then energized. B—Iron particles are spread over the head using a squeeze bulb. C—Cracks are highlighted by the iron particles, which are attracted to the magnetic flux or field inside any crack.

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VanSenus Auto

Figure 58-7. Use dye penetrant to find cracks in an aluminum head. A—Spray the dye penetrant onto the head surface and allow it to soak in for a few seconds. B—Wipe off excess dye penetrant with a clean shop towel. C—Spray developer onto the cylinder head surface. D—The developer makes dye that has collected in a crack show up as a bright red line.

Some larger machine shops have a cylinder ***head pressure testing machine***, which seals all oil and coolant passages and then pressurizes the head to check for leakage. A rubber gasket is clamped down on the deck surface to cover and seal passages through the cylinder head. Air is then forced into the water and oil jackets in the head. The assembly is lowered into a vat of water. Any leakage, such as from cracks or casting flaws, will be made evident by air bubbles in the tank of water. See **Figure 58-8**.

Repairing Cracked Heads

When a cylinder head is cracked, it can be welded, plugged, or more commonly replaced. Plugging involves drilling a series of holes and inserting metal plugs to fix the crack. Replacement is usually the most cost-effective fix. With expensive or discontinued heads, however, plugging or welding may be the only option.

Head Disassembly

Service Procedure

To remove the valves from a cylinder head:

1. Hit the spring retainers with a plastic hammer to free the keepers from the valve stems.
2. Compress the springs with a valve spring compressor, **Figure 58-9A**.
3. Use your fingers or a small magnet to lift the keepers out of the valve stem grooves.
4. Release the compressor and remove the spring assembly from the valve, **Figure 58-9B**.
5. Repeat this procedure on the other valves.

Keep all parts organized so that they can be reinstalled in the same locations. Valve stems may be select-fit from the factory. Reinstalling in the same location will also match any wear patterns on used parts during reassembly.

Warning

Wear eye protection when using a valve spring compressor. If it slips off the retainer, spring pressure could make parts fly off and injure your eyes severely.

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Sunnen

Figure 58-8. Pressure testing a cylinder head to find cracks. A—The head is mounted in the machine and ready for testing. All oil and coolant passages are sealed. B—Rubber gaskets are used to seal the head. C—A metal flange is placed over the rubber gasket so the clamp pressure will seal all oil and coolant passages. D—After the head is lowered into the vat of water, air pressure is injected into the head.



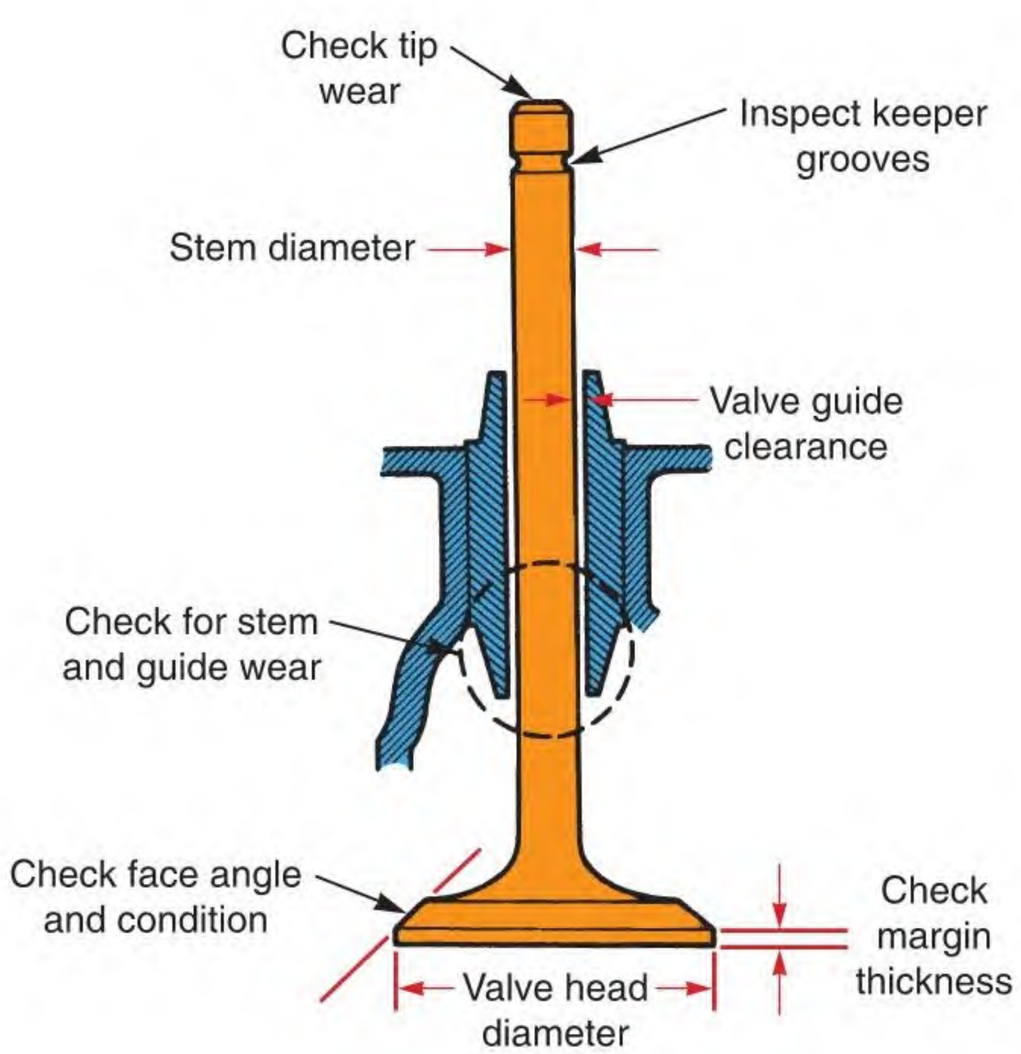
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Figure 58-9. Removing valves and valve springs from the head. A—Fit the valve spring compressor over the valve head and valve retainer. B—Once the valve spring is compressed, a small magnet is handy for removing the valve keepers.

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Valve Guide Service

Excess ***valve guide wear*** allows the valve stem to move sideways in its guide during operation. This is a common problem that can lead to a light knocking or tapping sound, burned valves, or valve breakage. Worn valve guides can also lead to oil consumption as oil leaks past the valve seal and through the guide. A burned valve occurs because of valve wobble in its guide and the poor valve-to-seat seal. See **Figure 58-10**.



Chrysler

Figure 58-10. Look for these kinds of problems when servicing valves and valve guides.

Measuring Valve Guide and Stem Wear

To check for valve guide wear, slide the valve into its guide. Pull it open about one-half inch. Then, try to wiggle the valve sideways. If the valve head visibly moves sideways in any direction, the guide or stem is worn.

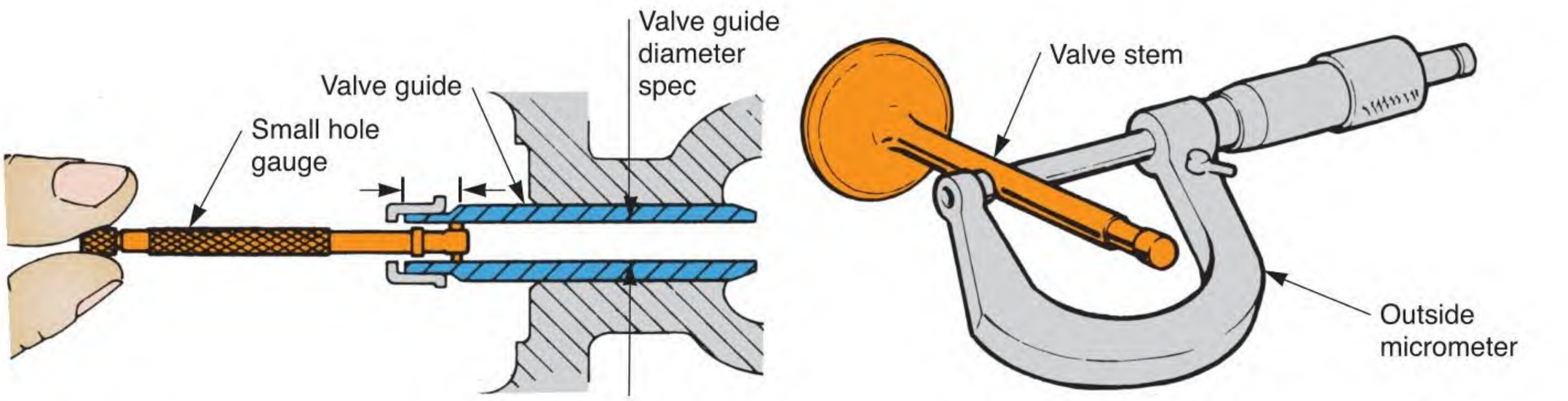
Figure 58-11 shows how a small hole gauge and an outside micrometer are used to measure valve guide and valve stem wear.

Figure 58-12 shows how a dial indicator is used to measure valve stem clearance. Mount the indicator stem against the side of the valve head. Wiggle the valve sideways and read the indicator. Check in different positions and compare readings to specs. If clearance is not within specs, part replacement or repair is needed.



Honda

Figure 58-12. Valve guide wear and clearance can be measured with dial indicator at the stem or valve head.



Chrysler; Honda

Figure 58-11. Note how to check for loose, worn valve guides. A—Use a hole gauge to measure the inside diameter of a valve guide. B— Measure the valve stem at these points. Subtract the valve stem diameter from the valve guide diameter to calculate clearance.

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Repairing Valve Guide Wear

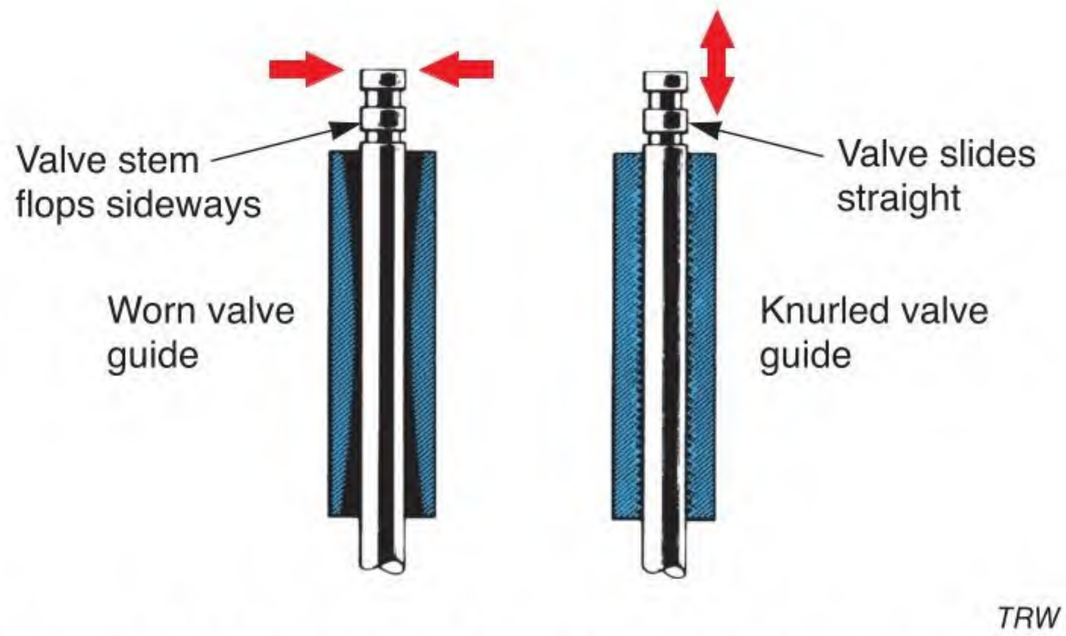
The following are four methods commonly used to repair worn valve guides:

- Knurling the valve guide—A machine shop tool is used to press indentations into the guide to reduce its inside diameter, **Figure 58-13**. A knurled guide must be reamed to size.
- Reaming the valve guide—The guide is hand cut to a larger diameter. New valves with oversize stems are then installed.
- Installing a new valve guide insert—The old guide is pressed or machined out and a new valve guide insert with the original ID is pressed into the oversize hole in the cylinder head. This allows the use of valves with standard OD stems. If possible, heat the cylinder head in hot water or an oven. This will expand the head casting and valve guide bores to help free the valve guide from the casting. Then, drive the valve guide out from the combustion chamber side of the cylinder head. Drive the new valve guide into place to restore valve-to-stem clearances. Refer to **Figure 58-14**.
- Installing a bronze guide liner—The old guide is reamed and a thin guide liner is installed to provide a normal clearance between the stem and guide.

Most machine shops have a valve guide machine to speed the rebuilding of cylinder head valve guides. This machine is basically a large, precision drill press that accurately drills and reams the valve guide holes to a larger diameter.

Place the head on the movable table and initially square it by sight, **Figure 58-15A**. An electronic gauge can then be inserted into a valve guide to help in final squaring of the cylinder head deck on the machine, **Figure 58-15B**. The electronic readout shows if the head is square on the machine or needs to be moved. A bubble gauge can also be used to square the head on the machine, **Figure 58-15C**. If the machine is level, the head must be level. The bubble must be centered inside the level lines on the gauge in both directions.

If the guides are an integral part of the head (not pressed in), they must be machined oversize to accept new valve guide inserts.



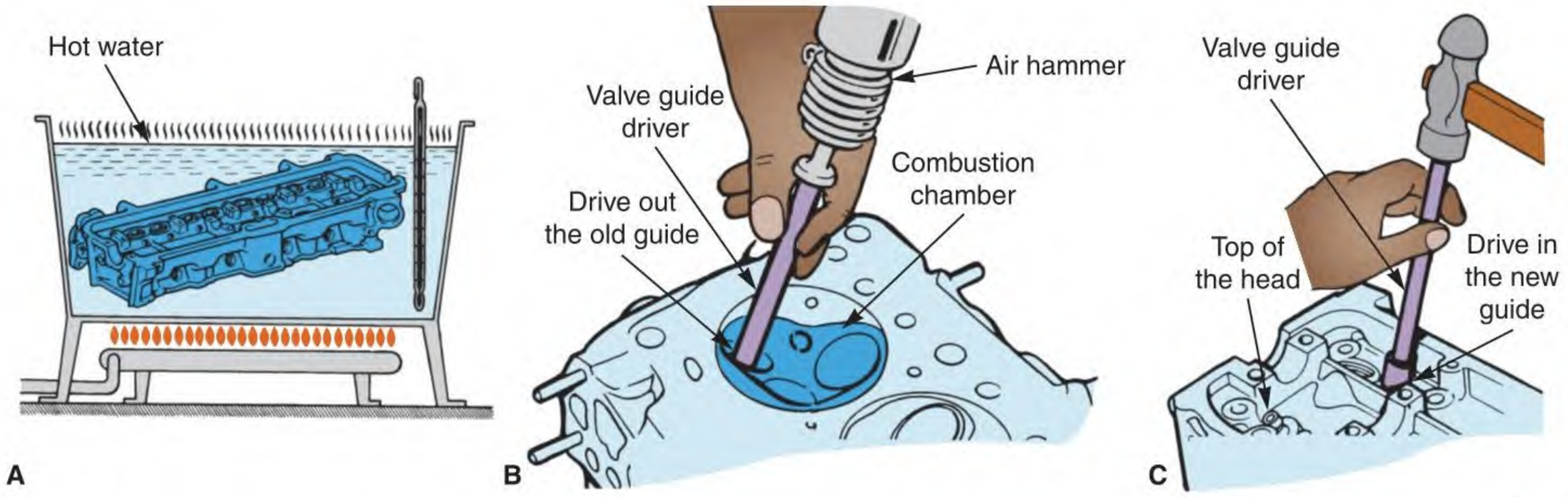
TRW

Figure 58-13. Knurling can be used to decrease the inside diameter of a valve guide, restoring proper stem-to-guide clearance.

Service Procedure

To replace an integral valve guide (formed in head casting):

1. Select the correct diameter drill bit and reamer specified for the valve guide insert.



Toyota

Figure 58-14. This aluminum head has pressed-in valve guide inserts. A—Heat the head in a hot water bath. B—Drive out the old guide from the combustion chamber side of the head. C—Drive in the new insert from the top of the head.

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Figure 58-15. Mounting a cylinder head in a valve guide machine. A—Place the head on the movable table and square it by sight. B—Use an electronic gauge inserted into a valve guide to square the head on the machine. C—A bubble level can also be used to square the head on the machine. The bubble must be inside level lines.

2. Install the core drill into the machine, **Figure 58-16A**. This is used to rough machine the bore to within about 0.015″ (0.38 mm) of the size needed for the insert.
3. Center the core drill over the integral guide.
4. Engage the machine head and lower the drill through the guide.
5. Disengage the machine head. Install the correct reamer.
6. Engage the machine head and ream the guide to the final size, **Figure 58-16B**. The reamer also creates a smooth surface for the press fit of the new guide insert.
7. Repeat this operation on other valve guides that are worn and must be replaced.
8. Use an air hammer and driver to force the new guide insert(s) into the cylinder head, **Figure 58-16C**.

Valve Seat Reconditioning

Valve seats are also exposed to tremendous heat, pressure, and wear. ***Valve seat reconditioning*** involves using a grinding stone or carbide cutter to resurface the cylinder head valve seats. Inspect the valve seats closely for problems such as burning, cracks, wear, and excess width. If the seat is badly worn or burned, too much grinding may be needed to recondition the seat.

Valve Seat Resurfacing

After new seat installation or when the old valve seats are in serviceable condition, grind or cut the face of the valve seats. The equipment needed to grind valve seats is shown in **Figure 58-17**.



Sunnen

Figure 58-16. Installing a valve guide insert. A—Select the correct size core drill and install it into the machine. B—After using the core drill, use a reamer to machine the bore to the final size and smoothness. C—Use an air hammer and driver to force the new guide insert into the cylinder head.

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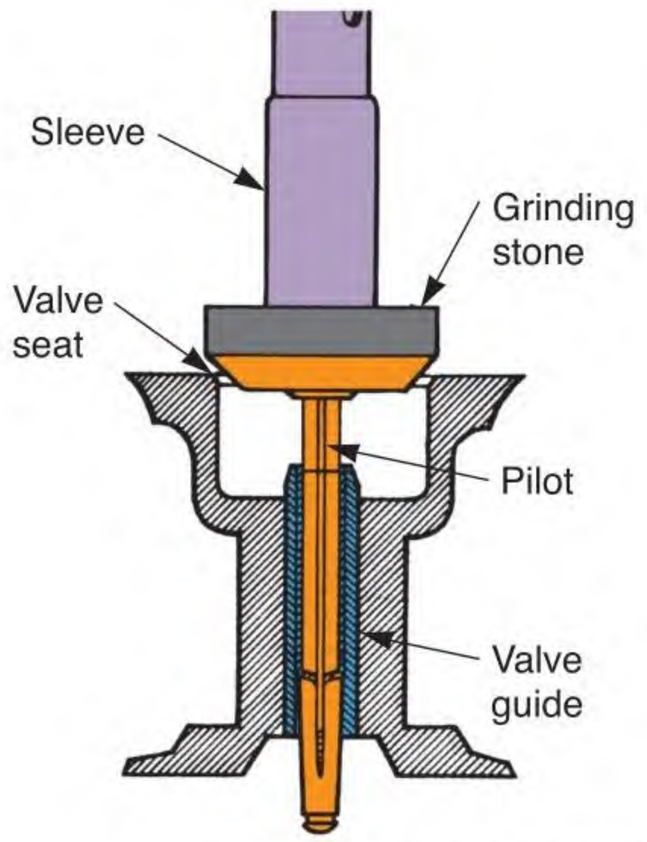
Sioux Tools

Figure 58-17. One type of valve seat grinding equipment.

Selecting Stone and Pilot

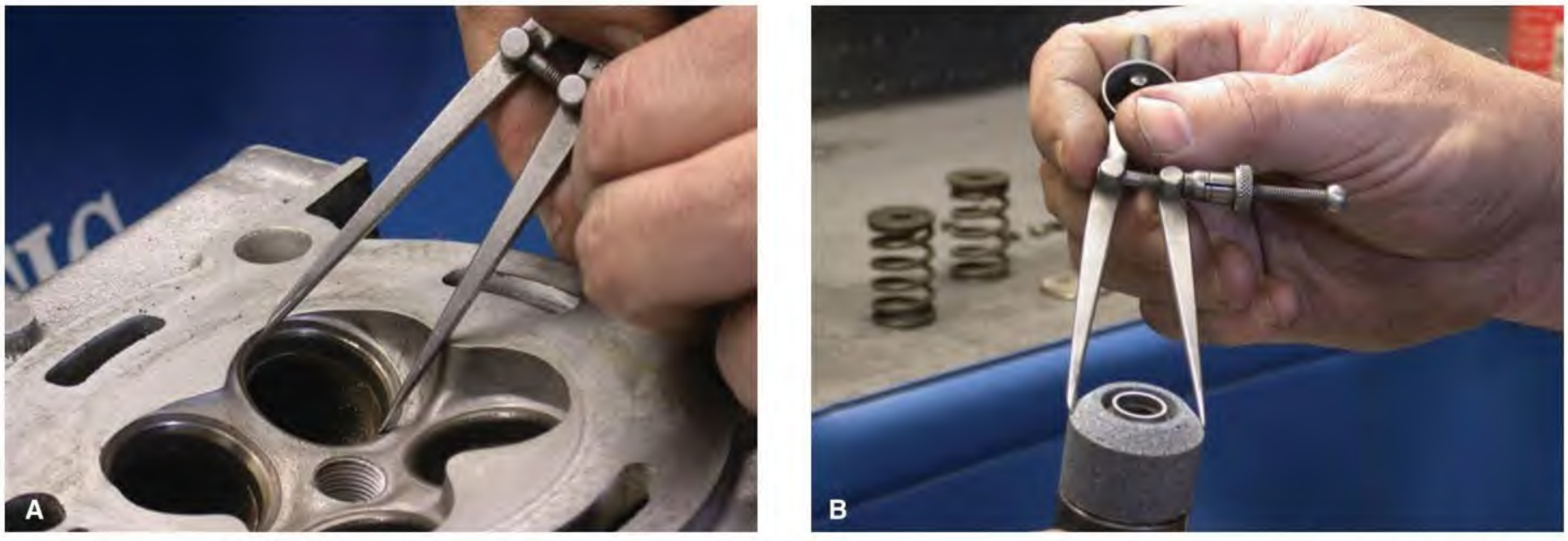
The ***seat stone*** is used to cut a fresh surface on the face of the valve seat. It is a grinding stone mounted on a metal drive attachment. To find the correct-size stone for the valve seat, first measure the valve seat diameter using dividers. Adjust the dividers to the largest diameter of the seat, and then compare the dividers to different stones until you find a stone that matches. See **Figure 58-18**. The stone should be slightly larger than the seat, but it must not hit the side of the combustion chamber. The stone must also have the correct angle, which is usually 45°, but sometimes 30°.

The ***pilot*** is a steel shaft that is installed in the valve guide to support the grinding stone. Since valve guide diameters vary, you must find the correct size pilot. Find one that slides down into the guide far enough, yet fits the guide snugly. See **Figure 58-19**.



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Figure 58-19. This cutaway view shows how the steel pilot, grinding stone, and drive sleeve fit on the cylinder head for valve seat grinding. The pilot must fit snugly in the valve guide so the stone accurately resurfaces the valve seat in combustion chamber.



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Figure 58-18. To determine the correct grinding stone size, first measure the valve seat diameter. The grinding stone must not hit the sides of the combustion chamber. It must also extend fully down inside valve seat. A—Adjust the dividers to the diameter of the valve seat. B—Compare dividers to the inner and outer edges of the stone to find the correct diameter stones for intake and exhaust valve seats.

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Dressing Stone

A ***stone dressing tool*** is used to resurface the face of the seat stone, **Figure 58-20**. The angle of the stone dressing tool must be set at the angle to which the seat will be ground. If you are going to do a three-angle valve job, you will need three stones, one dressed at 30°, one at 60°, and one at 45° (typically).

Always dress a valve seat stone before doing a valve job. The face of a stone that is used too much will wear away and become indented or curved, preventing a flat valve seat.

Service Procedure

To dress a stone:

1. Mount the correct size stone on its pilot and place it on the stone dressing tool.
2. Lubricate the pilot with a drop of oil. Adjust the diamond cutter so it almost touches the stone. Make sure the diamond will clear the stone slightly before spinning the stone with the power head.
3. Verify that everything is adjusted properly.
4. Spin the stone with the power head.
5. Slowly feed the diamond into the stone until it just touches the stone. The diamond cutter can be ruined if it is adjusted too far into the stone. The stone can grind metal away from the diamond and the diamond can fall out.
6. Move the lever up and down to true the entire face of the stone.
7. Only remove as much of the stone as needed to provide a proper grinding surface. This will resurface the stone and ready it for use on the cylinder head.

Warning

When dressing a seat stone, keep your hands, loose clothing, jewelry, and long hair away from the spinning stone. Make sure you are wearing eye protection.

Grinding Valve Seats

A T-handle tool is usually provided for installing the pilot. Push down and twist to fit the pilot into the guide. If the pilot is an expanding type, slide the pilot down into the guide and then tighten its adjusting bolt lightly until the pilot is locked into the guide. The pilot must not be loose in the guide. Refer to **Figure 58-21A**.

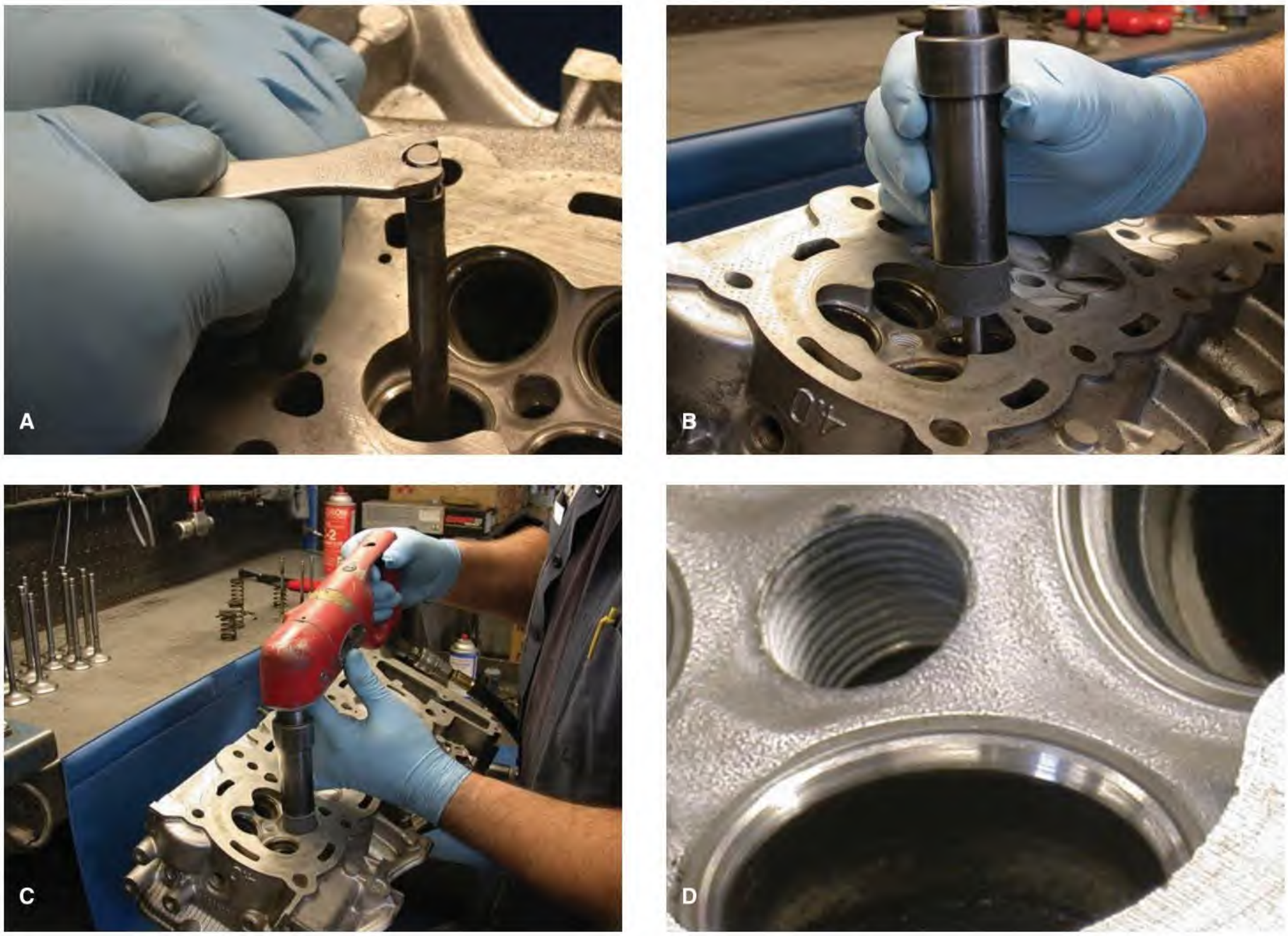
Screw the stone onto its drive head and check its fit on the seat. If the stone is too small, the seat can be ruined by even momentary grinding. After you are sure the stone is the correct size and dressed properly, you are ready to grind the valve seat.



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Figure 58-20. Dressing a valve seat grinding stone. A—Place the hand-tightened stone and arbor assembly on the dressing tool. Adjust the diamond so it clears the face of the stone. Spin the stone with the power head. B—Slowly feed the diamond dressing tool into the stone as you move the dressing tool across the face of the spinning stone. Turn the adjustment screw a small amount at a time to avoid tool and stone damage.

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Figure 58-21. Grinding valve seats. A—Select the correct diameter pilot and push it into the valve guide. Twist and push down or tighten the steel pilot until it is snug in the cylinder head. B—Fit the stone and arbor assembly over the pilot. Turn it by hand to check its fit on the seat. C—Spin the stone and arbor with the power head. Do not push down on the power head; just hold the tool straight as you grind the seat. D—After about three seconds of grinding, inspect each valve seat to make sure all pits and dark areas have been removed.

Service Procedure

To grind and resurface a valve seat:

1. Place a drop of oil on the pilot.
2. Slide the stone down over the pilot and onto the seat, **Figure 58-21B**.
3. Install the power head onto the stone driver.
4. Use one hand to support the power head and the other to operate the trigger. See **Figure 58-21C.**
5. Engage the power head and grind the seat for a second or two. Do not push down; just let the weight of the tool do the work. Simply hold the tool square and steady.
6. Remove the stone and inspect the seat, **Figure 58-21D**. If the seat is shiny all the way around, no more grinding is needed.

Caution

Grind as little as possible to achieve acceptable results. The more you grind, the more the valve will sink into the head, which in turn lowers compression and affects valve train geometry.

7. To improve efficiency, divide your work based on engine valve size. Grind all of the exhaust

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seats first. Then, install the correct-size stone for the intake seats and grind those. This will keep you from repeatedly changing the stone. Try to grind each valve seat for the same amount of time to remove an equal amount of metal.

8. Dress the grinding stone every couple of seats or as needed to true its cutting surface.

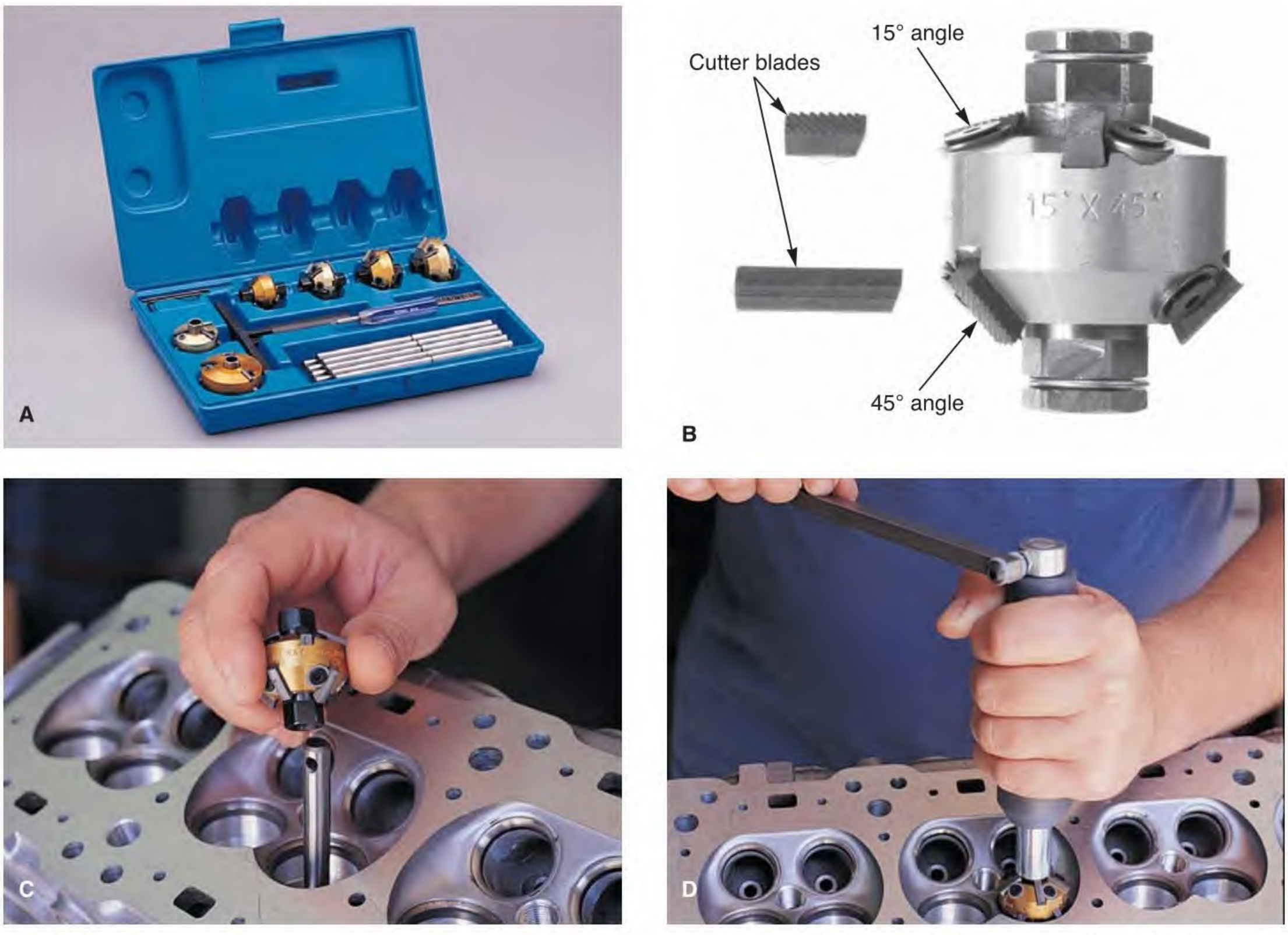
Cutting Valve Seats

The term *cutting valve seats* is used when a carbide cutter, not an abrasive stone, is used to recondition cylinder head seats. Cutters are made of very hard carbide steel that will machine the valve seat accurately. Note how the small carbide blades fit into the tool. **Figure 58-22** shows a carbide valve seat cutting tool.

To use the cutter, select the correct size and angle cutter. Make sure the blades are installed properly. Install the pilot in the head and slide the cutter over the pilot. Then, use the handle to rotate the cutter on the seat. Cut only long enough to clean up all dark areas on the seat. The cutter may also be rotated by a low-speed drill, but refer to the operating instructions supplied with the cutter. Repeat on the other seats as needed.

Checking Seat Concentricity and Width

After grinding or cutting the seats, most technicians or machinists check ***concentricity***, or seat runout. To



Neway Manufacturing, Inc.

Figure 58-22. Carbide steel cutters can be used instead of grinding stones. A—Note the different size arbors and pilots in this carbide steel valve seat cutter kit. B—This tool has a 15° angle on the top and 45° angle on the bottom. C—Select the correct size pilot for the size of valve guides in the cylinder head. Also, select the correct size and angle of the arbor. If valve seats have 45° angle, select a cutter with 44°. D—Rotate the cutter against the seat by hand until the seat is machined and cleaned up.

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do this, a special runout gauge is mounted on the seat, **Figure 58-23A**. Then, the gauge is rotated around the seat face. The indicator shows the seat runout. If it is not within specifications, the seat was installed or ground incorrectly.

Grinding or cutting widens the seat. You must check the ***seat width***, **Figure 58-23B**. This is the area of the valve seat that actually makes contact with the valve face. Measure the seat width. If it is wider than specifications, you will have to narrow the seat face to reposition the seat contact point.

Narrowing Valve Seats

After prolonged service, the seat can wear away from heat and friction created by the valve action. Then, after grinding, the seat can be too wide or contact the valve too far out on the face.

Seat narrowing, also called seat positioning, is needed so the seat contacts the valve face correctly. For example, if the seat angle is 45°, 15° (or 30°) and 60° stones can be used to move the seat and narrow it. Grinding the outer and inner seat surfaces can be done to narrow and move the seat. This is sometimes called a ***three-angle valve job*** because three different stone angles are used. It is sometimes done to increase engine power. A rounded or curved seat can be cut by some cutters. The radius allows more air-fuel flow past the opened valve. This is commonly done to racing engines to gain a few horsepower.

Figure 58-24 shows how a carbide cutter is used to position and narrow a valve seat. Estimating the seat width and location before cutting will help you know how much to cut with each angle. This principle also applies to using cutting stones to do a three-angle valve job. First, a 60° cutter is used to remove material from the inside diameter of the seat. Then, a 15° cutter is used to remove metal from the outside diameter of the seat as needed. Finally, the correct cutter angle (45° in this example) is used to resurface the face of the seat.

Moving the Seat Contact Point

If the valve seat does not touch the valve face properly because of the wrong width or location on the valve, regrind the seat using different stone angles. Just as when narrowing the seat, use 15° or 30° and 60° stones.

To move the seat *in* and narrow it, grind the valve seat with a 15° or 30° stone. This will remove metal from around the top of the seat. The seat face (valve contact surface) will move closer to the valve stem.

To move the seat *out* and narrow it, grind the valve seat with a 60° stone. This will remove metal from the inner edge of the seat. The seat contact point will move toward the margin, or outer edge of the valve. See **Figure 58-25**.

Valve Retrusion

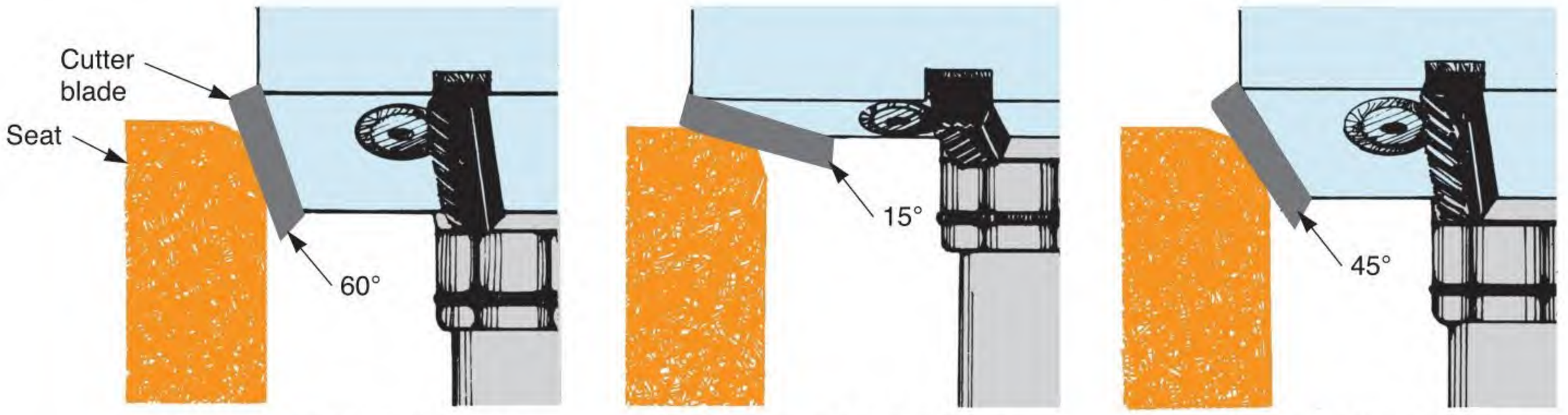
Valve retrusion occurs when the valve seat and valve face wear, resulting in the head of the valve being recessed in the head as shown in **Figure 58-26**.



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Figure 58-23. It is a good idea to check the valve seat concentricity around the valve guide after grinding. A—A dial indicator tool can be rotated to check that the seat is equidistant around the valve guide. Ideally, the indicator needle should not move when rotated 360° around the seat. B—A small graduated scale is used to measure the seat width and compare it to specifications. A badly worn seat will be too wide after grinding.

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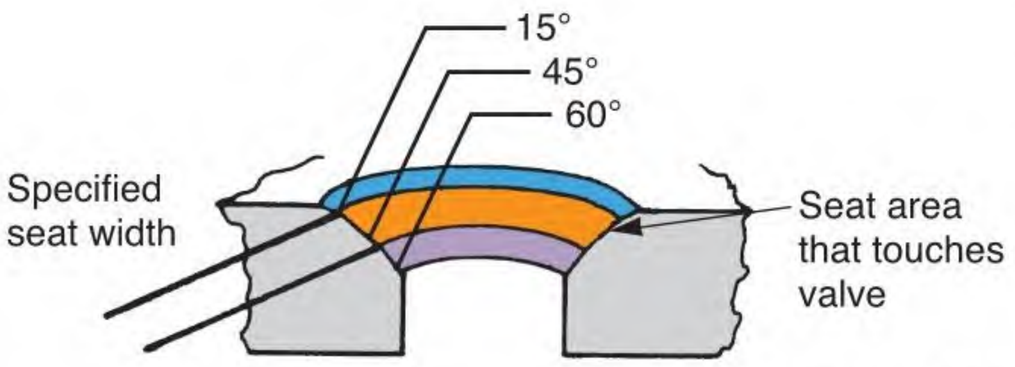
First cut cleans and reconditions area below seat.

Second cut cleans and reconditions area above seat.

Three or four revolutions of cutter produce a precision seat.

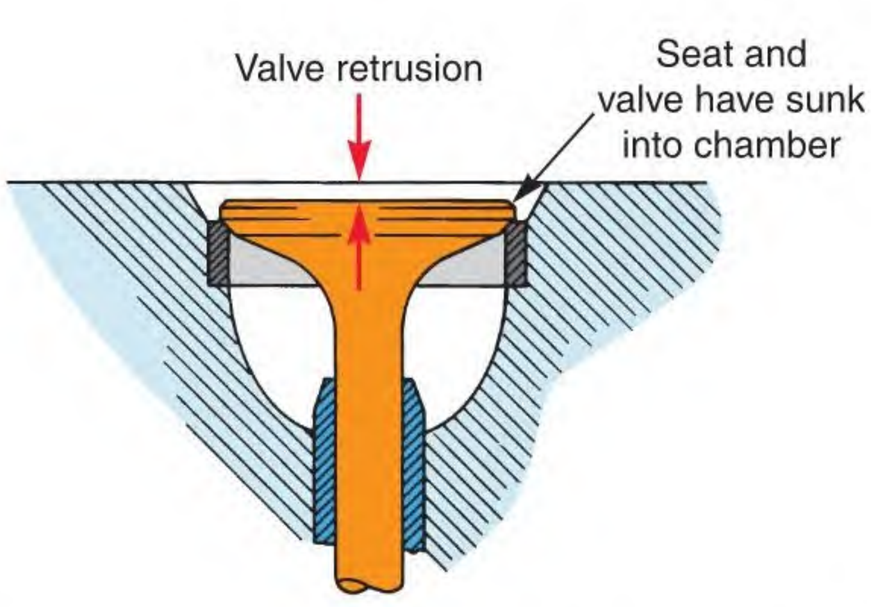
Neway Manufacturing, Inc.

Figure 58-24. Study how a high-performance, three-angle valve seat is produced using a carbide cutter. The three angles of the valve seat position and size the seat so that it touches valve properly. Three angles also form a more rounded surface over the valve seat to increase flow through the seat for more engine power.



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Figure 58-25. Different stone or cutter angles can be used to move or narrow a seat. A 60° cut would narrow seat and move it out on valve face. A 15° cut would narrow seat and move it in on valve face. Move seat in on valve to increase valve and seat longevity. Move seat out near edge of valve to increase flow and engine performance.



Ford

Figure 58-26. Valve retrusion is a condition in which the valve sinks into the combustion chamber due to wear on the valve seat and valve face. The stem also moves farther through the head.

Valve seat retrusion results from heat erosion or seat grinding that causes the valve head to sink into the combustion chamber. The valve stem also protrudes too far out of the other side of the head. Retrusion causes lowered compression, reduced flow through the port, incorrect valve train geometry, and decreased performance. Seat or cylinder head replacement is needed to correct retrusion.

Valve Seat Replacement

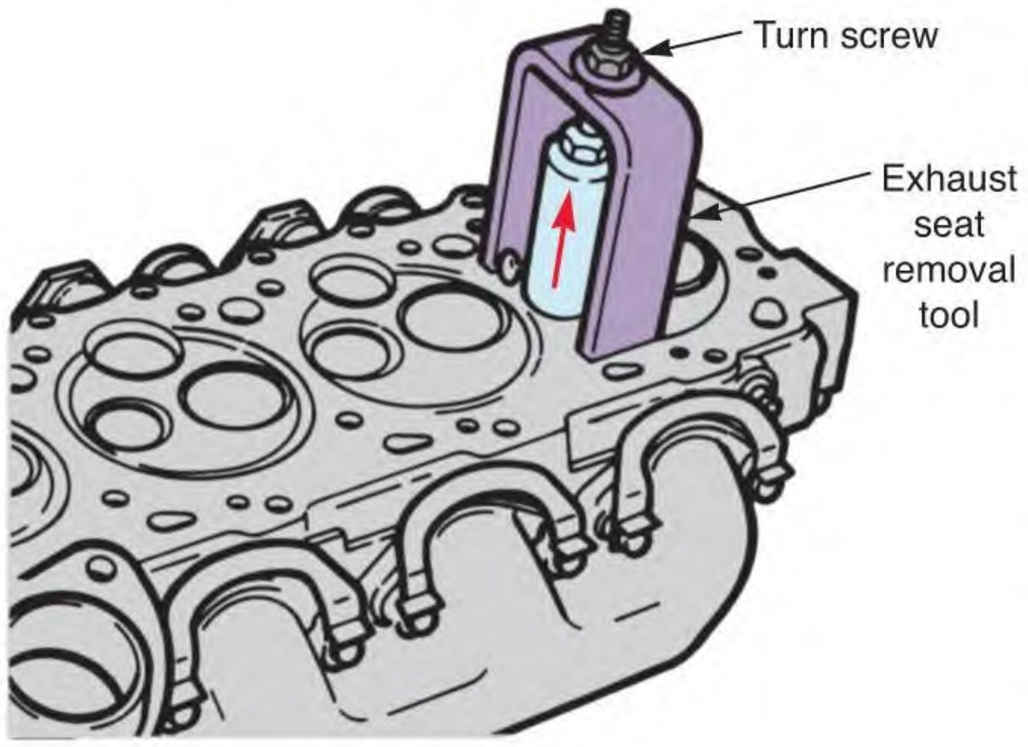
Normally, valve seats can be ground or cut and returned to service. Valve seat replacement is only needed when seat wear or damage is severe.

Most technicians send the cylinder head to an automotive machine shop for seat replacement. Most service shops do not have the specialized tools required for seat removal and installation, especially with integral seats. A new valve seat insert should have an interference fit of around 0.002″ to 0.004″ (0.05 mm to 0.10 mm) to lock the insert securely into the head.

Pressed-in valve seat replacement is not as difficult. Machining is often unnecessary. The old seat is pulled or forced out and a new one installed in the cylinder head. Another way to remove a pressed-in seat is to split the old seat with a sharp chisel. Then, pry out the old seat with a hook-nose chisel or similar tool. Extreme care must be taken not to damage the cylinder head casting. Study **Figure 58-27**.

To install a replacement valve seat, some machinists chill the seat in dry ice or with nitrogen to shrink its dimensions. Others heat the whole cylinder head

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Ford

Figure 58-27. Removing and installing a pressed-in valve seat. A—Use a puller to remove the damaged seat. B—Use a driver and hammer to force the new seat into the head. C—The new seat must be ground to the correct valve angle and contact.

in a furnace or oven to expand the casting and valve seat bores. Either method eases seat installation. When the head and seat return to room temperatures, they will be locked more tightly by an interference fit. Use a driving tool or hydraulic press to force the new seat into its recess in the head casting. Valve seat installation tools vary. Follow equipment directions.

Staking a valve seat so it will not vibrate out of the head involves placing small dents in the cylinder head next to the seat. The stakes push and form a metal tab or protrusion in the head over the seat. This forms a metal lip that keeps the seat in place during engine operation. Top cutting may also be needed to make the top of the seat flush with the surface of the combustion chamber.

Valve Seat Machine

A ***valve seat machine*** is a piece of equipment designed for valve guide and valve seat service. It is a specialized milling machine designed to service automotive cylinder heads. To be a more knowledgeable technician, you should be familiar with machine shop operations. Refer to **Figure 58-28**.

Service Procedure

To use a valve seat machine:

1. Mount and square the head on the worktable. If the machine table is perfectly level, you can use a small bubble level to square the head on the machine quickly.
2. Install the correct size pilot into the valve guide in the cylinder head. Find the valve seat with the most wear, since this will set your maximum cut depth for all of the seats.
3. Slide the damper spring over the pilot.
4. Select the correct tool cutter.
5. Fit the cutter down over the pilot to check its size with the valve seat.
6. Lower the power head and fit it onto the cutting tool.
7. Using the correct cutting speed and feed, machine the valve seat.
8. Use a dial indicator to check seat concentricity or roundness.

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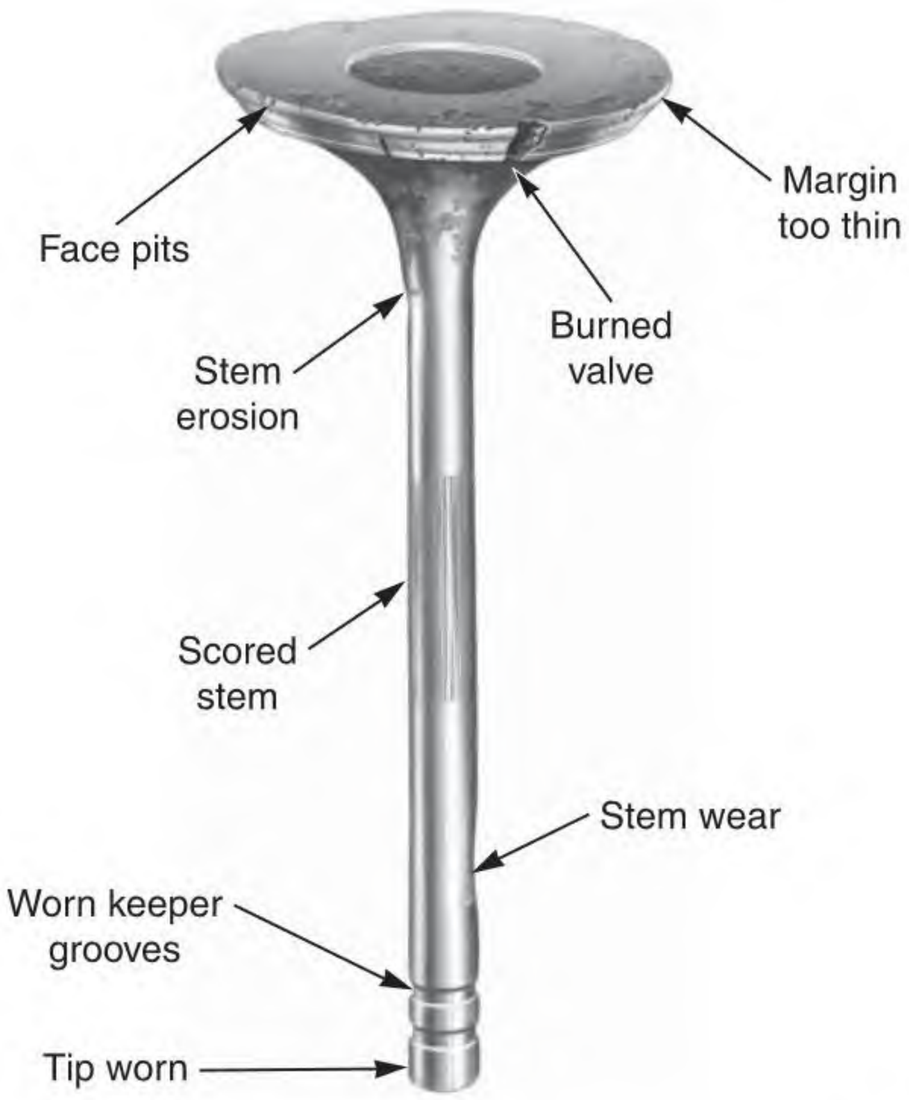
Sunnen

Figure 58-28. Using a valve seat machine to resurface new seats in a cylinder head. A—Fit the cutter down over the pilot to check its size. Rotate the cutter on the seat by hand. B—Slowly lower the power head and fit it onto the cutter. C—Using the correct cutting speed and feed, power rotate the cutter head on the valve seat to the correct depth of cut.

Grinding Engine Valves

Valve grinding creates a fresh, smooth surface on the valve face and stem tip. Valve faces suffer from burning, pitting, and wear due to opening and closing millions of times during the service life of an engine. Valve stem tips wear because of friction from the rocker arms or cam followers. **Figure 58-29** shows various valve problems.

Before grinding, inspect each valve face for burning and each stem tip for wear. Replace any valves that have badly burned or worn faces. New and reused valves must be ground.



Sioux Tools

Figure 58-29. Note some of the problems found on used, high-mileage valves.

Warning

Wear a full-face shield when grinding valves. The stone could shatter, sending debris into your face.

Valve Grinding Machine

A ***valve grinding machine***, shown in **Figure 58-30**, will resurface valve faces and stem tips. Although there are some variations in design, most valve grind machines are basically the same. They use a grinding stone and precision chuck to remove a thin layer of metal from the valve face and tip.

Valve Grinder Setup

Dress the stone with a diamond cutter to true the stone surface before grinding the valves. A diamond-tipped cutting attachment is provided with the machine. Follow the equipment manufacturer's instructions.

Set the chuck angle by rotating the chuck assembly on the valve grinding machine. A degree scale or digital readout is provided so the cutting angle can be set precisely. Normally, you must loosen a locknut and swivel the chuck assembly to the desired angle, as illustrated in **Figure 58-31**.

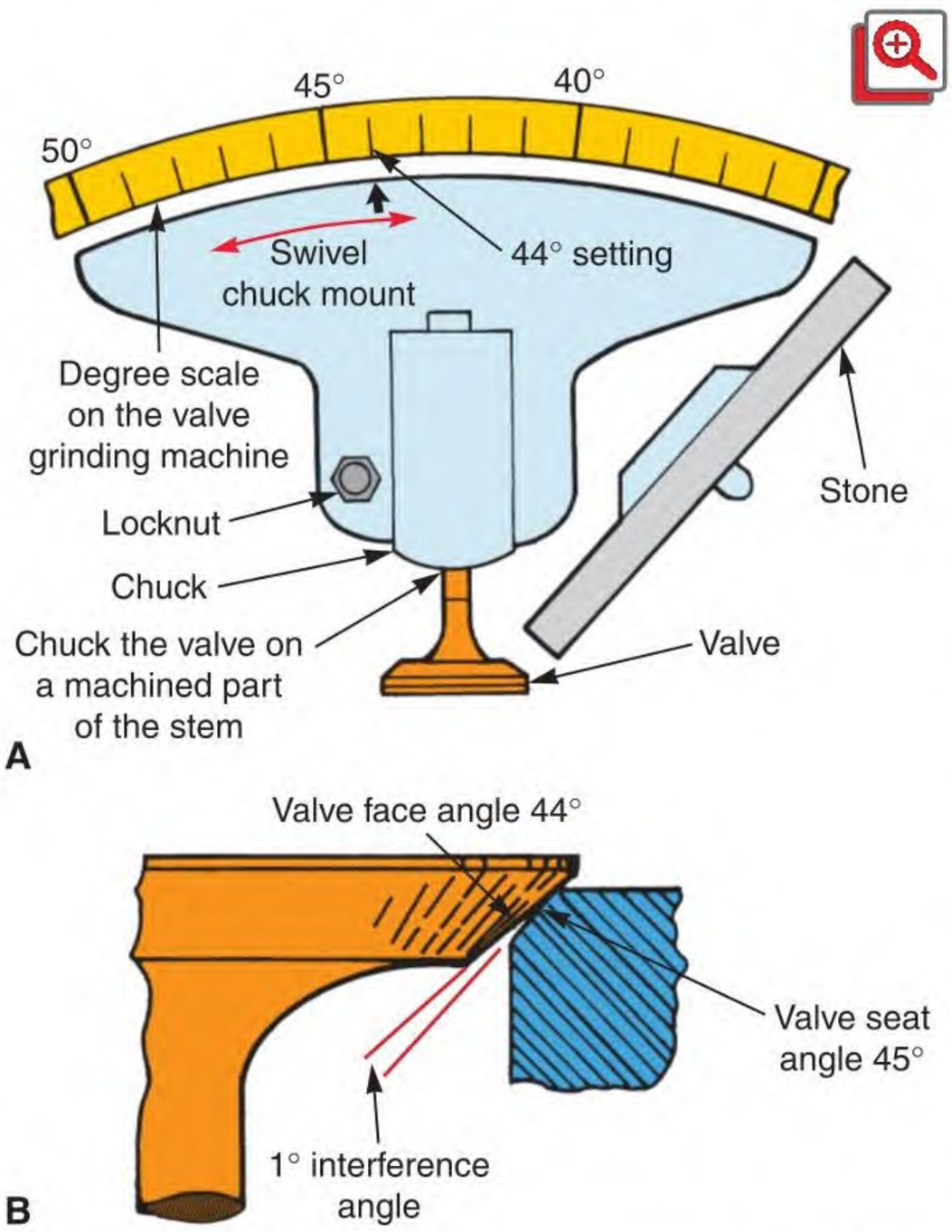
An ***interference angle*** is normally a 1° difference between the valve face angle and the valve seat angle. It is set on the valve grinding machine. If the valve seat angle is 45°, the chuck is set to 44°. This

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Figure 58-30. A valve grinding machine is used to resurface valve faces and stem tips. Note the names of the machine parts.



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Figure 58-31. A valve grinding machine must be adjusted for correct valve face angle, usually 30°–45°. A—Loosen the hold-down and swing the chuck until the scale reads correctly for the valve face angle. B—An interference angle speeds initial valve sealing and prevents rapid widening of the valve face in service. If you grind valve seats at 45°, grind valve faces at 44° to ensure valve sealing.

produces a 1° interference angle between the valve face and seat. The break-in and sealing time of the valve is reduced by using an interference angle.

Chuck the valve in the valve grinding machine by inserting the valve stem into the chuck. Tighten the chuck to hold the valve in the machine securely. Make sure the chuck grasps the machined surface of the stem near the valve head. The chuck must not clamp onto an unmachined surface of the stem, or runout will result. Adjust the feed so the stone does not touch the valve.

Warning

Be very careful when using a diamond tool to dress a stone. Wear eye protection and feed the diamond into the stone slowly. If the diamond is fed in too fast, tool or stone breakage may result.

Grinding Valve Faces

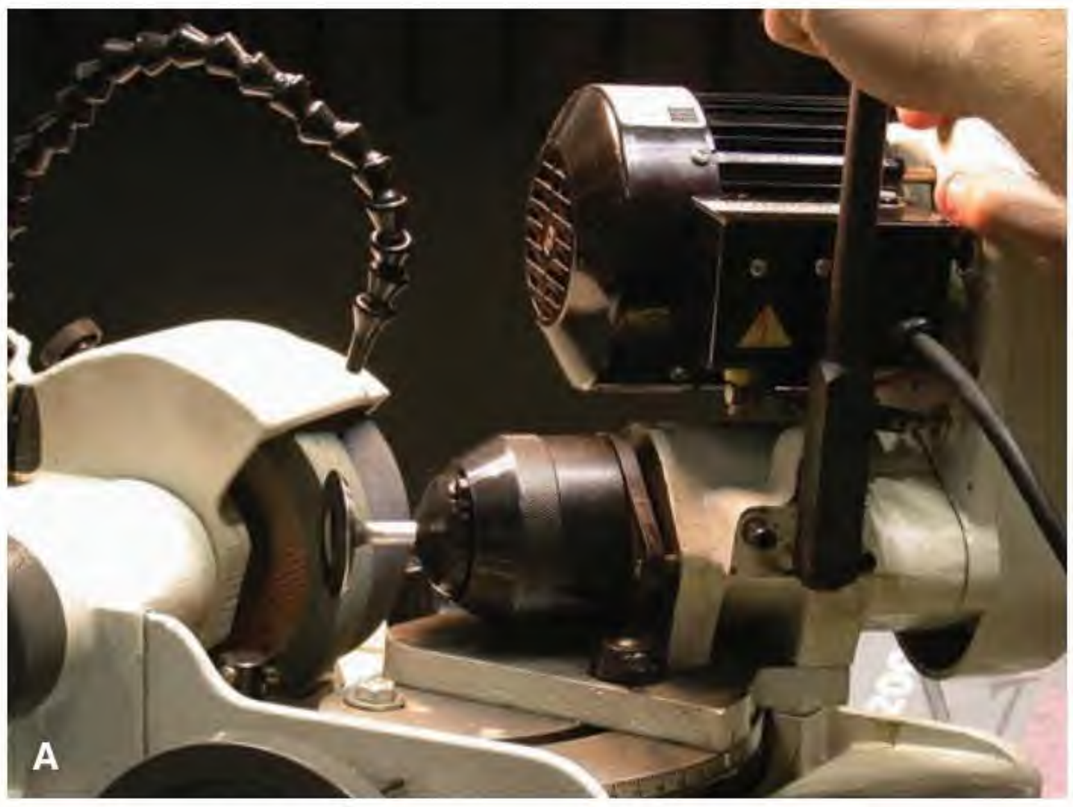
Once the machine is properly set up and the valve properly mounted, turn on the valve grind machine and cooling fluid. Direct coolant onto the valve head while grinding. Feed the valve into contact with the spinning stone very slowly to prevent valve or stone damage. While feeding, slowly move the valve back and forth over the stone. Use the full face of the stone, but do not let the valve face move out of contact with the stone while cutting. See **Figures 58-32** and **58-33**. Grind the valve only long enough to clean up its face. When the full face looks shiny with no darkened pits, shut off the machine and inspect the valve face more closely. Carefully look for pits or grooves.

Repeat the grinding and inspecting operation on the other valves. Return each ground valve to its place in an organizing tray. Used valves should be returned to the same valve guide in the cylinder head. The stems may have been select fit.

If not noticed during the initial inspection, a burned valve will show up when excess grinding is needed to clean up the valve face. A normal amount of grinding will not remove a deep pit or groove in the valve face. See **Figure 58-34A**. Replace the valve if it is burned.

A bent valve will show up when the valve head wobbles as it turns in the chuck. If the valve is chucked improperly, it can appear like a bent valve. Shut off the machine and find the cause. V-blocks and a dial indicator can be used to check the valve to see if it is bent, **Figure 58-34B**.

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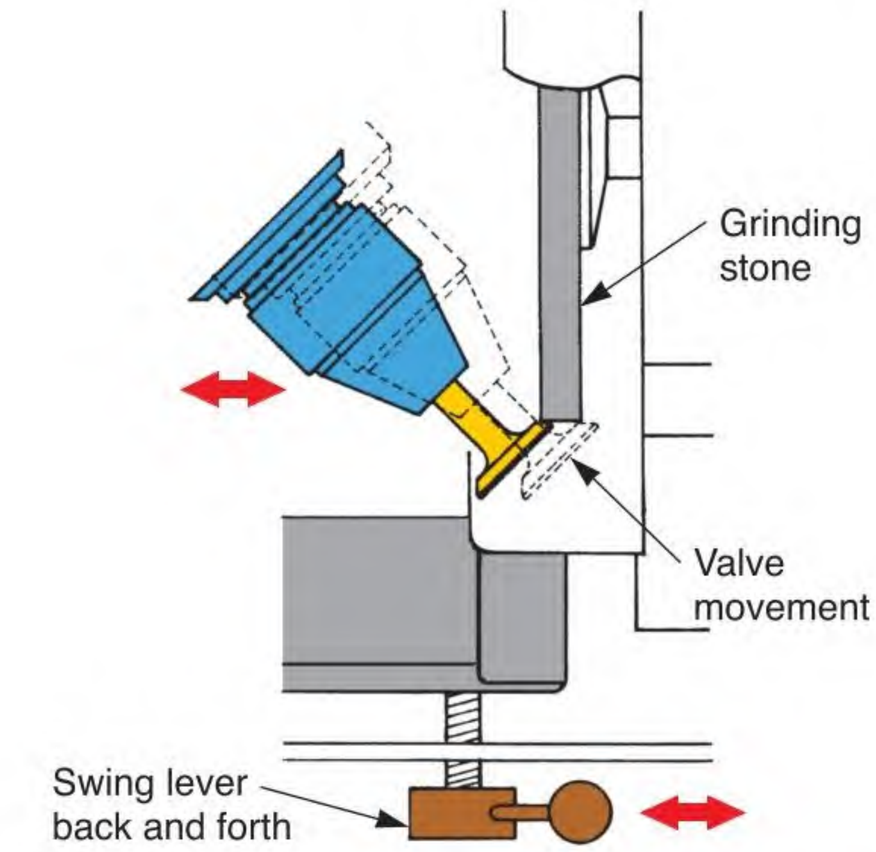
Sunnen

Figure 58-32. Grinding an engine valve face. A—Install the valve in the chuck. B—Direct coolant on the valve head while grinding. Move the valve into the stone slowly to prevent valve or stone damage.

By grinding metal from the valve face, the valve stem will extend through the head more. This will affect spring tension and rocker arm geometry. Grind the face of each valve as little as possible.

A sharp valve margin indicates excess valve face removal and requires valve replacement. Refer to the specification for minimum valve margin thickness. If the margin is too thin, the valve can burn when returned to service. It may not be thick enough to dissipate heat fast enough. The head of the valve can actually begin to melt, burn, and blow out the exhaust port. At high engine rpm, the valve will continue to burn and melt until the cylinder loses compression pressure and fails to fire (produce fuel combustion). See **Figure 58-35**.

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TRW

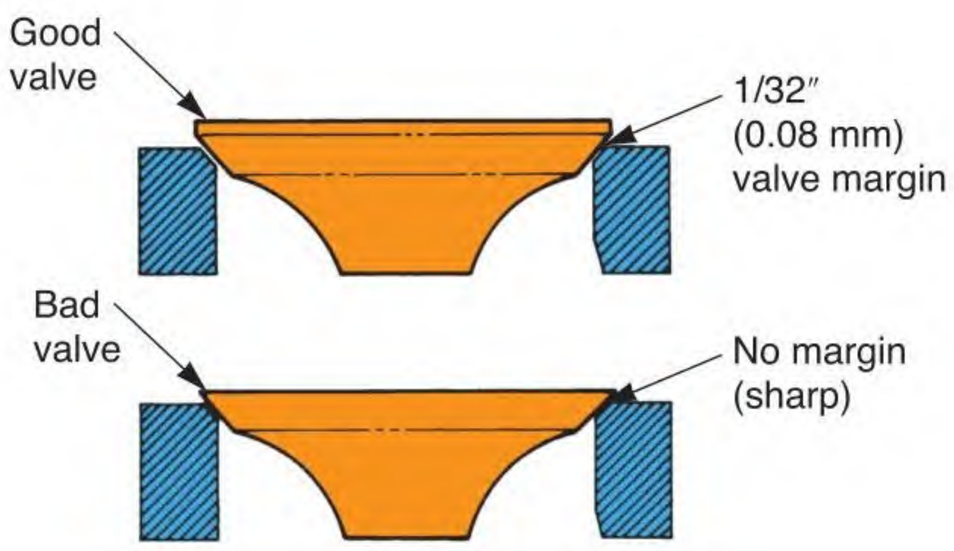
Figure 58-33. Use the lever to move the valve back and forth on the stone, but do not let the valve lose contact with the stone.





Sunnen

Figure 58-34. A close inspection of valve faces is very important. Even the smallest imperfection in a valve face can lead to major engine failure. A—This valve must be replaced. The erosion could not be removed without excessive grinding. B—Mount the valve in V-blocks and turn the valve. The dial indicator will quickly show any bent valves.



A



B

TRW

Figure 58-35. After grinding, measure and inspect every engine valve closely for flaws. A—Too much grinding can remove the margin and sharpen the valve head. B—Calipers can be used to measure the valve margin accurately for comparison to specifications. If the margin is thinner than about 1/16″ (1.5 mm), replace the worn valve.

Grinding Valve Stem Tips

After grinding valve faces, you should also true the valve stem tips. This is done so the valve tip is square to the valve stem. Truing the valve stem tips also corrects for the extra distance that the valve stem extends through the head after valve grinding. Proper valve train geometry is restored. However, if too much material has been worn off of a tip, the valve should be replaced. Check the service manual for specifications.

The second stone on a valve grind machine, which is usually on the right-hand side of the machine, is provided for truing and chamfering valve stem tips. Study **Figure 58-36**.

Service Procedure

To grind and chamfer valve stems:

1. Mount the valve in the V-block chuck that is perpendicular to the stone. Before turning the machine on, make sure the stem is close to the stone, but not too deep.
2. Use the thumbwheel to slowly feed the stem tip into the stone. The thumbwheel has graduations in thousandths of an inch or hundredths of a millimeter to keep track of how far you feed the tip into the stone.
3. Remove approximately the same amount of material from the tip as you removed from the valve face. Generally, cut the same amount of metal off the face and stem of every valve. This will help keep valve train geometry and engine compression ratio correct. Grind as little material as needed to clean up and true the surface of the tip.
4. If you need to chamfer the tip, mount the valve in the V-block chuck that is at an angle to the stone. Then, slowly feed the tip into the stone as you rotate the valve. See **Figure 58-37**.

Caution

Many valve stems are hardened. Too much grinding will cut through the hardened layer of metal. Since the softer metal is exposed to wear, the tip will rapidly wear when the valve is returned to service.

Checking Valve-to-Seat Contact

After the valve is ground, you need to check for proper valve-to-seat contact. To do so, use valve lapping compound or Prussian blue. Some manufacturers do not recommend valve lapping, so refer to a service manual for details. To many technicians and machinists, valve lapping is a good way to check the accuracy of the valve job.

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Lapping Engine Valves

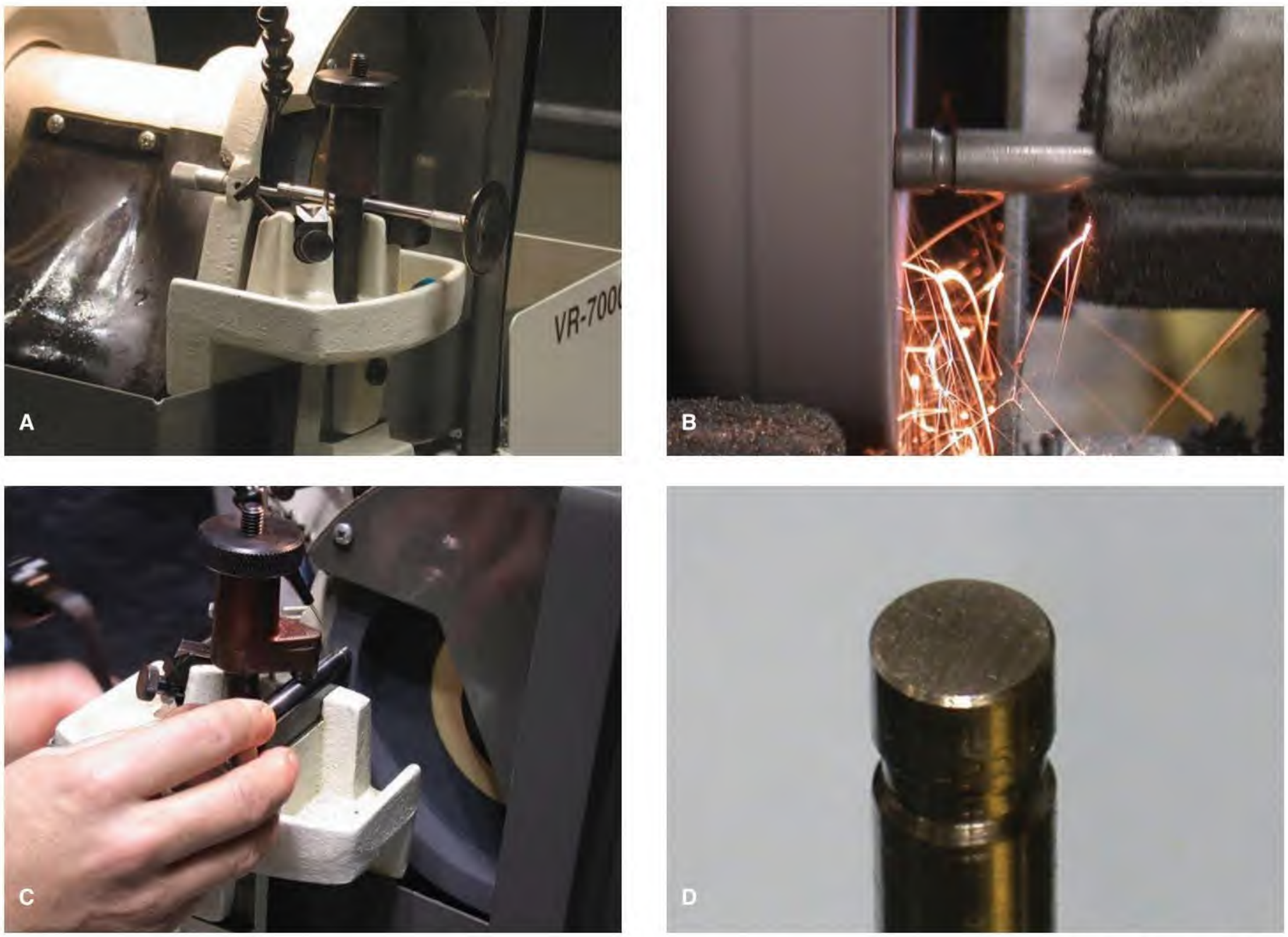
Valve lapping compound is an abrasive paste material. It was once used to resurface metals. It is now commonly used to double-check where the valve is touching its valve seat.

Service Procedure

To use lapping compound to check the valve-to-seat contact:

1. Place a small amount of the compound on the valve face. Spread the compound around the valve face.
2. Place the valve into place in the head.
3. Use a lapping stick to spin the valve on the seat. A ***lapping stick*** is a wooden rod with a suction cup on the end. To turn the stick, rub the palms of your hands together on each side of the stick.
4. Rotate the valve back and forth while picking it up and turning it to a new position on the seat.
5. Remove the valve and check the contact point.

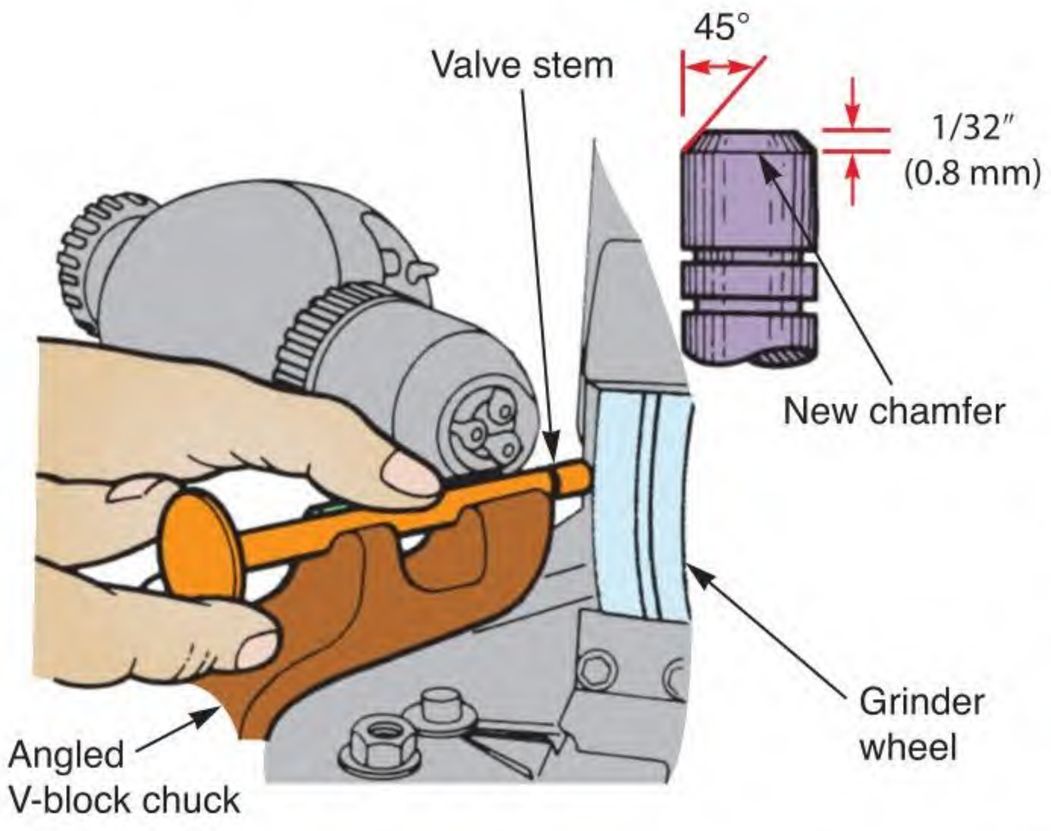
A dull gray stripe around the seat and face is where the valve is making contact with the seat. This will help you determine how to move the valve seat contact point, if needed. See **Figure 58-38**.



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Figure 58-36. Resurface the valve stem tips the same amount as you did on the valve face. A—Mount the valve in the V-block chuck that is perpendicular to the stone. B—Feed the valve stem into the stone slowly until sparks start flying off the valve stem tip. After the valve starts grinding, swing the valve back and forth until it is dressed smooth and flat. C—Grind as little material as needed to clean up and true the valve stem tip. D—The valve stem tip has been resurfaced flat and a small 45° chamfer has been ground on the edge of the valve stem.

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Ford

Figure 58-37. The valve must be mounted in the angled V-block to cut a chamfer around the perimeter of the stem.





VanSenus Auto

Figure 58-38. Hand-lapping valves with a grinding compound or metal particle–filled paste is an easy way to check seat location on the valve. A—Push the rubber suction cup down on the lapping stick so it will rotate the valve on its seat. Rotate the valve back and forth while picking it up and turning it to a new position on the seat. B—Remove the valve and look for the dull stripe all the way around the valve and seat. This stripe shows exactly where the seat touches the valve face.

Caution

Make sure you clean all the valve lapping compound off the valve, seat, and cylinder head. The compound can cause rapid part wear if left in the engine during service.

Prussian Blue

Service Procedure

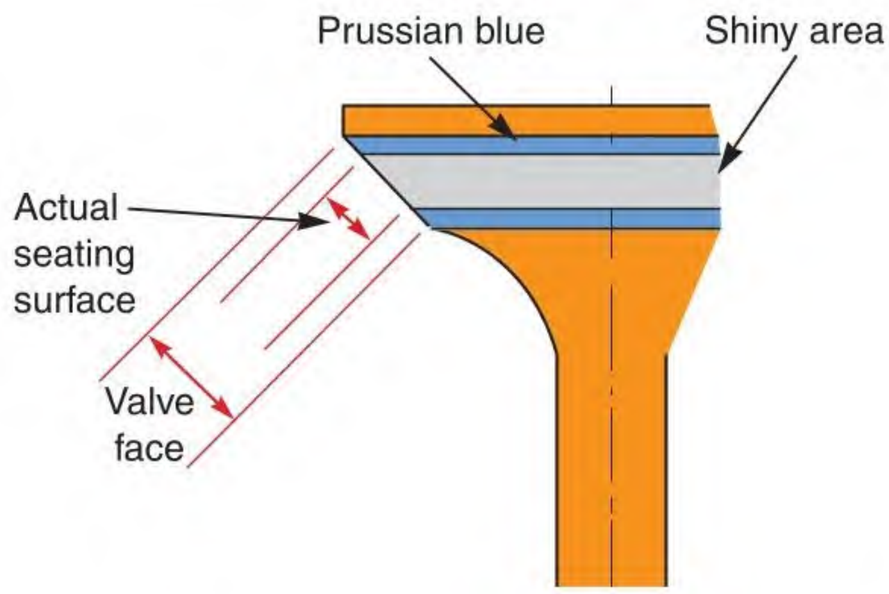
Prussian blue is a metal stain often used to lay out metal parts. It can be used to check valve-to-seat contact.

1. Wipe the dye over the full surface of the valve face.
2. Allow the dye to dry.
3. Insert valve into its correct valve guide in the head.
4. By hand, snap the valve closed on the seat several times.

The contact with the seat will wipe off some of the Prussian blue, making the valve face shiny at the point of contact. This will show you where the valve seat and valve face touch. See **Figure 58-39**.

Contact Patterns

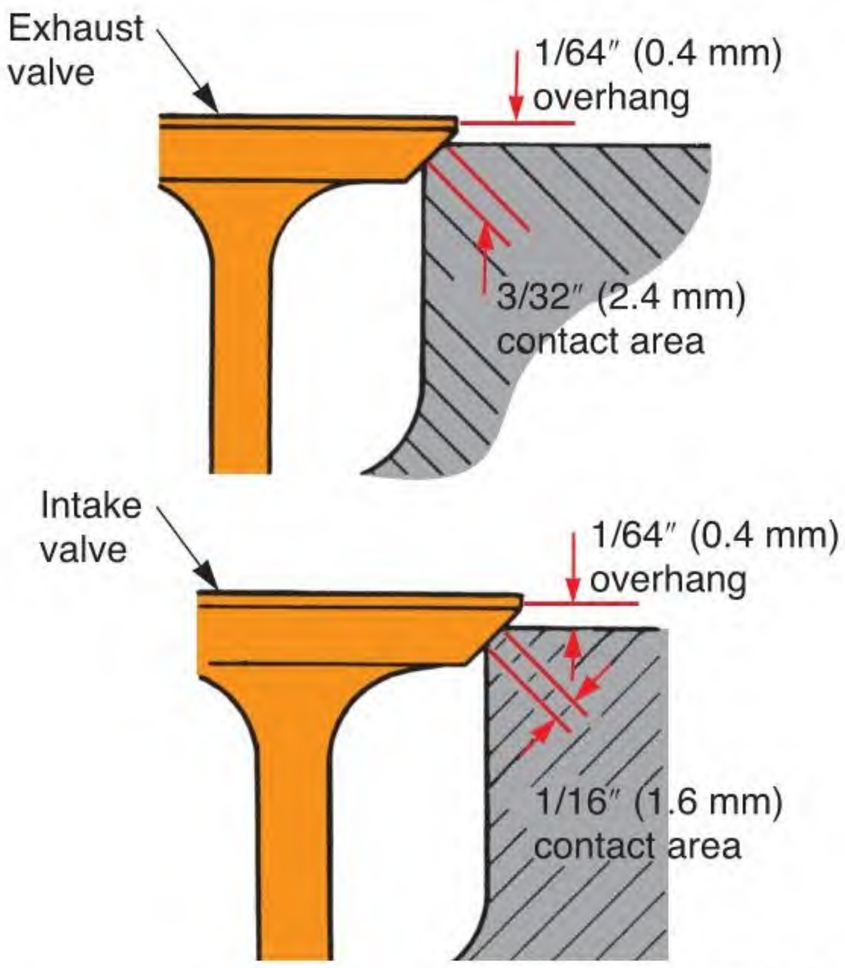
An intake valve should generally have a valve-to-seat contact width of about 1/16″ (1.5 mm). An



Honda

Figure 58-39. When using Prussian blue to check valve-to-seat contact, the shiny metal area, where the bluing compound has been rubbed off, shows the point of the valve-to-seat contact.

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Figure 58-40. Positioning valve-to-seat contact points on intake and exhaust valves. The exhaust seat must be slightly wider than the intake seat to help dissipate heat. Note typical contact width and overhang values.

exhaust valve should have a slightly larger valve-to-seat contact width of about 3/32″ (2.5 mm) to help dissipate heat. Refer to **Figure 58-40**. Check the service manual for exact specifications. Examples of good and bad seat contact patterns are shown in **Figure 58-41**.

Valve Spring Service

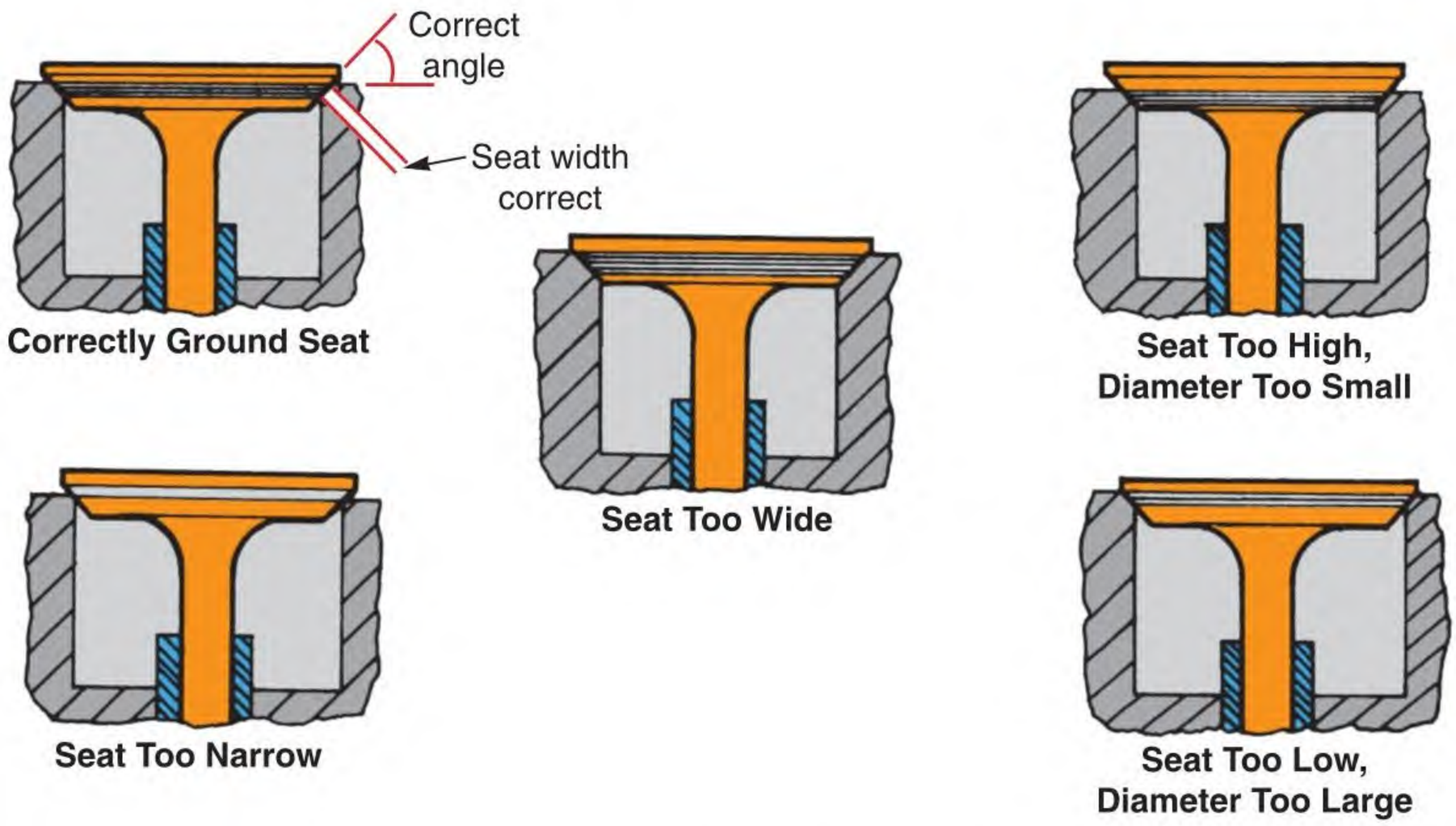
Valve springs tend to weaken, lose tension, or even break after extended service. Always test valve springs to make sure they can be reused. If the engine has over 100,000 miles (160,000 km) on it, install new valve springs.

Inspecting Valve Springs

Valve spring squareness is easily checked with a combination square, **Figure 58-42A**. Place the spring next to the square on a flat work surface. Rotate the spring while checking for a gap between the side of the spring and the square. Replace the spring if it is not square.

Valve spring tension or pressure is measured on a spring tester, **Figure 58-42B**. Compress the spring to installed height or the height given in the specification. Then, read the scale. The spring pressure must be within specifications. If too low, the spring has weakened and needs replacement or shimming. If too high, high-performance springs may have been installed, which may lead to premature valve train wear.

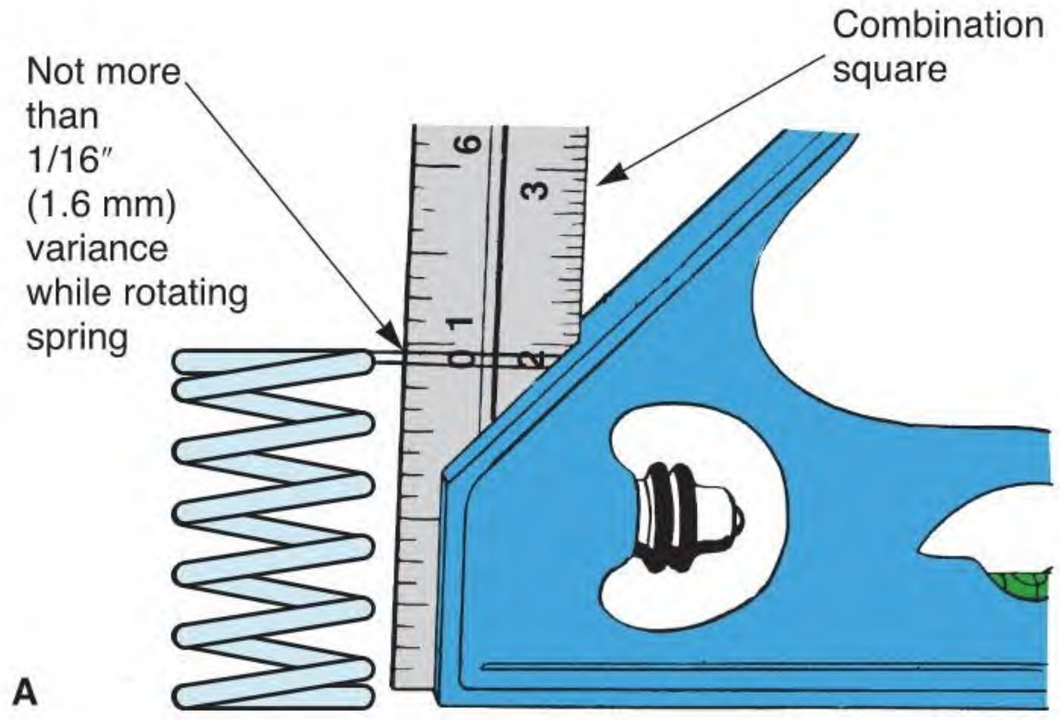
Valve spring free height can be measured with a combination square, caliper, or valve spring tester. Simply measure the length of each spring in a normal, uncompressed condition. Compare the measurement to specifications. If the spring is too long or too short, replace it.



Ford

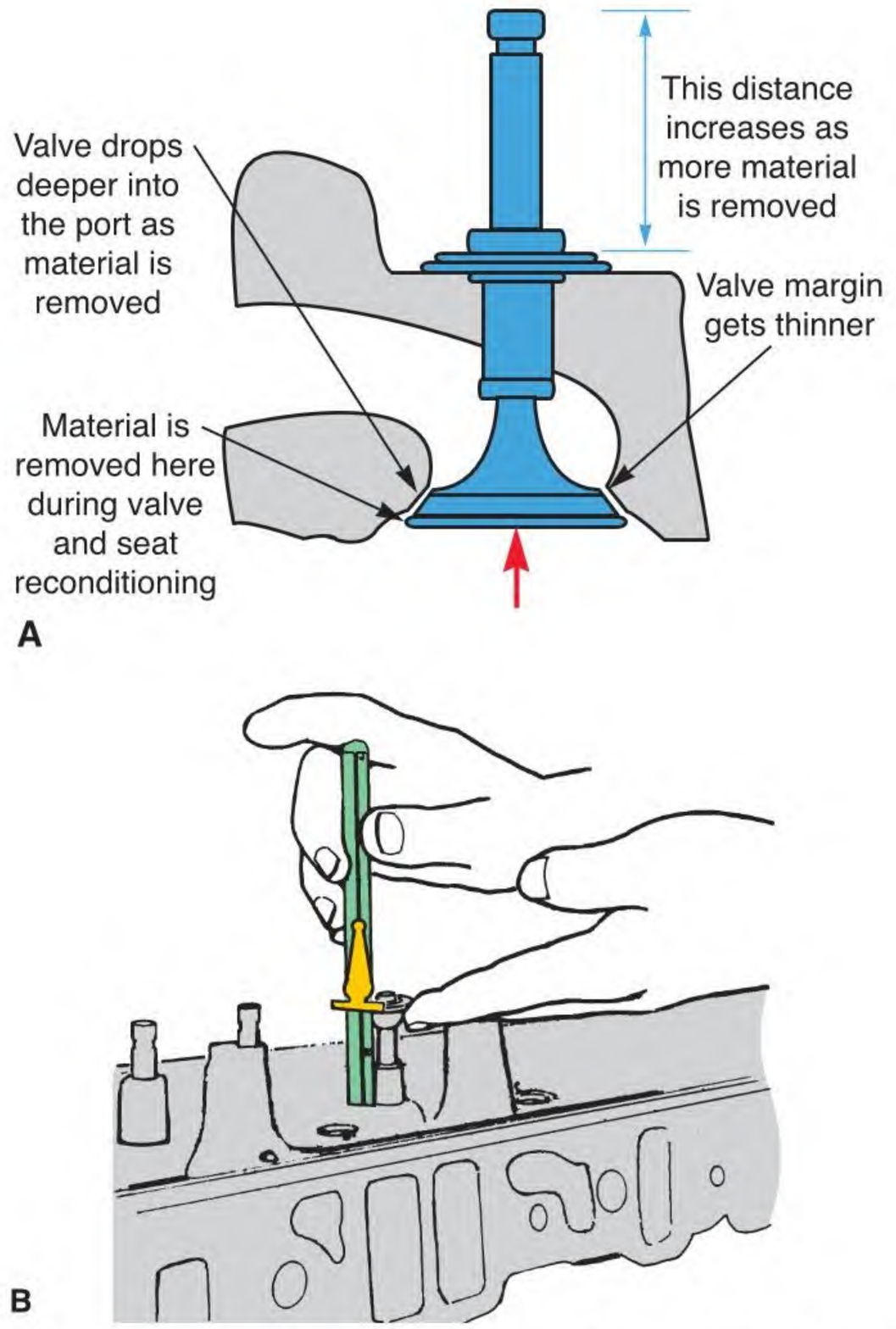
Figure 58-41. Examples of a good and several bad seat contact patterns are shown.

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Toyota

Figure 58-42. If valve springs are to be reused during an engine rebuild, they must be measured and tested before installation. A—A combination square can be used to check valve spring squareness. Replace springs that are not square. B—A valve spring tester measures spring pressure, or tension, at a specific spring height or length. Shim or replace weak springs.



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Figure 58-43. Measuring installed spring heights. A—When the valve and valve seat are ground, the valve stem will extend farther through the head. This will increase the installed spring height and affect spring tension. B—After grinding valves and valve seats, install the valve, retainer, and keepers as shown. Then, measure the valve spring installed height to determine if valve spring shims are needed.

Shimming Valve Springs

Valve spring shims are used to maintain the correct spring tension when the spring is installed on the cylinder head. When valves and seats are ground, the valve stems stick through the cylinder head more. This increases valve spring installed height and reduces spring pressure.

Valve spring installed height is the distance from the top to the bottom of the valve spring when the spring is installed on the cylinder head. Refer to **Figure 58-43**. If valves or seat requires considerable grinding for cleaning, make sure you measure actual installed spring heights. This will let you know what new springs to order or how much each existing spring must be shimmed to restore proper spring compression and tension. If the valve spring installed height is greater than specifications, subtract the stock spring height from the measured height. The result is the total shim thickness needed to return the spring pressure to normal.

Service Procedure

To measure valve spring installed height:

1. Inspect the valve spring retainers and locks for wear. Also, inspect the grooves on the valve stem for wear.

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2. Install the valve, retainer, and keepers.
3. Measure the height from the top of the head to the bottom of the retainer. This distance is equal to the valve spring installed height.
4. Compare the measured height to the specifications. If the height is greater than the specification, spring tension will be lower than normal and valve float may result.

A valve spring tester is used to determine the needed shim thickness if the spring pressure is lower than specifications. See **Figure 58-44**.





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Figure 58-44. Measuring valve spring tension with a valve spring tester. A—Place the engine valve spring on the tester table. Pull the handle to compress the valve spring to the installed height. B—With the spring compressed to the specification height, read the pressure scale. Compare the actual spring pounds reading to specifications.

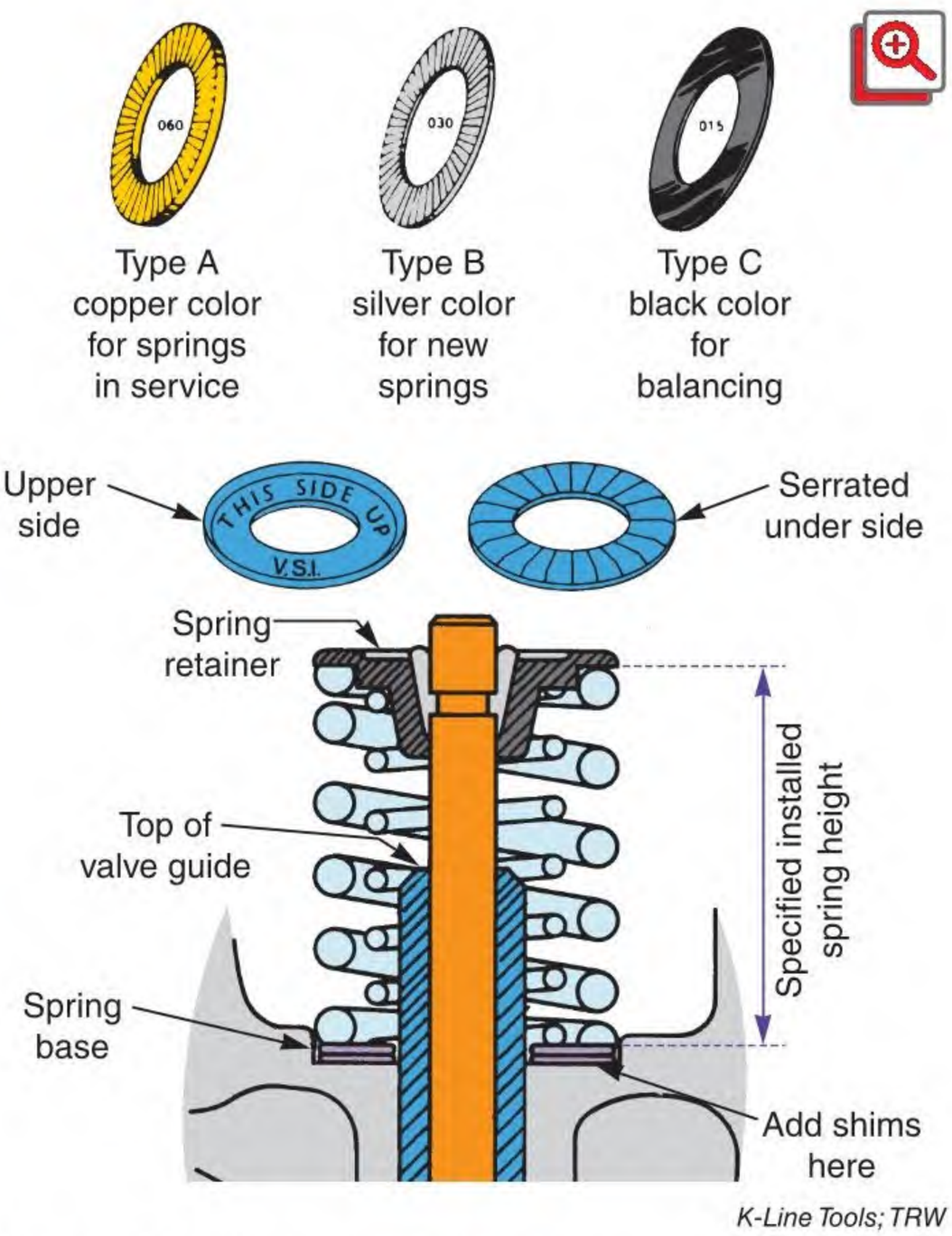
Service Procedure

To measure valve spring tension (pressure):

1. Place the valve spring into the compressor.
2. Press down on the lever until the pressure scale equals the spring pressure specification.
3. Read the height scale to find how far the spring has been compressed.
4. Subtract this measurement from the specification for installed spring height to determine the thickness of shim needed.

   For example, if you had to compress the spring 0.010″ more than the installed spring height specification to attain the spring pressure specification, the shim needs to be 0.010″ thick.

Place the shim(s) under the valve spring. The serrated side of the shim(s) should face away from the spring. Look at **Figure 58-45**.



K-Line Tools; TRW

Figure 58-45. Shims can be placed between the valve spring and the head to reduce installed height and to increase spring tension and engine rpm capabilities. The serrated side of the spacer or shim should face down for improved oiling.

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Never shim valve springs over 0.060″ (1.5 mm). Adding more shim thickness than this can cause the spring to bind and lead to valve train part breakage. ***Spring bind*** occurs when a valve spring is compressed too much and its coils hit each other, stopping more spring compression and the valve opening action.

Valve spring bind can be caused by too much shim thickness under a spring, too much valve lift, incorrect rocker arm ratio, or use of incorrect springs. When a valve spring binds, it will no longer compress. Instead, it acts as a solid piece of steel. When the camshaft tries to open the valve, push rods can be bent or rocker arms broken because of spring bind. Always visually inspect for spring bind during engine reassembly.

While measuring spring height, you should also check that the valve retainers do not hit and bind on the top of the valve guides. See **Figure 58-46**. There should be at least 1/16″ to 1/8″ (1.5 mm to 3 mm) clearance between the retainer and guide at full valve lift. This is only a problem if you installed new valve guides or different valve spring retainers with different-than-stock dimensions.

Cylinder Head Reassembly

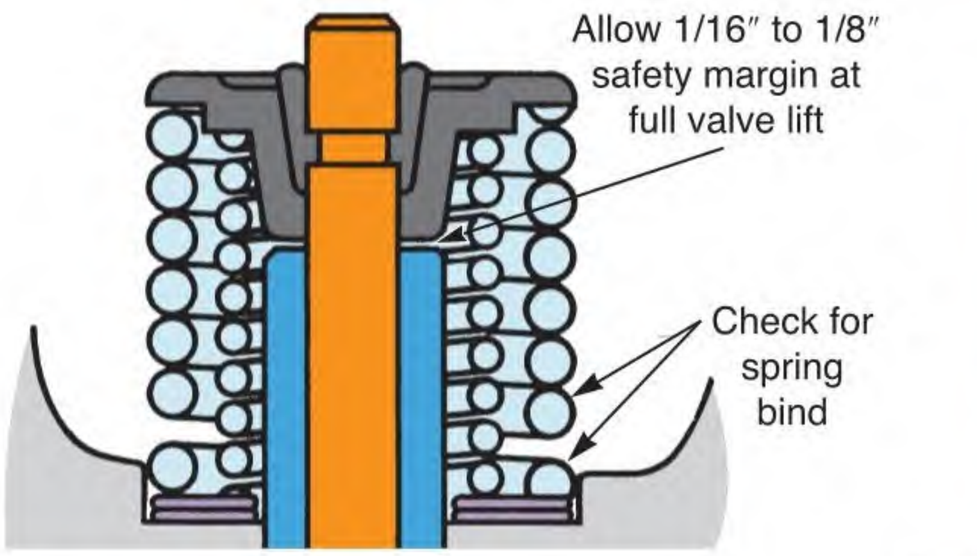
With all parts cleaned, inspected, measured, and machined, you are ready to assemble the cylinder head. First, lubricate the valve stems with motor oil or assembly lube. Then, slide the valves into their guides. Continue as described in the next sections.

Installing Valve Seals

To install an umbrella valve seal, simply slide the seal over the valve stem. This is done before the spring is installed. With some hard plastic umbrella seals, you should use a plastic sleeve to protect the seal from damage during installation, **Figure 58-47**.

When installing O-ring valve seals, compress the valve spring before fitting the seal on the valve stem. See **Figure 58-48**. If you install the seal first, it will be cut, split, or pushed out of its groove. Engine oil consumption and smoking will result.

In some OHC applications, the valve seal is part of the spring seat. To install these integral seats/seals, fit them down into their pockets in the cylinder head. See **Figure 58-49**.



TRW

Figure 58-46. Spring bind is a result of too much camshaft lobe lift (installation of high-lift, racing camshaft) or spring shims that are too thick. Any new guide insert must be short enough to clear the spring retainer without binding.



Fel-Pro

Figure 58-47. Use a plastic shield over the valve stem to protect a hard plastic umbrella seal from damage during installation.



Chrysler; Fel-Pro

Figure 58-48. When installing an O-ring type valve seal, compress the spring and fit the seal into the lower groove in the valve stem. Valve keepers install in the top grooves in the valve stem.

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Chrysler; Fel-Pro

Figure 58-49. Some OHC engines have valve seals that are integral to the valve spring seat. These seats/seals must be installed in the bottom of the spring pocket before installing the springs.

With a positive-lock-type valve seal, the top of the valve guide has been machined so that the seal locks onto the guide. First, a protective cap is placed over the valve stem. Then, an installation tool is used to force or snap the valve seal into position.

Installing Valve Springs

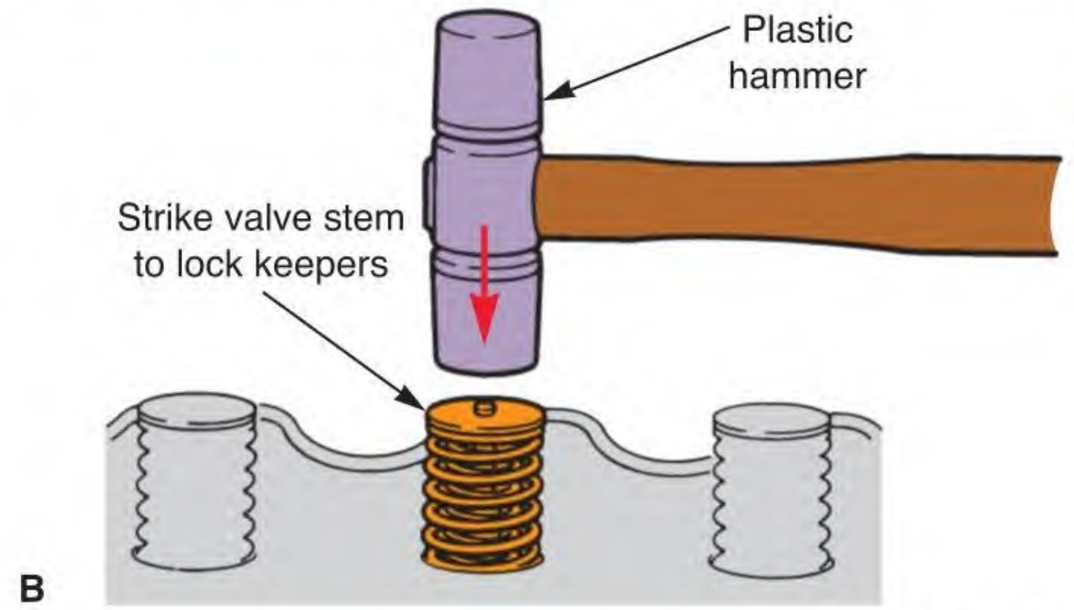
To reinstall the valve springs, place the valve spring over the valve stem and onto its seat. Some springs have a top and bottom so make sure the spring is not upside-down. Next, place the spring retainer over the spring and against the valve stem. Then, position the valve spring compressor over the spring retainer and valve head.

Hold the compressor square on the valve and compress the spring. Then, fit the retainer and keepers into their grooves on the valve stem. Be careful; keepers are very small and can be easily dropped.

Once the keepers are in their grooves, release the valve spring compressor. Check that the keepers stayed in place. See **Figure 58-50A**. Tap on the valve stems with a plastic or brass hammer to seat the keepers in their grooves, **Figure 58-50B**. To avoid severe engine damage, it is critical that keepers cannot pop out from between the valve stem and the retainer.

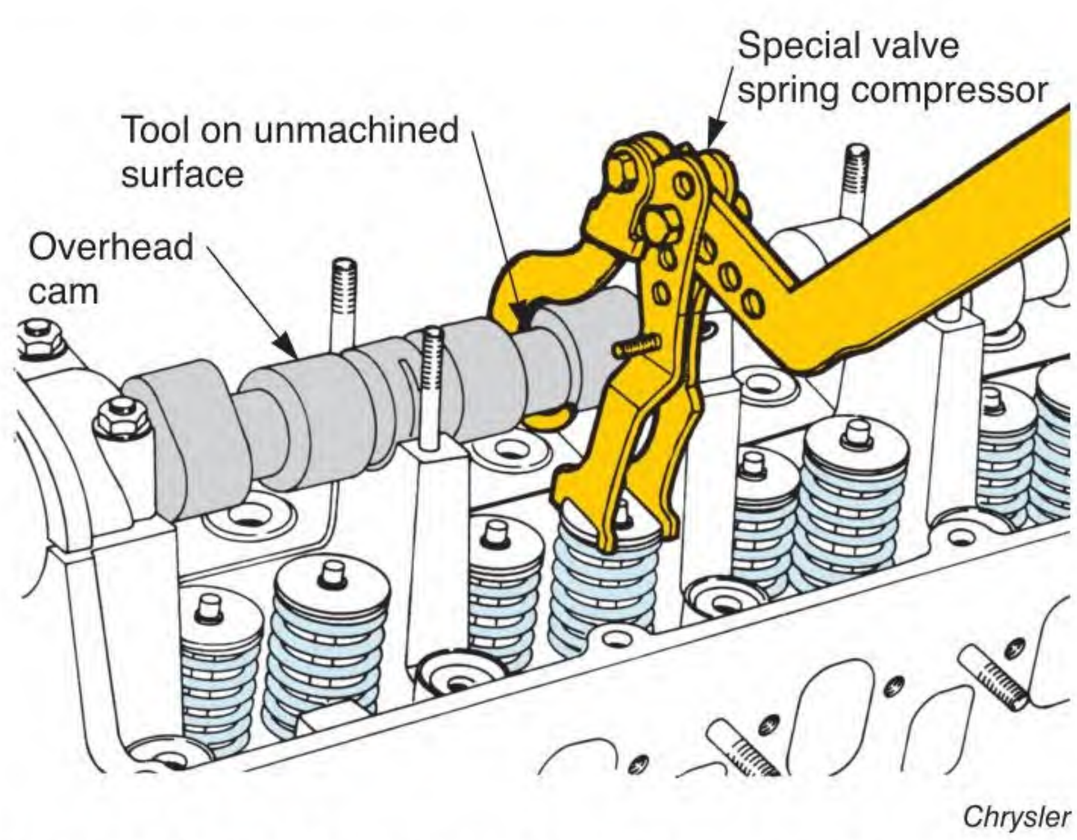
Some OHC engines require a special valve spring compressor, **Figure 58-51**. It is needed to reach down into the valve spring pockets. When working on an





Fel-Pro; Toyota

Figure 58-50. Reinstalling valve springs. A—With the valve seal in place, use your fingers or a magnet to install the keepers into their grooves. Then, release the compressor arm and check that both keepers are fully seated in their grooves and are securely holding the retainer and spring on the valve stem. B—Tap valve stems with a plastic mallet to fully seat keepers into their grooves. If any springs pop off their valves, you have caught a mistake that could have dropped a valve and caused major engine damage.



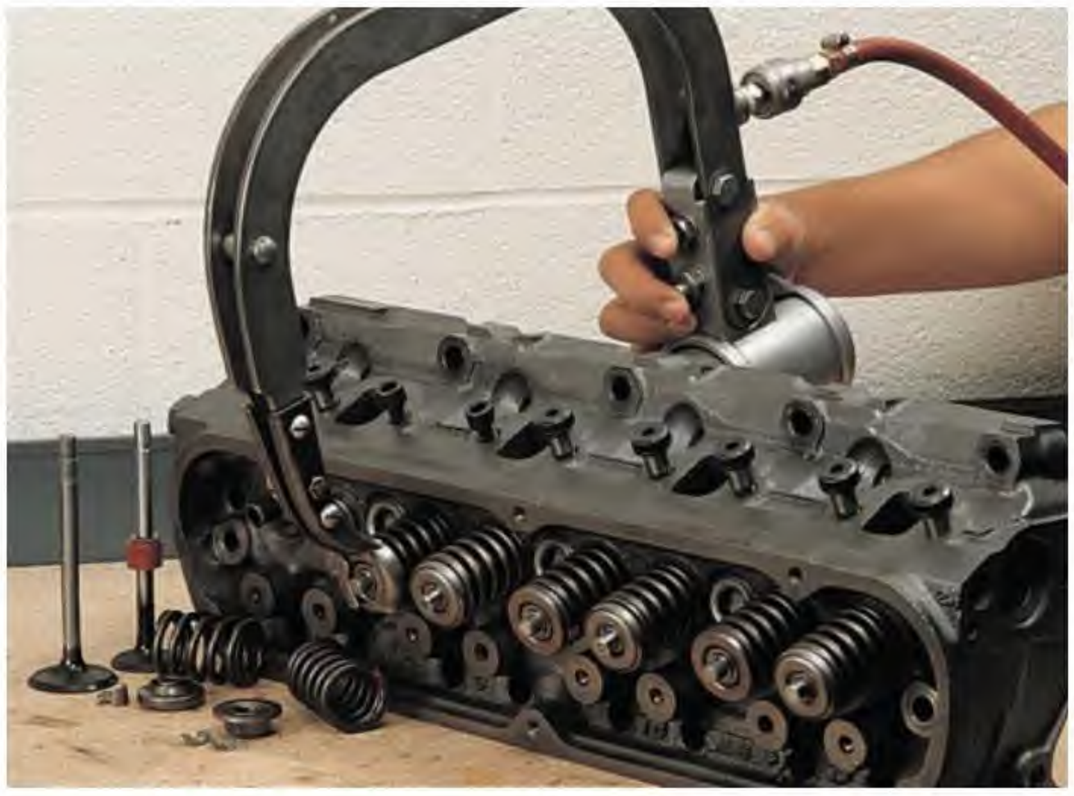
Chrysler

Figure 58–51. A special valve spring compressor may be needed on some OHC engines.

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overhead camshaft head with deep pockets for the springs, use an adapter on the spring compressor. You can reach through the adapter to fit the small valve keepers down into their groove in the valve stem. A small pick-type tool will help work the keepers down into place. An air-powered valve spring compressor is shown in **Figure 58-52**.

With some overhead camshaft engines, you cannot directly hit the stem with a mallet to seat the keepers. Instead, use a flat nose punch and hammer to hit each valve stem tip. Hit straight down on the tips to seat the keepers, and then double-check their installation. See **Figure 58-53**.



Fel-Pro

Figure 58-52. This air-powered valve spring compressor is handy for high-production work.



Honda

Figure 58-53. A flat nose punch and hammer can be used to tap or rap on valve stem tips when they are recessed into a pocket.

Warning

Wear safety glasses when using a valve spring compressor. Valve springs are very stiff and can fly out of the compressor with great force.

Checking for Valve Leakage

Placing a liquid in the cylinder head ports is a good way to double-check for valve leakage after head reconditioning. Lay the cylinder head on its side with the ports up. If intake and exhaust ports are on opposite sides of the head, you will need to test one side and then the other. Pour or spray clean solvent or water into the ports. Then, shake the head to splash the liquid around the valve heads. See **Figure 58-54**.





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Figure 58-54. Double-check for valve leakage before cylinder head installation. A—Pour or spray clean solvent or water into the ports. Try to find out if the liquid can flow past closed valves easily. B—If water or solvent pours out around the valve head and seat, something is wrong with your machine work.

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As you splash liquid around in the cylinder head, watch for leakage at the valve heads. If solvent or water drips from around a valve and its seat, that valve is leaking. When solvent is used, a small amount of seepage is acceptable. Solvent is normally thinner than water and can seep through smaller clearances. This solvent seepage is not a concern. The valve will wear and seal this seepage after only a few minutes of engine operation. However, the solvent must not leak or pour from the valve-to-seat contact point. If the valve leaks badly, remove the valve from the head and find the problem.

In-Vehicle Valve Seal Service

Valve seals and springs can often be serviced without cylinder head removal. When shop air pressure is blown into the cylinder, the valves will stick in the closed position for seal and valve spring replacement, without the need to remove the cylinder heads from the cylinder block.



Service Procedure

To replace valve seals or springs without engine disassembly:

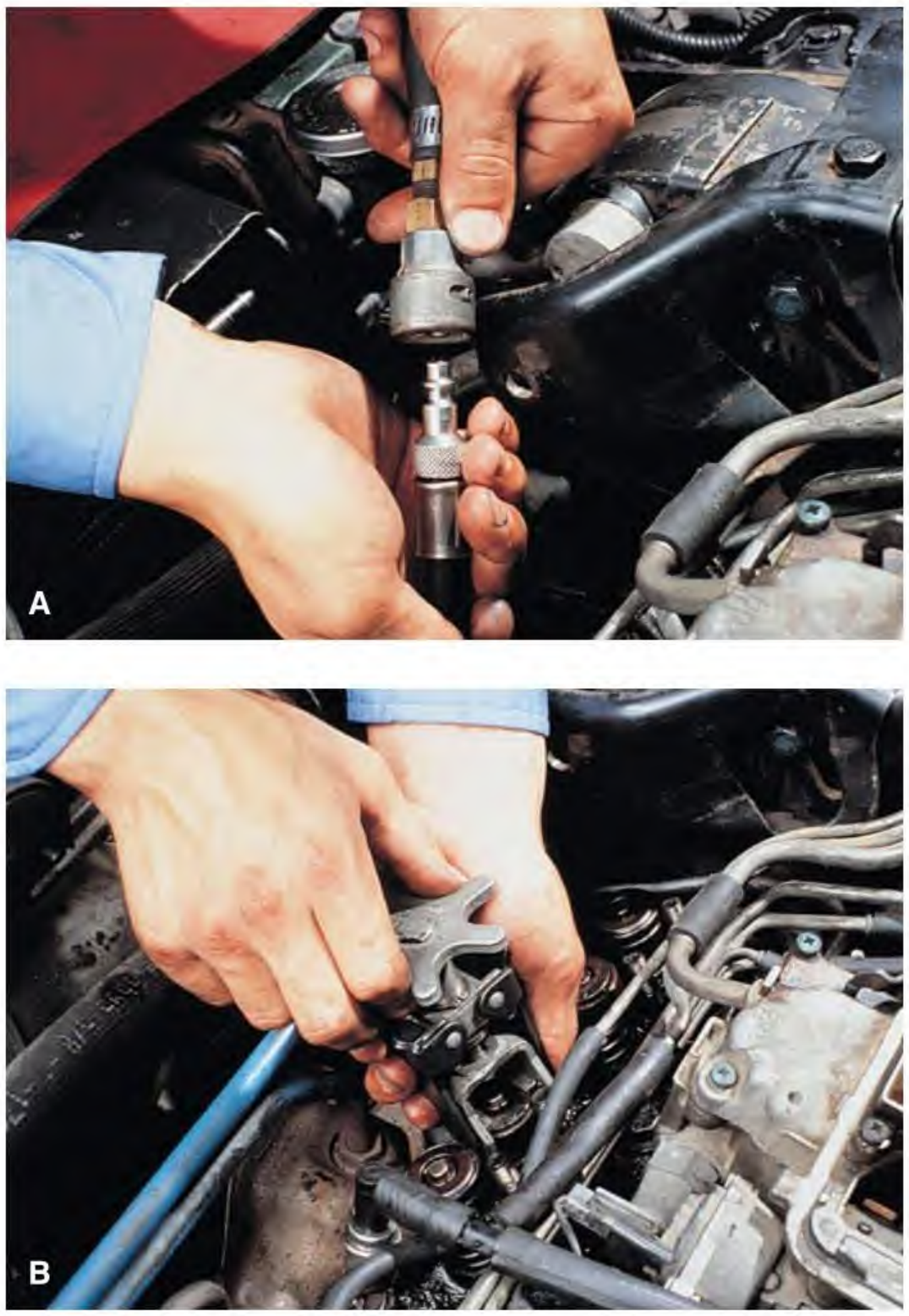
1. Remove the spark plugs, valve covers, and rocker arms.
2. Rotate the crankshaft until all valves in the cylinder to be worked on are closed.
3. Use a shop air hose and special fitting to inject air into the cylinder, **Figure 58-55A**. The air pressure will hold the valves in that cylinder up against their seats.
4. Only work on one spring at a time. Use a special pry bar- or screw-type compressor to compress the spring, **Figure 58-55B**.
5. Remove the keepers and spring.
6. Install a new valve seal on the valve.
7. Reassemble the valve spring, retainer, keepers, seal (if O-ring type), and any needed shims onto the valve.
8. Repeat for the other valve(s) in the cylinder.
9. Repeat for other cylinders as needed.
10. Reassemble the rocker arms, valve covers, and spark plugs.

Camshaft Service

Camshaft service involves measuring camshaft lobe and journal wear. It also includes measuring camshaft endplay and camshaft bearing clearance. See **Figure 58-56**.

Measuring Camshaft Wear

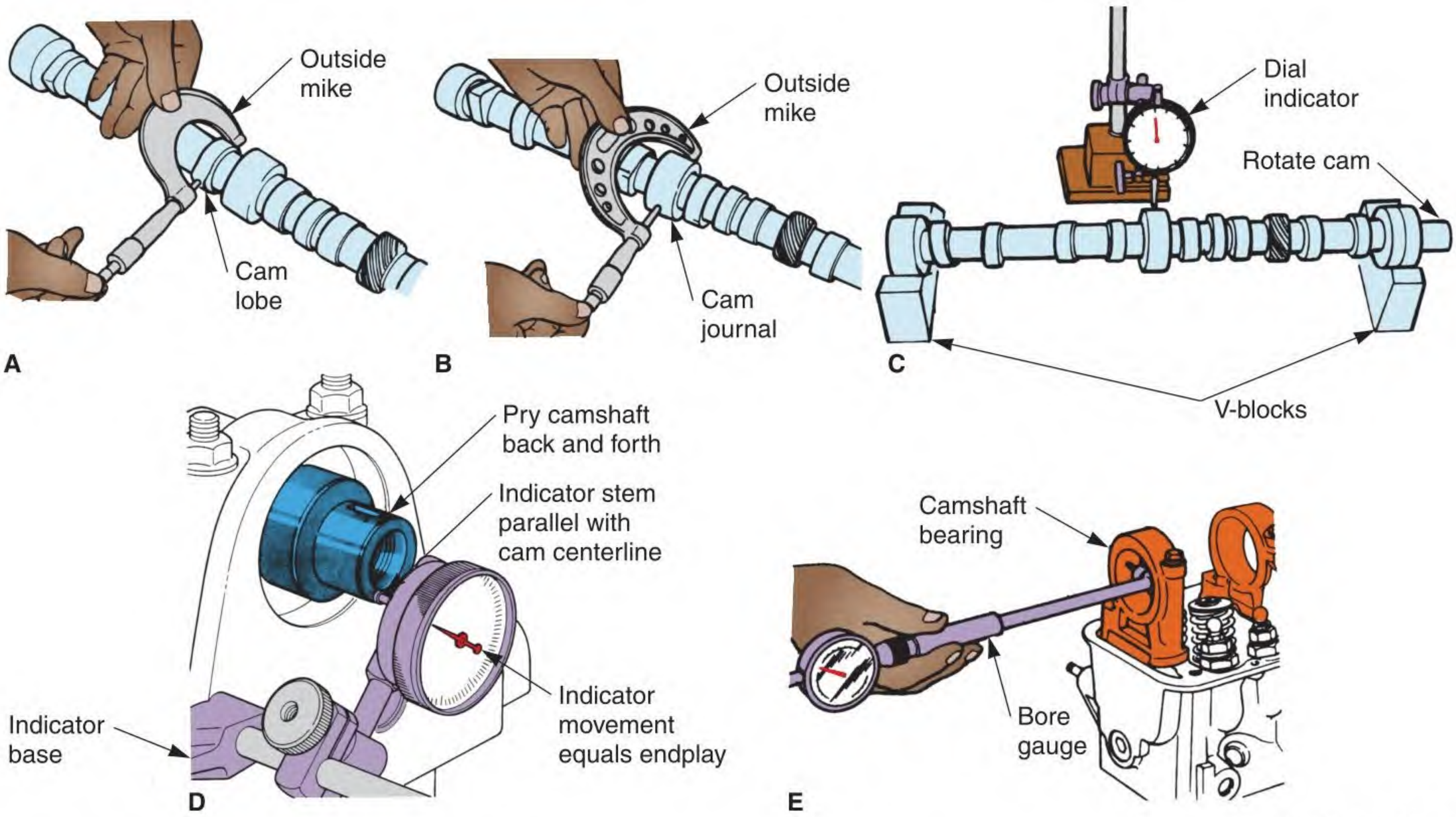
Camshaft lobe wear can be measured with a dial indicator with the camshaft installed in the engine, **Figure 58-57**. Mount the indicator so its stem is parallel to a push rod and contacts the rocker arm or end of the push rod. Then, zero the gauge and rotate



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Figure 58-55. Valve seals can be replaced with the cylinder heads and engine still in the vehicle. A—Use a hose screwed into the spark plug hole to inject shop air pressure into the engine cylinder. Air pressure on the heads of valves will keep them from falling down into the engine with the spring removed. B—Use a small screw-type spring compressor to remove the keepers, retainers, and seal. Install the new valve stem seal and then reassemble.

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Ford; Chrysler; Nissan

Figure 58-56. Checking the condition of the camshaft and cam bearings. A—Mike the cam lobe height and compare your reading to specifications. B—Measure the cam journal diameter and compare measurements to specifications. C—Mount the camshaft in V-blocks. Position the dial indicator on the center journal. Turn the cam and read the dial indicator. If the needle moves over a couple of thousandths, the camshaft is not straight. D—To check camshaft end play, install the cam in the engine. Position the dial indicator parallel to the camshaft centerline. Pry back and forth on the camshaft while reading the indicator. Needle movement is end play measured in thousandths of an inch or hundredths of a millimeter. E—A dial bore gauge can be used to check cam bearing or cam bore diameter.

the camshaft. The difference between the maximum and minimum indicator values is the valve lift. If the camshaft is out of the engine, use a micrometer to measure all lobes.

Subtract the measured lift from the specification for lift to determine wear. If wear on any lobe is out of specifications, over about 0.005″ (0.13 mm), replace or grind the camshaft.

Camshaft straightness is checked with the camshaft out of the engine, **Figure 58-58A**. Mount the camshaft in V-blocks. Then, mount a dial indicator and rotate the camshaft. If the dial indicator reads more than specifications, usually about 0.002″ (0.05 mm), the camshaft is bent or warped and must be replaced.

Camshaft journal wear is measured with an outside micrometer, **Figure 58-58B**. If worn more than specifications, approximately 0.002″ (0.05 mm), the camshaft is usually replaced. Worn camshaft journals lower engine oil pressure considerably.

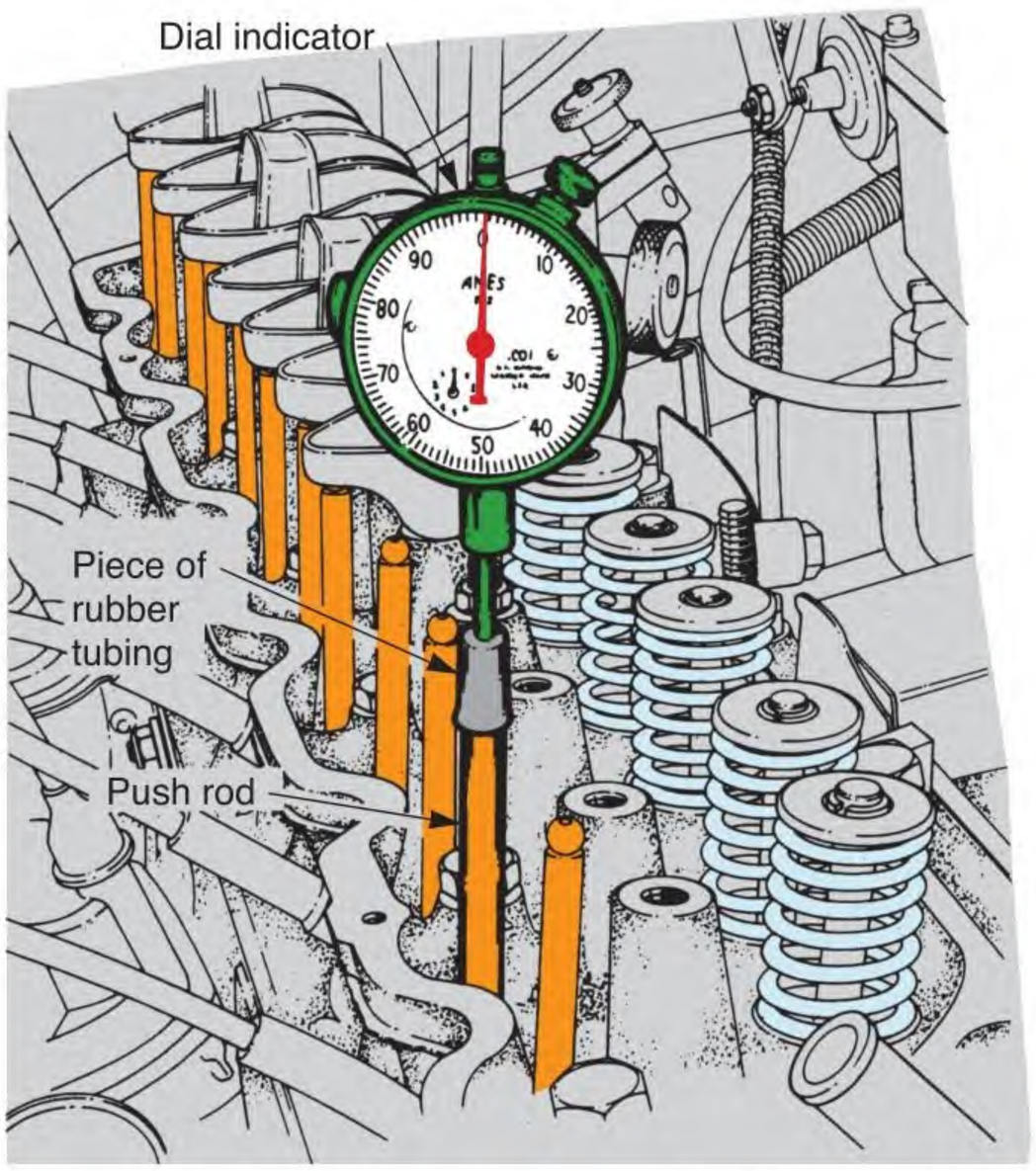
Figure 58-58C shows a technician using a telescoping gauge to check camshaft bearing dimensions. By subtracting the camshaft journal diameter from the camshaft bearing diameter, you can determine the bearing clearance. Normally, each camshaft journal is a different diameter. Check the service manual for specifications for each camshaft journal and bearing.

Camshaft Grinding

Camshaft grinding is done to restore camshaft lobe and journal dimensions to specifications. A camshaft grinding machine regrinds all of the camshaft lobes. If a journal is badly damaged, it can be welded and then ground down to size.

A ground camshaft may be less expensive than a new camshaft. As long as the lobes are hardened properly, a ground camshaft can give good service life. Always compare the price of a new camshaft with that of reconditioning a camshaft. Sometimes, a new camshaft may be more cost-effective when downtime is considered, or even less expensive off the shelf.

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Figure 58-57. Cam lobe lift and wear can be measured before engine teardown. Rotate the engine while reading a dial indicator on a push rod (cam-in-block design) or directly on a cam lobe (overhead cam design). If the lift is less than specifications, the camshaft is worn.

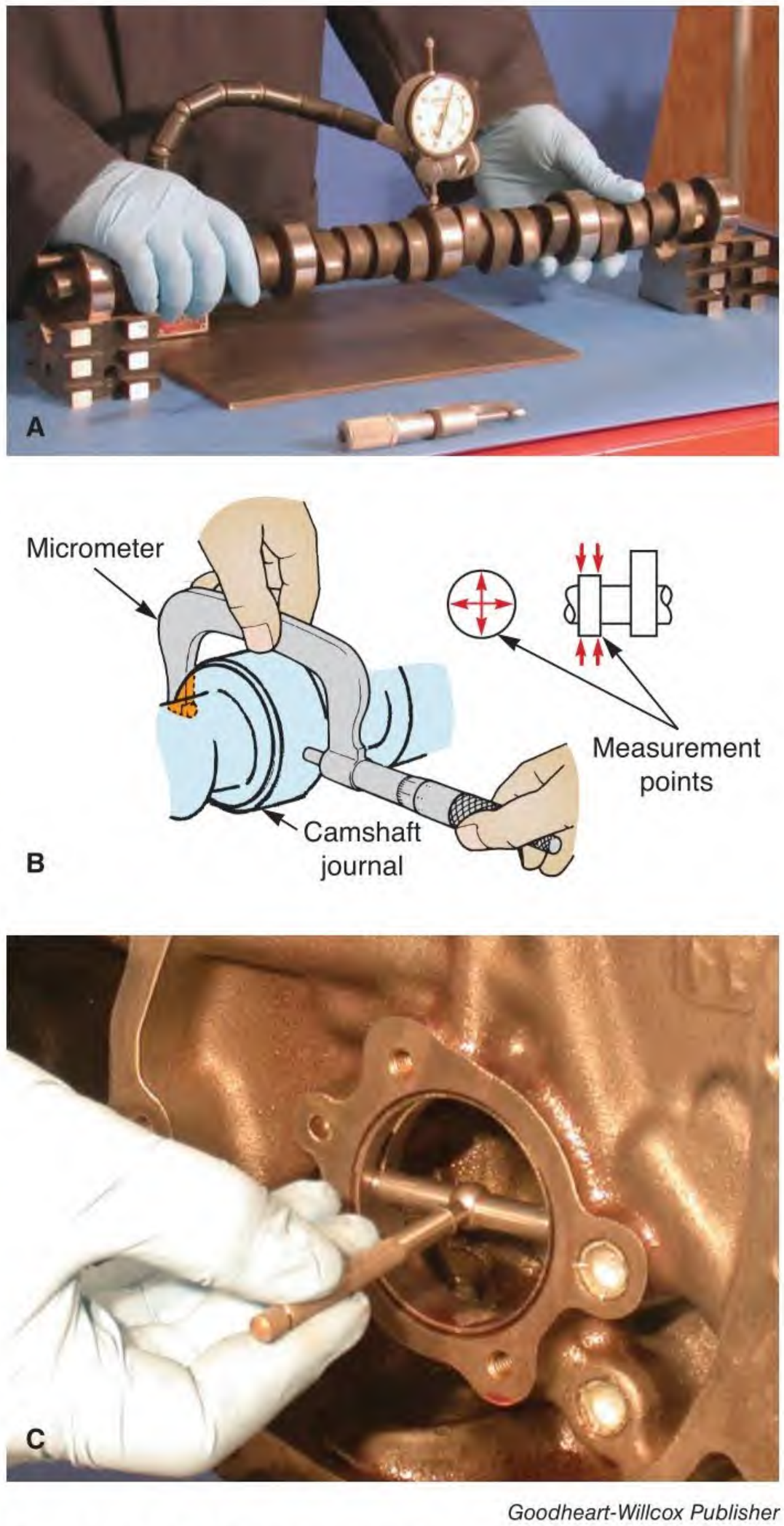
Installing an Overhead Valve Camshaft

Before installing the camshaft, lubricate the camshaft journals and camshaft bearings with assembly lube. Since the camshaft lobes endure very high friction on engine start-up, thick assembly lube is very important. It will protect the camshaft lobes and lifters from rapid wear during initial engine start-up.

Service Procedure

To install an overhead valve (OHV) camshaft into the cylinder block:

1. Slowly slide the camshaft into the camshaft bearings. Do not hit or nick the camshaft bearings.
2. Slowly rotate the camshaft to help feed it through each bearing.
3. Make sure you support the camshaft as it is inserted.



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Figure 58-58. Checking the condition of the camshaft and cam bearings to determine clearances. A—Checking camshaft straightness by measuring runout on V-blocks using a dial indicator. B—Measuring camshaft journal diameter. C—Measuring camshaft bearing diameters. Use a micrometer to measure the telescoping gauge. Compare inside diameters of cam bearings with cam journal diameters to find camshaft bearing clearances.

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4. To help feed the very end of the camshaft into the engine, a threaded handle or bolt should be installed into the camshaft. This will allow you to lift and guide the camshaft completely into the camshaft bearing bores. You must lift up the rear of the camshaft to get it to slide into its bearing.
5. Install the camshaft retainer plate. Make sure it is facing in the right direction. Sometimes the retainer plate has oil grooves that must face toward the inside of the engine.
6. Torque the bolt(s) to specifications.

Tech Tip

The inspection, removal, and installation of camshaft bearings for an overhead valve engine are discussed in the previous chapter.

Camshaft Endplay

Camshaft endplay is the front-to-rear movement of the camshaft in its bores. It is commonly measured with a dial indicator. Install a bolt in the end of the camshaft. Then, mount the dial indicator so the stem is parallel with the camshaft centerline and contacts the bolt. Zero the indicator. Then, pry back and forth on the bolt in the end of the camshaft. The maximum indicator needle movement equals the camshaft endplay.

If endplay is not within specifications, replace or repair parts as needed. The flange on the camshaft may be worn, or the thrust surface on the head or block may be damaged.

OHC Bearing Service

Camshaft bearings in the cylinder head of an overhead camshaft engine are serviced in much the same way as the camshaft bearings in cam-in-block engines. You must check the bearings for wear, damage, and clearance. Worn camshaft bearings can reduce engine oil pressure.

Camshaft bearing wear is checked by measuring the bearing's inside diameter. Use a dial bore gauge or telescoping gauge and micrometer. Subtract the specification diameter from the measured diameter to determine wear. If wear is more than specifications, about 0.002″ (0.05 mm), replace the bearings.

Most technicians replace the camshaft bearings during major engine service regardless of wear. The bearings are not very expensive and are important to engine service life. Cylinder head camshaft bearings can be a one- or two-piece design. One-piece design bearings, similar to cam-in-block camshaft bearings, must be driven in and out with a bearing driver. This is often done by a machine shop.

Two-piece design bearings simply snap into place like rod or main bearings. The back of each bearing should be clean and dry. Always make sure the camshaft bearing caps are installed in their correct locations in the proper orientation. If mixed up or turned backward, the camshaft bearing bore will not be round.

When installing any camshaft bearing, make sure the oil holes in the bearing align with the oil holes in the cylinder head and cap (if applicable). Do not dent or mar the bearing surfaces.

With two-piece camshaft bearings, you can measure ***camshaft bearing clearance*** with Plastigage™. Use the same basic procedure discussed in the previous chapter for determining main bearing or connecting rod bearing clearance. To find the bearing clearance on a one-piece bearing, subtract the measured camshaft journal diameter from the measured camshaft bearing diameter to calculate clearance.

Tech Tip

On many OHC engines, the cylinder head must be installed before the camshaft(s). Then, the camshafts must be timed with the crankshaft before tightening down the camshaft bearing caps. If you accidentally tighten down OHC bearing caps with the camshafts out of time (misaligned), valves can be bent and pistons can be damaged.

Rocker Assembly Service

Rocker assembly service involves cleaning, inspection, and measurement of the rocker arms, rocker arm shafts, and related components.

Inspect all wear points closely. Check the rocker shafts for signs of heavy wear or scoring. Check for bushing wear or wear on the external surfaces where

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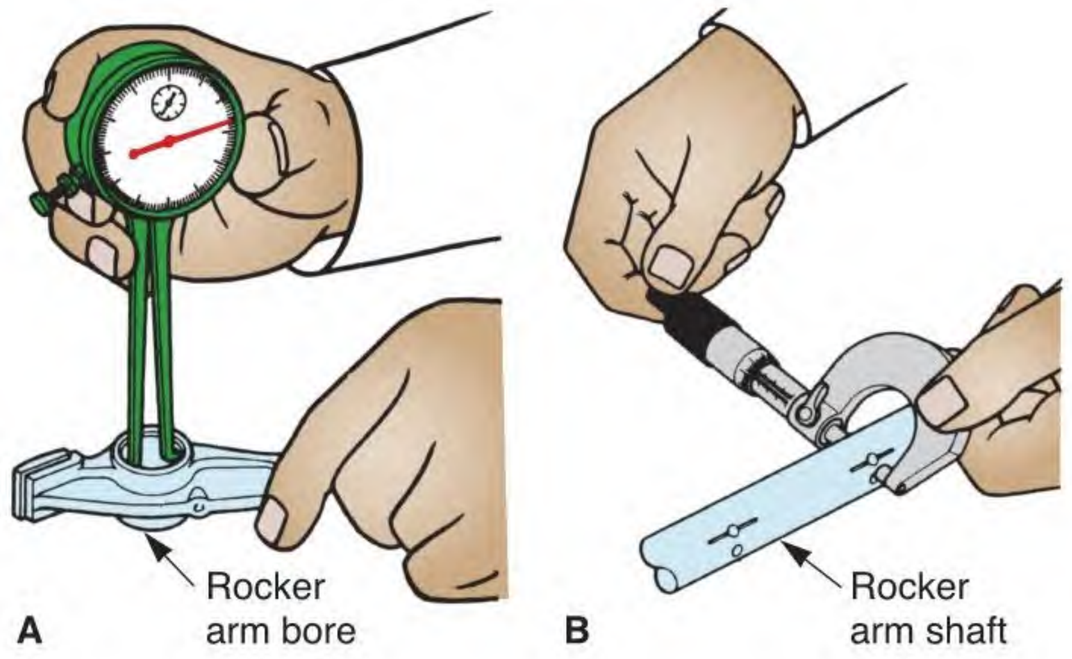
the rocker arm makes contact with the valve, lifter, push rod, or camshaft lobe. Also, check the adjuster threads to make sure they are not damaged.

A dial bore gauge is needed to measure rocker arm bushing or inside diameter wear, **Figure 58-59**. A telescoping gauge and micrometer can also be used. Measure for out-of-round. If out-of-round is greater than specifications, replace parts or install new rocker arm bushings, if applicable.

Use an outside micrometer to check the rocker arm shaft for wear. Measure the diameter of the rocker arm shaft at each location where the rocker arm contacts the shaft. If the diameter is not within specifications at any point, replace the shaft. Also, check the surface of the rocker arm shaft. It should be smooth without any nicks, gouges, or scoring.

During rocker arm reassembly, make sure the rocker shaft oil holes point down. The bottom of the shaft is the load-bearing side of the shaft. Oil is needed to reduce wear at this area of high friction. If the oil holes are installed up, the rocker arm shaft and rocker arms will wear rapidly due to lack of lubrication.

With a ball- or stand-type valve mechanism, inspect the ball, pivot, or stand for wear. If the rocker stand or pivot is aluminum, inspect it closely. Aluminum is soft and prone to wear. Replacement is frequently required. Replace any rocker part worn beyond specifications.



Toyota

Figure 58-59. Valve train rocker arms and shafts must be checked for excessive wear during an engine rebuild. A—Use a bore gauge to measure the inside diameter of the rocker arm bore. B—Check the rocker arm shaft diameter with a micrometer or digital calipers. If measurements are not within specifications, replace all badly worn components.

Rocker Arm Stud Service

Rocker arm studs need to be replaced if their threads are damaged or if pressed-in rocker arms pull out of the head. Some rocker arm studs are press-fit in the head; others screw into the head.

Service Procedure

To replace threaded rocker arm studs:

1. Use a deep socket to unscrew the rocker arm stud.
2. Verify that the threads in the cylinder head are not damaged. Make repairs as needed.
3. Compare the old rocker arm stud to the new one to make sure they are identical.
4. Thread the new rocker arm stud into the hole.
5. Use a torque wrench to tighten the rocker arm stud to specifications.

Service Procedure

To replace pressed-in cylinder head rocker arm studs:

1. Use a puller to remove the old stud. Unscrew threaded rocker arm studs.
2. You may need to ream the hole larger. For example, if the rocker arm stud had pulled out during service, the hole may be damaged. If the hole is reamed oversize, an oversize rocker arm stud can be installed.
3. Use an appropriate driver to press-in a new rocker arm stud.

Push Rod Service

Push rod service involves checking for tip wear and straightness. When a push rod tip is worn, the center where the push rod fits into the rocker arm tends to become pointed. A push rod does not wear as much at the lifter end of the push rod because it is submersed in oil.

You can usually check push rod straightness by rolling the push rods on a smooth, flat work surface. A more accurate, but more time-consuming, method is to mount the push rod in V-blocks and measure runout with a dial indicator. A bent push rod can result from a valve hitting a piston, stuck valve, spring bind, and other similar problems.

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Push rod straightness can also be checked by using a drill press. Chuck the push rod in the drill press, turn the drill press on, and watch the spinning push rod. If the push rod wobbles in the drill press, it is bent and must be replaced.

Replace any bent push rod. Do not attempt to straighten a push rod. Doing so will decrease the push rod's strength.

Most push rods are hollow to feed oil up to the rocker arms. If the push rod is hollow, look down through the push rods to make sure the hole is not clogged with debris. Run wire through the push rod if needed to clean it out.

Lifter (Tappet) and Follower Service

Hydraulic lifters are used in cam-in-block engines, and hydraulic followers are used in OHC engines. The contact surface between a lifter and camshaft lobe is one of the points in an engine that has the highest friction and wear. Hydraulic lifters can also wear internally, causing valve train noise. Lifter service, or follower service, involves inspecting, testing, and, if needed, rebuilding.

Some lifters can be oversize from the factory. This makes it important for you to keep all lifters in order so they can be reinstalled in the same location in the engine.

Inspecting Lifters

Inspect the bottoms of the lifters for wear. A reusable lifter has a slight hump or convex shape on the bottom. Worn lifters are flat or concave on the bottom. Replace the lifters if the bottoms are worn.

Never install used lifters on a new camshaft. The wear on the old lifters, even if acceptable, will cause rapid wear of the camshaft lobes and additional wear on the lifters. Normally, install new lifters when a camshaft is replaced.

Testing Lifter Leak-Down Rate

Hydraulic lifter ***leak-down rate*** is the amount of time it takes the pressure inside the lifter to bleed out. It is measured using a lifter tester, which pushes the lifter plunger to the bottom of its stroke under controlled conditions. The lifter leak-down rate is timed and compared to specifications.

Generally, fill the tester with a special test fluid. Place the lifter in the tester. Then, follow the tester's instructions to determine the lifter leak-down rate. If leak-down is too fast or slow, replace or rebuild the lifter.

Rebuilding Hydraulic Lifters and Followers

Rebuilding hydraulic lifters typically involves complete disassembly, cleaning, and measurement of lifter components. All worn or scored parts must be replaced following manufacturer instructions. Many shops do not rebuild hydraulic lifters. If the lifters are defective, new ones are installed. Replacing lifters usually saves time and money over rebuilding. However, on some OHC lifters or followers, it may be more cost-effective to rebuild rather than replace the units.

Bleeding Cam Followers

Many technicians will bleed down used cam followers before engine assembly. Hydraulic cam followers may retain oil after the engine is off. If the engine is rebuilt and the cam followers are not bled down, starting problems can result. The oil in the followers will hold the valves open and prevent a normal compression stroke. This will not allow engine starting until an extended period of engine cranking. The engine will not start until valve spring pressure pushes the extra oil out of the cam follower.

To avoid an engine starting problem after major repairs, you should bleed down hydraulic cam followers. This will also allow you to check for follower wear. See **Figure 58-60**.



Service Procedure

To bleed down a cam follower:

1. Pull the plunger out of the cam follower with pliers.
2. Use a pin punch to depress the check valve and relieve the oil pressure.
3. Inspect the follower for wear.
4. Push the plunger back into the follower.

The cam follower is now bled down and ready for reassembly.

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Figure 58-60. Many used overhead camshaft followers should be bled down before installation into an engine. A—Pull the plunger out of the follower with pliers. This will give you access to check for bleeding hydraulic pressure out of the follower. B—Use a pin punch to depress the check valve and relieve the oil pressure inside the follower. C—Push the plunger back into the follower so it is ready for installation.

Summary

- Cylinder heads can suffer from a wide range of problems, including warpage, cracks, burned seats, burned valves, and worn valve guides.
- Head warpage is checked with a straightedge and feeler gauge. Check at different angles across the head.
- Milling is used to correct head warpage.
- Magnafluxing is commonly used to find cracks in cast iron heads. Dye penetrant is used to find cracks in aluminum heads.
- A cracked cylinder head can be welded, plugged, or replaced.
- Excess valve guide wear allows the valve stem to move sideways in its guide during operation, which can lead to oil consumption, a light knocking or tapping sound, burned valves, or valve breakage.
- Valve guide wear can be checked with a dial indicator or a small hole gauge and micrometer.
- Valve guide wear can be corrected by knurling, reaming oversize, installing a new guide insert, or installing a bronze guide liner.
- Valve seat reconditioning involves grinding or cutting a new face on the seat. Valve seats can be resurfaced with a grinding stone or carbide cutter. The grinding stone must have the correct angle, which is usually 45°, but sometimes 30°.
- Valve seat retrusion results from heat erosion or seat grinding that causes the valve head to sink into the combustion chamber. The valve stem also protrudes too far out of the other side of the head. Seat replacement is needed to correct retrusion.
- Valve seat replacement is commonly done by a machine shop.
- Valve lapping compound or Prussian blue can be used to check seat location on the valve.
- An intake valve should have a seat contact width of about 1/16″ (1.6 mm). The exhaust valve needs a little more contact area, typically 3/32″ (2.4 mm).
- Valve springs should be tested to make sure they can be reused. Check spring squareness, spring tension, and spring free length.
- Valve spring shims are used to maintain the correct spring tension when the spring is installed on the cylinder head.
- Valve spring installed height is the distance from the top to the bottom of the valve spring when the spring is installed on the cylinder head. If the valve spring installed height is greater than specifications, subtract the stock spring height from the measured height to determine the total shim thickness needed to return the spring pressure to normal.
- A valve spring tester is used to determine the needed shim thickness if the spring pressure is lower than specifications.
- When a valve spring binds, it will no longer compress. Spring bind can be caused by too much shim thickness under a spring, too much valve lift, incorrect rocker arm ratio, or use of incorrect springs.
- Umbrella seals simply slide onto the valve stems before spring installation.
- Compress the valve springs before installing O-ring type valve seals to prevent O-ring seal damage.
- Placing a liquid in the cylinder head ports is a good way to double-check for valve leakage after head reconditioning.

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- When shop air pressure is blown into a cylinder, the valves will stick in the closed position. This will allow for seal and valve spring replacement, without the need to remove cylinder heads from the cylinder block.
- Camshaft service involves measuring camshaft lobe and journal wear. It also includes measuring camshaft endplay and camshaft bearing clearance.
- Camshaft grinding can be done to restore camshaft lobe and journal dimensions to specifications.
- Camshaft bearings in the cylinder head of an OHC engine are serviced in much the same way as the camshaft bearings in cam-in-block engines. Check bearings for wear, damage, and clearance. Check camshaft bearing wear by measuring the bearing's inside diameter.
- Rocker assembly service involves cleaning, inspection, and measurement of the rocker arms, rocker arm shafts, and related components.
- During rocker arm reassembly, make sure the rocker shaft oil holes point down.
- You can usually check push rod straightness by rolling the push rods on a smooth, flat work surface. Replace any bent push rod.
- A reusable lifter has a slight hump or convex shape on the bottom. Worn lifters are flat or concave on the bottom. Replace lifters if the bottoms are worn.
- Hydraulic lifter leak-down rate is the amount of time it takes the pressure inside the lifter to bleed out. If leak-down is too fast or slow, replace or rebuild the lifter.
- To avoid an engine starting problem after major repairs, you should bleed down hydraulic cam followers before engine reassembly.

Diagnostic Case Study

Concern: A customer enters the shop with the complaint of a rough engine idle and MIL light glowing in the dash. Duff says he will call the customer with an estimate of costs after he finds the cause of the problem.

Cause: When a scan tool is connected to the vehicle, it shows a misfire code for cylinder number six. Duff removes the ignition coil and spark plug from that cylinder. The spark plug is black but shows no signs of damage. A compression test on that cylinder shows only 10–15 psi. Duff informs the customer of the "mechanically dead cylinder" and that the cylinder head must be removed for further inspection and repair.

Correction: With the cylinder head removed, Duff can see that one of the exhaust valves in cylinder number six is badly burned. The head is sent to a machine shop for valve and seat grinding. Since the engine has over 100,000 miles on it, new valve springs are installed. One new valve is also required. Once the head is rebuilt and returned to the shop, it is reinstalled on the cylinder block and torqued to specs. The overhead cams are installed and timed before the cam caps are torqued to specs. New seals are installed in the valve covers before they are installed and torqued to specs.

After the trouble codes (misfire code) are erased, the vehicle is test driven and runs fine. No trouble codes are set and the vehicle is released to the customer after payment.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

camshaft bearing clearance
camshaft bearing wear
camshaft endplay
camshaft grinding
camshaft journal wear
camshaft lobe wear
camshaft service
camshaft straightness
concentricity
cylinder head milling
dye penetrant
fluorescent penetrant
head pressure testing machine
head warpage
interference angle
lapping stick
leak-down rate
magnafluxing
pilot
Prussian blue
push rod service
rocker assembly service
seat narrowing
seat stone
seat width
spring bind
staking
stone dressing tool
three-angle valve job
valve grinding
valve grinding machine
valve guide wear
valve lapping compound
valve retrusion
valve seat machine
valve seat reconditioning
valve spring free height
valve spring installed height
valve spring shims
valve spring squareness
valve spring tension

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Activities

1. Use a dial indicator to measure valve guide wear on all the valves of an engine. Make a chart showing your readings, and compare them to specs. If one or more guides are out of spec, determine which technique should be used to correct the problem.
2. Demonstrate the steps required to set up and operate a valve grinder machine. Study the operator's manual for the specific machine. With instructor permission, grind the face of an actual engine valve.
3. Micrometers are used to make many measurements during the service of engine top end parts. For practice in reading a standard outside micrometer, use one to check a variety of known thicknesses, such as the blades of a feeler gauge set. Further practice can be gained by checking components such as valve stems, cam journals, rocker shafts, or gaskets.

Review Questions

Answer the following questions using the information provided in this chapter.

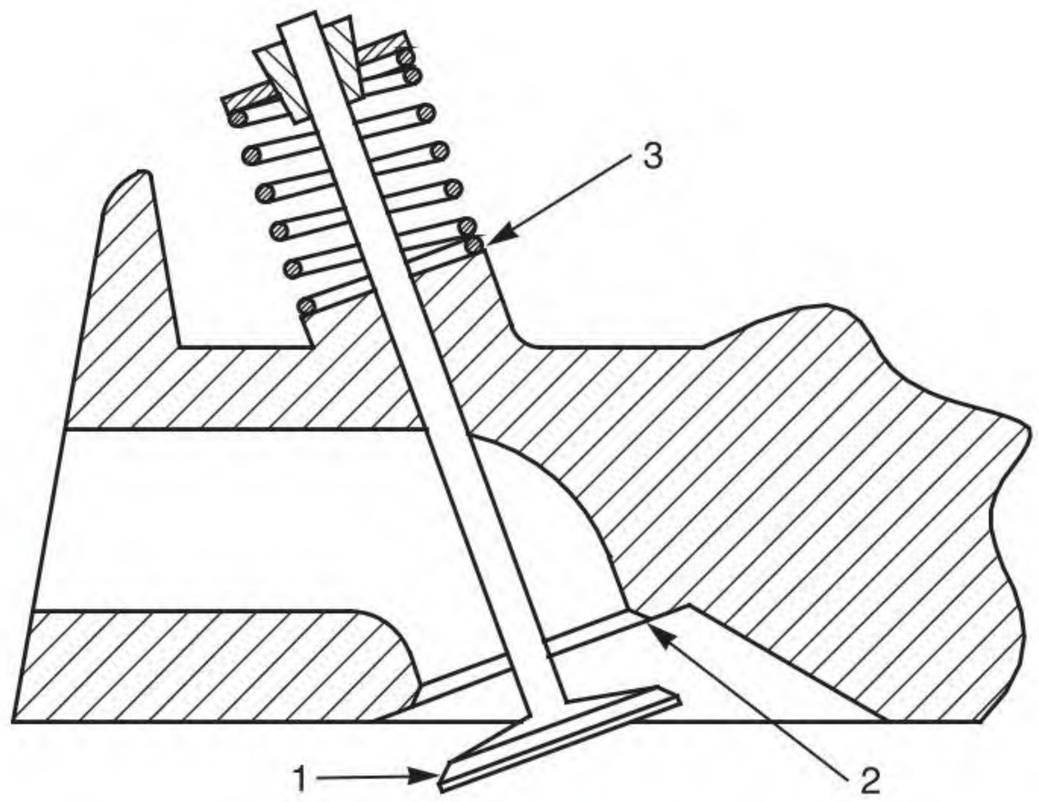
1. To measure _____, lay a straightedge across the cylinder head deck and slide feeler gauges under it.
2. _____ is a machine shop operation that removes a thin layer of metal from the head deck surface.
3. List two ways to locate cracks in a head.
4. List four ways of correcting valve guide wear.
5. A seat grinding stone should be slightly _____ in diameter than the valve seat.
6. The most common valve seat angle is _____°, but in some applications, the seat is ground at _____°.
7. What is a stone dressing tool?
8. How does valve seat cutting differ from valve seat grinding?
9. A 15° cut narrows the seat and moves it _____ on the valve face.
10. What is valve retrusion?
11. Define *interference angle*.
12. If a valve seat is ground at a 45° angle, what is the setting on the valve grinding machine in order to create an interference angle?
13. A sharp valve margin requires valve replacement. True or False?
14. Why are valve stem tips ground?
15. What are typical valve-to-seat contact widths for intake and exhaust valves?
16. If the valve spring installed height is greater than specifications, how do you determine the proper valve spring shim thickness?
17. Define *spring bind*.
18. After a cylinder head is reassembled, how can you check for valve leakage?
19. How do you measure camshaft straightness?
20. What is the purpose of camshaft grinding?
21. How do you measure camshaft bearing wear?
22. How do you measure the camshaft bearing clearance on a two-piece camshaft bearing in an OHC engine?
23. When installing a rocker arm shaft, the oil holes should face _____.
24. How can a drill press be used to check for push rod straightness?
25. Why should you bleed down cam followers before engine reassembly?

ASE-Type Questions

1. An engine has coolant in the oil, which is apparent from the milk-like substance in the crankcase. Technician A says the engine could have a warped head and blown head gasket. Technician B says that the engine could have a cracked head or block. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Technician A says that a badly worn head should be replaced with a new or used head. Technician B says that dye penetrant should be used to find cracks in aluminum cylinder heads. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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3. Technician A says that cracked cylinder heads can be welded easily. Technician B says that cracked cylinder heads should be replaced. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. Technician A says that valve guide wear can cause engine coolant leakage. Technician B says that valve guide wear can cause engine oil consumption. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. Technician A says that knurling is a common method used to repair worn valve guides. Technician B says that reaming is a common method used to repair worn valve guides. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Valve seat replacement should be performed _____.
   (A) anytime the cylinder head is removed from the engine
   (B) only when seat wear is severe
   (C) when replacing the valves
   (D) when replacing the valve springs
7. Technician A says that an interference angle is normally a 4° difference between the valve face angle and the valve seat angle. Technician B says that an interference angle reduces the break-in and sealing time of the valve. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. Technician A says that grinding material at Points 1 and 2 will reduce valve spring tension. Technician B says that adding the correct thickness of shim at Point 3 will restore spring tension specifications. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.



9. Technician A says that you should never shim a valve spring over 0.120″. Technician B says that you should never shim a valve spring over 0.145″. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. Technician A says that umbrella and O-ring valve seals are installed after the valve spring is compressed. Technician B says to install umbrella or O-ring valve seals and then compress the valve spring. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
11. Technician A says that camshaft lobe wear should be measured with a telescoping gauge. Technician B says that camshaft lobe wear can be measured with the camshaft installed in the engine. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
12. Technician A says that a bent push rod can result from a valve hitting a piston. Technician B says that a bent push rod can result from a stuck valve. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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Chapter 59
Engine Front End Service

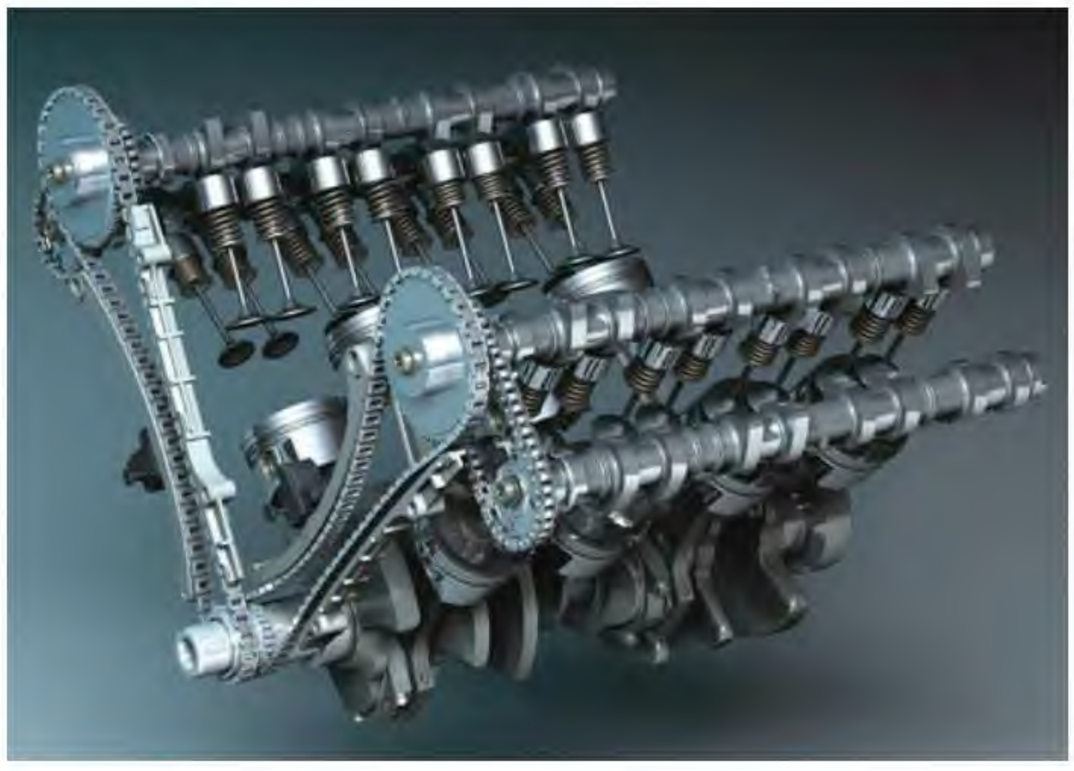
After studying this chapter, you will be able to:

- Check a timing chain for wear.
- Remove and install a timing chain assembly.
- Service timing chain tensioners.
- Replace a front cover oil seal.
- Remove and install an engine front cover.
- Remove and install a vibration damper.
- Remove and install timing gears.
- Check timing gear runout and backlash.
- Properly torque timing gear or sprocket fasteners.
- Remove and install a timing sprocket and belt.
- Adjust timing belt tension.
- Remove and install a timing belt cover.

An engine's front end includes the timing mechanism (belt and pulleys, chain and sprockets, or gears), front cover, and related seals. The timing mechanism rotates the camshaft(s) at one-half crankshaft rpm. See **Figure 59-1**.

Today's engines are much more complex than the ones used in passenger vehicles just a few years ago. V-8 engines with two or four overhead camshafts and variable valve timing are now built by most manufacturers. Long timing chains or timing belts are needed to smoothly and dependably rotate the camshafts with the crankshaft. Conventional cam-in-block engines with short timing chains or timing gears are also manufactured. The service of an engine front end is more challenging than ever before.

Timing mechanism service is critical. If a mistake is made, severe engine damage or performance problems may result. Improper crankshaft-to-camshaft timing can cause the engine pistons to slam into the



Jaguar

Figure 59-1. The front end or timing mechanism on today's engines can be complex. You must be knowledgeable about proper repair methods to successfully service modern engines.

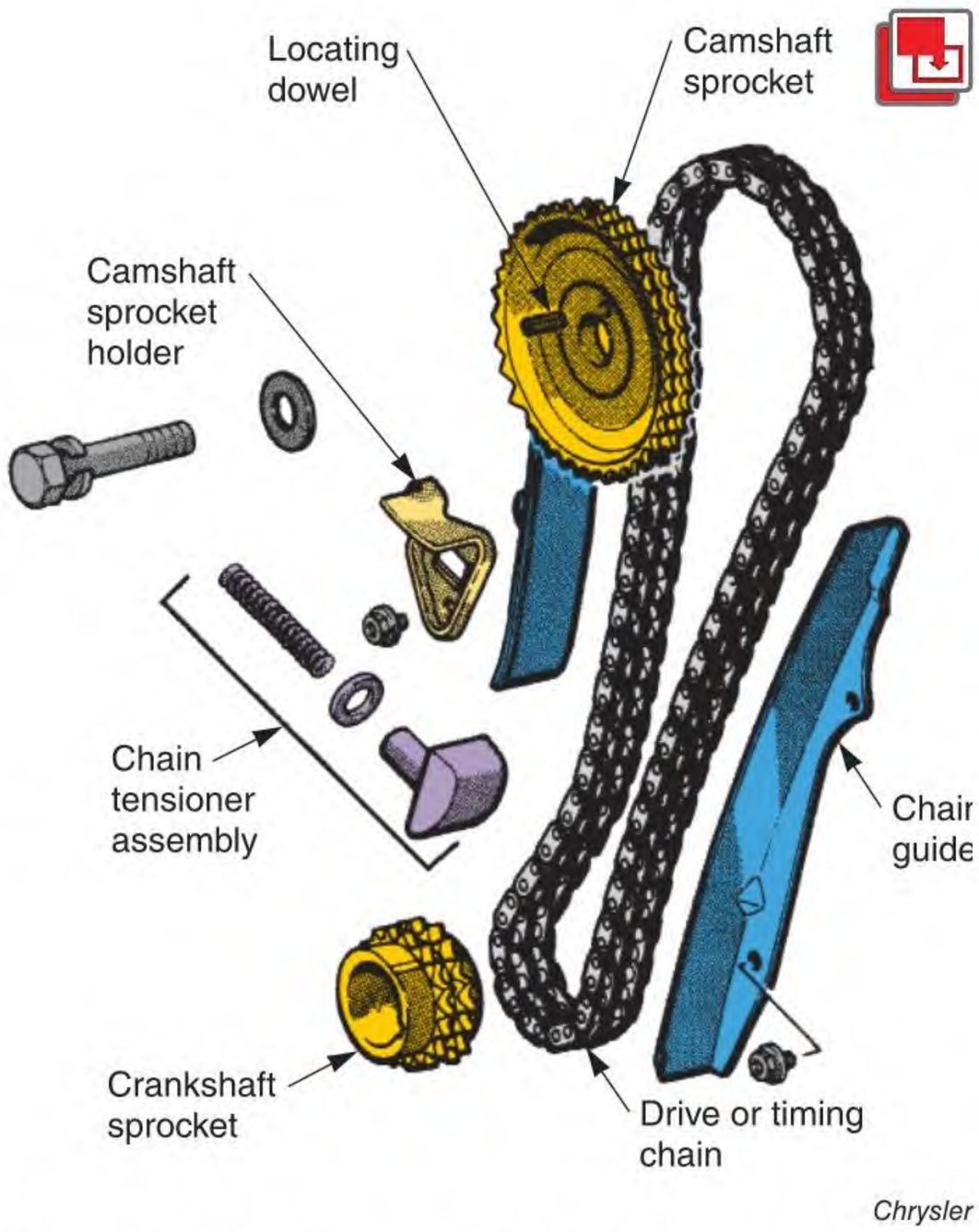
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opened valves. Valves can be bent or snapped off at their heads. Pistons, cylinder walls, and cylinder heads can also suffer severe damage when a valve is broken off by incorrect valve timing.

Timing Chain Service

Timing chains transfer rotation from the crankshaft to the camshaft at one-half engine speed. In some designs, they also power other devices such as cam phasers. Timing chains can be found in both overhead valve and overhead camshaft engines. OHC timing chains often have a complex set of guides, chain adjusters, and idler gears to maintain chain tension and prevent chain slap. Review **Figure 59-2**.

Often, a timing chain, belt, or gears can be serviced without removing the engine from the vehicle. Usually, the parts on the front of the engine (radiator, fan, etc.) and the timing cover can be removed without complete engine disassembly. In some OHC engines, the camshaft(s) must be secured before timing mechanism removal. If this is not done on these engines, the camshaft(s) will slip out of time and can cause engine damage. Refer to the service manual for specific directions as needed.



Chrysler

Figure 59-2. Overhead cam timing chains commonly use a tensioner to compensate for chain wear and stretch. Chain guides prevent chain vibrations, or slap. The tensioner and guides frequently have a fiber or plastic facing that can wear.

Timing Chain Problems

Timing chains and their drive sprockets suffer from wear after prolonged service. The chain links can wear and stretch. The sprocket teeth can also wear down. Worn sprocket teeth and chain wear can cause excess chain slack, or the chain can be loose on its sprockets. A badly worn timing chain can have so much slack that it hits the side of the front cover and produces a loud grinding noise.

Timing chain wear and slack can also allow the camshaft to go out of time with the crankshaft. As a result, valve timing can be thrown off. The valves can open too late during the four-stroke cycle, reducing compression, power, fuel economy, and exhaust cleanliness.

Inspecting a Timing Chain

You should inspect a timing chain before removal. Use a wrench to rotate the camshaft sprocket back and forth. Measure the distance the camshaft sprocket turns before the crankshaft begins to turn. Compare your measurement to specifications. Refer to **Figure 59-3**.

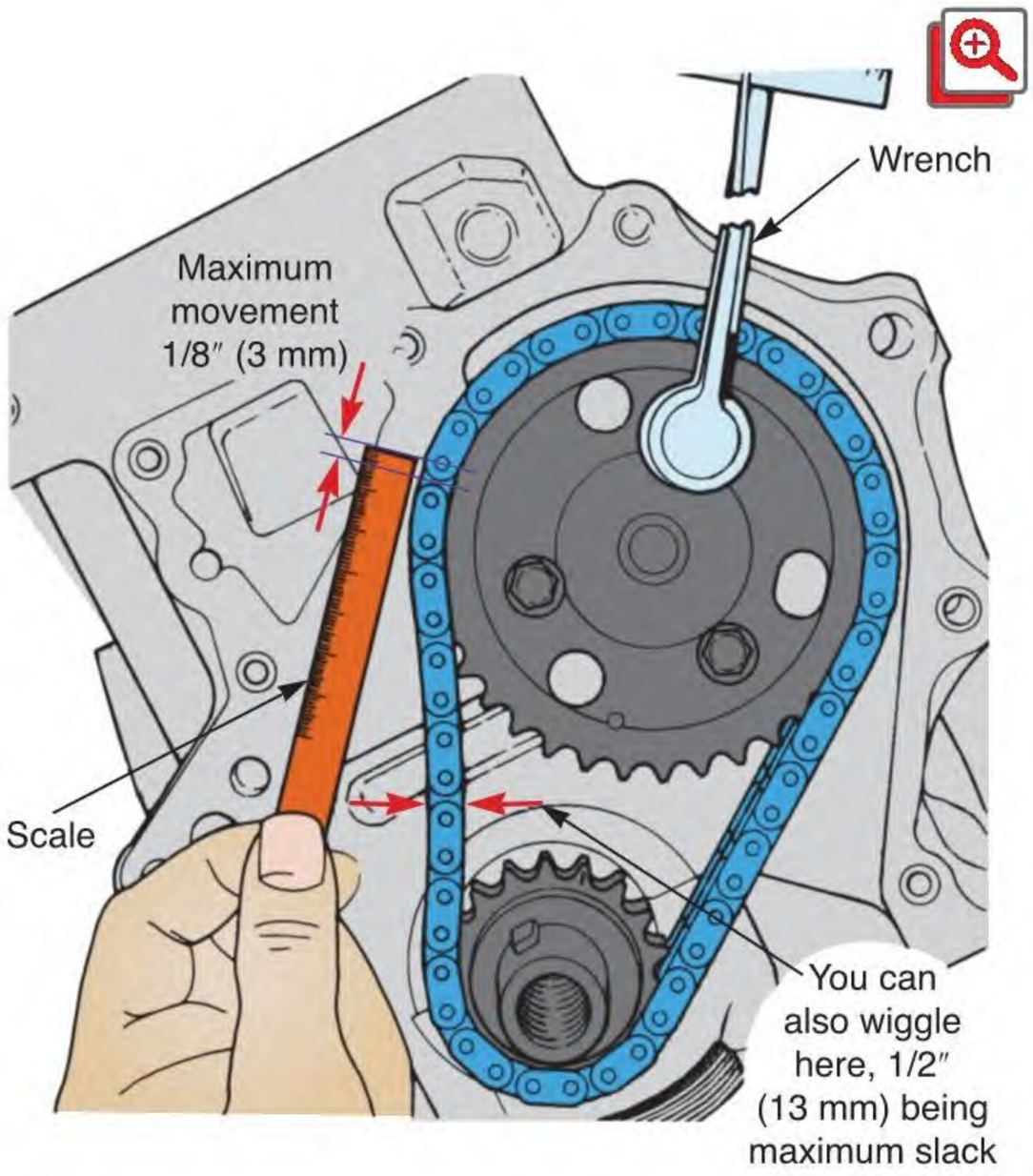
Another method to check wear is to measure the maximum deflection of the chain. Generally, if you can deflect one side of a timing chain more than about 1/2″ (13 mm), replace the chain and sprockets.

You can also check timing chain wear on an OHV engine without removing the timing cover. First, remove the valve cover. Then, place a large wrench on the crankshaft snout bolt. Rotate the crankshaft one way and then the other while watching the valve train. The valves should operate with little crankshaft movement. If you can turn the crankshaft more than about 5° to 10° without valve motion, the timing chain is worn and loose.

If the timing chain is worn more than specifications, it should be replaced. Many manufacturers recommend replacement of the chain and both sprockets as a set. Others allow you to reuse steel sprockets if they are not excessively worn.

Some camshaft sprockets have plastic teeth. The plastic teeth are prone to wear and failure. Plastic or fiber timing sprockets should be replaced whenever they are removed or disassembled for service.

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Chrysler

Figure 59-3. Timing chain wear can be checked by rotating the crankshaft back and forth. If sprocket rotation is excessive, the chain and sprockets should be replaced. You can also check for wear by measuring the deflection of the chain.

If the timing chain has a tensioner, check it for wear. The fiber rubbing block can wear down and its spring can lose tension. Replace all parts as needed.

Installing a Timing Chain

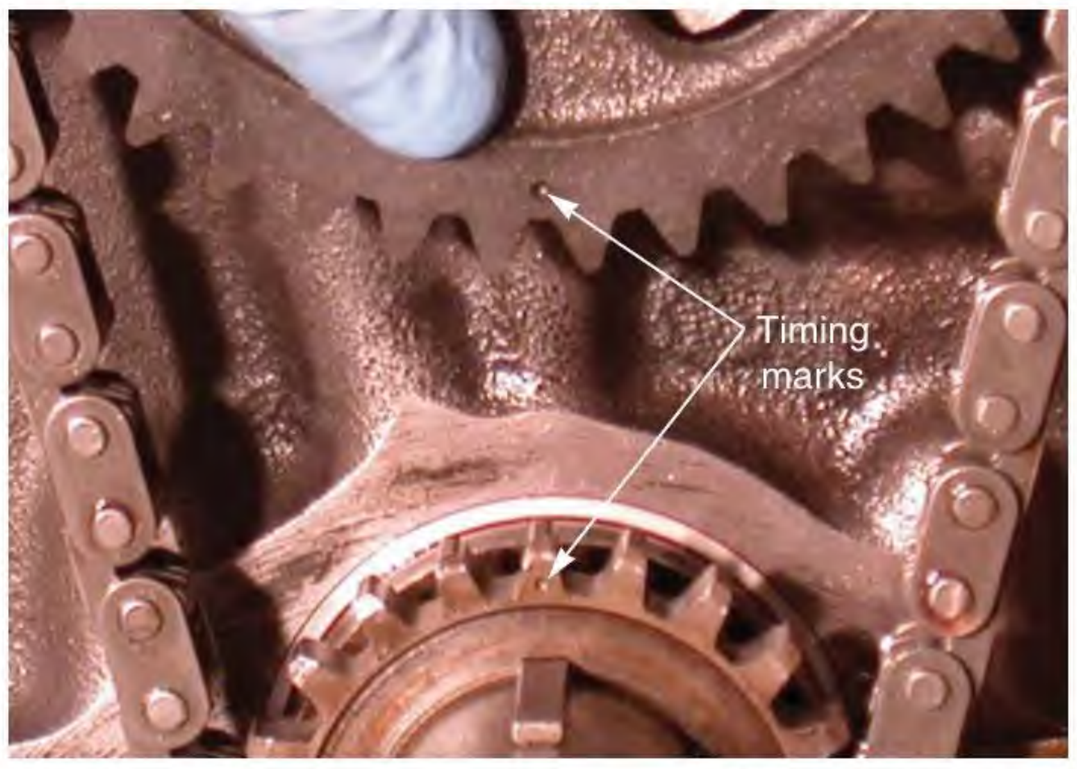
Before installing a timing chain, make sure the crankshaft key is the correct size, unworn, and properly installed in its groove, **Figure 59-4**. Also, check that the camshaft is installed properly. If necessary, measure camshaft endplay and check any fasteners holding a thrust plate on the front of the engine.

You must align ***timing marks*** on the crankshaft sprocket and camshaft sprocket, **Figure 59-5**. Timing marks may be dots, lines, circles, or other shapes indented or cast into the timing sprockets. Sometimes, a keyway or dowel is used as a timing mark. If needed, refer to the service manual. These sprocket markings must be pointing in the correct direction to time the camshaft and valves with the crankshaft and pistons.



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Figure 59-4. Make sure the crankshaft key is undamaged and properly installed in the crankshaft snout. Light hammer taps can be used to insert the key squarely into its groove. Some engines have two crankshaft keys.



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Figure 59-5. Timing marks must align when the chain and sprockets are installed, as shown here. Refer to service manual for the engine on which you are working.

Service Procedure

To install a timing chain:

1. Install the sprockets without the chain, **Figure 59-6**.
2. Turn the camshaft and crankshaft so that their timing marks align.
3. Remove the sprockets without turning the camshaft or crankshaft.
4. Fit the timing chain over the sprockets.

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5. Fit the sprockets and chain onto the engine with the camshaft and crankshaft in correct timing, **Figure 59-7**.
6. With both sprockets in place, make sure the timing marks align perfectly.
7. Torque the camshaft sprocket fastener(s) to specifications. See **Figure 59-8**. Many engine builders place a drop of thread lock on the camshaft sprocket bolt(s) to help keep the bolt(s) from loosening during engine operation.
8. Double-check the alignment by turning the crankshaft by hand until the timing marks realign.



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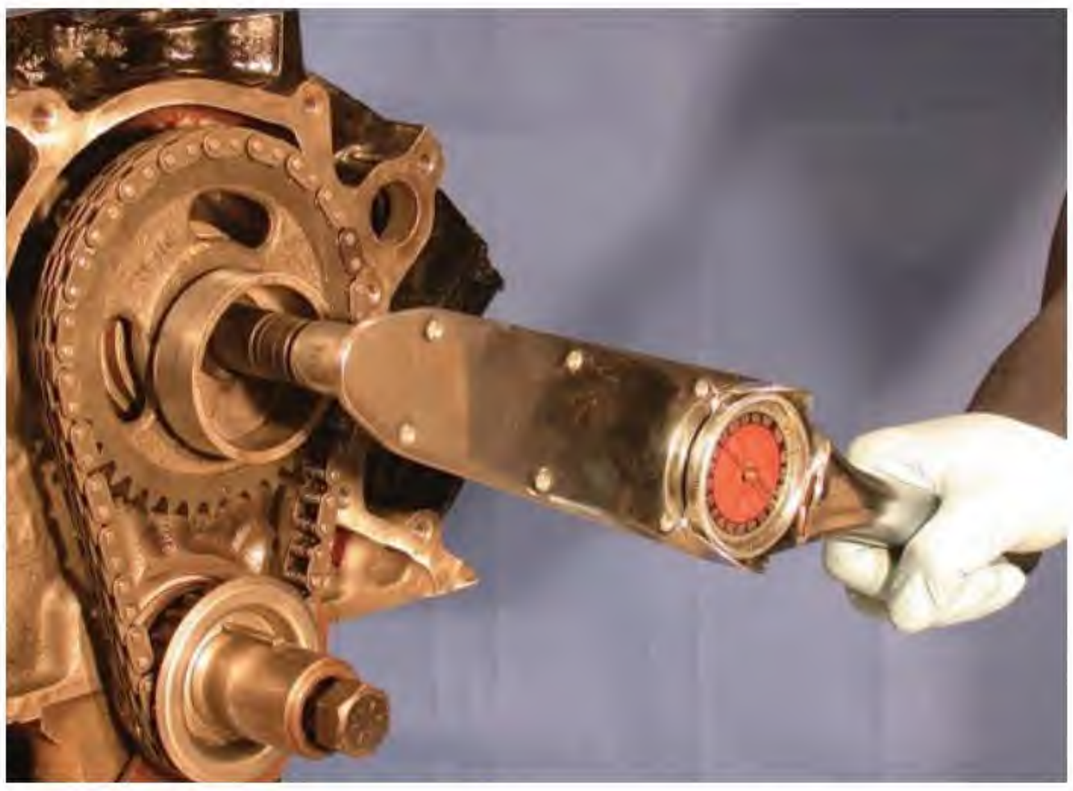
Figure 59-7. With the camshaft and crankshaft in correct positions, fit the chain and sprockets into place. Timing marks on the sprockets should align.





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Figure 59-6. Installing the sprockets. A—A driver is the best way to seat a crankshaft or camshaft sprocket. B—Fit the driver over the sprocket and hit the driver with a hammer until the sprocket is fully seated.



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Figure 59-8. Torque camshaft sprockets to factory specifications.

Usually, tightening the fastener(s) or hand pressure will slide the sprockets over the camshaft and crankshaft. If not, use a large socket or driver and a hammer to exert equal pressure in the center. This will drive the sprockets on squarely. Do not hammer on the outside of the sprockets to force them in place. Blows on the outside of the sprocket may result in misalignment.

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Caution

On some overhead camshaft engines, the starter motor should not be used to turn the crankshaft with the timing chain or belt removed. It is possible, in some designs, for the pistons to hit the valves. The valves could be bent. On these engines, turn the camshaft and crankshaft very slowly by hand to avoid part damage.

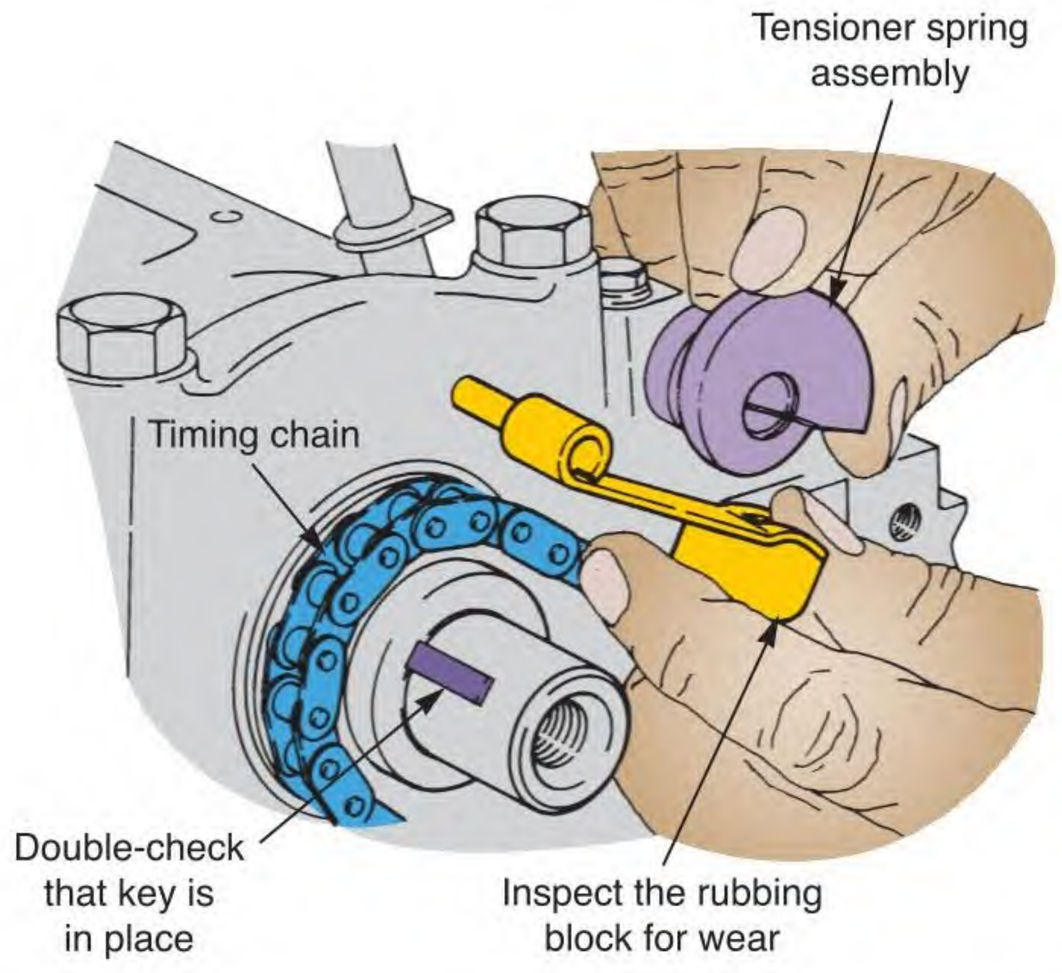
Installing a Chain Tensioner

A ***chain tensioner*** is used in most OHC timing chain mechanisms. Inspect it closely. The fiber rubbing block can wear off, **Figure 59-9**. Replace it if needed.

Fit the tensioner onto the engine. Then, pull on the chain to make sure the tensioner moves properly. Some plunger-type tensioners can bind if worn and extended too much.

Installing an Oil Slinger

The ***oil slinger*** fits in front of the crankshaft sprocket. It slings oil out of the chain and also prevents front seal leakage. An oil slinger is usually a trouble-free part. However, if bent or damaged, it should be straightened or replaced. Look at **Figure 59-10**.



Ford

Figure 59-9. Inspect the chain tensioner closely before installation. The fiber rubbing block can wear. Refer to wear specifications.



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Figure 59-10. Make sure the oil slinger is installed in the correct orientation. It you accidentally install the oil slinger backward, it will be crushed against the timing chain and crankshaft drive sprocket when the timing cover fasteners are torqued.

Make sure the slinger faces the correct direction. If installed backward, it can rub on the front cover. This mistake would require front cover removal, a time-consuming procedure. Then, slide the slinger facing in the right direction over the crankshaft snout.

Engine Front Cover Service

The ***engine front cover***, also called the *timing cover*, holds the front oil seal and encloses the ***timing gears*** or chain. It can be made of thin stamped sheet metal or, more commonly, cast aluminum. To service a front cover, double check that the old cover is not damaged, cracked, or warped and is clean and dry. If needed, check its gasket surface for straightness.

Install a new crankshaft oil seal in the front cover anytime it is removed for service. The old seal must be properly driven out without cover damage. The new seal can then be driven or pressed into the engine front cover properly. Plastic chain guides wear rapidly and are normally replaced on high mileage engines. Chain guides are often secured with small snap-rings. The snap-rings or other fasteners must be removed before the plastic guides will slide off their guide pins on the engine block or head(s).

Front Seal Service

The ***engine front seal*** can sometimes be serviced with the engine block still installed in the vehicle. It is just more difficult working in the confines of the engine

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compartment. Whether in-car repairs are possible depends on whether the engine is mounted transversely or longitudinally in the vehicle and the vehicle's construction. Check the service instructions for the specific make and model vehicle to determine whether in-car engine repairs are feasible and practical. Longitudinal engine front ends are much easier to service in-car than those in transverse-mounted engines.

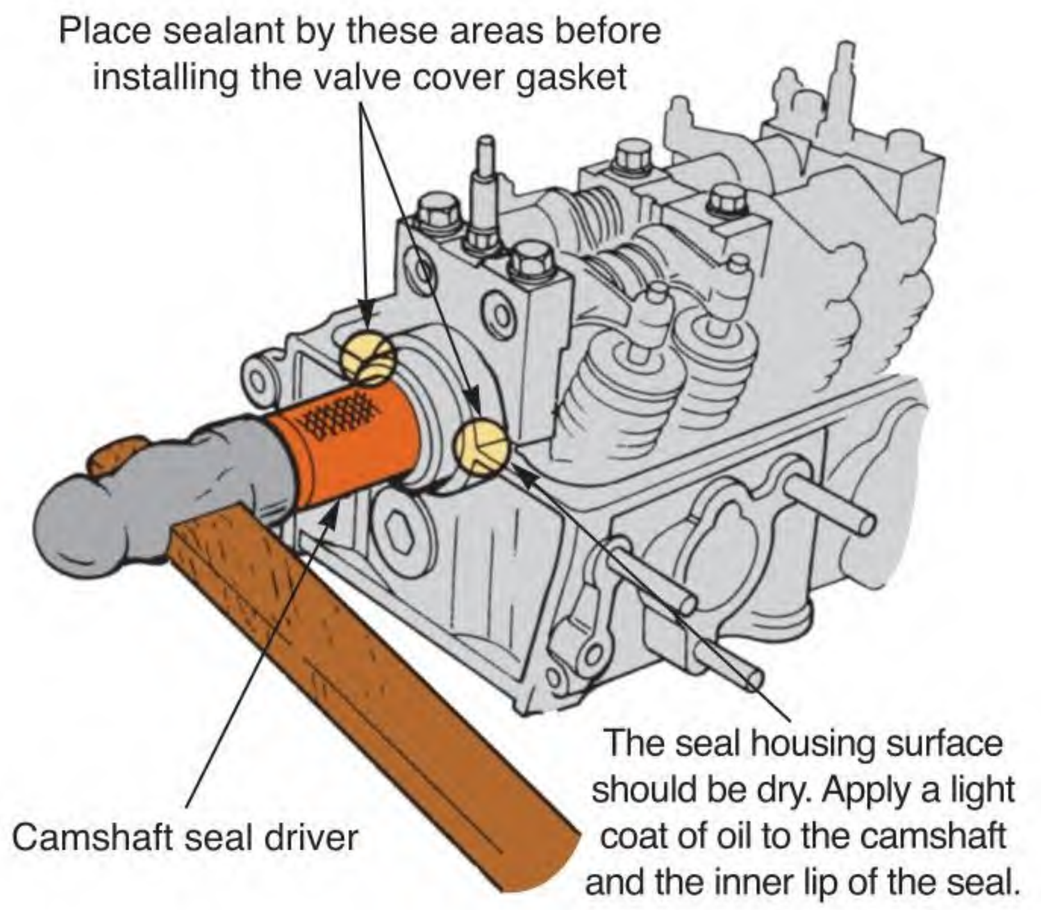
First, remove parts that are in the way of engine front end parts: radiator, cooling fans, and fan shroud. Use a wheel puller to remove the engine vibration damper. Then, depending upon front cover design, you might be able to remove the seal using a seal puller on the outside of the engine. You might also have to remove the front cover to access the inside of the cover to replace the engine front oil seal.

Always compare the old seal with the new one. The outside and inside diameters of the two seals must be the same. You may also be able to match part numbers stamped on the metal flange of the seals.

Before installing a front seal, coat the outside diameter of the seal with nonhardening sealer to prevent oil seepage between the seal body and the front cover. Coat the rubber sealing lip with engine oil to lubricate the seal during initial engine startup. Then, use a seal driver to squarely seat the new seal into its bore.

When available, a seal driver should be used to install the front seal. However, if you do not have one, a block of wood can be used. Drive the seal in squarely without damaging the metal housing of the seal.

Some camshafts also have a front seal, **Figure 59-11**. It seals the front camshaft bearing of an OHC engine. The outside diameter of this type of seal should be coated with nonhardening sealer. The seal housing surface should be dry. Place engine oil or grease on the inside diameter of the seal and on the camshaft. Then, drive the seal fully into place.



Honda

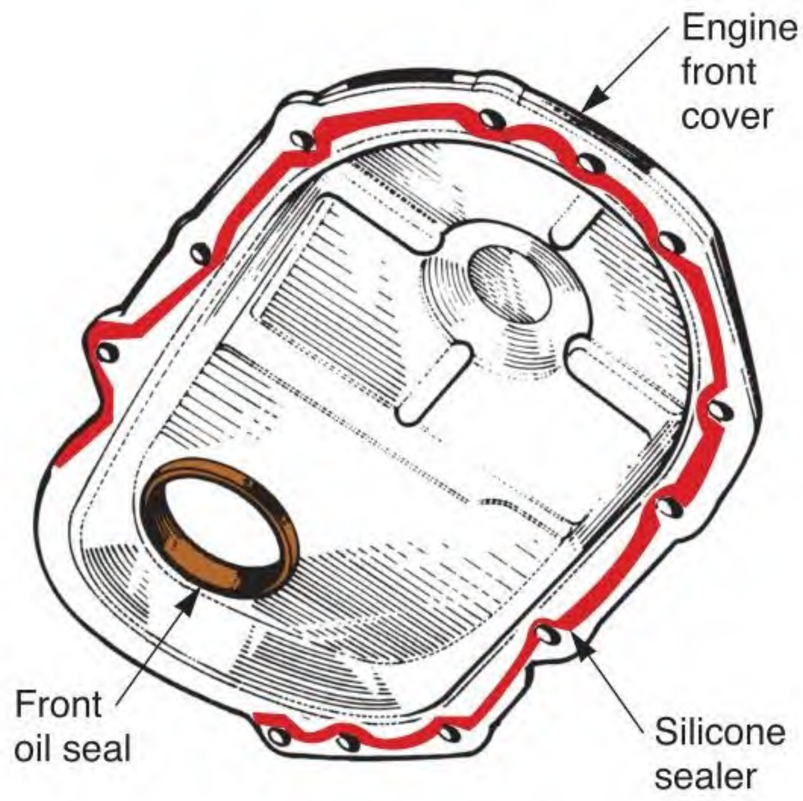
Figure 59-11. A front seal may be mounted in the cylinder head. A seal driver is the best way to install the seal without damaging it.

Installing a Front Cover

Before installing the front cover, check that all fasteners under the cover are properly torqued. Check the installation of the chain tensioner, if used. Double-check timing mark alignment.

Either a conventional gasket or chemical sealant can be used during front cover installation. Usually, both a gasket and sealer are used. Make sure you apply a bead of sealer where two gaskets or parts come together. This is a common leakage point. Also, check that all holes in the gasket align with the corresponding holes on the engine.

Anaerobic sealer is used on the sealing surface between two thick or solid pieces. RTV or silicone sealer is recommended where a flexible part, such as the oil pan, mates with the front cover. Use a small bead of sealer. Make sure to apply a continuous bead in order to prevent oil or coolant leakage. Circle all holes that carry oil or coolant. See **Figure 59-12**.



Fel-Pro

Figure 59-12. To use silicone sealer on a front cover, make sure the cover is perfectly clean and dry. Coat the flange with approved sealer. Use the correct diameter bead and surround all bolt holes and water passages.

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A front-end gasket set often includes the gaskets, oil seals, sealer, and other parts needed to replace a timing cover with the oil pan on the engine, **Figure 59-13**.When servicing a front cover with the engine in the vehicle and the oil pan in place, you must often cut off the existing oil pan gasket flush with the front of the block, **Figure 59-14**. The front cover gasket set often contains small pieces of gasket material for the protruding end of the oil pan. After cleaning the surfaces, apply sealer at the joint between the existing and new oil pan gaskets and fit the new gasket pieces into place. See **Figure 59-15**.



Fel-Pro

Figure 59-13. Note the items often included in a high-quality engine front end gasket set.



Fel-Pro

Figure 59-14. When you are servicing a timing cover only, the oil pan gasket may be damaged. Cut off the old gasket with a razor blade. Clean the surfaces on the pan and the cover thoroughly.



Fel-Pro

Figure 59-15. Extra silicone sealer is normally recommended where the front cover meets the oil pan. Without sealer, a gap could form, allowing oil leakage. A small piece of pan gasket can then be placed on the protruding flange of the oil pan.

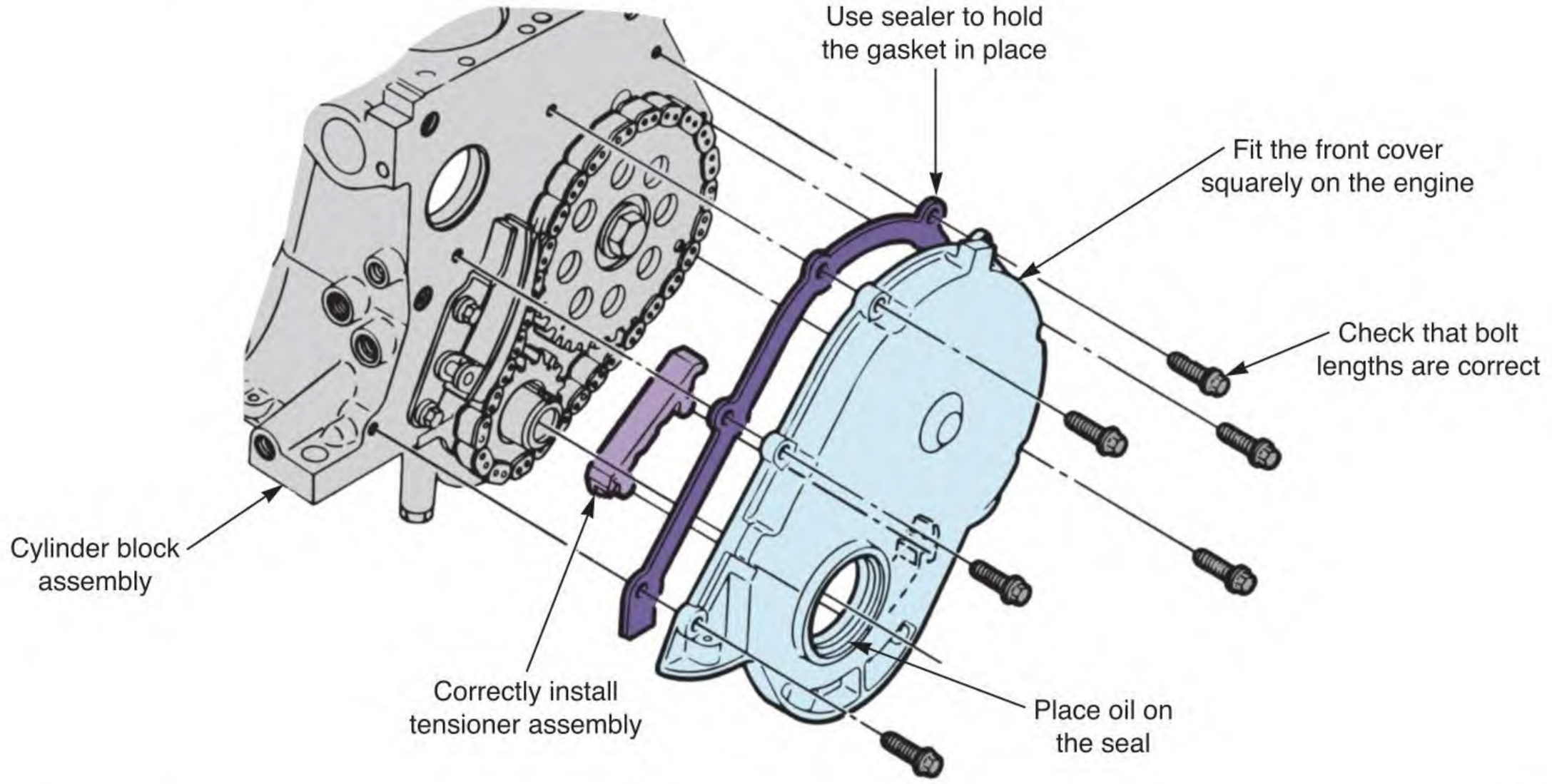
When installing the front cover, do not shift the gasket or smear the sealer, **Figure 59-16**. If the oil pan is on the engine, you may need to loosen the front oil pan bolts and pry down on the pan lightly so the front cover will fit into place. You may need to use a seal alignment tool that fits over the crankshaft snout. This tool positions, or centers, the front cover seal correctly around the crankshaft.

Service Procedure

To install an engine front cover on a cam-in-block engine:

1. Apply sealer to the front cover gasket. The sealer holds the gasket in place during assembly and helps keep it from leaking during service, **Figure 59-17**.
2. Place a small amount of nonhardening sealer on any bolt entering a coolant or oil passage. The service manual will indicate which bolts require sealer. See **Figure 59-18**.
3. Carefully fit the front cover and gasket onto the engine. For in-vehicle service, make sure the oil pan gasket is in place.
4. Install the front cover bolts. Make sure the bolt lengths and locations are correct.
5. Tighten the bolts to specifications in gradual steps following a crisscross pattern.

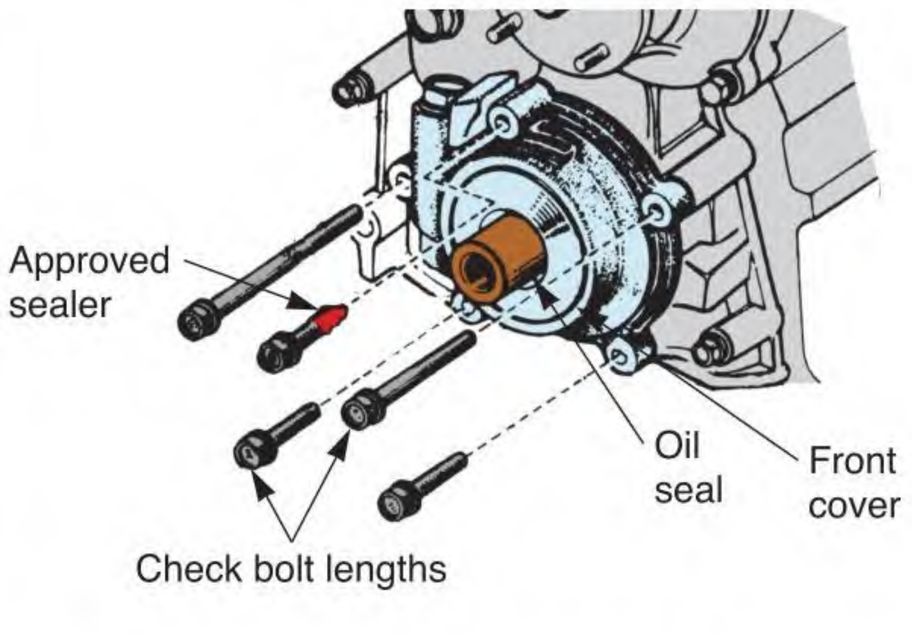
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Ford

Figure 59-16. Carefully position the front cover onto the engine without moving or shifting the gasket.

6. If used, remove the seal alignment tool.
7. Double-check that all bolts are installed properly. It is easy to miss a hidden hole under the lower section of the front cover.
8. Install the front oil pan bolts, if needed.
9. Assemble all other external components, such as the water pump, brackets, vibration damper, radiator, and so on.



Toyota

Figure 59-18. This overhead cam engine has a small front cover. Since an external timing belt is used, the cover does not have to enclose a timing chain or gears. Note that the lengths of the cover bolts differ and that one bolt requires sealer because it enters the water jacket.



Fel-Pro

Figure 59-17. Adhesive-sealer is commonly used to hold a gasket in place during assembly and to help prevent leakage. Make sure you use an approved product.

Vibration Damper Installation

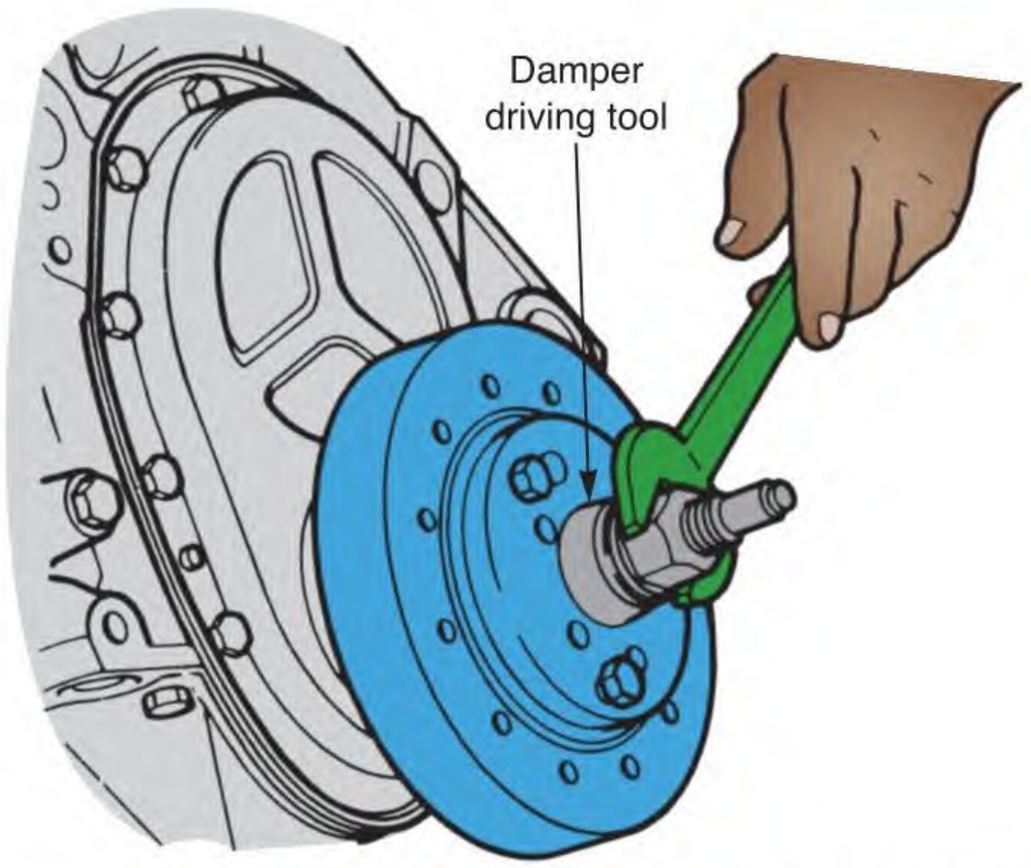
Before installing the vibration damper, check that the crankshaft snout key is properly installed, fully seated, and tight in its groove. Then, place lubricant on the damper seal surface, **Figure 59-19A**. Fit the

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damper onto the crankshaft without pushing the key out of its groove, **Figure 59-19B**. If the key slides out of its groove, the damper will not fully slide into place. Install the crankshaft snout bolt and washer.

Usually, the crankshaft snout bolt can be tightened to force the damper into position. If light hammering is necessary, tap in the center of the damper. Never hammer on its outer ring, which is mounted on rubber. Hammering on the outer ring could shift the ring or damage the rubber and ruin the damper. Sometimes, a special driver is needed to install the damper, **Figure 59-20**.

Make sure the damper seats squarely on the crankshaft snout. If it becomes misaligned during assembly, stop and align the damper to prevent part damage. Once the damper is fully seated, torque the large crankshaft snout bolt to specifications. Install any other parts, such as the crankshaft pulley, and accessory brackets.



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Figure 59-20. A special tool is required to install this press-fit damper.

Timing Gear Service

Timing gear service is similar to timing chain service. Timing gears are usually more dependable than timing chains. They provide thousands of miles of trouble-free operation. However, after prolonged use, timing gear teeth can wear or become chipped and damaged. Carefully inspect used timing gears for any signs of wear (excess backlash) or other problems. Replace the gears as a set, if needed.

Measuring Timing Gear Backlash

Timing gear backlash is the amount of clearance between the timing gear teeth. Backlash can be used to determine timing gear wear. A dial indicator is an accurate tool for measuring backlash.





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Figure 59-19. When installing a crankshaft damper, make sure the key in the crankshaft aligns with the groove inside the damper. A—Apply assembly lube to the seal journal on the vibration damper. B—Align the slot on the damper with the crankshaft snout key and slide the damper into place.

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Service Procedure

To measure timing gear backlash:

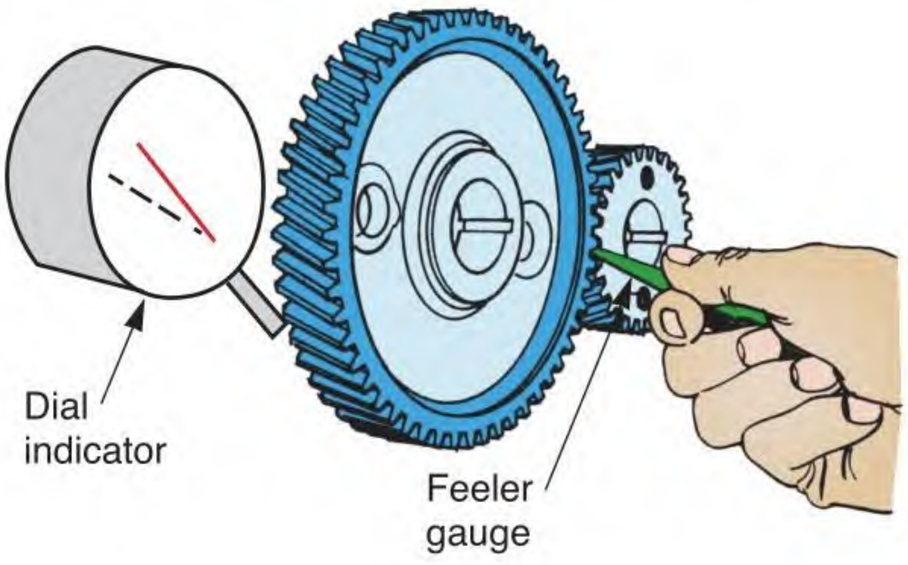
1. Set the dial indicator stand on the engine.
2. Locate the indicator stem on one of the camshaft gear teeth. The stem must be parallel with gear tooth travel. Look at **Figure 59-21**.
3. Rotate the camshaft gear one way and then the other, without turning the crankshaft.
4. Read the indicator at the end of tooth travel in each direction to determine backlash.

If timing gear backlash is greater than specifications, the gears are worn and should be replaced. Refer to the service manual for backlash specifications.

Replacing Timing Gears

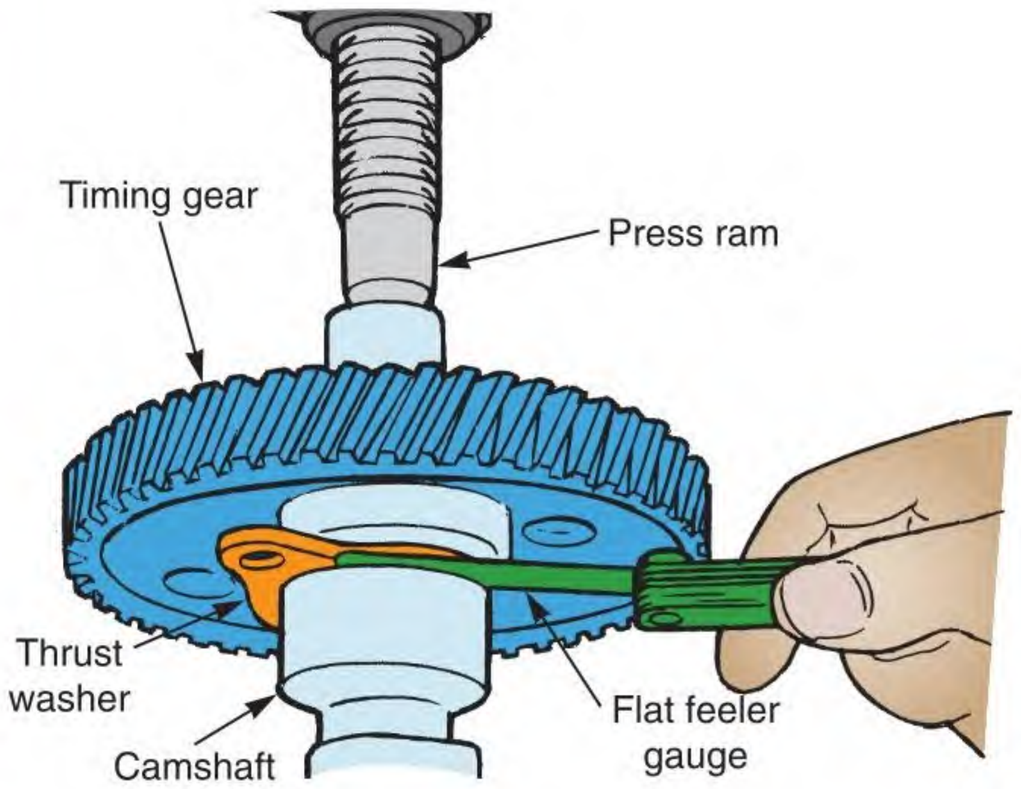
Timing gears are usually press-fit on the crankshaft and camshaft. A ***puller*** is normally needed to remove the crankshaft gear. Timing gears can often be installed using light blows from a brass hammer. Make sure the key seats and keyways are aligned. Tap in a circular motion to force the gears squarely into position. A press may also be needed to install the cam gear on the camshaft. See **Figure 59-22**.

As with a timing chain and sprockets, double-check the alignment of the timing marks. The timing marks must be positioned properly to time the camshaft with the crankshaft. See **Figure 59-23**.



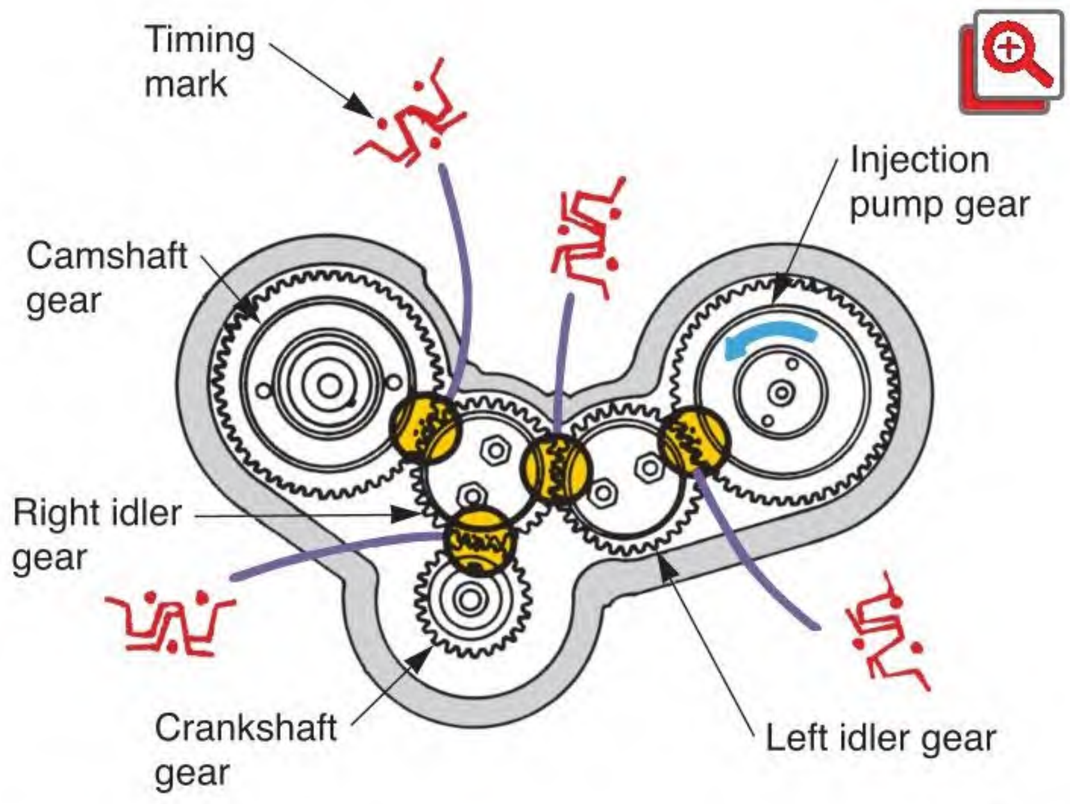
Deere & Co.

Figure 59-21. Position the indicator as shown. Rotate the cam gear back and forth while reading the indicator to find clearance. The largest feeler gauge that fits properly in the gear teeth also indicates clearance. If backlash is too great, the gears are worn.



Ford

Figure 59-22. This particular timing gear must be pressed onto the camshaft snout. Clearance must be maintained between the thrust plate and the camshaft cheek to allow proper camshaft endplay.



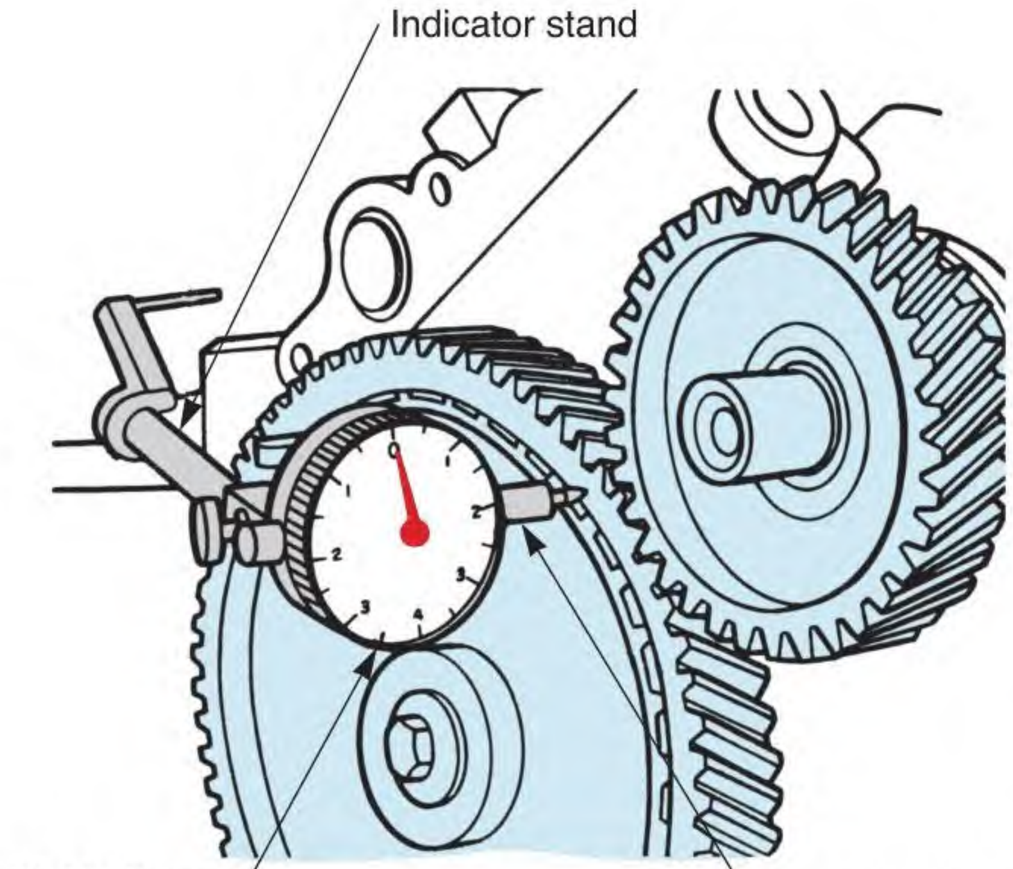
Ford

Figure 59-23. Study the timing marks on the timing gears in this diesel engine.

Measuring Timing Gear Runout

Timing gear runout, or wobble, is unwanted gear side movement, during rotation. Runout is measured with a dial indicator, as shown in **Figure 59-24**.

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Ford

Figure 59-24. After installing timing gears, check gear runout, or wobble, as shown. Turn the crankshaft and read the indicator. Correct the problem if runout is beyond specifications.

Service Procedure

To measure gear runout:

1. Position the indicator stand on the engine block.
2. Place the indicator stem on the outer edge of the camshaft timing gear. The stem should be parallel with the camshaft centerline.
3. Turn the crankshaft while noting indicator needle movement. The indicator reading denotes runout.

If runout is greater than specifications, remove the timing gear and check for problems. The gear may not be fully seated or it may be machined improperly. Also, check camshaft straightness.

Timing Belt Service

Many OHC engines use a synthetic rubber ***timing belt*** to operate the engine camshaft. The cogged (square-toothed) belt provides an accurate, quiet, light, and dependable means of turning the camshaft(s). Timing belt service is very important.

If the timing belt breaks or is improperly installed, engine valves, pistons, and other parts could be damaged. See **Figure 59-25**.

Inspecting the Timing Belt Mechanism

Most manufacturers recommend belt replacement about every 50,000 miles (80,500 km). The timing belts on some late-model engines are designed to last the life of the engine without adjustment or replacement. However, the timing belt should be replaced if oil or coolant has contaminated the belt. Refer to the owner's manual or service manual for belt service intervals if in doubt.

The timing belt is normally replaced during major engine repairs. Since timing belt removal can be very time-consuming, most technicians replace the belt whenever it is removed, regardless of how long the belt has been in service. Timing belts are relatively inexpensive.

During timing belt service, inspect not only the belt, but the sprockets, tensioner, and other parts for problems. Inspect the timing sprockets for rounded teeth or physical damage. Spin the tensioner wheel by hand to check for a dry, bad bearing, **Figure 59-26**. The wheel should spin freely and quietly. Replace the tensioner bearing if you can feel any roughness. Since timing belt tensioners are sealed, many technicians like to replace a tensioner whenever the front end is disassembled, especially on high-mileage engines.

Look for any engine oil leaks that will leak oil onto the timing belt. Any oil leaks on the front of the engine must be fixed before belt replacement. Oil will cause rapid failure of the timing belt.

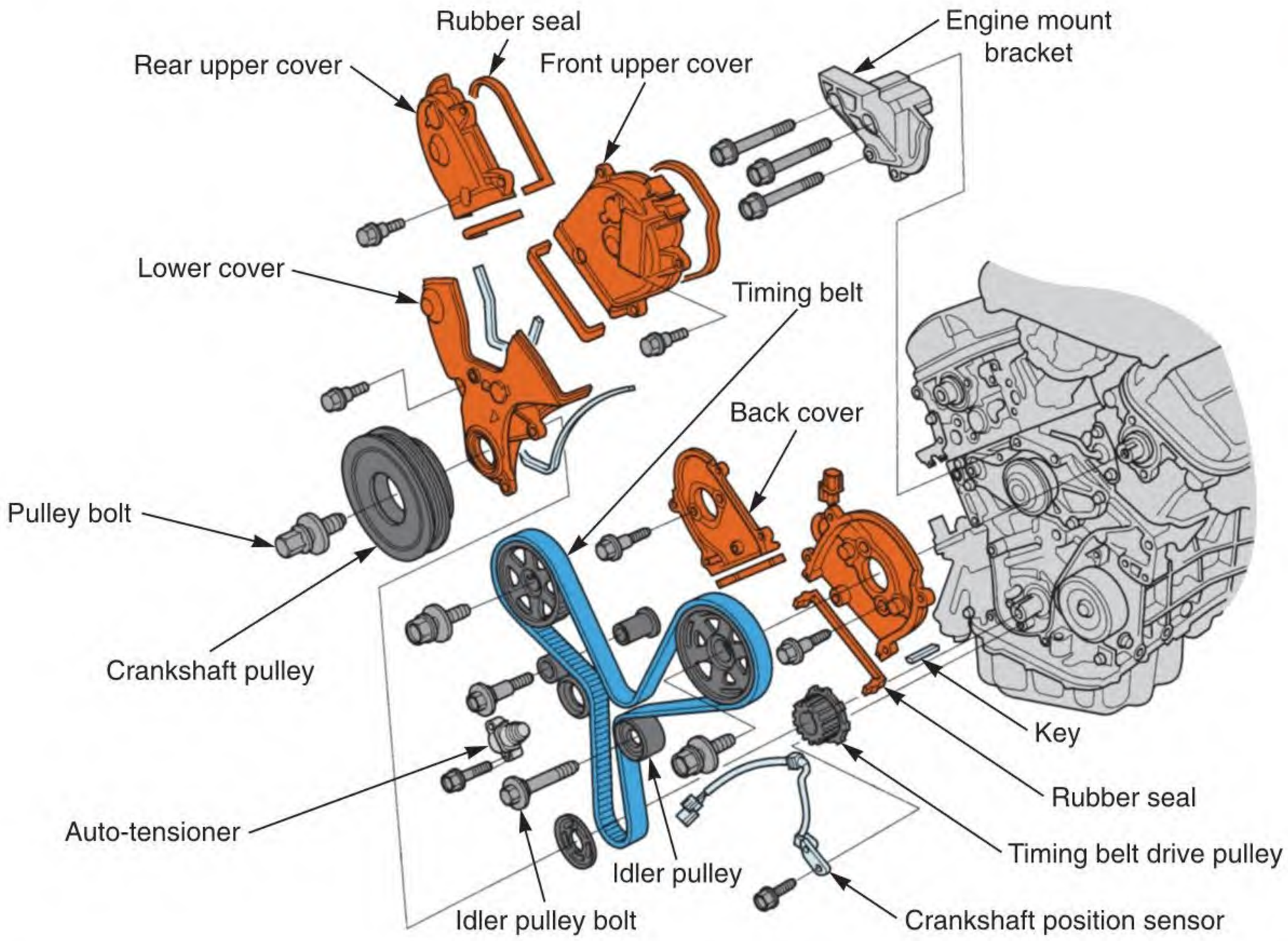
Caution

The lubrication in the belt tensioner bearings can dry out and the bearing can lock up, causing timing belt failure and severe engine damage. Never install a worn tensioner that has dry bearings.

Camshaft Positioning Tool

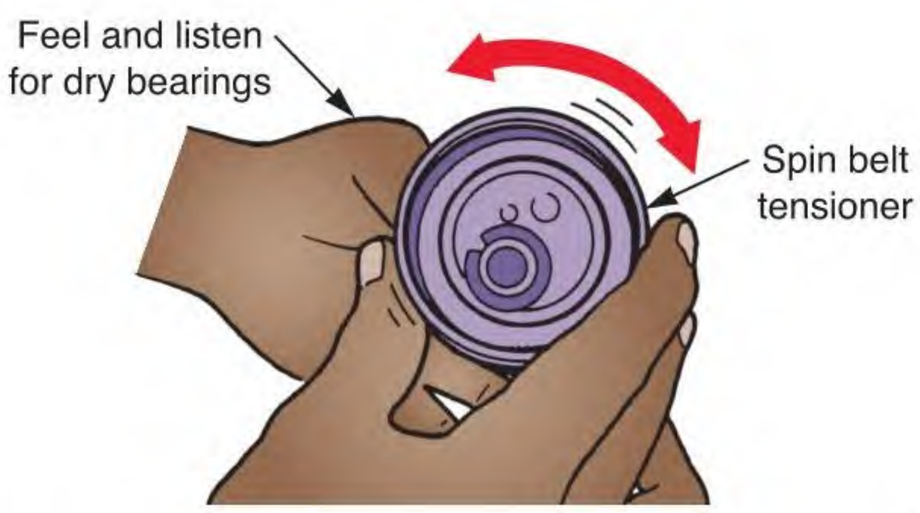
A ***camshaft positioning tool*** is often needed to hold dual-overhead camshafts in alignment during timing belt replacement or installation. Before belt removal, rotate the camshaft until the crankshaft and camshaft timing marks align with number one piston at TDC. Then, install the holding fixture for the specific

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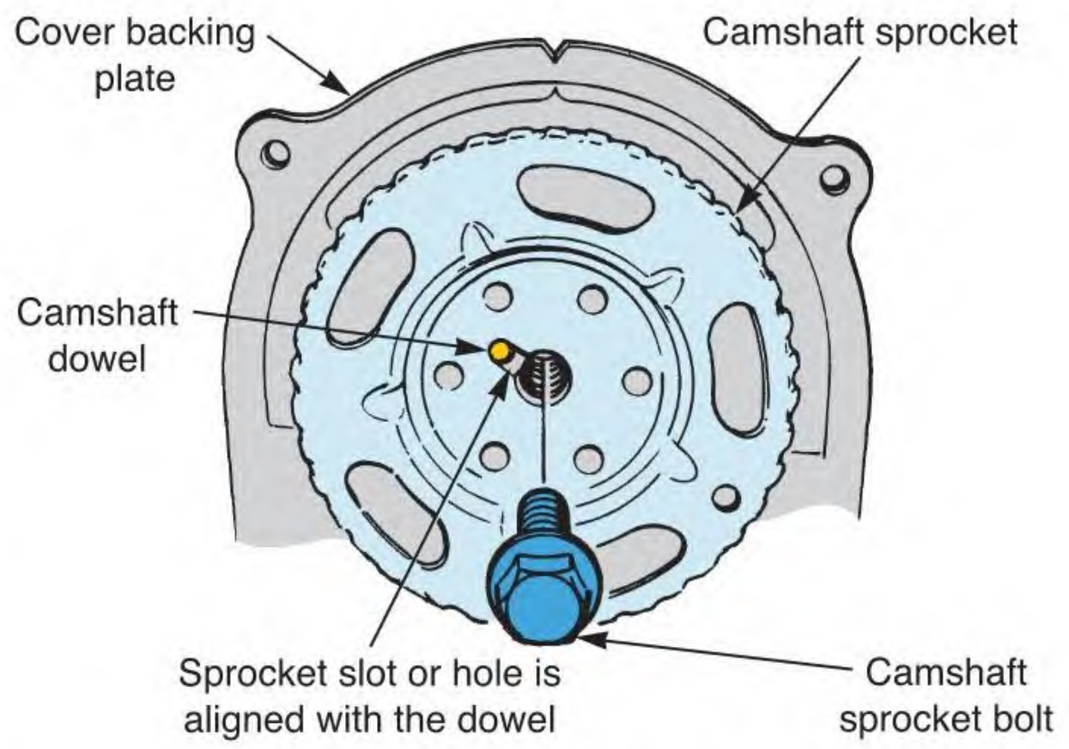
Honda

Figure 59-25. Study this exploded view of the front end on an OHC engine using a timing belt.



Mazda

Figure 59-26. Spin the timing belt tensioner by hand to check for dry or rough bearings. Replace the tensioner if it does not spin freely.



Goodheart-Willcox Publisher

Figure 59-27. A small dowel pin is often used to position the timing belt sprocket.

engine design. It will lock and hold the camshafts in position as you replace the timing belt.

Installing the Timing Belt Sprockets

The camshaft sprocket usually fits over a small steel dowel in the camshaft. The sprocket is secured by one or more bolts. See **Figure 59-27**.

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Service Procedure

To install timing belt sprockets:

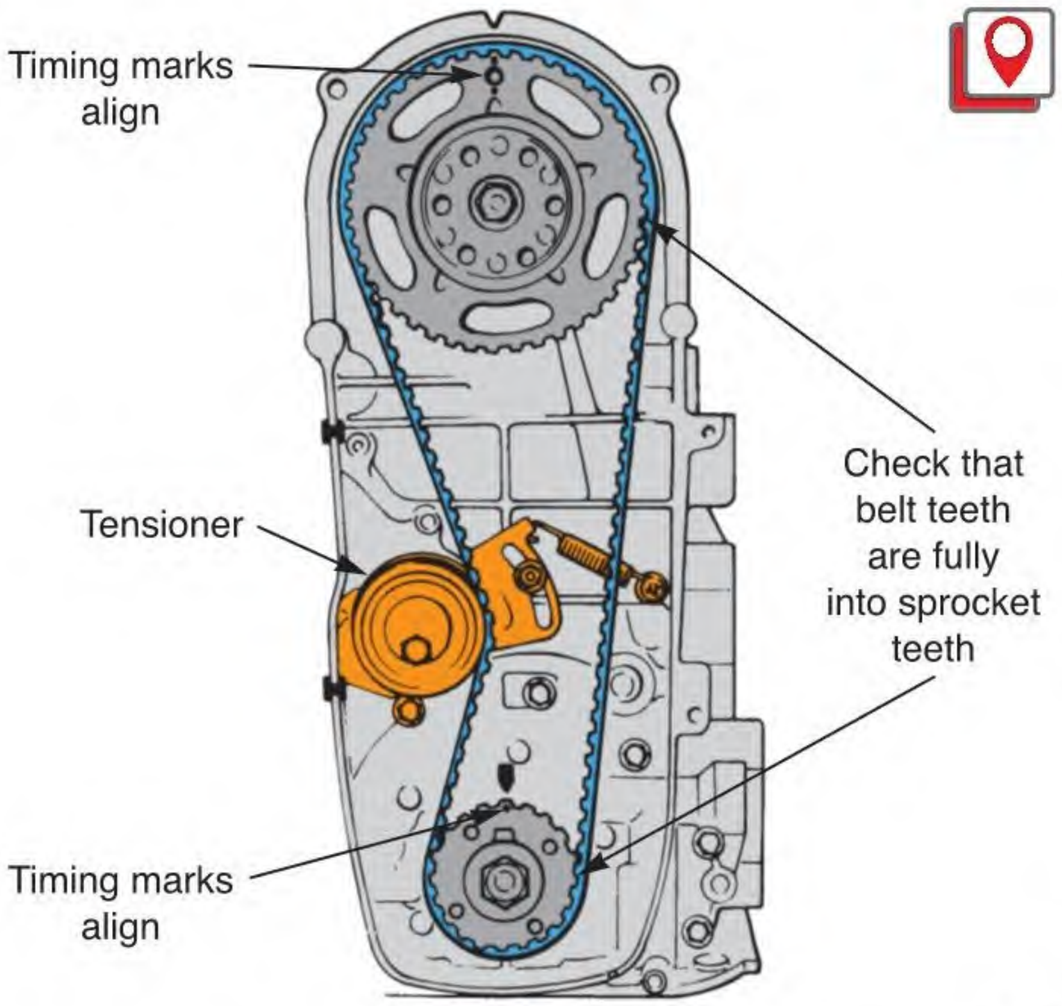
1. Install the camshaft sprocket onto the end of the camshaft. Align any drive pin or dowel on the camshaft.
2. Torque the camshaft sprocket fastener(s) to specifications. Usually, a flat is provided on the camshaft so you can hold the camshaft while tightening the bolt(s). Make sure you do not damage a camshaft lobe or the sprocket teeth when trying to hold the camshaft. Grasp an unmachined surface only.
3. Fit the crankshaft sprocket into position, as was described earlier for a timing chain.
4. Torque the crankshaft snout bolt to specifications.
5. Turn the sprockets until the timing marks align or until number one piston is at TDC on the compression stroke.

Caution

Do not crank the engine with the belt off, or the valves may be bent.

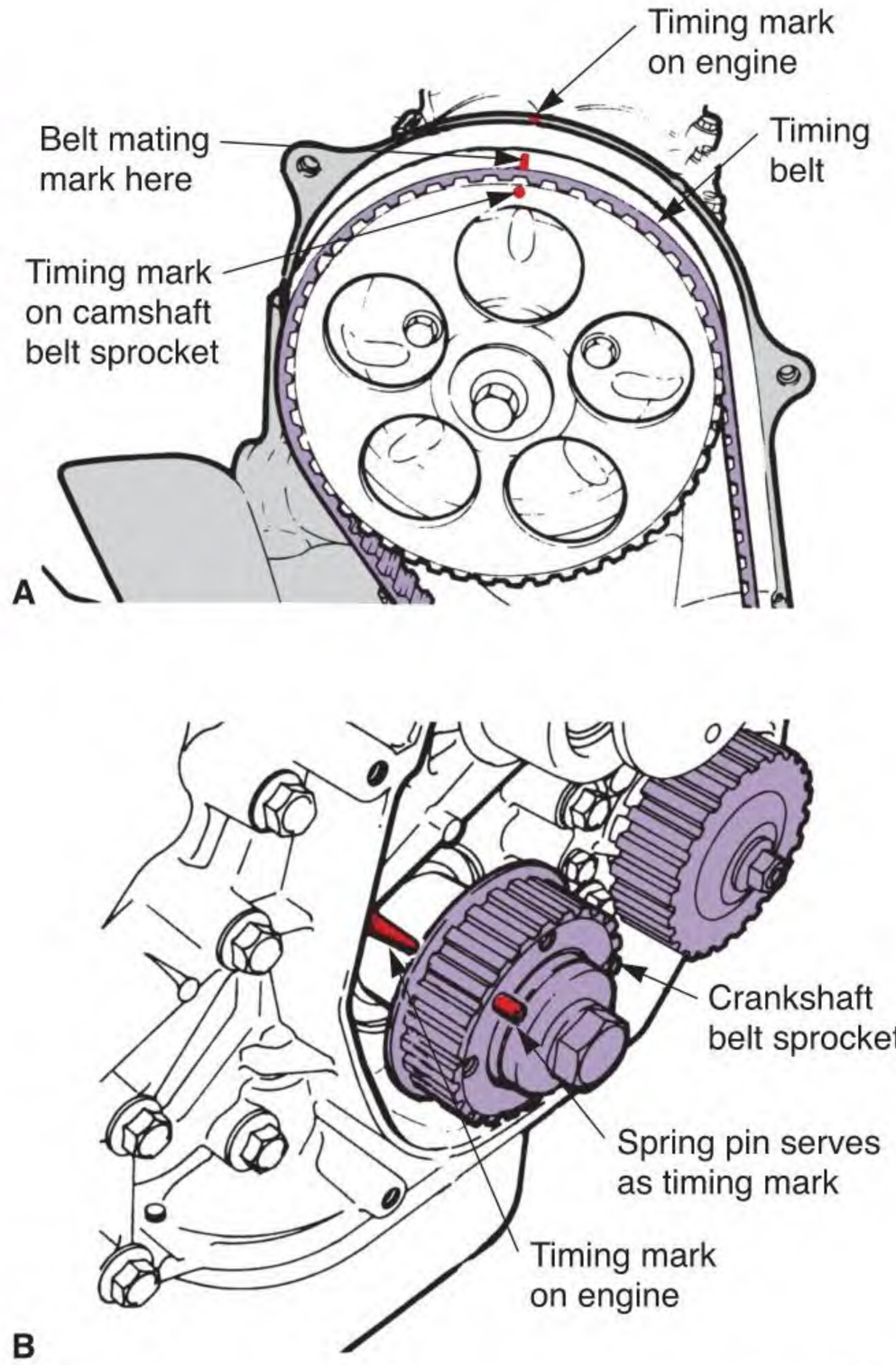
Installing the Timing Belt

Since exact belt installation procedures vary, refer to the service manual. It will explain special methods for aligning timing marks, positioning the camshaft and crankshaft, and installing the belt tensioner. Study **Figures 59-28** and **59-29**.



Ford

Figure 59-28. This is a typical OHC engine with the timing belt installed.



Chrysler

Figure 59-29. When installing a new timing belt, align the timing marks properly. The belt may also be marked. Turn the sprockets by hand. A—The camshaft belt sprocket mark is aligned with the belt marking and the timing mark on the engine. B—This crankshaft sprocket uses a dowel as a timing reference. Align the dowel with the timing pointer on the engine. Types of markings vary. Check the service manual.

If the timing belt is to be reused, the direction of rotation should have been marked on the belt before removal. A reused belt must be installed so it rotates in the same direction as before in order to prevent premature failure.

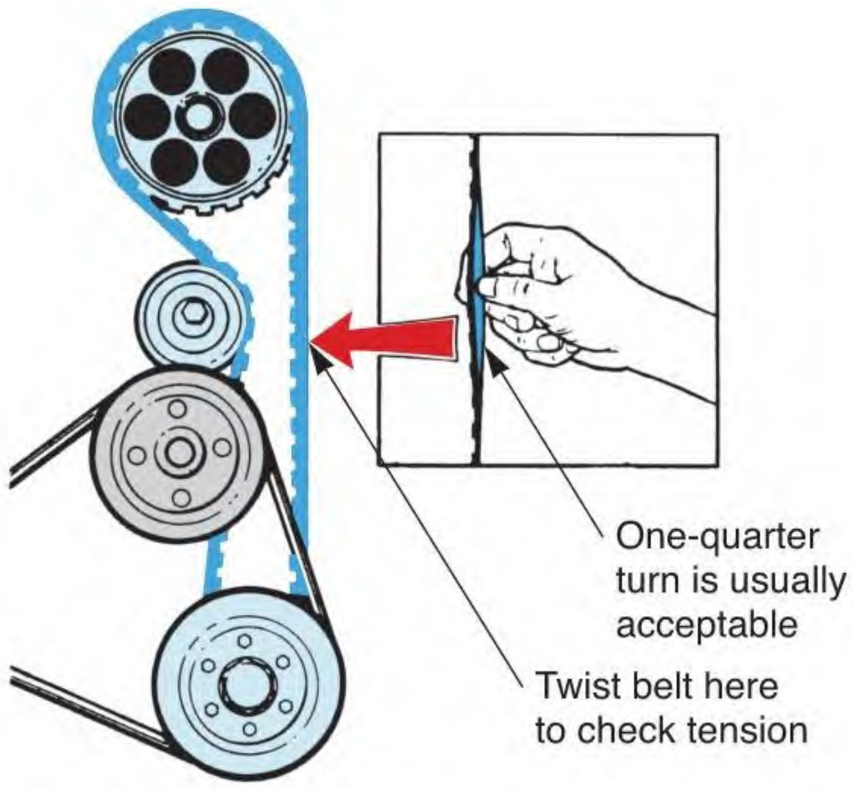
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Adjusting Timing Belt Tension

It is important that ***timing belt tension*** is adjusted properly. If too loose, the belt could flap or vibrate in service and fly off its sprockets. If too tight, the timing belt could snap. Both of these problems could lead to severe valve damage. Proper methods for adjusting tension are detailed in the service manual.

Note how you can loosen the attaching bolts and swivel the tensioner, **Figure 59-30**. Pry on the tensioner bracket to preload the belt. Do not pry on the wheel. The adjusting tool is turned with a wrench until the belt gauge reads within specifications. Tighten the tensioner bracket bolts to secure the adjustment.

There is a simple way to check timing belt tension if a gauge or tool is not available. Adjust the belt tension until moderate finger and thumb pressure is needed to twist the belt about one-quarter turn. This should provide enough tension to prevent belt slippage while also providing long belt, alternator bearing, and idler pulley bearing service life. See **Figure 59-31**.



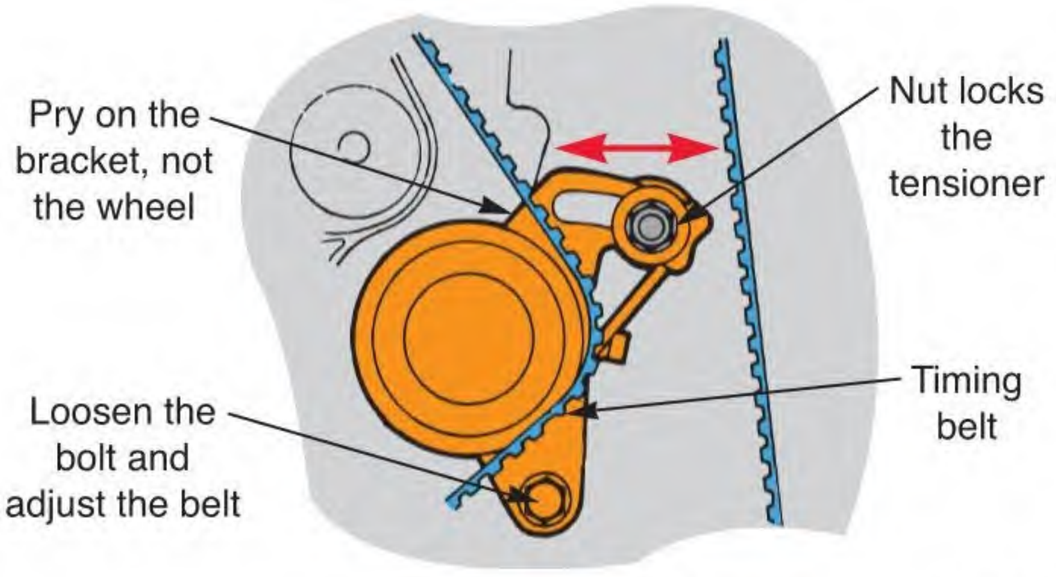
Chrysler

Figure 59-31. As a general rule, a timing belt should twist one-quarter turn with moderate finger pressure when belt tension is correct. However, refer to the service manual for the exact testing method.

Tech Tip

Many new engines have a spring-loaded timing belt tensioner. It can be rotated one way to release tension for belt removal and installation. No belt tension adjustment is required.

After installing and tensioning the belt, rotate the engine by hand. Use a wrench on the crankshaft snout bolt. Turn the crank in the direction of normal rotation until the timing marks come around and realign. Then, double-check alignment of the timing marks.

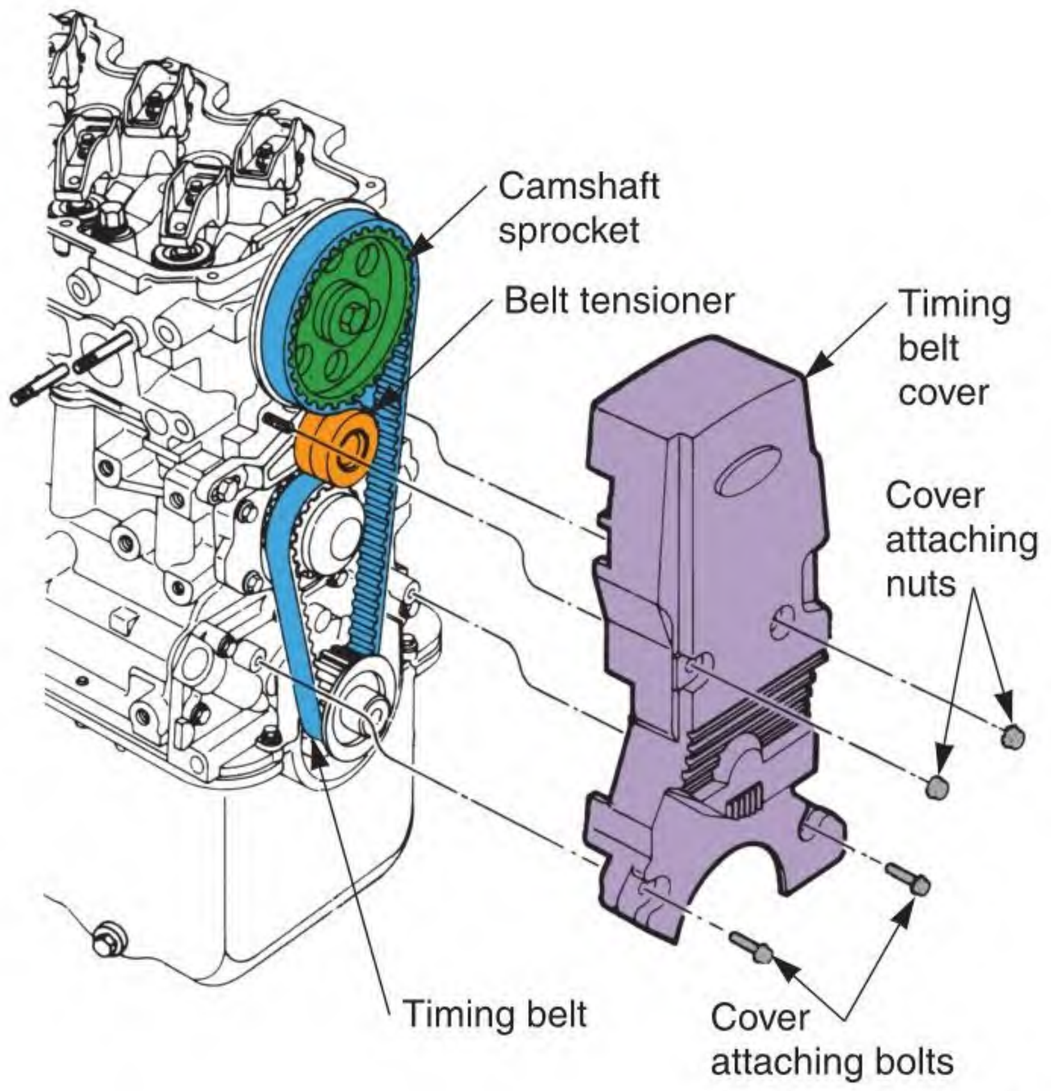


Goodheart-Willcox Publisher

Figure 59-30. This timing belt adjuster has a slot that lets you swivel the adjuster to the side. Pry on the adjuster and tighten the fastener, then check for proper timing belt tension.

Installing the Timing Belt Cover

The ***timing belt cover*** is simply a plastic or sheet metal shroud around the timing belt. See **Figure 59-32**. The timing belt cover keeps debris off



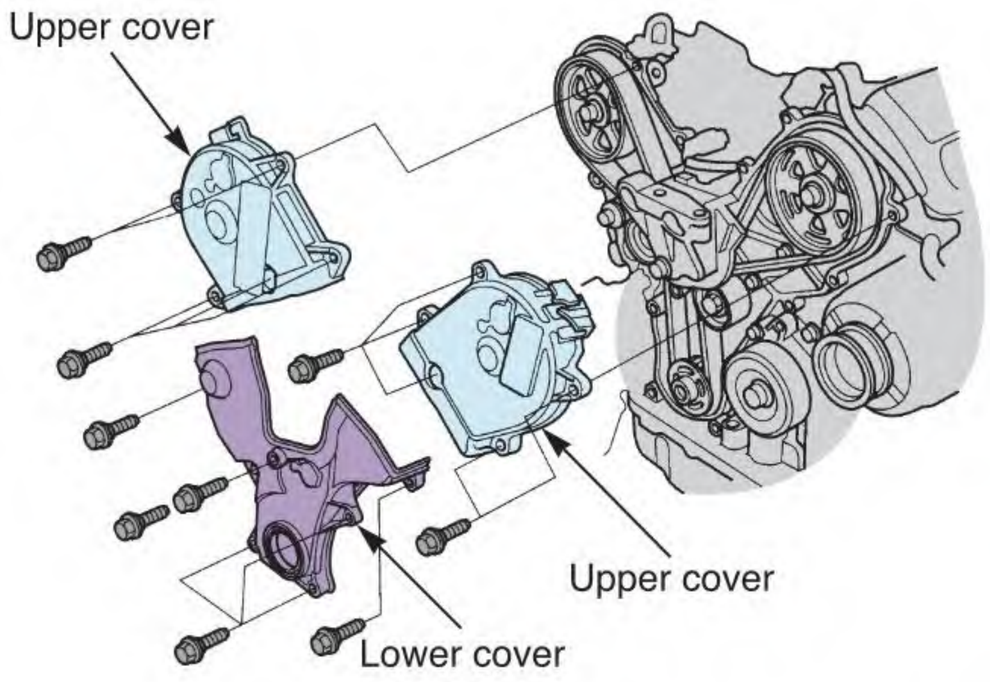
Ford

Figure 59-32. Double-check the timing marks and the belt tension. Then install the belt cover. Tighten the fasteners to specifications.

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the belt and protects your hands when you are working in the engine compartment. Unlike the front cover, the timing belt cover does not contain an oil seal, **Figure 59-33**.

To install the timing belt cover, simply fit it into place on the front of the engine. If rubber washers are used, make sure they are installed. The washers prevent cover vibration, noise, and cracking of the cover. Check that all fasteners are in place and that the belt and sprockets do not rub on the timing belt cover.



Honda

Figure 59-33. When installing a timing belt cover, make sure you use the correct bolts and that all rubber grommets or spacers are in place.

Summary

- Timing chain wear can allow the camshaft to go out of time with the crankshaft, reducing engine power and increase emissions.
- To check timing chain tension, rotate the camshaft sprocket back and forth and measure the distance the sprocket turns before the crankshaft begins to turn. You can also measure the maximum deflection of the chain and compare it to specifications.
- Timing chain tension on an OHV engine can be checked by turning the crankshaft back and forth and checking for valve train movement. If the crankshaft can be turned excessively without valve train movement, the chain is worn and loose.
- Timing sprockets with plastic gear teeth are prone to wear and failure.
- A bad chain tensioner can cause excess chain slack.
- When installing a timing chain, align timing marks on the crankshaft sprocket and camshaft sprocket. Sometimes, a keyway or dowel is used as a timing mark.
- Do not hammer on the outer edges of sprockets to force them into place. Use light blows in the center of the sprockets.
- An oil slinger fits in front of the crankshaft sprocket to prevent oil leakage and to lubricate the timing chain or gears. Make sure it is not installed backward.
- Replace the crankshaft oil seal whenever it is leaking or the front cover is removed. The front seal can be replaced in the vehicle with only partial engine disassembly.
- When installing a new front oil seal, coat the outside diameter of the new seal with nonhardening sealer and wipe engine oil on the rubber sealing lip. Drive the new seal in squarely.
- An engine front cover can be installed using a conventional gasket, chemical sealants, or both. Use anaerobic sealer to seal two thick or solid pieces, and RTV or silicone sealer where a flexible part mates with the front cover.
- When installing a vibration damper, make sure the damper seats squarely on the crankshaft snout. If it becomes misaligned during assembly, stop and align the damper to prevent part damage.

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- Timing gears are very dependable, but gear teeth can break and wear after extended service.
- Timing gears are usually press-fit on the crankshaft and camshaft.
- Timing gear backlash is the amount of clearance between the timing gear teeth. Backlash can be measured with a dial indicator.
- Timing gear runout is unwanted gear wobble during rotation. Runout is measured with a dial indicator.
- Inspect a timing belt for signs of deterioration. Most manufacturers recommend timing belt replacement every 50,000 miles or 80,500 km. Most mechanics replace the belt whenever it is removed for service.
- If a timing belt is reused, it should be installed to rotate in the same direction as before.
- Adjust timing belt tension to prevent belt breakage or looseness. Use a belt tension gauge, or adjust the belt until moderate finger pressure is needed to twist the belt about one-quarter turn.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

camshaft positioning tool
chain tensioner
engine front cover
engine front seal
oil slinger
puller
timing belt
timing belt cover
timing belt tension
timing chains
timing gear backlash
timing gear runout
timing gears
timing marks

Activities

1. Examine service manuals for as many different makes of cars or light trucks as you can find. Determine whether the engine uses timing gears, a timing chain, or a timing belt. Are certain sizes or types of engines more likely to use a particular timing device?
2. Demonstrate the proper use of a wheel puller in removing a pulley or a crankshaft damper (harmonic balancer).

Review Questions

Answer the following questions using the information provided in this chapter.

1. Generally, if you can deflect a timing chain more than _____, the chain should be replaced.
2. How can you check timing chain wear on an OHV engine without removing the timing cover?
3. _____ must align to time the camshaft and valves with the crankshaft and pistons.
4. Explain how to fit the timing chain and sprockets onto the engine.
5. Which part of a chain tensioner should be inspected for wear?
6. Why should you never crank an engine with the starting motor when the timing chain or belt is removed?
7. Which part keeps oil from spraying out the front seal and helps lubricate the timing chain or gears?
   (A) Tensioner.
   (B) Shroud.
   (C) Slinger.
   (D) Front cover.
8. What is the purpose of the engine front cover?
9. What is the purpose of the front seal?
10. What type of sealer should be used on the outside diameter of the front seal?
11. Why should you never hammer on the outer ring of the vibration damper?

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12. _____ is measured with a dial indicator with the indicator plunger resting on one of the timing gear teeth?
    (A) Timing gear runout
    (B) Timing gear diameter
    (C) Timing gear out-of-round
    (D) Timing gear backlash
13. What is timing gear runout?
14. If you do not have a belt tension gauge, how can you adjust belt tension properly?
15. What is the difference between a timing belt cover and an engine front cover?

ASE-Type Questions

1. Technician A says that most engines must be removed from the vehicle in order to replace the timing chain. Technician B says that normally, a timing chain can be replaced without removing the engine from the vehicle. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Technician A says that timing chain wear can reduce engine compression. Technician B says that timing chain wear can affect exhaust cleanliness. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. Technician A says that the camshaft sprocket mark should normally be aligned with a mark on the side of the engine. Technician B says that the camshaft sprocket mark should normally be aligned with a mark on the front of the engine. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. Technician A says that normally the snout bolt can be tightened to force the vibration damper into position. Technician B says that you can hammer on the outer edge of the vibration damper to force it into place on the crankshaft. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. Timing gear runout should be measured with a(n) _____.
   (A) dial indicator
   (B) inside micrometer
   (C) outside micrometer
   (D) feeler gauge
6. Technician A says that timing gear backlash is the amount of clearance between the crankshaft snout and timing gear. Technician B says that timing gear backlash is an indication of the wear on the timing gear teeth. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. An engine is being serviced. Worn camshaft lobes are found and the camshaft is being replaced. The car has 35,000 miles (56,300 km) on it. Technician A says that the timing belt should be replaced. Technician B says that the belt is good for 50,000 miles (80,500 km) and it should be reused. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. Most manufacturers recommend replacing an engine's timing belt about every _____.
   (A) 50,000 miles (80,500 km).
   (B) 70,000 miles (110,000 km)
   (C) 100,000 miles (160,000 km)
   (D) 200,000 miles (320,000 km)
9. Technician A says that a loose timing belt could lead to severe valve damage. Technician B says that if a timing belt is too tight, severe valve damage can occur. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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10. Technician A says that the function of a timing belt cover is to protect the oil seal and belt from debris. Technician B says that the function of a timing belt cover is to keep debris off the belt and protect your hands when working in the engine compartment. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Chapter 60
Engine Reassembly, Installation, and Break-In

After studying this chapter, you will be able to:

- Recall the general rules for proper engine reassembly.
- Install an oil pump and oil pan.
- Install and torque a cylinder head assembly.
- Install lifters or cam followers.
- Install exhaust and intake manifolds.
- Install a camshaft housing cover.
- Install an overhead camshaft.
- Adjust valve train clearance.
- Install valve and camshaft covers.
- Complete final engine assembly.
- Install the engine into the vehicle.
- Perform proper engine start-up and break-in.

This chapter summarizes the basic methods for installing cylinder heads, manifolds, and other external parts during a major engine rebuild. Previous chapters explained how to assemble the reciprocating assembly (crank, rods, pistons, rings) in the cylinder block and how to rebuild or recondition engine cylinder heads. This chapter builds on that knowledge by explaining how to install the cylinder heads, manifolds, and other external engine parts. You will also learn about valve train clearance adjustment, engine installation, initial engine start-up rules, and the proper engine break-in period after rebuilding.

General Engine Assembly Rules

Remember the following basic rules when assembling and installing an engine:

- All engine parts and tools should be perfectly clean and organized before assembly, **Figure 61-1**. The slightest bit of dirt, metal, plastic, or gasket material may cause major engine damage. For example, a new oil pump can be instantly ruined or locked up by just one tiny sliver of metal. A new engine bearing can be gouged and badly scored by a hard bit of plastic seal. Keep cleanliness in mind throughout your engine rebuild.
- Select-fit engine parts must be reinstalled in their same locations to establish correct part clearances. For example, if the pistons in a low-mileage engine are going to be reused, reinstall them in the same cylinder bores from which they were removed. Piston and cylinder diameters and wear patterns will then match up to avoid a second initial part surface break-in and wear with the other mating part.

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Mercedes-Benz

Figure 60-1. Before starting engine reassembly, all components should be perfectly clean and organized. Can you identify all of the parts that go into the cylinder block, cylinder head, or on the camshaft drive?

- Lubricate engine parts thoroughly with a higher-than-normal viscosity oil. All moving parts should be coated with the appropriate lubricant: engine assembly lube, 50-weight motor oil, thick camshaft lube, or high-temperature grease if the engine is to be stored. Using the correct lubricant will provide a strong film of petroleum to protect against high part friction during initial engine start-up.
- Make sure engine bolts and nuts are not mixed together. It is best to use the same fastener as those supplied by the manufacturer. Also, check bolt lengths. A bolt that is too long could damage parts by bottoming out. A bolt that is too short could strip and fail in service. Some bolts must be replaced with new ones every time they are removed from the engine. Check with the service manual when in doubt. Connecting rod and head bolts may require replacement.
- Keep engine parts covered until you are ready to assemble them. For example, keep a cloth over the short block while it is sitting on the engine stand to keep dust and debris out of the cylinders and off other areas in the block. Keep the intake manifold inlet covered, especially when the manifold is installed on the engine. Anything dropped into the manifold could cause severe damage to the pistons, valves, cylinder head, and cylinder block.
- Torque all engine fasteners properly to specifications. Do not try to save time by using an impact wrench on critical fasteners such as connecting rod bolts, main cap bolts, head bolts, manifold bolts, and oil pump bolts. Today's engines are cast with very thin walls. Improper torque can cause fluid leakage, part warpage, or even part breakage.
- Inspect everything one last time as you install engine parts. Look for signs of trouble, such as unusual wear, cracks, or scoring as you work. You do not want to find something wrong after the engine is assembled and installed in the vehicle.
- Do not rush your work. It is very easy to become excited about finishing an engine overhaul and wanting to see the engine "fire up" and run. You must have control and work at a steady pace. For example, rushing and forgetting to tighten a fuel line can produce disastrous results.
- Avoid talking to anyone while working on an engine. If you are distracted, it is very easy to forget to do something. Forgetting to torque even one bolt could result in major engine damage or a serious leak. Most auto manufacturers assign one mechanic to assemble an entire engine in order to avoid assembly line mistakes.
- Refer to a service manual if in doubt about any service task. The manual will answer any questions you might have concerning an assembly method, torque value, valve train clearance specification, and so on.

Engine Reassembly

This section describes the typical steps for engine reassembly. The methods given in this chapter are general and apply to most makes and models. However, follow the specific procedures given in the factory service instructions for the particular engine you are reassembling.

Secure the assembled short block on an engine stand. All connecting rods should be torqued and all surfaces perfectly clean.

Installing the Oil Pump

With the short block on an engine stand, begin engine final assembly by installing the engine ***oil pump***. Make sure any used pump is in good condition by measuring its internal wear. Many technicians prefer to use a new or factory-rebuilt oil pump anytime the pump is removed from the engine. The oil pump is very important to engine service life and is usually not expensive.

If the oil pump is mounted on the front cover, position the new gaskets, seals, pump rotors, and the other parts in correct sequence and orientation. Carefully

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torque all pump fasteners to specifications. Squirt heavy motor oil into the pump cavity after installation to prime the pump. Priming will help protect the pump and ensure full engine oil pressure sooner on initial starting of the engine. Turn the pump by hand to check for smoothness. Make sure the pump is well oiled.

If the oil pump mounts over the crankshaft snout, lubricate parts with high-viscosity oil. Slide the pump housing and rotors into place on the front of the engine. Make sure any crankshaft snout key and keyway are engaged properly with the oil pump or pump drive sprocket or gear.

Check that the oil pump and any gasket holes align properly. Never use sealer on an oil pump gasket. A gob of loose sealer could make the pressure control valve stick. The oil pump gasket is usually installed clean and dry. Start the pump bolts by hand and then torque them to specifications in a crisscross sequence.

If support brackets are provided on the oil pump, make sure they are installed properly. The brackets prevent pump vibration that could break the pump housing or cause bolt or bracket failure. The oil pump pickup tube and screen must also be in good condition and properly installed.

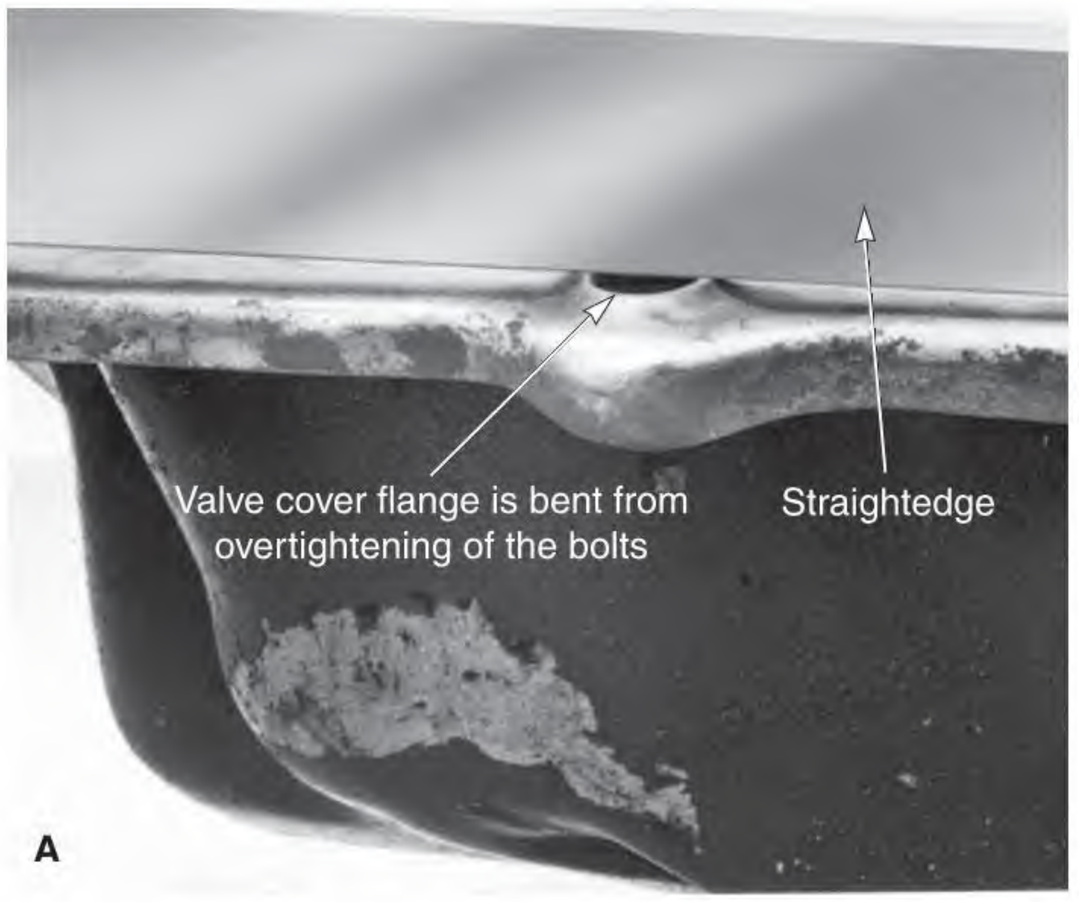


Figure 60-2. Always check the oil pan flange for warpage, cracks, or deformation. Also check the condition of the oil drain plug and threads in the pan. A—Lay the oil pan on a flat workbench to check for a bent flange like this one. B—The flange on a sheet metal oil pan can be straightened. A cast aluminum pan must be welded if its flange is cracked or damaged.

Tech Tip

Oil pump mounting bolts must be properly tightened to specifications. If these bolts loosen or fail in service, the engine will lose all oil pressure. Major bearing damage can result in a matter of seconds. It might be wise to use thread-locking compound on the oil pump bolt threads to prevent the bolts from loosening due to high-speed engine vibration.

Installing the Oil Pan

With the oil pump and front cover in place, you are ready to install the ***oil pan***.

Service Procedure

To install the oil pan:

1. Lay the pan face down on a flat work surface. Check for gaps between the oil pan and work surface. If the pan flange is bent or untrue, straighten it as shown in **Figure 60-2**. A bent flange can cause oil pan gasket leakage.
2. If the pan is aluminum, check its sealing surface for cracks, deep gouges, or any remaining gasket or sealant. Make sure the sealing surface is perfectly clean and dry.
3. Turn the pan upright and lay the oil pan gasket in place on the pan. Check that all bolt holes align and that you have the correct gasket.
4. Either adhere the gasket to the pan or to the engine block, depending on flange design.

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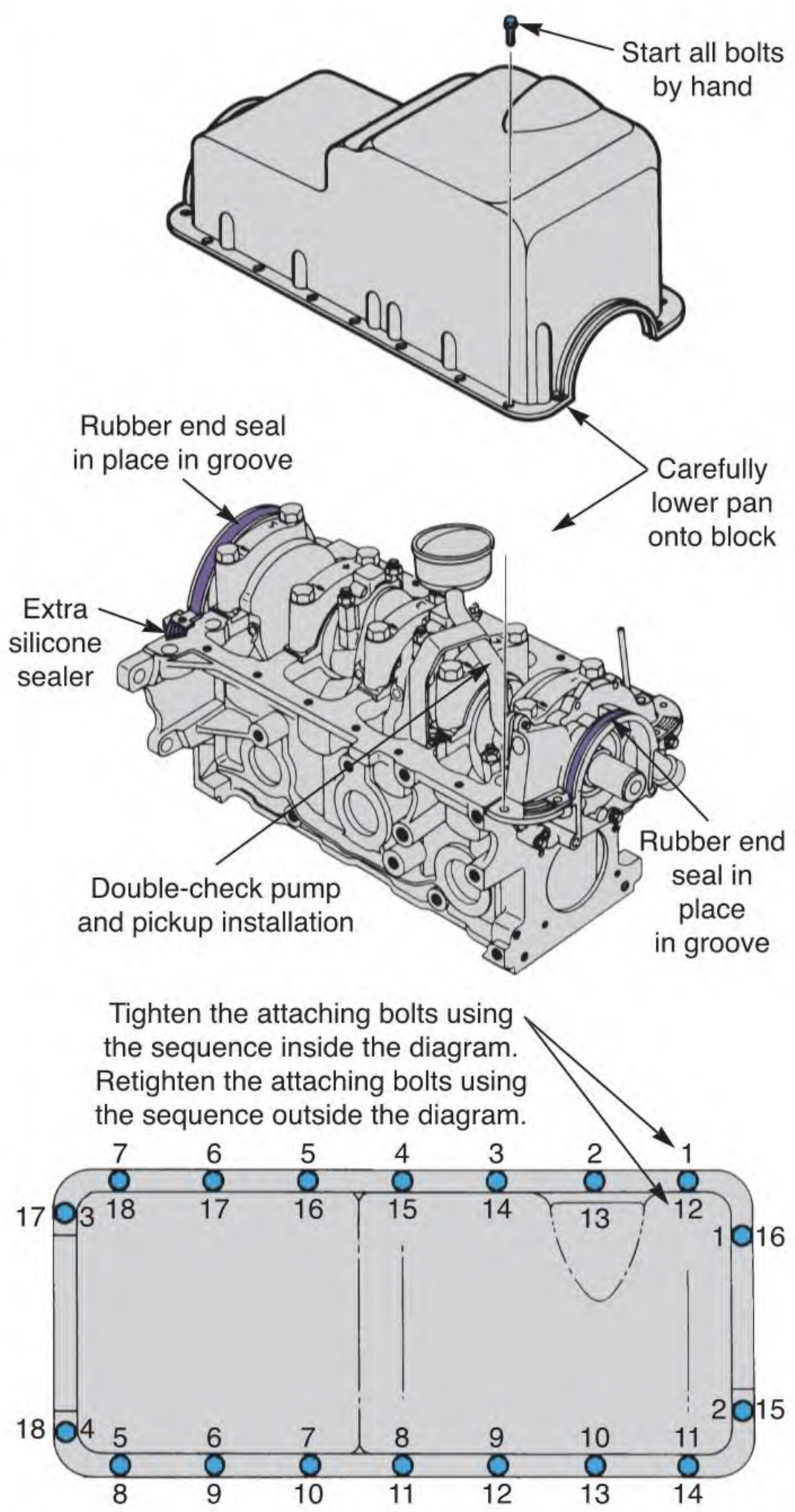
Tech Tip

If the engine is installed in the car, it might be easier to glue the gasket to the oil pan. If you are working on an engine stand, it might be better to bond the gasket to the cylinder block, **Figure 60-3**. There is less chance of the gasket falling or shifting during assembly.

5. If necessary, work the ***end seals*** for the oil pan down into grooves in the oil pan or front cover and block. The pan gasket should be installed next to or under the rubber end seals.
6. Use RTV sealer to help prevent leakage where the gasket and end seals overlap. Allow the gasket sealer to set up slightly before installing the pan. This will help keep bolt holes aligned.
7. Fit the pan into place on the engine block.
8. Start all oil pan bolts by hand before tightening any of the fasteners. If you tighten any of the bolts before others are started, the gasket can compress and block the other bolt holes.
9. With all bolts started, tighten the oil pan bolts to specifications. Use a crisscross pattern, or other specified pattern, to ensure even gasket compression. See **Figure 60-4**.

Fel-Pro

Figure 60-3. Sealer is often used to hold an oil pan gasket in perfect alignment during pan installation. Sealer also helps prevent oil pan leaks. Always place an extra dab of sealer where two seals overlap or come together.



Ford

Figure 60-4. When installing the oil pan, start all bolts by hand before tightening any bolts. Torque the bolts to specifications in the recommended sequence.

Tech Tip

Do not overtighten the oil pan bolts. Overtightening is a common mistake that leads to oil pan leakage. Torque the bolts to factory specs.

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Installing Accessory Units

With the engine upside down on the stand, install any components that are easily accessible. For example, you might bolt on the engine motor mounts, any sensors or sending units, the oil filter bracket, and so on. These parts are easy to access with the engine on the stand after oil pan installation.

When installing the water pump, check the fit of the new gasket or seal. Then, use gasket adhesive to hold the gasket on the pump or silicone to hold a rubber seal. If only a chemical gasket or RTV is used, form a continuous bead and circle all bolt holes and coolant passages. Fit the pump on the engine and start all bolts by hand. Check bolt lengths. Place sealer on threads of any bolts that extend into coolant and oil passages in the block.

Cylinder Head Installation

Installation methods are very critical when bolting the cylinder head to the engine block. Late-model cylinder head and block castings are thin-walled cast aluminum that can leak, warp, or crack if installed improperly. Cast iron cylinder castings of the past were not prone to these problems, but were "heavier than a boat anchor." The engines in late-model vehicles also operate at higher temperatures than in the past, which can increase the strain on the large gasket between the head and block. Great care must be taken to ensure proper installation techniques for modern cylinder heads.

Installing the Head Gasket

Before installing the head gaskets(s) and cylinder head(s), double-check that the engine pistons are installed in the right direction in their cylinders. Check the arrows or other markings on the piston heads. Also, rotate the crankshaft so the number one piston is at top dead center to prepare for front-end assembly and camshaft timing.

Caution

A *head gasket* can usually only be installed one way. If installed backward, the gasket may fit, but coolant or oil passages may be blocked. This mistake could cause oil starvation to the valve train or engine overheating damage.

Service Procedure

To properly install cylinder head gaskets on the block:

1. Find the cylinder head gasket markings that show the front or top of the head gasket. The head gasket may be marked "top" or "front," or it may have a line to show the installation direction. Study **Figure 60-5**.
2. Use the metal dowels provided to hold the head gasket on the block during assembly. If metal dowels are not provided, use two long stud bolts to align the head gasket and head during assembly.
3. Install Teflon-coated, permanent-torque type head gaskets onto the block clean and dry. Sealer is not recommended. Permanent torque means retorquing is not needed after engine operation.



Ford

Figure 60-5. A head gasket that is installed upside down or backward will usually block oil and coolant passages to the cylinder head. A—A word, arrow, or notch indicates the front or top of the head gasket. B—Dowels are often used to hold the head gasket in alignment as the head is installed.

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Installing the Cylinder Head

After the valves, valve seals, and springs have been tested, serviced, and reassembled in the bare head, the head is ready for installation. It cannot be overstressed that cleanliness is critical to the quality of the engine rebuild during all steps of reassembly.

Service Procedure

To install the cylinder head on the cylinder block:

1. Use compressed air to blow out every cylinder. Blow in a circular pattern over the top of each piston to dislodge any debris down on the rings.

Caution

Reinspect the piston orientation in the block to catch any previous assembly or machining mistakes. Make sure any valve clearance indentations in the pistons align with the intake and exhaust valves. If pistons were accidentally installed backward or machined improperly, severe piston and valve damage will result from torquing the cylinder heads. The valve heads would be crushed into the tops of the pistons.

2. Wipe motor oil onto the cylinder walls with a clean rag. This will also clean the cylinders and piston heads. Wipe off the block deck with a clean, solvent-soaked rag until dry.
3. Blow off the cylinder head assembly with compressed air. Wipe the head deck or gasket surface with a clean solvent-soaked rag until dry.
4. Check the dowels for holding the head gasket in alignment. They must be fully installed in the block and the head gasket must be fully down over the dowels.
5. Find the markings on the head gasket that show top and front. Also check the head gasket for gouges, dents, or cracks. If you find even a small flaw, the head gasket should be replaced with a new one.
6. Place the head gasket onto the block clean and dry. Never apply gasket adhesive or sealer on a head gasket, or the gasket will leak combustion pressure and water.
7. Make sure the head gasket is over the dowels. If dowels are not provided on the block deck, install stud bolts in the block, **Figure 60-6**.
8. Carefully place the cylinder head over the head gasket and block, **Figure 60-7**. Do not bump and damage the gasket. Try to lower the cylinder head straight down over its dowels or stud bolts.

Caution

If you bump the head on the gasket at an angle, remove the head to check the head gasket for damage. Even a light impact from a corner of the head can ruin the head gasket. In particular, check the metal O-rings that seal combustion pressure for dents, which could lead to a blown or burned head gasket.

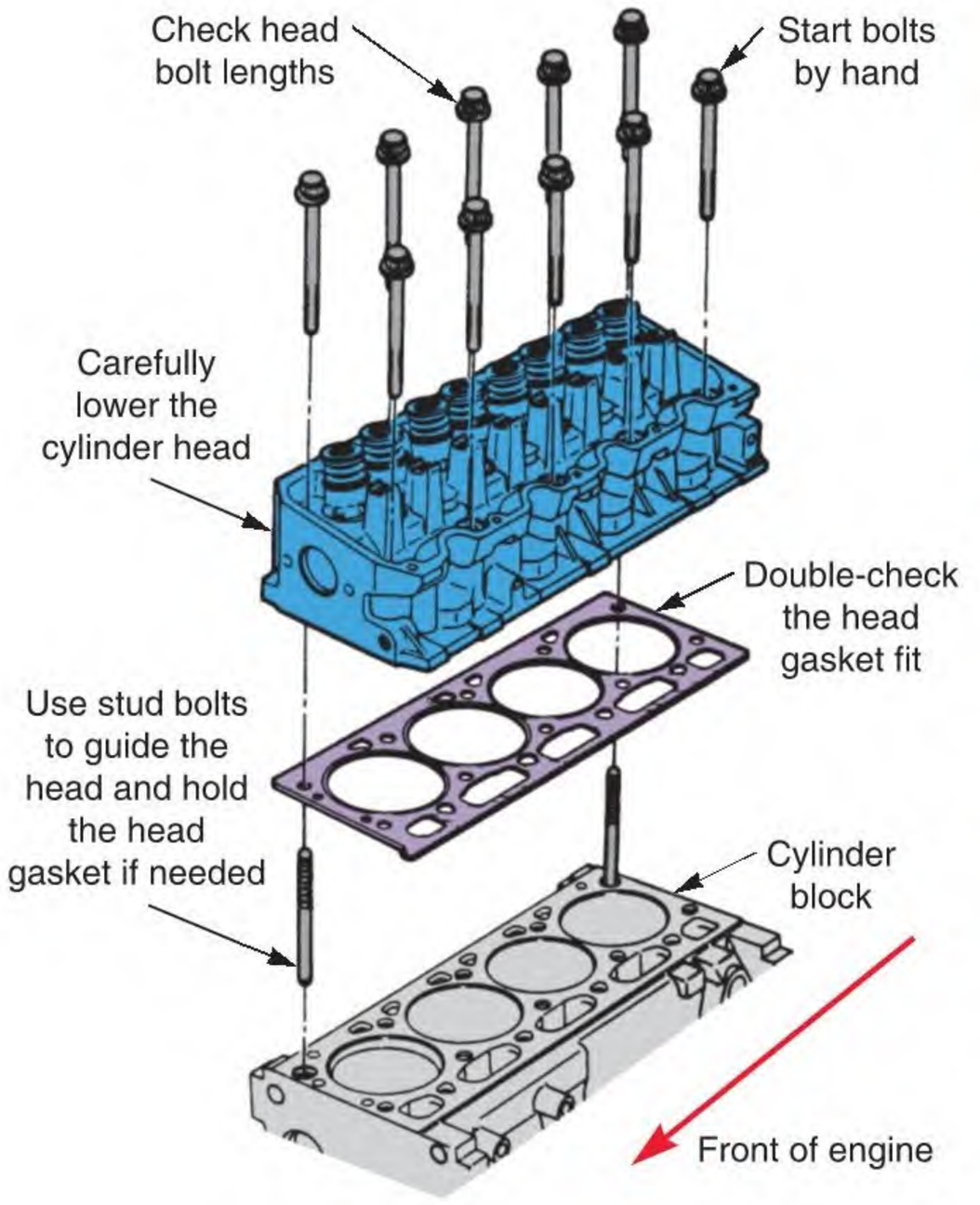
Installing and Torquing Head Bolts

Some engines are assembled with ***torque-to-yield bolts***. This type of bolt must be replaced during reassembly of the engine. Refer to the service manual to find out if the head bolts are torque-to-yield and must be replaced.

Some engines have head bolts of different lengths. Make sure you have not accidentally installed a head bolt in the wrong hole. This could cause severe cylinder block damage and engine failure. Double-check that the head bolts are all sticking out the same amount when hand-threaded into their holes.

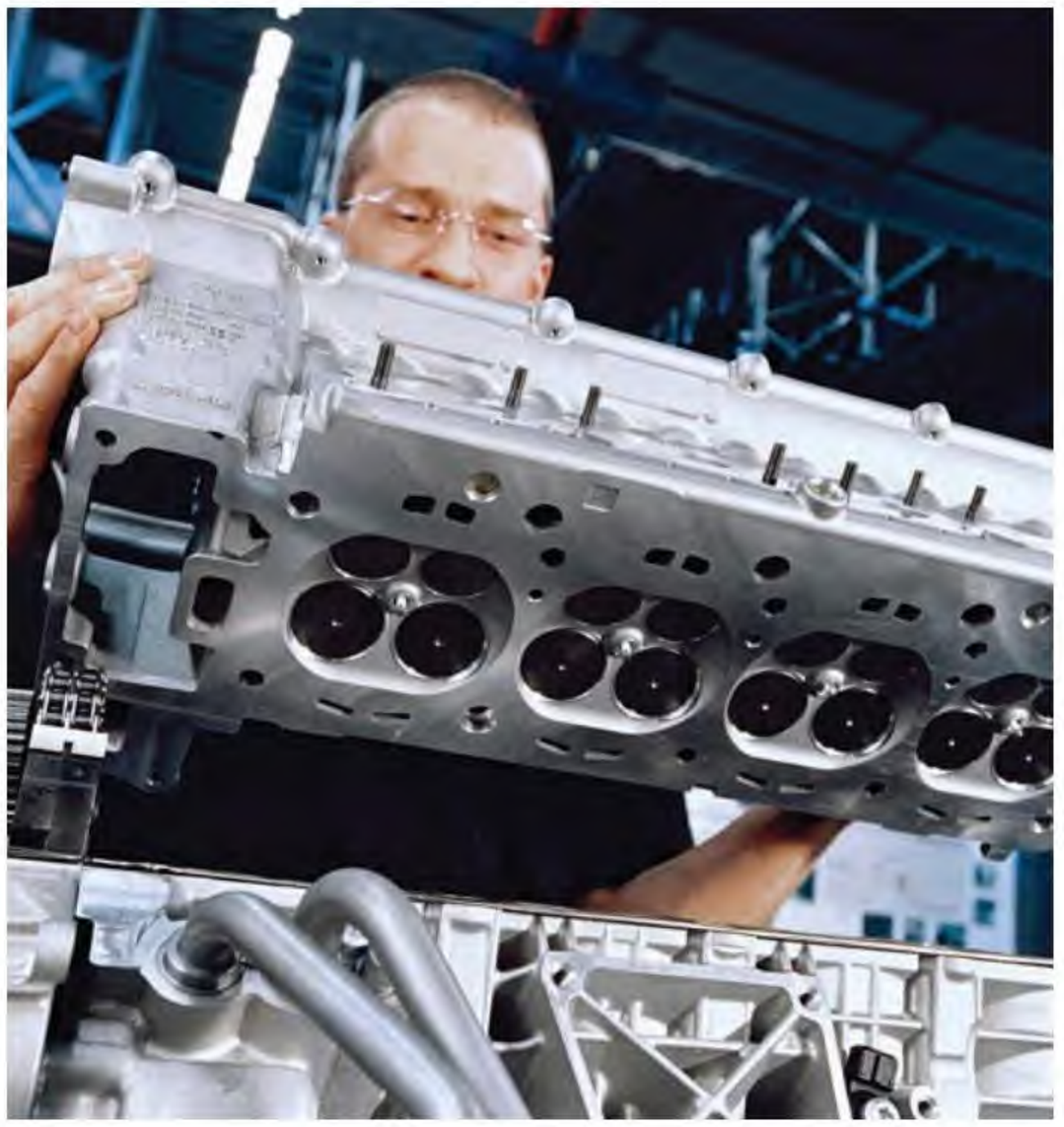
Some head bolts may extend into a coolant or oil passage. Place nonhardening sealer on the threads of these bolts, **Figure 60-8**. The service manual will show which bolts must be sealed. If sealer is not applied to the threads on these fasteners, oil or coolant may leak past the threads.

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Ford

Figure 60-6. If dowels are not provided, use two long stud bolts to align the head gasket and cylinder head during assembly.



Mercedes-Benz

Figure 60-7. Steadily and slowly lower the cylinder head straight down onto the cylinder block dowels or head studs. If you accidentally hit the edge or corner of the head on the gasket, recheck for gasket damage. Replace the head gasket if its condition is questionable.

Make sure all bolt holes in the block are clean. Use compressed air to blow them out if needed. Place a drop of oil on the head bolt threads that do not have sealer on them. This will ensure an accurate torque when tightening the head bolts.

Tech Tip

To prevent hydraulic lock and damage to the block, do not squirt oil into bolt holes. Hydraulic lock could prevent proper torquing or lead to part damage. To ensure accurate bolt torque, use only the lubricant recommended by the manufacturer. Using the wrong thread lubricant can greatly affect bolt torque and clamping pressure.



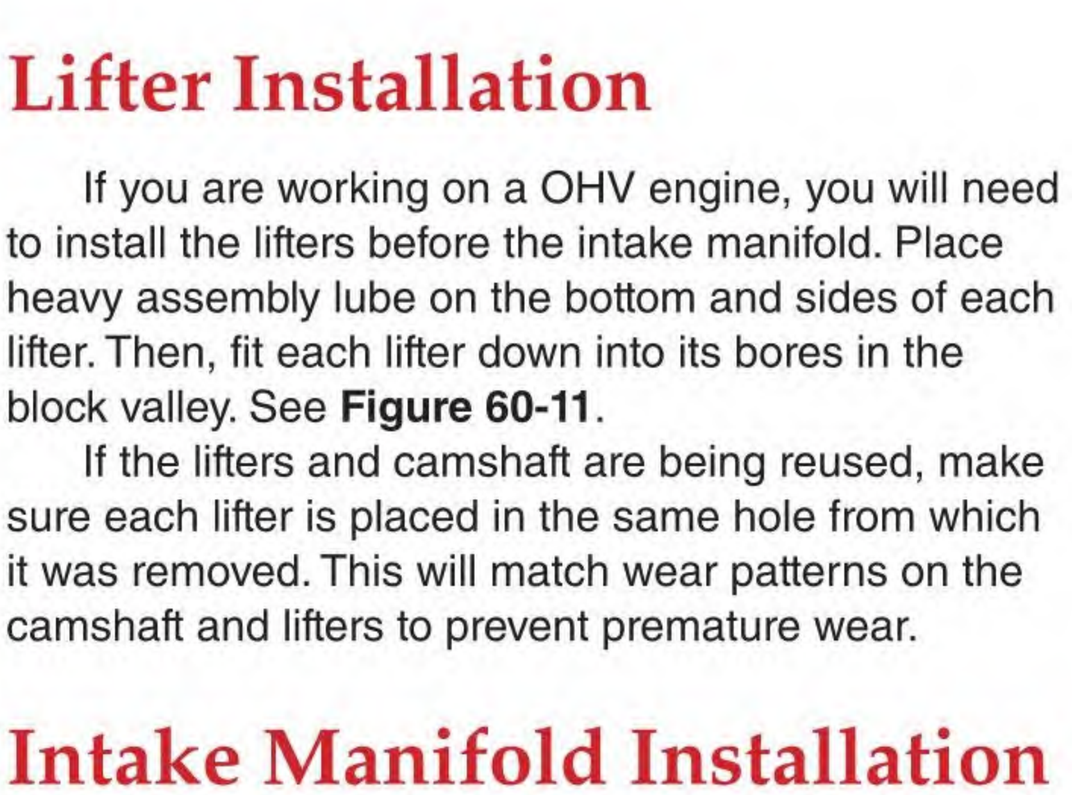
Fel-Pro

Figure 60-8. Head bolts that extend into an oil or coolant passage should have a nonhardening sealer applied to the threads. Refer to factory service literature for details about sealing head bolt threads on older engine designs.

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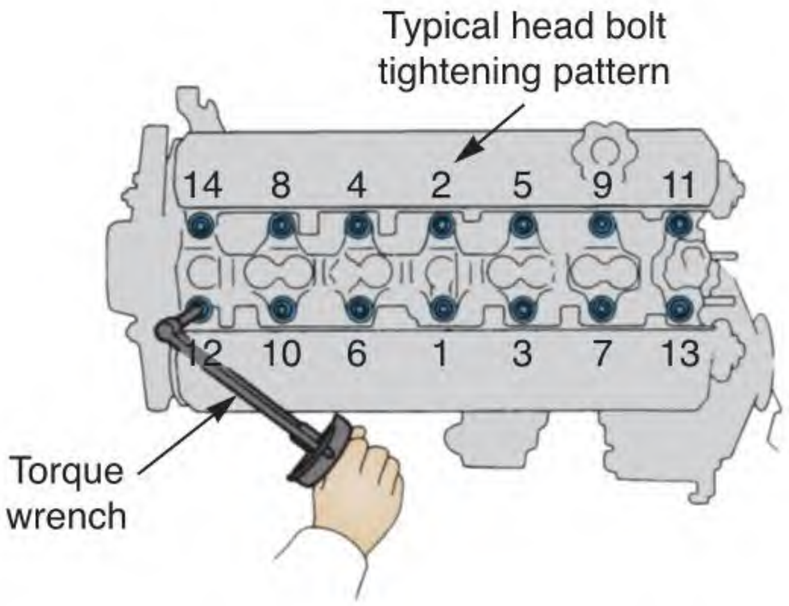
Service Procedure

1. Place the head bolts into the correct holes and start threading them by hand.
2. Use a speed handle or air ratchet to tighten the head bolts about finger tight. Use a criss-cross pattern or the proper torque sequence. Generally, tighten the bolts in the middle first and work your way outward, **Figure 60-9**. The service manual will explain the best sequence.
3. Remove any stud bolts that were installed to align the gasket and head. Install the correct bolts in their place.
4. Using a torque wrench, tighten the head bolts to 1/2 of the full torque specification in the proper sequence. For example, if the head bolt torque is 100 ft-lb (130 N·m), tighten all of the bolts to 50 ft-lb (70 N·m). A slow, steady pull on the wrench will produce the most accurate bolt torque. Look at **Figure 60-10**.
5. Tighten the bolts to 3/4 of the full torque specification in the proper sequence. If the head bolt torque is 100 ft-lb (130 N·m), tighten the bolts to 75 ft-lb (100 N·m).
6. Tighten the bolts to the full torque specification in the proper sequence.
7. Tighten each bolt to full torque one or two more times to ensure proper torque.



Snap-on Tool Corp.

Figure 60-10. Torque the head bolts to specifications using an even pull on the torque wrench.



Toyota

Figure 60-9. When tightening head bolts with an accurate torque wrench, generally start in the middle and work your way to the outer bolts threaded into the block. This will draw the head gasket down true on the block.

Lifter Installation

If you are working on a OHV engine, you will need to install the lifters before the intake manifold. Place heavy assembly lube on the bottom and sides of each lifter. Then, fit each lifter down into its bores in the block valley. See **Figure 60-11**.

If the lifters and camshaft are being reused, make sure each lifter is placed in the same hole from which it was removed. This will match wear patterns on the camshaft and lifters to prevent premature wear.

Intake Manifold Installation

Proper installation of an engine ***intake manifold*** is critical. Some manifolds not only seal vacuum, they carry coolant and hot exhaust gases. If incorrectly installed, the manifold can allow a vacuum or coolant leak. Partial engine teardown might be needed to correct the problem.

Inspecting the Intake Manifold

Intake manifold warpage is a measure of the flatness of a manifold's sealing surfaces. Use a straightedge and flat feeler gauge to check the intake manifold sealing surfaces for warpage.

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Figure 60-11. A technician is installing new mechanical lifters into a high-performance OHV engine. A—Lubricate the bottom and sides of each lifter with thick assembly lube. B—Place each lifter down into its bore with its flat facing down to contact its cam lobe.

Service Procedure

To check intake manifold sealing surfaces for warpage:

1. Lay the straightedge over the port openings.
2. Try to slide feeler gauge blades of different thicknesses under the straightedge. Measure at different points on the manifold.
3. The thickest blade that easily slides under the straightedge indicates the intake manifold warpage.
4. If warpage is more than specifications, the intake manifold sealing surfaces must be machined or a new manifold installed.

Also inspect the intake manifold, especially plastic ones, for cracks, burned areas, and other problems.

Installing the Intake Manifold Gasket

Place the new ***intake manifold gasket*** over the head to check its fit. Check all openings in the gasket and head to make sure they align. Any misalignment of ports or passages could cause a vacuum leak, coolant leakage, or even serious engine overheating damage.

If the intake manifold gasket is a metal-valley-tray type, use RTV or silicone sealer. See **Figure 60-12A**. The sealer should circle all ports and coolant passages. Since the thin metal gasket can leak easily, sealer provides added protection against leakage. However, before applying sealer, make sure the manifold is ready to be installed. If the intake manifold gasket is a multipiece, fiber type, place sealer where the gasket ends meet. Apply enough gasket adhesive to hold the gasket in place. Some technicians prefer to circle coolant passages with sealer for added protection. See **Figure 60-12B**.

With the head sections of the intake manifold gasket in place, install the end seals. Adhesive can be used to hold the seals in place if needed, **Figure 60-12C**. If large barbs are provided on the seals and they fit properly down into the block, no adhesive is needed. Place a small bead of silicone sealer where the end seals and main intake gaskets overlap. This will keep engine oil from weeping out during engine operation, **Figure 60-12D**. Allow time for the adhesive to set up or partially cure before manifold installation. This will help prevent gaskets from being dislodged when you lower the manifold onto the engine.

Some late-model vehicles have plastic intake manifolds. Depending on the design, these manifolds may have a separate rubber seal for each intake port in place of a traditional gasket. First, remove the old rubber seals. Then, clean all mating surfaces and the seal grooves. Finally, press the seals into their grooves. Make sure the seals are properly installed so they do not shift or fall out while lowering the manifold onto the engine. Many technicians like to coat the O-Ring seals with silicone sealer to help secure them in their grooves. See **Figure 60-13**.

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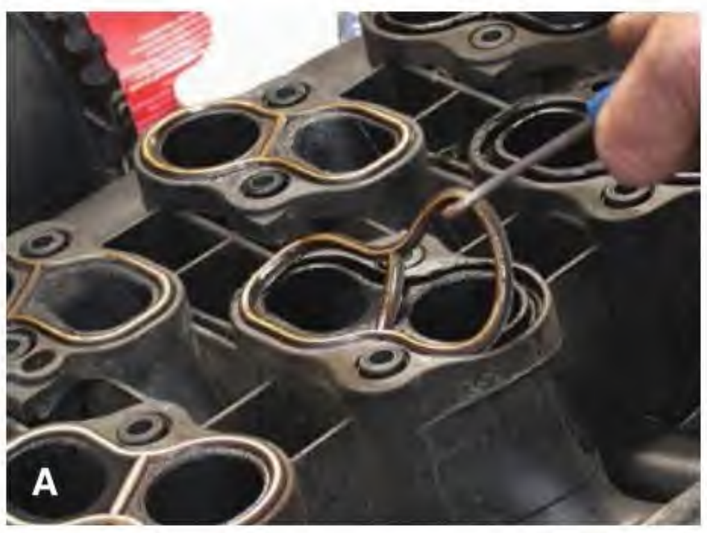






Fel-Pro

Figure 60-12. Note the basic steps for sealing a V-type intake manifold gasket. A—Read specific instructions that come with the gasket set. They will usually contain important information for avoiding vacuum leaks and coolant leaks between the intake manifold and cylinder heads. B—If recommended, apply continuous beads of gasket sealer around the intake ports and water jacket openings. Many intake gaskets have a synthetic rubber seal preformed around the ports, so gasket sealer or adhesive may not be required. C—A small amount of gasket adhesive will help hold the front and rear rubber seals in place. D—Silicone sealer is usually needed where gaskets and seals fit over each other in order to prevent oil seepage.







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Figure 60-13. Note how rubber seals install into this plastic intake manifold. A—Remove the old seals with a hooked pick tool. Use the point to reach behind the seal to pop it out. B—Clean the seal grooves and all mating surfaces with an approved solvent. C—Press the new intake manifold seals into their grooves in the manifold. Make sure they are fully seated in their grooves. These manifold seals are sticky and will stay in place on their own.

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Tech Tip

Inspect modern plastic intake manifolds closely for cracks and warpage. Plastic manifolds can often crack around bolt holes and thin flanges.

Carefully lower the intake manifold onto the engine. Be careful not to bump and shift the gasket or smear the sealer. In some applications, you might want to use guide studs so the manifold lowers straight down into place.

Tech Tip

You should be ready to install the intake manifold after the intake manifold gasket is in place. If you wait too long, the sealer can completely cure, preventing proper manifold sealing. The sealer or adhesive can be allowed to cure slightly, but should not completely dry or cure.

Torquing the Intake Manifold Bolts

After the intake manifold and gasket are in place, start all intake manifold bolts by hand. Otherwise, you will not be able to shift the manifold and start the remaining bolts.

Service Procedure

1. With all intake manifold bolts threaded in a few turns into the cylinder head, run them down lightly with a speed handle or air ratchet. Check manifold bolt lengths. None should be sticking up more than the others. If any are sticking above the manifold flange more than the other, remove it for length measurement.
2. Using a torque wrench, torque each bolt to 1/2 of the full torque. Use a crisscross pattern or the specified torque sequence to draw the manifold down evenly.
3. Tighten each intake manifold fastener to 3/4 of full torque.
4. Tighten each intake manifold fastener to full torque.
5. Tighten all intake manifold bolts to full torque one more time to ensure proper part clamping and gasket sealing.
6. Use the same basic procedure described for other manifolds.
7. Do the same for the center and upper sections of plastic or aluminum intake manifolds.

The upper section of the intake manifold, or upper plenum, may be constructed of plastic. With plastic engine parts, like intake plenums, brass thread inserts are usually pressed or molded into the plastic. This allows parts such as sensors and vacuum fittings to be bolted to the plastic part without thread failure.

Checking the Engine Thermostat

When doing major engine service, you should check the engine thermostat. Make sure a thermostat is installed and verify that it operates properly. Also, check that the thermostat heat range matches the service manual specification. Most technicians replace the thermostat as a routine part of an engine rebuild.

When installing the thermostat housing, make sure the thermostat is centered under the housing. Also, make sure the new gasket or O-ring is in place. Then, tighten each bolt a little at a time until the full torque specification is reached, **Figure 60-14**. Remember that the thermostat housing will warp or crack if the bolts are overtightened or tightened improperly.

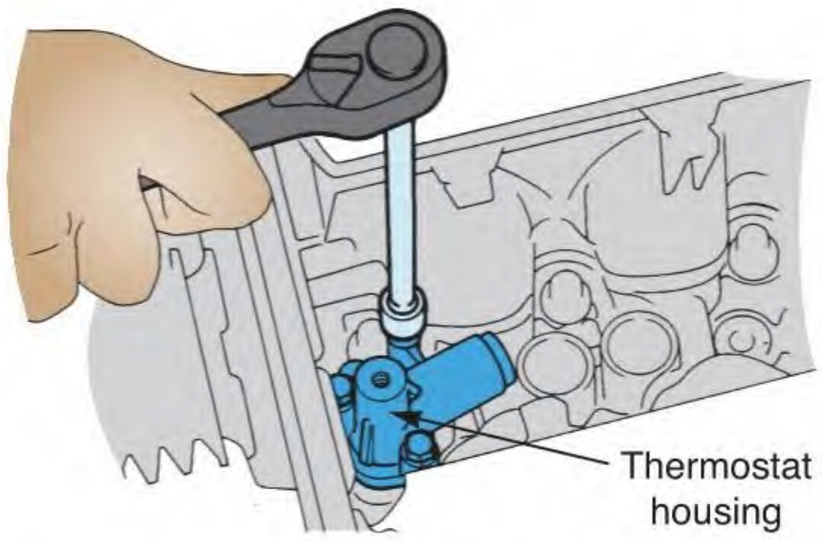
Tech Tip

A common mistake is thermostat housing breakage. If the thermostat slips out of its indentation in the engine or intake manifold, it can cause the housing to break when torqued to specs. The thermostat will be smashed between the engine and flange on the housing.

Exhaust Manifold Installation

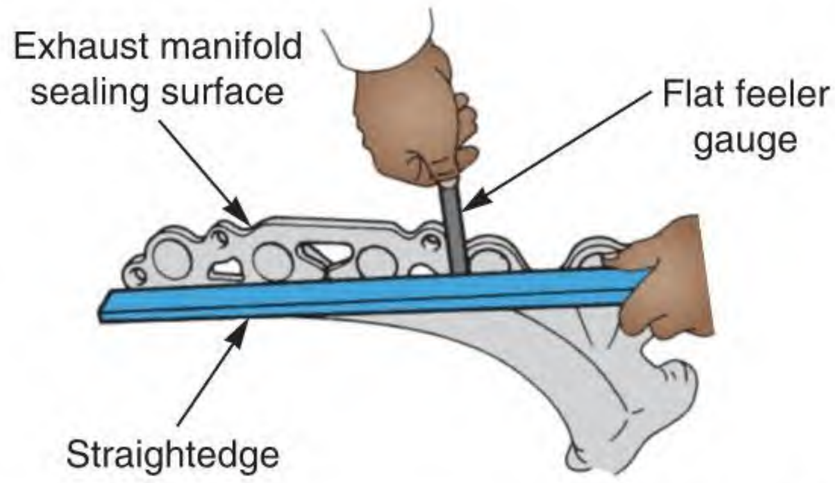
Exhaust manifolds route extremely hot gases into the vehicle's exhaust system. As a result, the manifolds can suffer from cracks, warpage, rust, and other problems. Always inspect an exhaust manifold

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Figure 60-14. Tighten the thermostat housing bolts evenly to prevent warpage or breakage. It is best to use a small, 3/8" drive, inch-pound torque wrench rather than a foot-pound wrench.



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Figure 60-15. Check the exhaust manifold for warpage with a straightedge. Also, inspect exhaust manifold for heat cracks that could be noisy on engine start-up.

closely before installation. Look for cracks, burned areas, eroded mating surfaces, and severe rust damage. Check for ***exhaust manifold warpage*** with a straightedge and flat feeler gauge, **Figure 60-15**. Use the same procedure described earlier for checking intake manifold warpage. A machine shop can usually true a slightly warped surface. Replace the manifold if it is excessively warped.

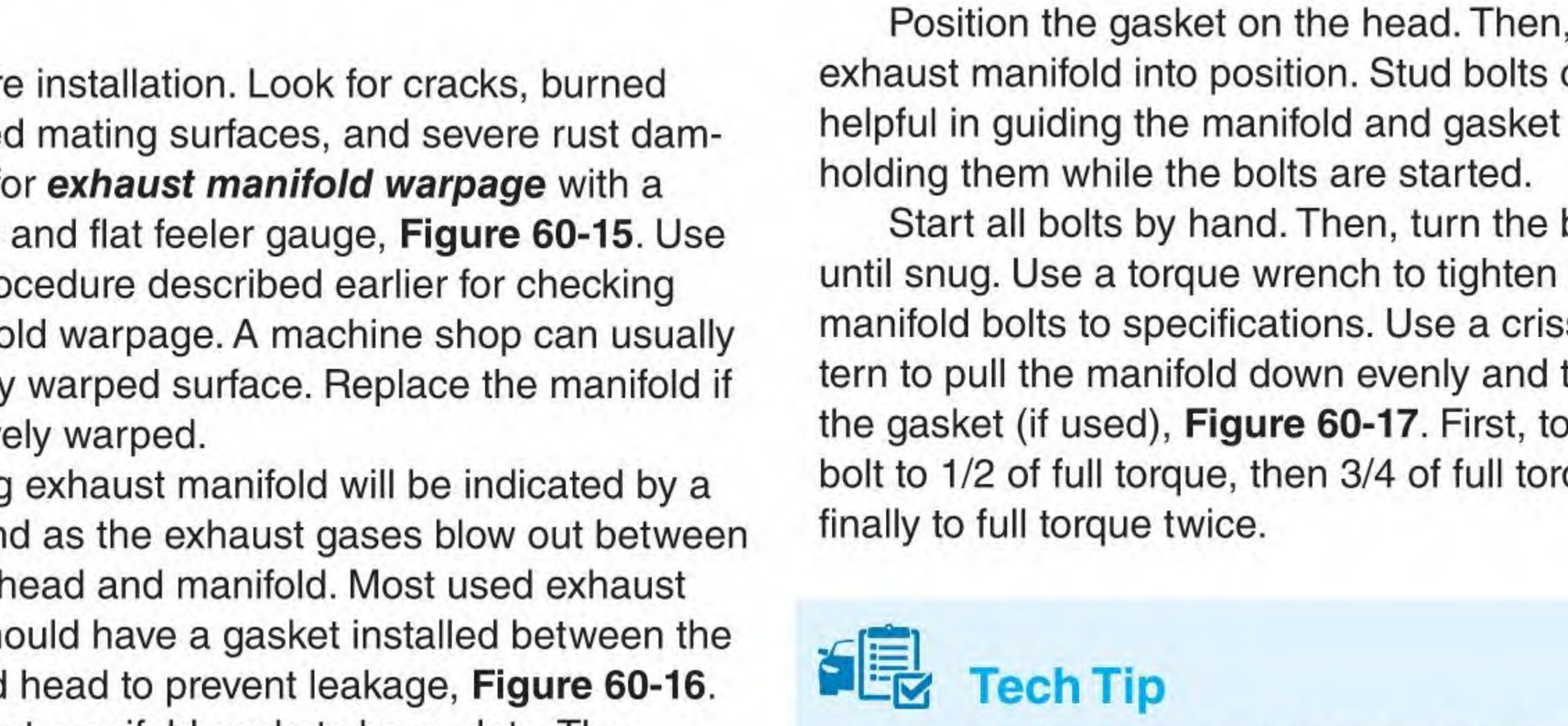
A leaking exhaust manifold will be indicated by a clicking sound as the exhaust gases blow out between the cylinder head and manifold. Most used exhaust manifolds should have a gasket installed between the manifold and head to prevent leakage, **Figure 60-16**. Some exhaust manifold gaskets have slots. The slotted gasket allows you to start the manifold bolts, holding the exhaust manifold in place, and then drop the gasket into place.

Position the gasket on the head. Then, slide the exhaust manifold into position. Stud bolts can be helpful in guiding the manifold and gasket in place and holding them while the bolts are started.

Start all bolts by hand. Then, turn the bolts down until snug. Use a torque wrench to tighten the exhaust manifold bolts to specifications. Use a crisscross pattern to pull the manifold down evenly and to compress the gasket (if used), **Figure 60-17**. First, torque each bolt to 1/2 of full torque, then 3/4 of full torque, and finally to full torque twice.

Tech Tip

When an exhaust manifold is installed, it is a good idea to check the condition of the oxygen sensor. Replace the sensor if it looks contaminated or if it

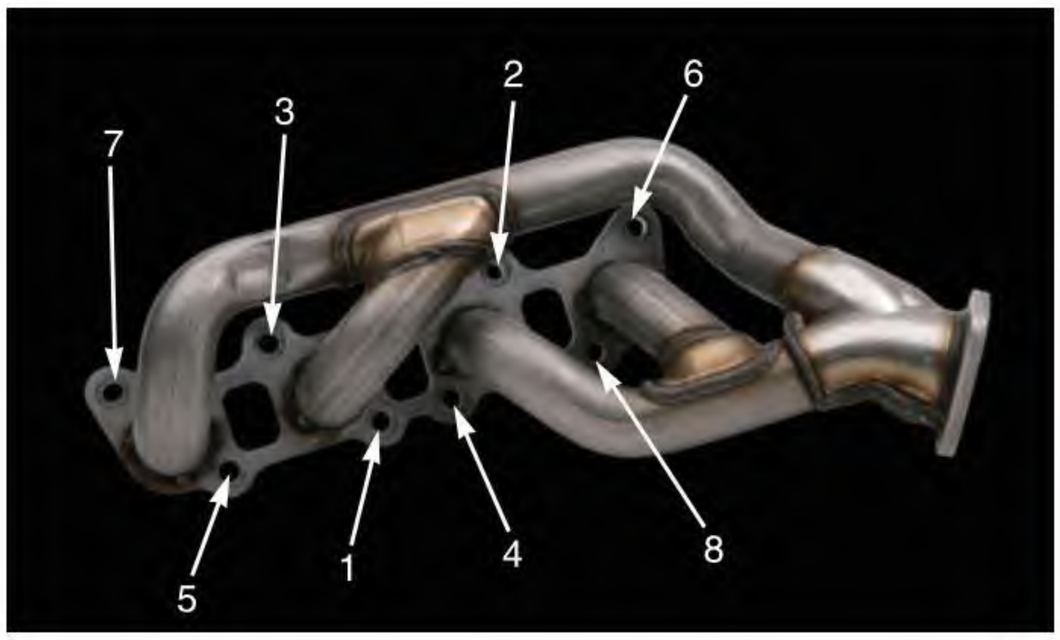


Toyota

Figure 60-16. A heat-resistant gasket or individual port gaskets are usually installed between the cylinder head and exhaust manifold.

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has been in service for over 100,000 miles (160,934 km). Remember to inform the shop manager before installing any engine parts or components (sensors) not included on the repair order signed by the customer.



Ford

Figure 60-17. Torque exhaust manifold bolts in a crisscross pattern to pull the manifold down evenly.

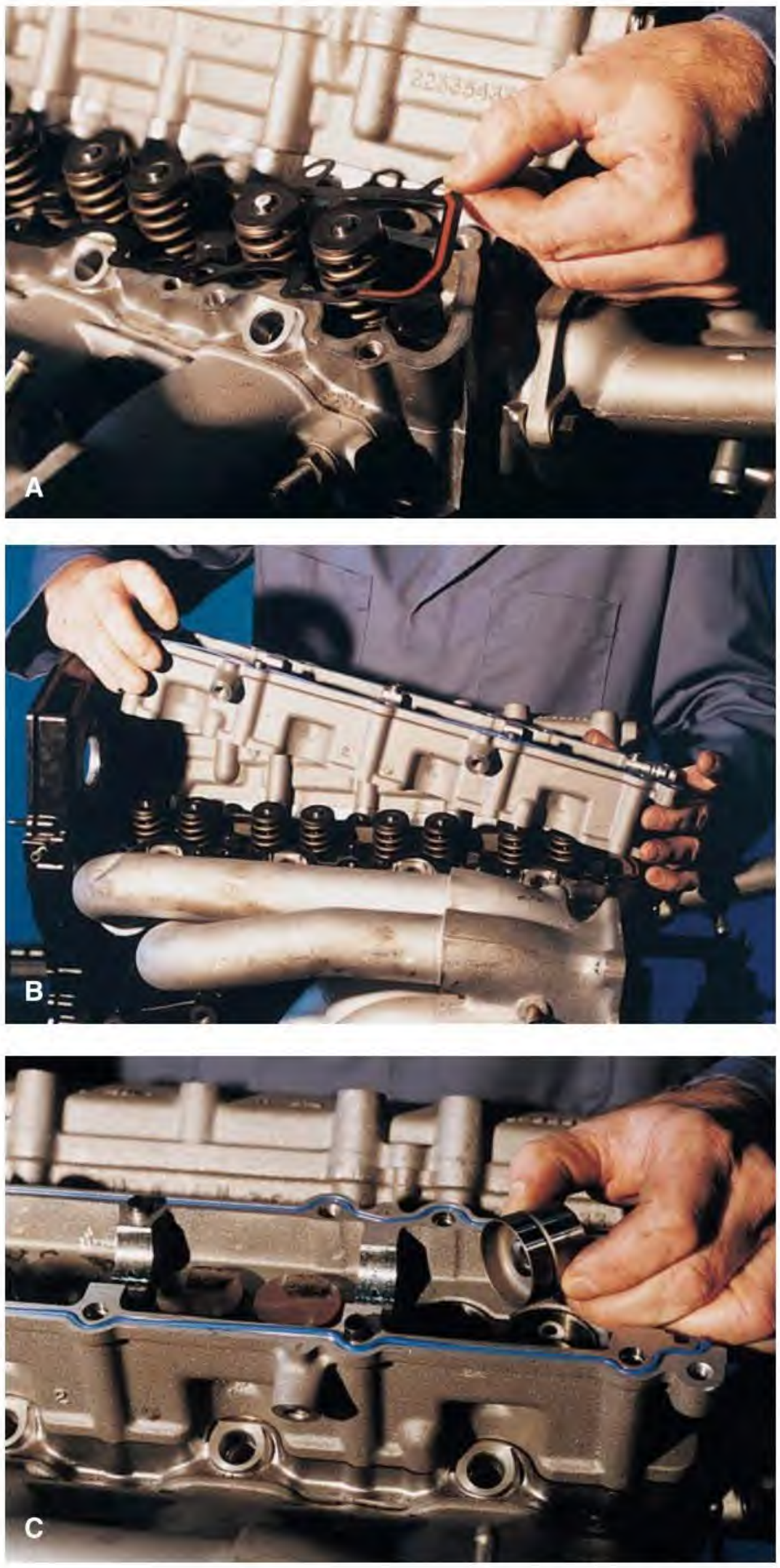
Camshaft Housing Installation

Some OHC engines have a ***camshaft housing*** that mounts on top of the cylinder head. See **Figure 60-18**. The camshaft housing holds the cam followers and camshaft(s).

Service Procedure

To install a camshaft housing:

1. Place a gasket on the top of the cylinder head.
2. Make sure everything aligns properly and you have the correct gasket.
3. Lower the camshaft housing onto the gasket and head.
4. Start all bolts by hand.
5. Tighten the bolts to specifications using the recommended torque sequence. Tighten in steps.
6. Place the cam followers into their pockets in the camshaft housing.
7. Install the camshaft(s), as described in the next section.



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Figure 60-18. Study the basic steps for installing a camshaft housing. A—Place a new gasket on top of the cylinder head. B—Lower the camshaft housing down onto the cylinder head without moving the gasket. C—Place the cam followers down into their pockets. Reused followers must go back into their same pockets in the head and on the same camshaft lobe.

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Overhead Camshaft Installation

The camshaft bearings in an overhead camshaft engine may be a one- or two-piece design. The one-piece bearings are pressed into the cylinder head with all oil holes aligned with passages in the head. The two-piece bearings snap into the head and camshaft bearing caps, like small rod and main bearings, **Figure 60-19**.

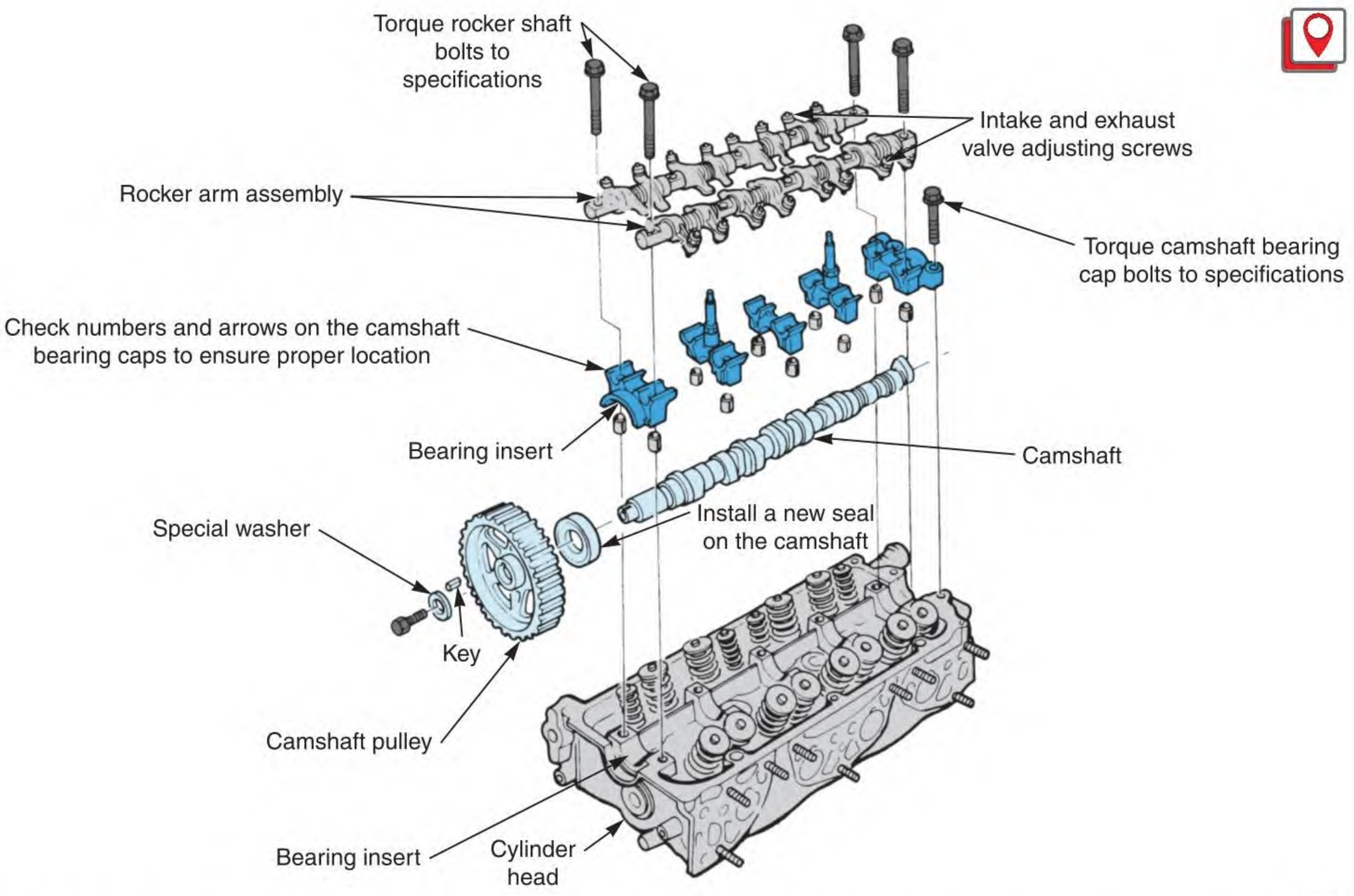
Installing a Camshaft with One-Piece Bearings

Make sure the camshaft bearings have been inspected and replaced if needed. White grease or thick assembly lube is commonly recommended to reduce friction and wear during initial start-up.

Service Procedure

To install a camshaft with one-piece bearings:

1. Lubricate the camshaft journals and lobes.
2. Slowly slide the camshaft into the camshaft bearings. Do not hit or nick the camshaft bearings.
3. Slowly rotate the camshaft to help feed it through each bearing.
4. Make sure you support the camshaft as it is inserted.
5. Install the timing sprocket and camshaft seal if applicable. Install any remaining parts as needed, such as the retainer plate, oil seal, and thrust bearing.



Honda

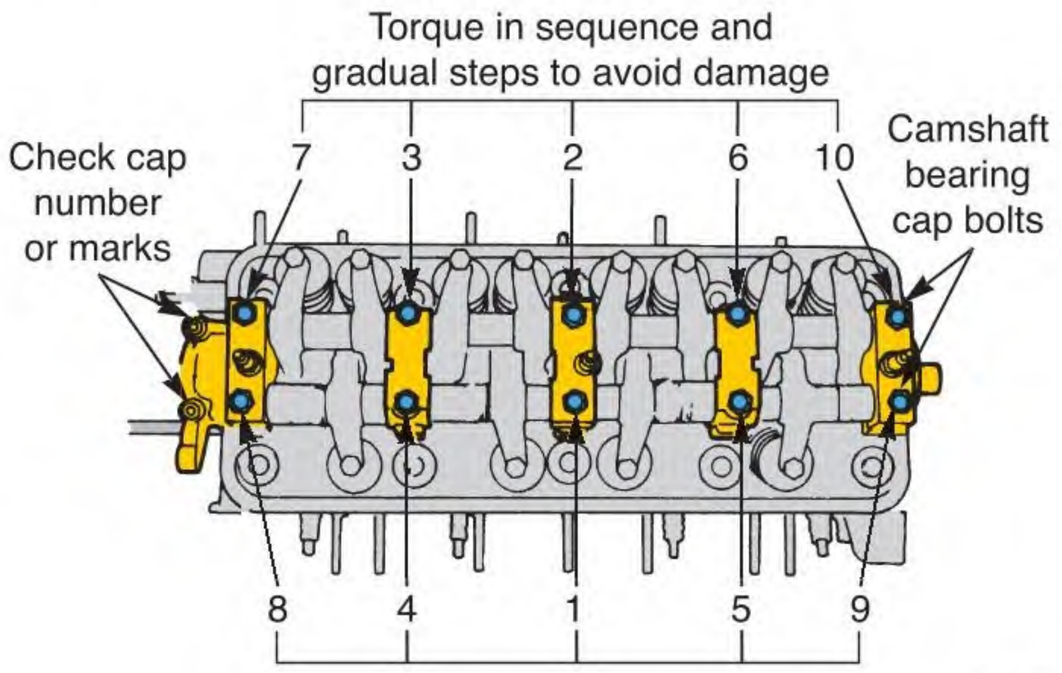
Figure 60-19. This engine cylinder head has two-piece camshaft bearings. Camshaft bearing caps and bolts secure the camshaft bearings and the camshaft to the cylinder head.

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Installing a Camshaft with Two-Piece Bearings

Some OHC engines have two-piece bearings. Camshaft bearing caps hold the upper cam bearing inserts and bolt over the camshaft journals. Just like block main caps, camshaft bearing caps are numbered and must be installed in their original locations. If you mix up caps or install them backward, the camshaft can lock in the cylinder head. The bearings and camshaft can be severely damaged on engine starting.

Before installing the camshaft, make sure the camshaft bearings are properly installed in the head and bearing caps. Also, make sure the proper bearing cap locations are identified.



Honda

Figure 60-20. Torque the camshaft bearing cap bolts to specifications in the proper torque sequence. Make sure you can still turn the camshaft after tightening the bolts.

Service Procedure

To install a camshaft with two-piece bearings:

1. Apply assembly lube or engine oil to the face of the bearings in the head.
2. Carefully lower the camshaft into the bearings. Make sure the front of the camshaft is at the front of the engine.
3. Make sure the camshafts are timed with the crankshaft in accordance with the manufacturer's specifications. Quite often, a special tool is needed to hold the camshafts in alignment before the cam bearing caps can be tightened.
4. Position the bearing caps on the head.
5. Install the bearing cap bolts hand tight.
6. Torque the bearing cap bolts to 1/2 of the full torque specification. Use the specified torque sequence or the general sequence shown in **Figure 60-20**.
7. Torque the bearing cap bolts to 3/4 of the full torque specification in sequence.
8. Torque the bearing cap bolts to full torque specification in sequence.
9. Torque the bearing cap bolts to full torque one more time to verify proper torque.
10. Apply assembly lube to the camshaft lobes. Coat the entire surface of each lobe.

Assembling Valve Train

Procedures for installing valve train components will vary by engine design. The following sections provide overviews of the most common procedures. Refer to the service manual for specific instructions for the engine you are working on.

Always make sure all parts are unworn and in usable condition. Inspect the push rod tips and make sure no push rods are bent. Check the rocker arm friction surfaces for wear. Replace any worn or damaged parts.

Installing Push Rods

If you are working on an overhead valve engine (cam-in-block), the push rods may pass through the bottom of the intake manifold or through the cylinder heads. If the push rods extend through the intake manifold, you cannot install the push rods until the intake manifold is installed. If the push rods pass through holes in the cylinder head, you can install the push rods and rocker arms before the intake manifold.

Make sure that the lower end of each push rod is installed fully into its lifter. It is very easy for the push rod to slide out of the lifter. Also, be careful if you have to pull a push rod back out of a lifter. Oil between the lifter and push rod may result in suction that can cause the lifter to be pulled out of its bore. You might then have to remove the intake manifold to put the lifter back into place.

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Installing Rocker Arms

Rocker arms are used on overhead valve engines and some overhead cam engines. Sometimes the intake and exhaust rocker arms are different. Usually, an *E* for exhaust or an *I* for intake will be stamped on the rocker arms if they are not the same.

If a rocker arm shaft is used, fit the assembly on the cylinder head. Start the bolts by hand. Then, torque the bolts to specifications in the sequence given in the service manual. Tighten in steps from 1/2 full torque, to 3/4 full torque, and then full torque. Tighten at full torque a second time to ensure proper torque.

If nonadjustable, individual rocker arm stands or studs are used, place the rocker arm over the stand or stud. Then, start the bolt or nut by hand. Torque the bolt or nut to specifications. Tighten in steps from 1/2 full torque, to 3/4 full torque, and then full torque. Tighten at full torque a second time to ensure proper torque.

With adjustable rocker arms, start the bolt or nut by hand. However, do not tighten the bolt or nut. You will have to adjust the valve train clearance, as described in the next section.

Adjusting Valve Train Clearance



After installation of the valve train components, you may have to adjust the clearance in the valve train. ***Valve train clearance adjustment***, also called ***valve lash adjustment*** or ***valve adjustment***, is done by turning the rocker arm fastener or adjusting screw, or by installing OHC follower shims.

Valve train clearance adjustment is critical to engine performance and service life. If the valves are too loose, valve train noise, sometimes termed *lifter clatter*, will result. ***Valve train noise*** is a light tapping or clicking sound produced from under the valve or camshaft cover. If the valves are too tight, burned valves can result. The valves may not close tightly, and hot exhaust gases can erode away metal from the valve face and valve seat.

Valve Train Clearance Adjustment with Nonadjustable Rocker Arms

Nonadjustable rocker arms are used on some push rod engines with hydraulic lifters. The hydraulic lifters automatically compensate for changes in valve train clearance to maintain a zero valve lash. ***Zero valve lash*** (no clearance in the valve train) provides quiet operation. The hydraulic lifters can adjust valve train clearance as parts wear, with changes in temperature (part contraction or expansion), and with changes in oil thickness.

If adjustment is needed because of valve grinding, head milling, or other modifications, different push rod lengths can sometimes be purchased for use with nonadjustable rocker arms. Refer to the service manual or a part supplier for details. Normally, torquing the rocker arm nut or bolt to specifications properly adjusts the valve train clearance.



Caution

Overtightening the fastener on a nonadjustable rocker arm can cause engine missing and rocker stud damage. Torque the fastener to specifications.

Valve Train Clearance Adjustment with Hydraulic Lifters

With some OHV engine designs, you must adjust the rocker arms to center the hydraulic lifter plungers. Centering the lifter plungers in their bores allows the lifters to automatically adjust to take up or allow more valve train clearance. Some manuals recommend adjustment with the engine off. However, many technicians adjust hydraulic lifters with the engine running.



Service Procedure

To adjust valve train clearance in a valve train with hydraulic lifters with the engine off:

1. Remove the valve cover.
2. Turn the crankshaft until the first lifter is on the camshaft base circle, not on the lobe. The valve must be fully closed.
3. Loosen the rocker arm fastener until you can wiggle the push rod up and down.
4. Slowly tighten the rocker arm fastener until all play is out of the valve train (the push rod cannot be wiggled).
5. Tighten the rocker arm fastener about one more turn to center the lifter plunger. Refer to the service manual for details because the procedure can vary with engine design.
6. Repeat the adjustment on the other lifters.

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Service Procedure

To adjust the valve train clearance in a valve train with hydraulic lifters with the engine running:

1. Remove the valve covers.
2. Install oil deflecting rocker arm clips to prevent oil spray off of the rocker arms.
3. Start and warm the engine to operating temperature.
4. Tighten all of the rocker arm fasteners until the valve train is quiet.
5. On the first rocker arm, loosen the fastener until valve train noise appears.
6. Tighten the rocker arm fastener slowly until the valve train noise disappears. At this point, there is zero valve lash.
7. To center the lifter plunger, tighten the rocker arm fastener about ½ – 1 turn more. Tighten the fastener slowly to give the lifter time to leak down and prevent engine missing or stalling.
8. Repeat the adjustment on the other rockers.

Other adjustment methods may be recommended. Check the service literature for more detailed information.

Valve Train Clearance Adjustment with Mechanical Lifters

Mechanical lifters are used on some heavy-duty engines, such as those in taxicabs, pickup trucks, and diesel engines, and on some high-performance engines. Since mechanical lifters, also called solid lifters, are not self-adjusting, you must periodically adjust the valve train clearance to maintain the correct valve lash. A valve train that contains mechanical lifters makes a clattering or pecking sound during normal engine operation.

Check the service manual for valve train clearance adjustment intervals and specifications. A typical valve train clearance, or valve lash, specification is approximately 0.014″ (0.35 mm) for the intake valves and 0.016″ (0.40 mm) for the exhaust valves.

Service Procedure

To adjust the valve train clearance in a valve train with mechanical lifters:

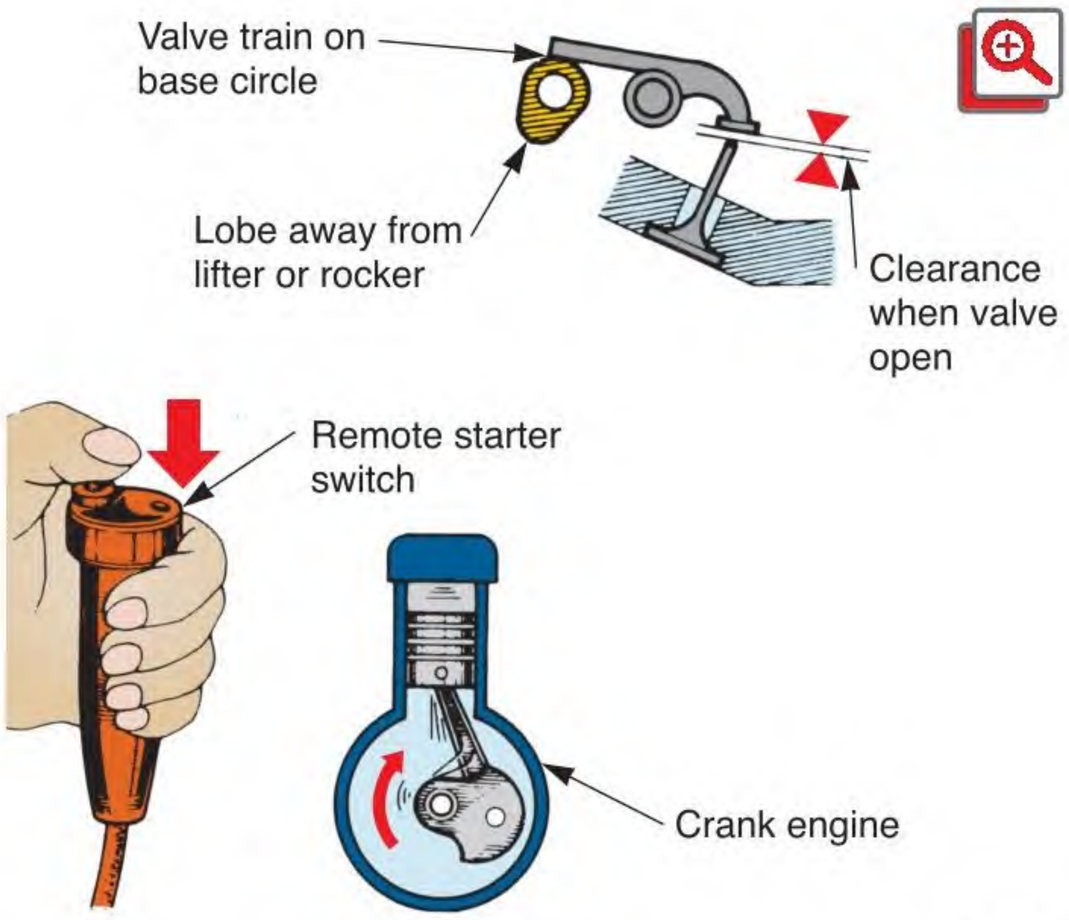
1. Remove the valve covers.
2. Crank the engine until the first piston is at TDC on its compression stroke. On the compression stroke, you will be able to feel air blow out of the spark plug hole with the spark plug removed. This positions the intake and exhaust lifters for that cylinder on the camshaft base circle; intake and exhaust valves are fully closed. The valve train clearance can be adjusted for both intake and exhaust valves in that cylinder. See **Figure 60-21**.
3. Select the correct size of flat feeler gauge.
4. Slide the feeler gauge between the rocker arm and the valve stem.
5. When properly adjusted, the feeler gauge should slide between the valve and rocker arm with a slight drag, **Figure 60-22**.
6. If the feeler gauge does not fit, loosen the rocker arm fastener or adjusting screw until the feeler gauge fits, **Figure 60-23**.
7. If the feeler gauge fits without a drag, tighten the rocker arm fastener or adjusting screw.
8. Repeat this procedure on the other lifters.

To tighten or loosen a rocker arm adjusting screw, you will normally have to loosen a locknut and then turn the adjusting screw. After making the adjustment, tighten the locknut and recheck the clearance.

Tech Tip

In some cases, valve train clearance is adjusted with the engine cold. In other cases, the adjustment must be made with the engine at operating temperature. Check the engine manufacturer's recommendations. A change in temperature will cause part expansion or contraction, which then causes a change in valve train clearance.

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Renault

Figure 60-21. When adjusting valves, crank the engine until the lifter or rocker for the valve being adjusted is on its base circle. This will ensure that the valve is fully closed and that the proper clearance adjustment will be made.



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Figure 60-22. When adjusting valve train clearance on an engine with mechanical lifters, tighten the rocker arm fastener until there is a slight drag on the feeler gauge.

Valve Train Clearance Adjustment on OHC Engines

There are many methods of adjusting the valve train clearance on OHC engines. Sometimes the adjustment is made like the adjustment for a valve train with mechanical lifters in a push rod engine. The rocker arm adjuster screw is turned until the correct size feeler gauge fits between the rocker or camshaft lobe and the valve stem or cam follower.

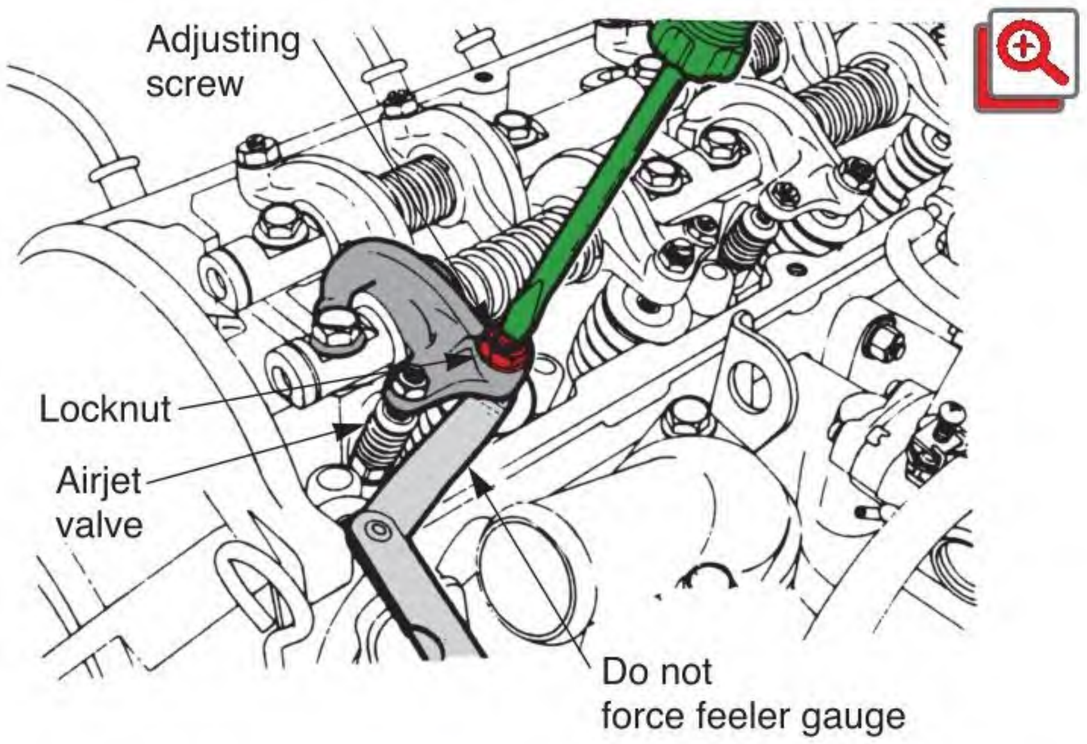
Some OHC engines have hydraulic cam followers. These followers are self-adjusting, like hydraulic lifters. Valve train clearance adjustment is not necessary on these engines.

Valve adjusting shims can also be used on OHC engines. By installing different shim thicknesses, the clearance between the camshaft lobe and the valve stem or follower can be adjusted. Refer to **Figure 60-24**.

To calculate the proper shim thickness, first measure the clearance between the camshaft lobe and shim with a feeler gauge. Compare your measurement to the clearance specifications. For example, if the engine requires 0.015″ clearance and the measured clearance is 0.020″, the shim must be 0.005″ thicker than the existing one (0.020″ – 0.015″ = 0.005″). Use a micrometer to measure the thickness of the existing shim and add 0.005″ to determine the correct thickness of the new shim.

Some OHC engines have an adjusting screw in the cam followers. Turning the screw changes the valve train clearance. Refer to the service manual for detailed directions. Exact procedures for valve train clearance adjustment vary with OHC engine designs.

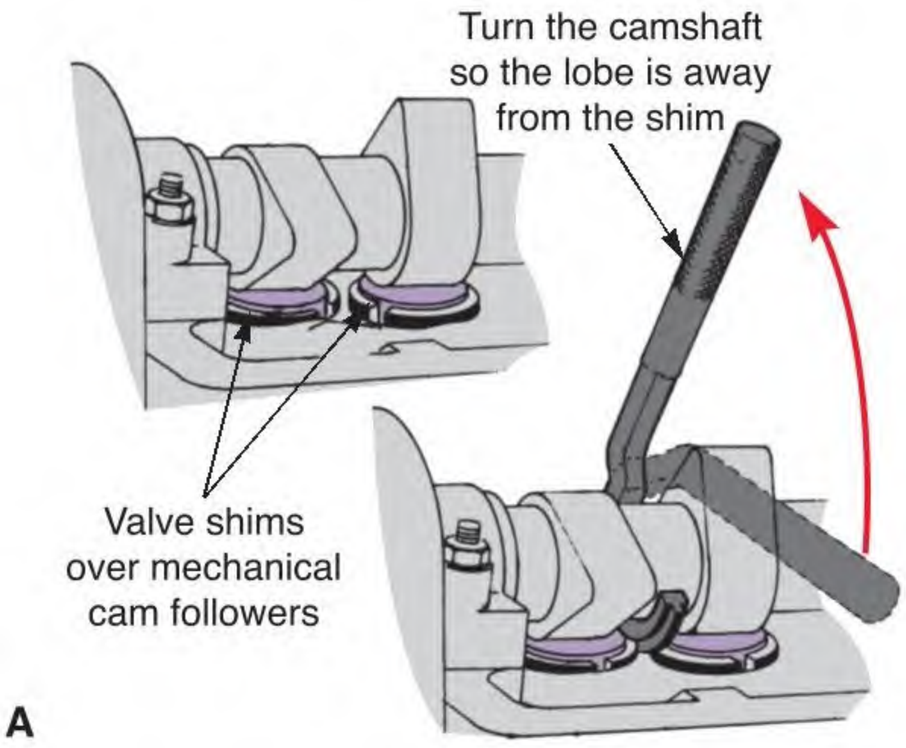
Push down on each rocker arm to check that each one moves properly. If the rocker arms move properly, the hydraulic follower is functioning normally. See **Figure 60-25**.



Chrysler

Figure 60-23. To adjust mechanical lifters, bump the engine until the cam lobe is away from the lifter or rocker. Insert the specified thickness feeler gauge between the rocker and the valve stem. If needed, loosen the locknut and turn the adjusting screw to obtain the correct clearance. The feeler gauge should have a light drag when pulled back and forth.

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Volvo

Figure 60-24. Study the basic steps for adjusting valve train clearance with shims on an OHC engine. A—Position the camshaft lobe by turning it until the base circle is centered over the valve. B—Measure the clearance with a feeler gauge. C—If the clearance is not within specifications, remove the existing shim. D—After measuring the thickness of the existing shim, calculate the required shim thickness. E—Obtain a new shim that will result in the correct clearance. F—Oil and install the new shim.

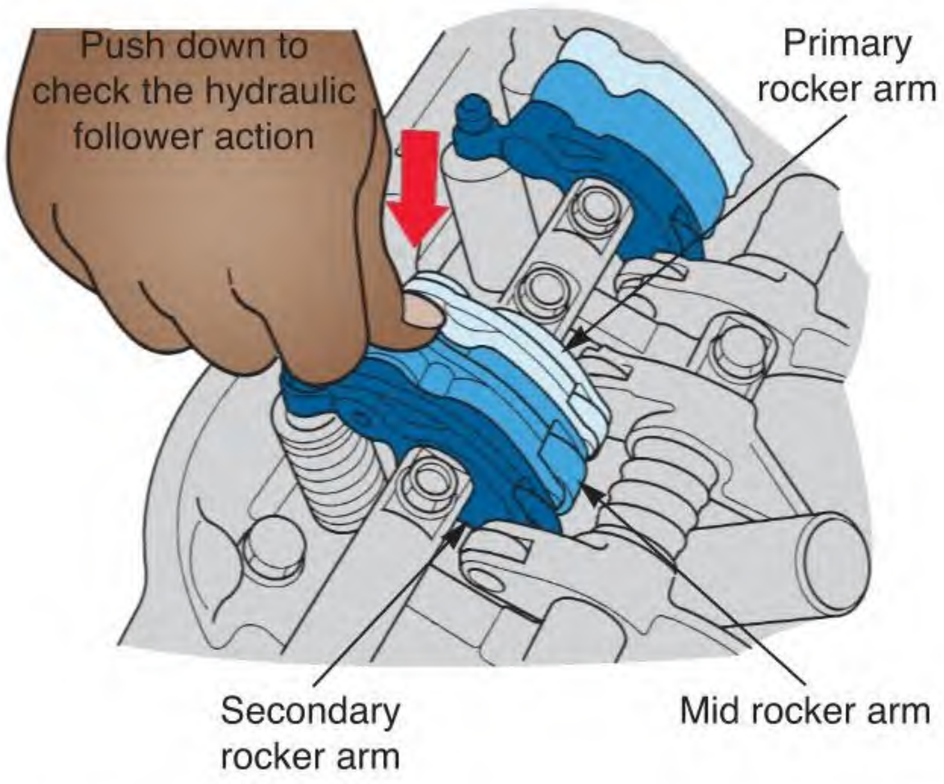
Valve Cover Installation

A ***valve cover*** is a sheet metal or plastic cover fastened to the top of the cylinder heads. The valve covers and valve cover gaskets prevent oil spraying from the valve train from leaking out of the engine. A ***camshaft cover*** serves the same purpose as a valve cover, but fits over the camshaft housing of an OHC engine. Most camshaft covers are made of cast aluminum or plastic.

Camshaft Cover Installation

Camshaft covers are installed with a gasket or seal between the cover and cylinder head or camshaft housing. When installing a camshaft cover, make sure all gaskets and seals are placed properly. If any fall

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Honda

Figure 60-25. This service manual illustration shows how to check the action of hydraulic followers on a particular variable valve timing system.

out during cover installation, you will have a major oil leak and engine repair failure. In some designs, O-rings are also placed around the spark plug holes, as shown in **Figure 60-26**.

Valve Cover Installation

If not installed properly, a valve cover, also termed *rocker cover* or *cam cover*, can leak oil very easily. Some valve covers use a cork or synthetic rubber gasket or seal. Valve covers on many late-model vehicles are sealed at the factory with silicone sealer or a large rubber seal. When reinstalling a valve cover, sealer, seals, or gaskets may be used, depending on cover design and accessibility of the cover.

Before installing a valve cover, make sure the cover flange is not bent or damaged in any way. Lay the cover on a flat workbench. View between the gasket surface and the workbench to detect gaps. A straightedge can also be used to verify that the flange is not bent. Gaps are caused by dents, bends, or warpage.

If the valve cover is made from sheet metal, the flange can be straightened with taps from a small, ball peen hammer. A cast aluminum valve cover can sometimes be sent to a machine shop for resurfacing. A warped plastic valve cover must be replaced.



Chrysler

Figure 60-26. O-rings must be installed around the spark plugs in this camshaft cover design. Many mechanics like to coat these with silicone sealer to help hold them in place during cover installation.

Installing the Valve Cover Gasket

Service Procedure

To install a valve cover gasket:

1. Place a very light coating of approved adhesive around the edge of the valve cover, **Figure 60-27**. This adhesive is mainly needed to hold the gasket in place during assembly.
2. Fit the gasket on the cover and align the bolt holes. Inserting a couple of bolts through the holes can help in alignment.
3. Let the adhesive cure slightly.
4. Make sure the mating surface on the cylinder is clean.
5. Carefully place the cover and gasket onto the cylinder head.
6. Hand start all the valve cover bolts.
7. Torque the valve cover bolts to specifications. Use the recommended torque sequence or a crisscross pattern.

Tech Tip

A very common mistake is to overtighten valve cover bolts. Overtightening can smash and split the gasket or bend the valve cover. Oil leakage will result. Torque the bolts to the specification, which is generally just enough to lightly compress the gasket.

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Fel-Pro

Figure 60-27. Apply a bead of quick-drying adhesive to the valve cover. This will hold the gasket in place during assembly.

Installing the Valve Cover with Silicone Sealer

Service Procedure

To use silicone or RTV sealer on the valve cover in place of a gasket:

1. Double-check that the valve cover and cylinder head mating surfaces are perfectly clean. Sealer will not bond to and seal dirty, oily surfaces.
2. Apply a continuous bead of sealer all the way around the valve cover sealing surface. Typically, the bead should be about 3/16″ (1.5 mm) wide.
3. Carefully lower the valve cover onto the head. Do not wait for the sealer to cure.
4. Make sure the bead of silicone sealer is not smeared or broken as the valve cover is lowered.
5. Hand start all of the valve cover bolts.
6. Torque the fasteners to specifications. Use the recommended torque sequence or a crisscross pattern.

Service Procedure

To install a valve cover with a large rubber seal:

1. Clean the valve cover in cold tank solvent to remove oil deposits and debris. Use a stiff bristle brush to clean the inside and outside of the valve cover.
2. Pay particular attention to the groove in the valve cover. Look for problems such as cracks, splits, and debris. Inspect and clean out the groove all the way around the valve cover.
3. Use your fingers to apply silicone sealer to the valve cover rubber seal and any spark plug O-rings. This will help hold the seals in place during valve cover installation.
4. Wipe all sealing surfaces on the head clean and dry. Apply silicone sealer on the curved surfaces at the front and rear of the valve cover gasket. These are common leakage points, and silicone will help prevent oil leakage on the curved surfaces of the valve cover seal.
5. Slowly lower the valve cover down over the cylinder head without disturbing the valve cover seal and spark plug seals.
6. Hand start the bolts that secure the valve cover to the engine and then torque them to specs.
7. Reinstall the spark plug wires, hoses, and wires to complete valve cover installation.

Final Engine Assembly

Before the engine is ready to be installed in the vehicle, final engine assembly must be completed. This involves installing the flywheel and clutch or torque converter. Final assembly also involves attaching external components, such as brackets or sensors.

Tech Tip

Before installing the flywheel and clutch or torque converter, the engine must be removed from the engine stand. Support the engine with an engine lift or hoist. Then, unbolt the engine from the stand. Lower the engine to the floor, but maintain tension on the lifting chain so the engine does not shift or fall over as you work on it.

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Installing External Engine Parts

Before fitting the engine back into the vehicle, install all external parts that will not get in the way of engine installation. This includes engine sensors, actuators, brackets, engine mounts, and sometimes the oil filter and other parts. It will save time if many of these parts are installed now rather than waiting until the engine is back in the vehicle.

Installing the Engine Flywheel

Before installing the flywheel, check its ring gear teeth. Make sure none of the teeth are worn or broken off. Ring gear teeth damage will cause problems with starter motor engagement and operation. If necessary, replace the ring gear or flywheel.

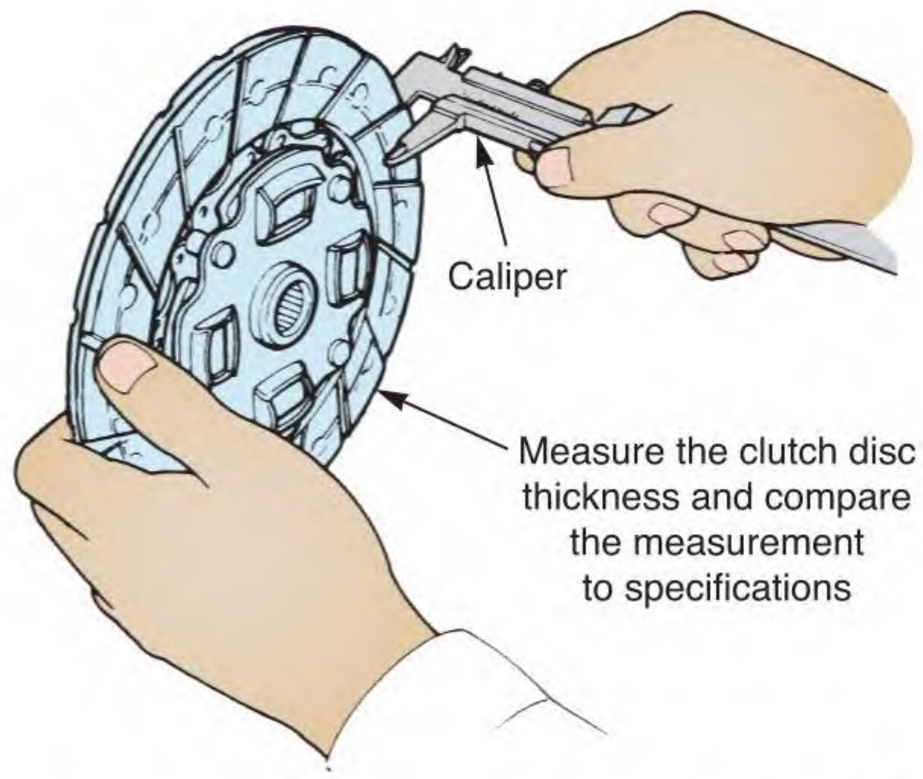
Automatic transmission and transaxle flywheels do not typically have a removable ring gear. However, most manual transmission and transaxle flywheels have a removable ring gear. To replace the ring gear on a manual transmission or transaxle flywheel, use a chisel to split and remove the damaged or worn ring gear. Evenly heat the new ring gear with a torch to expand it. Use a hammer to tap the heat-expanded ring gear over the flywheel lip until it is seated on the flywheel. Do not strike the gear teeth with the hammer. Tap on the inner diameter of the ring gear with a large flat nose punch.

Once the ring gear is replaced, install the flywheel on the crankshaft. Do not forget to use any spacer plate that fits between the engine and transmission or transaxle. The flywheel and crankshaft flange normally have offset bolt holes so the flywheel will only go on in one position. Turn the flywheel on the crankshaft until all bolt holes align. Install the flywheel bolts by hand and then torque them to specifications.

Installing a Clutch

With a manual transmission or transaxle, you will have to check and install the clutch before engine installation. Most technicians prefer to use a new pilot bearing, clutch disc, and throw-out bearing. These parts wear and fail in relatively few miles. Some technicians even like to replace the pressure plate. Obtain customer approval before replacing these parts. In any case, check these parts closely before reuse. Be sure to wear appropriate respiratory protection when working with clutches.

If the disc is thinner than specifications, it should be replaced. Study **Figure 60-28**. Also, replace the disc if it is contaminated with oil or shows signs of slippage and overheating.



Honda

Figure 60-28. Inspect the clutch disc closely. Measure the thickness. If the disc is worn too thin, it must be replaced.

Check the pressure plate friction surface for heat checking, signs of overheating, worn release arms, weakened springs, and so on. The throw-out bearing must turn freely with no signs of bearing roughness.

To install the clutch, fit the disc and pressure plate onto the flywheel. Insert an alignment tool or old transmission input shaft through the clutch disc and into the pilot bearing, **Figure 60-29**. This will hold the clutch and center it while you are torquing the pressure plate bolts. Use the proper torque sequence specified in the service manual.

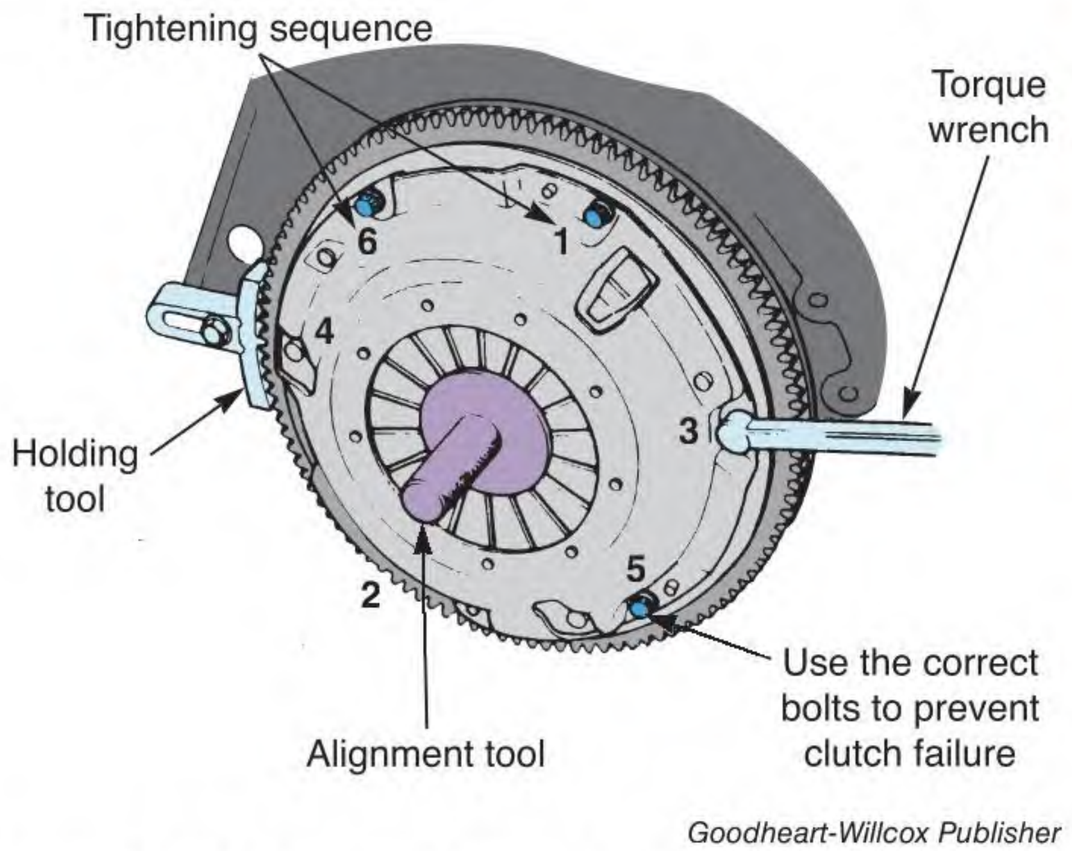
Most technicians install a new throw-out bearing whenever the clutch is disassembled. Fit the throw-out bearing onto its release arm and make sure it is secure, **Figure 60-30**. The throw-out bearing must stay in place when bolting the transmission or transaxle to the engine.

Bolt the bell housing to the rear of the engine block. Torque the bell housing fasteners to specifications. Attach any other components to the bell housing, such as the clutch bracket.

Caution

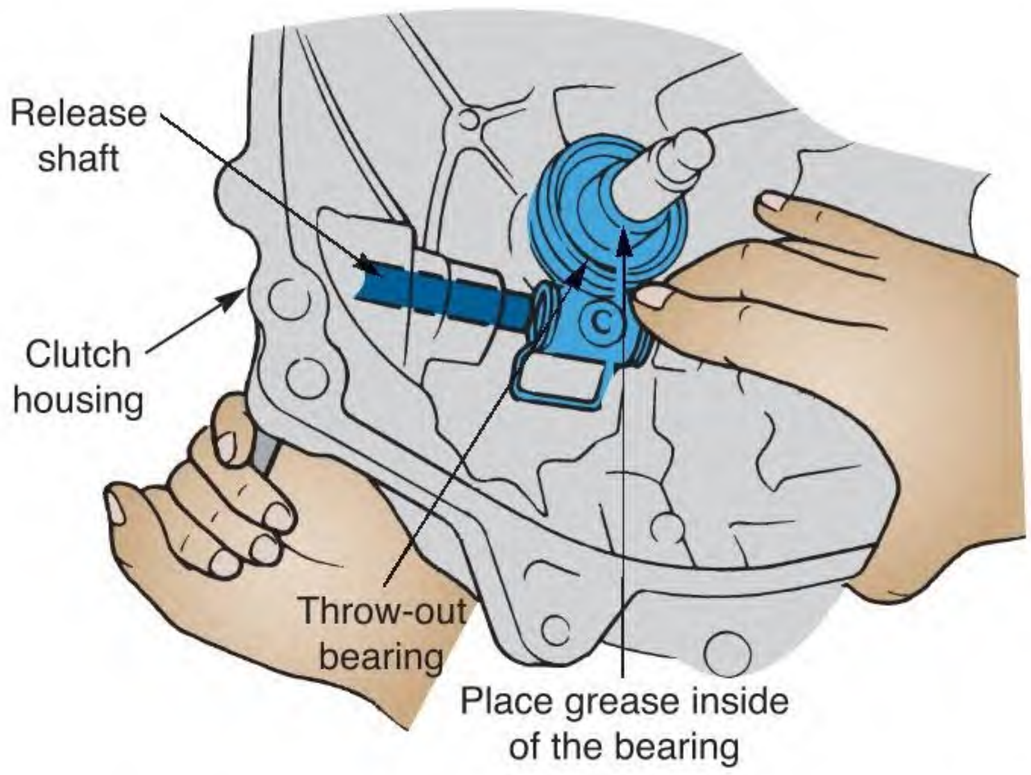
Make sure you use the factory bolts to install a pressure plate. They have a high tensile strength and are usually not threaded near the head. If you use incorrect bolts, they can break and lead to serious part damage!

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Figure 60-29. Place an alignment tool in the pilot bearing to align the clutch assembly on the flywheel. Bolt a flywheel holding tool to the engine block. Torque the factory crankshaft flange bolts to specifications using the proper torque sequence.



Honda

Figure 60-30. Carefully position the throw-out bearing. It must stay in place when bolting the transmission or transaxle to the engine.

Installing a Torque Converter

When installing the torque converter, make sure it is completely seated over its shaft. Wiggle the converter up and down while pushing in. Look down the side of the transmission or transaxle to make sure the converter is not sticking out too far.

Tech Tip

If you accidentally bolt the transmission or transaxle to the engine and the converter is not completely over its shaft, severe transmission or transaxle damage can occur. The front pump, housing, or converter could be cracked and ruined—a time-consuming and costly mistake.

Servicing Hybrid Motor-Generators

Motor-generators are generally trouble free, but they can fail. For example, a car hit by lightning or that is flooded can easily experience sudden high-voltage drive system failures. After extended service, some motor-generator bearings can wear and fail. If the bearings are worn enough, the rotor, or armature, can wobble and contact the stator winding. This can cause winding damage. The resulting high current draw from a shorted winding might then damage the circuitry in the hybrid power control module.

Refer to factory service information for instructions on the proper service of hybrid power train parts. Part locations and procedures vary considerably. Most motor-generators bolt to the back of the cylinder block in place of the clutch or torque converter. Sometimes, one large, 3-phase, high-horsepower motor-generator is attached directly to the bolt flange cast on the rear of the engine block. With the permanent magnet armature bolted directly to the crankshaft, the cylinder block main bearings serve as the motor-generator bearings. As long as the engine main bearings are not worn, the motor-generator offers tremendous service life and a dependable means of high horsepower traction motor propulsion.

Warning

Hybrid voltage levels of 600 volts dc or higher ac 3-phase can explode into a shower of molten metal droplets if any HV circuit is accidentally shorted to frame or earth ground. You must wear rubber lineman's gloves and use electrically insulated tools when working anywhere on a hybrid vehicle.

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Installing the Transmission or Transaxle

If the transmission or transaxle is out of the vehicle, you can usually install the engine and transmission or transaxle into the vehicle as a single unit. To do so, the transmission or transaxle must be attached to the engine. Refer to the service manual for specific details. The general installation procedure is discussed in this section.

Make sure the engine lifting chain has tension on it from the engine lift. This will ensure that the engine will not fall over. Then, using an appropriate lifting device, lift the transmission or transaxle to the level of the engine.

On a manual transmission or transaxle, slide its input shaft through the clutch. You might have to wiggle the unit while pushing in. Make sure to hold the transmission or transaxle perfectly straight with the centerline of the crankshaft or it will not slide fully into the pilot bearing. Once fully seated against the clutch housing, install the transmission or transaxle bolts to attach the unit to the bell housing. Torque the fasteners to specifications using the appropriate torque sequence.

On an automatic transmission or transaxle, slide the transmission forward until the torque converter meets the flywheel. If the torque converter has a drain plug, rotate the torque converter so the plug is down. The hole in the flywheel for the drain plug must also be rotated down. When the torque converter is bolted to the flywheel, the converter drain plug will stick through this hole in the flywheel. This will also help you align everything as you bolt the automatic transmission or transaxle to the engine. Install the transmission or transaxle bolts to attach the unit to the back of the engine. Torque the fasteners to specifications using the appropriate sequence. Then, align the bolt holes in the torque converter with those in the flywheel. Install the torque converter bolts through the flywheel. Torque the fasteners to specifications using the appropriate torque sequence.



Caution

Never use the transmission or transaxle bolts to pull the engine and transmission together. The engine block should slide freely up against the transmission bell housing. If you use the bolts to pull them together, the input shaft can smash into the side of the pilot bearing and cause part damage, or the torque converter can smash into the front pump in the automatic transmission.

Installing the Engine

Before installing the engine, double-check that all small components have been reinstalled. For example, check that all core and oil plugs have been installed in the front, sides, and rear of the cylinder block and heads. If you fail to install the rear camshaft bore plug, for example, and try to start the engine, the engine will lack oil pressure and oil will pour out of the back of the engine. The engine will need to be removed from the vehicle to correct this mistake.

When preparing to install the engine, make sure all needed parts are close by. See **Figure 60-31**. This can save time looking for items such as brackets, bolts, and cables when you are installing the engine.

Engine Installation Rules

Always observe accepted safety practices and use common sense. When installing an engine, remember the following basic safety rules:

- Keep your hands and feet out from under the engine.
- Never work on an engine that is supported only by the hoist or lift.
- Lower the engine slowly. Check for any obstructions as you lower.
- Never use the bell housing bolts to force the engine against the transmission or transaxle or part damage may result.



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Figure 60-31. Before installing the engine, place all parts that you will need near your work area. Be sure to keep walkways free to prevent tripping and other accidents.

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Installing the Engine without the Transmission or Transaxle

Installing the engine in the vehicle is basically the reverse of removing it.

Service Procedure

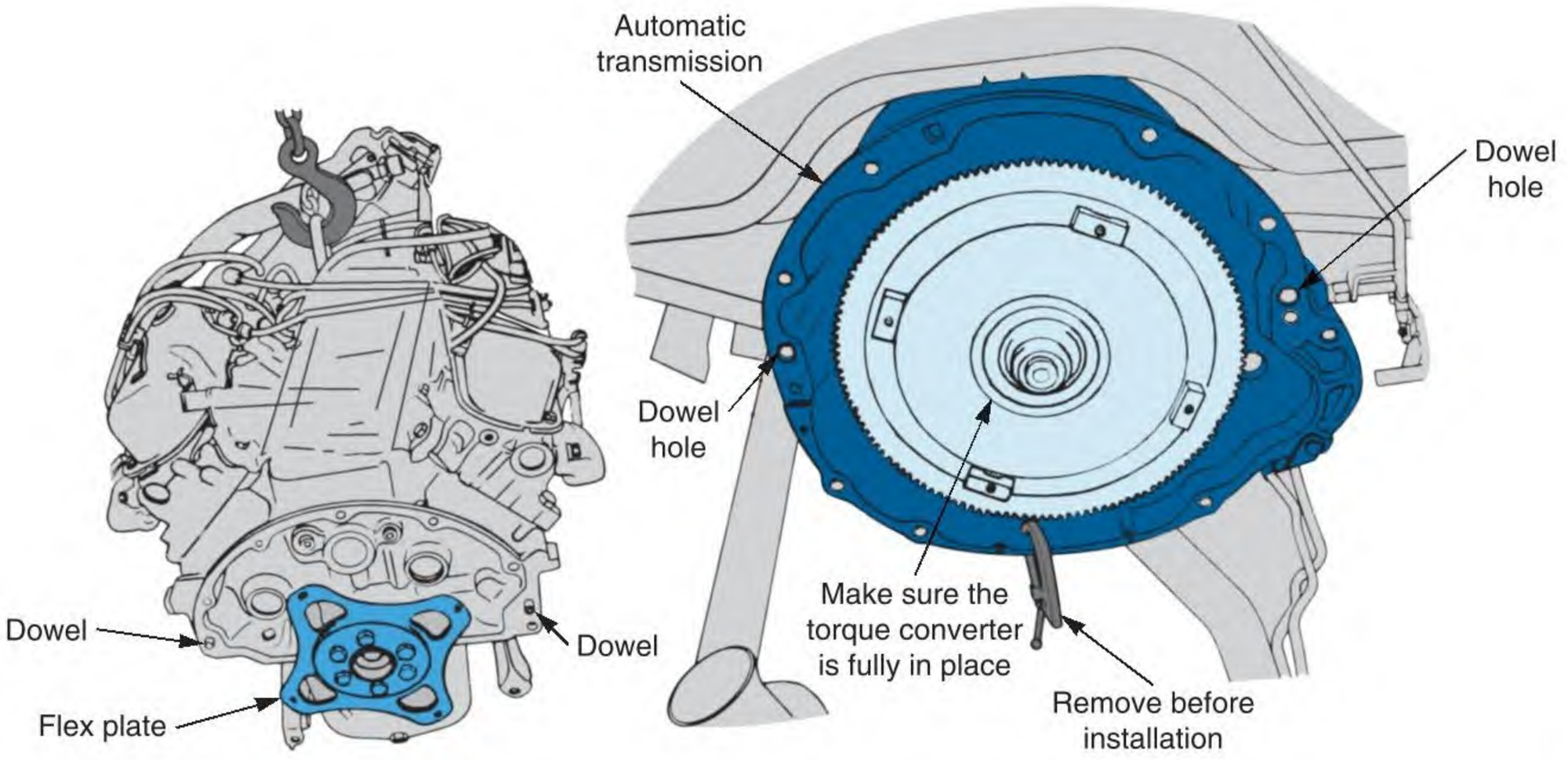
To install the engine without the transmission or transaxle:

1. Slowly lower the engine into the vehicle while watching for clearance all around the engine compartment. Position the engine so its crankshaft centerline aligns with the transmission/motor-generator input shaft centerline.
2. Push the engine back and align the engine dowel pins with the holes in the transmission or motor-generator. Use a large bar to shift the engine until the block and crankshaft flange engage fully.
3. As soon as the dowel pins slide fully into their holes, install an engine-to-transmission bolt, but do not tighten it. Start another bolt on the other side of the engine.
4. Check that the torque converter is properly lined up with the holes in the flywheel, **Figure 60-32**. Turn the converter if needed. Never use the bell housing bolts to force the engine against the transmission or transaxle or part damage can result. The two should slide together freely.
5. Finish installing the other components: motor mounts, oil filter, fuel lines, wiring, vacuum hoses, throttle cable or linkage, battery cable ground, fan belts, front drive axles, and so on. Refer to **Figures 60-33** through **60-36**.

Caution

Never reroute wires on computer-controlled vehicles. Keep all wires in their original locations and reinstall them in their original positions. If you reroute spark plug wires or some high-current-carrying wires, current can be induced into a low-current sensor or computer feedback wires, which could upset computer system operation.

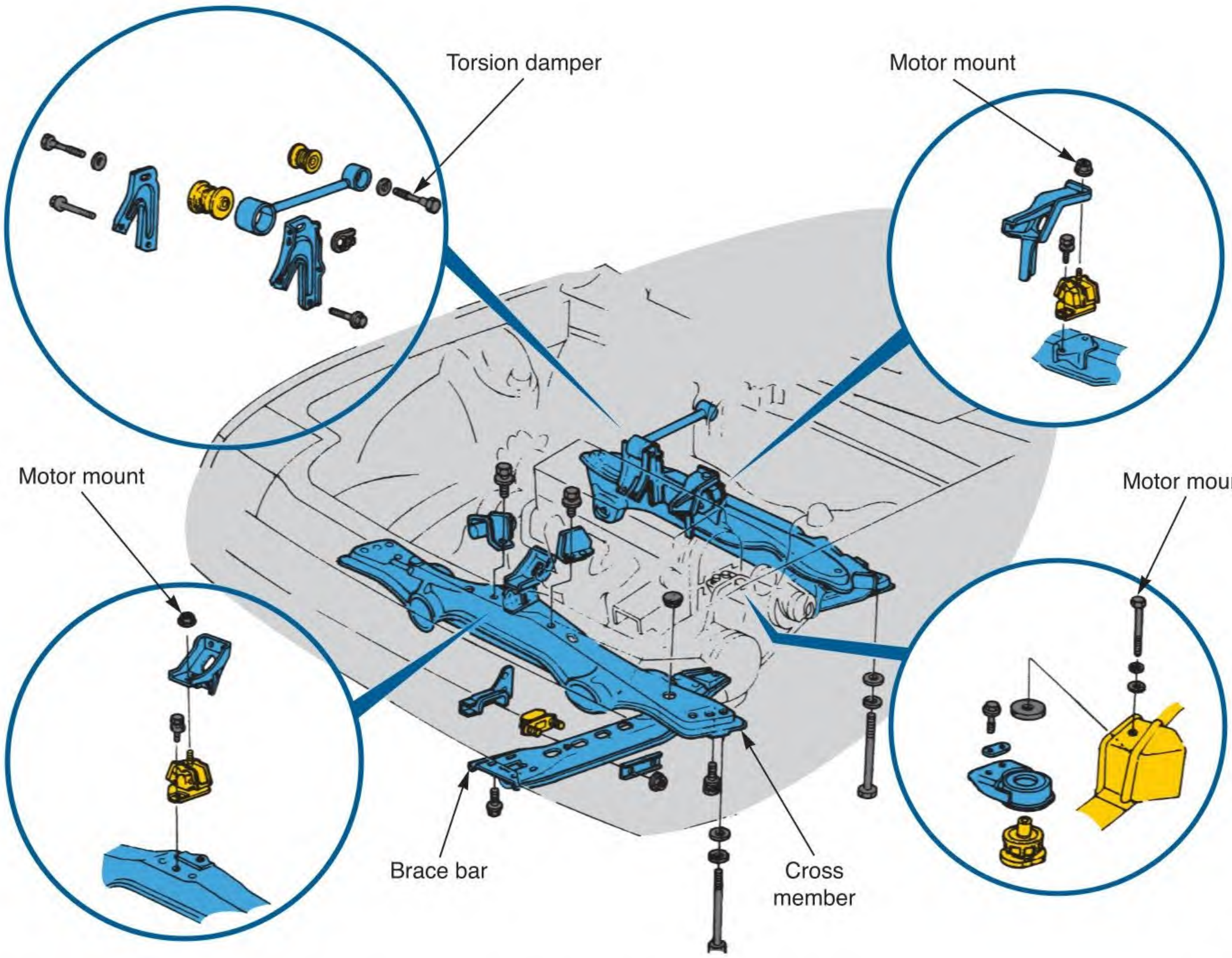
6. Fill the engine with motor oil, radiator with coolant, and transmission or transaxle with fluid, **Figure 60-37**.
7. Replace and align the hood. Visually double-check everything.



Chrysler

Figure 60-32. With an automatic transmission or transaxle, make sure the torque converter is fully installed over its shaft.

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Honda

Figure 60-33. Once the engine is in place, attach and secure all motor mounts, as shown.

Installing the Engine with the Transmission or Transaxle

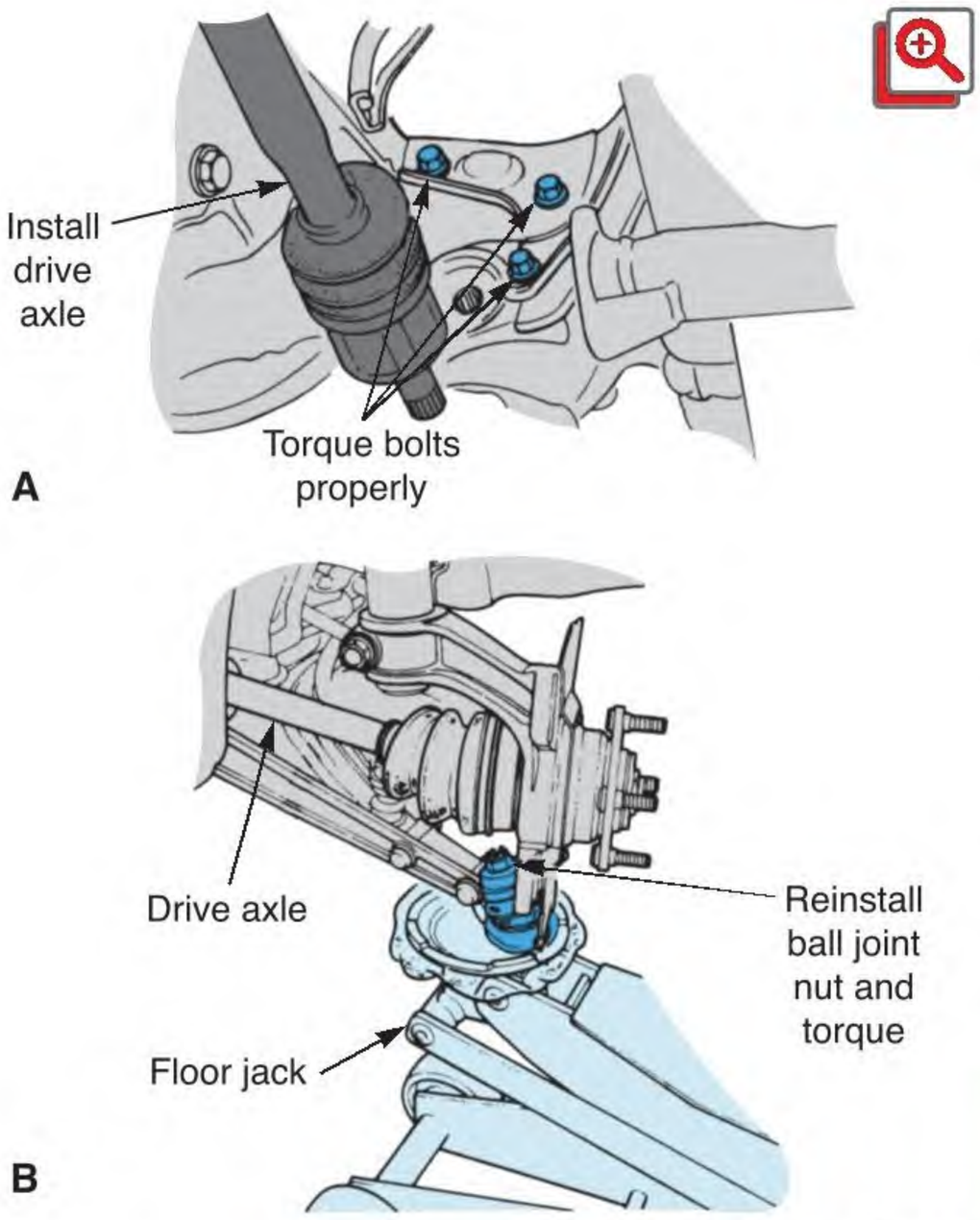
If the engine and transmission or transaxle are to be installed together as an assembly, first mate the engine to the transmission or transaxle.

Service Procedure

To install the engine with the transmission or transaxle:

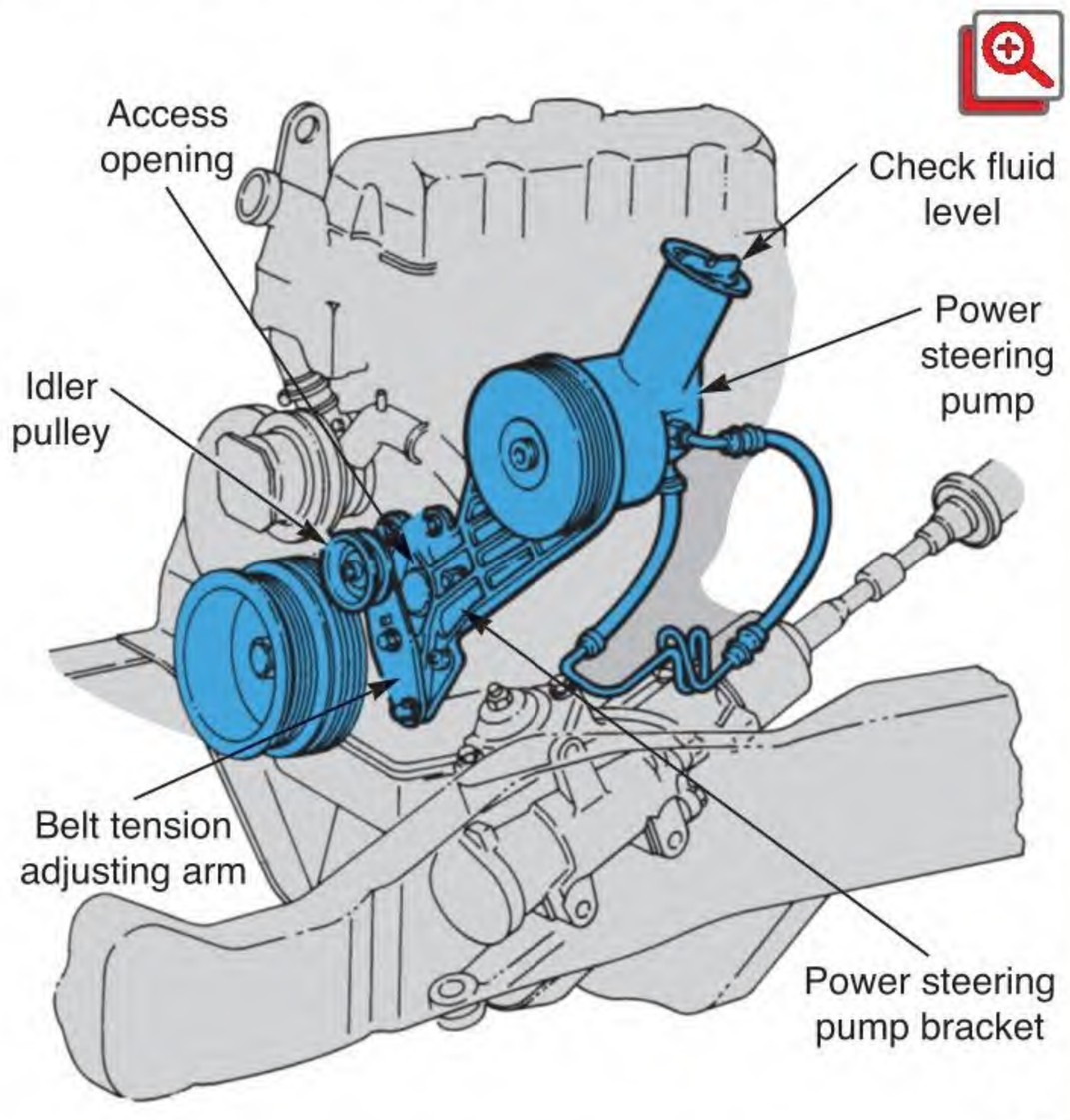
1. Secure the engine with an engine crane and lifting fixture. You might want to place the engine on a large block of wood to raise it a little off of the floor.
2. Secure the transmission or transaxle to another crane or a floor jack. Position it at the rear of the engine.
3. Raise the engine off the floor only if needed to provide working room to mate the transmission or transaxle to the engine.
4. Raise the transmission or transaxle until its centerline is perfectly aligned with the crankshaft centerline.
5. Have someone hold the engine as you slide the transmission or transaxle into the engine. The dowel pins on the rear of the engine should smoothly engage the holes in the transmission or transaxle bell housing.
6. Double-check that the torque converter is fully installed over its input shaft. If the torque converter has partially slid out, the engine and transmission or transaxle will not fully mate. Make sure any torque converter stud bolts feed through the holes in the flex plate or flywheel.

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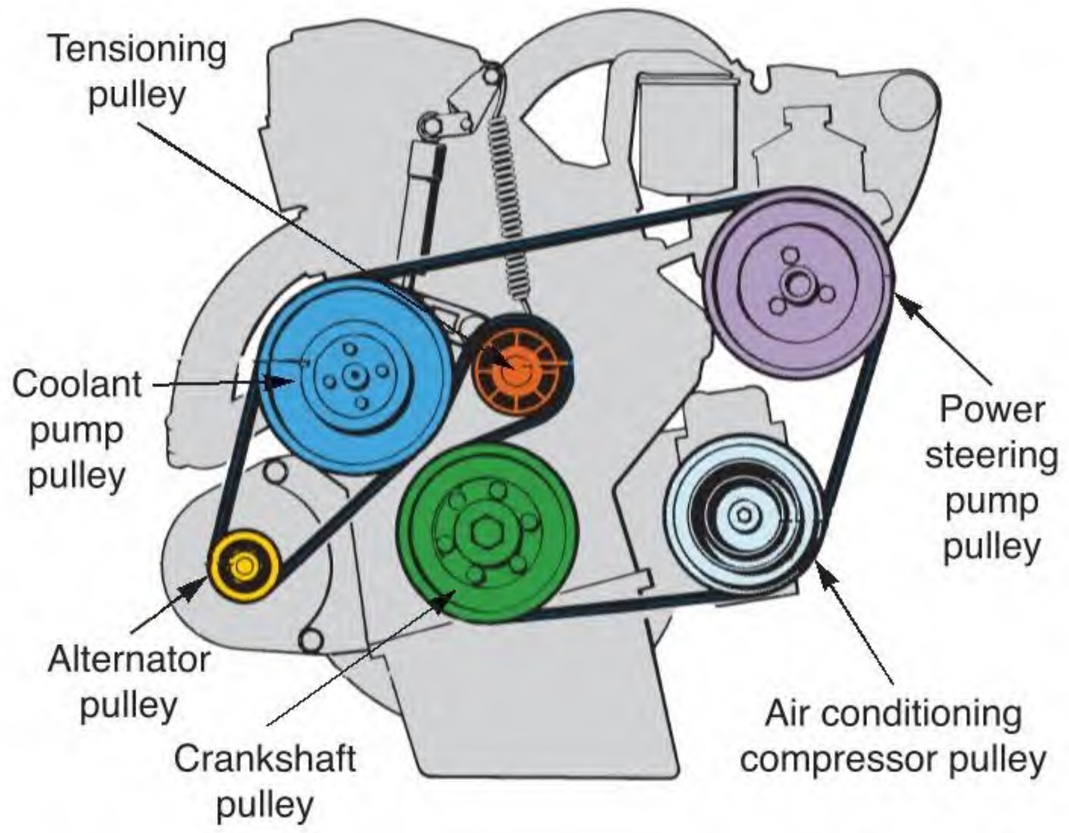
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Figure 60-34. With a front-wheel-drive car, you will have to install the front drive axles as you install the engine and transaxle. Refer to service manual for particular car. A—Install the drive axle. B—Reassemble the ball joint and related parts.



Ford

Figure 60-35. Install all accessory units in correct sequence. Sometimes, one bracket will block access to other bolts.

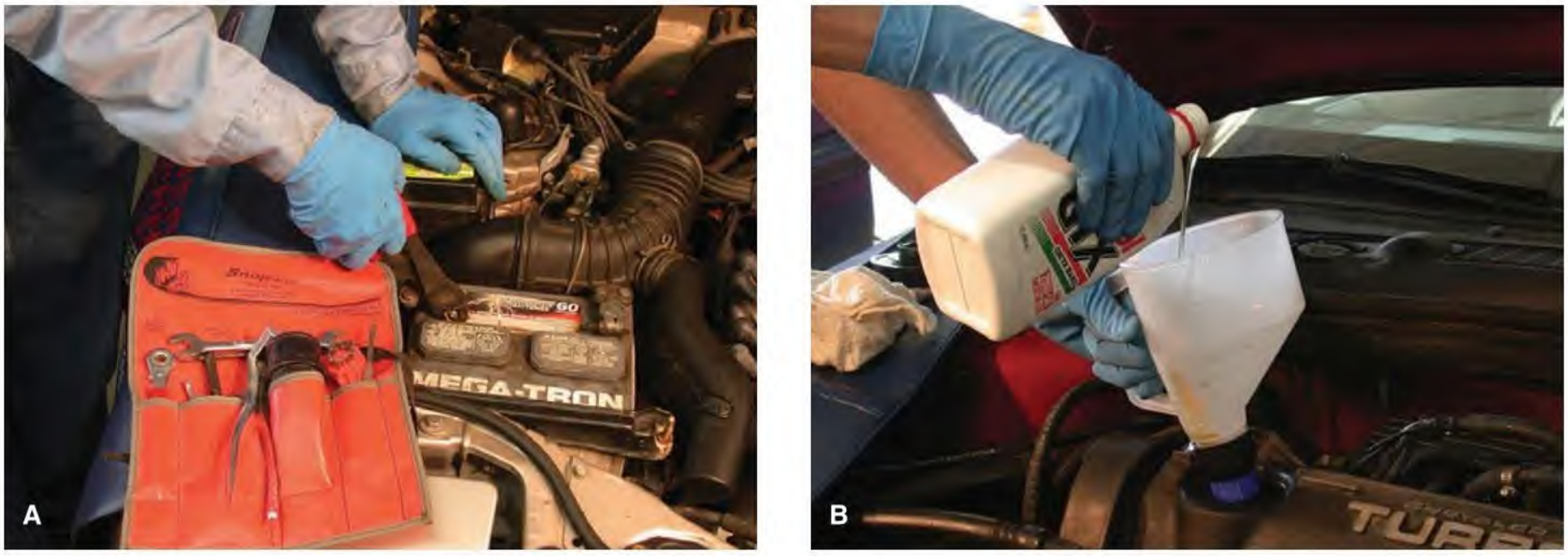


Mercedes-Benz

Figure 60-36. Make sure belts are installed properly and are in good condition.

7. Wiggle the transmission or transaxle sideways while pushing it against the engine. After the dowels have fully seated in the bell housing, start the bell housing bolts.
8. Tighten all bell housing bolts using the proper torque and sequence.
9. Remove the jack or crane from the transmission or transaxle. Lower the engine and transmission or transaxle assembly so it is resting on the floor.
10. Install all parts onto the engine and transmission or transaxle that will not prevent engine installation in the vehicle, such as the transmission dipstick, brackets, and sensors.
11. Reposition the lifting fixture so the engine and transmission or transaxle assembly can be raised level.
12. Raise the engine and transmission or transaxle assembly so it is just off the floor. Roll the crane in front of the engine compartment.
13. Check the engine bay to make sure all wires, hoses, brackets, and other parts are out of the way. They should be lying on the firewall or fender aprons to prevent damage during engine installation.
14. Raise the crane just high enough so the assembly clears the radiator support. Then, roll the crane back so the assembly is over the engine compartment. Tilt the assembly as needed so the rear of the transmission clears the firewall. Keep moving the assembly rearward as you lower it so the engine rests on the motor mounts.

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Figure 60-37. There are several things to check before trying to start the engine. A—Clean the battery cable connections and reinstall cables. Charge the battery if needed so cranking speed is high enough to start the engine. B—Fill the engine with the proper amount of recommended motor oil. C—Fill the radiator and reservoir with coolant. D—Add fluid to the transmission or transaxle, if needed.

15. While still supporting the engine and transmission or transaxle assembly with the crane, install any cross member that had to be removed. Also, install the motor mount bolts.
16. Once the engine is secured in the vehicle, lower the crane and remove the lifting fixture.
17. Install all remaining parts, such as wiring, hoses, brackets, and clamps onto the engine.
18. Fill the engine with motor oil, the radiator with coolant, and the transmission or transaxle with fluid.
19. Replace and align the hood. Visually double-check everything.

Installing the Engine from under the Vehicle

Many front-wheel-drive vehicles require that the engine and transaxle be removed and installed from underneath the engine compartment because the assembly will not clear the unibody or frame. Procedures vary from one vehicle to another, so be sure to consult the service manual for exact instructions.

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Service Procedure

To install an engine and transaxle assembly from the bottom:

1. Secure the engine with an engine crane and lifting fixture.
2. Secure the transaxle to another crane or a floor jack. Position it at the rear of the engine.
3. Raise the engine off of the floor only if needed to provide working room to mate the transaxle to the engine.
4. Raise the transaxle until its centerline is perfectly aligned with the crankshaft centerline.
5. Have someone steady the engine as you slide the transaxle into the engine. The dowel pins on the rear of the engine should smoothly engage the holes in the bell housing.
6. Double-check that the torque converter is fully installed over its input shaft. If the torque converter has partially slid out, the engine and transaxle will not fully mate. Make sure any torque converter stud bolts feed through the holes in the flex plate or flywheel.
7. Wiggle the transaxle sideways while pushing it against the engine. After the dowels have fully seated in the bell housing, start the bell housing bolts.
8. Tighten all bell housing bolts using the proper torque and sequence.
9. If the suspension cradle (front suspension components) was removed with the engine and transaxle assembly, place the cradle on jack stands or wooden blocks. Then, raise the engine and transaxle assembly so it clears the suspension cradle. Position the engine and transaxle assembly over the suspension cradle, lower the assembly, and secure the suspension to the assembly. See **Figure 60-38**.
10. Raise the engine and transaxle assembly and secure it to the engine removal/installation jack. Once the assembly is secured to the jack, lower the crane and remove the engine lifting fixture.
11. Raise the vehicle on a lift.
12. Position the engine removal/installation jack under the vehicle.
13. Slowly raise the jack, making sure the engine and transaxle assembly is not hitting on anything on the chassis.



Mercedes-Benz

Figure 60-38. When installing the engine from under the vehicle, you will have to reinstall the front drive axles, exhaust downpipe, engine cradle, and related parts that were disassembled during engine removal.

14. By hand, start the bolts that secure the suspension components to the chassis. Once all bolts have been started, tighten them to the proper specification.
15. Reinstall the front drive axles, exhaust downpipe, and other parts that are attached between the engine and transaxle assembly and the chassis. Also, install any brackets, cross members, or motor mounts between the engine and transaxle assembly and the chassis.
16. Reinstall all other parts underneath the engine and transaxle that were removed during engine removal.
17. Reinstall all parts in the top of the engine compartment, such as wires, throttle cable, hoses, air conditioning, transaxle cooler lines, and dipstick, which were removed or disconnected during engine removal.
18. Once the engine is secured in the vehicle, lower the crane and remove the lifting fixture.
19. Fill the engine with motor oil, the radiator with coolant, and the transmission or transaxle with fluid.
20. Replace and align the hood. Visually double-check everything.

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Tech Tip

If you do not have access to an engine removal/installation jack for installing an engine from below, you can use a standard transmission jack and use the vehicle lift to lower the vehicle down onto the engine and transaxle assembly.

Caution

When road testing and breaking in an engine, drive the vehicle on a road that is free of traffic. Do not exceed posted speed limits or normal safe driving standards.

Engine Start-up

Service Procedure

1. After ensuring the vehicle's fluids are at the proper levels, start and fast idle the engine until warm. Watch the engine oil light or gauge to make sure you have good oil pressure. Also, watch the engine temperature for signs of overheating.
2. After the engine "fires" and warms up, check the dash oil pressure warning light or gauge immediately. Make sure the engine has oil pressure.
3. If the engine will not start, check for spark at ignition coil secondary and fuel pressure at the test fitting.
4. Let the engine run at a fast idle. Watch for leaks under the engine and make sure the engine does not overheat.

Engine Break-In

Engine break-in is done mainly to seat and seal new piston rings. It also aids the initial wearing-in of other parts under controlled conditions.

After warm-up at a fast idle, most mechanics road test the car. At the same time, they use moderate acceleration and deceleration for engine break-in. Generally, accelerate the vehicle to about 40 mph (65 km/h). Then, release the gas pedal fully and let the vehicle coast down to about 20 mph (30 km/h). Do this several times while carefully watching engine temperature and oil pressure. Do not allow the engine to overheat during break-in because ring damage and cylinder scoring may result.

Customer Delivery

Inform the vehicle owner of the following rules concerning the operation of a freshly overhauled engine:

- Avoid prolonged highway driving during the first 100–200 miles (150 – 300 km). This will prevent ring friction from overheating the rings and cylinders, possibly causing damage.
- Do not worry about oil consumption until after about 2000 miles (3200 km) of engine operation. It will take this long for full ring seating.
- Check engine oil and other fluid levels frequently.
- Change the engine oil and filter after approximately 2000 miles (3200 km) of driving. This will remove any particles trapped in the oil from the engine.

Inform the customer of any problems not corrected by the engine repair or overhaul. For example, if the radiator is in poor condition, explain the consequence of not correcting the problem. If the customer refuses the repair, have the customer sign a release form, which will protect you if the unserviced part fails.

Summary

- When assembling an engine, all parts must be perfectly clean. Parts should be reinstalled in their same locations. Lubricate moving parts. Make sure bolt lengths are correct. Keep components covered until assembly. Torque all fasteners properly. Inspect everything as it is installed.
- When installing a used engine oil pump, make sure the pump is in good condition by measuring its internal wear. Many technicians prefer to use a new or factory-rebuilt oil pump anytime the pump is removed from the engine.

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- When installing the oil pan, straighten its flange if bent. Adhere the gasket to the pan or block. Use RTV sealer where the end seals overlap the pan gasket.
- When installing a head gasket, make sure it is facing in the right direction. Markings are normally provided showing the top or front of a head gasket. If dowels are not provided in the engine, install long stud bolts to align the head gasket during assembly.
- Lower the cylinder head onto the block without hitting the head gasket. Start all of the bolts by hand and turn them down lightly. Use new bolts if they are torque-to-yield fasteners. Use a torque wrench to tighten the head bolts in an approved sequence. Tighten the bolts in steps and at full torque at least twice.
- Before installing an intake manifold, check mating surfaces for warpage with a straightedge. Also, check the fit of the gasket. Adhere the gasket in place, if needed. If the gasket is a multipiece, fiber type, simply place a bead of sealer where the gasket and end seals overlap. With a valve cover seal, apply silicone sealer to the ends of the seal where they curve around the ends of the camshaft. Also apply silicone sealer to the round spark plug hole seals to help hold them in place.
- Place the intake manifold into position without shifting the gasket or end seals. Start all bolts by hand and then torque them to specifications using a crisscross sequence. Tighten all bolts to 1/2, then 3/4, and finally to full torque twice.
- Check the exhaust manifold for damage or warpage before installation.
- Camshaft bearings in an OHC engine may be a one- or two-piece design. One-piece bearings are pressed into the cylinder head. Two-piece bearings snap into the head and camshaft bearing caps.
- If push rods extend through the intake manifold, you cannot install the push rods until the intake manifold is installed. Make sure that the lower end of each push rod is installed fully into its lifter.
- After installation of the valve train components, you may have to adjust the clearance in the valve train. If the valves are too loose, valve train noise will result.
- Nonadjustable rocker arms are used on some push rod engines with hydraulic lifters. The hydraulic lifters automatically compensate for changes in valve train clearance to maintain a zero valve lash. If adjustment is needed, torquing the rocker arm nut or bolt to specifications normally adjusts the valve train clearance. Different push rod lengths can sometimes be purchased.
- With some OHV engine designs, you must adjust the rocker arms to center the hydraulic lifter plungers. Centering the lifter plungers in their bores allows the lifters to automatically adjust to take up or allow more valve train clearance.
- There are many methods of adjusting valve train clearance on OHC engines. OHC engines may have self-adjusting hydraulic cam followers, valve adjusting shims, or an adjusting screw in the cam followers.
- Before installing a valve cover, make sure the cover flange is not bent. Adhere the gasket to the cover or use a continuous bead of silicone in place of the gasket. Make sure the mating surface on the cylinder is clean, and then carefully lower the cover into place. Start all bolts by hand and then tighten them in a crisscross sequence. Overtightening valve cover bolts can bend the cover or split the gasket.
- Final engine assembly involves installing the flywheel and clutch or torque converter, as well as attaching external components, such as brackets or sensors.
- Before installing the flywheel, check its ring gear teeth for damage.
- When installing the torque converter, make sure it is completely seated over its shaft.
- When preparing to install the engine, make sure all needed parts are close by. Engine installation is basically the reverse of engine removal. Keep the engine crankshaft and transmission or transaxle input shaft in perfect alignment during installation. Do not use the bell housing bolts to force the transmission against the engine. Make sure all external parts are installed.
- After the engine is secured in the vehicle, fill the engine with motor oil, the radiator with coolant, and the transmission or transaxle with fluid.
- For engine start-up, start and fast idle the engine. Check oil pressure and do not let the engine overheat. Let the engine run at fast idle and watch for leaks.

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- Engine break-in is done to seat and seal new piston rings and wear in other components. Test drive the vehicle, accelerating and decelerating several times.
- Advise the vehicle owner about driving methods after an engine overhaul.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

camshaft cover
camshaft housing
end seals
exhaust manifold warpage
exhaust manifolds
head gasket
intake manifold
intake manifold gasket
intake manifold warpage
nonadjustable rocker arms
oil pan
oil pump
torque-to-yield bolts
valve adjustment
valve cover
valve lash adjustment
valve train clearance adjustment
valve train noise
zero valve lash

Review Questions

Answer the following questions using the information provided in this chapter.

1. List five general rules to remember during engine assembly.
2. What is the purpose of priming the oil pump?
3. Teflon-coated, permanent-torque head gaskets should be installed _____.
   (A) with a bead of RTV sealant
   (B) with a thin coating of shallac
   (C) with a bead of silicone sealant
   (D) dry
4. If dowels are not provided in the block for alignment of the head gasket and cylinder head, how should you provide for alignment?
5. Used torque-to-yield head bolts must be _____ when the engine is reassembled.
6. If a bolt will extend into an oil or coolant passage, what must be done when installing the bolt?
7. The lifters are installed before the push rods. Also, if you are working on an OHV engine, you will need to install the lifters before installing the _____.
8. Briefly describe how to install an intake manifold.
9. When doing major engine service, make sure the _____ is installed, that it operates properly, and that its heat range matches the service manual specification to help ensure proper cooling system operation.
10. To check for exhaust manifold _____, use a straightedge and a flat feeler gauge.
11. Some overhead camshaft engines have a(n) _____ that holds the cam followers and camshaft(s).
12. To adjust valve train clearance with nonadjustable rocker arms, you must:
    (A) Run the rocker arm nuts down with an impact wrench.
    (B) Grind material off of valve stems for adjustment.
    (C) Torque the rocker arm nuts or bolts to specifications.
    (D) None of the above.
13. The valve train clearance on an engine with _____ lifters can be adjusted with the engine off or with the engine running.
14. List four basic safety rules for engine installation.
15. On a freshly rebuilt engine, oil consumption during the first _____ miles is not unusual.

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ASE-Type Questions

1. When assembling and installing an engine, you should _____.
   (A) tighten head bolts as tight as possible
   (B) reuse torque-to-yield bolts
   (C) coat all moving parts with assembly lube or high-temperature grease
   (D) install the oil pump dry
2. Technician A says that you should use sealer on the oil pump gasket. Technician B says that the oil pump should be primed before installation. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. Technician A says that the oil pan gasket can be adhered to the engine block mating surface. Technician B says that the oil pan gasket can be adhered to the oil pan. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. Technician A says that new head bolts should always be used when installing an engine's cylinder head. Technician B says that torque-to-yield head bolts can be reused during cylinder head installation. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. Technician A says that when torquing head bolts, you should start at one end of the cylinder head and work inward. Technician B says that torque-to-yield head bolts are first torqued, then tightened an additional number of degrees. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Technician A says that an improperly installed intake manifold may result in a coolant leak. Technician B says that an excessively warped manifold should be brought to a machine shop. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. You should use a(n) _____ to check an intake manifold sealing surface for warpage.
   (A) dial indicator and flat feeler gauge
   (B) straightedge and flat feeler gauge
   (C) outside caliper and straightedge
   (D) dial indicator and straightedge
8. Technician A says that the camshaft bearing caps in an OHC engine must be installed in their original location. Technician B says that the camshaft bearings in an OHC engine may be a pressed-in, two-piece design. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Technician A says that the valve train clearance in an engine with hydraulic lifters can be adjusted with the engine running. Technician B says that the valve train clearance in an engine with hydraulic lifters can be adjusted with the engine off. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. After an engine has been overhauled, prolonged highway driving should be avoided during the first _____.
    (A) 500 miles (800 km)
    (B) 2000 miles (3200 km)
    (C) 1000 miles (1600 km)
    (D) 100 miles (150 km)

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Section 11

Drive Train and Axle Technology

Chapter 61
Clutch Technology

Chapter 62
Clutch Diagnosis, Service, and Repair

Chapter 63
Manual Transmission Technology

Chapter 64
Manual Transmission Diagnosis, Service, and Repair

Chapter 65
Automatic Transmission Technology

Chapter 66
Automatic Transmission Diagnosis, Service, and Repair

Chapter 67
Drive Shaft and Transfer Case Technology

Chapter 68
Drive Shaft and Transfer Case Diagnosis, Service, and Repair

Chapter 69
Differential and Rear Drive Axle Technology

Chapter 70
Differential and Rear Drive Axle Diagnosis, Service, and Repair

Chapter 71
Transaxle and Front Drive Axle Technology

Chapter 72
Transaxle and Front Drive Axle Diagnosis and Repair

The drive train transfers turning force from the engine crankshaft to the drive wheels. Drive train configurations vary, depending on vehicle design. The drive train parts commonly found on a front-engine, rear-wheel-drive vehicle include the clutch, transmission, drive shaft, and rear axle assembly. The drive train parts used on most front-engine, front-wheel-drive vehicles include the clutch, transaxle, and drive axles.

Section 11 explains the operation, construction, and repair of all types of automotive drive trains. You will learn about front-wheel drive, rear-wheel drive, and all-wheel drive. This will give you the knowledge needed to work on any make or model car, truck, or sport utility vehicle. This section will help you pass two ASE certification tests: Test A2, *Automatic Transmission/Transaxle*, and Test A3, *Manual Drive Train and Axles*.



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Chapter 61
Clutch Technology

After studying this chapter, you will be able to:

- List the basic parts of an automotive clutch.
- Explain the operation of a clutch.
- Describe the construction of major clutch components.
- Compare clutch design differences.
- Explain the different types of clutch release mechanisms.
- Explain the operation of a wet clutch.
- Compare single and dual clutch systems.
- Explain automatic manual clutch engagement systems.
- Correctly answer ASE certification test questions that require knowledge of clutch designs and operation.

This chapter begins your study of a vehicle's drive train. The clutch is the first drive train component powered by the engine crankshaft.

The textbook chapters that follow cover clutch service, manual and automatic transmissions, drive shafts, transfer cases, differentials, transaxles, and hybrid transmissions in more detail. To fully understand these later chapters, you must first understand clutch operation and design. Study carefully!

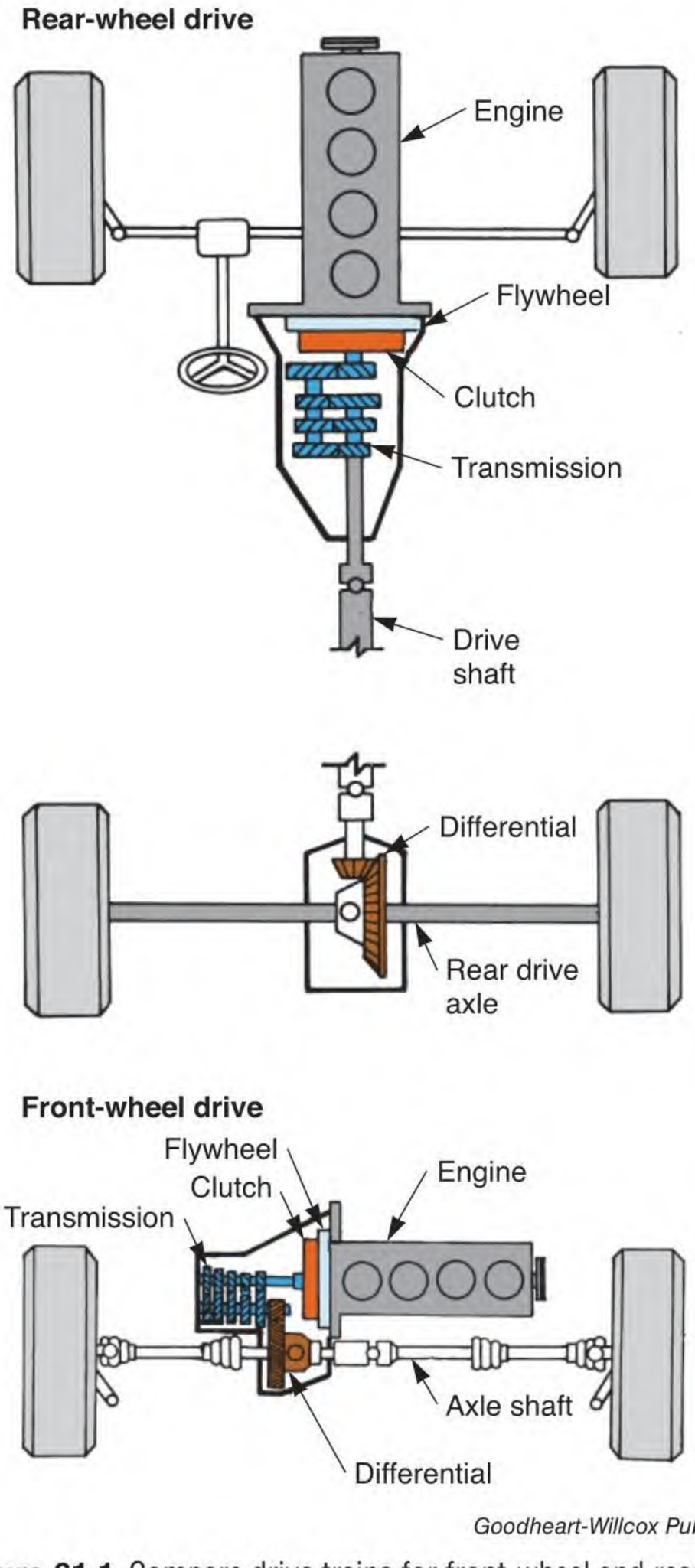
Clutch Principles

An ***automotive clutch*** is used to connect and disconnect the engine and manual (hand-shifted) transmission or transaxle. The clutch is located between the engine and the transmission. The clutch is operated using a third pedal on the floor of the vehicle. The driver presses down on the clutch pedal to disengage engine power from the driveline as needed. **Figure 61-1** shows the basic parts of drive trains for both rear-wheel-drive and front-wheel-drive vehicles. Review the relationship of the parts.

Power flow between the engine and the transmission or transaxle (transmission-differential assembly) can be controlled with a drive disc and a driven disc. In an automotive clutch, one disc (engine flywheel) is fastened to the rear of the engine crankshaft and the other disc (friction disc) is attached to the input shaft of the transmission. Look at **Figure 61-2**.

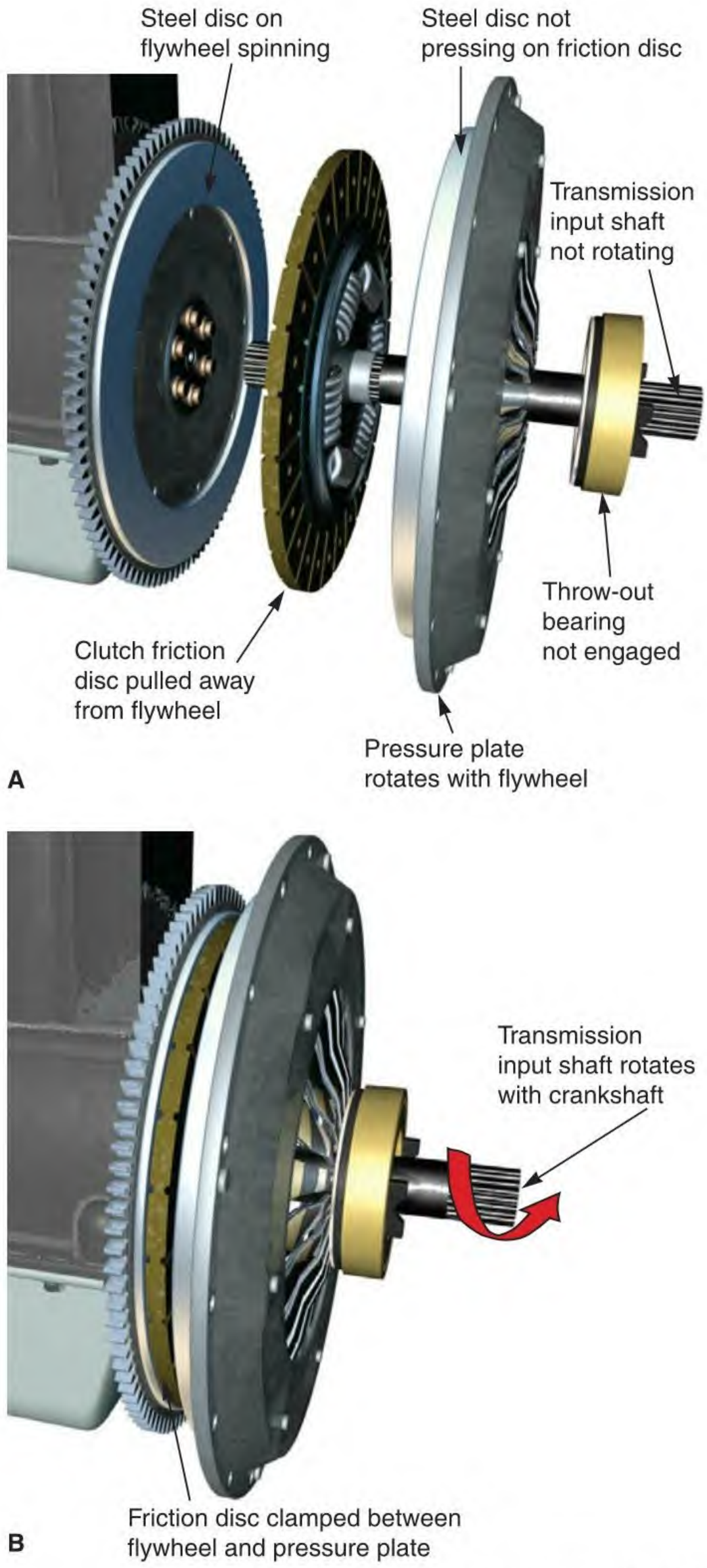
When the discs do not touch, the crankshaft can rotate while the transmission input shaft remains stationary. However, when the transmission disc is forced into the spinning disc on the crankshaft, both spin together. Power flow is then transferred out of the engine and into the transmission.

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Figure 61-1. Compare drive trains for front-wheel and rear-wheel drives. The clutch mounts on the engine flywheel.



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Figure 61-2. Rotating discs demonstrate the action of a clutch. A—The crankshaft spins the drive disc. The driven disc is not in contact with the drive disc. No power transfers. B—The two discs are pushed together. Friction causes the crankshaft disc to turn the other disc connected to the transmission input shaft. Power is transferred through the clutch.

Some newer vehicles with automatic transmissions and automatic manual transmissions use a ***wet clutch*** submersed in transmission fluid. In these vehicles, the wet clutch replaces the fluid coupling or torque converter between the engine crankshaft and the transmission gearsets, which automatically disengages the engine and transmission at low engine speeds. A wet clutch does not slip, as a fluid coupling or torque converter may, and is more energy efficient.

A ***motor-generator clutch*** is required to engage the armature shaft to and from the engine crankshaft

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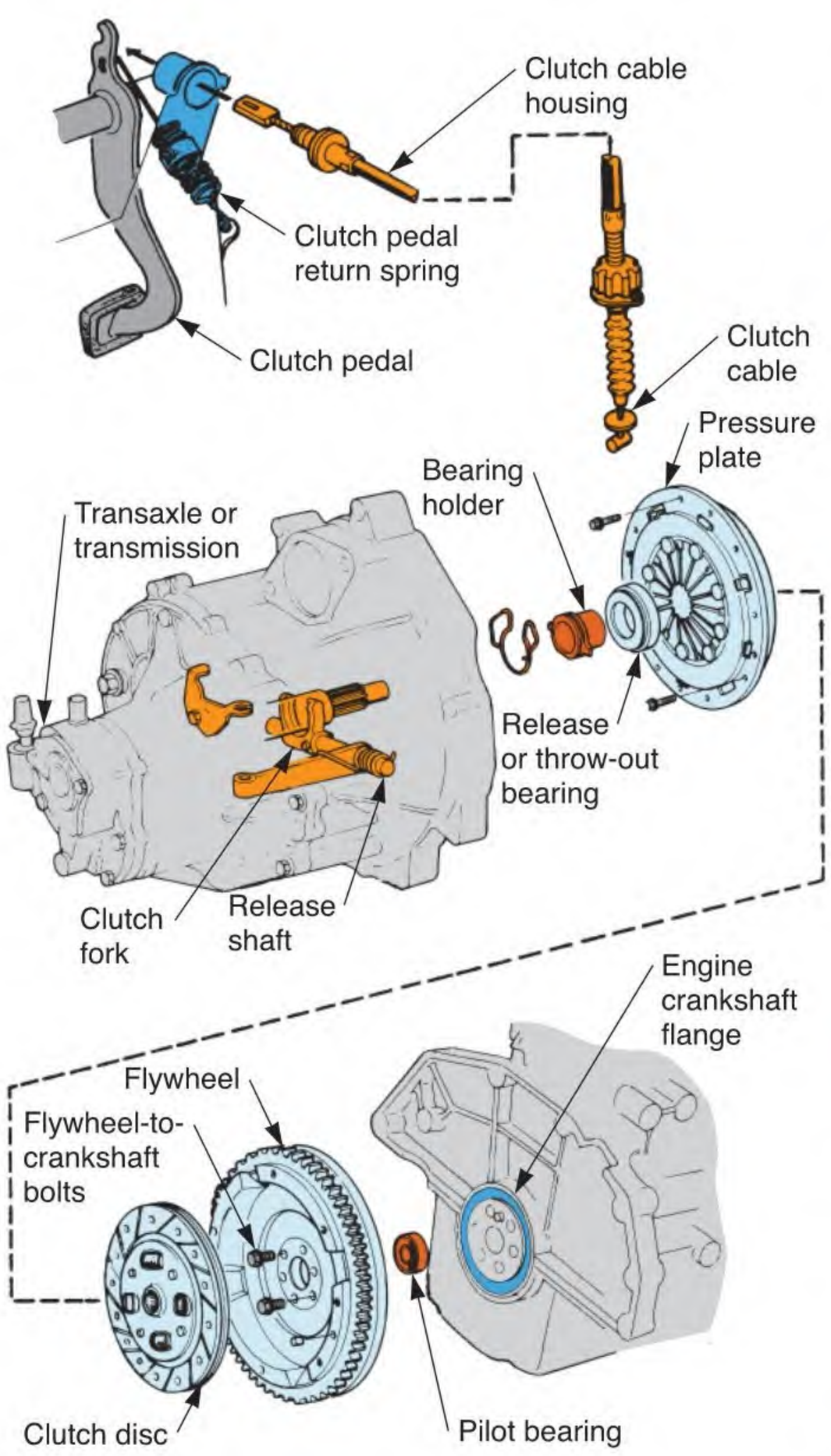
and the transmission shaft. When engaged to the engine crankshaft, the motor-generator can spin the crankshaft for starting or propulsion, or be spun by the crankshaft to serve as a generator to recharge the HV battery.

Basic Clutch Parts

Figure 61-3 shows the major parts of an automotive clutch. Study the names, locations, and relationship of the components.

The basic parts of a clutch include:

- ***Clutch release mechanism***—This cable, linkage, or hydraulic system allows the driver to disengage the clutch with a foot pedal.
- ***Clutch fork***—A lever that forces the release bearing into the pressure plate.
- ***Release bearing***—A bearing that reduces friction between the clutch fork and pressure plate.
- ***Pressure plate***—This spring-loaded device presses the clutch disc against the flywheel.
- ***Clutch disc***—A friction disc that is splined (fastened) to the transmission input shaft and pressed against the face of the flywheel.
- ***Flywheel***—This heavy steel disc provides a mounting place for the clutch and a friction surface for the clutch disc.
- ***Pilot bearing***—A bushing or bearing that supports the forward end of the transmission input shaft.



Honda

Figure 61-3. Note the fundamental components of a clutch and how parts are located in relation to each other.

Clutch Action

When the driver presses the clutch pedal, the clutch release mechanism pulls or pushes on the clutch fork. The fork moves the release bearing into the center of the pressure plate. This causes the pressure plate face to pull away from the clutch disc, releasing the disc from the flywheel. The engine crankshaft can then turn without turning the clutch disc and the transmission input shaft. See **Figure 61-4A**.

When the clutch pedal is released by the driver, pressure plate spring tension causes the pressure plate face to push against the clutch disc. This locks the flywheel, disc, pressure plate, and transmission input together. The engine again rotates the transmission input shaft, transmission gears, drive train, and wheels. Refer to **Figure 61-4B**.

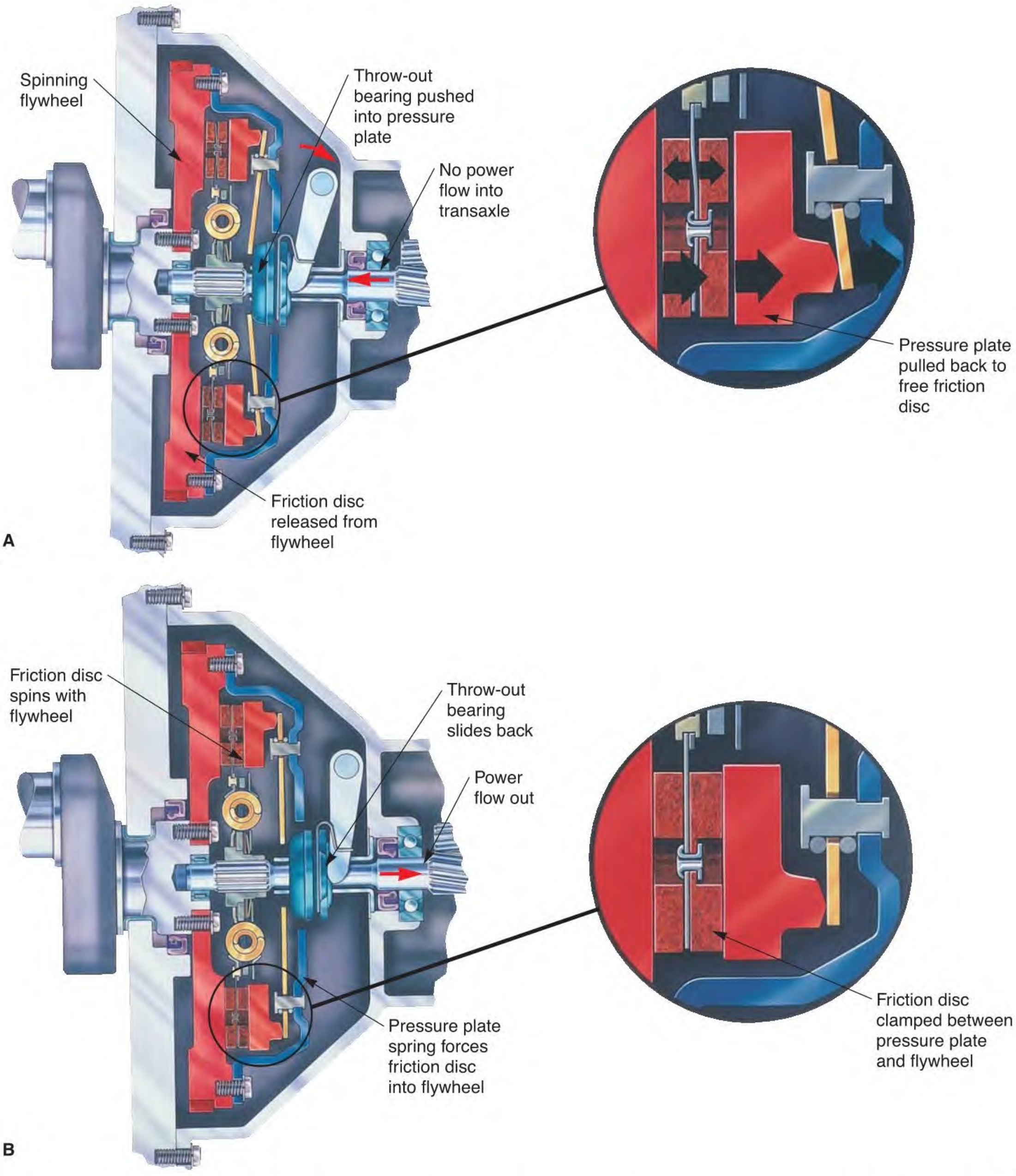
Clutch Construction

Now that you understand the basic action of a clutch, we will discuss, in more detail, how each part is made. This information will be useful when learning to diagnose and repair a clutch. Refer to **Figure 61-5** throughout the discussion.

Pilot Bearing

A pilot bearing, or ***pilot bushing***, is pressed into the end of the crankshaft to support the end of the transmission input shaft. Usually, the pilot is a solid bronze bushing. It may also be a roller or ball bearing.

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LuK

Figure 61-4. Study what happens when you press and release the clutch pedal. A—The clutch pedal is pressed. The release mechanism forces the throw-out bearing into the pressure plate. This pushes in on the center spring of the pressure plate to pull it away from friction disc. The disc is then free of the spinning flywheel and no engine power transfers into transmission or transaxle. B—When the driver releases the clutch pedal, the throw-out bearing moves away from pressure plate. The pressure plate spring presses the friction disc up against the flywheel. Power is transferred into the transmission or transaxle to propel the vehicle.

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The end of the transmission input shaft has a small journal machined on its end. This journal slides inside the pilot bearing. The pilot prevents the transmission shaft and clutch disc from wobbling up and down when the clutch is released. It helps the input shaft center the disc on the flywheel.

Flywheel

The flywheel is the mounting place for the clutch. The pressure plate bolts to the flywheel face. The clutch disc is pinched and held against the flywheel by the spring action of the pressure plate. Look at **Figures 61-4** and **61-5**.

The face of the flywheel is precision machined to a smooth surface. Normally, the face of the flywheel that touches the clutch disc is made of iron. Even if the flywheel is aluminum, the face is iron because it wears well and dissipates heat well.

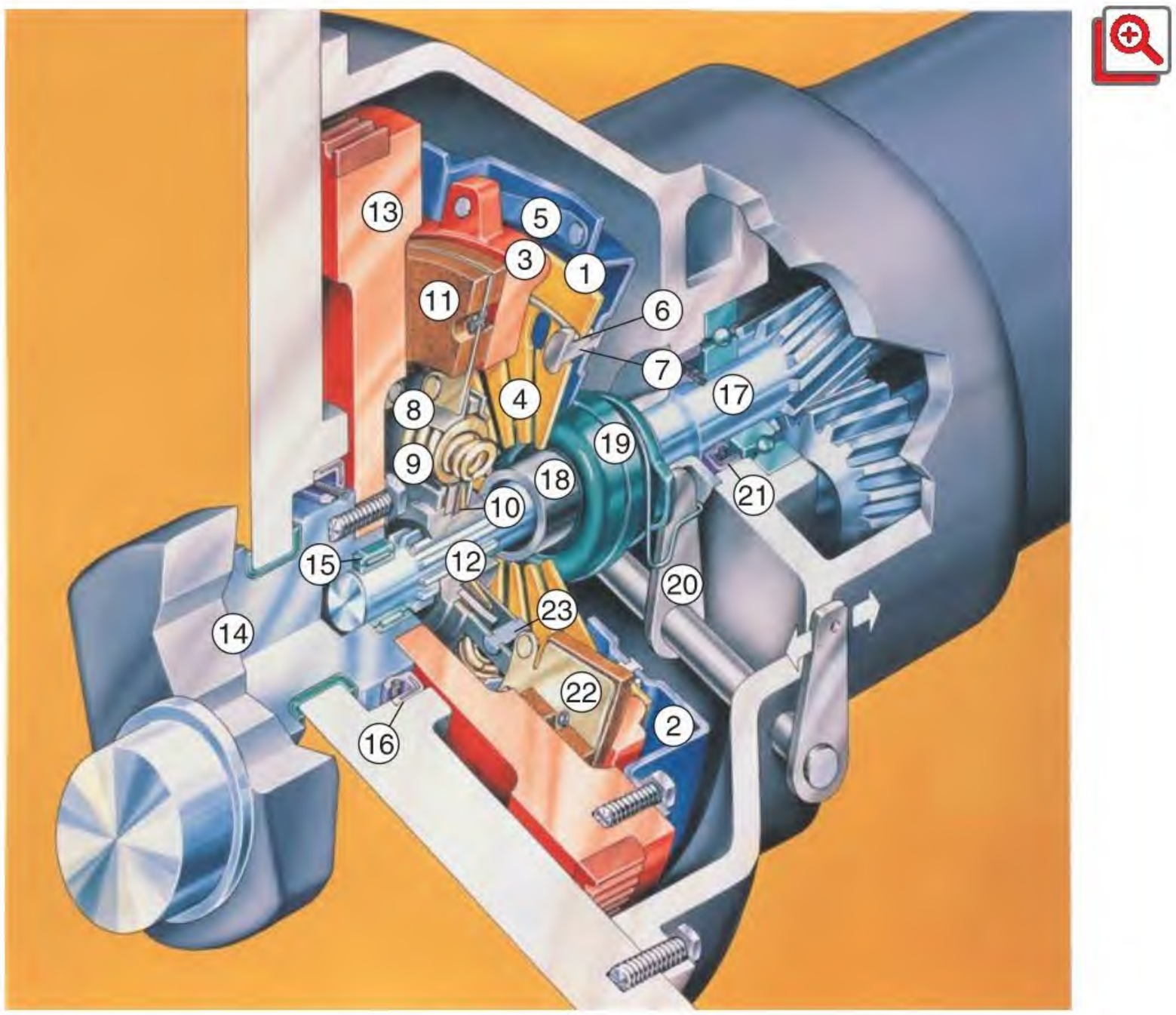
Clutch Disc

The clutch disc, also called ***friction disc***, consists of a splined hub and a round metal plate covered with friction material (lining). See **Figure 61-6**. The splines (grooves) in the center of the clutch disc mesh with splines on the transmission input shaft. This makes the input shaft and disc turn together. However, the disc is free to slide back and forth on the shaft.

The clutch disc ***friction material***, also called ***disc lining*** or ***facing***, is made of heat-resistant substances. Grooves are cut in the friction material to aid cooling and release of the clutch disc. Rivets are used to bond the friction material to both sides of the metal body of the disc.

Clutch Disc Springs

Clutch disc ***torsion springs***, also called ***damping springs***, help absorb some of the vibration and shock



LuK

Figure 61-5. Cutaway view shows an assembled clutch. Note how the transmission input shaft extends through the clutch and into the pilot bearing in the crankshaft. 1. Clutch pressure plate. 2. Clutch cover. 3. Pressure plate. 4. Diaphragm spring. 5. Leaf springs/straps, 6. Pivot ring. 7. Diaphragm rivet. 8. Disc plate. 9. Torsion damper. 10. Friction device. 11. Clutch facing. 12. Hub. 13. Flywheel 14. Crankshaft. 15. Pilot bearing. 16. Main seal (crank). 17. Transmission shaft. 18. Quill. 19. Throw-out bearing. 20. Clutch fork. 21. Shaft seal. 22. Cushion segment. 23. Stop pin.

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produced by clutch engagement. They are small coil springs located between the clutch disc splined hub and the friction disc assembly.

When the clutch is engaged, the pressure plate jams the stationary disc against the spinning flywheel. The torsion springs compress and soften the shock as the disc first begins to turn with the flywheel, **Figure 61-6**.

Clutch disc ***facing springs***, also called ***cushioning springs***, are flat, metal springs located under the disc's friction material. These springs have a slight wave (curve). They allow the friction material to flex inward slightly during initial clutch engagement, which smoothes engagement.

Pressure Plate

The pressure plate is a spring-loaded device that bolts to the flywheel and can either lock or unlock the clutch disc and the flywheel. The clutch disc fits between the flywheel and pressure plate. Refer to **Figure 61-5**. There are two basic types of pressure plates: coil spring and diaphragm spring.

Coil Spring Pressure Plate

A ***coil spring pressure plate*** uses small coil springs, similar to valve springs. Study **Figure 61-7**.

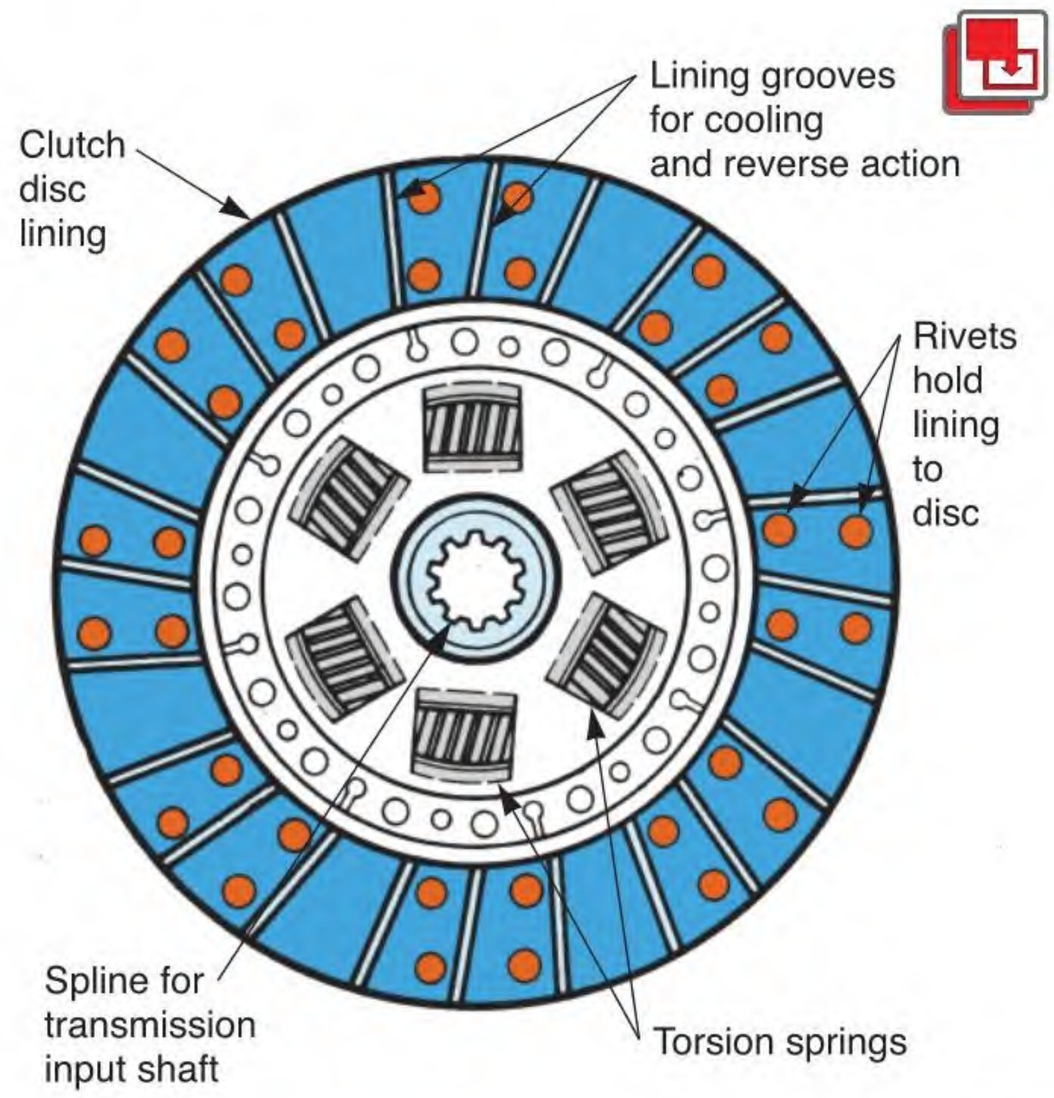
The ***pressure plate face*** is a large ring, normally made of iron, that contacts the friction disc during clutch engagement. The back of the pressure plate face has pockets for the coil springs and brackets for hinging the release levers. During clutch action, the pressure plate face moves back and forth inside the clutch cover.

Pressure plate release levers are hinged inside the pressure plate to move the pressure plate face away from the disc and flywheel. Small clip springs fit around the release levers to keep the levers in a fully retracted (released) position. The springs also keep the levers from rattling.

The ***pressure plate cover*** fits over the springs, release levers, and pressure plate face. Its main purpose is to hold the parts of the pressure plate assembly together. Holes around the outer edge of the cover are for bolting the pressure plate assembly to the flywheel.

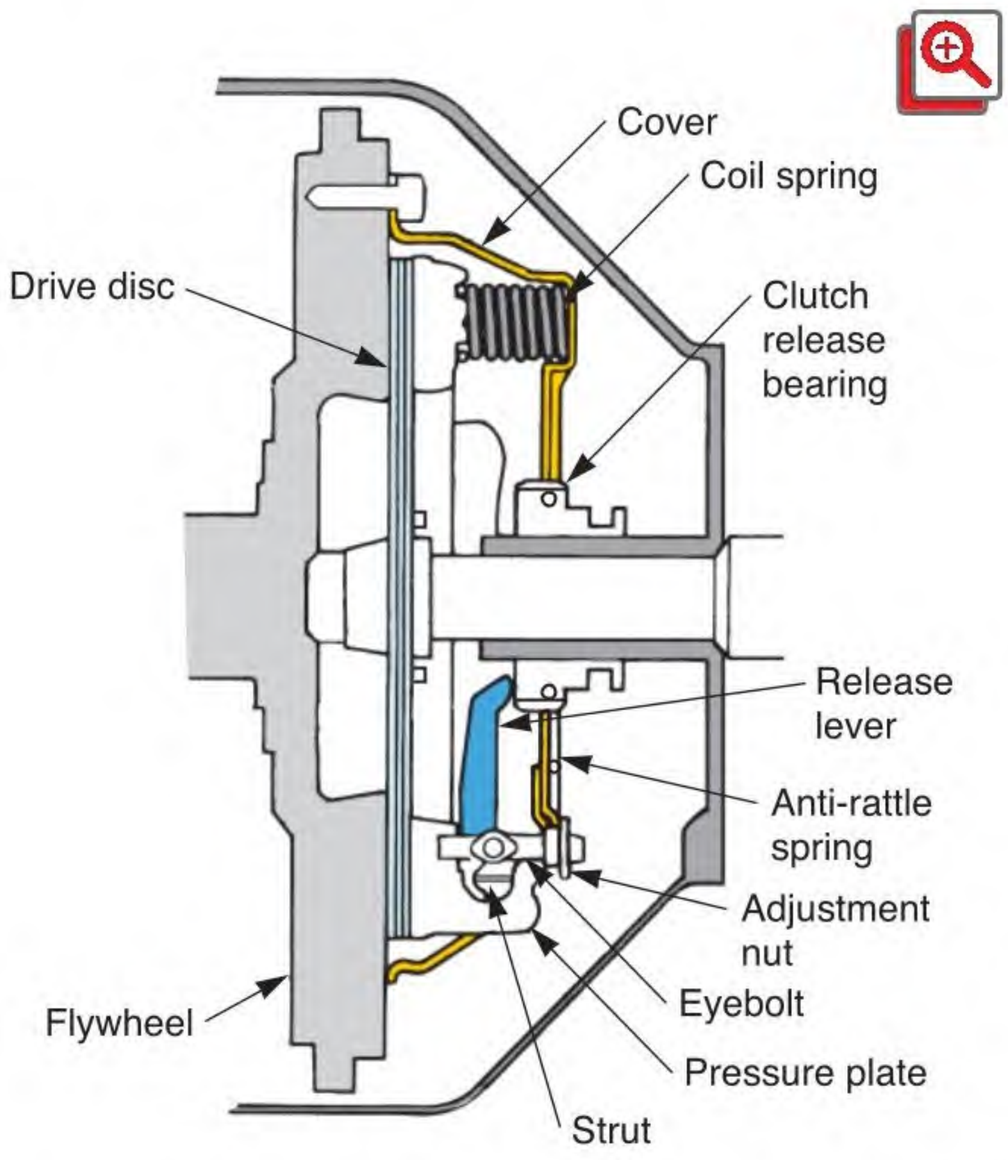
When the clutch is disengaged, the release levers are pushed forward, toward the flywheel. This pries the pressure plate face away from the flywheel, compressing the coil springs. The clutch disc slides back and power is not transferred into the transmission.

When the clutch is engaged, the release bearing moves away from the release levers. The pressure



Chrysler

Figure 61-6. Clutch disc construction. Friction material is held on metal disc by rivets. Splines in center of the disc fit over splines on the transmission input shaft to make them rotate together.



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Figure 61-7. Cutaway view of coil spring pressure plate. Study the parts.

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plate springs force the face and disc forward, into the rotating flywheel. The disc and transmission input shaft begin to spin and transmit power.

A ***semi-centrifugal pressure plate*** uses weighted release levers or rollers and the resulting centrifugal force to increase clamping pressure on the clutch disc. The weights on the release levers or the rollers are positioned so that, as engine speed increases, their outward thrust acts on the release levers. The extra force helps keep the clutch from slipping. It also permits the use of slightly weaker coil springs to reduce the amount of foot pedal pressure required to disengage the clutch.

Diaphragm Spring Pressure Plate

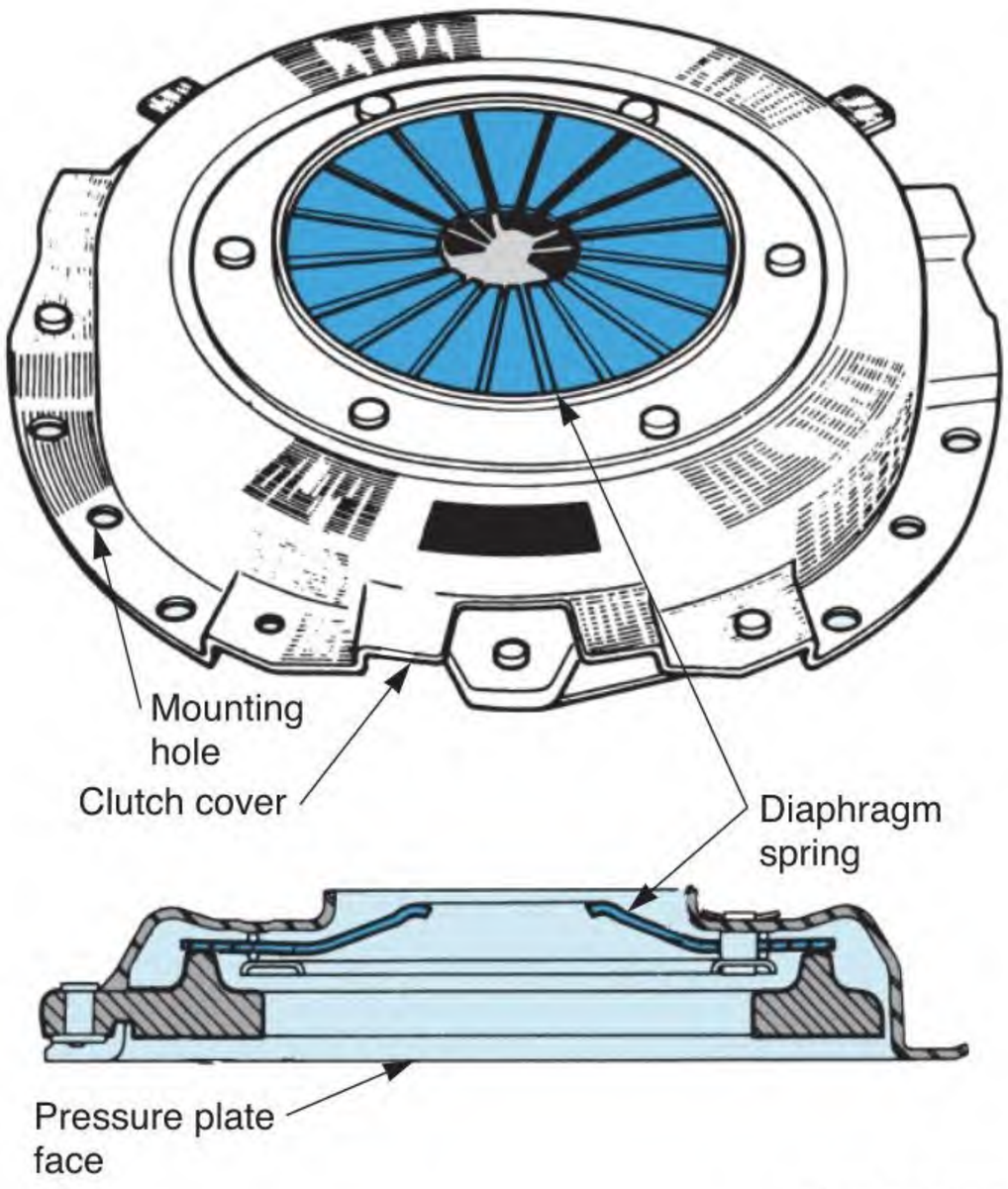
A ***diaphragm spring pressure plate*** uses a single diaphragm spring instead of several coil springs. This type of pressure plate functions similarly to a coil spring pressure plate. See **Figure 61-8**.

The ***diaphragm spring*** is a large, round disc of spring steel. The spring is bent (dished) and has pie-shaped segments running from the outer edge to the center opening. The diaphragm spring is mounted in the pressure plate with the outer edge touching the back of the pressure plate face.

A ***pivot ring*** mounts behind the diaphragm spring. It is located part way in from the outer edge of the diaphragm spring.

When the center of the diaphragm spring is pushed toward the engine, its outer edge bends back away from the engine. This lets the pressure plate face and clutch disc slide away from the spinning flywheel.

When the center of the diaphragm spring is released, the spring tries to return to its normal dished shape. As a result, the outer edge of the spring pushes the pressure plate face into the clutch disc.



Renault; Chrysler

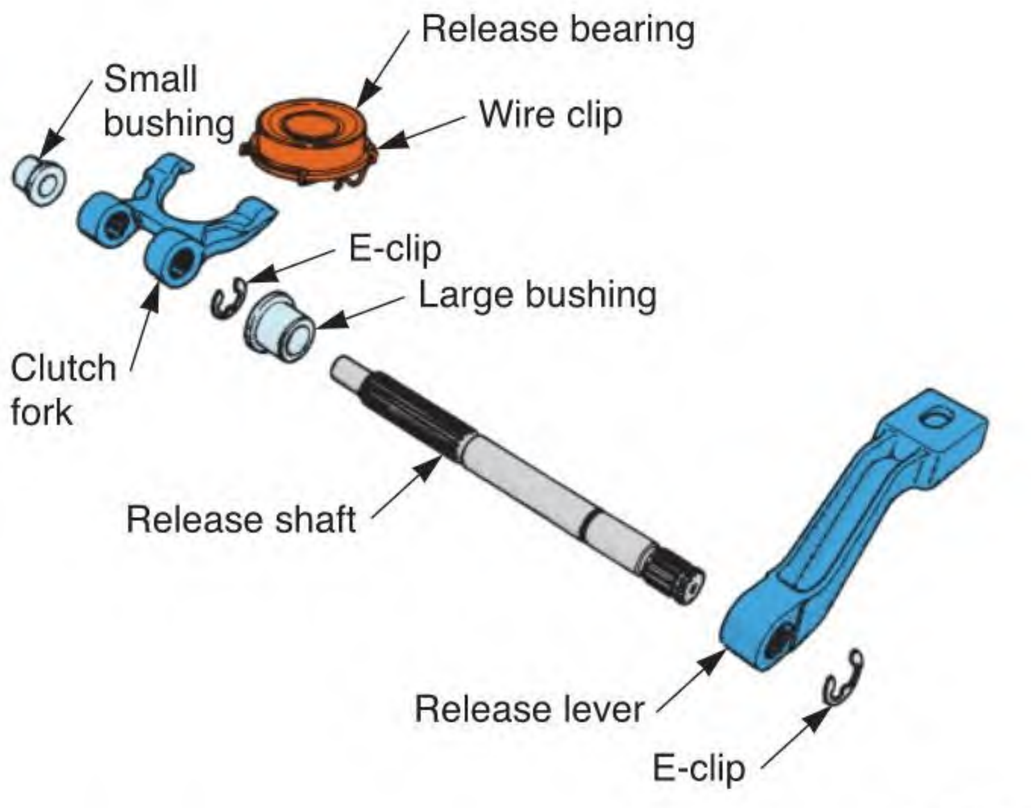
Figure 61-8. A diaphragm spring pressure plate uses a single spring instead of several small coil springs. Pushing in on the center of the spring bends the outer edge away from the drive disc. This releases the clutch disc.

Release Bearing

The release bearing, also called a ***throw-out bearing***, is usually a ball bearing and collar assembly that reduces friction between the pressure plate levers and the clutch fork. The release bearing is a sealed unit packed with grease. It slides on a hub or sleeve extending out from the front of the manual transmission or transaxle. Refer to **Figure 61-9**.

A few vehicles, particularly foreign vehicles, use a graphite throw-out bearing. The ring-shaped block of friction resistant graphite presses on a smooth, flat plate on the clutch release levers.

The throw-out bearing usually snaps over the end of the clutch fork. Small spring clips hold the bearing on the fork (throw-out lever). Then, fork movement in



Chrysler

Figure 61-9. The throw-out bearing acts on the center of the pressure plate. It is an antifriction bearing that cuts down rubbing contact between the clutch fork and the pressure plate. Note other parts that operate this throw-out bearing.

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either direction slides the throw-out bearing along the transmission hub sleeve.

Clutch Housing

The ***clutch housing***, sometimes called a ***bell housing***, bolts to the rear of the engine, enclosing the clutch assembly. It can be made of aluminum, magnesium, or cast iron. The manual transmission bolts to the back of the clutch housing. Look at **Figure 61-10**.

A hole is provided in the side of the clutch housing for the clutch fork. The fork or fork shaft sticks through the housing. A bracket or ball is needed to hold an arm-type fork.

The lower front of the clutch housing usually has a thin, sheet metal cover. It can be removed for flywheel ring gear inspection or when the engine must be separated from the clutch assembly.

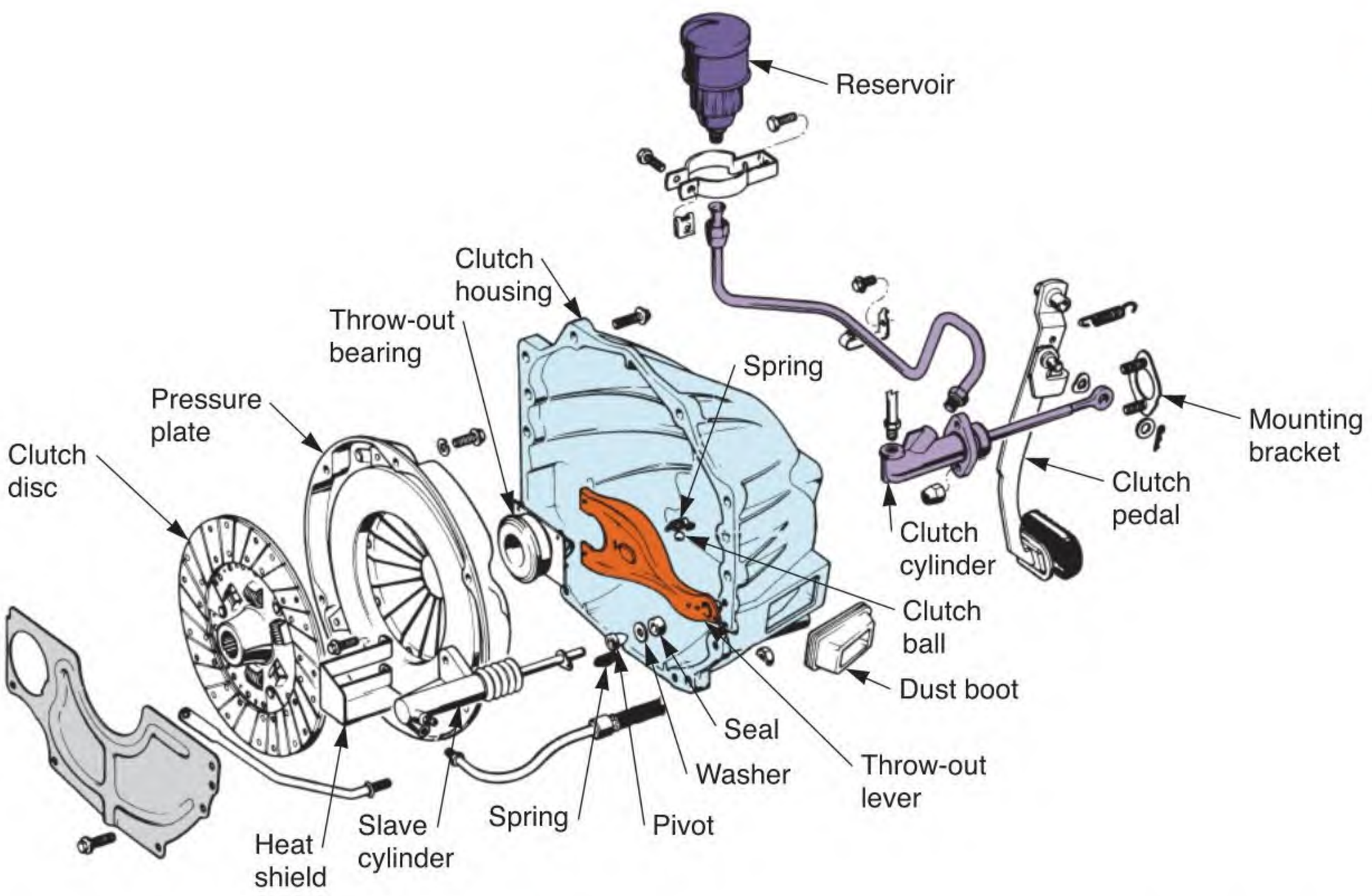
Clutch Fork

The clutch fork, also called a ***clutch arm***, ***throw-out lever***, or ***release arm***, transfers motion from the clutch release mechanism to the throw-out bearing and pressure plate. There are several basic types of clutch forks.

A lever-type clutch fork sticks through a square hole in the bell housing and mounts on a pivot. When moved by the release mechanism, the clutch fork pries on the throw-out bearing to disengage the clutch. See **Figure 61-10**. A rubber dust boot fits over this type of clutch fork to keep road dirt, rocks, oil, water, and other debris from entering the clutch housing.

The second type of clutch fork has a round shaft. When the lever on the outer end of the assembly is moved, the shaft rotates. This swings the fork to push on the throw-out bearing, releasing the pressure plate.

A shaft-type clutch fork has a round shaft that extends through the bell housing and over the pressure plate release levers. When the lever on the outer end of the assembly is moved, the shaft rotates. This swings the clutch fork to slide the throw-out bearing into the revolving pressure plate, releasing the pressure plate. In a motor-generator, this allows the friction disc to stop revolving even with the engine running to generate electricity for hybrid propulsion.



Chrysler

Figure 61-10. This diaphragm clutch is operated by a hydraulic release mechanism (slave cylinder). When the driver presses the clutch pedal, the clutch master cylinder develops pressure in the system. Pressure actuates the slave cylinder piston and operates the clutch fork to release the clutch.

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Clutch Release Mechanisms

A clutch release mechanism allows the driver to operate the clutch. Generally, it consists of the clutch pedal assembly (mechanical linkage, a cable, or a hydraulic circuit) and the clutch fork. Many manufacturers include the throw-out bearing as part of the clutch release mechanism.

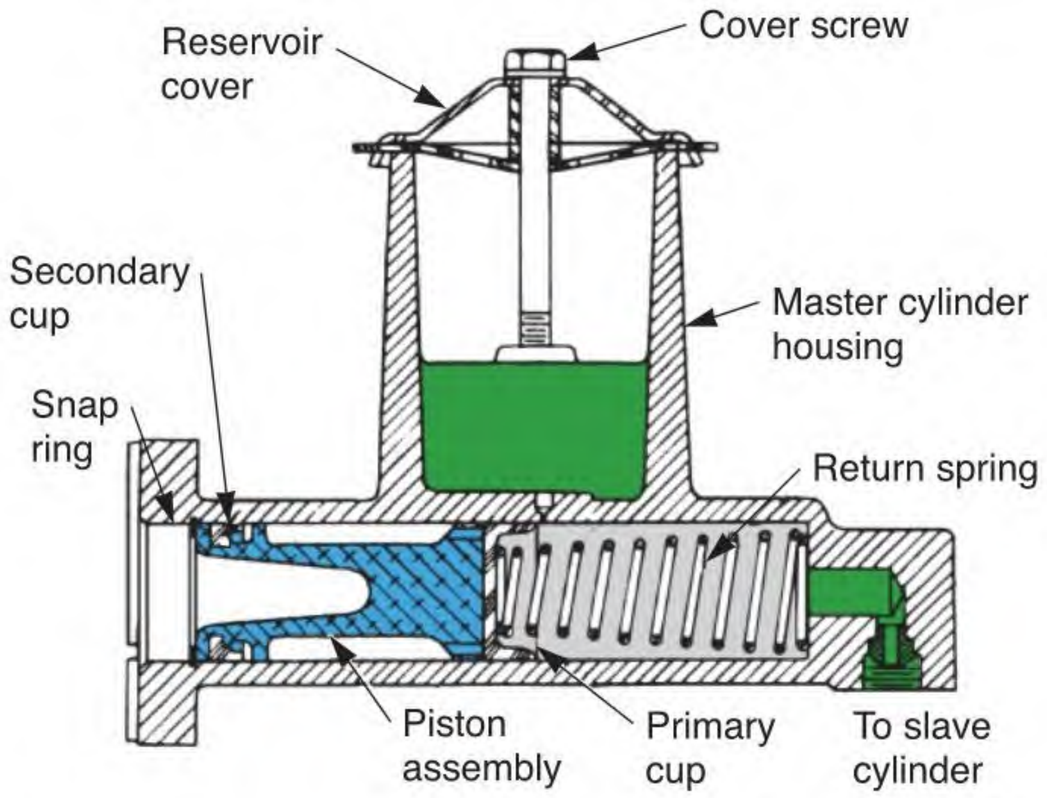
Hydraulic Clutch Release Mechanism

A ***hydraulic clutch release mechanism*** uses a simple hydraulic circuit to transfer clutch pedal action to the clutch fork. It has three basic parts: clutch cylinder, hydraulic line, and slave cylinder. Refer to **Figure 61-10**.

The ***clutch cylinder***, sometimes called the ***clutch master cylinder***, produces the hydraulic pressure for the system. It contains a piston mounted in a cylinder. The piston has rubber cups that produce a leakproof seal between the piston and cylinder wall. Look at **Figure 61-11**.

A fluid reservoir is mounted above or on top of the clutch cylinder to hold extra fluid. Most hydraulic clutch systems use brake fluid as the medium for pressure transfer. A cap and seal are threaded onto the reservoir to keep fluid from leaking out and to keep road dirt and water from entering the system.

The clutch cylinder usually mounts on the firewall. A push rod links the clutch pedal and the cylinder piston. When the clutch pedal is pressed, the push rod moves the piston to produce pressure in the cylinder.



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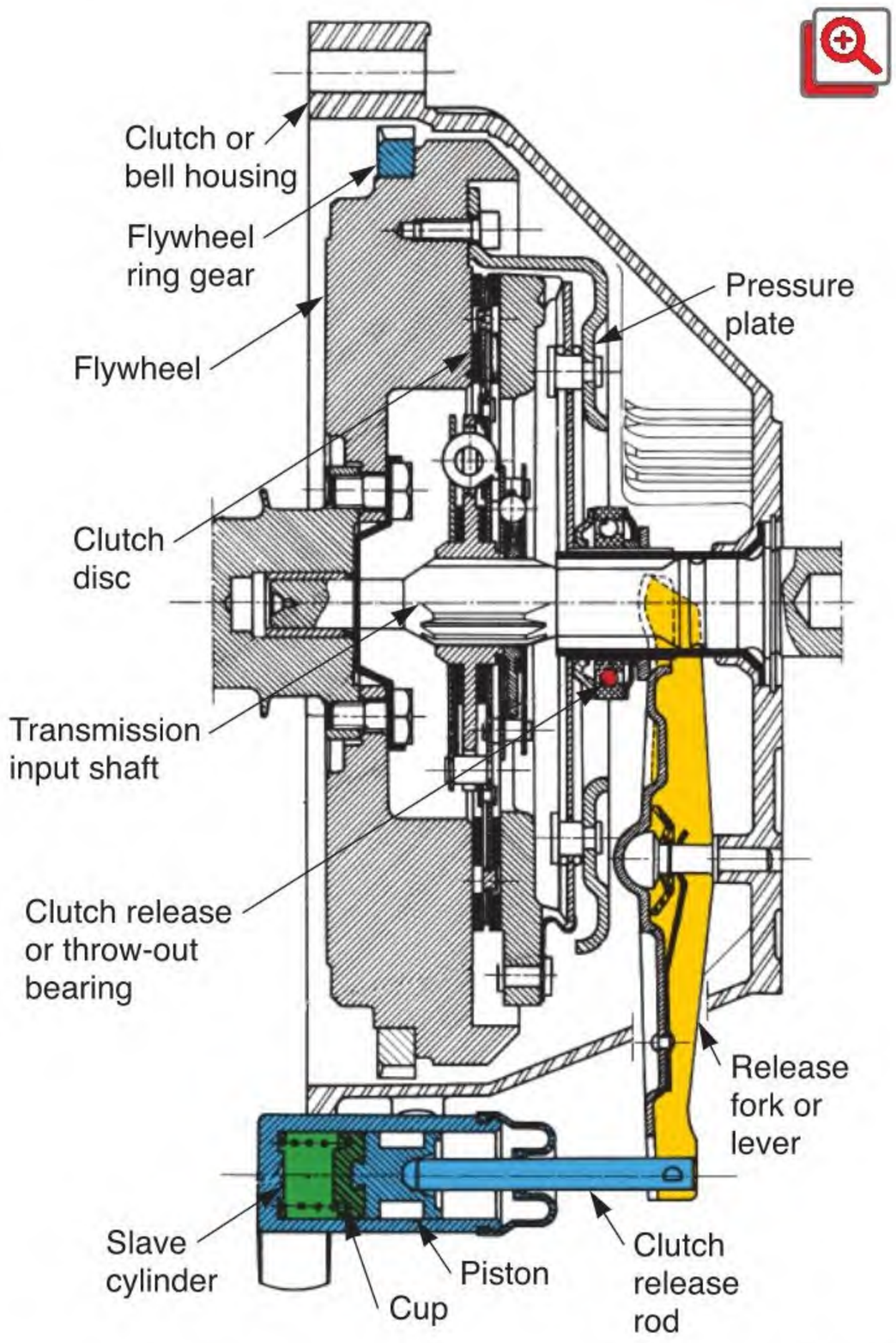
Figure 61-11. Cutaway view shows the inside of a clutch master cylinder. The clutch pedal and linkage push the piston and cup into the cylinder, producing hydraulic pressure.

The ***hydraulic line*** is an assembly comprised of rubber hose and metal tubing that moves high-pressure fluid from the clutch cylinder to the slave cylinder. When pressure is produced in the clutch cylinder, fluid flows through the hydraulic line.

The ***slave cylinder*** uses the system's hydraulic pressure to cause clutch fork movement. It contains a piston assembly inside a cylinder. When the master cylinder forces fluid into the slave cylinder, pressure pushes the piston outward, as in **Figure 61-12**.

Hydraulic Clutch Action

When the clutch pedal is depressed, linkage pushes on the piston in the clutch cylinder. A check valve in the clutch cylinder keeps fluid from entering the reservoir. As a result, fluid flows into the hydraulic line and slave cylinder. Pressure forms in the system and the slave cylinder piston is pushed outward. The



Peugeot

Figure 61-12. The slave cylinder releases this clutch. Pressure from the master cylinder enters the slave cylinder, moving the small piston toward the clutch fork. Study the other components.

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slave cylinder piston and push rod then act on the clutch fork to disengage the clutch.

When the clutch pedal is released, a spring on the clutch pedal pulls it back. Other springs inside the two cylinders push the pistons back into their retracted positions. Brake fluid flows back through the line and into the reservoir through the check valve.

Clutch Linkage Mechanism

A ***clutch linkage mechanism*** uses levers and rods to transfer motion from the clutch pedal to the clutch fork. When the pedal is pressed, a push rod shoves on the bellcrank. One arrangement is shown in **Figure 61-13**.

The ***bellcrank*** reverses the forward movement of the clutch pedal. The other end of the bellcrank is connected to a ***release rod***. The release rod transfers bellcrank movement to the fork and usually provides a method of adjustment.

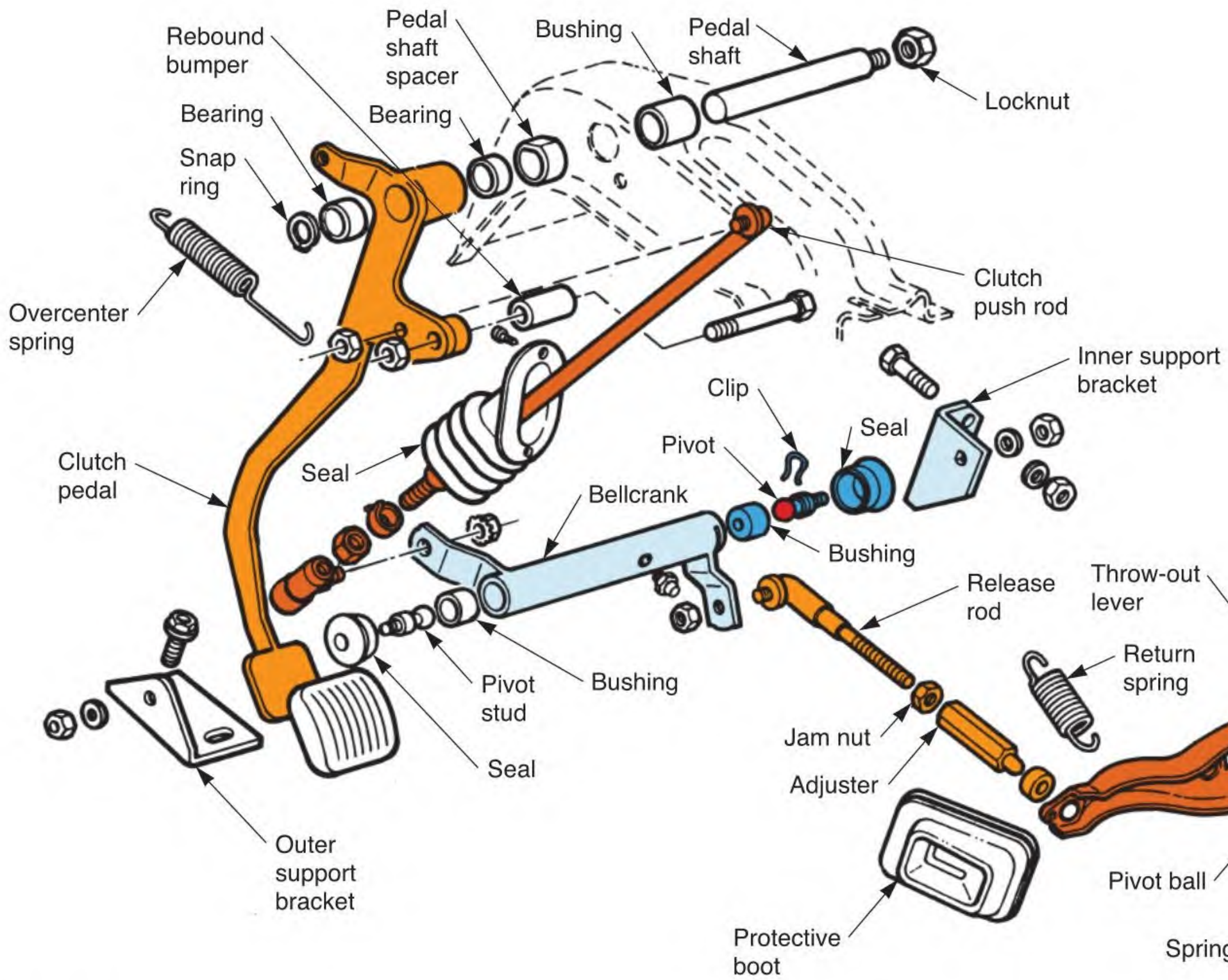
Clutch Cable Mechanism

A ***clutch cable mechanism*** uses a steel cable inside a flexible housing to transfer pedal movement to the clutch fork. This is a simple mechanism, as shown in **Figure 61-14**. The cable is usually fastened to the upper end of the clutch pedal. The other end of the cable connects to the clutch fork. The cable housing is mounted in a stationary position. This causes the cable to slide inside the housing whenever the clutch pedal is moved.

When the clutch pedal is depressed, the cable pulls on the clutch fork to disengage the clutch. When the clutch pedal is released, a strong spring pulls back on the pedal, cable, and fork to engage the clutch. One end of the clutch cable housing usually has a threaded sleeve for clutch adjustment.

Automatic Clutch Adjuster

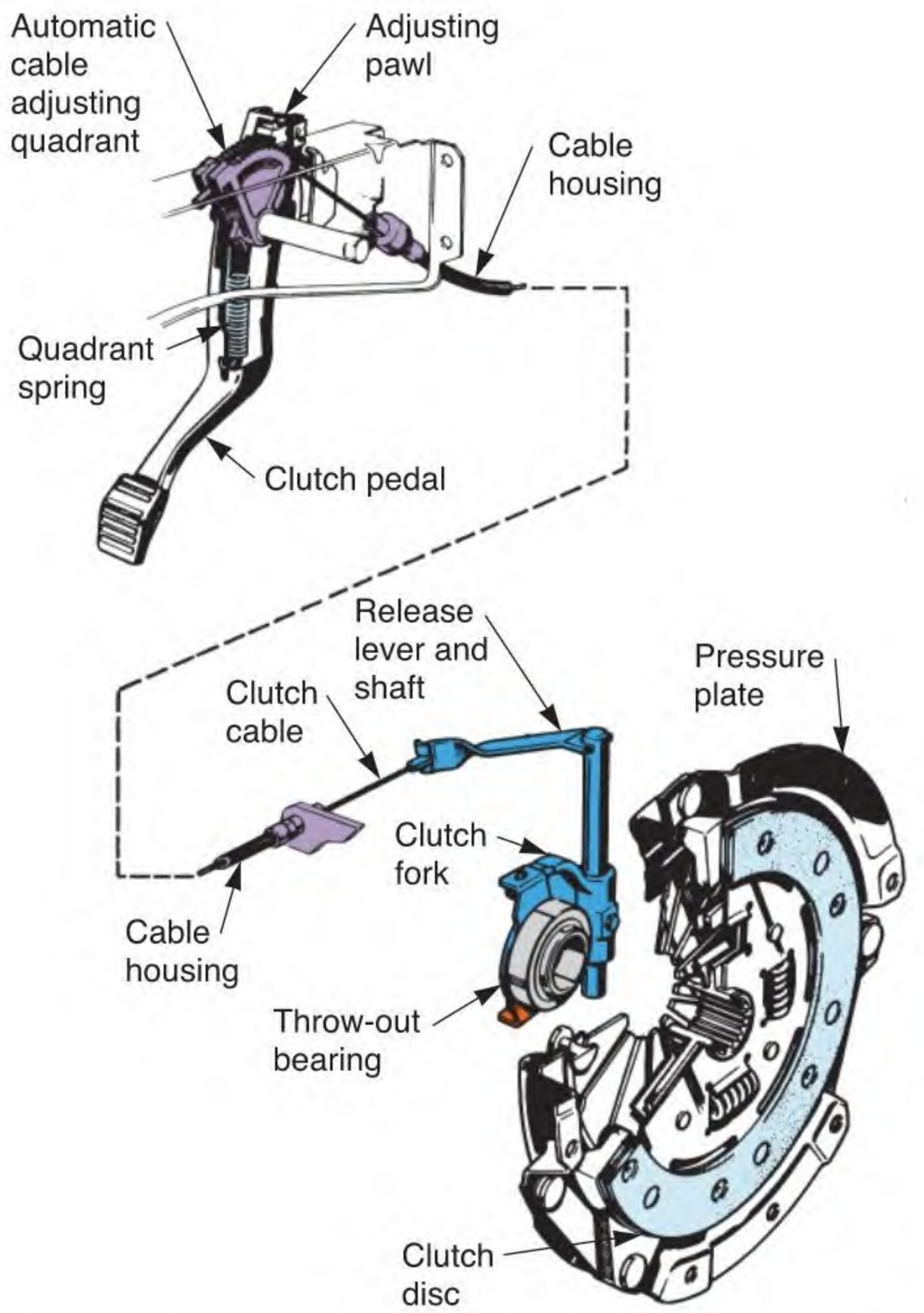
An ***automatic clutch adjuster*** removes play from the clutch cable as components wear. The clutch



Chrysler

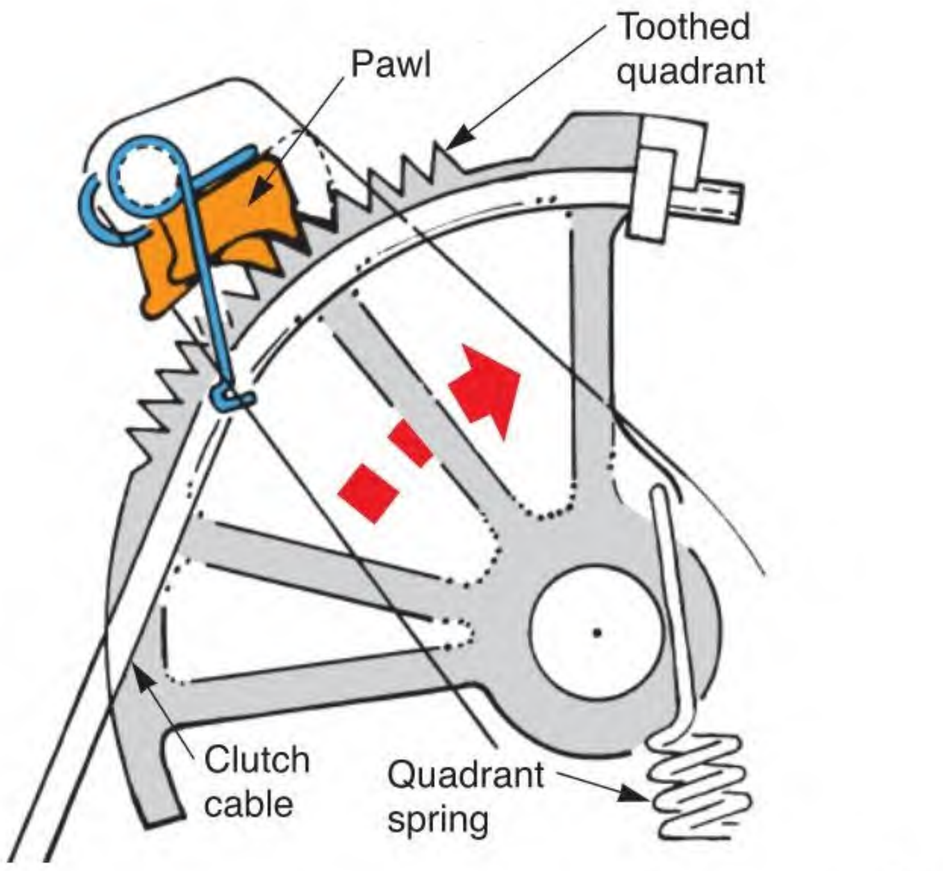
Figure 61-13. Clutch linkage release mechanism. Arms and rods transfer clutch pedal action to clutch fork.

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Ford

Figure 61-14. Clutch cable mechanism. Steel cable runs through stationary housing. When the clutch pedal is pressed, the cable slides in the housing to operate the release lever and throw-out bearing. Also note automatic cable adjuster on foot pedal assembly.



Ford

Figure 61-15. Automatic clutch cable adjusting device. With excess slack in the cable, the pawl ratchets over teeth on the quadrant. This takes up play in the cable as parts wear.

pedal has a quadrant and pawl device. A spring inside the quadrant applies light tension on the cable to take up extra slack.

When the clutch is applied, the pawl locks into one of the quadrant teeth and the clutch cable is activated. If there is too much play in the cable, the pawl will ratchet over the quadrant teeth when the clutch pedal is released. This positions the pawl in another quadrant tooth and takes up any slack in the clutch cable, **Figure 61-15**.

Clutch Start Switch

The ***clutch start switch*** prevents the engine from cranking (starting motor operation) unless the clutch pedal is depressed. It serves as a safety device that keeps the engine from starting while in gear. The clutch start switch is usually mounted on the clutch pedal assembly.

Wires from the ignition switch feed starter solenoid current through the clutch start switch. Unless the switch is closed (clutch pedal depressed), the switch prevents current from reaching the starter solenoid.

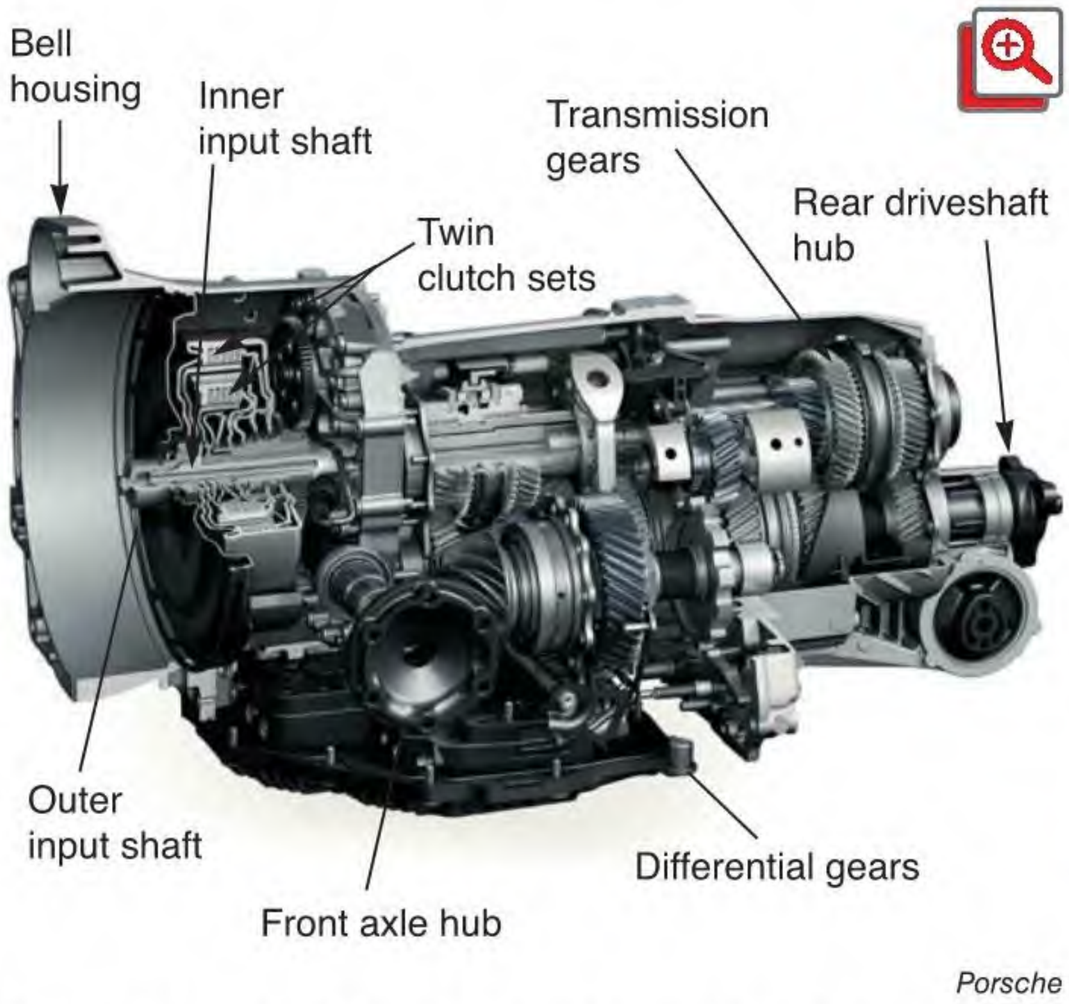
When the transmission is in neutral, the clutch pedal switch is usually bypassed so that the engine will crank and start.

Automatic Manual Clutch

An ***automatic manual clutch*** requires the driver to press electric steering wheel-mounted shift buttons or a console shift lever to change gears manually. New high-performance cars usually incorporate manual transmissions with computer-controlled dual wet clutches to engage each set of transmission gears without an interruption in power flow. A dual wet clutch on the front of a high performance twin-input shaft transmission is shown in **Figure 61-16**.

A ***dual-clutch transmission*** has two input shafts, a solid steel shaft inside a hollow steel shaft. When gear ratios are changed, one clutch disengages as the other clutch engages without an interruption of power flow. With twin clutches and dual input shafts, the engine or motor-generator power is not interrupted during gear changes. Full engine power is applied to the driveline as each gearset is engaged.

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Porsche

Figure 61-16. Twin clutch manual transmission. Note the use of twin wet clutches between a high-performance engine and a high power-handling helical gear transaxle. Also note the two input shafts entering the transaxle gear case and three output shafts for all-wheel drive.

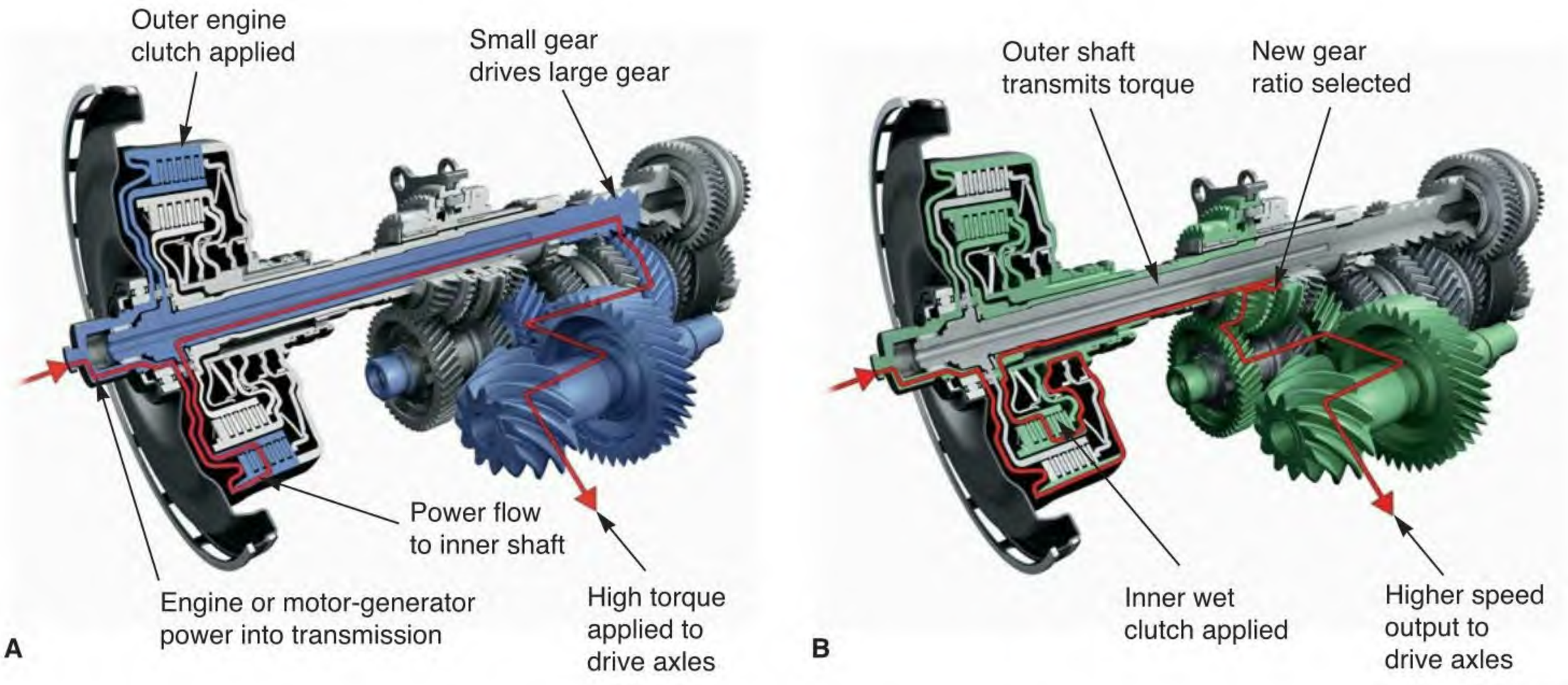
Since engine power output is not temporarily reduced during gear changes, a dual-clutch system provides both faster acceleration and improved fuel economy. The engine can then be kept closer to its optimum rpms for maximum power and combustion efficiency. The motor-generator can also be kept at optimum rpms for maximum thermal and electrical efficiency. Study **Figure 61-17**.

Some vehicles with electronically shifting transmissions are totally computer controlled. Many factors allow the engine, motor-generator, and transmission control modules to shift gears more quickly for better fuel economy and improved tire traction. For example, a high-performance transmission with helical gearsets has movable gear engagement cogs or synchronizing rings to lock each helical gear ratio to its output shaft. The driver can select a transmission ratio for the speed of the vehicle. An all-wheel drive system with a dual-clutch, input shaft transaxle is shown in **Figure 61-18**.

Hybrid Vehicle Clutch

The clutch in a hybrid vehicle is a device for connecting and disconnecting crankshaft torque to and from the transmission (or transaxle) and motor-generator. Study **Figures 61-19** and **61-20**.

With modern hybrid vehicle drivelines, the gas engine is shut off when the vehicle is coasting, during electric drive, and during regenerative braking to save fuel. With a single input shaft going from the clutch into the transmission, motor-generator and engine power must be temporarily interrupted. Power flow must be stopped for a fraction of a second to shift and engage progressively lower ratio gearsets during vehicle acceleration. Power flow is also interrupted



Porsche

Figure 61-17. Study how twin clutches function with a twin-input shaft transmission or transaxle.

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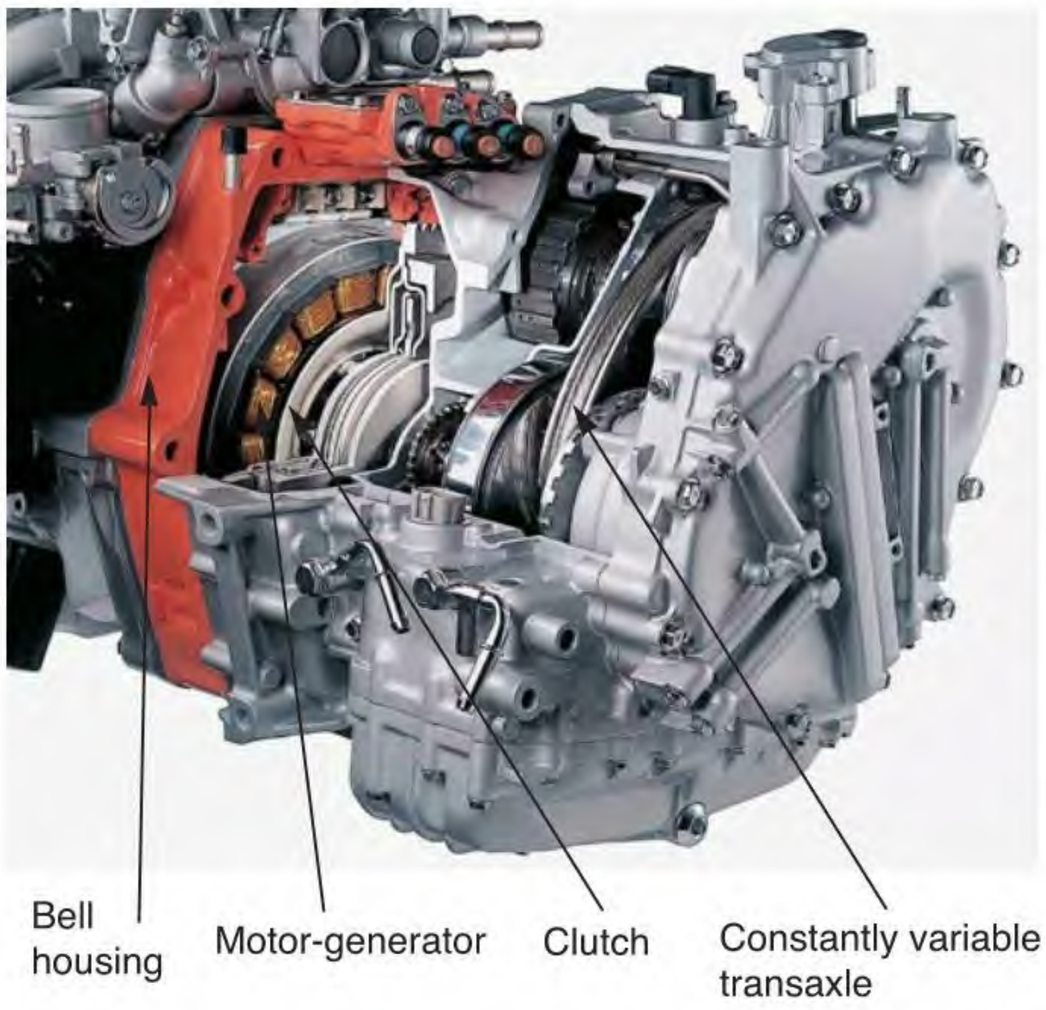
Audi

Figure 61-18. A high-performance V-8 engine is coupled to an all-wheel drive transaxle with twin engine clutches for high-speed gear shifting without slippage.

when changing from traction motor propulsion to battery recharge and gas engine propulsion.

Hybrid Vehicle Wet Clutch

A hybrid vehicle with a wet clutch uses two wet clutches to control power flow into and out of the motor-generator. Often mounted inside the large diameter motor-generator, wet clutches are splined to the engine crankshaft and to the motor-generator armature. If both clutches are engaged, the engine and the motor-generator are locked to the drive train for propulsion. Either of the wet clutches can be disengaged for all-electric or gas engine-only propulsion. Study **Figure 61-21**.



Honda

Figure 61-19. Note the location of the clutch on this hybrid engine. Since the motor-generator armature is bolted directly to the crankshaft flange, the clutch cannot disengage the engine from the motor-generator—just both from the transmission input shaft for stopping the vehicle.

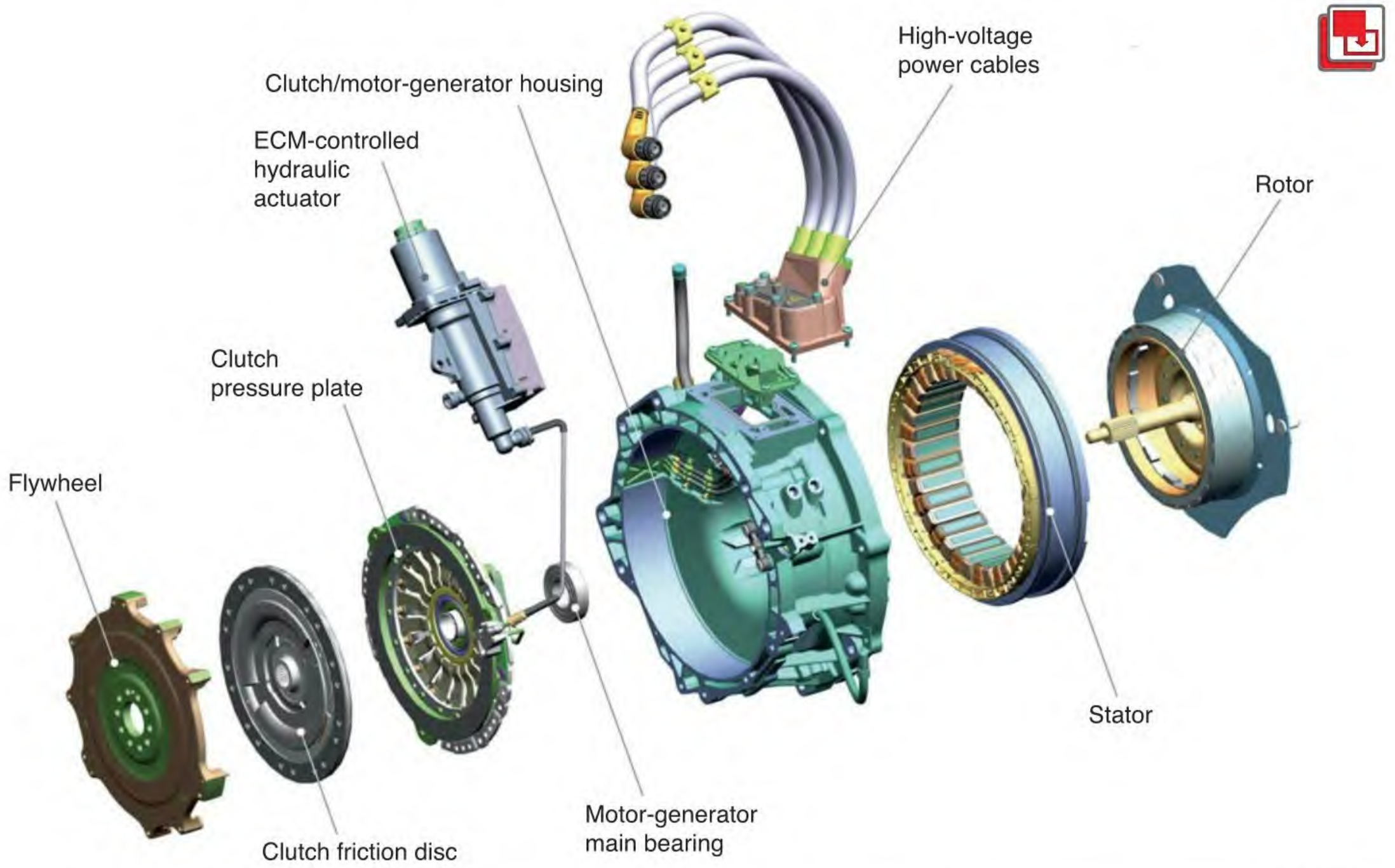
Hybrid Power Splitter

A hybrid ***power splitter*** is a planetary gearset used to control the transfer of power through some hybrid drive trains. The hybrid power splitter and transaxle are under computer control. The transmission control module can energize solenoids to control fluid flow to the wet clutches. The wet clutches can be applied or released to engage the proper gearset for engine and motor-generator power flow control by the vehicle driver. Study **Figure 61-22**.

When the driver moves the gearshift selector in the passenger compartment, an electric signal is sent from the shift lever position sensor to the hybrid control module. The hybrid control module then energizes or shuts off specific solenoids in the transaxle. The solenoids can apply or release friction bands and clutches to hold or release members of the power splitter. By holding or releasing different parts of the power splitter, the solenoids control the planetary gearset(s) and the flow of torque from both the internal combustion engine and the electric drive system.

When a motor-generator is operating as a generator, the splitter can transfer driveline torque into the

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Volkswagen

Figure 61-20. Study the parts in this exploded view of a clutch formed as an integral part of a motor-generator assembly. Gas engine power in the form of torque is fed into the flywheel. The spinning engine flywheel then transfers power into the transmission and/or into the motor-generator for HV battery recharging. If energized into a traction motor, the motor-generator can also transmit hundreds of additional pounds of torque to add to engine horsepower for even more rapid acceleration to highway speeds.

motor-generator armature during braking or coasting. The engine crankshaft is connected to a shaft running through the front motor-generator and into the planetary gearset. The planet gearset carrier is splined to the engine crankshaft. The planet ring gear is connected to the front motor-generator armature. The rear motor-generator is connected to the front motor-generator and to a reduction gear mechanism.

Workplace Skills

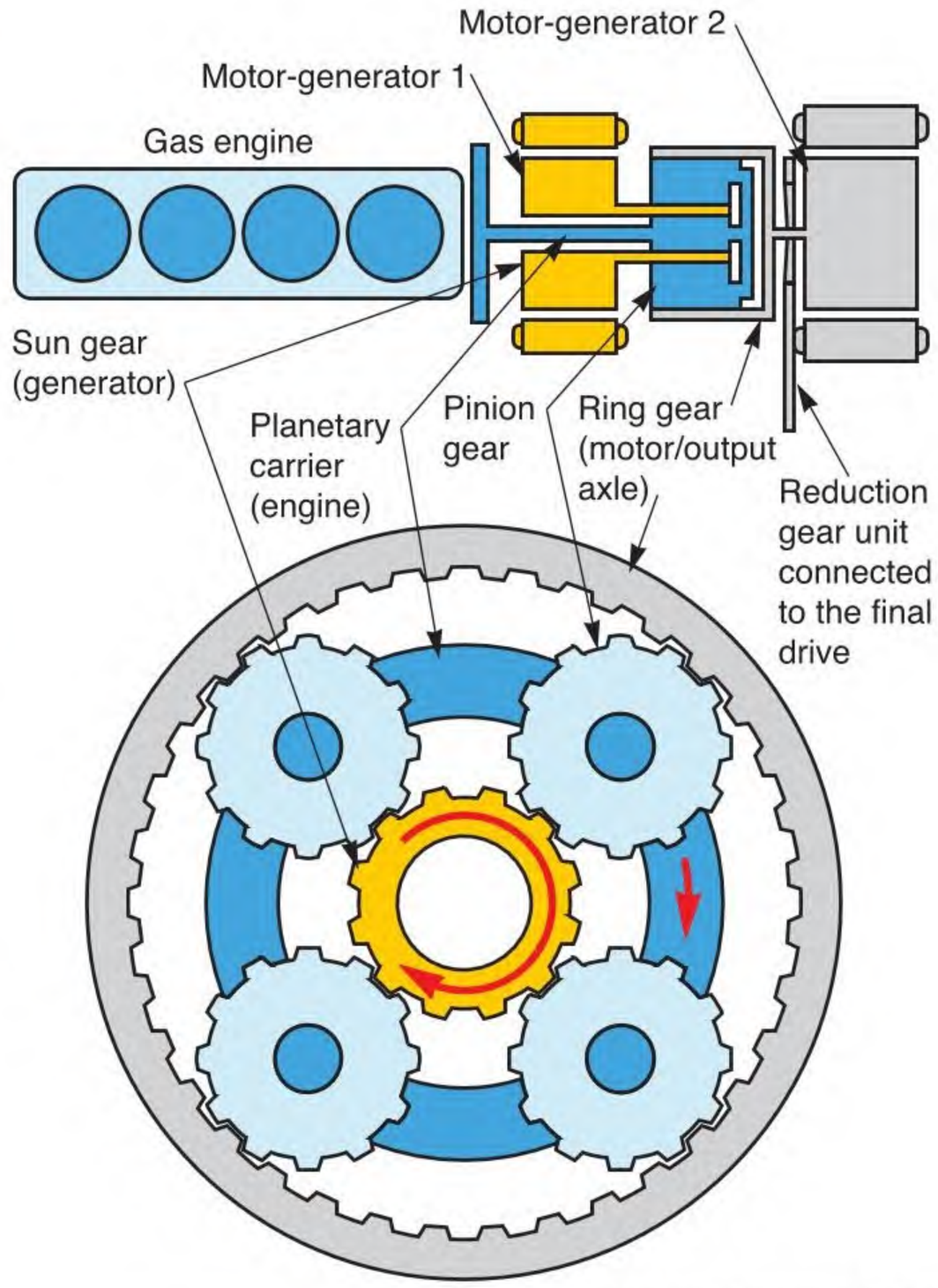
Always conduct yourself with professionalism. Professionals are customer oriented. They keep up-to-date with vehicle and product developments, and know that vehicle safety and integrity depend on quality repair. Professional technicians pay attention to detail and make sure their work meets specifications. True professionals take the time to become ASE-certified and strive to improve their skills by participating in trade associations. Lastly, professional technicians keep their tools clean and organized and help other technicians when needed.

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General Motors

Figure 61-21. Note how the power splitter or wet clutches and planetary gearset are mounted compactly inside the stationary magnetic field of electric propulsion motor-generator. If one set of clutches is engaged, the motor-generator can spin the engine for starting. It could also be spun by the engine for HV battery charging. When the HV battery is fully charged, the motor-generator clutch set is locked to the armature shaft for all-electric propulsion with the gas engine shut off. Also note the large helical cut transmission and differential drive gears in this hybrid transmission.



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Figure 61-22. Many early-model hybrids use a simple planetary gearset as a power splitter between the gas engine and the electric traction motor (motor-generator). Wet clutches and friction bands can be applied to engage each or both propulsion motors and/or the gas engine for vehicle propulsion.

Summary

- An automotive clutch is used to connect and disconnect the engine and manual (hand-shifted) transmission or transaxle.
- A wet clutch does not slip and is more energy efficient than a fluid coupling or torque converter.
- The major parts of an automotive clutch include the clutch release mechanism, clutch fork, release bearing, pressure plate, clutch disc, flywheel, and pilot bearing.
- When the driver presses the clutch pedal, the clutch disc is released from the flywheel. When the clutch pedal is released by the driver, the input of the flywheel, disc, pressure plate, and transmission are locked together.
- The clutch housing, sometimes called a bell housing, bolts to the rear of the engine, enclosing the clutch assembly.
- An automatic manual clutch requires the driver to press electric steering wheel-mounted shift buttons to change gears manually.
- In a dual-clutch transmission, one clutch disengages as the other clutch engages without an interruption of power flow.
- The clutch in a hybrid vehicle is a device for connecting and disconnecting crankshaft torque from the transmission or transaxle and motor-generator.
- A hybrid vehicle with a wet clutch uses two wet clutches to control power flow into and out of the motor-generator.

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Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

automatic clutch adjuster
automatic manual clutch
automotive clutch
bell housing
bellcrank
clutch arm
clutch cable mechanism
clutch cylinder
clutch disc
clutch fork
clutch housing
clutch linkage mechanism
clutch master cylinder
clutch release mechanism
clutch start switch
coil spring pressure plate
cushioning springs
damping springs
diaphragm spring
diaphragm spring pressure plate
disc lining
dual-clutch transmission
facing
facing springs
flywheel
friction disc
friction material
hydraulic clutch release mechanism
hydraulic line
motor-generator clutch
pilot bearing
pilot bushing
pivot ring
power splitter
pressure plate
pressure plate cover
pressure plate face
pressure plate release levers
release arm
release bearing
release rod
semi-centrifugal pressure plate
slave cylinder
throw-out bearing
throw-out lever
torsion springs
wet clutch

Activities

1. Identify principles of fluids that underlie the operation of a hydraulic clutch; explain its operation to the class.
2. Sketch out a simple clutch, label its parts, and explain its operation.

Review Questions

Answer the following questions using the information provided in this chapter.

1. An automotive _____ connects and disconnects the engine and manual transmission or transaxle.
2. What is the benefit of a wet clutch?
3. List and explain the seven basic parts of an automotive clutch.
4. Describe what happens when the driver presses the clutch pedal and what happens when the pedal is released.
5. Clutch disc _____ springs help absorb some of the vibration and shock produced by clutch engagement.
6. The pressure plate is a spring-loaded device that can either lock or unlock the clutch disc and the flywheel. True or False?
7. What is the main purpose of the pressure plate cover?
8. The clutch housing, or bell housing, is made of:
   (A) aluminum.
   (B) magnesium.
   (C) cast iron.
   (D) All of the above are correct.
9. Explain clutch fork action.
10. A(n) _____ uses a simple hydraulic circuit to transfer clutch pedal action to the clutch fork.
11. What is the function of an automatic clutch adjuster?
12. The clutch start switch allows the engine to crank even if the clutch pedal is not depressed. True or False?
13. Describe the operation of a dual-clutch transmission.
14. What is the function of a clutch in a hybrid vehicle?

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ASE-Type Questions

1. Technician A says an automotive clutch connects and disconnects the engine and drive shaft. Technician B says an automotive clutch connects and disconnects the engine and torque converter. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Technician A says a clutch fork is a linkage that allows the driver to disengage the clutch by pressing down on the foot pedal. Technician B says a clutch fork is a lever that forces the release bearing into the pressure plate. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. Technician A says a pilot bearing is a bushing that supports the forward end of the transmission input shaft. Technician B says a pilot bearing is a bushing that reduces friction between the clutch fork and pressure plate. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. While discussing the functions of a pressure plate, Technician A says the purpose of a pressure plate is to press the pilot bearing against the engine's flywheel. Technician B says the pressure plate is used to press the clutch disc against the engine's flywheel. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. Technician A says the clutch disc is bolted to the transmission input shaft. Technician B says the clutch disc is splined to the transmission input shaft. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Technician A says a pilot bearing is normally an aluminum bushing. Technician B says a pilot bearing is usually a solid bronze bushing. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. Which of the following is another name for an automotive clutch disc?
   (A) Throw-out plate.
   (B) Friction disc.
   (C) Pressure plate.
   (D) None of the above.
8. Technician A says clutch disc torsion springs are used to fasten the clutch disc to the transmission input shaft. Technician B says clutch disc torsion springs help absorb some of the vibration produced by clutch engagement. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Which of the following is another name for a "throw-out bearing?"
   (A) Pilot bushing.
   (B) Fork bushing.
   (C) Release bearing.
   (D) Pressure plate hub.
10. Technician A says an automobile's clutch housing is sometimes made of aluminum. Technician B says an automobile's clutch housing is sometimes made of cast iron. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
11. Technician A says a dual-clutch transmission has twin clutches and dual input shafts. Technician B says a dual-clutch system provides both faster acceleration and improved fuel economy. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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12. Technician A says the wet clutches in a hybrid vehicle are splined to the engine crankshaft and to the motor-generator armature. Technician B says both of the wet clutches must be disengaged for all-electric or gas engine-only propulsion. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Chapter 62
Clutch Diagnosis, Service, and Repair

After studying this chapter, you will be able to:

- Troubleshoot common clutch problems.
- Describe symptoms of typical clutch troubles.
- Adjust a clutch.
- Remove, repair, and install a clutch.
- Inspect clutch parts for wear and damage.
- Service the clutch in a hybrid engine/motor-generator.
- Cite safety rules and demonstrate safe work procedures.
- Correctly answer ASE certification test questions on clutch diagnosis and repair.

An automotive technician must be able to quickly and accurately diagnose and repair clutch problems. Simply replacing parts is not sufficient. A technician must know why the old clutch failed. If she or he installs new parts without properly diagnosing the cause of the failure, the new parts could also fail in a short period of time. With today's hybrid drive trains, you must also know how to diagnose automated clutch release and automatic manual gear change mechanisms under computer control.

This chapter will help develop the skills needed to service automotive clutches. It will also provide you with the background needed to use a service manual properly.

Diagnosing Clutch Problems

An automobile clutch normally provides dependable service for thousands of miles. However, the service life of clutch components varies greatly from vehicle to vehicle. One vehicle's clutch might last 100,000 miles, while another's could fail in only 50,000 miles. See **Figure 62-1**.

Stop-and-go driving will wear out a clutch quicker than highway driving. Every time the clutch is engaged, the clutch disc and other components are subjected to considerable friction, heat, and wear. Driver abuse commonly causes premature clutch trouble, as well. For instance, "riding the clutch" (slipping the clutch or resting a foot on the clutch pedal while driving) and "speed shifting" (shifting gears without letting off the gas) can cause early clutch failure.

Verify the Clutch Problem

After talking to the service writer or the customer about the problem, verify the complaint. Test-drive the vehicle and make your own decisions about the

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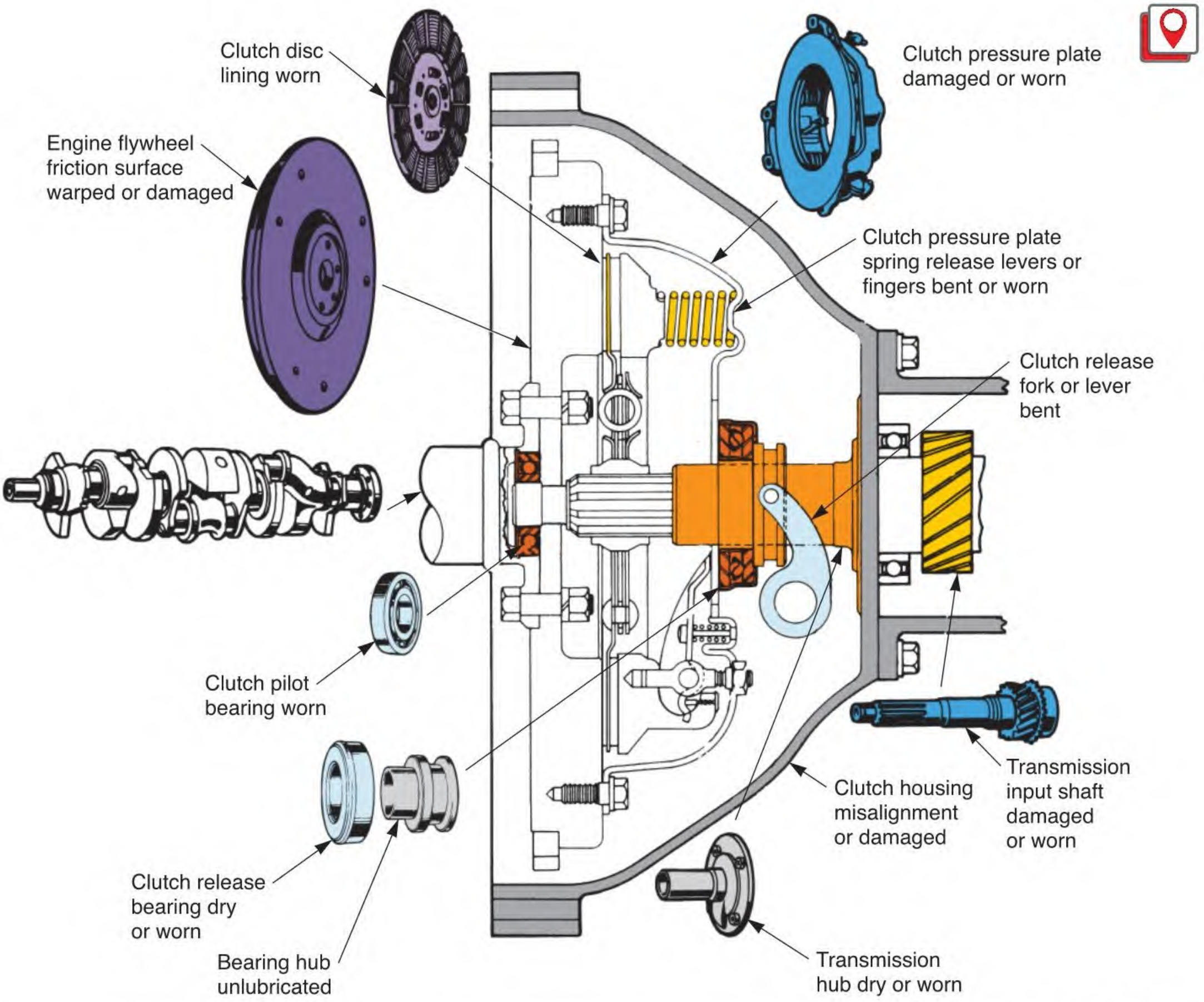


Figure 62-1. Some typical problems that can develop in a clutch. Keep these problems in mind during further discussion of clutch diagnosis and repair.

clutch troubles. Gather as much information as you can. Check the action of the clutch pedal. Listen for unusual noises. Feel for clutch pedal vibrations.

Use this information, your knowledge of clutch operating principles, and a service manual trouble-shooting chart to decide which components are at fault. You must determine whether the clutch failure was due to normal wear, improper driving techniques, incorrect clutch adjustment, or other problems.

Common Clutch Part Failures

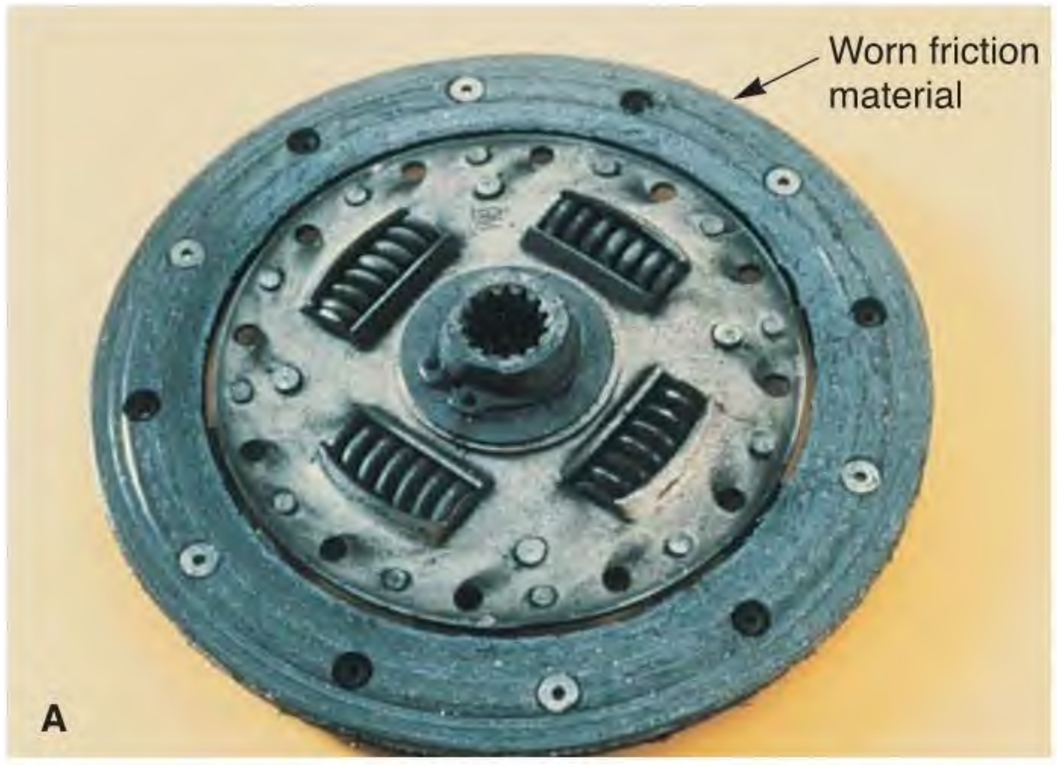
Damaged or worn clutch parts can cause a variety of clutch problems: slipping, grabbing, dragging, abnormal noises, and vibration. It is important to know the symptoms produced by these problems and the parts that might be the cause.

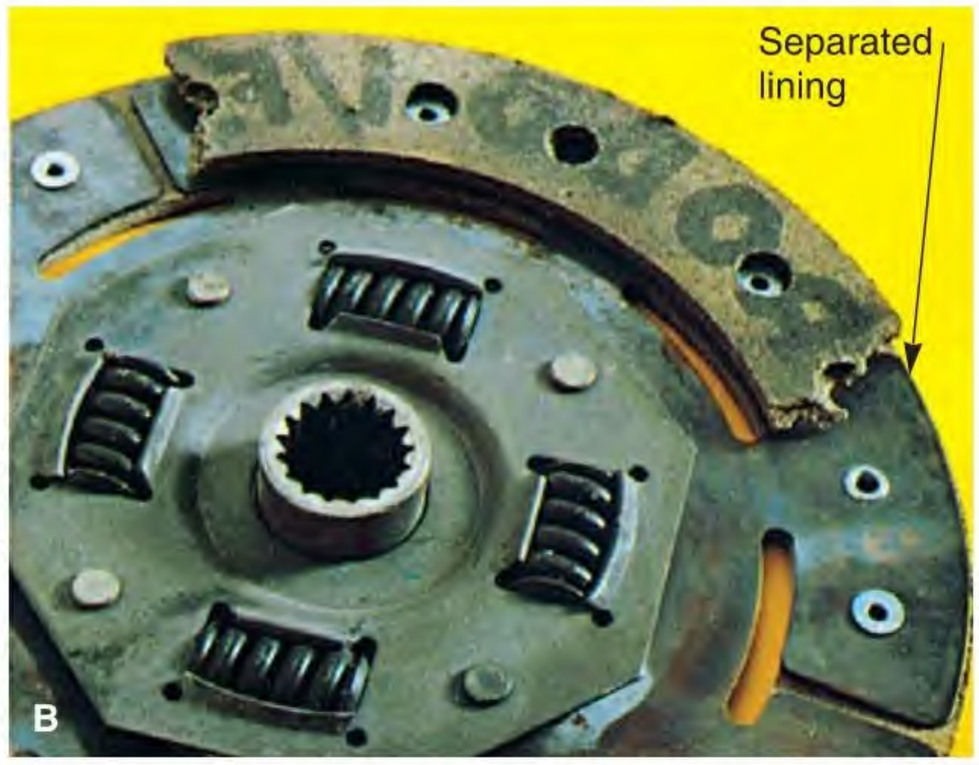
A worn clutch disc will cause clutch slippage and, sometimes, damage to the flywheel and pressure plate. See **Figure 62-2**.

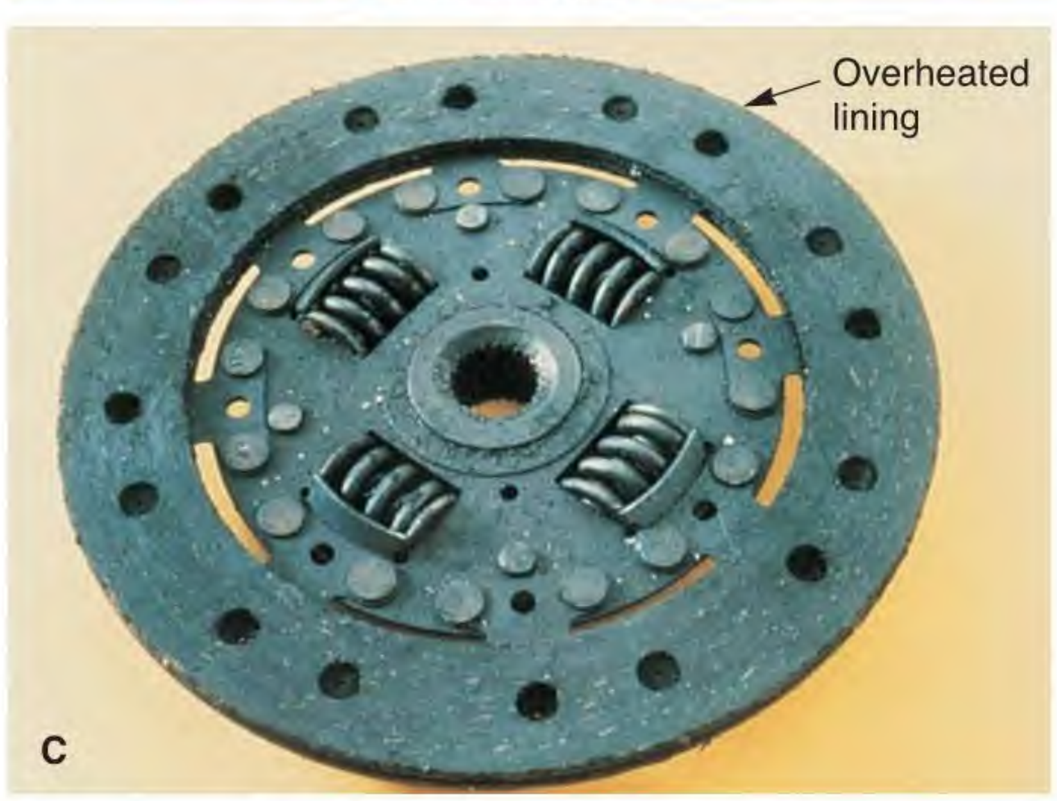
An overheated flywheel can have surface cracks and hardened or warped areas that degrade clutch operation. Cracks in the surface of a flywheel can cause rapid clutch disc wear. If the flywheel is warped, the clutch may grab or vibrate upon acceleration.

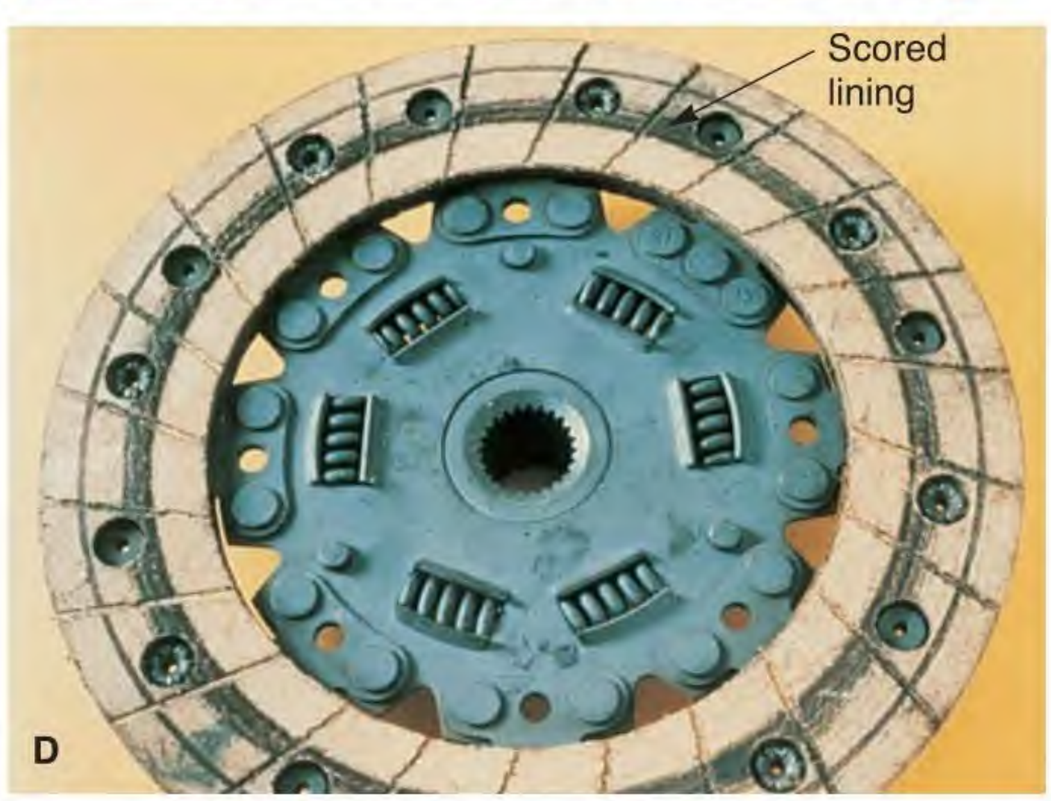
A bad throw-out bearing will produce a grinding noise whenever the clutch pedal is pushed down. The roller bearings may be dry (out of grease). See **Figure 62-3**.

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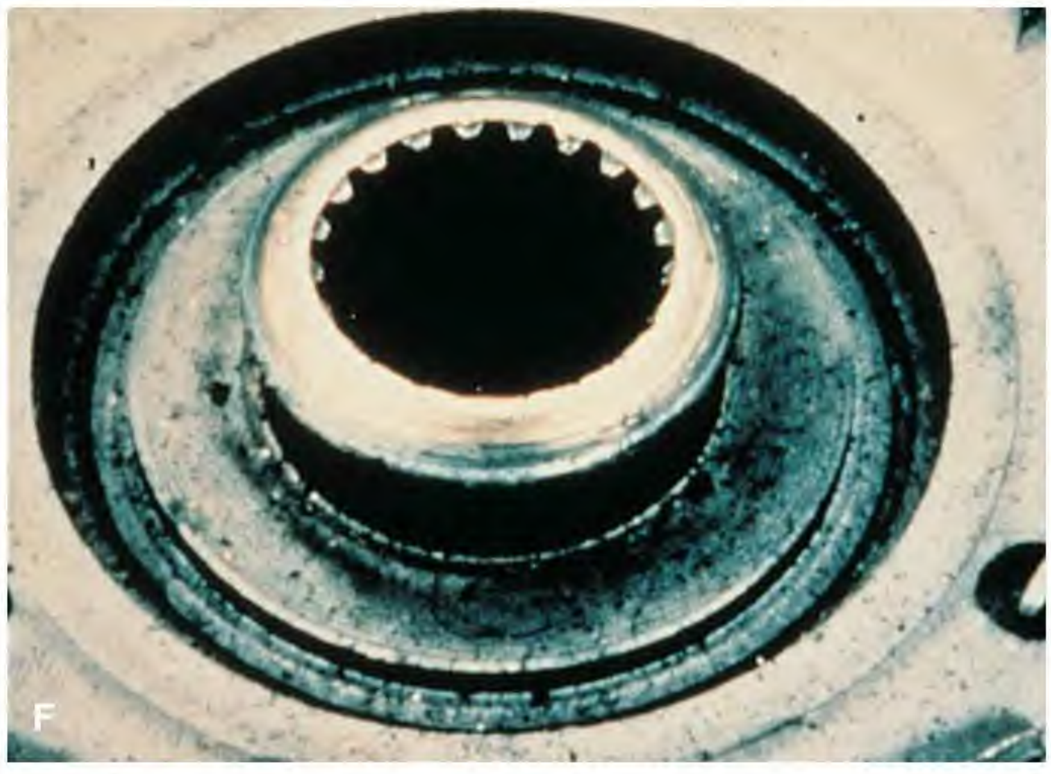












LuK

Figure 62-2. Study clutch disc problems and their causes. A—This clutch disc has worn friction material from extended use, a slipping clutch, or weak pressure plate springs. B—This clutch disc exploded from high-speed shifts. Note how friction material has fallen off the disc. This clutch slipped so badly that the vehicle would not move. C—Clutch friction material has been overheated and burned because of oil contamination, not enough release mechanism clearance, or from the driver riding the clutch pedal. D—This clutch disc has scored friction material from an unmachined flywheel or the reuse of a badly scored pressure plate. E—Friction disc hub splines were badly damaged when the transmission was drawn into place with bolts. The transmission input shaft was forced through the splines. F—Clutch disc hub wear was caused by installing the disc backward. The metal hub rubbed on the flywheel and held the friction material away from the flywheel.

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A



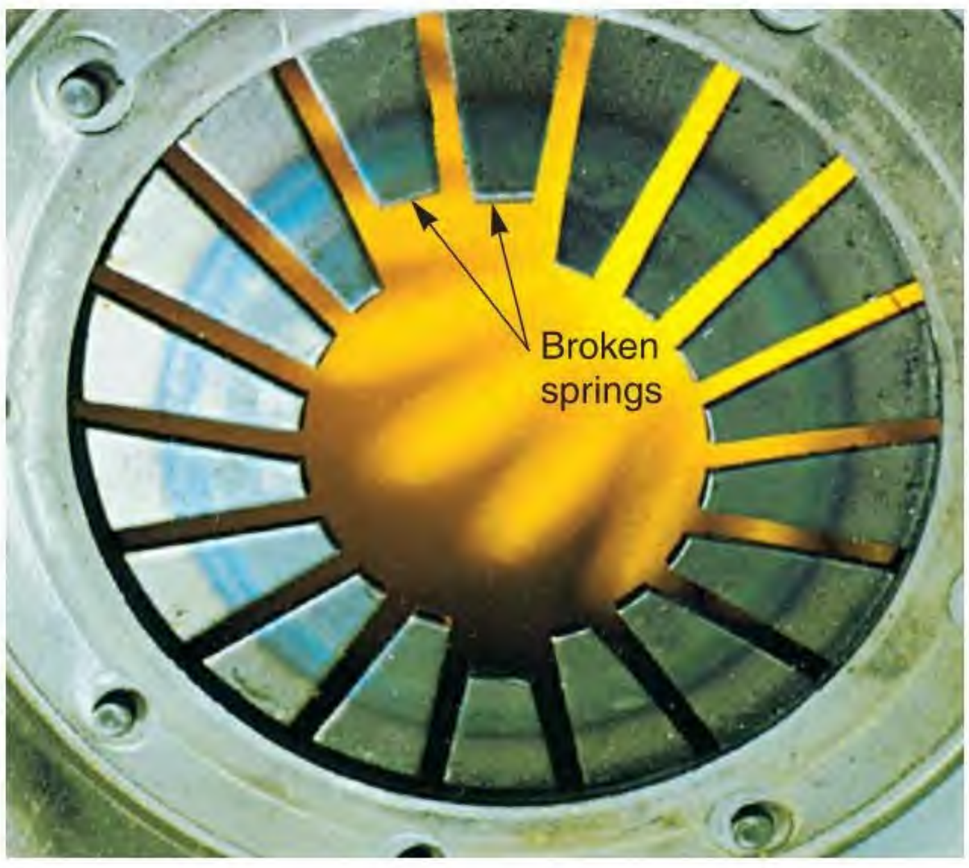
B

LuK

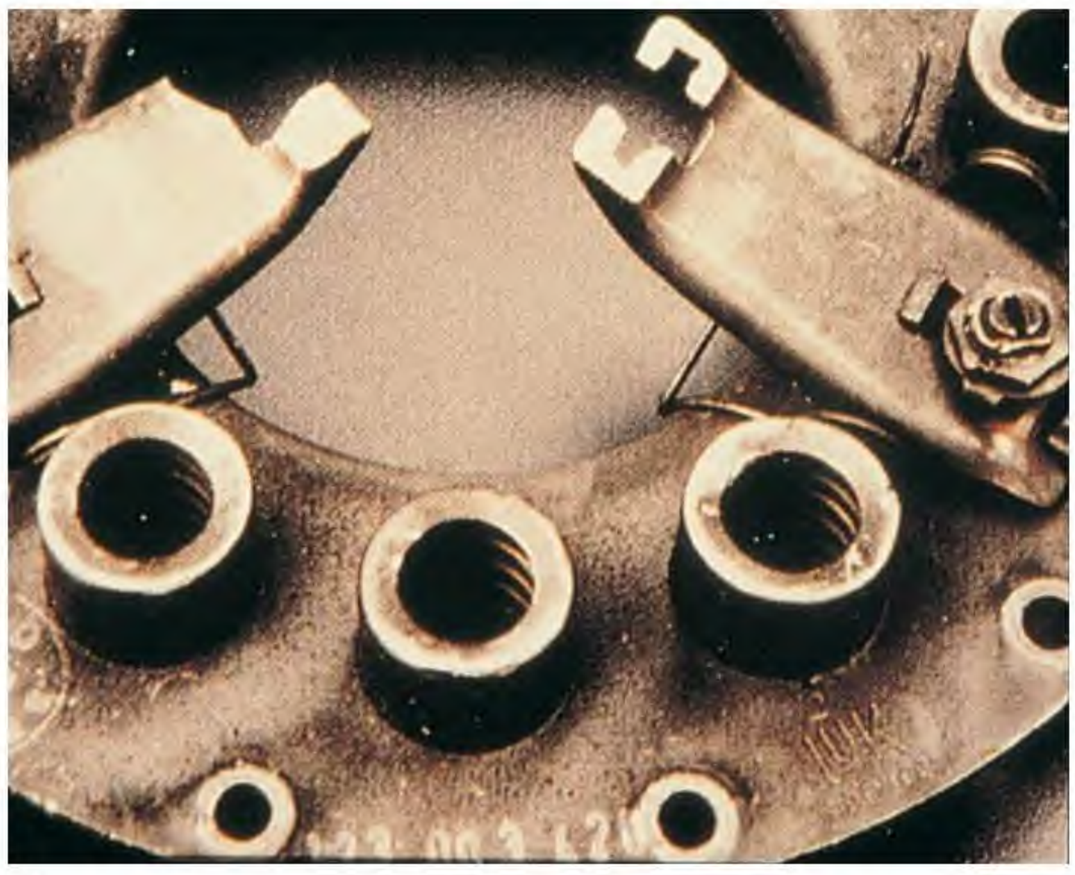
Figure 62-3. Common throw-out bearing related failures. A—This dry throw-out bearing made a loud grinding noise any time the clutch pedal was pressed. The bearings had run dry of grease and started rapid wear and high friction. B—This transmission front bearing retainer hub was badly worn and damaged by a dry, locked, spinning throw-out bearing.

A bad pressure plate can cause clutch slippage, as well as clutch release problems (stiff clutch pedal, abnormal noises, clutch grabbing, or clutch dragging). The springs inside the clutch could lose tension or break. The release levers could be bent or out of adjustment. See **Figure 62-4**. The face of the pressure plate could also be scored. Look at **Figure 62-5**.

A worn pilot bearing will allow the transmission input shaft and clutch disc to wobble up and down. This can cause clutch vibration, abnormal noises, and



A

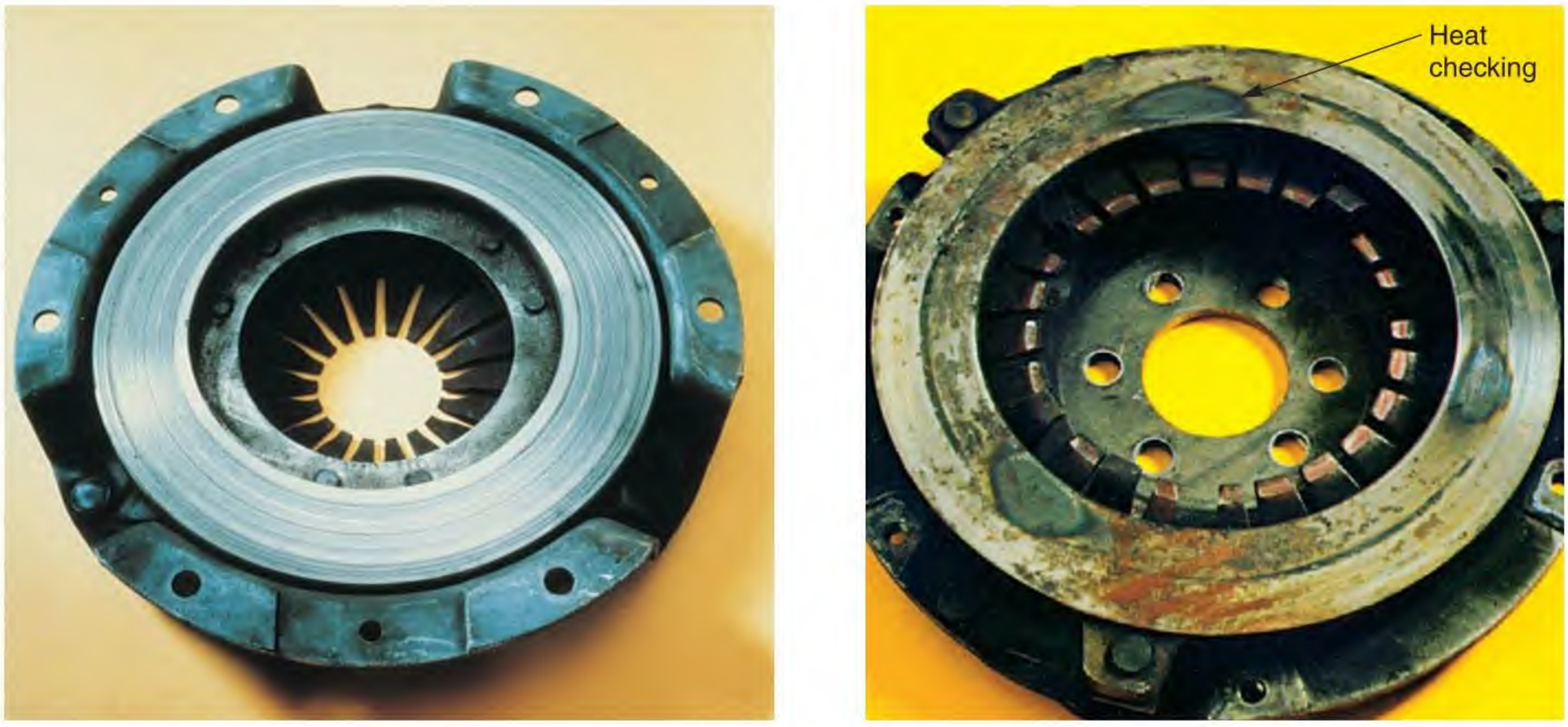


B

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Figure 62-4. Pressure plate spring and release finger problems. A—This pressure plate has broken diaphragm springs. This could be due to installation error, poor adjustment (too tight, forcing the throw-out bearing too far into pressure plate), or clutch spring problems. B—The release levers on this pressure plate are broken. This could be due to no free play in the release mechanism, bad release bearing, or improper part alignment.

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A B

LuK

Figure 62-5. Common pressure plate friction surface failures. A—This pressure plate surface was badly scored. Causes could be a worn friction disc, the driver slipping the clutch, or binding linkage. B—This pressure plate shows heat-checking damage resulting from massive slippage that generated high friction and heat. Causes could be oil or grease contamination, poor clutch adjustment (too tight), binding linkage, or engaging the clutch at high engine speed.

damage to the transmission. A bent or worn clutch fork can prevent the clutch from releasing properly.

Free travel (free play) is the distance the clutch pedal or clutch fork moves before the throw-out bearing acts on the pressure plate. Free travel is needed to ensure complete clutch engagement. See **Figure 62-6**.

Excess clutch pedal free travel is often due to part wear that reduces clutch release action. This can cause the clutch to drag even when the pedal is fully pushed to the floor. Insufficient clutch pedal free travel can be due to bent parts and similar mechanical problems. Insufficient free travel in the clutch release mechanism can cause the clutch to stay partially disengaged, resulting in clutch slippage.

Clutch Slippage

Clutch slippage occurs when the clutch friction disc fails to grip the surface of the flywheel, pressure plate, or both. As a result, the friction disc generates tremendous heat by rubbing and slipping against the surfaces rather than locking and transferring torque. Typically, clutch slippage causes the engine to ***race*** (engine speed increases quickly) without a corresponding increase in the vehicle's road speed.

Clutch slippage usually occurs as the vehicle is accelerated from a standstill, when shifting, or when under a heavy load (climbing a hill or pulling a trailer).

Service Procedure

To test the clutch for slippage:

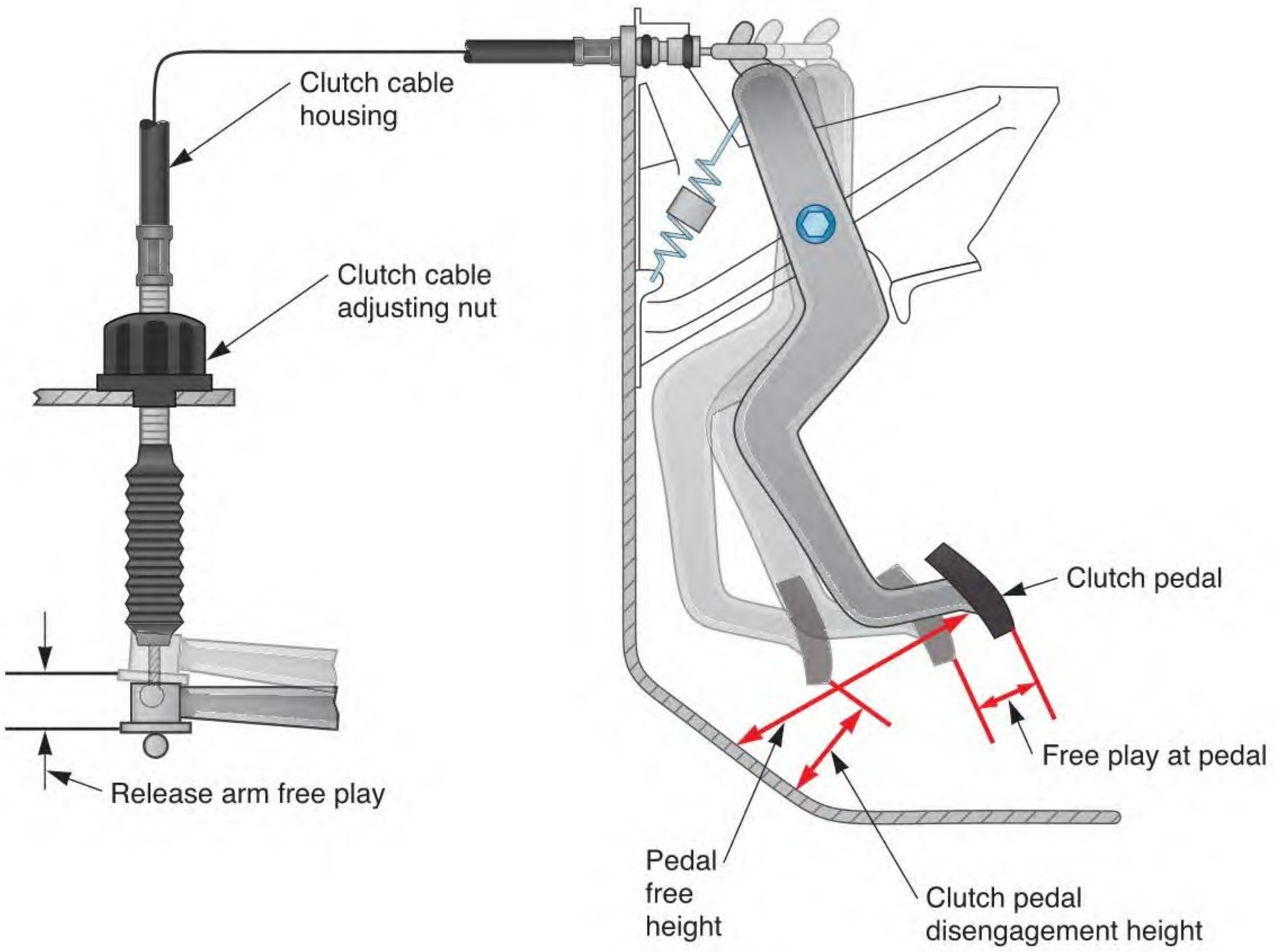
1. Set the emergency brake.
2. Start the engine.
3. Place the transmission or transaxle in high gear.
4. Try to drive the vehicle forward by slowly releasing the clutch pedal.

   A clutch in good condition should lock up, killing (stalling or stopping) the engine immediately. A badly slipping clutch may allow the engine to run, even with the clutch pedal fully released. Partial clutch slippage may allow the engine to run momentarily before stalling.

Caution

Never let a clutch slip for more than a second or two when testing for clutch slippage. The extreme heat generated by slippage can damage the flywheel or pressure plate faces.

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Honda

Figure 62-6. Clutch pedal free play is the distance the pedal moves until the throw-out bearing touches the pressure plate. Release arm or fork free play is the distance the end of the arm moves back and forth with the clutch released. Note the adjuster nut for changing cable free play.

Some common causes of clutch slippage include a misadjusted clutch, binding clutch linkage or cable, worn clutch disc, broken motor mount, and oil or grease on the clutch disc (leaking oil seal).

Improper clutch adjustment can cause slippage by keeping the throw-out bearing in contact with the pressure plate in the released position. Even with your foot off the pedal, the release mechanism acts on the clutch fork and throw-out bearing. This can make the clutch slip under load.

A binding clutch release mechanism can also cause clutch slippage. Parts can become rusted, bent, misaligned, or damaged.

A broken motor mount (engine mount) can cause clutch slippage by allowing engine movement to bind the clutch linkage. Under load, the engine can lift up in the engine compartment. This can shift the clutch linkage and push on the clutch fork.

If clutch slippage is not caused by a problem with the clutch release mechanism, then the trouble is normally inside the clutch housing. In this case, you need to remove the transmission and clutch components for further inspection.

Grabbing Clutch

A ***grabbing clutch***, or ***chattering clutch***, produces a very severe vibration or jerking motion when the vehicle is accelerated from a standstill. Even though the driver is slowly releasing the clutch pedal, it feels as if the clutch pedal is being rapidly pumped up and down. A loud banging or chattering sound may be heard as the vehicle's body vibrates.

Normally, clutch grabbing is caused by problems with components inside the clutch housing (friction disc, flywheel, or pressure plate). Disassembling the clutch is usually required to correct these problems. However, a broken motor mount can also cause erratic clutch linkage operation. Check the engine mounts before removing the clutch from the vehicle.

Dragging Clutch

A ***dragging clutch*** normally makes the transmission or transaxle grind when trying to engage and shift gears. Something causes the friction disc to stay engaged to the flywheel, which keeps the

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transmission input shaft spinning, even when the clutch is disengaged. Severe clutch drag will make the vehicle move forward whenever the engine is running and the transmission is in gear.

One of the most common causes of a dragging clutch is too much pedal free travel. With excessive free travel, the pressure plate is not fully released when the pedal is pushed to the floor. Always check clutch adjustment when symptoms point to a dragging clutch.

A dragging clutch can also be caused by a warped or bent friction disc, oil or grease or corrosion on the friction surfaces, rusted or damaged transmission input shaft splines, or other problems inside the clutch housing.

Abnormal Clutch Noises

Various noises can be made by faulty clutch parts. To diagnose noises, determine the circumstances under which clutch noise is produced. Does the sound occur when the pedal is moved, when in *Neutral*, when in gear, or when the pedal is held to the floor? This will help determine which parts are producing the abnormal noises.

A worn, unlubricated, or dry clutch release mechanism will produce odd sounds (squeaks, clunks, scrapes) whenever the clutch pedal is moved up or down. With the engine shut off, pump the clutch pedal while listening for the sound. If needed, have a helper work the pedal while you locate the source of the noise. Use a stethoscope or a section of vacuum hose as a listening device. Clean, lubricate, and replace parts as required.

Sounds produced when the clutch is initially engaged are normally due to friction disc problems. The lining could be worn, causing an abrasive, metal-on-metal grinding sound. If the friction disc damper springs are weak or broken, a knocking or rattling sound may be produced.

Abnormal sounds from the clutch that occur when the clutch is disengaged may be from a bad throw-out bearing. It may be dry and badly worn.

A worn pilot bearing in the crankshaft may also produce noises during clutch disengagement. The worn pilot can permit the transmission input shaft and clutch disc to vibrate up and down.

Abnormal sounds that are heard only in *Neutral* and disappear when the clutch pedal is pressed are usually caused by problems inside the transmission. The manual transmission input shaft is still spinning whenever the clutch is engaged. However, the input shaft stops turning when the clutch is disengaged. The front input shaft bearing could be worn, for example.

Pulsating Clutch Pedal

A ***pulsating clutch pedal*** is normally caused by the runout (wobble or vibration) of one of the rotating components of the clutch assembly. Slight up and down movements of the clutch pedal can be felt with light foot pressure. The flywheel may be warped. The clutch housing might not be properly aligned with the engine. The pressure plate release levers could be bent or maladjusted.

To correct a pedal pulsation problem, the clutch must be removed and inspected. Then, the faulty or misaligned parts can be replaced or repaired.

Stiff Clutch Pedal

A ***stiff clutch pedal*** results from a problem with one of the parts involved in clutch release: linkage, cable, hydraulic components, clutch fork, throw-out bearing, or pressure plate. One of these parts is resisting normal movement and is increasing the amount of pedal pressure needed to release the clutch. A part may be worn or lacking lubrication.

If the clutch fork has fallen off its pivot ball or bracket, the clutch pedal can be very hard to push down. Normally, bell housing removal is needed to reinstall the clutch fork or repair the pivot.

Servicing a Clutch

Clutch service is fairly common. After prolonged service or abuse, the clutch parts wear and fail in service. The friction disc can wear out, causing clutch slippage and, sometimes, damage to the pressure plate and flywheel. The throw-out bearing can run dry and start making noise whenever the clutch pedal is pressed. This section of the chapter will explain how to repair these and other clutch problems.



Warning

Clutch disc lining or friction material sometimes contains asbestos. This is especially true of older clutch discs. Asbestos is a known cancer-causing substance. Do not breathe asbestos dust (or even dust from newer non-asbestos friction lining). Avoid using an air hose to blow asbestos dust off clutch parts. Wear a respirator or use an enclosed vacuum system.

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Adjusting the Clutch

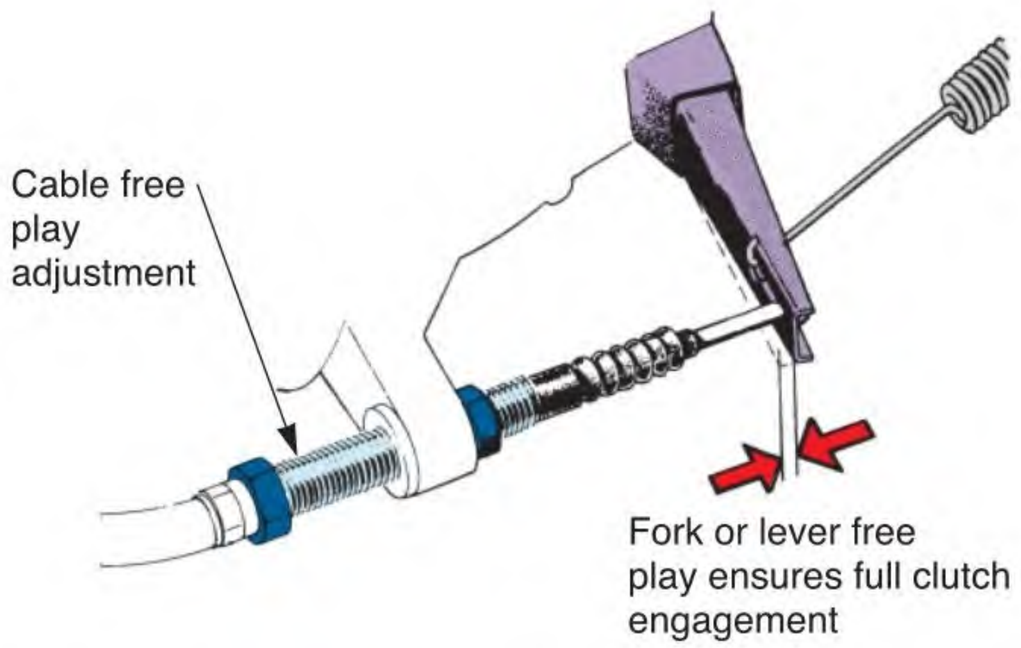
Clutch adjustment involves setting the correct amount of free play in the release mechanism. Too much free play could cause the clutch to drag during clutch disengagement. Too little free play could cause clutch slippage.

It is important for you to know how to adjust the three basic types of clutch release mechanisms: clutch linkage, clutch cable, and hydraulic clutch release mechanism.

Clutch Linkage Adjustment

Mechanical clutch linkage is usually adjusted at the push rod attached to the clutch fork. One end of the fork push rod is threaded. The effective length of the rod can be increased to raise the clutch pedal (decrease free travel). Rod length can also be shortened to lower the clutch pedal (increase free travel).

To change the clutch adjustment, loosen the push rod nuts. You may need to grasp the unthreaded portion of the push rod with vise grips to free them. Turn the nuts on the threaded push rod until you have the correct pedal free travel.



Volvo

Figure 62-7. Without free play in the clutch release mechanism, the fork could push the throw-out bearing into the pressure plate, even with the clutch pedal fully released. Clutch slippage could result.

Tech Tip

Specific adjustment procedures and free travel specifications vary. Always refer to a service manual for exact details.

Clutch Cable Adjustment

As with the linkage release mechanism, a clutch cable may require periodic adjustment to maintain the correct pedal height and free travel. Typically, the clutch cable housing will have an adjusting nut. When the nut is turned, the length of the cable housing increases or decreases. Look at **Figure 62-7**.

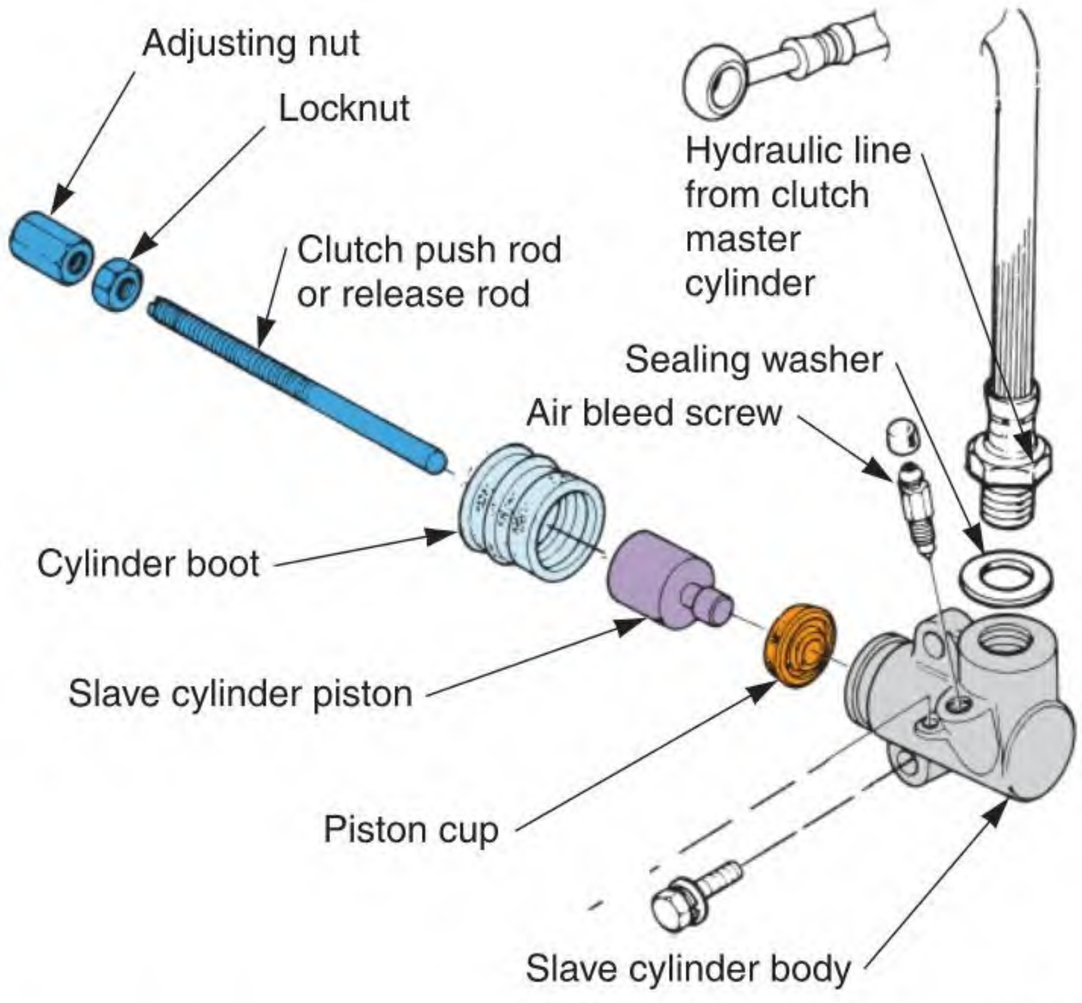
In most cases, to increase clutch pedal free travel, turn the cable housing nut to shorten the housing. To decrease clutch pedal free travel, lengthen the clutch cable housing.

Some cable release mechanisms have an automatic adjusting mechanism. If the clutch requires adjustment, the automatic clutch adjuster may be faulty or the clutch may be badly worn.

Hydraulic Clutch Release Mechanism Adjustment

A hydraulic clutch release mechanism may need adjustment after prolonged clutch operation. Normal wear of the friction disc, throw-out bearing, and other parts can cause the pedal free travel to increase. The adjusting nut on a hydraulic clutch can be located on the fork push rod or the clutch master cylinder push rod. See **Figure 62-8**.

To adjust a hydraulic clutch, simply turn the nut on the push rod as needed. Generally, lengthening the rod decreases pedal free travel. Shortening the rod increases free travel. Check a service manual for specifications and procedures.



Honda

Figure 62-8. Exploded view of a clutch slave cylinder. To rebuild the unit, hone the cylinder and replace the cup and boot. Note the adjustable push rod for setting free play.

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Removing the Clutch

Clutch removal procedures vary from one vehicle to another. However, general procedures and safety warnings should be understood.

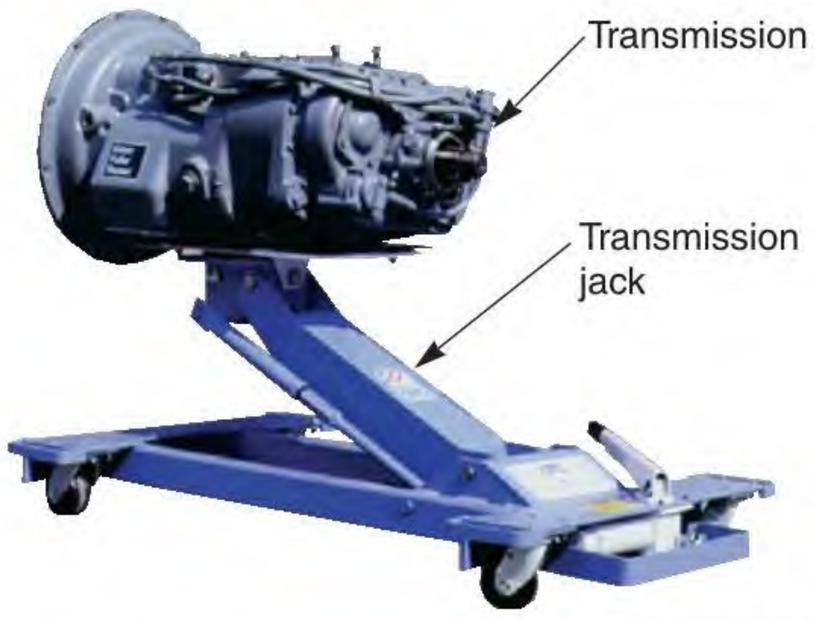
Warning

Always disconnect the battery ground when removing a clutch assembly. This will prevent accidental cranking of the engine and possible injury. It can also prevent electric shorts that could damage the vehicle's wiring.

Transmission or transaxle removal is needed to service a clutch. Always follow the detailed directions in the service manual. To remove the clutch on a rear-wheel-drive vehicle, begin by removing the drive shaft, clutch fork release rod or cable, and the transmission. Use a transmission jack when lifting a transmission or transaxle out of a vehicle, **Figure 62-9**. On a front-wheel-drive vehicle, the axle shafts (drive axles), transaxle, and sometimes the engine must be removed for clutch repairs. Use the specific instructions in a shop manual.

Caution

When removing a transmission or transaxle, support the weight of the engine. Never let the engine, transmission, or transaxle hang unsupported. The transmission input shaft, clutch fork, motor mounts, and other parts could be damaged.



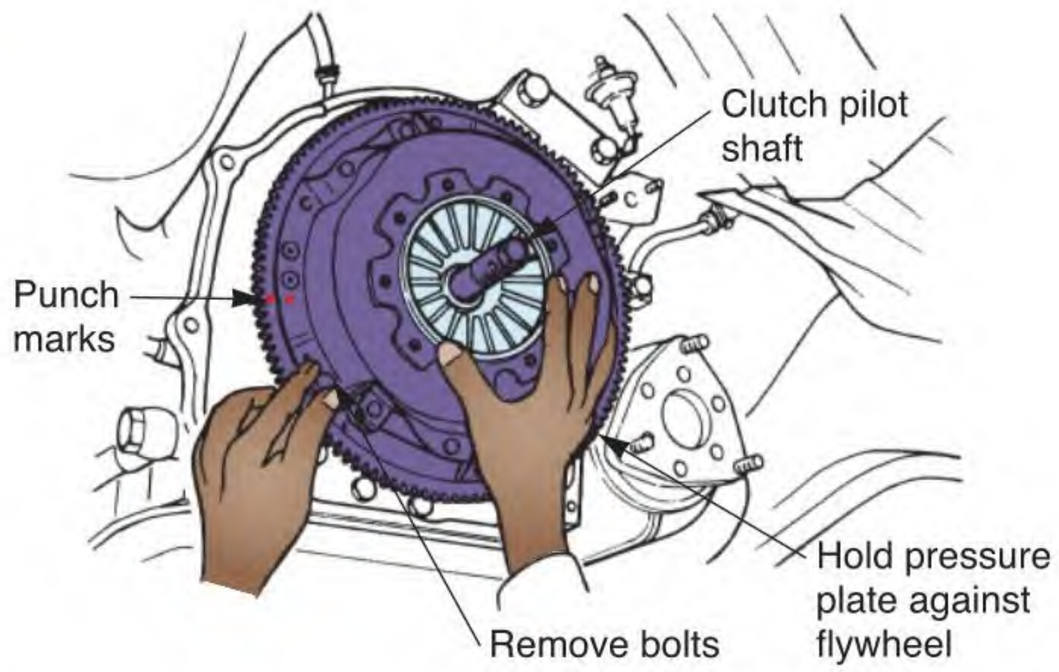
OTC Div. of SPX Corp.

Figure 62-9. Transmissions and transaxles are very heavy. Use a transmission jack to remove the assembly during clutch repairs.

Service Procedure

After removing the transmission or transaxle:

1. Unbolt the bell housing from the rear of the engine. Support the housing as the last bolt is removed. Be careful not to drop the bell housing as you pull it off its dowel pins.
2. Use a hammer and center punch to mark the pressure plate and flywheel. These marks may be needed if the same pressure plate is to be reinstalled. Lining up the marks ensures correct balancing of the clutch. Look at **Figure 62-10**.
3. Slide a ***pilot shaft*** (clutch alignment tool or old transmission input shaft) into the clutch. This will keep the clutch disc from falling as you unbolt the pressure plate.
4. Loosen each pressure plate bolt a little at a time to avoid placing too much stress on any one bolt. Hold the pressure plate against the flywheel as the last bolt is removed.
5. Lift the pilot shaft, pressure plate, and clutch disc off the back of the engine without dropping them. They are fairly heavy. Be prepared to support their weight.
6. With the clutch removed, check the rear of the engine and the front of the transmission for oil leaks. If oil were to leak on the new clutch, it would be ruined. Check the crankshaft rear main seal and the transmission front seal.



Mazda

Figure 62-10. Punch mark the pressure plate and flywheel before disassembly. You will need to align these marks to reuse the old pressure plate. A pilot shaft will keep the disc from falling as pressure plate bolts are removed.

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Inspecting and Cleaning Clutch Parts

With the clutch removed, each component must be cleaned and carefully inspected for wear and damage, **Figure 62-11**.

Warning

Be careful how you clean the parts of a clutch. Avoid using compressed air to blow clutch dust off the parts. A clutch disc often contains asbestos, a powerful cancer-causing substance.

Wipe the clutch parts down with a clean rag. Use sandpaper to deglaze and polish the surface of the flywheel and the face of the pressure plate. Keep cleaning solvent, which might contain traces of oil, off the friction surfaces (clutch disc, flywheel, and pressure plate faces).

Caution

Do *not* wash the throw-out bearing in solvent. This could wash the grease out of the bearing and ruin it.



OTC Div. of SPX Corp.

Figure 62-11. Inspect all parts as the clutch is serviced. Replace worn and damaged parts.

Pilot Bearing Service

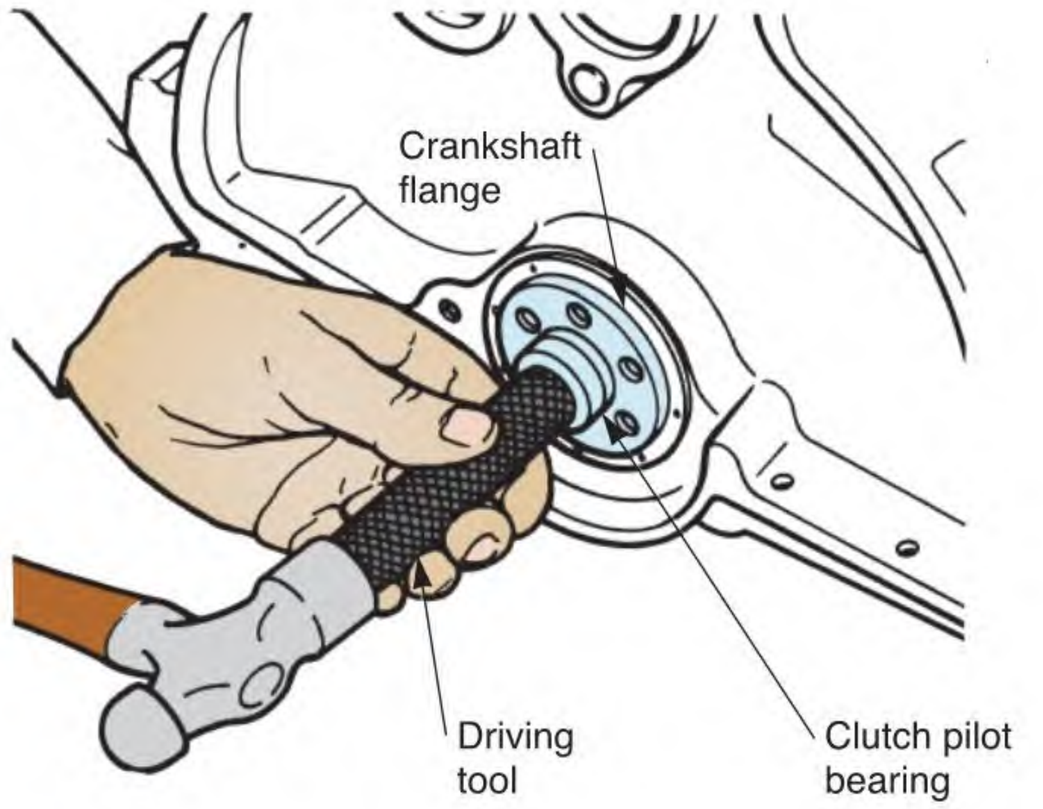
Closely inspect the pilot bearing or bushing. Using a telescoping gauge and micrometer, measure the amount of wear in the bushing. If a roller bearing is used, turn the bearing with your finger. Feel for roughness and wear. If needed, replace the bearing.

Service Procedure

To remove the pilot bearing in a crankshaft:

1. Deliver a few light blows with a slide hammer puller to drive the bearing out of the crank.
2. If a puller is not available, fill the inside of the crankshaft flange and pilot bearing with heavy grease.
3. Insert the metal pilot shaft into the hole in the bearing. The shaft must be almost as large as the hole in the pilot bearing.
4. Tap on the shaft with a mallet and the pressure in the grease behind the bearing will force the pilot bearing out of the crankshaft.

Check the fit of the new pilot bearing by sliding it over the input shaft of the transmission. Then, drive the new pilot bearing into the end of the engine crankshaft, **Figure 62-12**. If needed, place a small amount of grease in the pilot bearing cavity. Do not completely



Ford

Figure 62-12. Always check the pilot bearing for wear during clutch service. If worn, remove the old bearing. Install a new pilot bearing, as shown.

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fill the cavity, or grease may squirt out onto the friction disc when you install the transmission or transaxle.

Flywheel Service

After a prolonged service, the friction surface on the face of a flywheel can crack, split, and fail. If not noticed, these small surface cracks can lead to premature clutch disc wear and failure.

Closely inspect the surface of the flywheel. Look for discolored areas and cracks. Measure flywheel runout with a dial indicator. If warped or damaged, either replace the flywheel or have it resurfaced at a machine shop. Also, check the ring gear teeth on the flywheel. If they are worn or chipped, a new ring gear should be installed.

Service Procedure

To install a new flywheel ring gear:

1. Heat the old ring gear with an acetylene torch to expand the gear.
2. Knock the ring gear off the flywheel with a hammer and punch.
3. Heat the new ring gear with your torch.
4. Carefully position the ring gear and drive it on with light hammer blows.

   Note that some engine flywheels do not allow for ring gear replacement. For these models, a new flywheel must be purchased if you find problems with the old one.

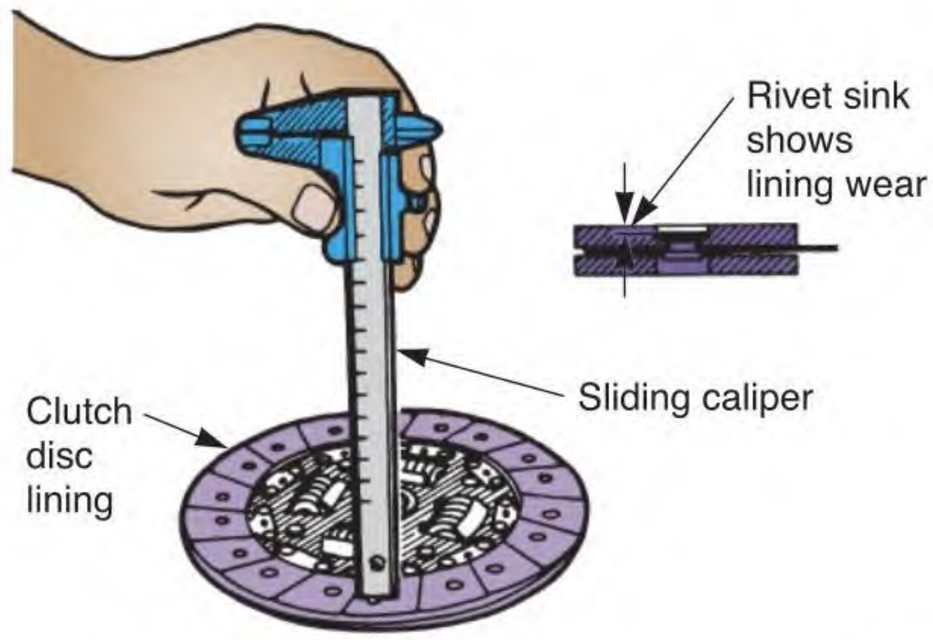
Clutch Disc Service

To check disc wear, inspect the depth of the rivet holes. The closer the rivets are to the surface of the friction material, the more worn the disc. Look at **Figure 62-13**. Normally, the friction disc is replaced any time the clutch is torn down for repairs. The disc is reasonably inexpensive and highly prone to wear.

Pressure Plate Service

Inspect the pressure plate closely using the information in a service manual. The manual will describe various measurements to determine its condition.

Modern practice is to replace worn or defective pressure plates. Most technicians no longer rebuild or repair them. Considering the cost of labor, it is normally cheaper to purchase and install a new or rebuilt unit.



Chrysler

Figure 62-13. Measure clutch disc lining wear at the rivets. If the distance from the surface of the lining to the top of the rivet head is too small, install a new clutch disc. Refer to a service manual for specifications. A disc should be reused only if it is relatively new. Keep grease and oil off friction surfaces.

Throw-Out Bearing Service

To check the action of the throw-out bearing, insert your fingers into the bearing. Then, turn the bearing while pushing in on it. Try to detect any roughness. The throw-out bearing should rotate smoothly. Also, inspect the spring clips on the throw-out bearing or fork. These clips hold the bearing on the end of the clutch fork. If bent, worn, or fatigued, the bearing collar or fork must be replaced.

To replace the throw-out bearing, drive it off its collar using a vise and hammer or a hydraulic press. Follow the detailed procedures in a service manual to avoid damaging the collar and new bearing.

The throw-out bearing is subject to considerable wear and is a frequent cause of clutch problems. Therefore, most technicians replace the throw-out bearing any time the clutch is disassembled for repairs. Before installation, lubricate the throw-out bearing collar as shown in **Figure 62-14**.

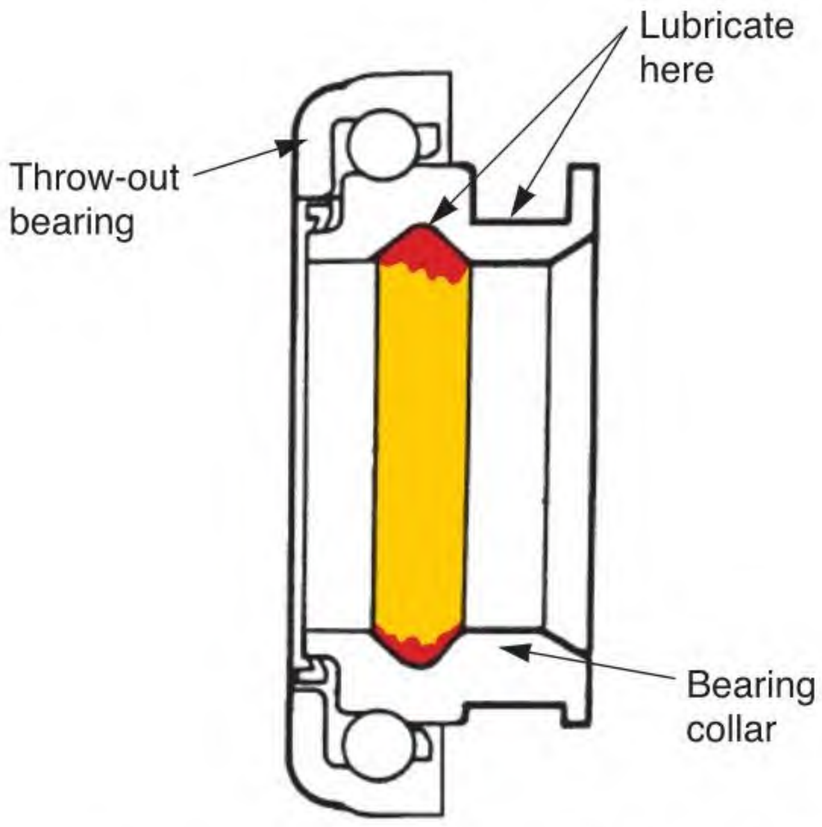
Clutch Fork Service

Inspect both ends of the fork carefully. Also, check the fork pivot point in the bell housing. The pivot ball or bracket should be undamaged and tight. Replace worn parts, as needed. Place a small amount of grease on the fork pivot point.

Hydraulic Clutch Release Mechanism Service

Hydraulic clutch release mechanism problems are usually caused by fluid leakage. The rubber cups

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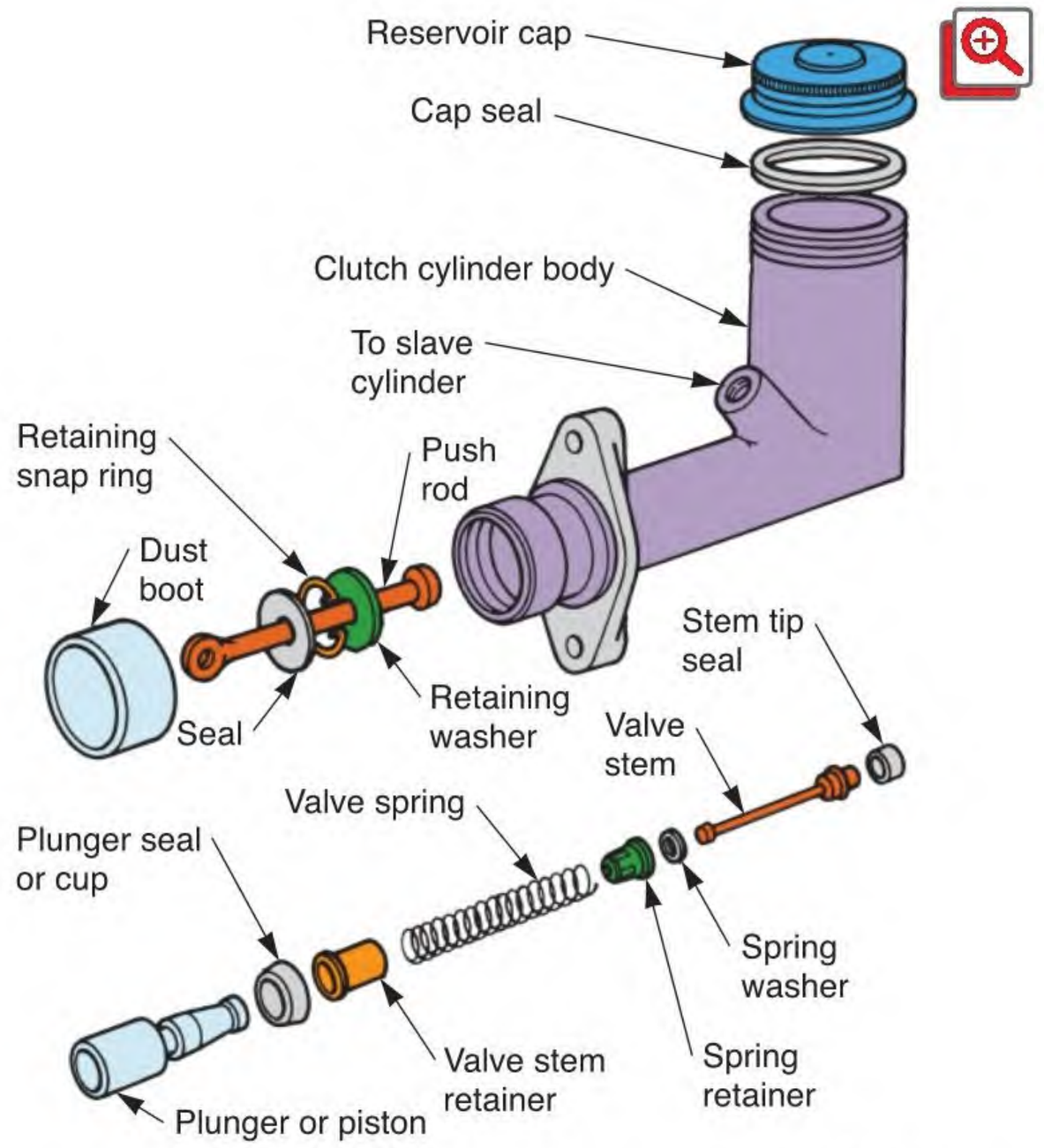
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Figure 62-14. When installing a new throw-out bearing, place high-temperature grease on the areas shown. This allows the bearing collar to freely slide on the transmission hub. Do not use too much grease; it could ruin the clutch disc.

inside the cylinders can wear and begin to leak. After enough fluid loss, the reservoir can empty and the clutch will not release.

If leakage is indicated, inspect the system carefully. Look behind the master cylinder and at the end of the slave cylinder. If leaks are found, replace or repair the components, as needed. Refer to **Figure 62-15**.

After reassembly, the hydraulic clutch will require ***bleeding*** (removal of air from inside the system). Air is compressible and will cause the clutch pedal to be very soft and spongy.



Chrysler

Figure 62-15. A clutch master cylinder is serviced much like a brake system master cylinder. When leaking, either rebuild or replace the unit. Study the part names.

Caution

Install only the recommended type of fluid in a hydraulic clutch system. Oil, kerosene, and grease must *never* enter the hydraulic system. These substances will cause the rubber cups to swell and deteriorate. *Keep your hands clean!*

Servicing a hydraulic clutch (bleeding, honing cylinders, replacing cups, etc.) is very similar to servicing a hydraulic brake system. For more information on how to work on hydraulic components, refer to the brake system service and repair chapter of this book.

Service Procedure

To bleed a hydraulic clutch release, use the same procedures outlined in the section on bleeding brakes:

1. Use a pressure bleeder or manually pump the clutch pedal to force fluid and any air out of the system. A bleeder screw is normally located on the slave cylinder.
2. When the system is pressurized, open the bleeder screw to allow fluid and air to flow from the system.
3. Repeat until air bubbles stop flowing out, and only clear hydraulic fluid flows. This should purge all air from the lines and cylinders.

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Installing the Clutch

Service Procedure

Install the clutch in the reverse order of removal:

1. Mount the clutch disc and pressure plate on the flywheel.
2. Use a clutch alignment tool (pilot shaft) to center the disc.
3. Align any punch marks.
4. Make sure the friction disc is facing the proper direction. Usually, the disc's offset center section (hub and torsion springs) fits into the pressure plate.
5. Start all the pressure plate bolts by hand.

Caution

Never let oil or grease contact with the clutch friction surfaces. The slightest amount of oil or grease could cause clutch slippage or grabbing. *Keep your hands and tools clean!*

6. Tighten each pressure plate bolt a little at a time in a crisscross pattern, **Figure 62-16**. This will apply equal stress on each bolt as the pressure plate springs are compressed.
7. When all the bolts are snug, torque them to specifications.

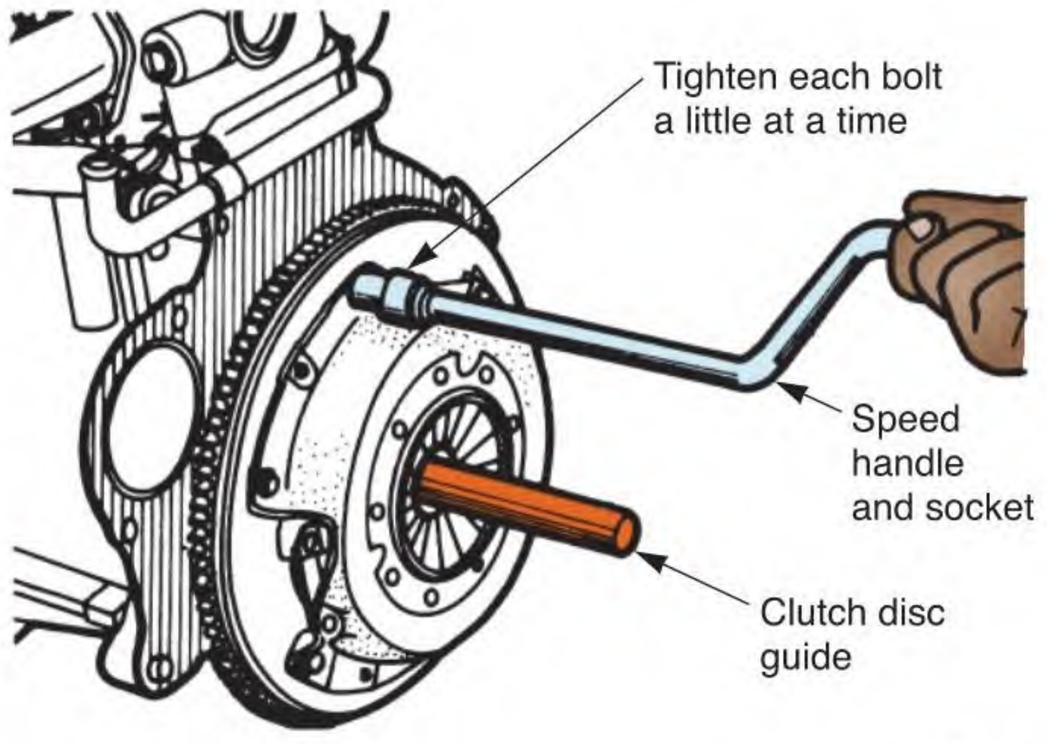
Tech Tip

Never replace clutch pressure plate bolts with weaker bolts. Always install the special case-hardened bolts recommended by the manufacturer. Weaker bolts could break, causing severe part damage.

8. With the pressure plate bolts properly torqued, slide the pilot out of the clutch. The pilot ensures that the clutch friction disc is centered on the flywheel. If a pilot is not used, the transmission input shaft will not slide into the crankshaft pilot bearing. It would be impossible to install the transmission or transaxle.
9. Install the clutch fork and throw-out bearing in the bell housing.
10. Fit the bell housing over the rear of the engine. Large dowels are provided to align the housing on the engine.
11. Install and tighten the bell housing bolts in a crisscross pattern.
12. Install the transmission and drive shaft or the transaxle assembly and axle shafts.
13. Reconnect the linkage, cables, wires, battery, and other parts.
14. Adjust clutch pedal free travel, as described earlier.
15. Test-drive the vehicle.

Engine/Motor-Generator Clutch Service

An ***automatic engine clutch*** uses computer control and several control modules to operate a conventional clutch or a set of wet clutches. Large, computer-controlled shift solenoids and/or servo motors are used to disengage the clutch disc while engaging each manual transmission helical gearset. The vehicle control modules network to operate the clutch release solenoid or servo in response to engine speed, engine load, boost pressure, motor-generator power output, wheel rpms, suspension measurements, shift button actuation, and other variables.



Chrysler

Figure 62-16. Tighten each pressure plate bolt a little at a time. Then, torque them to specifications. Remove the pilot after the bolts are fully torqued. Slide the shaft in and out of pilot bearing to double-check disc alignment.

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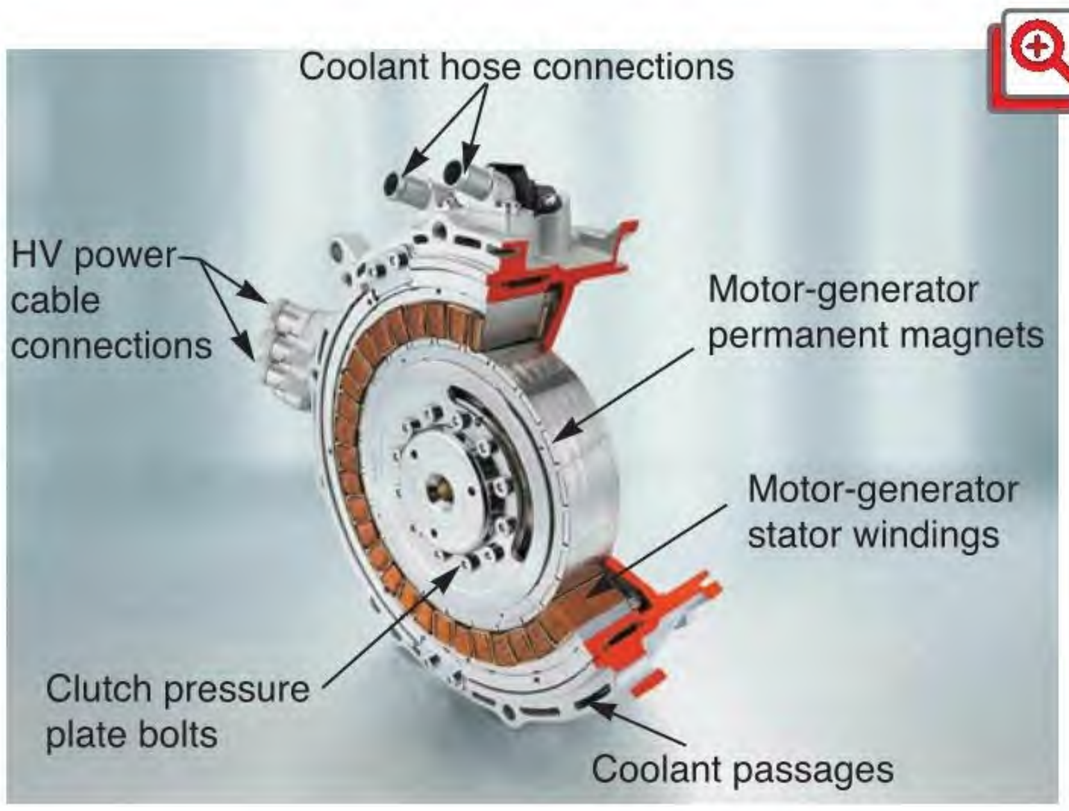
The engine and transmission control modules electronically release and engage the engine clutches to change gear ratios under driver/computer control. If the driver selects first gear for a rapid launch into freeway traffic, when the driver floors the gas pedal, computer memory will limit maximum engine rpms until the driver releases the brake pedal. The "brake off" signal allows the computer to engage low gear as engine power is applied, and the vehicle accelerates very quickly with minimum tire spin.

Service procedures for hybrid automatic or manual clutches vary with vehicle design. A typical hybrid engine/motor-generator clutch assembly is shown in **Figure 62-17**.

Service Procedure

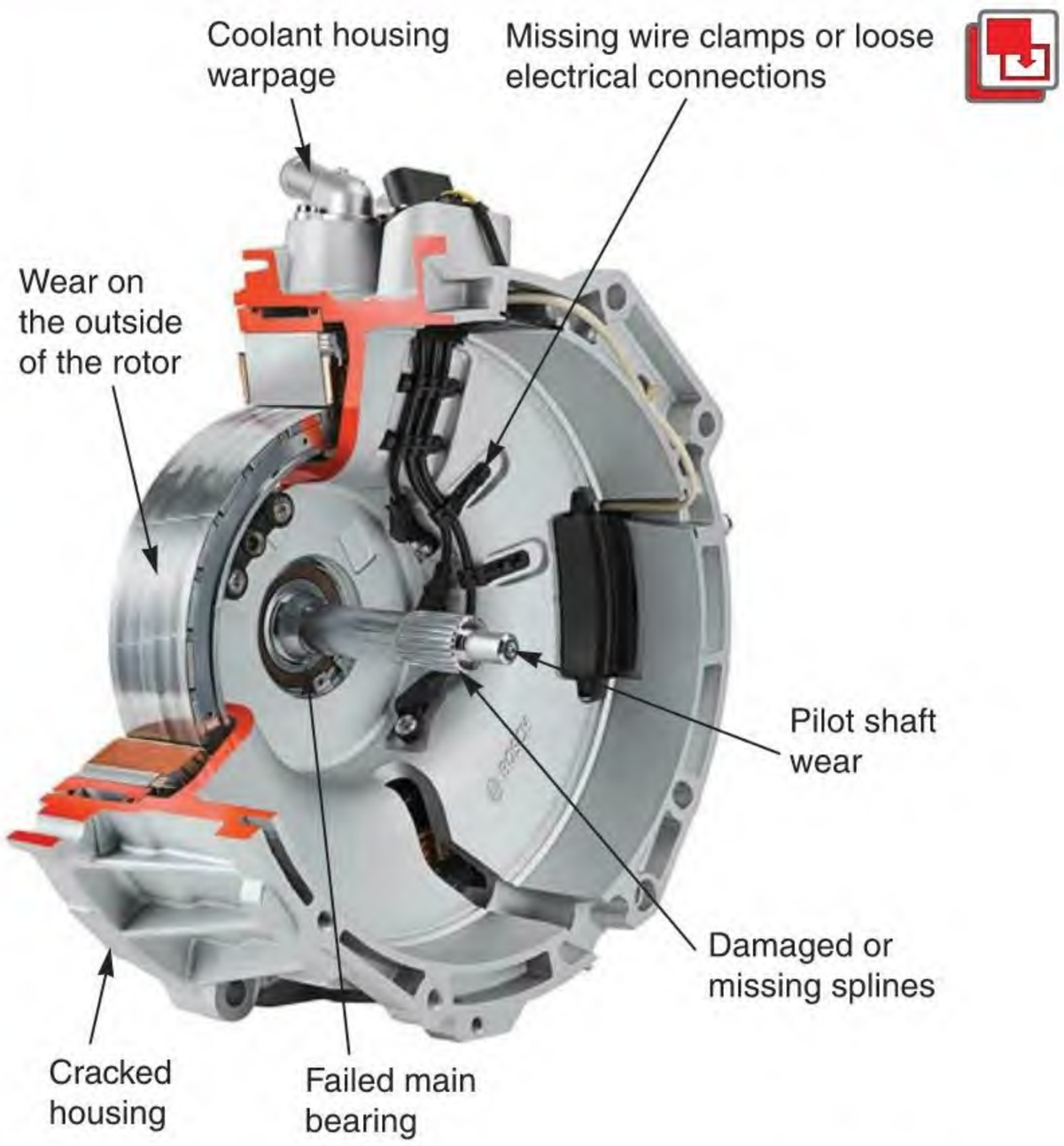
To service a hybrid engine/motor-generator clutch:

1. Disable the HV battery by pulling its safety plug. Also disconnect any 12-volt battery.
2. Raise the vehicle on a lift and make sure the lift's mechanical safety catch is engaged.
3. On a rear-wheel-drive car, remove the bolts securing the drive shaft and remove the drive shaft. Insert a plastic plug into the transmission rear oil seal to avoid considerable fluid leakage.
4. Disconnect the orange power cables going into the motor-generator. Make sure you are wearing electrician's gloves and using insulated tools.
5. Disconnect any coolant lines going to the motor-generator.
6. Disconnect all electrical connections to the motor-generator or transmission.
7. Remove all bolts connecting the transmission to the engine or motor-generator.
8. Use a transmission jack to slide the transmission back, and then down and out of the vehicle.
9. Remove the clutch and motor-generator assembly, as required by further component testing.
10. Always replace the friction disc with a new disc during service.
11. Inspect the pressure plate for heat damage, broken springs, and other problems. Measure the friction surface for warpage. Replace the pressure plate if you see any signs of damage or wear. See **Figure 62-18**.
12. Reinstall the engine/motor-generator clutch in reverse order. Refer to **Figure 62-19**.
13. Refer to the previous instructions for using a clutch alignment tool, if needed.



Bosch

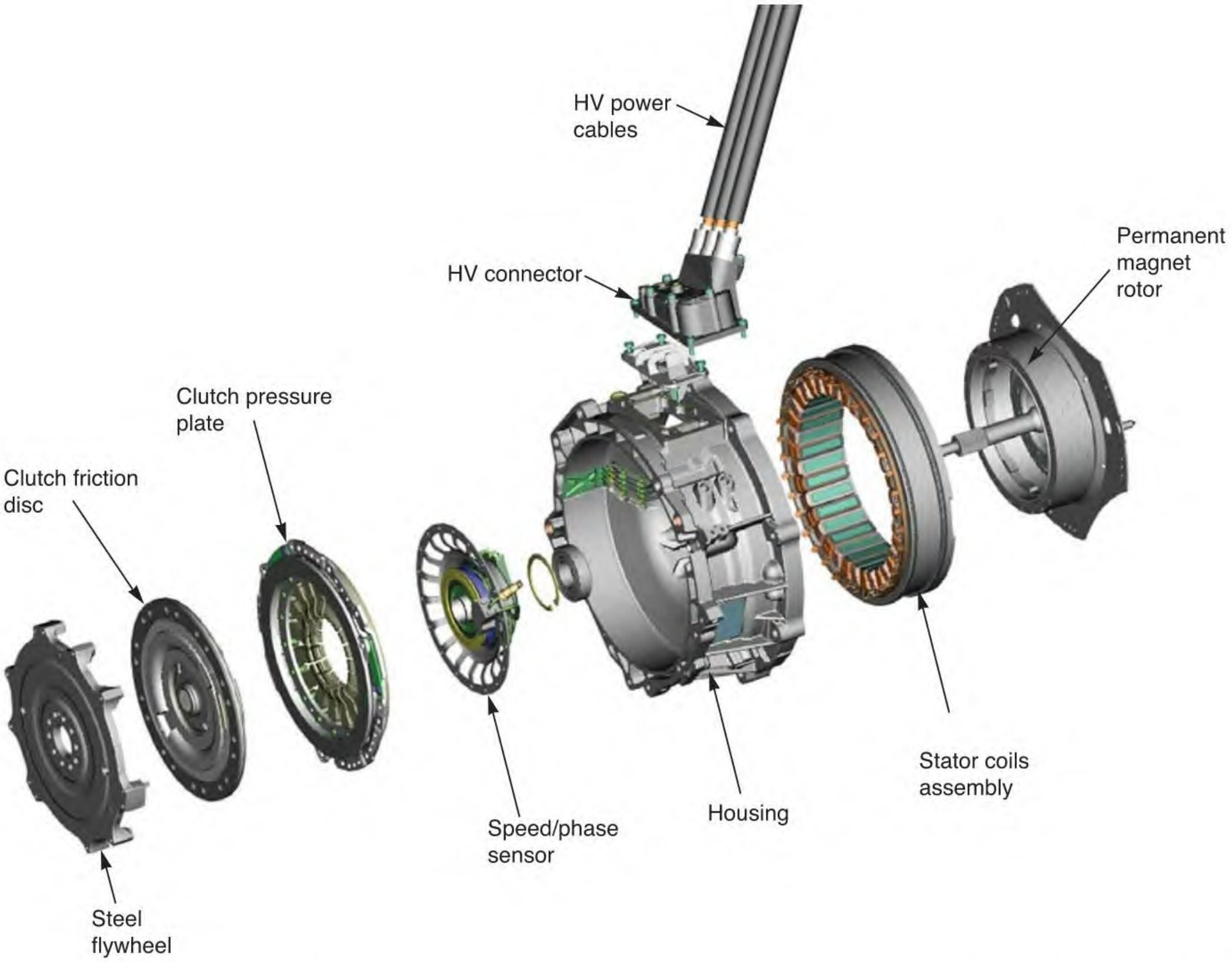
Figure 62-17. Study the hose, power cable, and sensor connections on this typical motor-generator clutch assembly. The inner clutch set is splined to the transmission and motor-generator. The magnetic rotor is often bolted to the engine crankshaft flange.



Bosch

Figure 62-18. Inspect, test, and repair any of these problems before returning a motor-generator clutch back to service in any vehicle.

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Bosch

Figure 62-19. This exploded view shows a motor-generator clutch assembly. Most technicians prefer to install a complete clutch kit (new throw-out bearing, motor-generator main bearing, new friction disc, and often a new pressure plate). The speed/phase sensor is very dependable and would set a trouble code if defective.

Engine/Motor-Generator Wet Clutch Service

Large engine/motor-generator wet clutches are larger versions of the wet clutch sets found in automatic transmissions. The wet clutches in a hybrid transmission use hydraulic pressure, not spring pressure, to clamp several friction discs together to lock the motor-generator shaft or engine crankshaft for propulsion or HV battery recharging.

Your scan tool will help retrieve trouble codes to pinpoint many problems with the motor-generator, its clutches, and transmission. If the clutches are slipping, vehicle road speed (transmission shaft speed sensor) will not match engine speed, which can set a trouble code informing you of the clutch slippage. You might also have trouble codes for clutch system sensors and actuators. Perform pinpoint tests before determining that any part of an engine/motor-generator clutch mechanism has failed.

Automated Manual Clutch Service

An automated clutch uses the vehicle's main control module to automatically operate the clutch and engage each helical gear ratio in response to vehicle speed, engine speed, engine vacuum (load), engine temperature, throttle opening, and gear position selected by the driver. Again, late-model vehicles have extensive on-board diagnostics.

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For more information on automated clutch service, refer to the text index for more information on hybrid transmissions, torque converters, and automatic transmission wet clutch operation and service.



Diagnostic Case Study

Concern: Mrs. Tyner brings her 2005 Mustang to the shop. She complains of a slipping clutch. When asked to describe the symptoms, she says the engine revs up without giving her additional power. She also describes a burning smell.

Cause: Duff test-drives the car and experiences a badly slipping clutch. Engine speed increases without a corresponding increase in vehicle speed. The condition is especially evident during hard acceleration and in high gears. Duff checks the clutch cable adjustment but finds normal play at the clutch release lever.

Duff turns the car over to the shop's transmission and clutch technician. The technician removes the drive shaft, transmission, and clutch from the vehicle. He discovers that the clutch disc is worn down to the rivets. The rivets have ground grooves into the flywheel and pressure plate.

Correction: The technician removes the flywheel and sends it to a machine shop for resurfacing. When the resurfaced flywheel is returned from the machine shop, the clutch assembly is reinstalled with a new pilot bearing, throw-out bearing, friction disc, and pressure plate. When Mrs. Tyner comes in to pick up her car, Duff tactfully advises her to make sure she takes her foot all the way off the clutch pedal between shifts.

- Clutch slippage causes the engine to race (engine speed increases quickly) without an increase in the vehicle's road speed.
- A grabbing or chattering clutch produces a very severe vibration or jerking motion when the vehicle is accelerated from a standstill.
- With a dragging clutch, the transmission or transaxle grinds when trying to engage or shift gears.
- A pulsating clutch pedal is normally caused by the runout (wobble or vibration) of one of the rotating components of the clutch assembly.
- A stiff clutch pedal results from a problem with one of the parts involved in clutch release: linkage, cable, hydraulic components, over-center spring, clutch fork, throw-out bearing, or pressure plate.
- Clutch adjustment involves setting the correct amount of free play in the three basic types of clutch release mechanisms: clutch linkage, clutch cable, and hydraulic clutch release mechanism.
- Transmission or transaxle removal is needed to service a clutch. Always follow the detailed directions in the service manual.
- The friction disc is replaced anytime the clutch is torn down for repairs.
- Install a clutch in the reverse order of removal.
- An automatic engine clutch uses computer control and several control modules to operate a conventional clutch or a set of wet clutches.
- The wet clutches in a hybrid transmission use hydraulic pressure (not spring pressure) to clamp several friction discs together to lock the motor-generator shaft or engine crankshaft for propulsion or HV battery recharging.

Summary

- Stop-and-go driving and driver abuse are common causes of premature clutch trouble.
- Common clutch part failures include a worn clutch disc, flywheel with surface cracks or warped areas, bad throw-out bearing, bad pressure plate, and worn pilot bearing.
- Free travel (free play) is the distance the clutch pedal or clutch fork moves before the throw-out bearing acts on the pressure plate. Free travel is needed to ensure complete clutch engagement.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

automatic engine clutch
bleeding
chattering clutch
clutch adjustment
clutch slippage
dragging clutch
free travel
grabbing clutch
pilot shaft
pulsating clutch pedal
race
stiff clutch pedal

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Activities

1. Study damaged and worn clutch parts and try to determine why they failed.
2. Study a shop manual for manual clutch service. Demonstrate to your instructor the proper procedure for removal and disassembly.

Review Questions

Answer the following questions using the information provided in this chapter.

1. A driver complains of a grinding sound when the clutch pedal is pressed. Otherwise, clutch operation is normal. Technician A says that the clutch lining is worn, resulting in metal-on-metal contact. The transmission and clutch will require removal for disc replacement. Technician B says that the problem could be a worn, dry throw-out bearing. The bearing is grinding when the clutch fork pushes the bearing into the spinning pressure plate. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Define the term clutch pedal "free play."
3. What are the symptoms of clutch slippage?
4. How do you check for clutch slippage?
5. A(n) _____ clutch, produces a very severe vibration or jerking motion when the vehicle is accelerated from a standstill.
6. A dragging clutch makes the transmission or transaxle gears grind during shifting. True or False?
7. Describe some causes of a dragging clutch.
8. What is the common cause of a pulsating clutch pedal?
9. Clutch disc lining may contain _____, which is a known cancer-causing substance.
10. A hydraulic clutch release mechanism requires bleeding after major repairs. True or False?
11. Why should you disconnect the car battery when servicing a clutch?
12. What precautions should you take when cleaning clutch parts prior to reinstalling them?
13. Describe how to remove and install a pilot bearing.
14. Normally, the _____ is replaced anytime the clutch is torn down for repairs.
15. Why should you use an alignment tool or pilot shaft when installing a clutch?
16. The wet clutches in a _____ transmission use hydraulic pressure to clamp friction discs together to lock the motor-generator shaft or engine crankshaft.

ASE-Type Questions

1. A car is brought into the shop with a worn clutch. Technician A tells the owner of the car that highway driving will wear out a clutch faster than city driving. Technician B tells the owner that city driving wears out a clutch faster than highway driving. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. The clutch in a manual transmission vehicle is dragging. Technician A says that excessive clutch free travel can produce this problem. Technician B says that damaged transmission input shaft splines can cause this problem. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. An automobile is brought into the shop with "clutch pedal vibration." Technician A says pedal vibration may be due to improper clutch adjustment. Technician B says clutch pedal vibration is a normal operating condition of the clutch assembly. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. A manual transmission has a "clutch slippage" problem. Technician A says this condition may be caused by damaged clutch linkage. Technician B says this problem may be caused by a worn pressure plate. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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5. A clutch is being tested for slippage. Technician A says when performing this test, the emergency brake should be engaged. Technician B says when testing a clutch for slippage, the car's transmission should be placed in high gear. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. A clutch is being tested for slippage. Technician A says you shouldn't let the clutch slip for more than one or two seconds during this test. Technician B says you shouldn't let the clutch slip for more than ten to fifteen seconds during this test. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. The shop's service writer wants a clutch slippage problem diagnosed. Technician A checks for a broken motor mount. Technician B checks for a binding clutch linkage. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. An automobile with a clutch "free play" problem is brought into the shop. Technician A checks clutch free play at the clutch fork. Technician B checks clutch free play at the clutch pedal. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. An automobile has a "stiff" clutch pedal. Technician A says this problem can be caused by a faulty throw-out bearing. Technician B says this problem can be caused by a pressure plate malfunction. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. An automobile's clutch has too much "free play." Technician A says this problem can cause clutch slippage. Technician B says this problem can cause clutch dragging. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
11. A manual transmission's input shaft and clutch disc wobble up and down. Technician A says this problem is probably the result of a damaged clutch housing cover. Technician B says this problem is probably the result of a worn pilot bearing. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
12. An automotive clutch assembly needs to be removed from an automobile. Technician A disconnects the car's battery before performing this task. Technician B disconnects the clutch linkage before performing this task. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
13. The parts of a clutch assembly are being inspected and cleaned. Technician A says during this procedure you should clean the throw-out bearing in cleaning solvent. Technician B says during this procedure the throw-out bearing should be cleaned only with a shop rag. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
14. Technician A is using compressed air to remove clutch dust from a clutch disc. Technician B is using an enclosed vacuum to remove clutch dust from a clutch disc. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
15. A clutch grabs when the car is accelerated. Technician A checks the condition of the engine's flywheel. Technician B inspects the clutch pedal return spring. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Clutch Diagnosis

Condition	Possible Causes	Correction
Clutch slips.	1. Insufficient pedal free travel. 2. Disc facing soaked with oil or grease. 3. Broken or weak pressure plate spring or springs. 4. Worn clutch disc facing. 5. Sticking hydraulic or mechanical linkage.	1. Adjust free travel. 2. Correct source of oil contamination. Clean clutch and pressure plate. Replace disc. 3. Rebuild or replace pressure plate. 4. Replace clutch disc. 5. Clean, align, and lubricate linkage.
Clutch chatters and/or grabs.	1. Oil- or grease-soaked clutch disc facing. 2. Burned clutch disc facing. 3. Warped or worn clutch disc. 4. Warped pressure plate. 5. Scored pressure plate or flywheel surface. 6. Binding pressure plate fingers. 7. Clutch housing-to-transmission surface out of alignment with crankshaft centerline. 8. Sticking linkage. 9. Worn pilot bearing. 10. Improperly adjusted pressure plate release fingers. 11. Loose or worn engine mounts. 12. Loose transmission. 13. Loose rear spring shackles or axle housing control arms. 14. Worn splines on transmission input shaft. 15. Faulty throw-out bearing.	1. Replace clutch disc. Correct source of leak. 2. Replace clutch disc. 3. Replace clutch disc. 4. Grind or replace pressure plate. 5. Grind or replace pressure plate or flywheel. 6. Free fingers. 7. Align or replace housing. 8. Free linkage. 9. Install new pilot bearing. 10. Adjust fingers. 11. Tighten or replace mounts. 12. Tighten transmission fasteners. 13. Tighten shackles or replace control arm insulators and tighten. 14. Replace input shaft. 15. Replace throw-out bearing.
Clutch will not release properly.	1. Excessive pedal free travel. 2. Warped clutch disc. 3. Clutch facing torn loose and folded over. 4. Warped pressure plate. 5. Misaligned clutch housing. 6. Clutch disc hub binding on transmission input shaft. 7. Worn pilot bearing. 8. Faulty throw-out bearing. 9. Throw-out fork off pivot. 10. Clutch disc is frozen (corroded) to flywheel and pressure plate. 11. Excessive idle speed.	1. Adjust pedal travel. 2. Replace clutch disc. 3. Replace clutch disc. 4. Grind or replace. 5. Align housing. 6. Free hub. 7. Replace pilot bearing. 8. Replace throw-out bearing. 9. Install fork properly. 10. Replace disc and clean flywheel and pressure plate. 11. Adjust idle speed.
Clutch is noisy when pedal is depressed—engine running.	1. Dry or worn throw-out bearing. 2. Worn pilot bearing. 3. Excessive total pedal travel. 4. Throw-out fork off pivot. 5. Misaligned clutch housing. 6. Excessive crankshaft end play.	1. Replace bearing. 2. Replace pilot. 3. Adjust pedal travel. 4. Install fork correctly. 5. Align housing. 6. Correct end play.

Continued

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Clutch Diagnosis

Condition	Possible Causes	Correction
Clutch is noisy when pedal is depressed—engine not running.	1. Dry, sticking linkage. 2. Dry or scored throw-out bearing sleeve. 3. Pressure plate drive lugs rubbing clutch cover.	1. Lubricate and align linkage. 2. Lubricate or replace. 3. Lubricate with high temperature grease.
Clutch noisy when pedal is fully released—engine running.	1. Insufficient pedal free travel. 2. Worn clutch disc. 3. Broken clutch disc springs. 4. Misaligned clutch housing. 5. Worn clutch disc hub splines. 6. Worn input shaft splines. 7. Sprung input shaft. 8. Worn input shaft transmission bearing.	1. Adjust free travel. 2. Replace clutch disc. 3. Replace clutch disc. 4. Align housing. 5. Replace clutch disc. 6. Replace input shaft. 7. Replace input shaft. 8. Replace transmission bearing.
Excessive pedal pressure.	1. Dry, sticking linkage. 2. Binding pressure plate release fingers. 3. Linkage misaligned. 4. Throw-out bearing sleeve binding on transmission bearing retainer. 5. Sticking linkage in master or slave cylinder.	1. Lubricate linkage. 2. Free and lubricate. 3. Align linkage. 4. Free and lubricate retainer. 5. Clean or replace as needed.
Rapid clutch disc wear.	1. Insufficient pedal free travel. 2. Scored flywheel or pressure plate. 3. Driver “rides” the clutch. 4. Driver races engine and slips clutch excessively during starting. 5. Driver holds vehicle on hill by slipping clutch. 6. Weak pressure plate springs.	1. Adjust free travel. 2. Resurface or replace. 3. Advise driver. 4. Advise driver. 5. Advise driver. 6. Rebuild or replace pressure plate assembly.

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Chapter 63
Manual Transmission Technology

After studying this chapter, you will be able to:

- Describe gear operating principles.
- Identify and define all the major parts of a manual transmission.
- Explain the fundamental operation of a manual transmission.
- Compare the construction of different types of manual transmissions.
- Trace the power flow through transmission gears.
- Explain the purpose and operation of a transmission overdrive ratio.
- Correctly answer ASE certification test questions requiring a knowledge of manual transmission operating principles.

Automatic transmissions use hydraulic pressure and sensing devices to shift gears—engine speed and load are detected and used to determine shift points. Automatic transmissions also use a fluid coupling instead of a clutch. A ***manual transmission*** must be shifted by hand to change the amount of torque going to various parts of the drivetrain. It is normally bolted to the clutch housing at the rear of the engine.

A ***transaxle*** combines both the transmission and the differential into a single housing. It is commonly used in front-wheel-drive vehicles. A transaxle can contain either a manual or an automatic transmission.

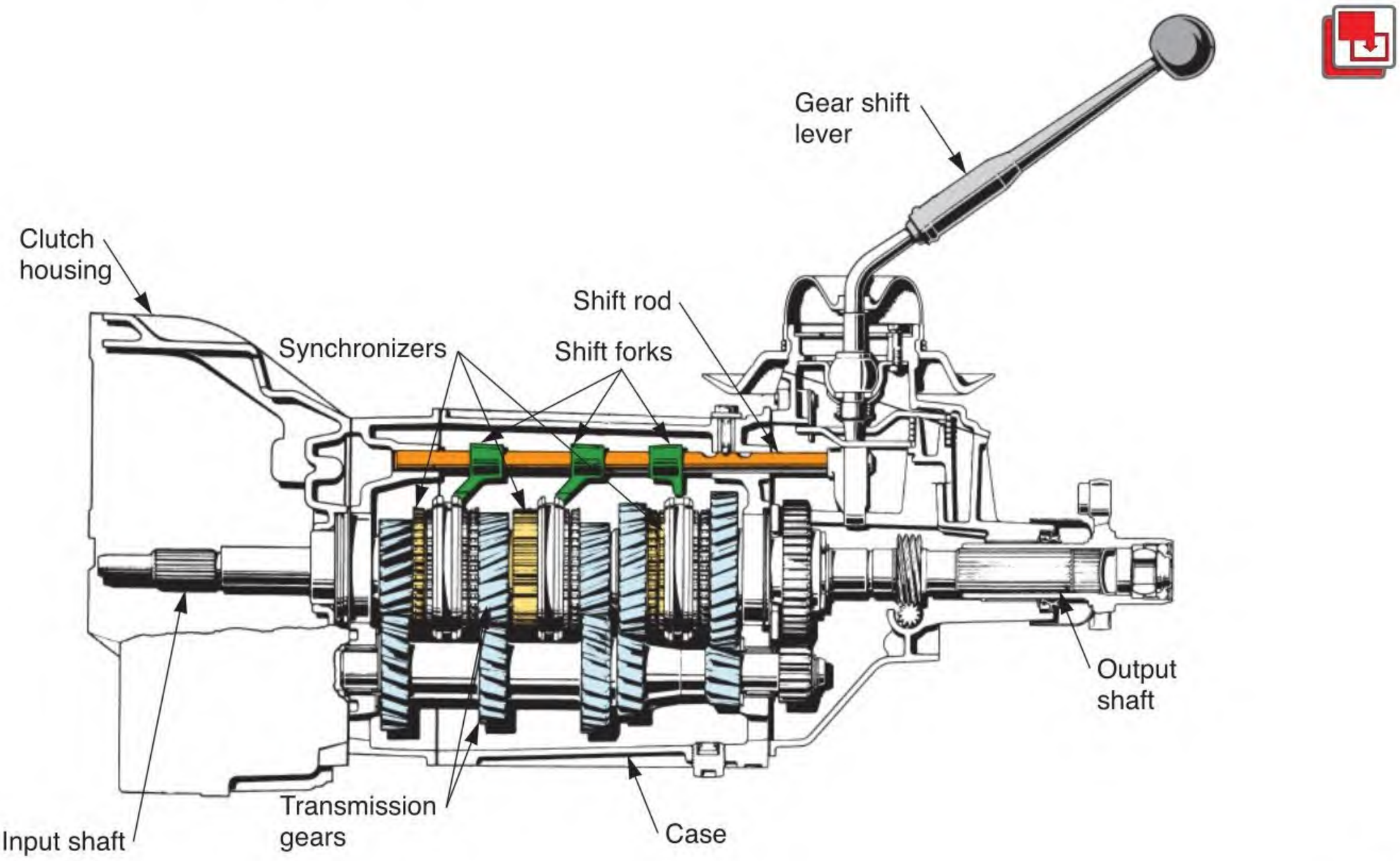
As you have learned, the clutch disc rotates the transmission input shaft using torque from the gas engine or motor-generator. Gears inside the transmission transfer this power in the form of torque rotating the vehicle's drive wheels. A shift lever (or paddle shift buttons) allows the driver to select which set of manual transmission gears to engage. A manual transmission that uses electronic or automated shifting can automatically engage the clutch for gear changes. New designs allow for uninterrupted power flow through the driveline as gear changes are initiated by the manual transmission control module.

Basic Transmission Parts

To understand later sections of the chapter, study the parts of the manual transmission in **Figure 63-1**. Learn to identify and locate the fundamental components. This knowledge will prepare you for more specific details of transmission construction and operation. The basic parts of a manual transmission include:

- ***Input shaft***—Operated by the clutch, this shaft turns the helical gears inside the transmission.

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Figure 63-1. Study the basic parts of a manual transmission.

- ***Transmission gears***—These gears provide a means of changing output torque and speed of the transmission output shaft.
- ***Synchronizers***—These devices make the two matching helical gears spin at the same speed so they can be locked to the output shaft for engagement.
- ***Shift forks***—Shift forks are pronged mechanisms that move gears or synchronizers onto their shafts for gear engagement.
- ***Shift linkage***—Linkage includes arms, rods, cables, or hydraulic circuits that connect the shift lever to the shift forks.
- ***Gear shift lever***—This lever allows the driver to change transmission gear ratios after depressing the clutch pedal.
- ***Output shaft***—This steel shaft transfers rotating torque out of the transmission to the remainder of the transmission driveline.
- ***Transmission case***—This housing encloses the transmission shafts, gears, synchronizers, shift rods or forks, and lubricating oil.

Purpose of a Manual Transmission

A manual transmission is designed to change the vehicle's drive wheel speed and torque in relation to engine speed and torque. Without a transmission, the engine would not develop enough power to accelerate the vehicle from a standstill. The engine would stall as soon as the clutch was engaged. Just as if you try to take off in fifth or sixth gear, the engine will stall out when the clutch pedal is released.

With a transmission in low (first) gear, the engine crankshaft must turn several times to make the drive shaft and wheels turn once. This increases the torque going to the wheels, but reduces vehicle speed. First gear typically takes the vehicle up to about 20 mph before you need to shift into second gear.

As the transmission is shifted through the gears and into high, the engine and drive shaft begin to turn at approximately the same speed. Wheel and vehicle speed increases, while engine speed drops. Little torque is needed to keep the vehicle moving at highway speeds on level ground.

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A manual transmission in proper operating condition should:

- Be able to increase torque going to the drive wheels for quick acceleration.
- Supply different gear ratios to match different engine load conditions.
- Have a reverse gear for moving backwards.
- Provide the driver with an easy means of shifting transmission gears.
- Allow downshifting into any gear while the vehicle is moving, with all gears synchronized.
- Operate quietly, with minimum power loss.

Gear Fundamentals

Gears are round wheels with teeth machined on their perimeters (rims). They are used to transmit turning effort from one shaft to another. Basically, one gear is used to turn another gear. When the gears are different sizes, the output speed and torque (turning power) change. This is illustrated in **Figure 63-2**.

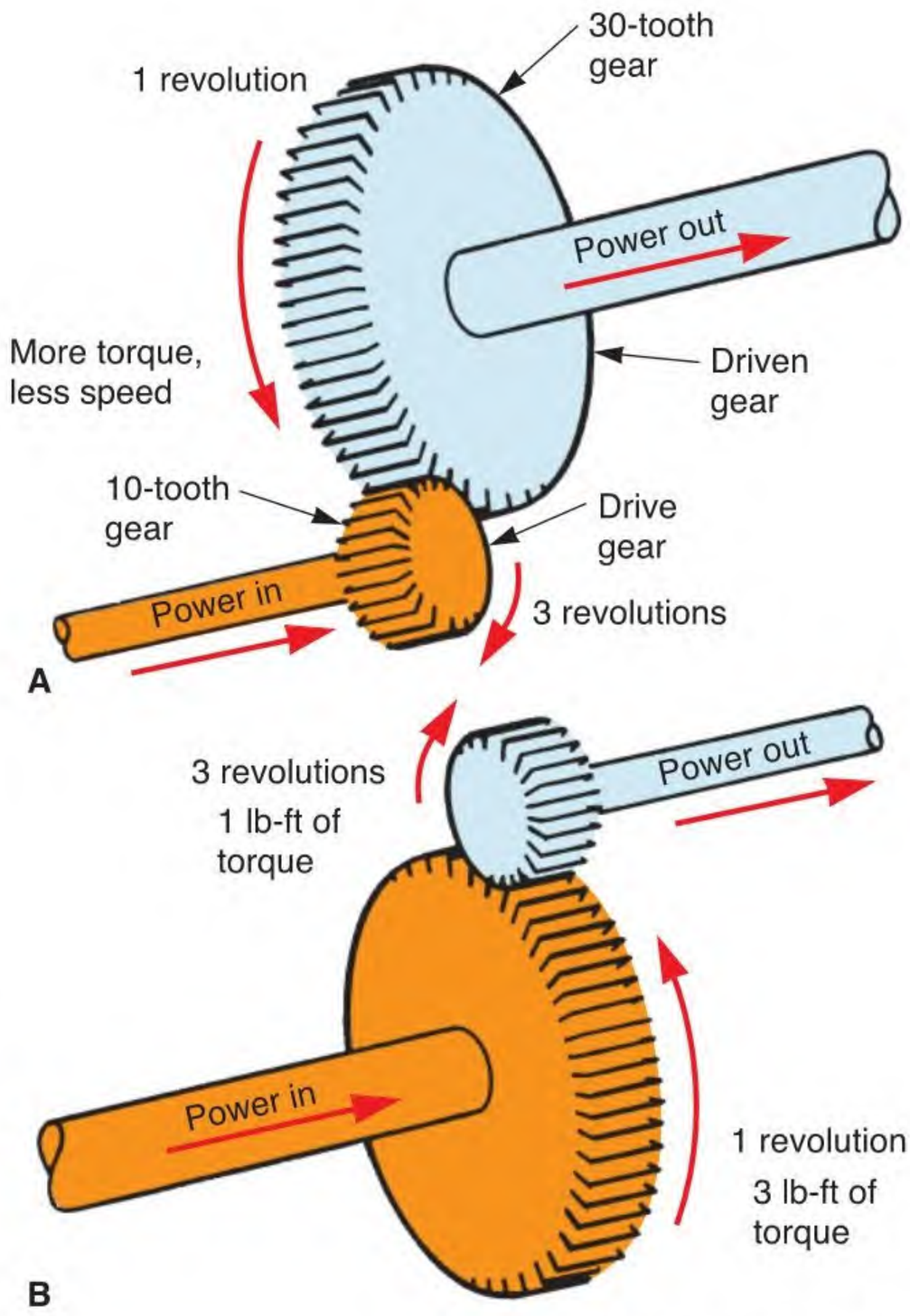
Gear Ratios

A ***gear ratio*** is the number of revolutions a drive gear must turn before the driven gear completes one revolution. Gear ratio is calculated by dividing the number of teeth on the driven gear by the number of teeth on the drive gear. See **Figure 63-3**. If the drive gear has 12 teeth and the driven gear has 24 teeth, the gear ratio is *two-to-one* (24 divided by 12), written 2:1. In this example, the drive gear would have to revolve two times to turn the driven gear once. As a result, the speed of the larger, driven gear would be half that of the drive gear. However, the torque on the shaft of the larger gear would be twice that of the input shaft.

Various sizes of drive and driven gears can be used to produce any number of gear ratios. As the number of teeth on the driven gear increase in relation to the number of teeth on the drive gear, the gear ratio increases. For example, a gear ratio of 10:1 is larger than a ratio of 5:1.

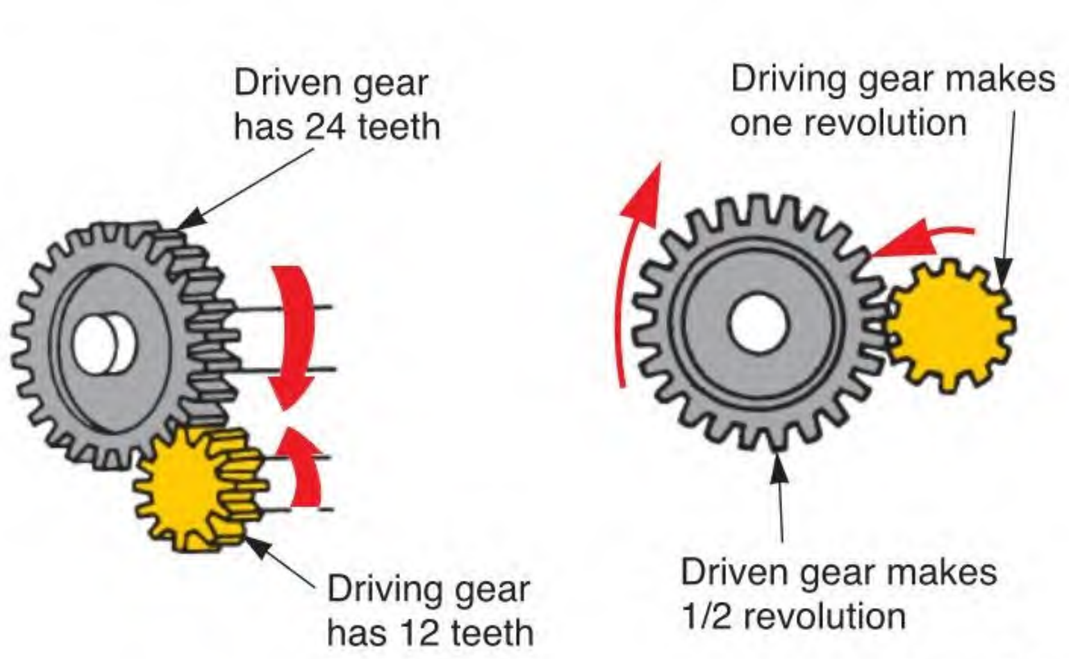
Transmission gear ratios vary from one manufacturer to another. However, approximate gear ratios are: 3:1 for first gear, 2:1 for second gear, 1:1 for third (or high) gear, and 3:1 for reverse gear.

First (low) gear has a high gear ratio—a small gear drives a larger gear. This reduces output speed, but increases output torque. The car accelerates



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Figure 63-2. A—When a small gear drives a larger gear, it increases torque output but reduces rotating speed of output. B—When a large gear drives a smaller gear, torque is reduced but rotating speed is increased.



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Figure 63-3. Gear ratio is determined by the number of teeth on the perimeter of the gears. If the drive gear has half as many teeth as the driven gear, a two-to-one (2:1) gear ratio is produced.

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easily, even with low engine speed and low power conditions.

In high gear, the transmission often has a 1:1 gear ratio. The transmission output shaft spins at the same speed as the engine crankshaft. There is no ***torque multiplication*** (increase in turning force), but the vehicle travels faster at relatively low engine speeds. Very little torque is needed to propel a vehicle at a constant speed on level ground.

Gear Reduction and Overdrive

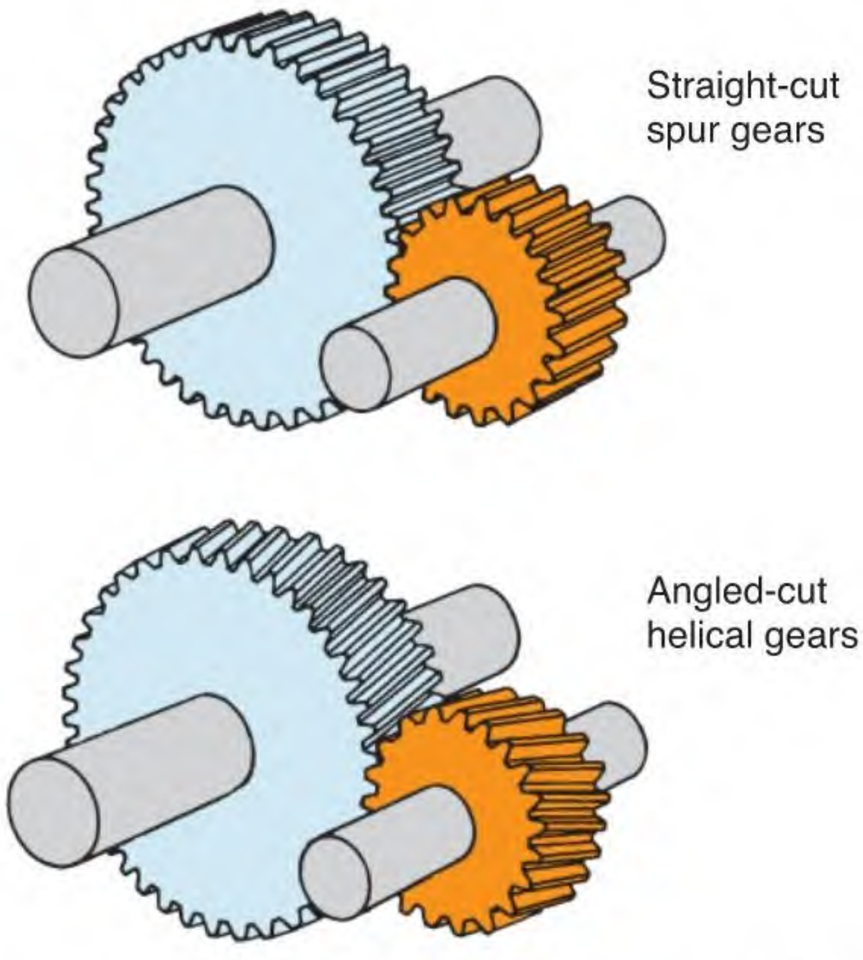
Gear reduction occurs when a small gear drives a larger gear to increase turning force, or torque. Gear reduction is used in the lower transmission gears.

An ***overdrive ratio*** results when a larger gear drives a smaller gear. The speed of the output gear increases, but torque drops.

Gear Types

Manual transmissions commonly use two types of gears: spur gears and helical gears. See **Figure 63-4**.

The teeth on ***spur gears*** are cut parallel to the centerline of the gear shaft. Spur gears are sometimes called *straight-cut gears*. Straight-cut spur gears reduce friction for increasing efficiency, but suffer "gear whine" (a loud, low-frequency whirring noise) as the parallel-cut teeth make contact with each other. These gears are no longer used as the main drive gears in a transmission. They may be used for the sliding (moves sideways) reverse gear, however.



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Figure 63-4. The two basic types of gears used in manual transmissions are straight-cut spur gears and angled-cut helical gears.

The teeth on ***helical gears*** are machined at an angle to the centerline of the gear shaft. Modern transmissions commonly use helical gears as the main drive gears. Helical gears are quieter and stronger than spur gears.

Manual Transmission Lubrication

The bearings, shafts, gears, and other moving parts in a transmission are lubricated by oil throw-off, or ***splash lubrication***. As the gears rotate, they sling oil around inside the transmission case.

Typically, 80W or 90W ***gear oil*** is recommended for use in a manual transmission. However, follow the manufacturer's recommendations.

Gear backlash is the small clearance between the meshing gear teeth. Backlash allows lubricating oil to enter the high-friction area between the gear teeth. This reduces friction and wear. Backlash also allows the gears to expand during operation without binding or damage.

Transmission Bearings

Bearings are used to reduce the friction between the surfaces of rotating parts in the transmission. Manual transmissions normally use four basic types of bearings: ball bearings, roller bearings, needle bearings, and bushings. These are shown in **Figure 63-5**.

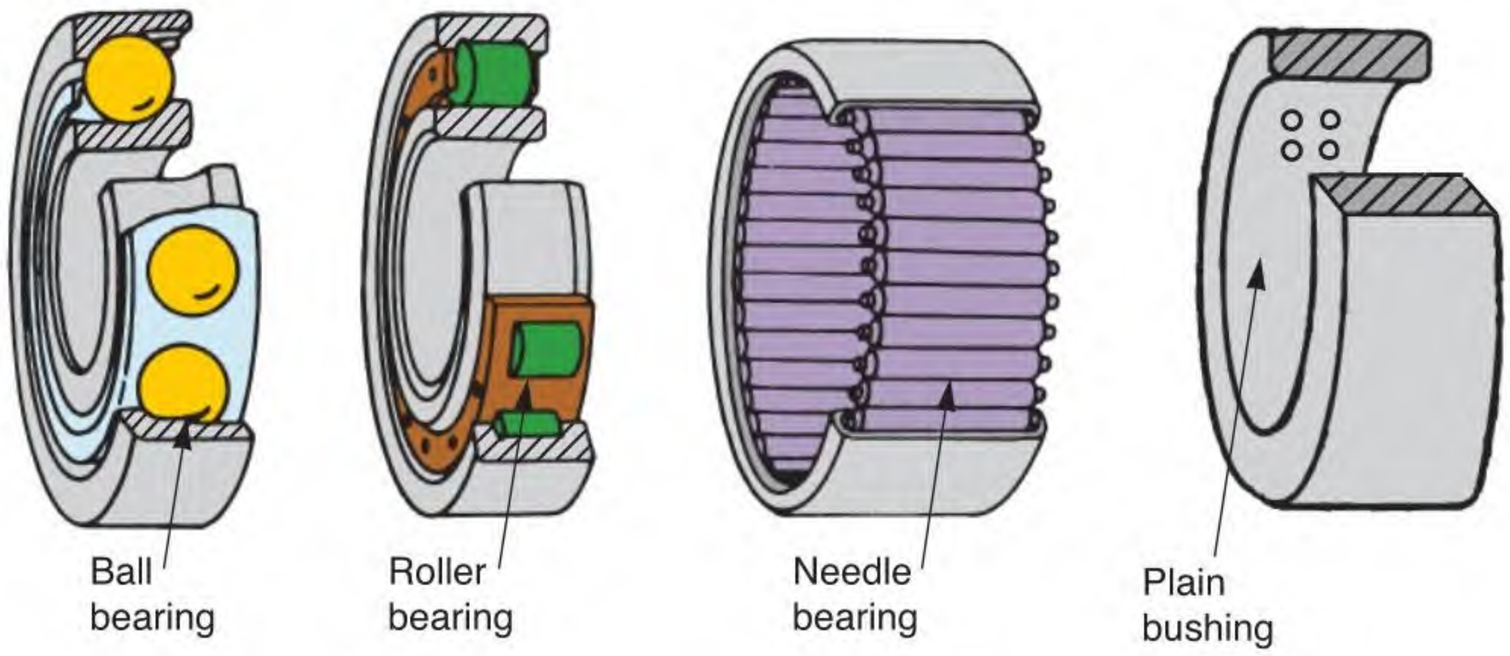
Bearings are lubricated by oil thrown off of the spinning transmission gears. Some of the new automated manual transmissions use an oil pump to force-feed lubricant to manual transmission bearings, and hydraulic pistons for gear engagement.

Typically, ***antifriction bearings*** (bearings that use rolling action) fit between the transmission shafts and the housing, or between some of the gears and the shafts. These are high-friction points that must be capable of withstanding the power of the engine or motor-generator. A plain bearing or bushing is often used on the end of the output shaft to support the drive shaft.

Manual Transmission Construction

Now that you have a general grasp of gear and transmission principles, we will assemble each part of

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Figure 63-5. Four types of antifriction bearings are found in transmissions: ball, roller, needle, and bushings.

a working transmission. We will start with the case, and then install the shafts, gears, bearings, and other parts.

Transmission Case

The transmission case is the center section of a transmission and must support the transmission bearings and shafts, and provide an enclosure for gear oil. Refer to **Figure 63-6**. A manual transmission case is usually made of cast iron or aluminum. Aluminum is becoming more common because of its light weight.

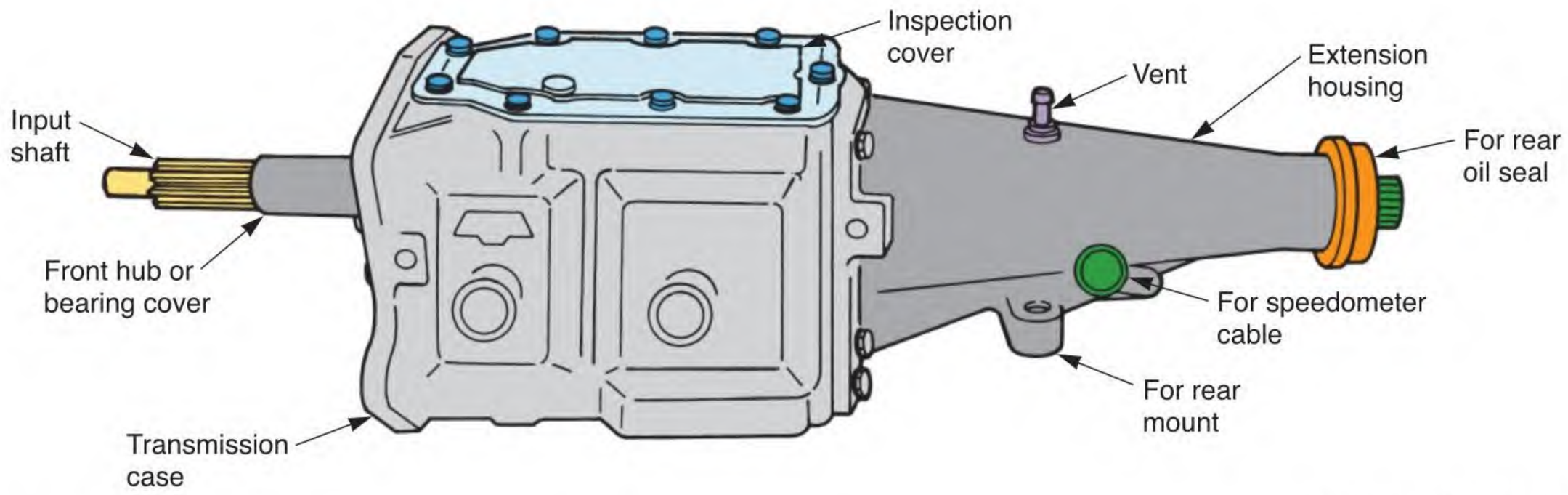
A drain plug and a fill plug are usually provided in the transmission case. The drain plug is on the bottom of the case, and the fill plug is on the side of the case. The fill plug also serves as a means of checking the oil level in the transmission. Typically, the oil level should be even with the bottom of the fill plug hole when the transmission is at operating temperature.

Extension Housing and Front Bearing Hub

The ***extension housing***, also called the ***tail shaft housing***, bolts to the rear of the transmission case. It encloses the transmission output shaft and holds the rear oil seal. See **Figure 63-6**.

A flange on the bottom of the extension housing provides a base for the rubber transmission mount, or rear motor mount. A gasket usually seals the mating surfaces between the transmission case and the extension housing.

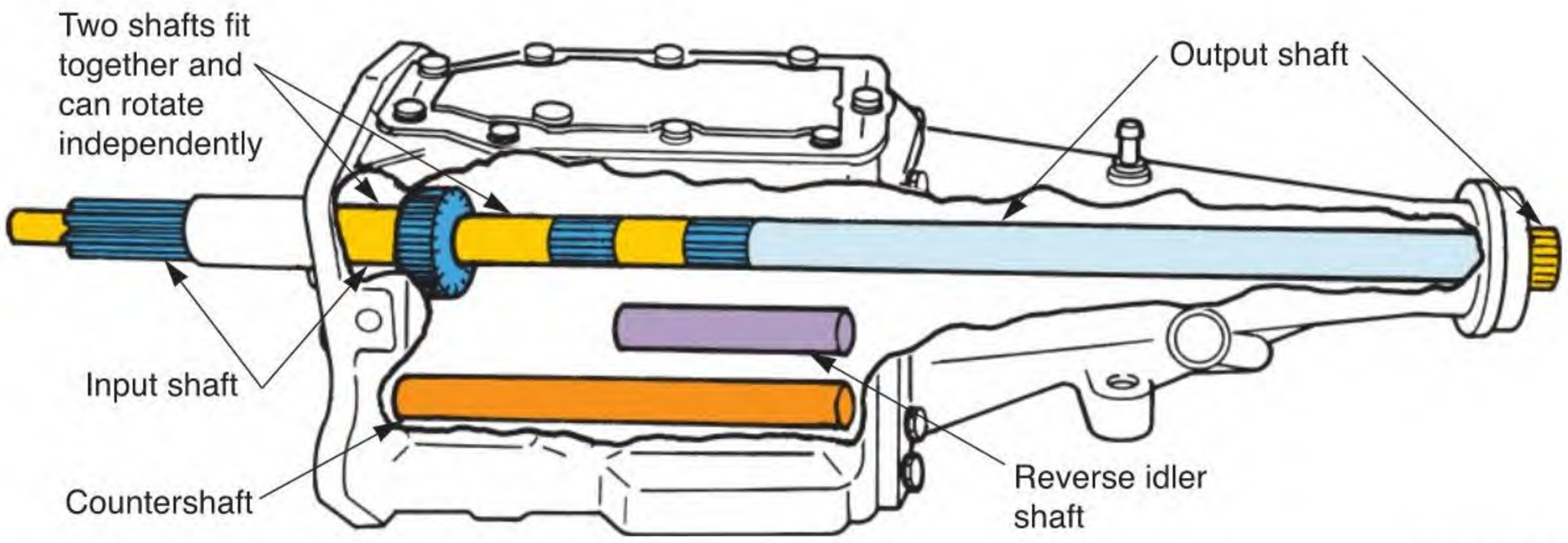
A ***front bearing hub***, sometimes called ***front bearing cap***, covers bolts to the ***front transmission bearing*** and acts as a sleeve for the clutch throw-out bearing. It bolts to the transmission case and supports the spinning input shaft. A gasket fits between the front hub and the case to prevent oil leakage.



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Figure 63-6. Common design of a transmission case. This transmission has a sheet metal inspection cover bolted to the top of the case.

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Figure 63-7. Note how transmission shafts are located in the transmission case. The input shaft is driven by the clutch. The output shaft is on the same centerline as the input shaft. The countershaft and reverse idler shaft mount below and to one side in the case.

Transmission Shafts

A manual transmission normally has four steel shafts mounted inside its case: an input shaft, a countershaft, a reverse idler shaft, and an output shaft. See **Figure 63-7**. **Figure 63-8** shows the components associated with these four shafts.

The input shaft, often termed ***clutch shaft***, transfers rotation from the clutch disc to the countershaft gears in the transmission. The outer end of the shaft is splined. The inner end of the shaft has a gear machined on it. A bearing in the transmission case supports the input shaft in the case. Anytime the clutch disc turns, the input shaft gear turns.

The ***countershaft***, also called ***cluster gear shaft***, holds the countershaft gear into mesh with the input gear and other gears in the transmission. It is located slightly below and to one side of the input shaft, **Figure 63-9**. Normally, the countershaft does not turn—it is locked in the case by either a steel pin, a force fit, or lock nuts. A long countershaft gear rotates on the countershaft to transfer torque from the input shaft gear to the output shaft gears.

The ***reverse idler shaft*** is a short shaft that supports the reverse idler gear. It normally mounts in the case, midway between the countershaft and the output shaft. Refer to **Figures 63-7** and **63-8**. In this position, the reverse idler gear can mesh with gears on both the countershaft and output shaft.

The transmission output shaft, or ***main shaft***, holds the output gears and synchronizers. The rear of this shaft extends to the back of the extension housing and connects to the drive shaft to turn the wheels of the vehicle. The output shaft is splined in the center. In modern transmissions, the gears are free to revolve on the output shaft, but the synchronizers are locked on the shaft by splines. The synchronizers only turn when the shaft itself turns.

Transmission Gears

Transmission gears can be typically classified into four groups: input shaft gear, countershaft gear, reverse idler gear, and output shaft gears.

The input shaft gear turns the countershaft gears. The countershaft gears turn the output shaft gears and reverse idler gear, **Figure 63-9**.

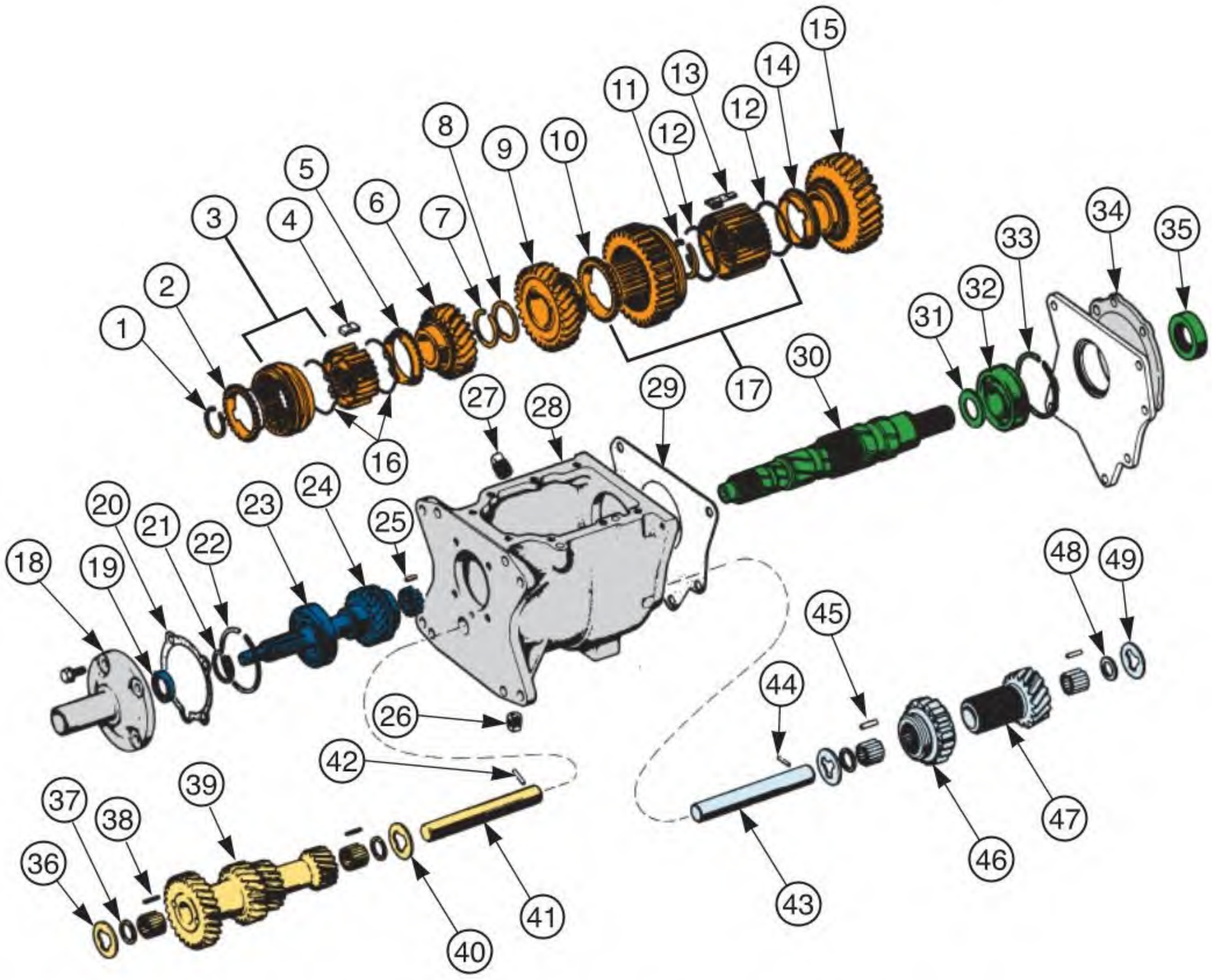
In low gear, a small gear on the countershaft drives a larger gear on the output shaft. This provides a high gear ratio for accelerating, **Figure 63-10A**. In high gear, a larger countershaft gear drives an equal-size or smaller output shaft gear. This reduces the gear ratio, and the vehicle moves faster. See **Figure 63-10B**.

When in reverse, power flows from the countershaft gear to the reverse idler gear. Power is then transferred from the reverse idler gear to the engaged gear on the output shaft. This reverses output shaft rotation, as shown in **Figure 63-10C**.

Input Gear

The transmission ***input gear*** is a machined part of the steel input shaft. The input gear drives the forward gear on the countershaft gear. A small spur gear is usually located next to the main helical drive gear. This small gear is used for synchronizer engagement. **Figure 63-11** shows an input gear with its related parts. Study the shape and relationship of each component carefully.

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1. 3rd–4th gear snap ring
2. 4th gear synchronizer ring
3. 3rd–4th gear clutch assembly
4. 3rd–4th gear plate
5. 3rd gear synchronizer ring
6. 3rd speed gear
7. 2nd gear snap ring
8. 2nd gear thrust washer
9. 2nd speed gear
10. 2nd gear synchronizer ring
11. Main shaft snap ring
12. 1st–2nd synchronizer spring
13. Low–2nd plate
14. 1st gear synchronizer ring
15. 1st gear
16. 3rd–4th synchronizer spring
17. 1st–2nd gear clutch assembly
18. Front bearing cap
19. Oil seal
20. Gasket
21. Snap ring
22. Lock ring
23. Front ball bearing
24. Input shaft
25. Roller bearing
26. Drain plug
27. Fill plug
28. Case
29. Gasket
30. Output shaft
31. 1st gear thrust washer
32. Rear ball bearing
33. Snap ring
34. Adapter plate
35. Adapter seal
36. Front countershaft gear thrust washer
37. Roller washer
38. Rear roller bearing
39. Countershaft gear
40. Rear countershaft thrust washer
41. Countershaft
42. Pin
43. Reverse idler shaft
44. Pin
45. Idler gear roller bearing
46. Reverse idler sliding gear
47. Reverse idler gear
48. Idler gear washer
49. Idler gear thrust washer

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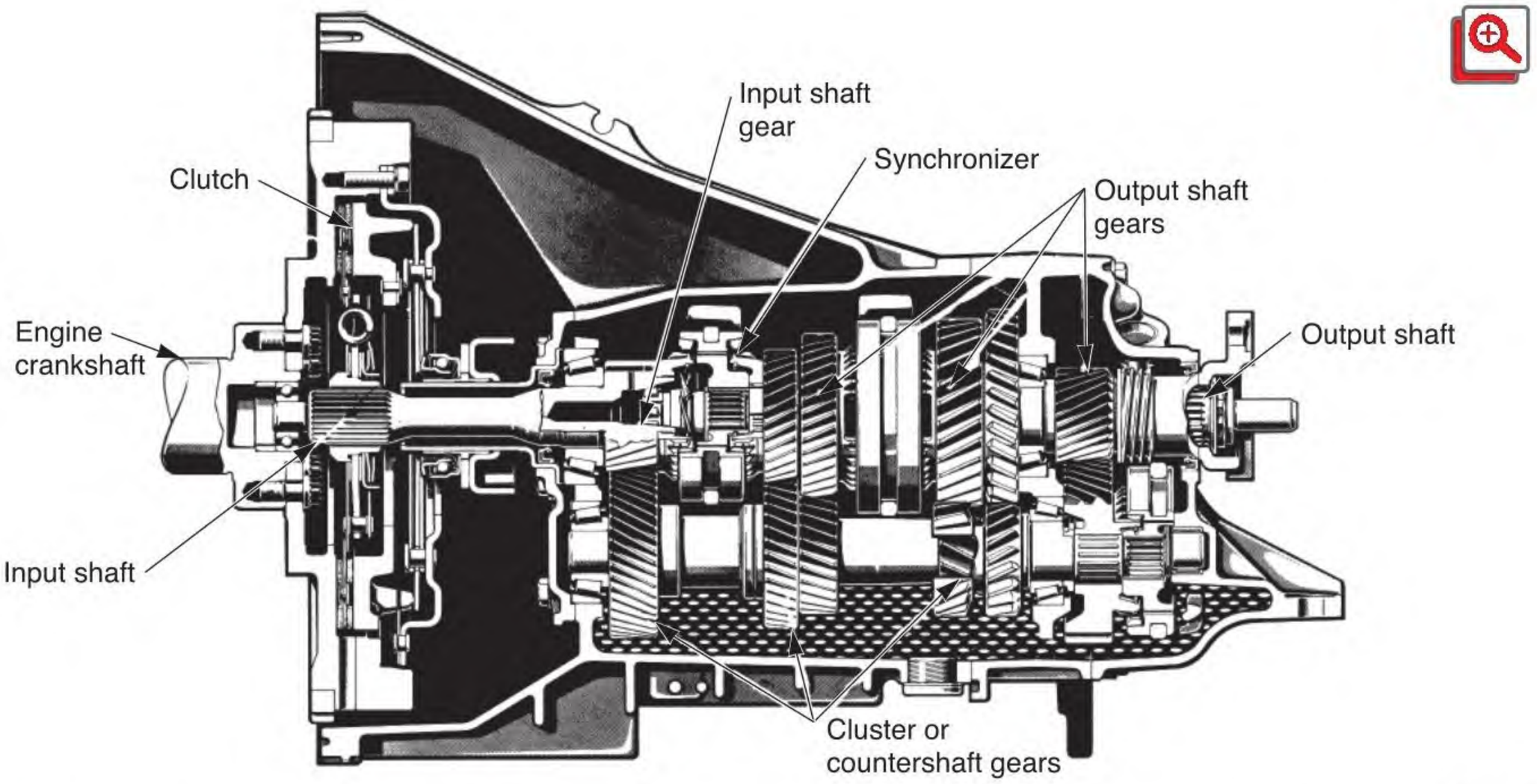
Figure 63-8. This exploded view shows the major parts of a typical transmission. Note the four shafts and components.

Countershaft Gear

The ***countershaft gear***, or ***counter gear***, turns the gears on the output shaft. This gear is actually several gears machined out of a single piece of steel. It is often called the ***cluster gear***.

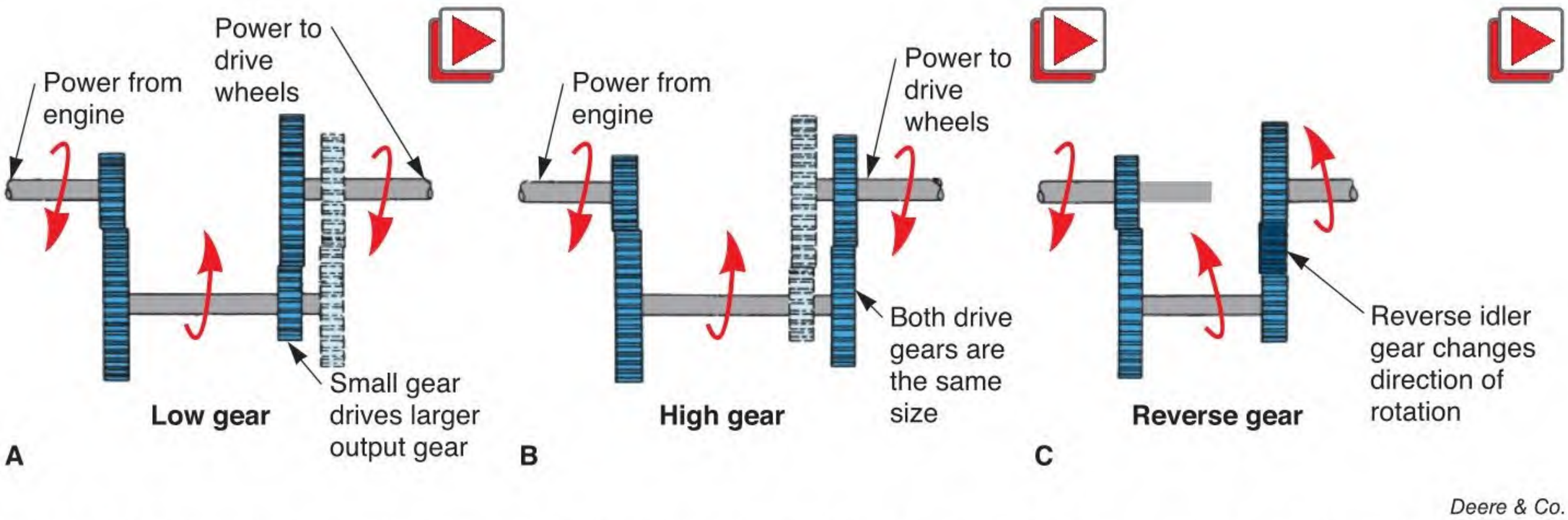
Each gear on the countershaft provides one forward gear ratio in a manual transmission. The countershaft gear rides on roller bearings. Thrust washers fit on each end of the gear to set end play or case-to-gear clearance. See **Figure 63-12**. When the input gear drives the engaged countershaft gear, all the countershaft gears turn as a unit. However, since each forward gear is a different size, the countershaft gear unit is capable of providing several gear ratios.

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Figure 63-9. Cutaway view of a transmission shows gears assembled on their shafts. The gear on the input shaft drives the countershaft gears. Countershaft gears turn the gears on the output shaft.



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Figure 63-10. Simplified transmission action. A—Low gear. The input shaft gear turns the countershaft gears. A small countershaft gear drives a larger output shaft gear, producing gear reduction. B—High gear. Engaged gears are the same size. Less torque is needed. C—Reverse. The reverse idler gear is used between the countershaft gear and the output shaft gear. This reverses the rotation direction of the output shaft.

Reverse Idler Gear Assembly

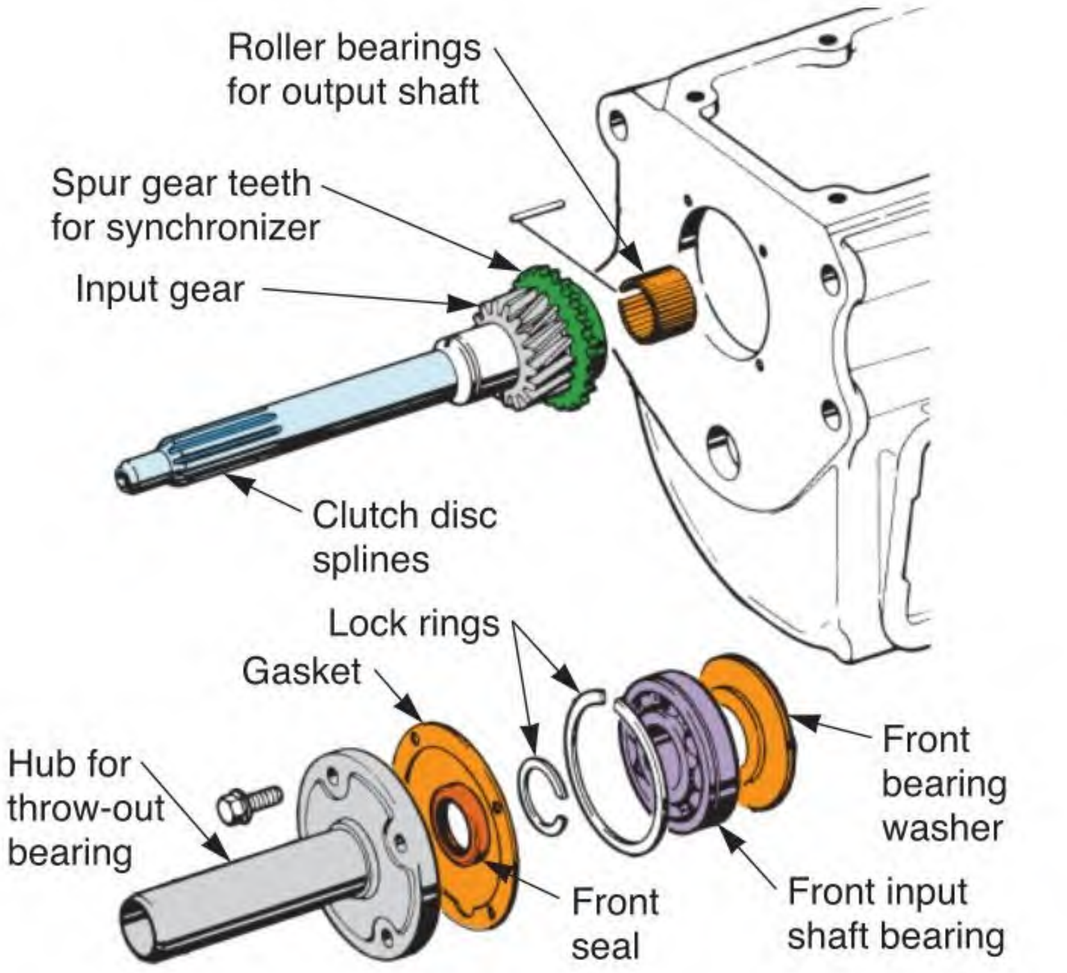
A ***reverse idler gear assembly*** changes the direction of gear rotation so the vehicle can be moved in reverse. Note that the reverse idler gear assembly is constructed like the other transmission shaft-gear assemblies just discussed. See **Figure 63-13**.

Output Shaft Gears

The ***output shaft gears***, or ***main shaft gears***, transfer rotation from the countershaft gears to the output shaft. Only one of the output shaft gears is normally engaged and locked to the shaft at a time.

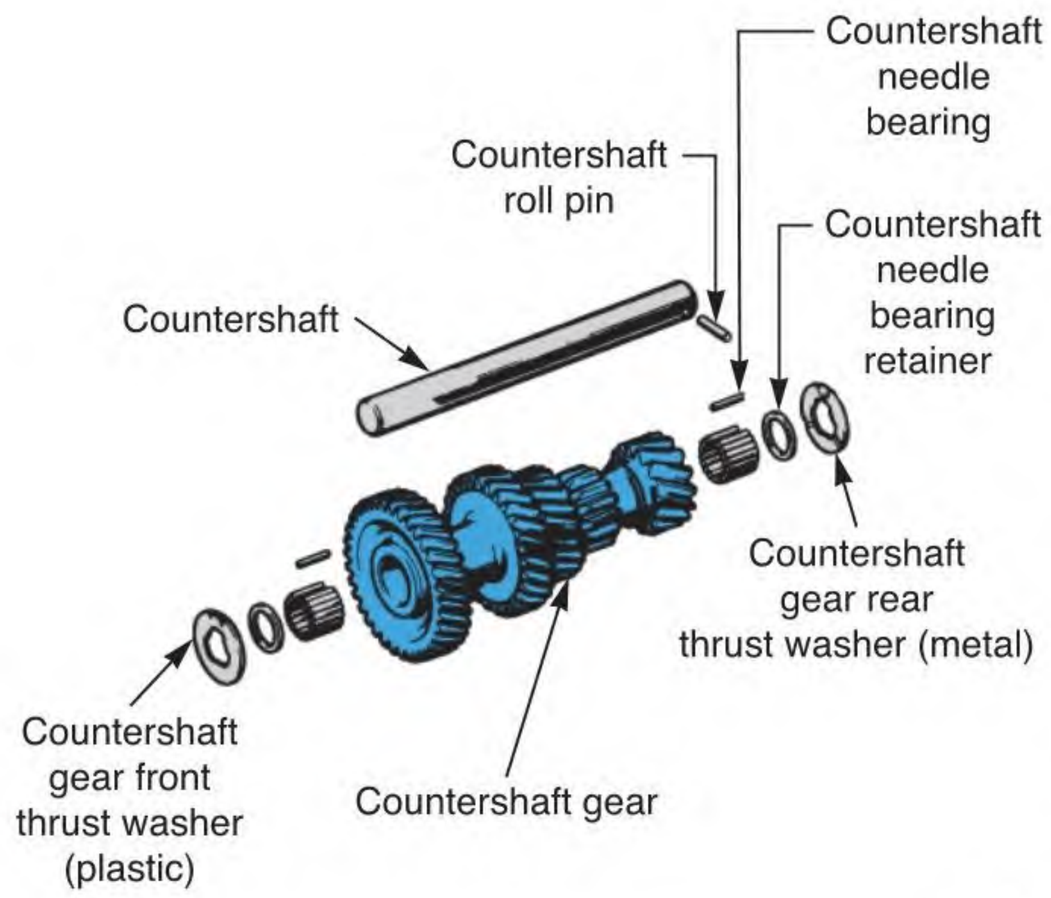
A set of output shaft gears is shown in **Figure 63-14**. Notice how each consists of a main drive gear (helical gear) and a smaller synchronizer gear (spur gear).

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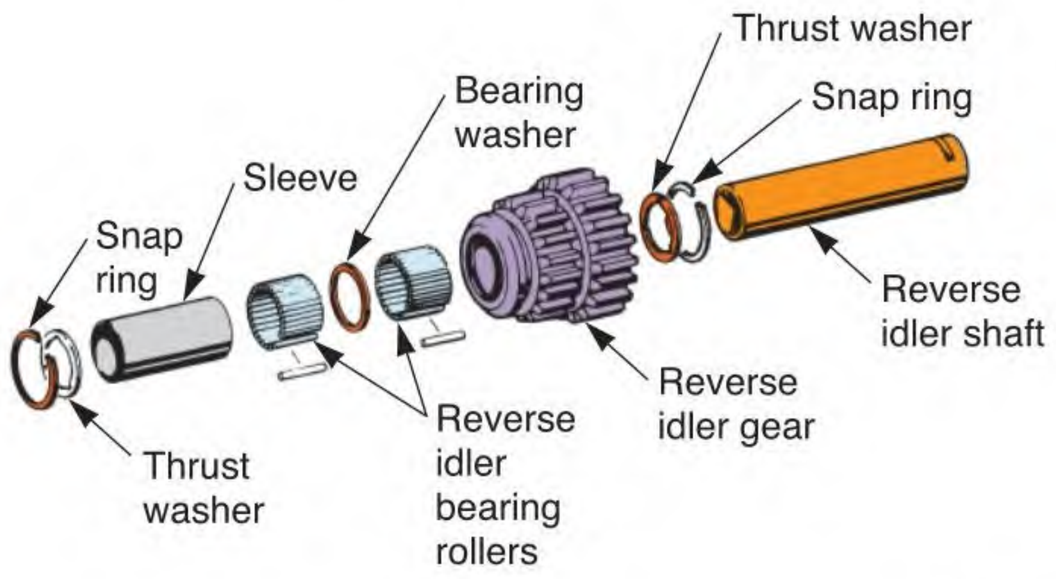
Figure 63-11. An exploded view showing the input shaft and gear. A large bearing supports the shaft in front of the transmission case. Individual roller bearings support the rear of the shaft. Snap rings secure the assembly in the case.



Ford

Figure 63-12. A countershaft gear has several gears machined onto a large shaft. The countershaft and its gears mount on roller bearings so they mesh with gears on the output shaft. Washers control end play of the unit.

The inside bore of each output shaft gear is smooth so that it can spin freely on its shaft when not engaged. Normally, one output shaft gear is provided for each transmission speed, including reverse.



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Figure 63-13. Reverse idler gear and shaft assembly.

Transmission Synchronizers

A transmission synchronizer has two functions:

- Prevent the gears from clashing (grinding) during engagement.
- Lock the output gear to the output shaft.

When the synchronizer is away from an output gear, the output gear freewheels (spins) on the output shaft. When the synchronizer slides against the output gear, the gear is locked to the synchronizer and to the output shaft. Power is then sent out of the transmission and directed to the rear wheels.

Synchronizer Construction

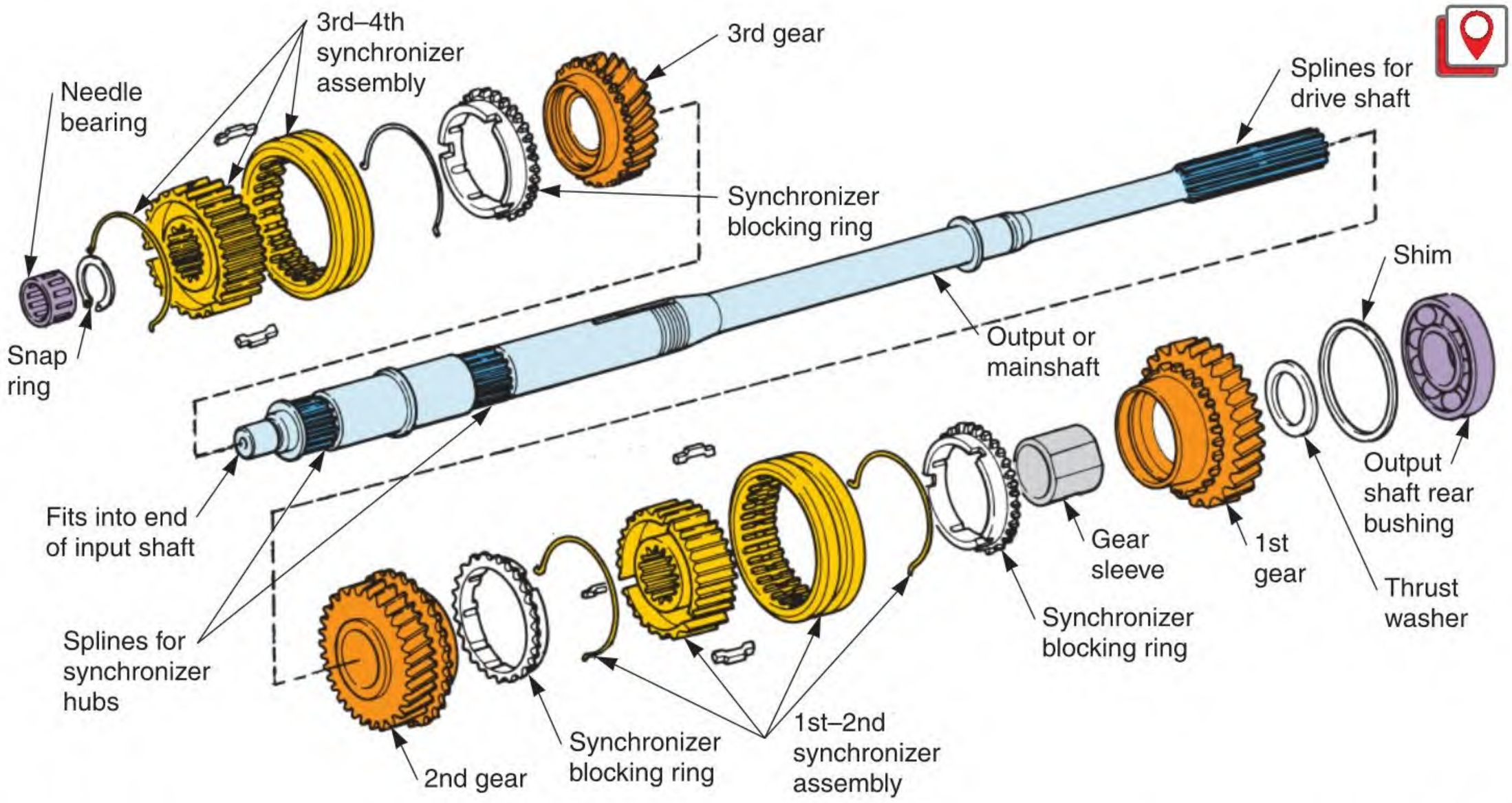
The most popular synchronizer consists of an inner splined hub, inserts, insert springs, an outer sleeve, and blocking rings. See **Figure 63-15**.

The synchronizer hub is splined on the output shaft and is held in a stationary position between the transmission gears. Inserts fit between the hub and sleeve. The insert springs push the inserts into the sleeve to help hold and center the sleeve on its hub. The blocking rings fit on the outer ends of the hub and sleeve.

Synchronizer Operation

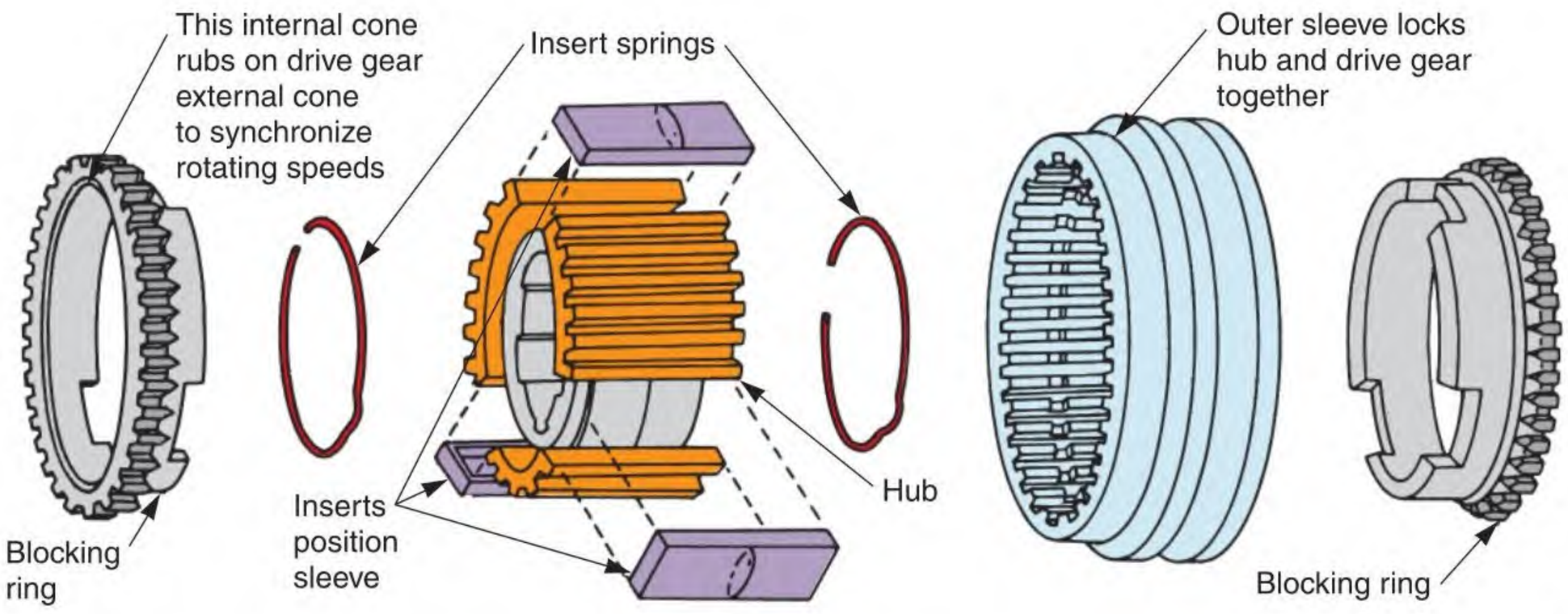
When the driver shifts gears, the synchronizer sleeve slides on its splined hub toward the output gear. First, the ***blocking ring*** cone rubs on the side of the drive gear cone, causing friction between the two. This causes the output gear, the synchronizer, and the output shaft to begin spinning at the same speed, **Figure 63-16**. As soon as the speed is equalized (synchronized), the sleeve can slide completely over the blocking ring and over the small spur gear teeth on the output gear. This locks the output gear to the

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Mazda

Figure 63-14. The output shaft is a long shaft extending through the transmission extension housing. The drive shaft is splined to the rear of this shaft.



Deere & Co.

Figure 63-15. Basic synchronizer components. The hub is splined to the output shaft. A sleeve fits over the hub, and shifter plates position the sleeve. Blocking rings allow the sleeve to slide into and mesh with the output gear without clashing or grinding.

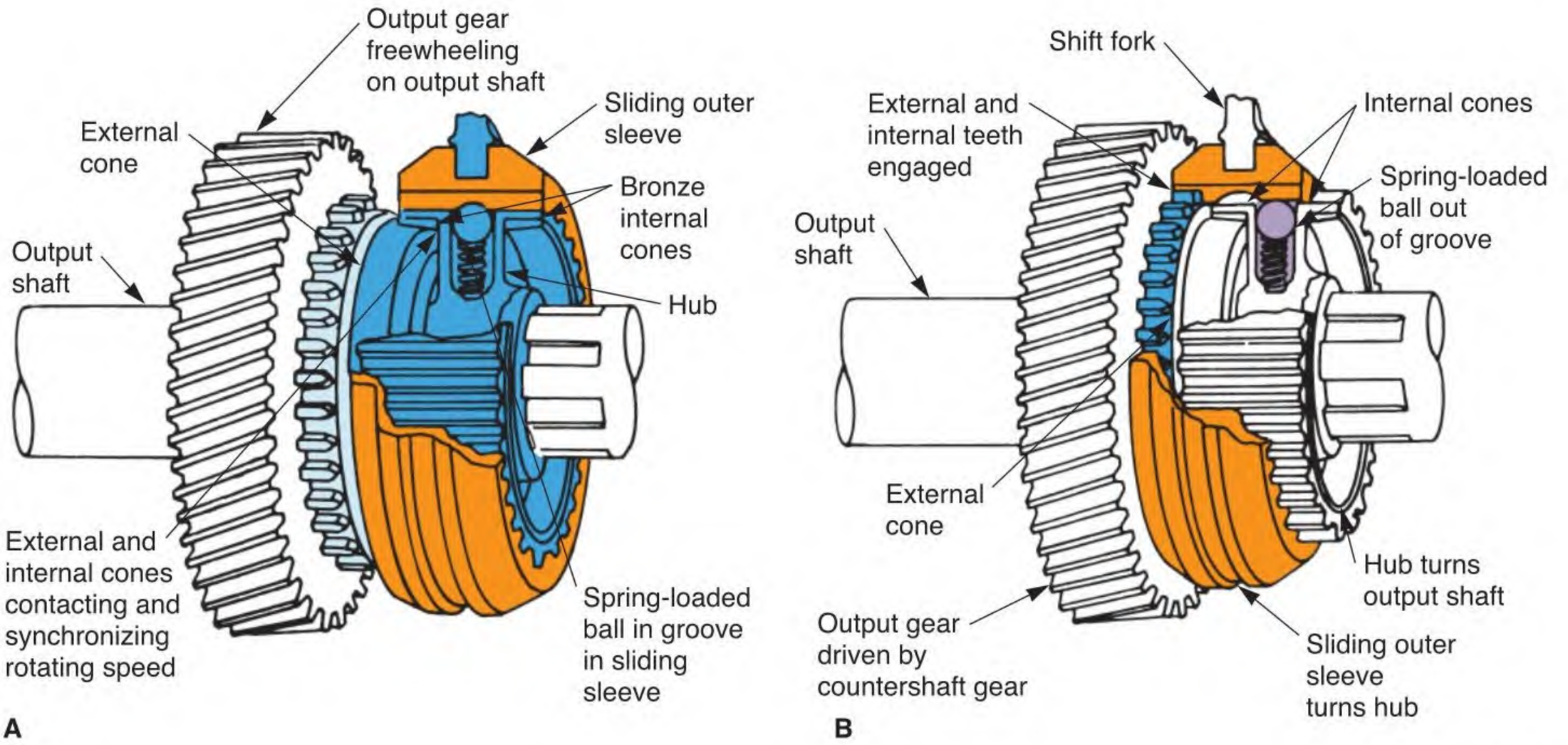
synchronizer hub and to the shaft. Power then flows through the output gear to the rear wheels.

Fully Synchronized Transmission

In a ***fully synchronized transmission***, all the forward output gears use a synchronizer. This allows the driver to downshift into any lower gear (except reverse) while the car is moving. Most modern manual transmissions are fully synchronized.

Many older three-speed transmissions did not have a synchronized first gear. In these vehicles, the driver had to wait until the vehicle came to a complete

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Figure 63-16. Synchronizer operation. A—As the synchronizer sleeve moves into the output gear, the cone on the sleeve rubs against the cone on the gear. Friction makes the gear and sleeve begin to turn at the same speed. B—When at the same speed, the sleeve can slide over and mesh with the small spur teeth on the side of the output gear. The output gear is then engaged to the output shaft.

stop before downshifting into first. Shifting into first while the vehicle was in motion would cause first gear to grind.

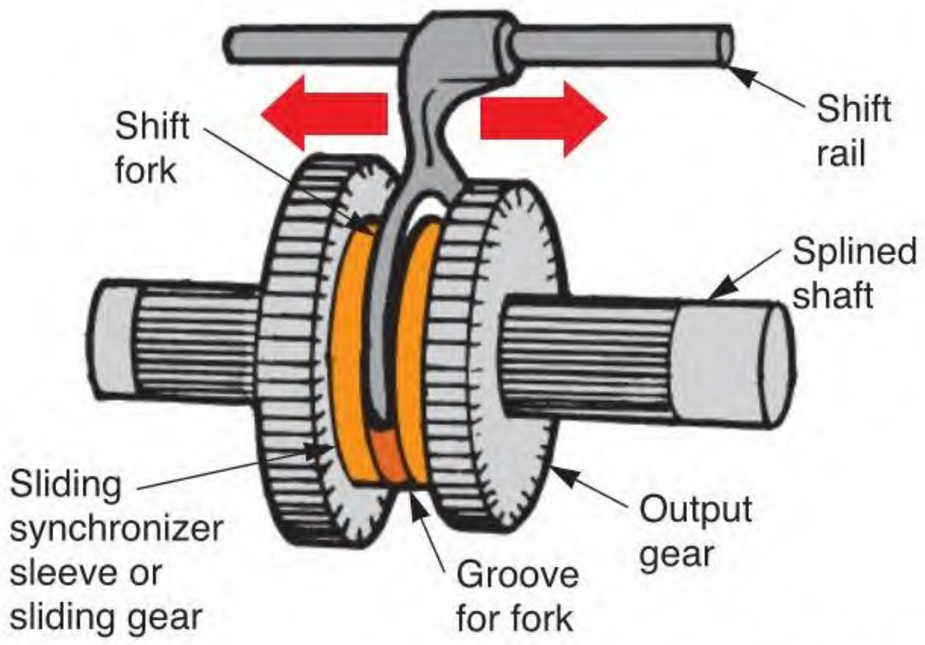
Tech Tip

An automated clutch manual transmission uses computer control and transmission sensors to allow shifting gears without clutch pedal disengagement. Computer control synchronizes the speed of the engine with the transmission so that no load is sent through the transmission while shifting. A clutch is only needed when the engine must be kept running at idle, as with most conventional (non-hybrid) drivelines.

Shift Forks

Shift forks fit around the synchronizer sleeves to transfer movement from the gear shift linkage to the sleeves. This is illustrated in **Figure 63-17**.

The shift fork fits into a groove cut into the synchronizer sleeve. A shift rail, or linkage rod, connects the fork to the driver's shift lever. When the shift lever moves, the rail moves the shift fork and the synchronizer sleeve



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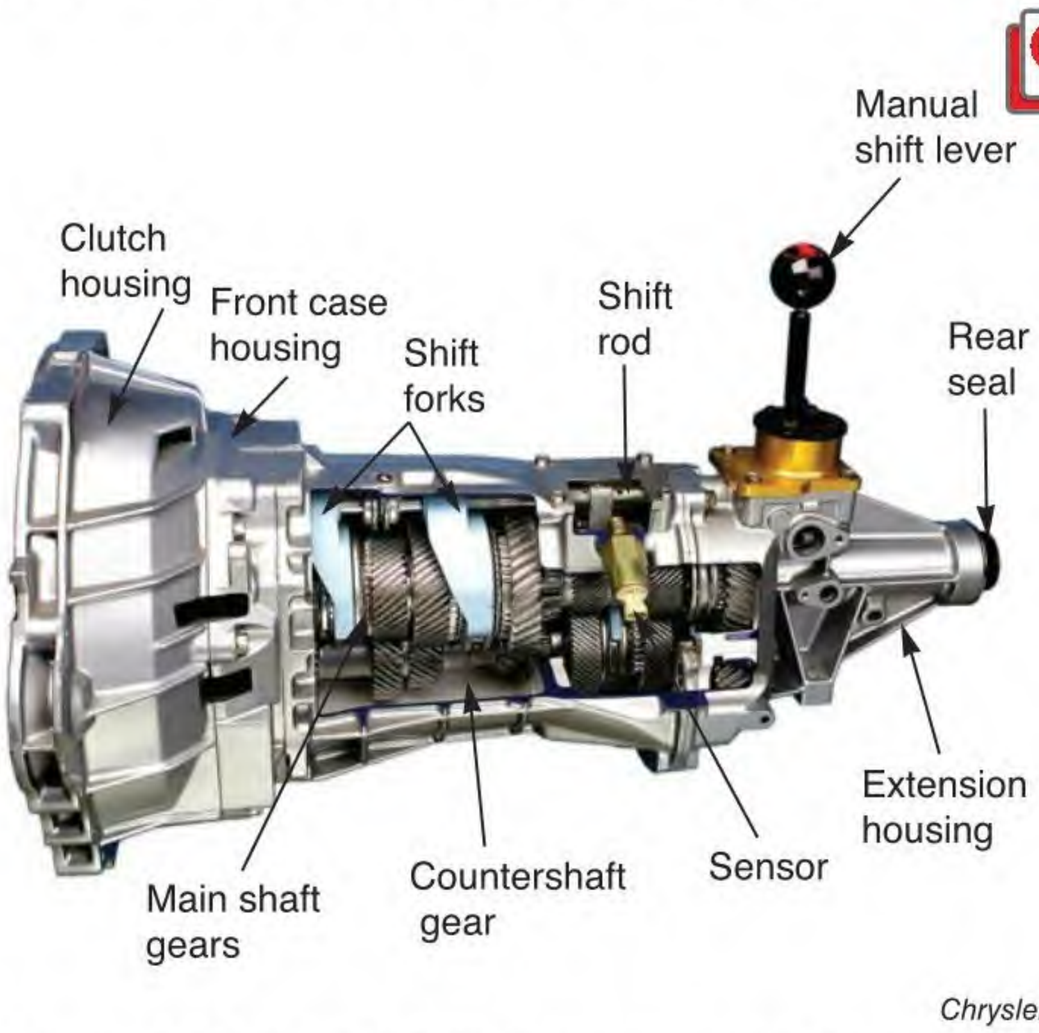
Figure 63-17. A shift fork is used to move the synchronizer sleeve. Motion is transferred to the shift fork through the shift rail.

to engage the correct transmission gear. **Figure 63-18** shows a typical shift fork assembly. Study the parts and how they fit together.

Shift Linkage and Shift Lever

There are two general types of transmission linkage: the external shift rod and the internal shift rail. Both types perform the same function—they connect the shift lever with the shift fork mechanisms.

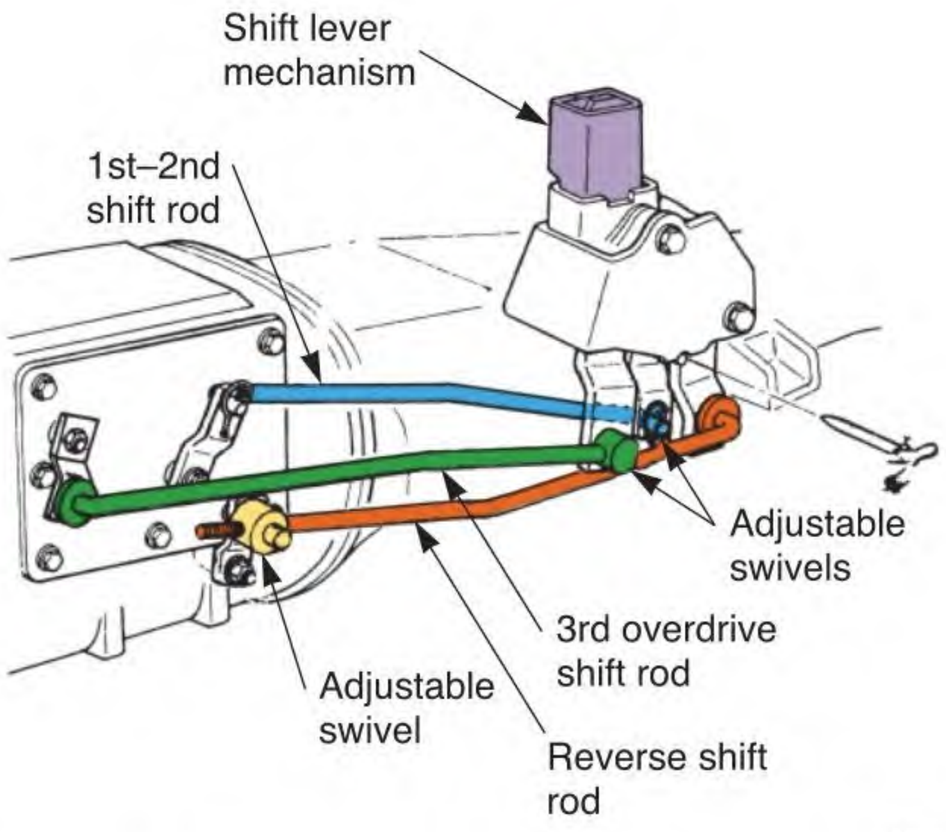
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Chrysler

Figure 63-18. The shift forks fit over grooves in the center of the synchronizer sleeves. Movement of shift linkage moves the shift forks to engage different output gears.

The components of an external shift rod linkage are shown in **Figure 63-19**. The rods fit into levers on the shift mechanism and fork assembly. Spring clips hold the rods in the levers. One end of each linkage rod is threaded so that the linkage can be adjusted.



Chrysler

Figure 63-19. Side view of a transmission showing external shift rod linkage.

Tech Tip

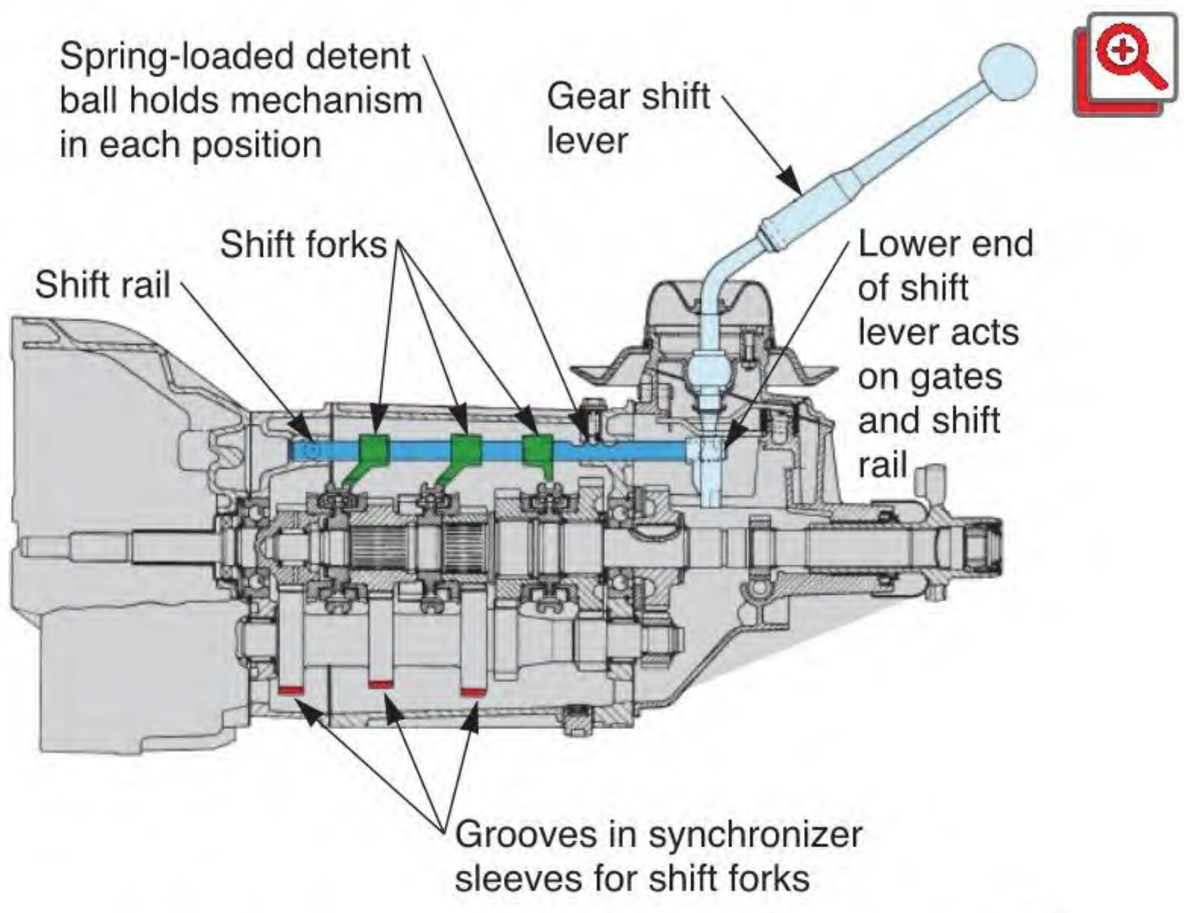
In some cases, a shift cable is used instead of linkage rods. A cable is often needed if the manual transmission does not mount under the center console of the vehicle, as in a rear- or mid-engine vehicle.

An internal shift rail linkage is shown in **Figure 63-20**. When the driver shifts gears, the bottom of the shift lever catches in one of the ***gates*** (notched unit attached to shift rail), **Figure 63-21**. Each gate is mounted on a shift rail. As a result, movement of the lever places a prying action on the rail. Since the fork is located on the rail, it is also moved when changing gears. Spring-loaded detent balls are sometimes used to lock the shift rails into position.

Variations in shift rail linkages are also available. However, the basic construction and operation are similar for all systems. The transmission shift lever assembly is moved to cause movement of the shift linkage, shift forks, and synchronizers.

Manual Transmission Types

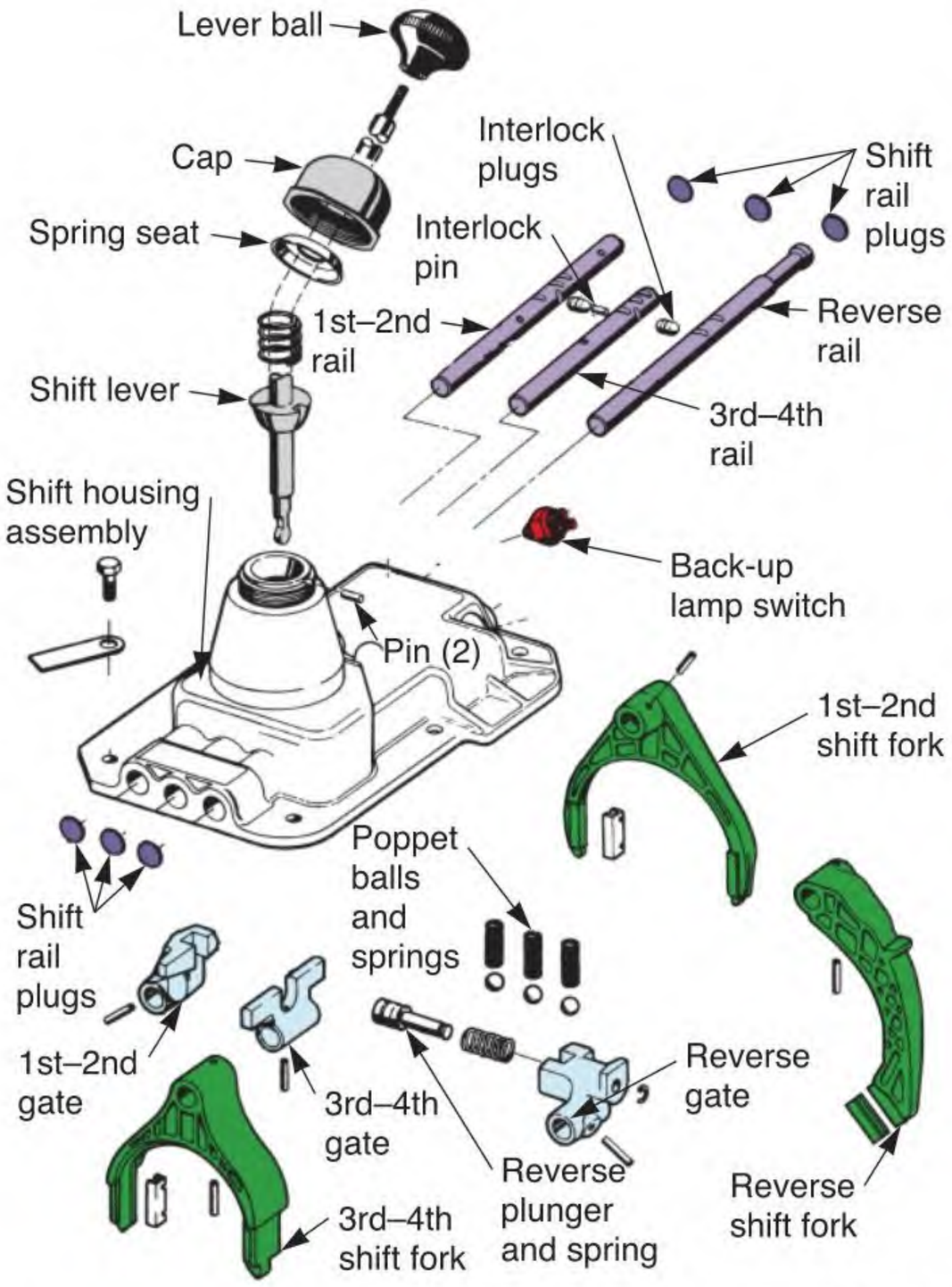
There are several types of manual transmissions: three-speed, four-speed, five-speed, six-speed, seven-speed, and even eight-speed. Older vehicles were commonly equipped with three- and four-speed



Fiat

Figure 63-20. This transmission uses an internal shift rail mechanism instead of external shift rods. The shift lever acts on the rail. The rail then operates the shift forks and synchronizer sleeves.

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Figure 63-21. Exploded view of a transmission with an internal shift mechanism. The shift lever acts on shift gates, which are attached to shift rails. The rails move shift forks for gear changes. Note the back-up lamp switch.

transmissions. Modern vehicles, however, frequently have transmissions with four or more gear ratios.

Transmissions with more forward speeds provide a better selection of gear ratios for improved acceleration. Some transmissions have an overdrive in high gear to increase fuel economy by lowering engine rpms at highway speeds.

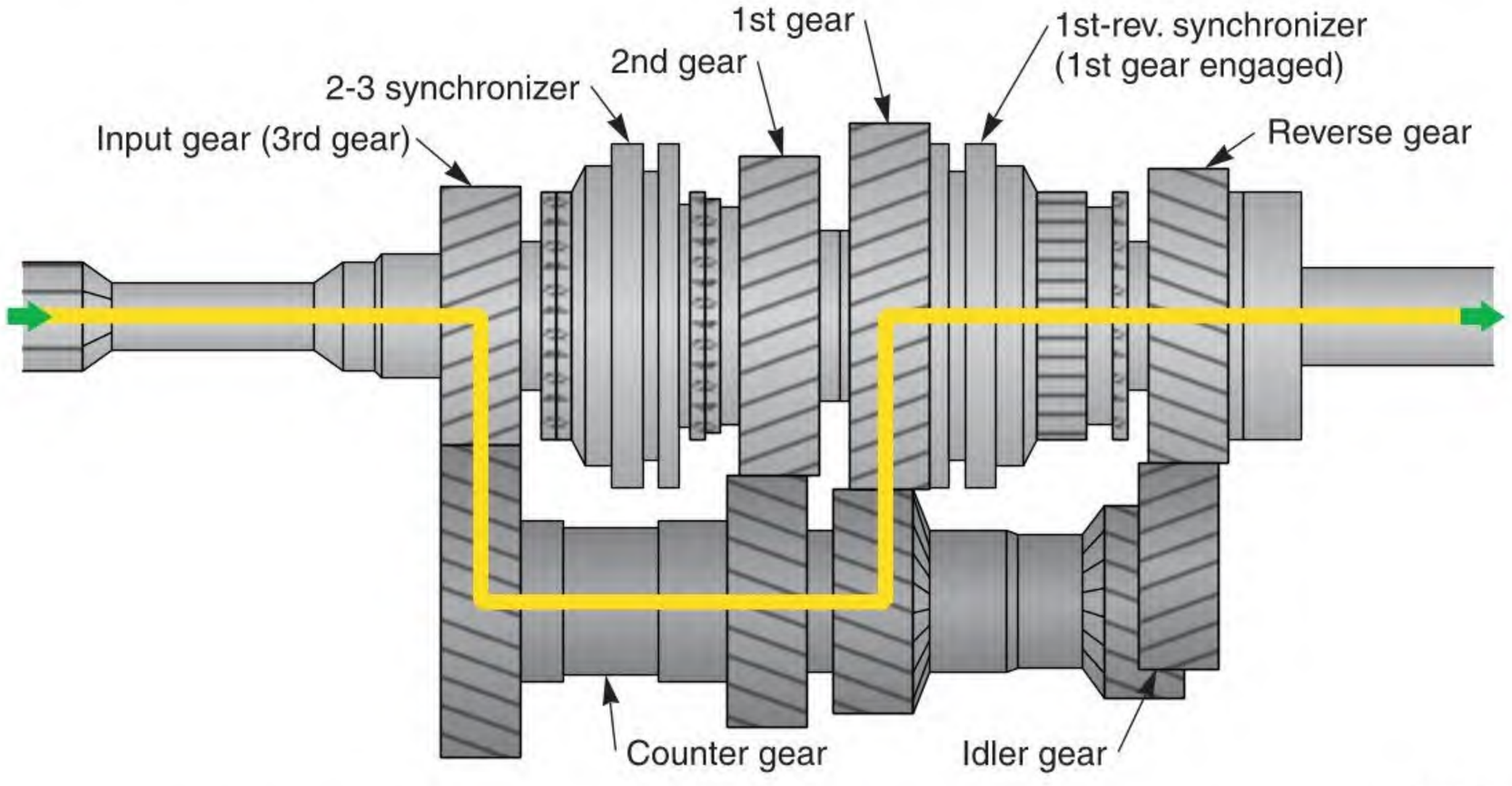
Manual Transmission Power Flow

To begin your study of manual transmission power flow, you will trace torque flow through a simple three-speed manual transmission with reverse. Any time a manual shift is made to a higher gear, the manual clutch pedal must be depressed to engage and lock a higher gear ratio.

First Gear

To get the vehicle moving from a standstill, the driver moves the gear shift lever into first gear. The clutch pedal must be pressed to stop power flow into the transmission. With no power flow into the manual transmission, the shift linkage rods or cables move the shift fork so that first gear synchronizer is engaged to the first (and largest) output gear. The other output gears are in neutral (freewheeling on the output shaft) and are not locked to the output shaft. Look at **Figure 63-22**.

As the driver releases the clutch pedal, the clutch shaft and its gear begin to spin the countershaft gears



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Figure 63-22. A transmission in first gear. The first-reverse synchronizer is engaged with the first output gear. The other synchronizer is in neutral position. First gear is locked to the output shaft and transfers high torque to drive shaft.

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under engine or motor-generator power. Since only the first gear is locked to the output shaft, a small gear on the countershaft drives the larger gear on the output shaft. The gear ratio is approximately 3:1 and the vehicle accelerates easily with tremendous drive train torque.

Second Gear

To shift into second, the driver depresses the clutch and moves the shift lever into second gear position. With the engine momentarily disconnected from the transmission, the first gear synchronizer slides away from first gear. The second-third synchronizer then engages the 2nd gear. See **Figure 63-23**. Now power flow is through second gear on the output shaft. A gear ratio of about 2:1 is produced to give the vehicle a little more speed and a little less torque.

Third Gear

When the gearshift lever is moved into third gear, the synchronizer slides over the small teeth on the input shaft gear. The synchronizer sleeve uses shaft splines to lock the input shaft directly to the output shaft. Refer to **Figure 63-24**. A 1:1 gear ratio results, and there is no torque multiplication. All the output shaft gears freewheel on the shaft and power flow is straight through the transmission. The vehicle travels at highway speeds while the engine speed is relatively low.

Reverse

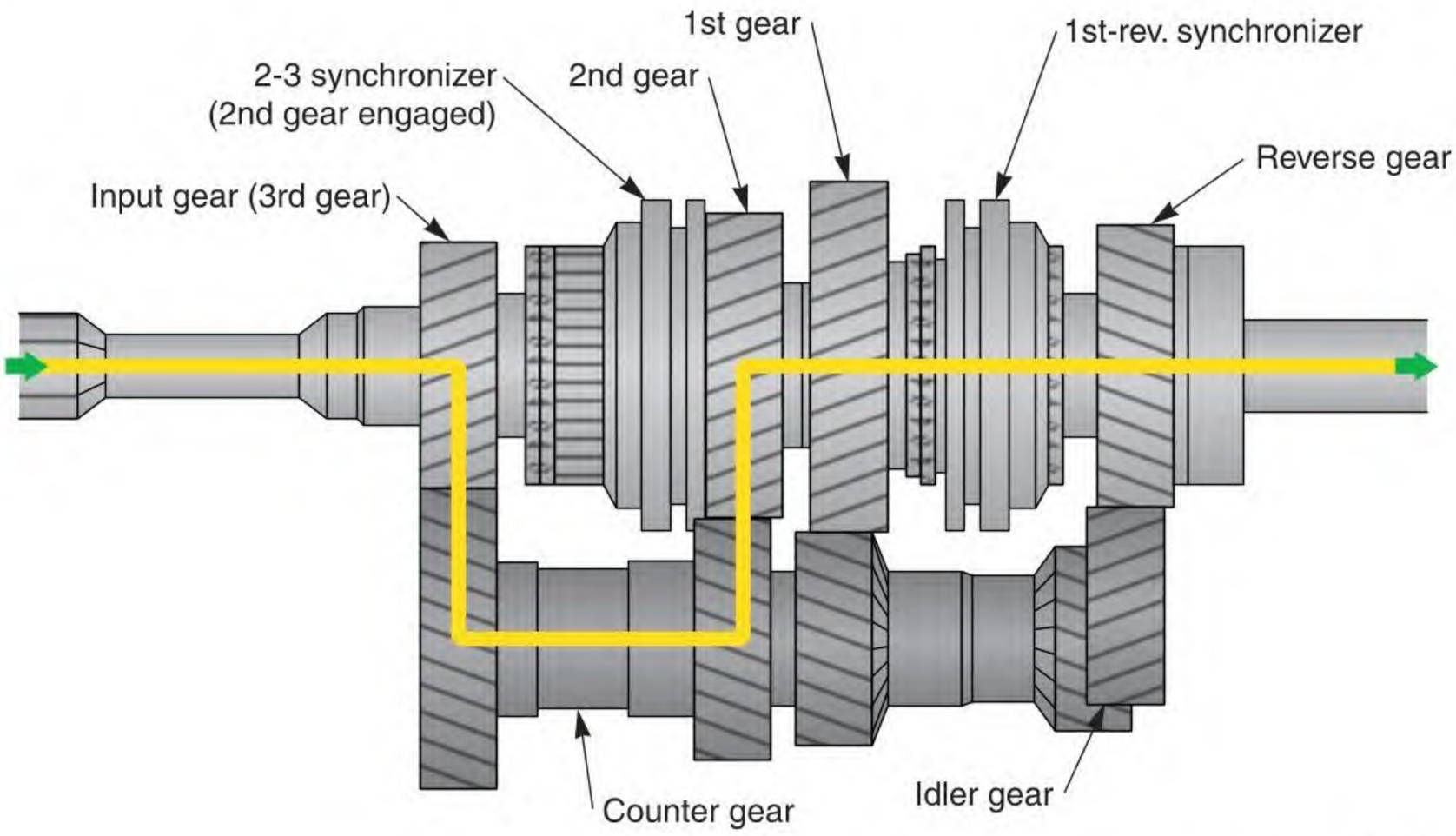
When shifted into reverse, the first-reverse synchronizer is moved into the reverse gear on the output shaft. This locks the gear to the output shaft. Power flows through the countershaft, reverse idler gear, reverse gear, and to the output shaft, **Figure 63-25**.

Neutral

In neutral, all the synchronizer sleeves are located in the center of their hubs. This allows all the output shaft gears to freewheel on the output shaft. No power is transmitted to the output shaft, **Figure 63-26**.

Overdrive Gear

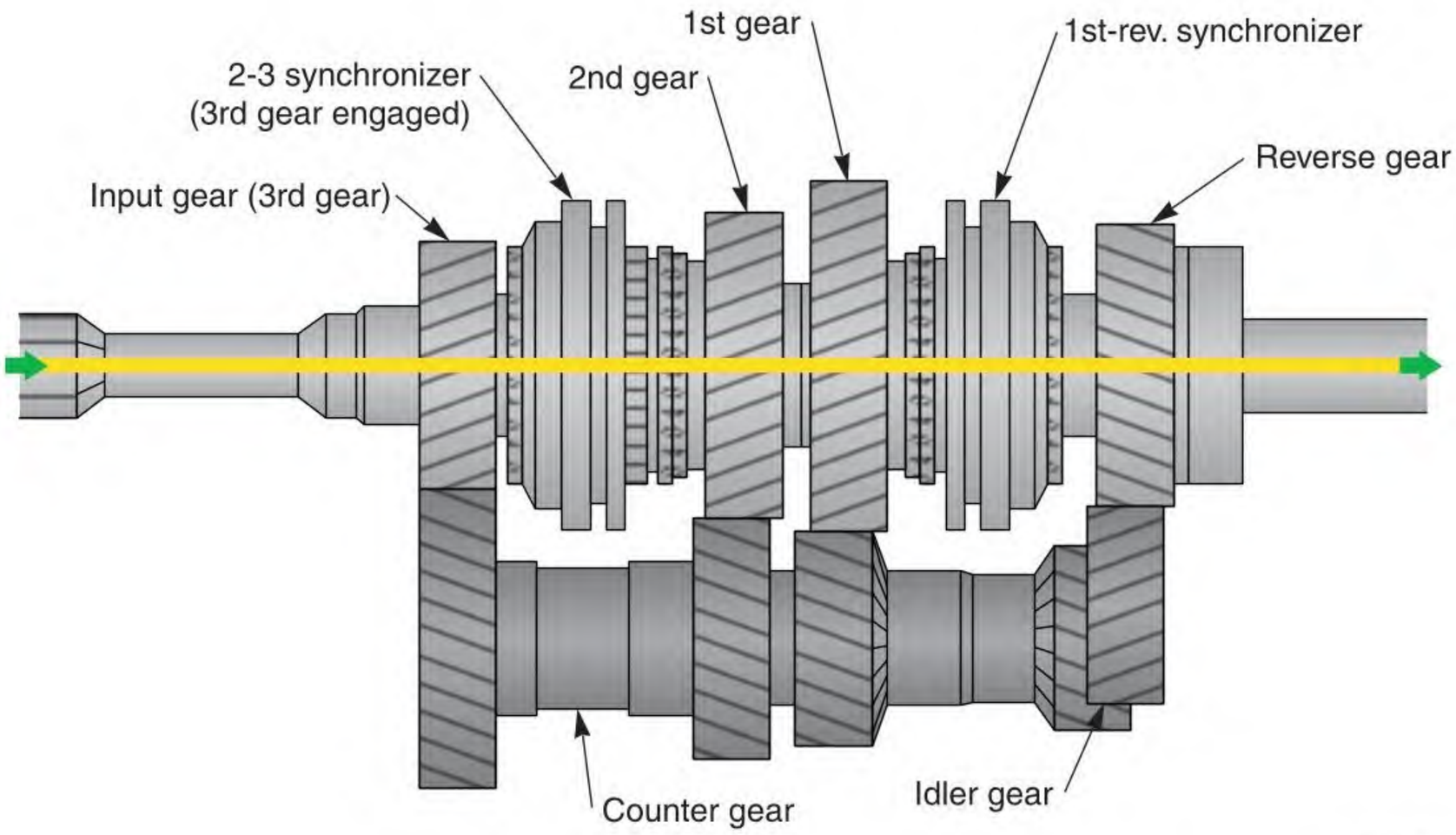
In many modern transmissions, high gear is an overdrive gear ratio. Either fifth (five-speed) or sixth (six-speed) has a ratio of less than 1:1 (0.87:1, for example) to increase fuel economy. **Figure 63-27** shows the power flow through a late-model, five-speed, overdrive transmission. It is designed for a low-horsepower, diesel engine. Trace the power flow through the transmission in each gear. The first four forward speeds allow the vehicle to accelerate quickly. The overdrive gear keeps engine speed down at highway speeds to increase both fuel economy and engine service life.



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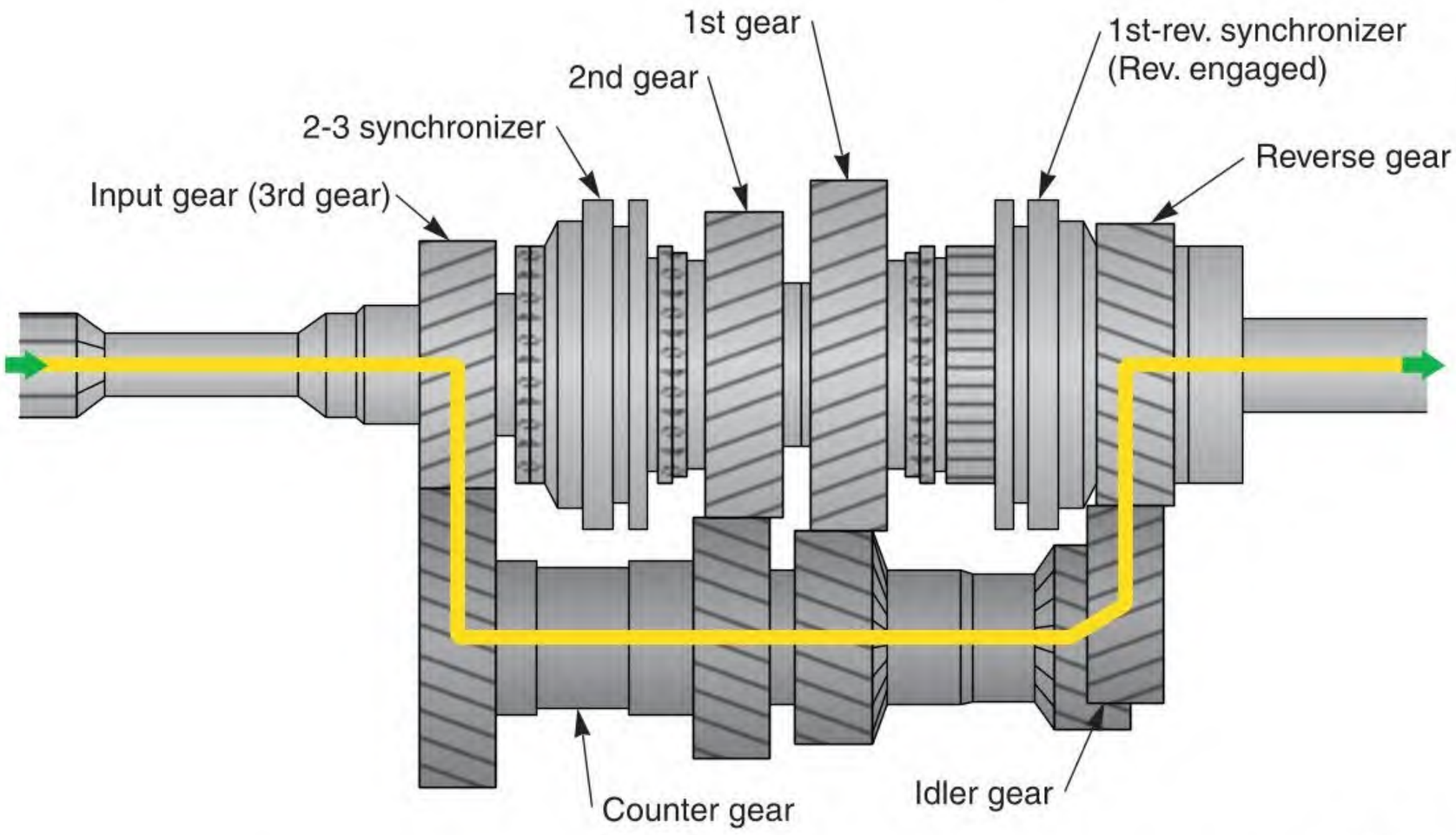
Figure 63-23. A transmission in second gear. The first-reverse synchronizer is moved into neutral. The second-third synchronizer is engaged with the second output gear, locking it to its shaft.

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Figure 63-24. A transmission in third gear. The second-third gear synchronizer is slid to engage the input shaft gear. This locks the input shaft directly to the output shaft, and both shafts turn at the same speed for no gear reduction.



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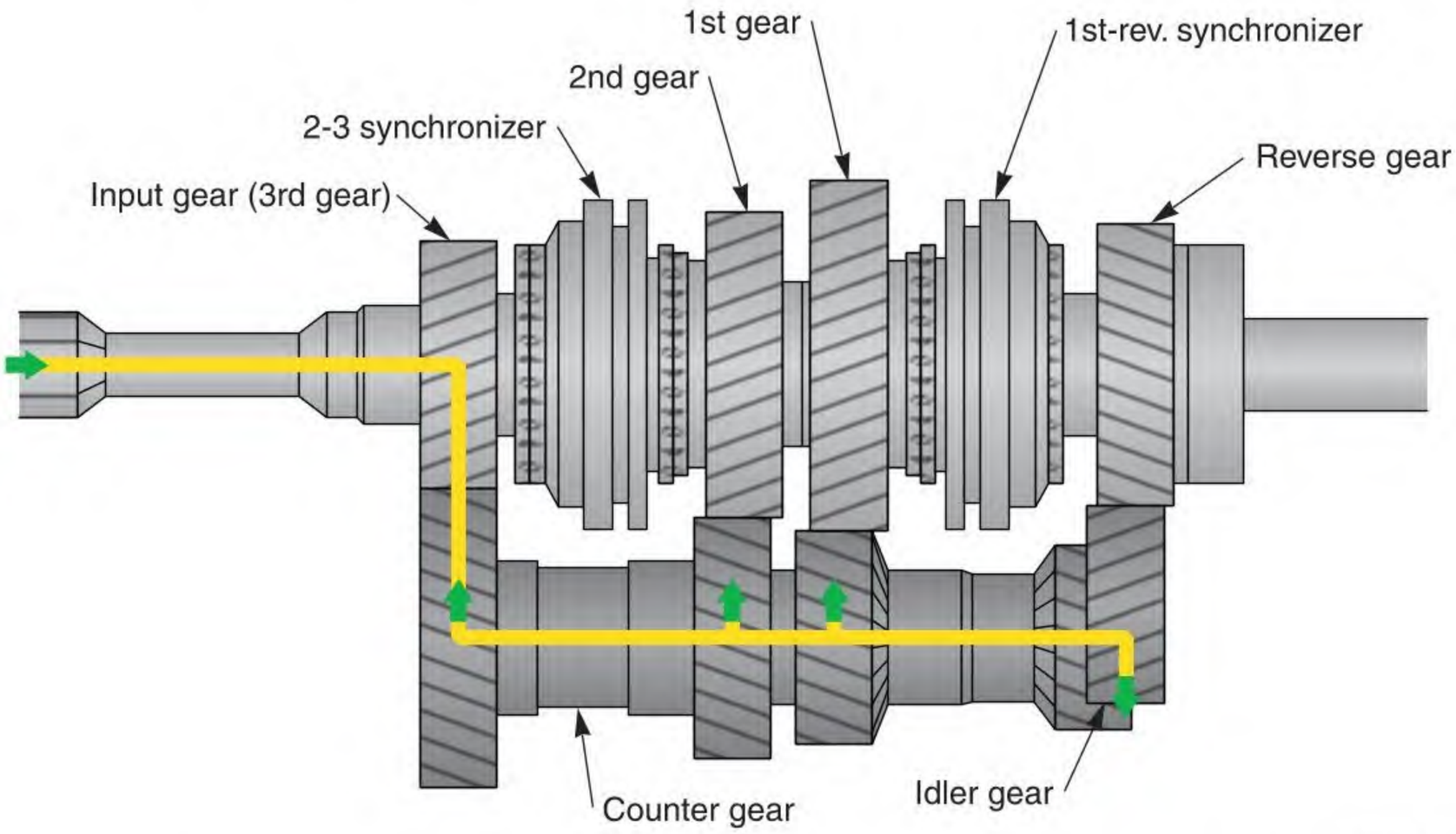
Figure 63-25. A transmission in reverse. The second-third synchronizer is moved into neutral. The first-reverse synchronizer meshes with the reverse output gear. The countershaft gear drives the reverse idler gear, which drives the output shaft backwards.

Speedometer Drive

An ***electronic speedometer*** uses a transmission output shaft speed sensor to operate the dash instrumentation. An instrumentation control module electronically converts the shaft sensor signal into a reading of miles per hour and kilometers per hour on the dash display screen. The control module compares sensor signals to data in memory and accounts for the vehicle's differential ratio and tire diameter to determine the correct mph and km/h road speed.

Before electronics, mechanical speedometers used a worm gear on the transmission or transaxle output shaft that spun a matching gear and speedometer cable. The long,

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Figure 63-26. In neutral, both synchronizers are in center positions. No output gears are locked to the output shaft. The output gears freewheel and do not transfer power to the drive shaft.

flexible wound steel cable ran up and into the speedometer head. The faster the speedometer cable was spun by the transmission shaft, the more the mph or km/h gauge needle would deflect to the right, representing vehicle road speed.

Manual Transmission Actuators

Late-model ***automated manual transmissions*** use computer-control and electric solenoids or servo motors to actuate the manual gearbox. The driver can still manually select and engage each gear ratio by pressing electric shift buttons or a shift lever. If engine speed and other factors are within specification limits, the computer will instantly apply voltage to the correct solenoid, servo motor, or transmission clutch to physically shift the correct synchronizer into the selected gear (first, second, third, etc.). Refer to **Figure 63-28**.

A ***manual transmission shift solenoid*** is a computer-controlled electromagnet that moves a metal plunger when grounded to voltage. Solenoid plunger movement can physically slide each synchronizer into position directly or by using a hydraulic circuit. With modern wet clutches, the shift solenoid opens and closes hydraulic spool valves going to engine and/or motor-generator wet clutches. Oil flow can be controlled to apply hydraulic servos or pistons to instantly synchronize and engage only one gearset ratio.

Transmission shift solenoids operate using a control module duty cycle or varying frequency wave of voltage to control how far the electromagnet extends its steel plunger. The transmission control module can vary the amount of plunger and valve movement by varying the solenoid coil's field strength or flux strength. By changing the voltage level applied to the solenoid's electromagnet, the extension distance of the plunger can be adjusted to meter the exact amount of fluid going to clutches and servos in the manual transmission.

The engine, transmission, brake, and suspension control modules monitor and control all system voltages depending on input signals from both the driver and vehicle. The control modules are programmed to provide manual transmission shift points as soon as the driver requests (pressing paddles or moving a lever), but only if within limits for all the engine and transmission operating parameters. The primary control module can then use power transistors in the smaller transmission control module to apply the correct solenoid or servo motor.

Manual Transmission Sensors and Switches

Several sensors and electric switches may be mounted on manual and automated manual

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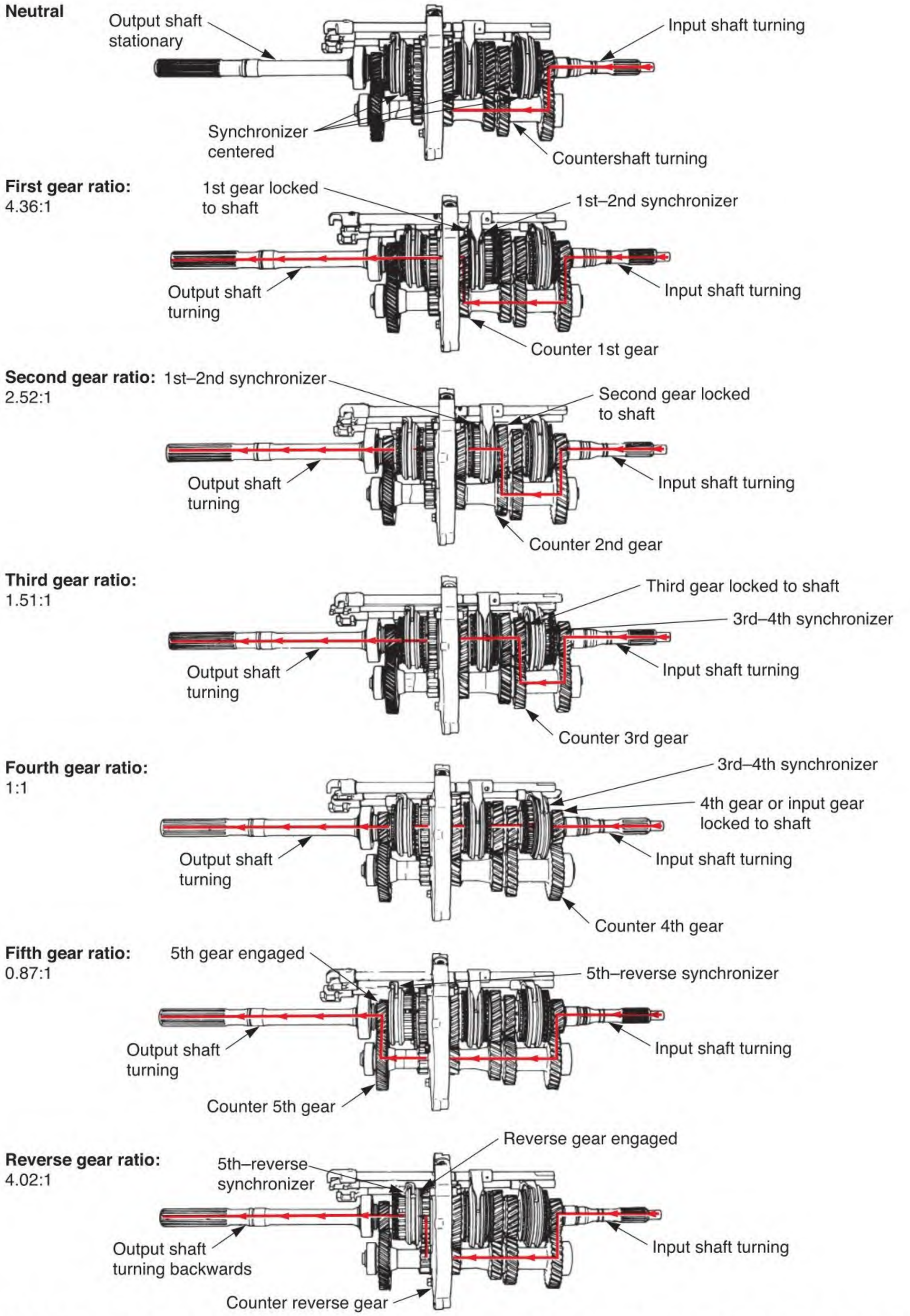


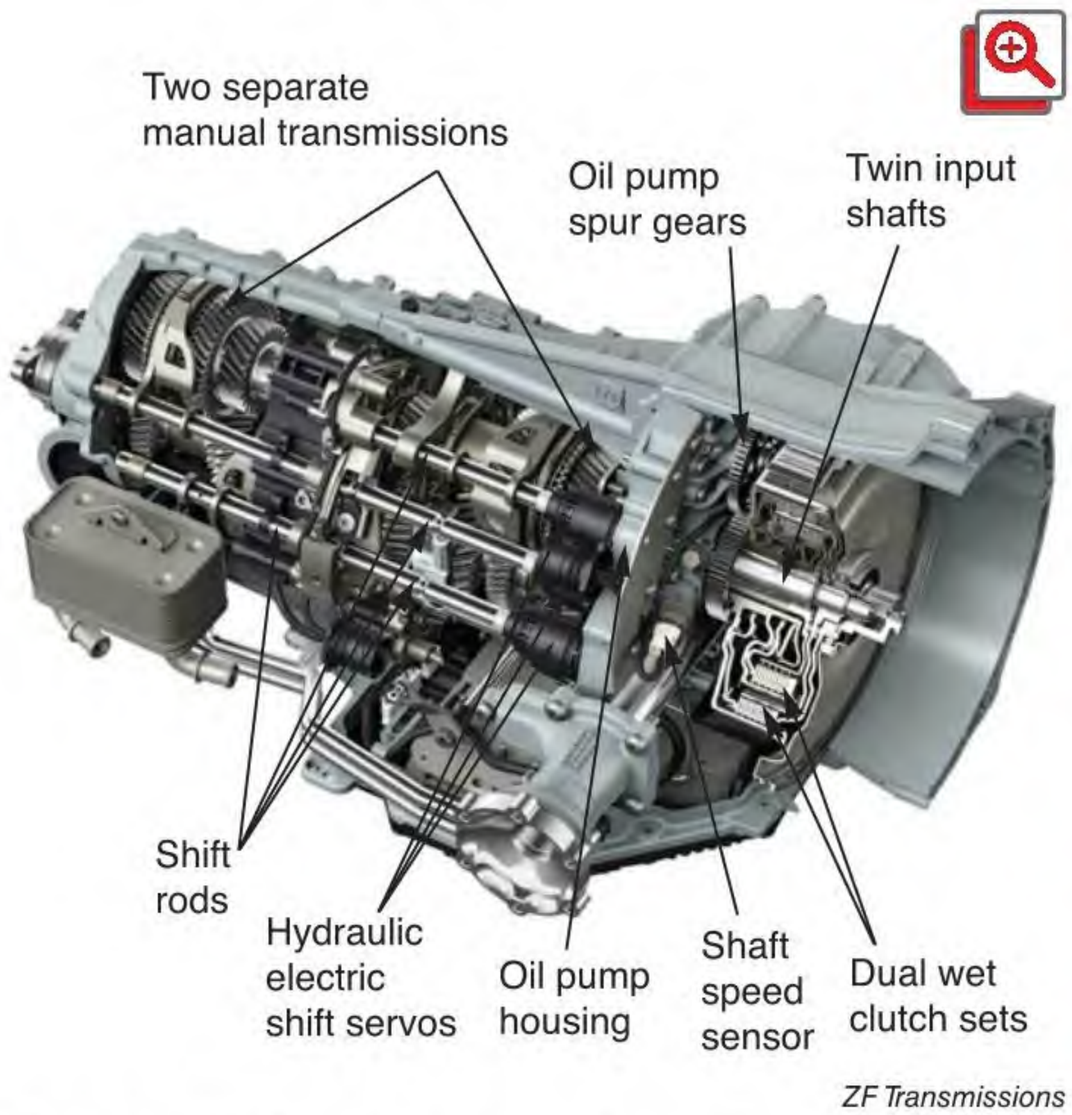
Figure 63-27. Trace the power flow through a five-speed transmission with overdrive in high gear. Study each illustration carefully.

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transmissions. See **Figure 63-28**. You must understand the operation of each transmission sensor and switch to diagnose sensor problems during repairs.

The ***backup light switch*** is an electric switch closed by the action of the reverse gear shift linkage, solenoid, or servo. When shifted into reverse, the linkage closes the switch to connect the backup lamps to the 12-volt dc battery voltage. Older cars connected the backup switch directly to the backup light circuits. Modern vehicles use the instrumentation control module power transistors to operate the backup lights and other taillights.

A ***brake pedal switch*** signals the main control module when the driver begins to slow or stop the vehicle. The main control module shuts down the engine and locks the motor-generator clutch to generate electrical energy while resisting drive train rotation. This signal is also used by the control modules to illuminate the rear brake lights, disengage cruise control, and capture all of the kinetic energy by allowing the transmission gears to spin the large motor-generator rotor and generate huge amounts of electrical energy for HV battery recharging.



ZF Transmissions

Figure 63-28. A modern automated manual transmission. Note the dual wet clutches and dual input shafts going into a gearbox. Hydraulic servos or pistons replace the manual shift lever. The transmission control module changes gear ratios depending on many sensor variables. Also, large electric solenoids can actuate hydraulic spool valves in the valve body. The hydraulic spool valve movement then alters circuit pressures to operate the hydraulic servos that snap shift rods back and forth in the case.

A ***manual transmission speed sensor*** measures the speed of the output shaft so the control module can calculate vehicle road speed in mph or km/h. This sensor produces a pulsing ac signal, which represents driveshaft and vehicle speed.

A ***manual transmission gear sensor*** (***switching sensor***) can be used to check gearbox gear positions for reverse, neutral, and all forward gear ratios. These sensors are often used as safety switches to avoid catastrophic transmission failure if any transmission gear failed to engage or disengage properly.

A ***manual transmission pressure sensor*** is used in automated manual transmissions to measure the pressure of the hydraulic fluid used to operate the wet clutches that transfer power to different shafts and gears.

Workplace Skills

If you miss work, you affect everyone in the shop. If you are scheduled to repair a vehicle and you are not there, someone else has to do your work or the vehicle will not be repaired on time. If your co-workers have to complete your work in addition to their own, they may be understandably upset with you. If customers' vehicles are not ready on time, the shop may develop a bad reputation and lose valuable business. In the end, you may be out of a job.

Summary

- A manual transmission must be shifted by hand to change the amount of torque going to the other parts of the drive train.
- A transaxle combines both the transmission and the differential into a single housing. It is commonly used in front-wheel-drive vehicles.
- The basic parts of a manual transmission include the input shaft, transmission gears, synchronizers, shift forks, shift linkage, gear shift lever, output shaft, and transmission case.
- A manual transmission is designed to change the vehicle's drive wheel speed and torque in relation to engine speed and torque.
- Gears are used to transmit turning effort from one shaft to another.

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- A gear ratio is the number of revolutions a drive gear must turn before the driven gear completes one revolution.
- First (low) gear has a high gear ratio and produces more torque. High gear has a low gear ratio and produces very little torque.
- Manual transmissions commonly use two types of gears: spur gears and helical gears.
- The moving parts in a transmission are lubricated by splash lubrication, typically using 80W or 90W gear oil in a manual transmission.
- Bearings reduce the friction between the surfaces of rotating parts in the transmission.
- The transmission case supports the transmission bearings and shafts, and provides an enclosure for gear oil.
- The extension housing encloses the transmission output shaft and holds the rear oil seal input shaft.
- A manual transmission normally has four steel shafts mounted inside its case: an input shaft, a countershaft, a reverse idler shaft, and an output shaft.
- The transmission output shaft, also called main shaft, holds the output gears and synchronizers.
- Transmission gears can be typically classified into four groups: input shaft gear, countershaft gear, reverse idler gear, and output shaft gears.
- A transmission synchronizer has two functions: it prevents the gears from grinding or clashing during engagement and locks the output gear to the output shaft.
- The shift forks fit around the synchronizer sleeves to transfer movement to the sleeves from the gear shift linkage.
- Transmissions with more forward speeds provide a better selection of gear ratios for improved acceleration.
- In neutral, all the synchronizer sleeves are located in the center of their hubs and no power is transmitted to the output shaft.
- The overdrive gear keeps engine speed down at highway speeds to increase both fuel economy and engine service life.
- An electronic speedometer uses a transmission output shaft speed sensor to operate the dash instrumentation.
- Several sensors and electric switches may be mounted on manual and automatic manual transmissions.
- Late-model automated manual transmissions use computer-control and electric solenoids or servo motors to actuate the large gearbox.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

antifriction bearings
automated manual transmissions
backup light switch
blocking ring
brake pedal switch
cluster gear
cluster gear shaft
clutch shaft
counter gear
countershaft
countershaft gear
electronic speedometer
extension housing
front bearing cap
front bearing hub
front transmission bearing
fully synchronized transmission
gates
gear backlash
gear oil
gear ratio
gear reduction
gear shift lever
gears
helical gears
input gear
input shaft
main shaft
main shaft gears
manual transmission
manual transmission gear sensor
manual transmission pressure sensor
manual transmission shift solenoid
manual transmission speed sensor
output shaft
output shaft gears
overdrive ratio
reverse idler gear assembly
reverse idler shaft
shift forks
shift linkage
splash lubrication
spur gears
switching sensor
synchronizers
tail shaft housing
torque multiplication
transaxle
transmission case
transmission gears

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Activities

1. Locate a drive gear and a driven gear on a manual transmission and determine the gear ratio when the two gears are meshed. Show your calculations.
2. Locate the transmission section in a shop manual and study the names of the gears. Locate these same gears on an actual transmission.
3. Demonstrate the adjustment procedures for a manual transmission linkage.

Review Questions

Answer the following questions using the information provided in this chapter.

1. List the eight major parts of a manual transmission. Explain the function of each.
2. Identify four functions of a manual transmission in proper operating condition.
3. Define the term "gear ratio."
4. How is gear ratio calculated? Give an example.
5. A certain manual transmission's drive gear has 12 teeth and the driven gear has 72 teeth. What is the gear ratio in this situation?
   (A) 3:1.
   (B) 6:1.
   (C) 2:1.
   (D) 4:1.
6. Approximate manual transmission gear ratios are _____ for first, _____ for second, _____ for high, and _____ for reverse.
7. Gear reduction results when a small gear drives a larger gear to increase turning force. True or False?
8. The teeth on _____ gears are machined at an angle to the centerline of the gear shaft.
9. What type of gear oil is typically recommended for use in a manual transmission?
10. What is *gear backlash*?
11. What is the transmission extension housing?
12. Name and describe the four shafts in a manual transmission.
13. What are the four categories of transmission gears? Explain the function of each.
14. A manual transmission synchronizer is used to:
    (A) prevent gear clashing or grinding.
    (B) lock output gear to output shaft.
    (C) Both of the above.
    (D) None of the above.
15. Describe the two major types of transmission shift linkages.
16. Why is an overdrive ratio used?
17. How does an electronic speedometer operate?
18. A(n) _____ switch signals the main control module when the driver begins to slow or stop the vehicle.
19. Transmission shift solenoids operate using a control module duty cycle or varying frequency wave of voltage. True or False?

ASE-Type Questions

1. Technician A says a manual transmission normally bolts to the engine's torque converter. Technician B says a manual transmission normally bolts to the automobile's clutch housing. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Technician A says a transaxle is an automatic transmission and a differential combined in a single housing. Technician B says a transaxle is a manual transmission and a differential combined in a single housing. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. Which of the following shafts are *not* mostly contained inside a manual transmission's case?
   (A) Input shaft.
   (B) Countershaft.
   (C) Reverse idler shaft.
   (D) Output shaft.

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4. While discussing the functions of the basic parts of a manual transmission, Technician A says the input shaft transfers rotating power out of the transmission to the drive shaft. Technician B says the input shaft is used to turn the gears inside the transmission. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. Technician A says a manual transmission's synchronizers are devices used to disengage the transmission gears. Technician B says a manual transmission's synchronizers are devices used to engage the transmission's output shaft. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. All of the following are basic functions of an automotive manual transmission, *except:*
   (A) Increase drive wheel torque for quick acceleration.
   (B) Supply different gear ratios to match engine load.
   (C) Operate efficiently, with minimum power loss.
   (D) Distribute torque between front and rear drive shafts.
7. A particular transmission's drive gear has 10 teeth and the gear being driven has 30 teeth. Technician A says the gear ratio in this situation would be 3:1. Technician B says the gear ratio in this situation would be 4:1. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. Technician A says a gear ratio of 10:1 is smaller than a gear ratio of 5:1. Technician B says a gear ratio of 10:1 is larger than a 5:1 gear ratio. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Technician A says a 1:1 gear ratio is generally used for a manual transmission in first gear. Technician B says a 3:1 gear ratio is generally used for a manual transmission in first gear. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. Technician A says "gear reduction" is common in the lower gears of a manual transmission. Technician B says "gear reduction" is common in the high gear of a manual transmission. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
11. Technician A says "spur" gears are commonly used in a manual transmission. Technician B says "helical" gears are commonly used in a manual transmission. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
12. Technician A says "gear backlash" helps lubricate the rotating gears in the transmission. Technician B says "gear backlash" helps prevent gear damage during transmission operation. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
13. Technician A says 90W gear oil is normally recommended for use in a manual transmission. Technician B says 50W gear oil is normally recommended for use in a manual transmission. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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14. Technician A says a transmission's synchronizer prevents the gears from grinding during engagement. Technician B says a transmission's synchronizer locks the output gear to the output shaft. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
15. Technician A says when a manual transmission is in neutral, all of the synchronizer sleeves are located at the end of the countershaft. Technician B says when a manual transmission is in neutral, all of the synchronizer sleeves are located in the center of their hubs. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Chapter 64
Manual Transmission Diagnosis, Service, and Repair

After studying this chapter, you will be able to:

- Diagnose common manual transmission problems.
- Remove a standard manual transmission from a vehicle.
- Disassemble and inspect a manual transmission.
- Assemble a manual transmission.
- Install a manual transmission.
- Adjust manual transmission linkage.
- Cite and observe safety rules for transmission service.
- Correctly answer ASE certification test questions on manual transmission diagnosis and repair.

Most makes of manual transmissions use similar construction methods. Therefore, if you learn the common methods for disassembling, inspecting, and rebuilding a typical unit, you will have most of the knowledge needed to repair any manual transmission, even automated manual transmissions and transaxles.

This chapter discusses basic methods and rules that apply to the service of any type of manual transmission. It will give you the information needed to understand and use a service manual when working on any manual transmission. The service manual gives specific instructions and specifications for the exact make and model transmission.

Manual Transmission Problem Diagnosis

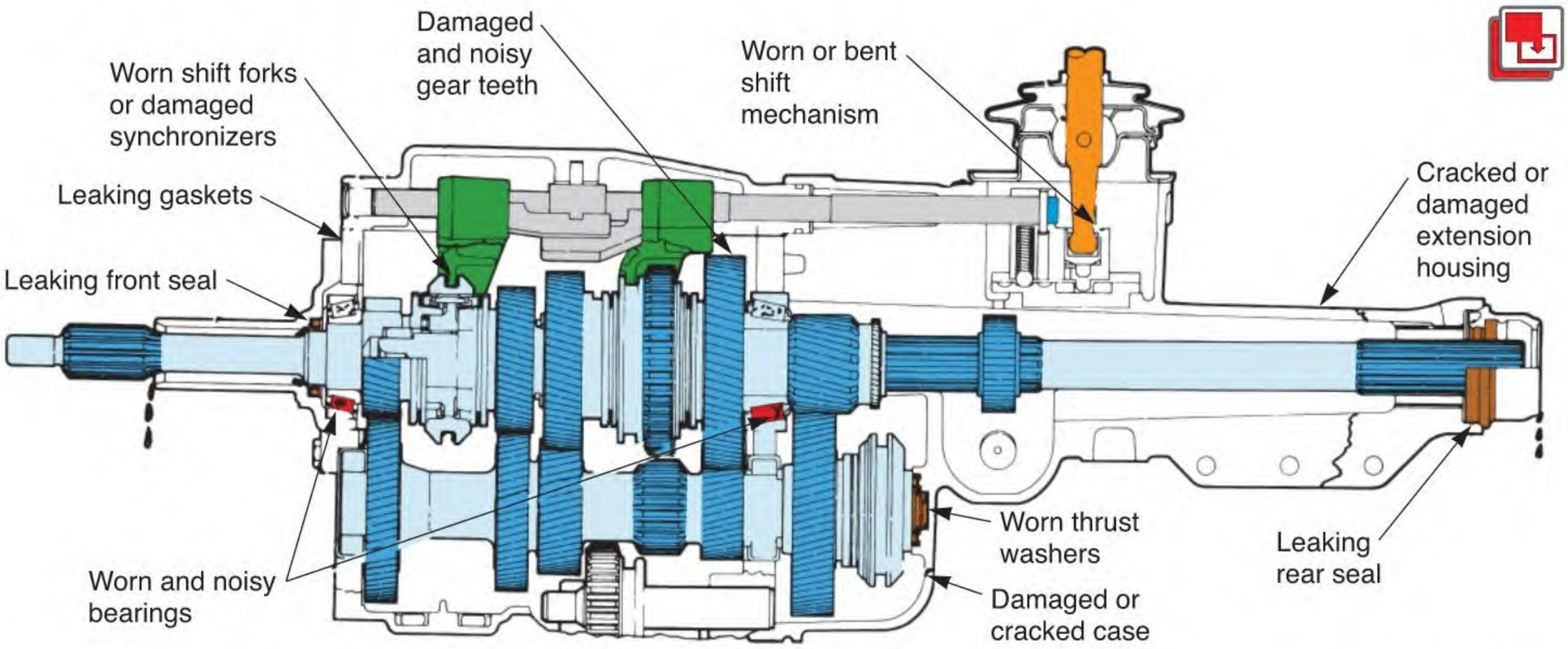
Normally, a manual transmission will provide thousands of miles of trouble-free service. Quite often, it will last the life of the vehicle without major repairs. However, driver abuse and normal wear after prolonged service can cause transmission failure.

A technician's first step toward fixing a transmission is to determine why the problem developed. Was it because of driver abuse (speed shifting, drag racing, lack of maintenance), normal wear (extremely high mileage), or another cause?

After proper diagnosis, the service technician can decide whether the transmission must be removed for major repairs. Sometimes, a simple linkage or clutch adjustment may correct the problem.

To begin diagnosis, gather basic information about the transmission trouble from the customer. Then, test-drive the vehicle to verify the complaint. Find out which gears in the transmission act up: first, second, high, all forward gears. Does it happen at specific

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Figure 64-1. Common problems found in manual transmissions.

speeds? This information will help determine which parts are at fault.

Figure 64-1 shows typical transmission troubles. Study them carefully.

Manual Transmission Problems

Many transmission problems are a result of driver abuse. Speed shifting, down shifting at high speeds, and improper clutch use can damage internal manual transmission parts. With high mileage, parts can also wear and fail. The next section of this chapter will summarize common manual transmission problems.

Tech Tip

Dual clutch, dual input shaft automated manual transmissions are two individual transmissions housed in a single case or housing. Each clutch and transmission input shaft drives its own three-speed gearbox. Two three-speeds (six forward gear ratios) or two four-speeds (eight forward ratios) combine to make a single complex multispeed helical racing gearbox. Although they have more parts, auto shift manual transmissions use the same basic parts used for years in "good, old, hand-shifted, foot-clutched" gearboxes.

Gears Grind When Shifting

A grinding sound (gear clashing) when shifting is frequently caused by incorrect transmission linkage adjustment. If the transmission linkage is badly worn, the gears inside the transmission may not engage properly. If the clutch is dragging, the synchronizer teeth can grind while trying to equalize gear and output shaft speed, especially when shifting out of neutral.

Problems inside the transmission can also cause gear grinding during shifts. Worn or damaged synchronizers, shift forks or rails, and excessive wear in bearings, cones, and shafts may prevent the gears from engaging smoothly.

Transmission Noise

When a manual transmission is noisy (roaring, humming, or whirring sound), first check the transmission lubricant. It may be low or contaminated with metal particles.

Transmission noises will usually tell the experienced technician where the problem is. For example, if the transmission is noisy in all gears, something common to all of the gears is at fault. Transmission bearings or shaft end play spacers may be worn, or a shaft may be damaged. On the other hand, if there is only a noise in one gear, the problem is due to components related to that specific gear.

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Transmission Difficult to Shift

When the hand shifter is difficult to move through the gears, check the linkage or shift mechanism. Make sure the linkage is lubricated and moving freely. A bent or misaligned shift rod will cause hard shifting. Also, inspect the operation of the clutch linkage. If the clutch is not releasing completely, the transmission can be hard to shift.

Transmission Jumps out of Gear

When a transmission jumps out of gear, the driver's shift lever "pops" or moves into neutral while driving.

First, check the transmission linkage and shift lever arms. If the shifter assembly is badly worn, it should be rebuilt or replaced.

A worn clutch pilot bearing may also cause the transmission to jump out of gear. Severe vibration, caused by the wobbling transmission input shaft, can wiggle and move the shift forks and synchronizers.

Other problems inside the transmission can cause it to jump out of gear, including worn synchronizer inserts and springs, worn shift fork assemblies or shift rails, and wear and excessive play in the countershaft and output shaft assemblies.

Transmission Leaks Lubricant

Manual transmission lubricant leaks are caused by ruptured gaskets, worn seals, loose fasteners, or damage to the case, housings, or covers. When this problem occurs, check the lubricant level in the transmission. If the lubricant level is too high, lubricant may leak from the transmission vent or from otherwise good seals. Also check that all housing or cover bolts are tight.

When a seal leaks, always check the shaft bearing or bushing. A worn bearing or bushing and the wobbling action of the shaft can make a new seal leak.

Some of the gaskets and seals in a transmission can be replaced without removing the transmission from the vehicle. For example, the rear housing seal and gasket can normally be installed with the transmission in the vehicle.

Transmission Locked in Gear

When the shifter is locked in one gear, check the transmission shifter assembly and linkage. Look for bent shift rods, worn linkage, bushings, and shifter arms. Also check linkage adjustment. With a shift rail mechanism, worn or damaged rails, detents, or forks could be the cause.

A transmission can also become locked in gear when drive gear teeth are broken. The teeth can jam together and be locked by bits of metal from chipped gear teeth.

Diagnosis Chart

Refer to the transmission diagnosis chart in a service manual when a problem is difficult to locate. It will be written for the exact type, make, and model of transmission.

Transmission Identification

When repairing a manual transmission, you must be able to identify the exact type of transmission. Usually, there will be an ID tag (identification label) or stamped set of numbers on the transmission. These numbers can be given to the parts counter person when you are ordering new parts.

Manual Transmission Service

Many problems that seem to be caused by the transmission are caused by clutch, linkage, or driveline problems. Keep this in mind before removing and disassembling a transmission.

If you are servicing an electronically controlled manual transmission, make sure you check for transmission-related trouble codes. Also, check live data stream circuit values for all transmission sensor and actuator circuits in and on the gearbox.

Manual Transmission Removal

When removing a transmission, use a transmission jack, if one is available. A ***transmission jack*** has a special saddle and chains for securing the transmission to keep it from falling during removal and installation. See **Figure 64-2**.



Warning

A manual transmission is heavy and clumsy. If you are not using a transmission jack, ask another technician to help you lift the transmission out of the vehicle. A transmission jack is needed when working alone to prevent injury.

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Figure 64-2. A transmission jack should be used to avoid injuries when a transmission is removed or installed by hand.

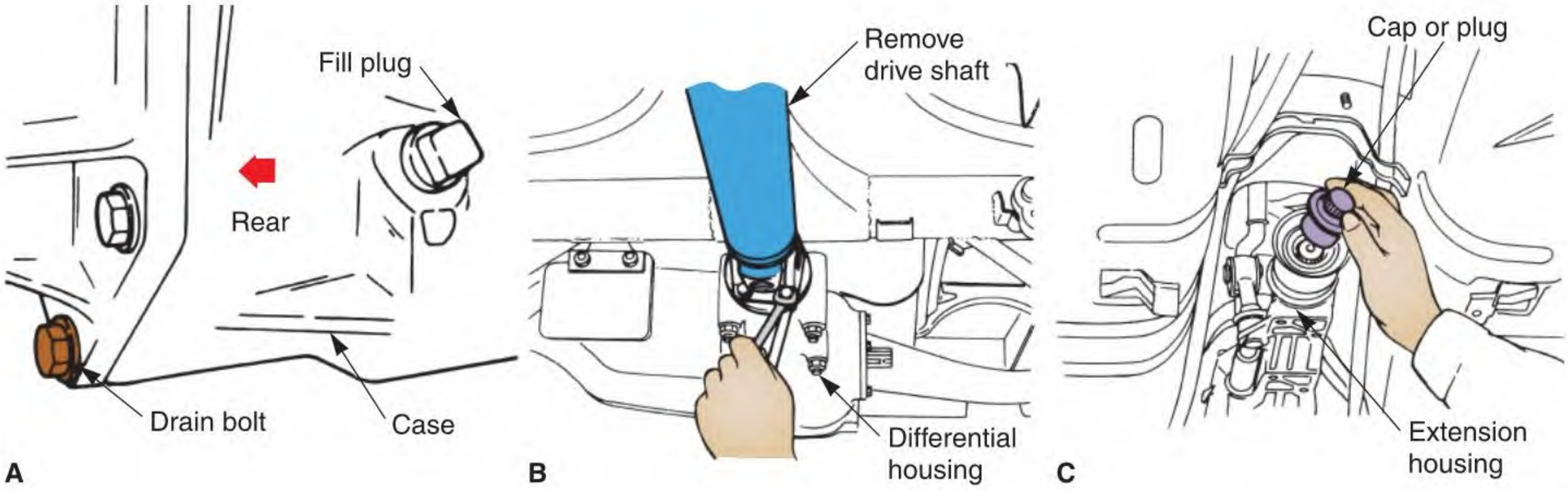
Service Procedure

To remove a manual transmission:

1. Secure the vehicle on a hoist or set of jack stands. A hoist is better because it allows you to stand while working.
2. Remove the transmission drain plug and drain the oil into a catch pan, **Figure 64-3A**.
3. Remove the drive shaft, **Figure 64-3B**.
4. Install a plastic cap over the end of the transmission shaft, **Figure 64-3C**. This will help keep oil from dripping out.
5. Disconnect the transmission linkage at the transmission.
6. Unbolt and pull the speedometer cable out of the extension housing.
7. Remove all electrical wires going to switches on the transmission.
8. Often, a cross member (transmission support bolted to the frame) must be removed. Support the transmission with a jack and use another jack under the rear of the engine. Operate the jack on the engine to take the weight off the transmission. Be careful not to crush the oil pan. Never let the engine hang suspended by only the front motor mounts.
9. Depending on what is recommended in the service manual, remove either the transmission-to-clutch cover bolts or the bolts going into the engine from the clutch cover.
10. Slide the transmission straight back, holding it in alignment with the engine. You may have to wiggle the transmission slightly to free it from the engine.
11. Clean the outside of the transmission and take it to a workbench.

Manual Transmission Disassembly

Teardown procedures vary from one transmission make and model to another. Always consult a service manual. Improper disassembly methods could cause major part damage.



GMC; Subaru

Figure 64-3. Preparing for transmission removal. A—Drain gear oil by removing the plug on the bottom of the transmission case. B—Remove the driveshaft. C—If you do not drain the transmission, install a plastic cap to prevent oil leakage.

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Service Procedure

To disassemble a manual transmission:

1. Remove the shift fork assembly and cover. With a shift rail type, remove the shift lever assembly. If the transmission has an inspection cover, observe transmission action with the cover removed.
2. Shift the transmission into each gear by moving the small levers on the shift forks. At the same time, rotate the input shaft while inspecting the condition of the gears and synchronizers.
3. Unbolt the rear extension housing. Tap the extension housing off with a brass hammer, as shown in **Figure 64-4A**.
4. On the front of the transmission, remove the front bearing cover and any snap rings.
5. Carefully pry the input shaft and gear forward far enough to free the main output shaft.
6. Use a ***dummy shaft*** (shaft tool designed for driving) to drive out the countershaft and reverse idler shaft. See **Figure 64-4B**.
7. Remove the input shaft and output shaft assemblies. Slide the output shaft and gears out of the back or top of the transmission as a unit. Be careful not to nick the gears on the case, **Figure 64-4C**.

Cleaning and Inspecting Parts

With all of the parts removed from the case, inspect everything closely. Check the inside of the case for metal shavings. If brass-colored particles are found, one or more of the synchronizers or thrust washers are damaged. These are normally the only parts in the transmission made of this material.

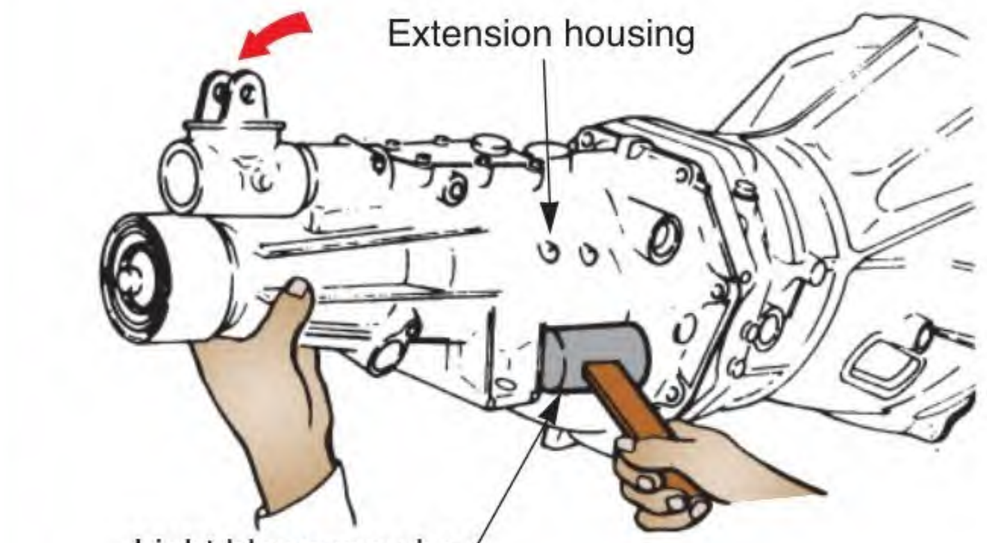
If iron chips are found, the output drive gears are probably damaged. After checking the case, clean the inside with solvent and blow it dry with compressed air while wearing eye protection. Also, clean the transmission bearings.

Warning

When blowing bearings dry with compressed air, do not allow the bearing to spin. Air pressure can make the bearing whirl at tremendously high speed. The bearing can explode and fly apart with lethal force.

Next, inspect all of the output gears. Look for wear patterns or chips on the gear teeth. The gears are usually case-hardened. If wear is more than a few thousandths of an inch, the hard outer layer will be worn through and the gear must be replaced.

Transmission shaft runout is the amount of wobble produced when a bent or worn shaft is rotated. If gear tooth wear is uneven, check the shaft bearings and shafts. They may be worn or bent. A dial indicator



Nissan; GMC; Chrysler

Figure 64-4. Follow service manual directions during transmission disassembly. A—A soft mallet may be needed to free the extension housing from the case. B—A dummy shaft is used to drive out the countershaft and reverse idler shaft. C—After removing snap rings and front bearing cover, lift the output shaft and other components out of the case.

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can be used to check the transmission shafts for straightness. Refer to specifications for the amount of allowable runout, **Figure 64-5**.

Inspect the synchronizer assemblies, especially if the transmission had gear shifting problems. Check the teeth, splines, and grooves on the synchronizers. Replace parts as needed, **Figure 64-6**.

When removing the gears from the output shaft, keep everything organized on your workbench. All snap rings, spacers, and other parts should be installed exactly as removed. A service manual normally provides an illustration for the exact transmission being repaired. This can be helpful during teardown and reassembly.

If synchronizers are to be reused, scribe alignment marks on the sleeve and hub. This will let you realign the same splines during reassembly.

Replace Worn or Damaged Parts

Any worn or damaged part in the transmission must be replaced. This is why your inspection is very important. If any trouble is not corrected, the transmission rebuild may fail. You would have to complete the job a second time—probably free of charge.

Always replace all gaskets and seals in the transmission. Even though a seal or gasket might not leak before teardown, it could start to leak after reassembly. **Figure 64-7** shows a common way of replacing a rear seal.

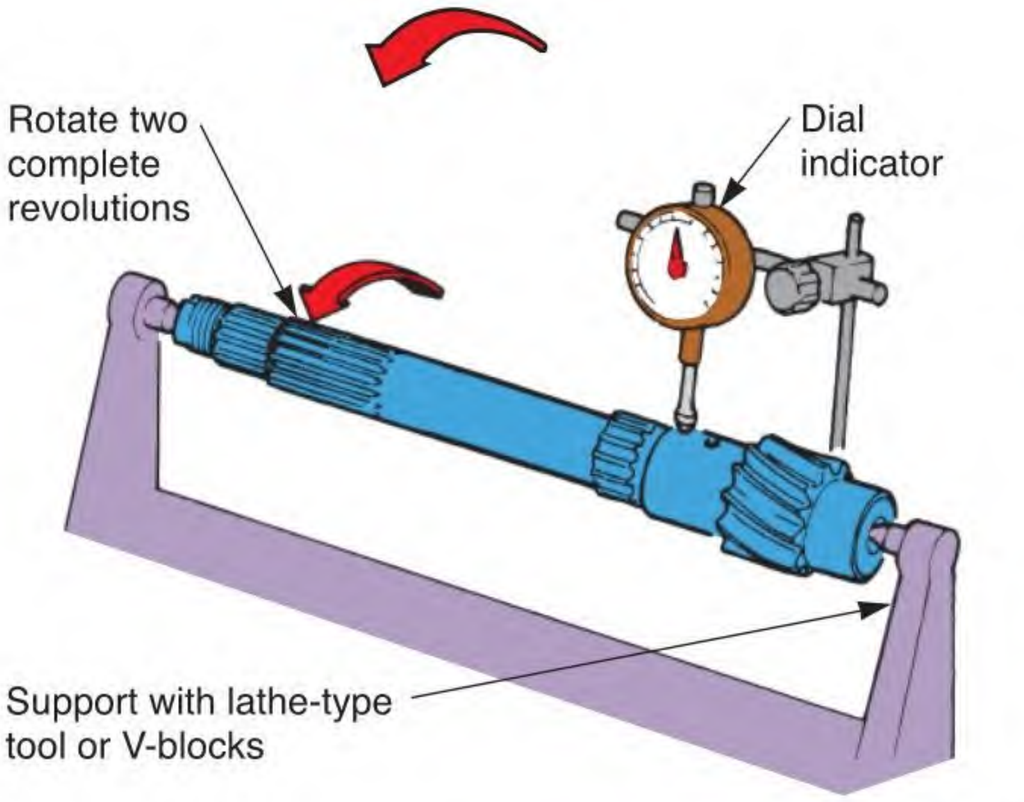
When replacing a gear on the output shaft, you should also replace the matching gearset on the countershaft. If a new gear is meshed with an old worn gear, gear noise can result.

Frequently, you will need to replace input shaft bearings, output shaft bearings, and sometimes countershaft bearings. These bearings are prone to wear because they support a great amount of load, **Figure 64-8**.

Some transmissions use metric fasteners. If a new bolt or nut is needed, make sure it is the correct thread type and length. Mixing threads will cause part damage.

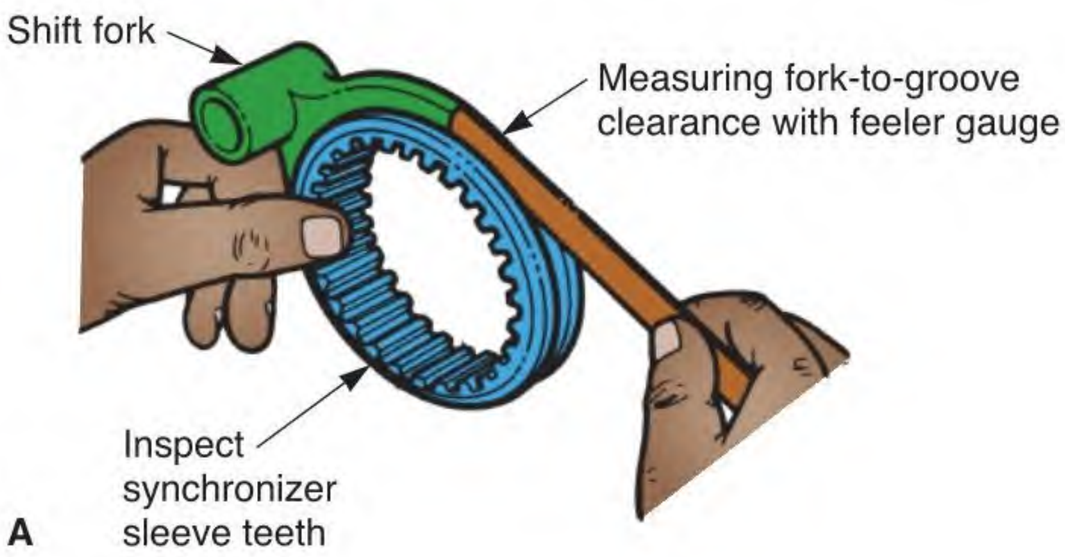
Tech Tip

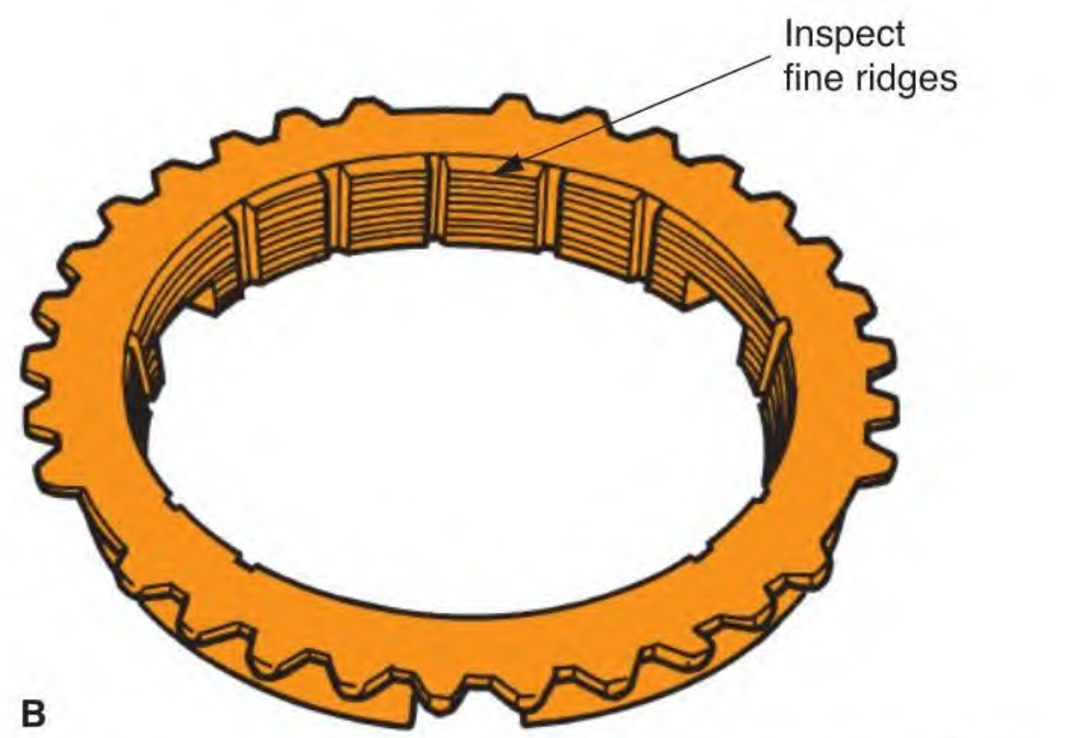
With the transmission out of the vehicle, it is wise to disassemble and inspect the condition of the clutch. If the customer will not pay for the extra labor, you will no longer be responsible for any clutch problems.



Honda

Figure 64-5. If gear wear is irregular, check shafts for runout. Use a lathe-type support or V-blocks to hold the shaft. Use a dial indicator to measure runout.

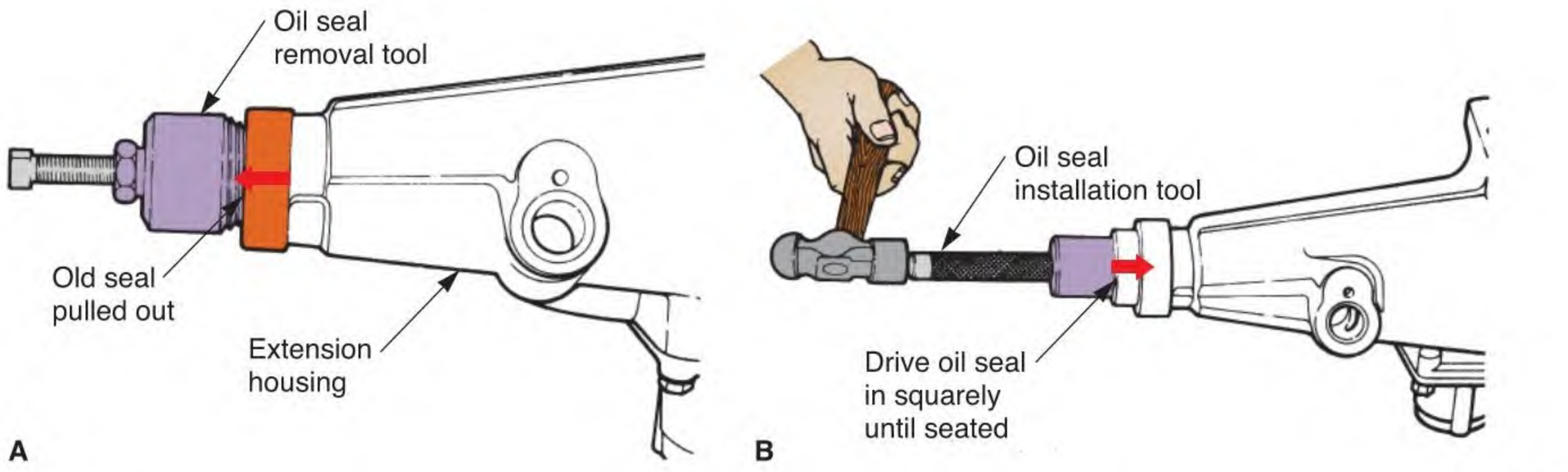




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Figure 64-6. A—Check shift forks and synchronizers for wear. Use a feeler gauge between the fork and the groove. If the measurement is greater than specifications, replace parts as needed. B—Ridges on the inside of blocking rings must be sharp. If rounded off and worn, replace blocking rings to prevent gear clashing when shifting gears.

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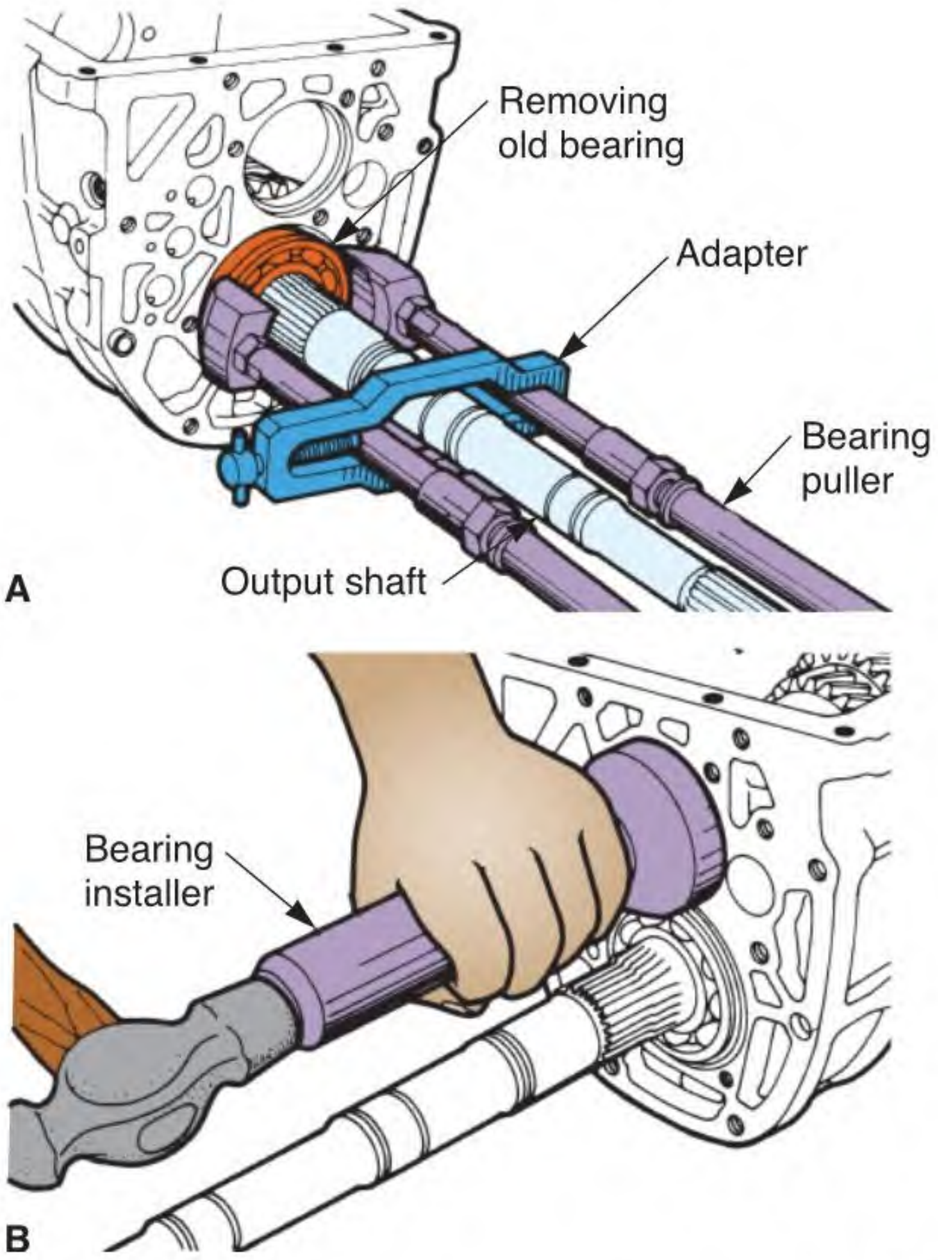
Ford

Figure 64-7. The rear seal can be removed and installed with the transmission still in the vehicle. A—Remove the oil seal without damaging the seal housing. B—Coat the outside of the new seal with nonhardening sealer to help avoid leakage, and drive in new seal.

Transmission Reassembly

After obtaining new parts to replace the old worn ones, you are ready for transmission assembly. Generally, the transmission is assembled in reverse order of disassembly. Again, refer to a service manual for exact directions.

The service manual will usually have an exploded view of the transmission, showing how each part is located in relation to the others. Step-by-step instructions will accompany the illustrations.



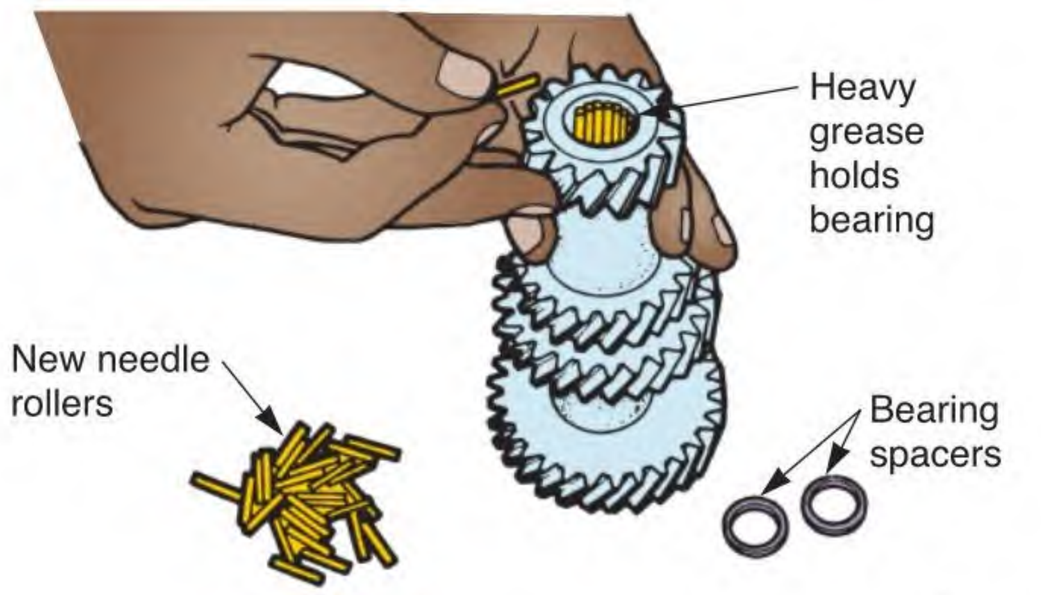
Chrysler

Figure 64-8. If bearings show signs of wear or feel rough when turned by hand, replace them. A—A special puller may be needed on some bearings. B—Use a driver to install new bearings. Do not hammer on the inner portion of the bearing or damage will result.

Service Procedure

To reassemble a manual transmission:

1. Coat the needle bearings with heavy grease to hold them in the countershaft gears. Then, fit each bearing into position. The grease will hold the bearings as you slide the countershaft into the gear, **Figure 64-9**.



Chrysler

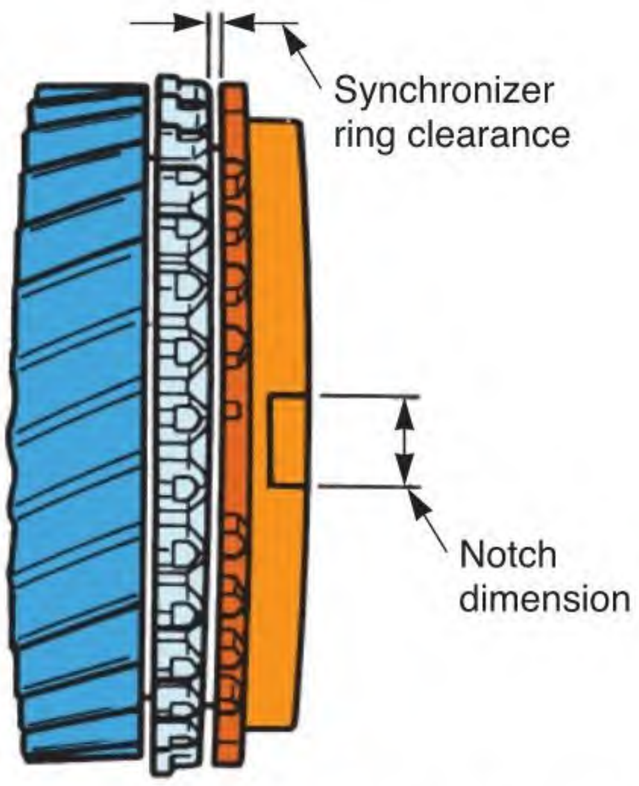
Figure 64-9. Heavy grease is commonly used to hold small needle bearings in the countershaft gear as the countershaft is slid into place.

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2. Following the manufacturer's instructions, measure the end play or clearance of the gears and synchronizers as needed. Look at **Figure 64-10**. If the end play between the countershaft gear and case is excessive, thicker thrust washers are required.
3. After the transmission shafts and gears are in place, pour the recommended quantity of oil into the case.
4. Assemble the shift fork mechanism.
5. With the synchronizers and shift forks in neutral, fit the shift fork assembly on or in the case. Check the action of the shift forks. Look at **Figure 64-11**.
6. Make sure the transmission shifts properly before installing it. This could save you from having to remove the transmission if there are still problems.

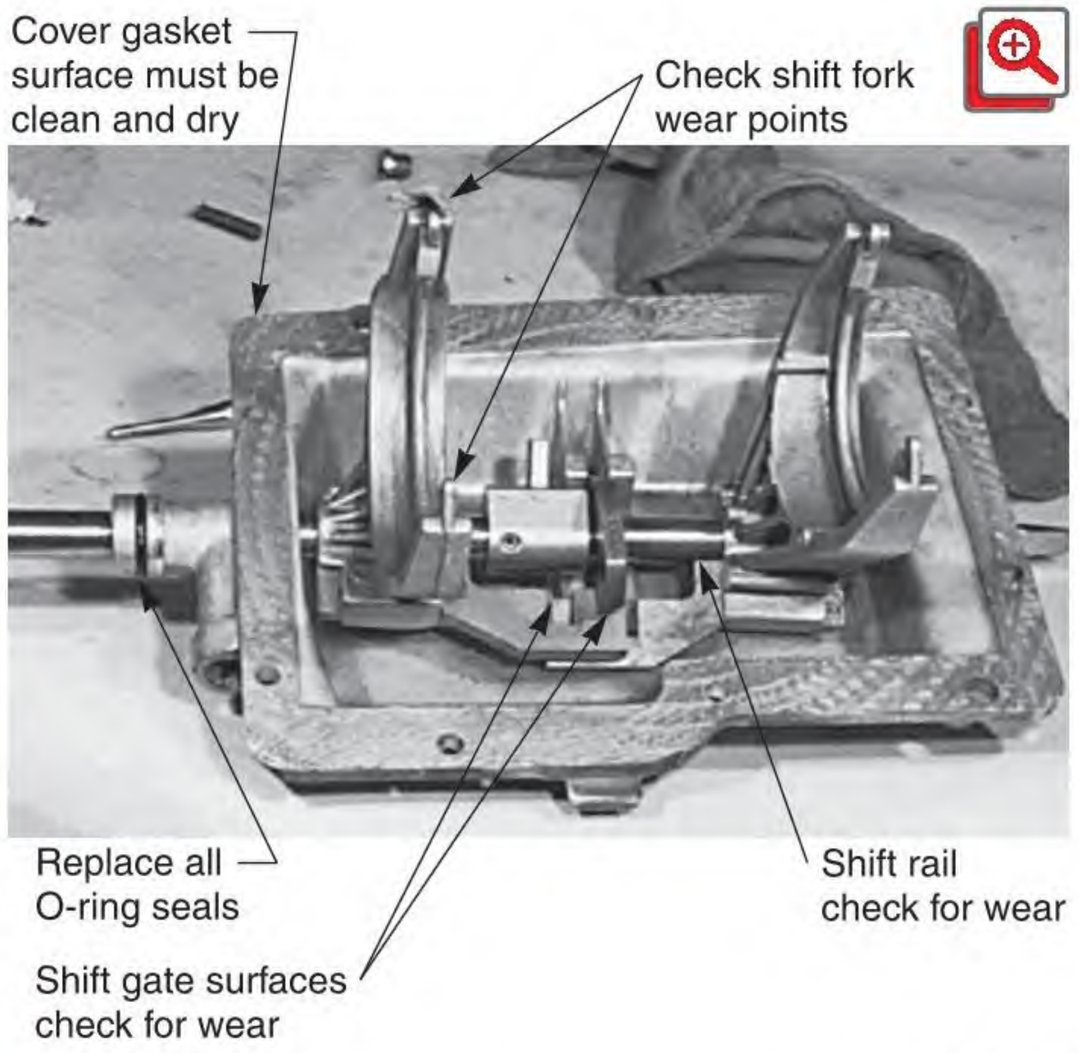
Transmission Installation

Before installing the transmission, place a small amount of grease in the pilot bearing and on the inner surface of the throw-out bearing. Do not place lubricant on the end of the clutch shaft, input shaft splines, or pressure plate release levers. Grease in these locations can spray onto the clutch friction disc, causing clutch slippage and failure.



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Figure 64-10. The service manual will give specifications for important transmission measurements, such as synchronizer ring clearance. Replace parts if not within factory specifications.



Chrysler

Figure 64-11. Make sure nothing in the shift mechanism is worn or damaged. Check shift rail, fork-to-synchronizer contact points, shift gates, and other components. Use an approved method of sealing the shift cover on the case. Refer to a service manual for details.

Shift the transmission into high gear to help position the input shaft into the clutch disc during transmission installation.

Service Procedure

To install a manual transmission:

1. Place the transmission on the transmission jack and position it behind the engine.
2. Double-check that the throw-out bearing is in place on the clutch fork.
3. Carefully align the transmission with the engine. The input and output shaft must line up perfectly with the centerline of the engine crankshaft. If the transmission is tilted, even slightly, it will not fit into place.
4. With the transmission in high gear to hamper input shaft rotation, slowly push the transmission into the clutch housing. You may need to raise or lower the transmission slightly to keep it in alignment.

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5. When the transmission is almost in place, wiggle the extension housing in a circular pattern while pushing toward the engine. This should help start the input shaft in the crankshaft pilot bearing. If the clutch and pilot bearing are installed correctly, the transmission should slide fully into place by hand.



Caution

Do *not* use the transmission bolts to draw the transmission into the clutch housing. The transmission input shaft could be smashed into the crankshaft pilot bearing, which may result in serious part damage.

6. Bolt the transmission to the clutch cover.
7. Install the rear cross member and motor mount.
8. Reinstall the clutch linkage, transmission linkage, and other parts.
9. Adjust the clutch linkage.



Diagnostic Case Study

Concern: Mr. Linn brings his 2003 Miata to the shop. He complains that the car's manual transmission grinds gears.

Cause: Duff takes the car for a test-drive and finds that shifting into first or second gear causes gear clashing noise and vibration.

Duff gives the car to the shop's transmission and clutch technician. The technician raises the car on the lift and checks the clutch and shift linkage adjustments. The linkage adjustments are not the problem. Since the transmission only clashes when shifting into first or second gear, the symptoms point to a bad first-second gear synchronizer.

Correction: The technician removes and rebuilds the transmission. He replaces the first-second gear synchronizer, second mainshaft gear, and all bushings, gaskets, and seals. After reassembling the transmission and reinstalling it, he takes the car for a test-drive to check for proper operation. The car performs well and is released to the owner.

Summary

- Most makes of manual transmissions use similar construction methods.
- The first step toward fixing a transmission is to determine why the problem developed.
- When a manual transmission is noisy (roaring, humming, or whirring sound), first check the transmission lubricant.
- Many manual transmission problems are caused by incorrect transmission linkage and shifter adjustment.
- Some of the gaskets and seals in a transmission can be replaced without removing the transmission from the vehicle.
- Service manuals are written for the exact type, make, and model of transmission.
- Any worn or damaged part discovered during transmission teardown must be replaced.
- Always replace all gaskets and seals in the transmission.
- Generally, the transmission is assembled in reverse order of disassembly.

Technical Terms



Write the definitions for the following terms on a separate sheet of paper.

dummy shaft

transmission jack

transmission shaft runout

Activities

1. Disassemble a defective transmission assigned by your instructor. Clean and examine the parts, listing those that are defective.
2. Remove a transmission from a vehicle.
3. Reassemble a transmission and reinstall it in the vehicle.
4. Operate a transmission selected by your instructor. Identify noises and possible causes.

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Review Questions

Answer the following questions using the information provided in this chapter.

1. A grinding or gear clashing noise when shifting out of neutral could be caused by:
   (A) incorrect linkage adjustment.
   (B) worn synchronizers.
   (C) dragging clutch.
   (D) All of the above.
2. If a transmission is only noisy in second gear, what does that tell you about the problem?
3. A(n) _____ is commonly used to secure a transmission during removal.
4. How is a dummy shaft used during transmission disassembly?
5. If you find bronze- or brass-like metal shavings in the case, synchronizers or thrust washers may be damaged. True or False?
6. What is the potential danger of spinning a bearing with compressed air?
7. Only replace gaskets and seals in the transmission when they are leaking or look deteriorated. True or False?
8. The _____ usually has an exploded view of the transmission, showing how each part is located in relation to the others.
9. What is the purpose of shifting the transmission into high gear before installation?
10. Which of the following parts should be greased during transmission installation?
    (A) Input shaft splines.
    (B) Pilot bearing.
    (C) Pressure plate release levers.
    (D) All of the above.

ASE-Type Questions

1. A manual transmission is not operating properly. Technician A says the first step is to remove the transmission from the vehicle and begin teardown. Technician B says the first step is to determine the cause of the problem. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. All of the following are common manual transmission problems, *except*:
   (A) bent shift mechanism.
   (B) worn thrust washers.
   (C) clogged modulator valve.
   (D) damaged extension housing.
3. The gears of a manual transmission grind during shifting. Technician A checks the transmission linkage adjustment. Technician B looks for a damaged synchronizer. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. An automobile's manual transmission is noisy in all gears. Technician A looks for a damaged transmission shaft. Technician B checks the condition of the first output gear. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. A manual transmission is hard to shift into gear. Technician A looks for a bent shift rod. Technician B checks the condition of the clutch. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. An automobile's manual transmission keeps "jumping out of gear." Technician A thinks the transmission's shift lever arms are not operating properly. Technician B looks for a worn clutch pilot bearing. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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7. Lubricant is leaking out of a manual transmission. Technician A says this problem may be caused by an excessive amount of oil in the transmission case. Technician B checks the condition of the rear housing seal. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. All of the following problems can cause a manual transmission to "lock in gear", *except*:
   (A) bent shift rod.
   (B) faulty shift mechanism adjustment.
   (C) valve body malfunction.
   (D) broken drive gear teeth.
9. Certain parts in a manual transmission need to be replaced. Technician A says that to identify the particular transmission being serviced, you should look for an ID tag located on the transmission. Technician B says that to identify the type of transmission being serviced, you should look for a stamped set of numbers located on the transmission. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. Brass-colored particles are discovered in the case of a manual transmission during disassembly. Technician A checks the condition of the thrust washers. Technician B believes one or more synchronizers could be damaged. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
11. A manual transmission's shafts are being checked for runout. Technician A is going to use a dial indicator to perform this task. Technician B is going to use an inside micrometer to perform this task. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
12. A manual transmission is being installed back into a vehicle. Technician A places a small amount of lubricant on the input shaft splines before installing the transmission. Technician B places a small amount of lubricant on the pressure plate release levers before installing the transmission. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Manual Transmission/Transaxle Diagnosis

Condition	Possible Causes	Correction
Shifts hard—all gears.	1. Excessive clutch pedal free travel. 2. Worn or defective clutch. 3. Failure to fully depress clutch pedal when shifting. 4. Loose shift cover. 5. Worn or loose shift fork, shafts, levers, or detents. 6. Improper shift linkage adjustment. 7. Linkage needs lubrication. 8. Binding, bent, or loose linkage. 9. Wrong transmission lubricant. 10. Insufficient lubricant. 11. Excess lubricant. 12. Misaligned transmission. 13. Loose or cracked input shaft bearing retainer. 14. Worn, damaged, or improperly assembled synchronizer.	1. Adjust free travel. 2. Replace worn parts. 3. Advise driver. 4. Tighten cover. 5. Tighten or replace. 6. Adjust linkage. 7. Lubricate linkage. 8. Free, straighten, or tighten as needed. 9. Drain and fill with recommended lubricant. 10. Add lubricant to filler plug level. 11. Drain excess lubricant. 12. Correct transmission alignment. 13. Tighten or replace retainer. 14. Replace or reassemble synchronizer.
Gear clash during downshifting.	1. Worn, damaged, or improperly assembled synchronizer. 2. Shifting too fast (ramming into lower gear). 3. Shifting to a lower gear when vehicle speed is too high. 4. Clutch not releasing properly. 5. Excessive output shaft end play.	1. Replace or reassemble synchronizer. 2. Force into gear with a smooth, slower shift. 3. Slow down to appropriate speed before shifting. 4. Adjust or repair as needed. 5. Adjust end play.

Continued

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Manual Transmission/Transaxle Diagnosis

Condition	Possible Causes	Correction
Jumps out of gear.	1. Loose or misaligned transmission. 2. Loose or misaligned clutch housing. 3. Improperly adjusted shift linkage. 4. Worn shift rail detents or weak detent springs. 5. Worn synchronizer clutch sleeve teeth. 6. Loose shifter cover. 7. Worn shift fork, shaft, or levers. 8. Worn clutch teeth on input shaft or other gears. 9. Worn gear teeth. 10. Worn counter gear bearings and/or thrust washers. 11. Worn reverse idler gear bushing or bearings. 12. Worn output shaft pilot bearing. 13. Loose input shaft bearing retainer. 14. Other parts striking shift linkage. 15. Worn input or output shaft bearings. 16. Worn input shaft bushing in flywheel. 17. Bent output shaft.	1. Tighten or align transmission. 2. Tighten or align clutch housing. 3. Adjust linkage. 4. Replace rail detents and/or springs. 5. Replace synchronizer. 6. Tighten shifter cover. 7. Replace worn parts. 8. Replace input shaft or gears. 9. Replace gears. 10. Replace counter gear shaft, bearings, and washers. 11. Replace gear, bearings, and shaft. 12. Replace rollers. Replace shafts, if necessary. 13. Tighten bearing retainer. 14. Make adjustments to provide clearance. 15. Replace bearings. 16. Replace input shaft bushing or bearing. 17. Replace output shaft.
Noise in all gears.	1. Insufficient lubrication. 2. Worn or damaged bearings. 3. Worn or damaged gears. 4. Wrong lubricant. 5. Excessive synchronizer wear. 6. Defective speedometer drive gears. 7. Misaligned transmission. 8. Excessive input or output shaft and/or counter gear end play. 9. Contaminated lubricant.	1. Fill to filler plug. 2. Replace bearings. 3. Replace gears. 4. Drain and fill with recommended lubricant. 5. Replace synchronizer. 6. Replace speedometer drive gears. 7. Correct alignment. 8. Adjust end play. 9. Disassemble, clean, and repair transmission.
Noise in neutral with engine running.	1. Worn or damaged input shaft bearing. 2. Worn or damaged gears. 3. Lack of lubrication. 4. Worn or damaged countershaft bearings. 5. Worn or damaged output shaft pilot bearing. 6. Worn or damaged counter gear anti-lash plate. 7. Lubricant contaminated with broken metal.	1. Replace input shaft bearing. 2. Replace gears. 3. Fill transmission to the proper level. 4. Replace bearings, counter gear, and shaft. 5. Replace all rollers. 6. Replace plate or counter gear as required. 7. Disassemble, clean, and repair transmission.
Noise in direct-drive gear.	1. Defective input shaft bearing. 2. Defective output shaft bearing. 3. Defective synchronizer. 4. Defective speedometer drive gears.	1. Replace input shaft bearing. 2. Replace output shaft bearing. 3. Replace synchronizer. 4. Replace speedometer drive gears.

Continued

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Manual Transmission/Transaxle Diagnosis

Condition	Possible Causes	Correction
Noise in reduction or overdrive gear.	1. Counter gear rear bearings worn or damaged. 2. Defective synchronizer. 3. Constant mesh gear loose on shaft. 4. Constant mesh gear teeth worn or chipped.	1. Replace counter gear bearings. Replace shaft and counter gear, if needed. 2. Replace synchronizer. 3. Replace gear and/or shaft. 4. Replace gear.
Noise in reverse.	1. Worn reverse idler bushings. 2. Worn or damaged reverse idler gear. 3. Worn or damaged counter gear reverse gear. 4. Defective reverse sliding gear (synchromesh low gear).	1. Replace idler gear or bushings. 2. Replace reverse idler gear. 3. Replace counter gear. 4. Replace reverse sliding gear.
Sticks in gear.	1. Insufficient lubricant. 2. Burred synchronizer clutch sleeve teeth. 3. Sticking shift rails. 4. Synchronizer blocking ring stuck to mating gear. 5. Defective shift linkage. 6. Insufficient clutch pedal free travel. 7. Misaligned transmission.	1. Fill to filler plug. 2. Replace synchronizer. 3. Free and lubricate shift rails. 4. Free, lubricate, or replace blocking ring or mating gear. 5. Repair or replace linkage. 6. Adjust clutch pedal free travel. 7. Correct alignment.
Gear clash when shifting from neutral to low or reverse.	1. Insufficient clutch pedal free travel. 2. Wrong lubricant. 3. Engine rpm too high. 4. Insufficient time between depressing clutch and shifting. 5. Sticking input shaft clutch pilot bearing.	1. Adjust free travel. 2. Drain and fill with correct lubricant. 3. Set to correct idle rpm. 4. Advise driver. 5. Replace pilot bearing.

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Chapter 65
Automatic Transmission Technology

After studying this chapter, you will be able to:

- Identify the basic components of an automatic transmission.
- Describe the function and operation of the major parts of an automatic transmission.
- Trace the flow of power through an automatic transmission.
- Explain how an automatic transmission shifts gears using shift solenoids and an ECM.
- Compare the different types of automatic transmissions.
- Correctly answer ASE certification test questions requiring a knowledge of automatic transmission operation and construction.

An ***automatic transmission*** performs the same functions as a manual transmission, but it "shifts gears" and "releases the clutch" automatically and more smoothly using a torque converter or fluid coupling. An automatic transmission also uses compact planetary gearsets instead of large helical gearsets. Most modern vehicles use an automatic transmission (or transaxle) because it saves the driver from having to move a shift lever and depress a clutch pedal.

Today's automatic transmissions are computer controlled. Solenoids are used to operate hydraulic circuits to engage each gear ratio. The transmission, engine, and body control modules sense engine speed (rpms); load (engine vacuum); road speed; and other engine, suspension, and brake input signals to determine shift points.

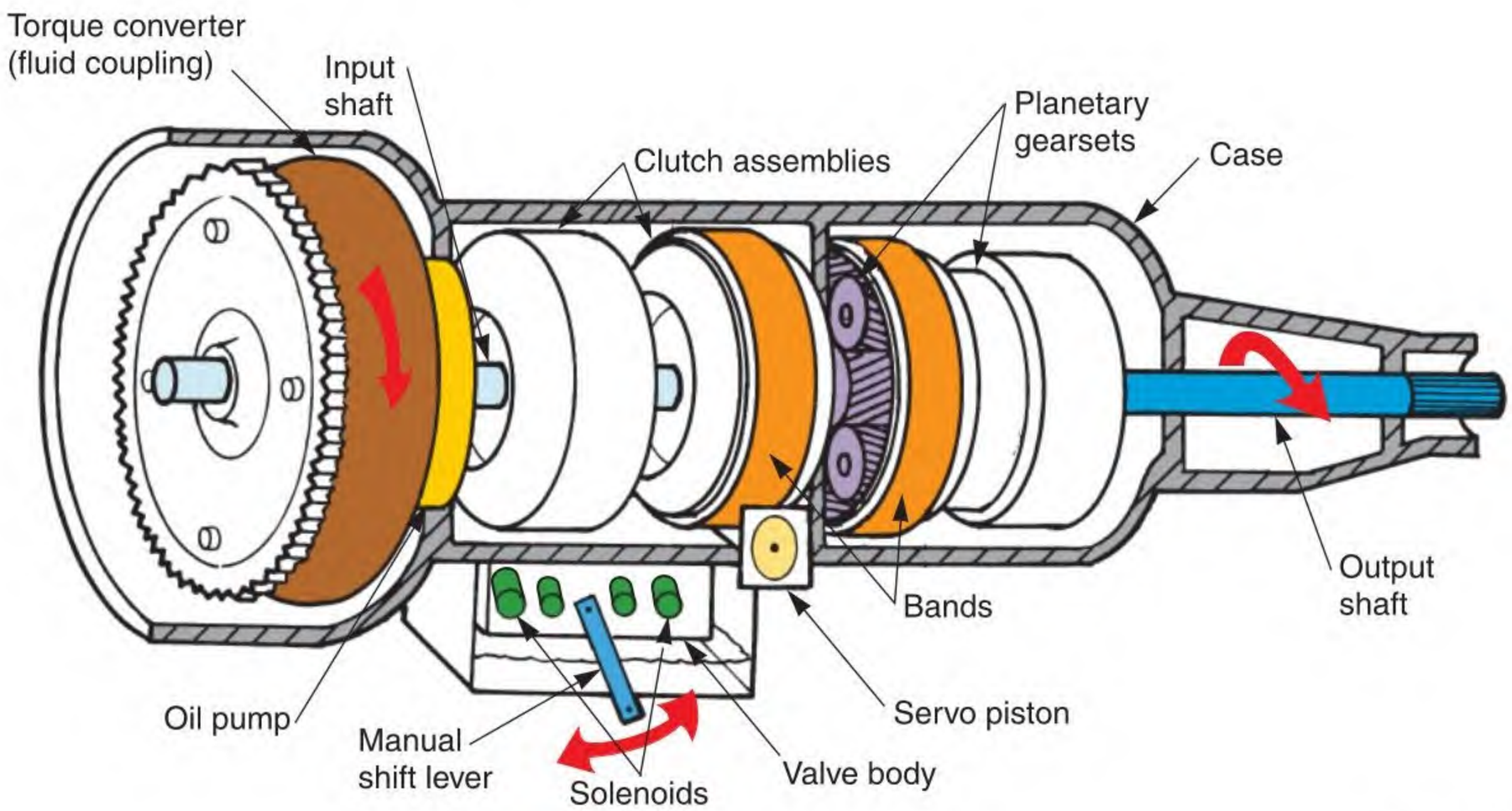
Basic Automatic Transmission

Before studying the construction and operation of individual parts in detail, you must have a general idea of how an automatic transmission works. Then, you will be able to relate the details of each part to the complete transmission assembly.

Refer to **Figure 65-1** as the basic parts of an automatic transmission are introduced.

- Torque converter—A torque converter is a fluid coupling that connects and disconnects the engine crankshaft and transmission.
- Input shaft—The input shaft transfers power from the torque converter to the internal drive members and gearsets.
- Transmission oil pump—This pump produces pressure to operate the hydraulic components in the transmission.

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Figure 65-1. Study the basic parts of this simplified automatic transmission with round planetary gearsets, clutches, and bands.

- Valve body—The valve body is an electro-hydraulic assembly that routes fluid pressure to specific hydraulic pistons and servos to hold or release different planetary gearsets.
- Pistons and servos—Pistons and servos actuate bands and clutches in the automatic transmission case that engage different planetary gearsets.
- Planetary gearsets—These gearsets provide different gear ratios and reverse gear.
- Bands and clutches—Bands and clutches apply clamping pressure on different parts of the planetary gearsets to operate them.
- Output shaft—The output shaft transfers engine torque from the gearsets to the drive shaft.

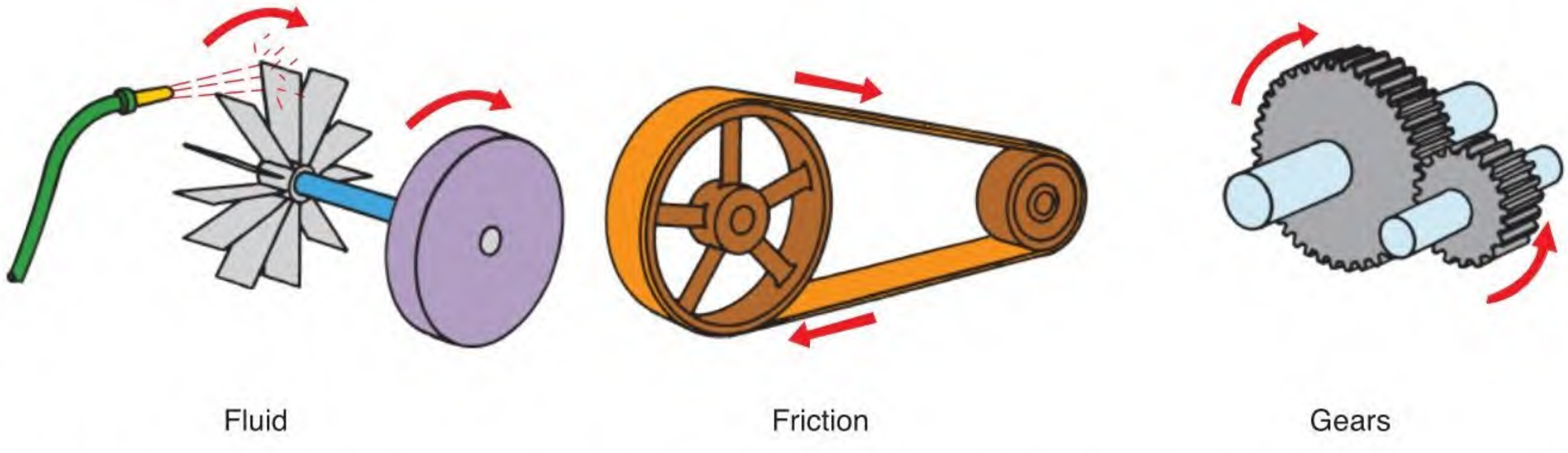
Transmitting Power

As you will see, an automatic transmission uses three methods to transmit power: fluid, friction, and gears. This is illustrated in **Figure 65-2**.

The torque converter uses *fluid* to transfer power from the transmission to the engine or motor-generator. The bands and clutches use *friction* to lock or hold parts together. The transmission *gears* not only transmit power, but they can increase or decrease speed and torque.

Transmission Housings and Case

An automatic transmission is normally constructed with four main components: bell housing, case, pan,



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Figure 65-2. An automatic transmission uses three methods of transmitting power: fluid, friction, and gears.

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and extension housing. These parts support and enclose all the other components in the transmission. Refer to **Figure 65-3**.

The ***bell housing*** is usually made of aluminum. It surrounds the torque converter and holds the transmission against the engine. On a hybrid automatic vehicle, the motor-generator can also be mounted inside the bell housing.

Bolts fit through holes in the bell housing and attach to the engine block. The bell housing also keeps road dirt, rocks, and other debris off the spinning torque converter and flywheel.

The ***transmission case*** encloses the clutches, bands, gearsets, and inner ends of the transmission shafts. The bell housing bolts to the front of the aluminum case, and the extension housing bolts to the rear of the case. The valve body and pan bolt to the bottom of the case.

The ***oil pan***, also called the ***transmission pan***, collects and stores a supply of transmission oil. It is usually made of thin, stamped steel or cast aluminum and fits over the valve body. A gasket or sealant prevents leakage between the case and the oil pan.

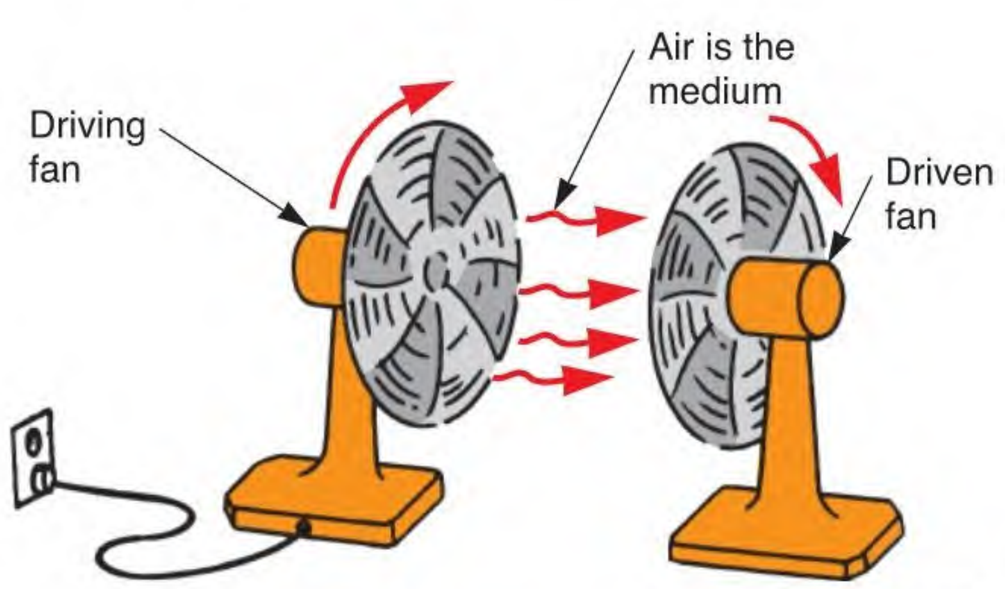
The ***extension housing*** slides over and supports the output shaft. A gasket is used on the front of the housing and a seal on the rear to prevent fluid leakage. The housing is made of aluminum.

Torque Converter

The ***torque converter*** is a fluid clutch that performs the same basic function as the clutch in a manual transmission—it provides a means of coupling and uncoupling the engine from the transmission.

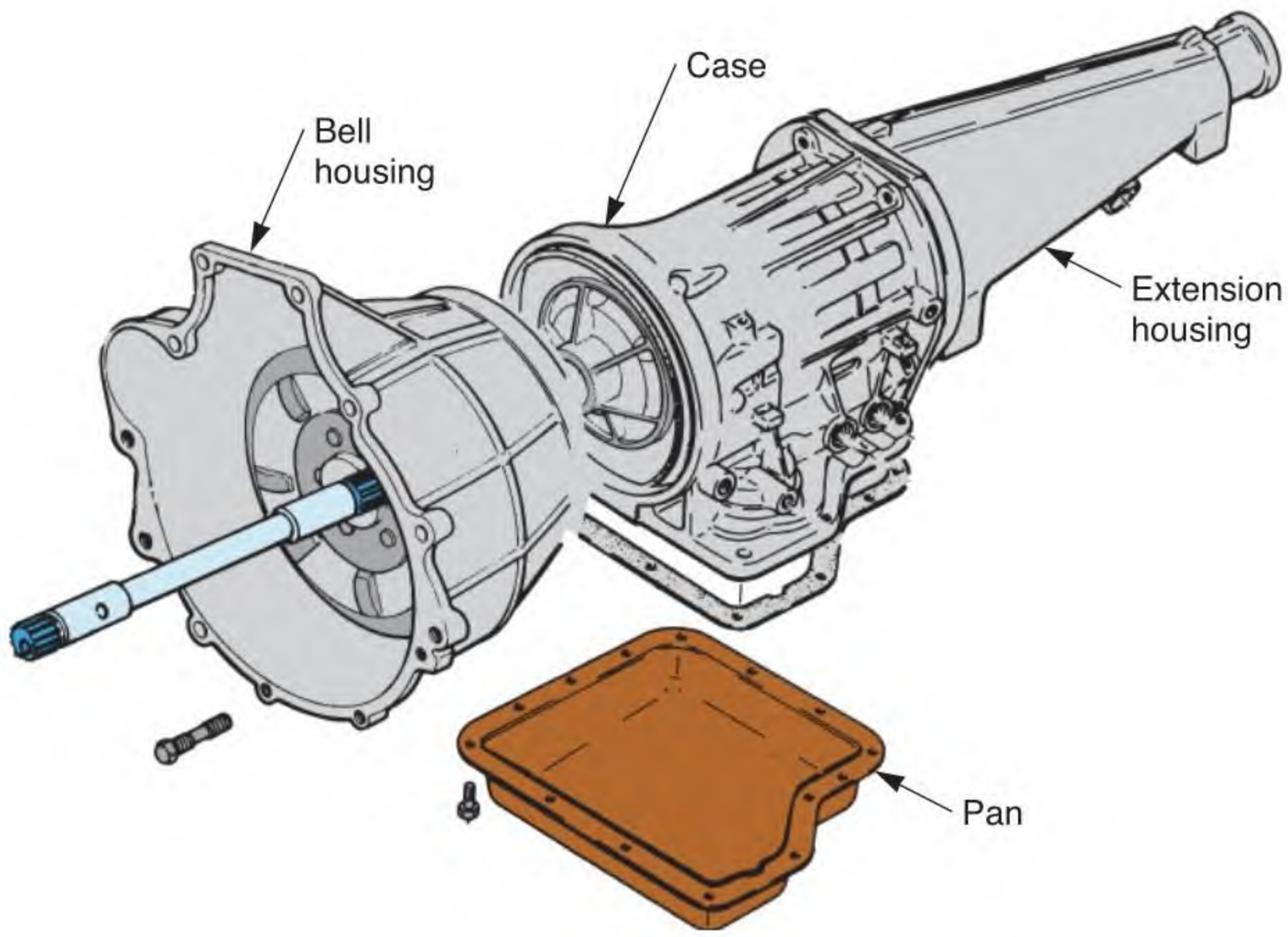
Torque Converter Principles

Two house fans can be used to demonstrate the basic action inside a torque converter. Look at **Figure 65-4**. One fan is plugged in and is spinning. The other fan is not plugged into electrical power.



Deere & Co.

Figure 65-4. Two fans demonstrate the principle of torque converter operation. One part can drive another using the force of fluid (air or oil).



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Figure 65-3. Most automatic transmissions are constructed with an aluminum front bell housing, central case, rear extension housing, and lower steel or aluminum pan. Most parts are located inside the case.

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Since the spinning fan is facing the other, it can be used to spin the unplugged fan, transferring power through a fluid (air). This principle applies inside a torque converter, but oil is used instead of air.

Torque Converter Construction

A torque converter consists of four basic parts: the outer housing, an impeller or pump, a turbine, and a stator. These parts are shown in **Figure 65-5A**.

The impeller, stator, and turbine have curved fan blades. They work like our simple example of one fan driving another. The impeller drives the turbine, as shown in **Figure 65-5B**.

Converter Housing

The impeller, stator, and turbine are contained inside a doughnut-shaped converter housing. This housing is normally made of two pieces of steel welded together and is filled with transmission oil (fluid). See **Figure 65-6**.

The ***impeller***, sometimes called the ***converter pump***, is the driving fan that produces oil movement inside the converter whenever the engine is running. It is an integral part of the housing.

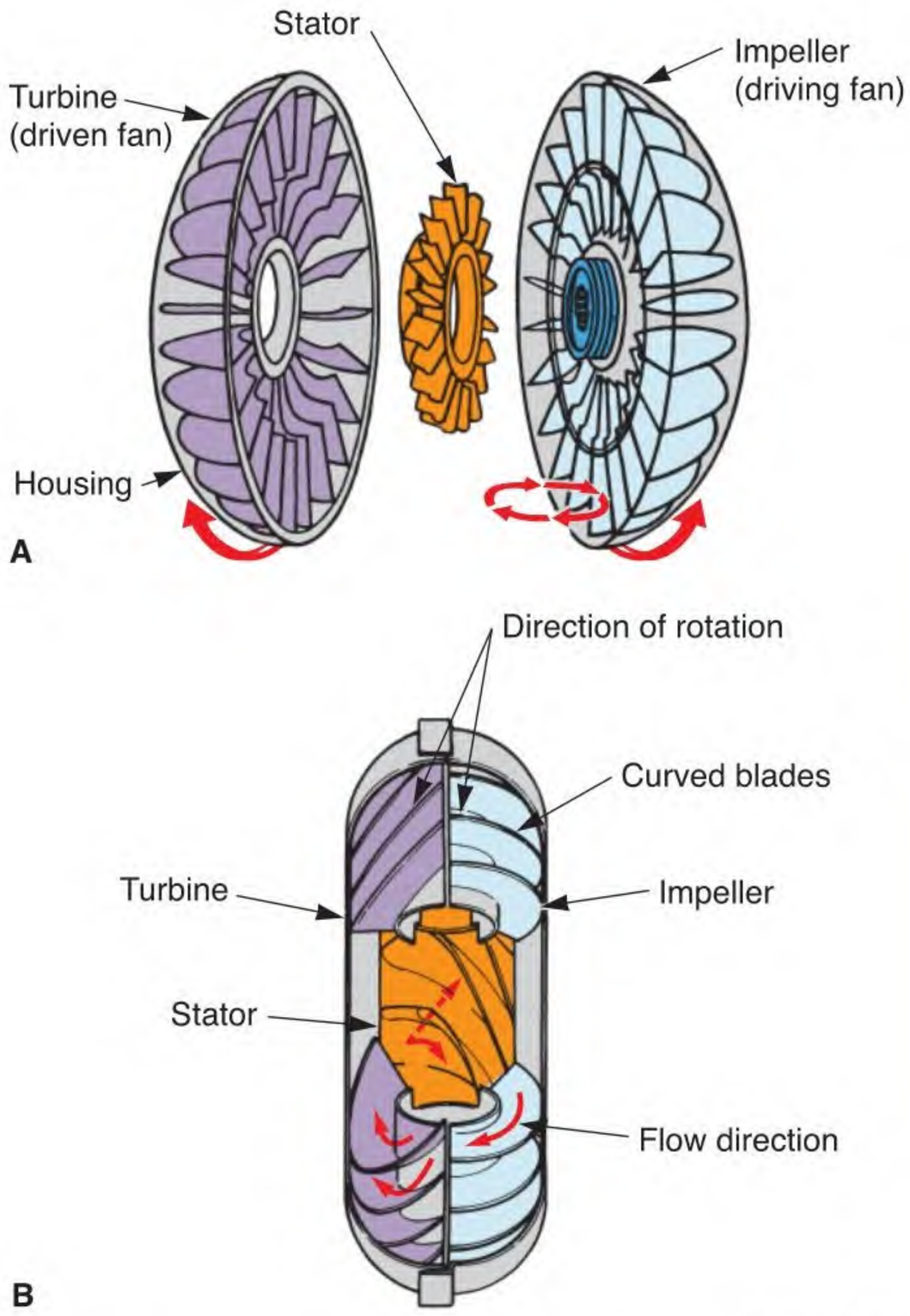
The ***turbine*** is a driven fan splined to the input shaft of the automatic transmission. It fits in front of the stator and impeller in the housing. The turbine is not fastened to the impeller or the housing—it is free to turn independently. Oil is the only connection between the two.

The ***stator*** is designed to improve oil circulation inside the torque converter. It increases efficiency and torque by causing the oil to swirl around inside the converter housing. This helps make use of nearly all the force produced by the moving oil, **Figure 65-7**.

Torque Converter Operation

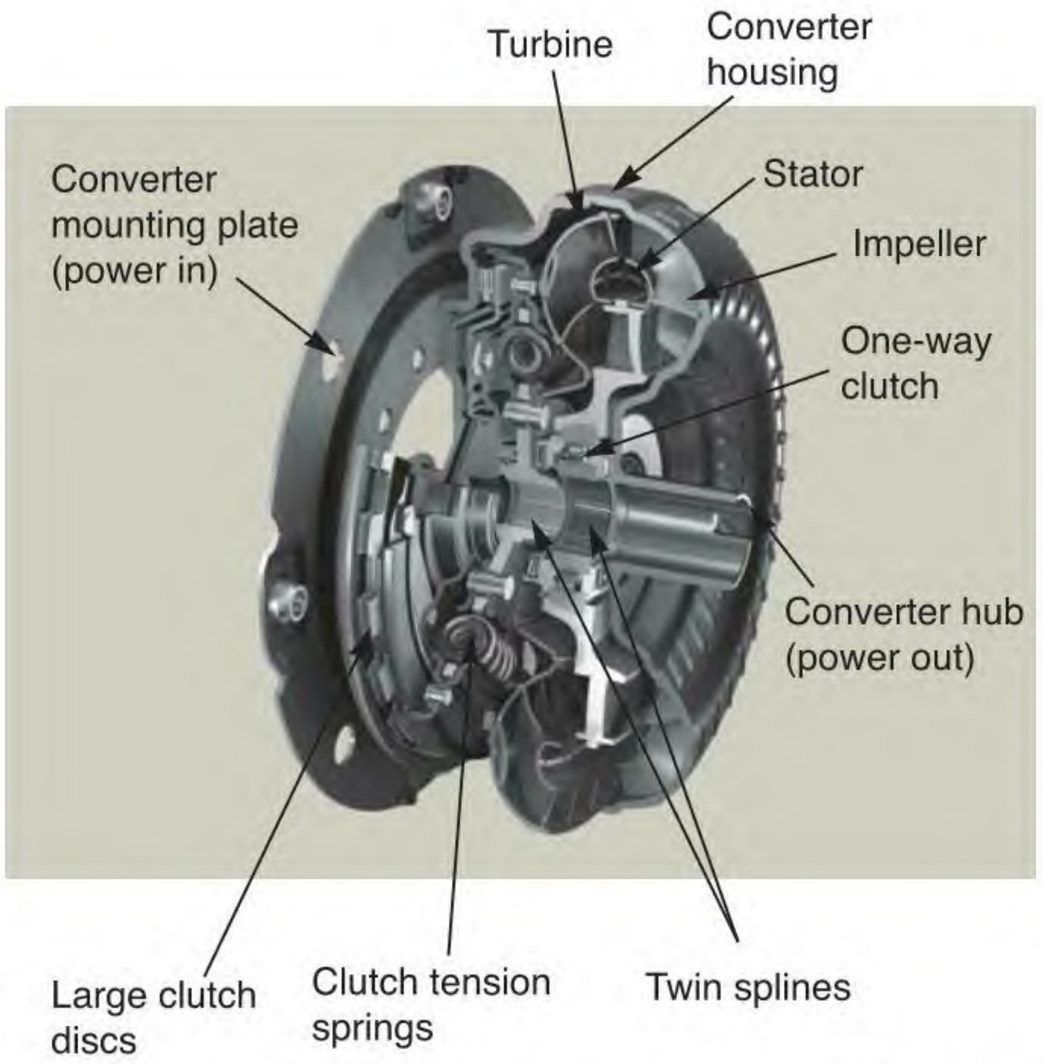
The torque converter is very large and heavy, which allows it to serve as a flywheel to smooth out engine power pulses. Its inertia reduces vibration entering the transmission and driveline.

An automatic transmission uses a very thin and light flywheel. It is simply a stamped disc with a ring gear



Texaco; Subaru

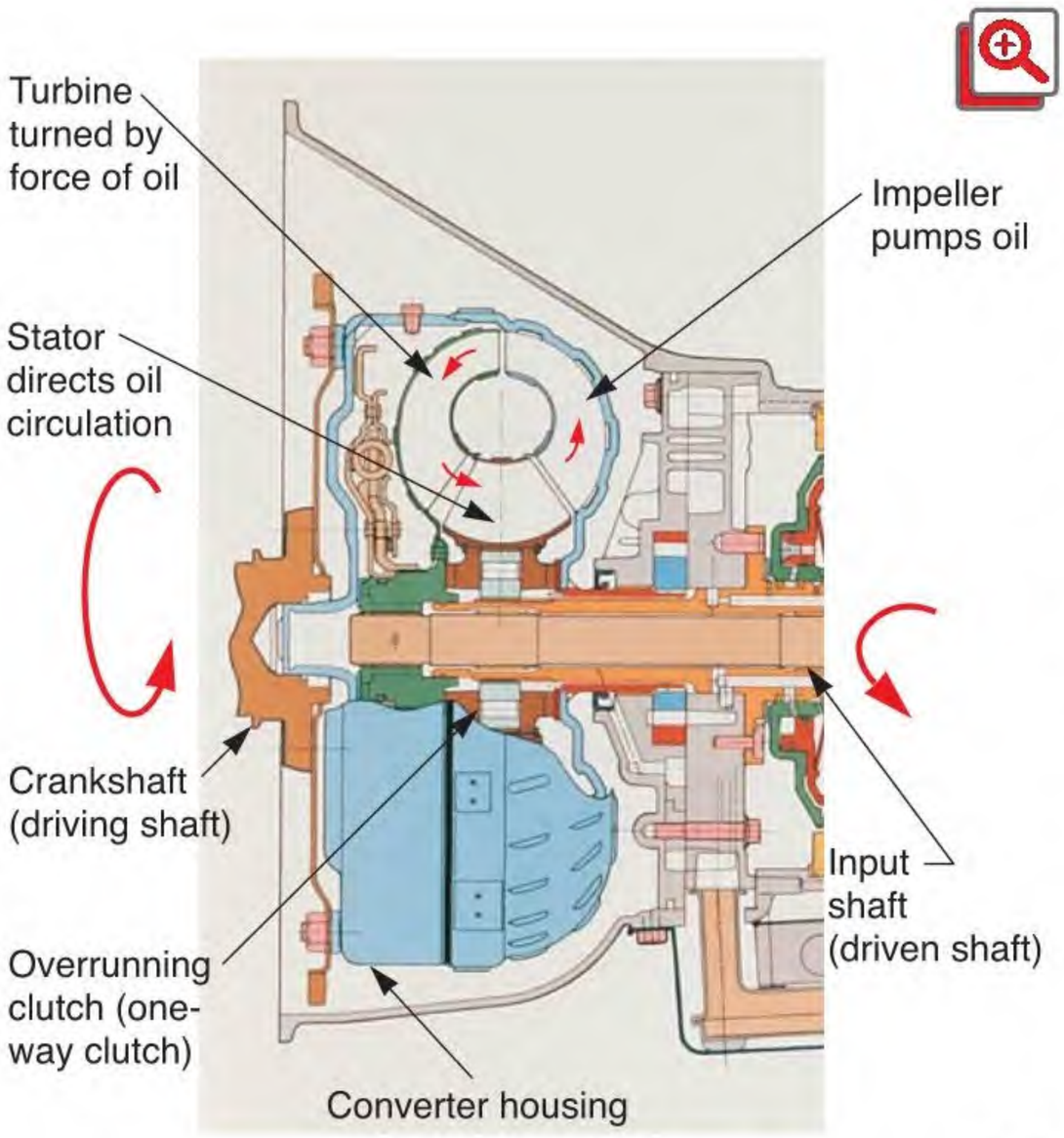
Figure 65-5. A torque converter. A—Four major parts: housing, impeller, stator, and turbine. B—Blades on the impeller and stator direct oil circulation onto blades of the turbine. The impeller is driven by the engine. The turbine is driven by the impeller.



ZF Transmissions

Figure 65-6. The torque converter fits inside a housing at the rear of the engine. It is bolted to the crankshaft flange and splined to the transmission input shaft.

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Figure 65-7. The crankshaft is fastened to the converter housing and impeller. The stator is mounted on a one-way clutch. When the engine crankshaft spins fast enough, oil movement rotates the turbine and transmission input shaft.

for the starting motor. If the ring gear is on the torque converter, a flex plate (without a ring gear) can be used to connect the crankshaft to the torque converter. The crankshaft bolts to one side of the flywheel or flex plate, and the torque converter bolts to the other side.

With the engine idling, the impeller spins slowly. Only a small amount of oil is thrown into the stator and turbine. Not enough force is developed inside the torque converter to spin the turbine. The car remains stationary with the transmission in gear.

During engine acceleration, the engine crankshaft, converter housing, and impeller begin to spin faster. More oil is thrown out of the impeller by centrifugal force. This makes the turbine begin to turn. As a result, the transmission input shaft and vehicle start to move, but with some slippage. At cruising speeds, the impeller and turbine spin at almost the same speed, with very little slippage.

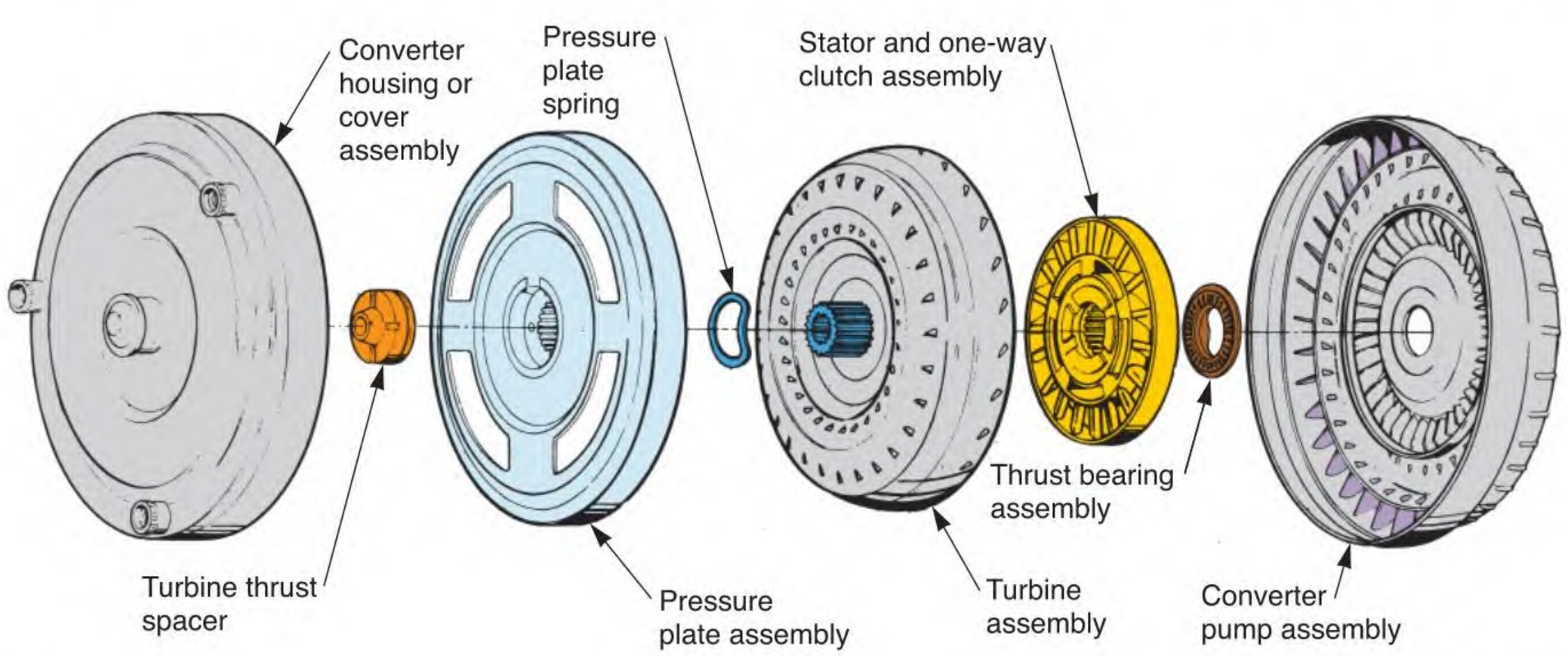
Converter One-Way Clutch

A ***one-way clutch*** (overrunning clutch) allows the stator to turn in only one direction. The stator mounts on the one-way clutch mechanism. Stator action is needed only when the impeller and turbine are turning at different speeds. See **Figure 65-8**.

The one-way clutch locks the stator when the impeller is turning faster than the turbine. This causes the stator to properly route oil flow over the impeller vanes. Then, when turbine speed equals or exceeds impeller speed, the stator can freewheel on its shaft, so as not to obstruct oil flow.

Torque Multiplication

Torque multiplication refers to the ability of a torque converter to increase the amount of engine torque applied to the transmission input shaft. Just as a small gear driving a large gear increases torque,



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Figure 65-8. This lockup torque converter is a conventional converter with a friction pressure plate added. The pressure plate can be used to lock the turbine to the converter housing, eliminating slippage and increasing fuel economy.

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the torque converter can act as several different gear ratios to alter torque output. Torque can be doubled by the converter under certain conditions.

Torque multiplication occurs when the impeller is spinning faster than the turbine. For instance, if the engine is accelerated quickly, the engine and impeller speed might increase rapidly while the turbine is almost stationary. At this time, torque multiplication would be at maximum. As the turbine speed nears impeller speed, torque multiplication drops off.

Torque is increased in the converter by sacrificing motion. The turbine spins slower than the impeller during torque multiplication.

Stall Speed

The ***stall speed*** of a torque converter occurs when the impeller is at maximum speed without rotation of the turbine. This causes the oil to be thrown off the stator vanes at tremendous speeds. The greatest torque multiplication occurs at stall speed.

Lockup Torque Converters

A ***lockup torque converter*** has an internal friction clutch mechanism that locks the impeller to the turbine when the transmission is in high gear. In a conventional converter, there is always some slippage between the impeller and turbine. By locking these components with a friction clutch, the torque converter does not slip and fuel economy is improved.

Typically, a lockup mechanism in a torque converter consists of a hydraulic piston, torsion springs, and clutch friction material. See **Figure 65-9A**.

In lower transmission gears, no oil pressure acts on clutch apply piston—the converter clutch is released. See **Figure 65-9B**. The torque converter operates normally, allowing slippage and torque multiplication. Then, when the transmission is shifted into high gear, oil is channeled to the converter piston. The piston pushes the friction discs together to lock the converter. See **Figure 65-9C**. The turbine is mechanically locked to the converter housing and impeller. The torsion springs help dampen engine power pulses entering the drive train.

Automatic Transmission Shafts

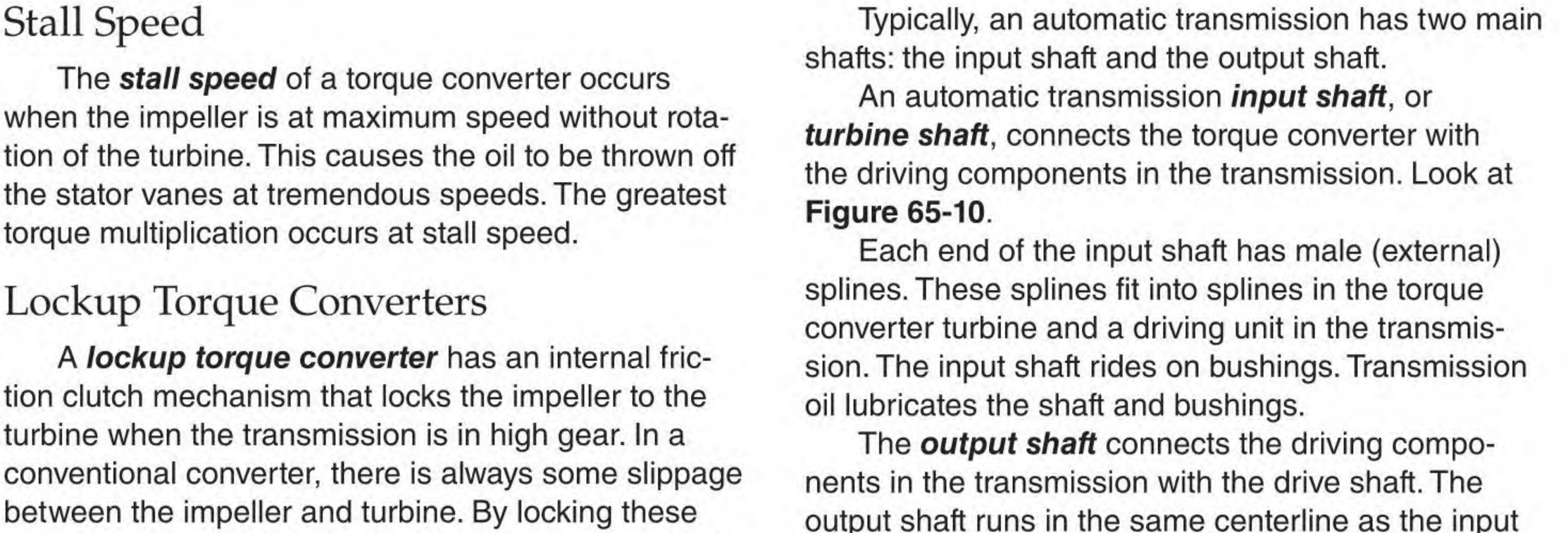
Typically, an automatic transmission has two main shafts: the input shaft and the output shaft.

An automatic transmission ***input shaft***, or ***turbine shaft***, connects the torque converter with the driving components in the transmission. Look at **Figure 65-10**.

Each end of the input shaft has male (external) splines. These splines fit into splines in the torque converter turbine and a driving unit in the transmission. The input shaft rides on bushings. Transmission oil lubricates the shaft and bushings.

The ***output shaft*** connects the driving components in the transmission with the drive shaft. The output shaft runs in the same centerline as the input shaft. Its front end almost touches the input shaft.

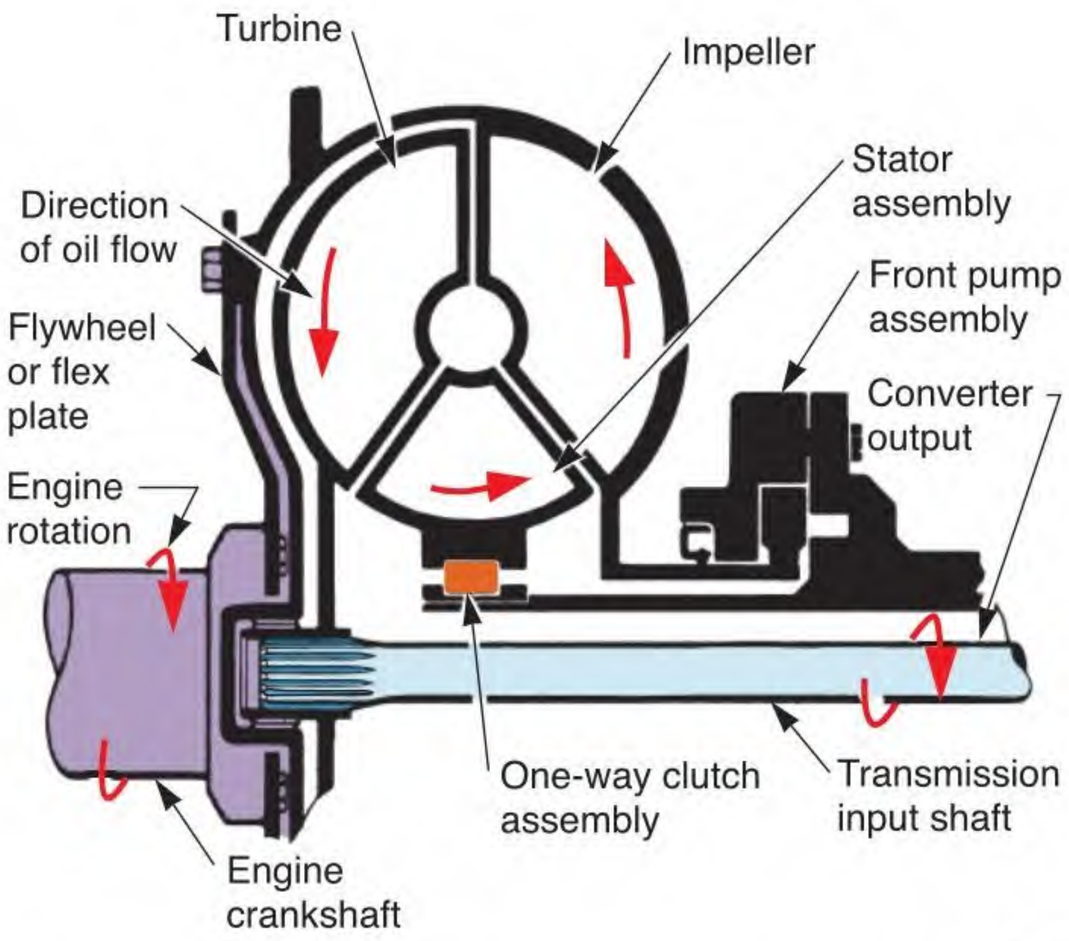
The ***stator support***, also called ***stator shaft***, is usually a stationary shaft splined to the stator assembly. It is a tube that extends forward from the front of the transmission and surrounds the input shaft.



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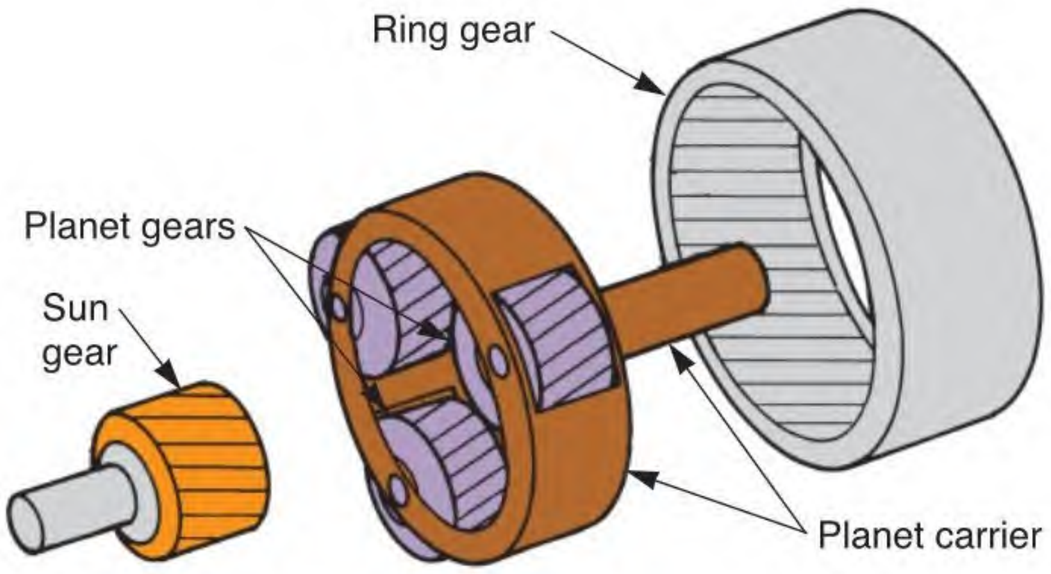
Figure 65-9. Lockup torque converter operation. A—Parts of a lockup converter. B—In lower gears, the torque converter operates and slips like a conventional unit, and the impeller drives the turbine. C—In high gear, the crankshaft drives the transmission input shaft directly, without slippage.

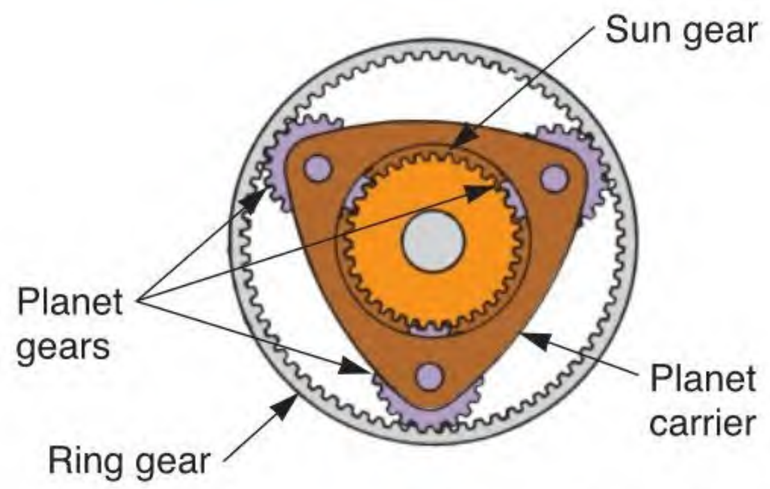
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Figure 65-10. The transmission input shaft extends through the stator support and is splined to the turbine. Note how the stator mounts on a one-way clutch.





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Figure 65-11. Simplified planetary gearset. Planet gears fit between a ring gear and a sun gear. The planet gears are mounted on the planet carrier.

Planetary Gears

A ***planetary gearset*** consists of a sun gear, several planet gears, a planet gear carrier, and a ring gear. The name planetary gearset refers to our solar system. Just as our planets circle the sun, the planet gears revolve around the sun gear. A simple planetary gearset is shown in **Figure 65-11**.

A planetary gearset is very strong and compact, and is always in mesh. An automatic transmission commonly uses two or more planetary gearsets.

By holding or releasing the components of a planetary gearset, it is possible to:

- Reduce output speed and increase torque (gear reduction).
- Increase output speed while lowering torque (overdrive).
- Reverse output direction (reverse gear).
- Serve as a solid unit to transfer power (one-to-one ratio).
- Freewheel to stop power flow (park or neutral).

Planetary Reduction

One method of obtaining a gear reduction and torque increase is to hold the sun gear (stop it from turning) while driving the ring gear. In such a configuration, the planet carrier becomes the output member. Refer to **Figure 65-12A**.

When input power turns the ring gear, the planet gears "walk" (rotate) around the locked sun gear. The planet gears move in the same direction as the ring gear, but not as fast. As a result, more torque is applied to the output member (planet carrier) and output shaft. Gear reduction can also be produced in the planetary gearset by turning the sun gear and holding the ring gear.

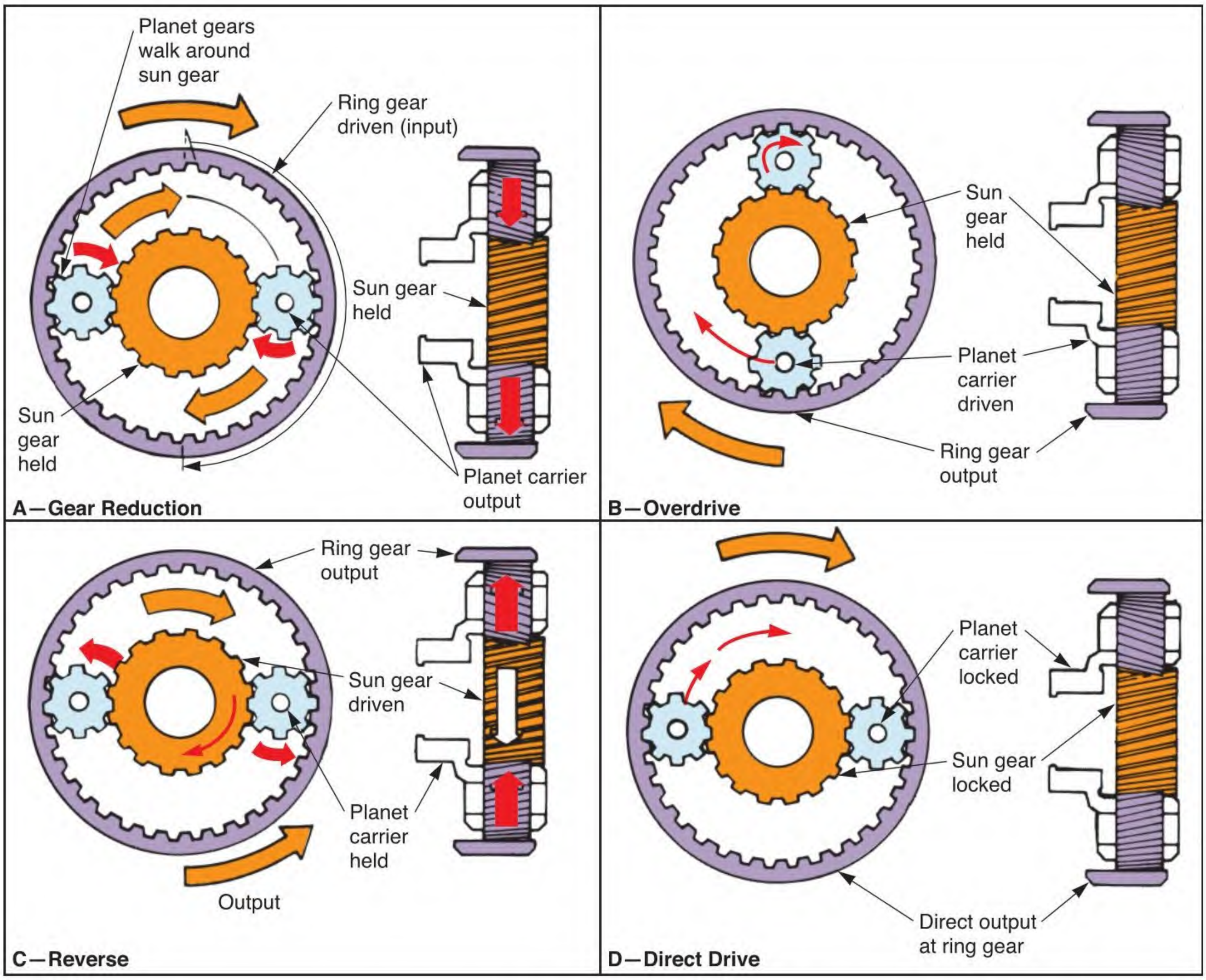
Planetary Overdrive

Holding the sun gear stationary while driving the planet carrier achieves an overdrive ratio in a planetary gearset. Look at **Figure 65-12B**. The input shaft powers the planet carrier. The ring gear is the output member and spins faster than the carrier, driving the output shaft. Torque is lost, but speed is increased.

Planetary Reverse

A planetary gearset can also reverse output direction. The input shaft drives the sun gear. The carrier is held and the ring gear turns the output shaft. The planet gears simply act as idler gears; they reverse the direction of rotation between the sun gear and ring gear. See **Figure 65-12C**.

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Figure 65-12. Different planetary gearset members can be held to provide different gear ratios and reverse. A—Simple gear reduction. Input torque increases and speed decreases. B—Planetary overdrive. The ring gear, which turns faster than the input, is the output. C—Reverse gear. The ring gear turns backward as output. D—Direct drive. Input and output members turn at the same speed.

Planetary Direct Drive

A planetary gearset acts as a solid unit when two of its members are held. This causes the input and output members to turn at the same speed, **Figure 65-12D**.

Planetary Neutral

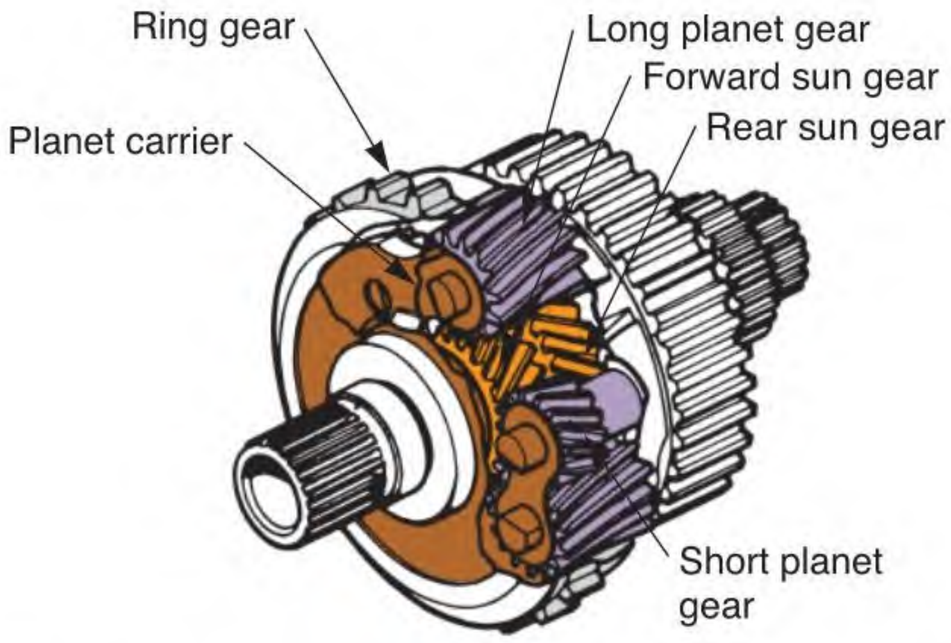
When none of the planetary members are held, the unit will not transfer power. This freewheeling condition is used when an automatic transmission is placed in *Neutral* or *Park*.

Compound Planetary Gearset

A ***compound planetary gearset*** combines two planetary units in one housing or ring gear, **Figure 65-13**. A compound planetary gearset is used because it can provide more forward gear ratios than a simple planetary gearset.

Some compound planetary gearsets contain two sun gears. In this design, short planet gears engage the forward sun gear. Long planet gears mesh with the rear sun gear. The ring gear engages both sets of planet gears.

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Subaru

Figure 65-13. A compound planetary gearset acts like two gearset assemblies mounted together. Normally, a common ring gear is used for two separate sets of sun and planet gears.

The Simpson compound gearset is a compound planetary gearset that uses a single sun gear to operate two sets of planet gears on the same ring gear. The Simpson compound gearset is the most common type of compound planetary gearset used in automatic transmissions.

Clutches and Bands

Automatic transmission ***clutches*** and ***bands*** are friction devices that drive or lock planetary gearset members. They are used to cause the gearsets to transfer power. Refer to **Figure 65-14**.

Multiple Disc Clutches

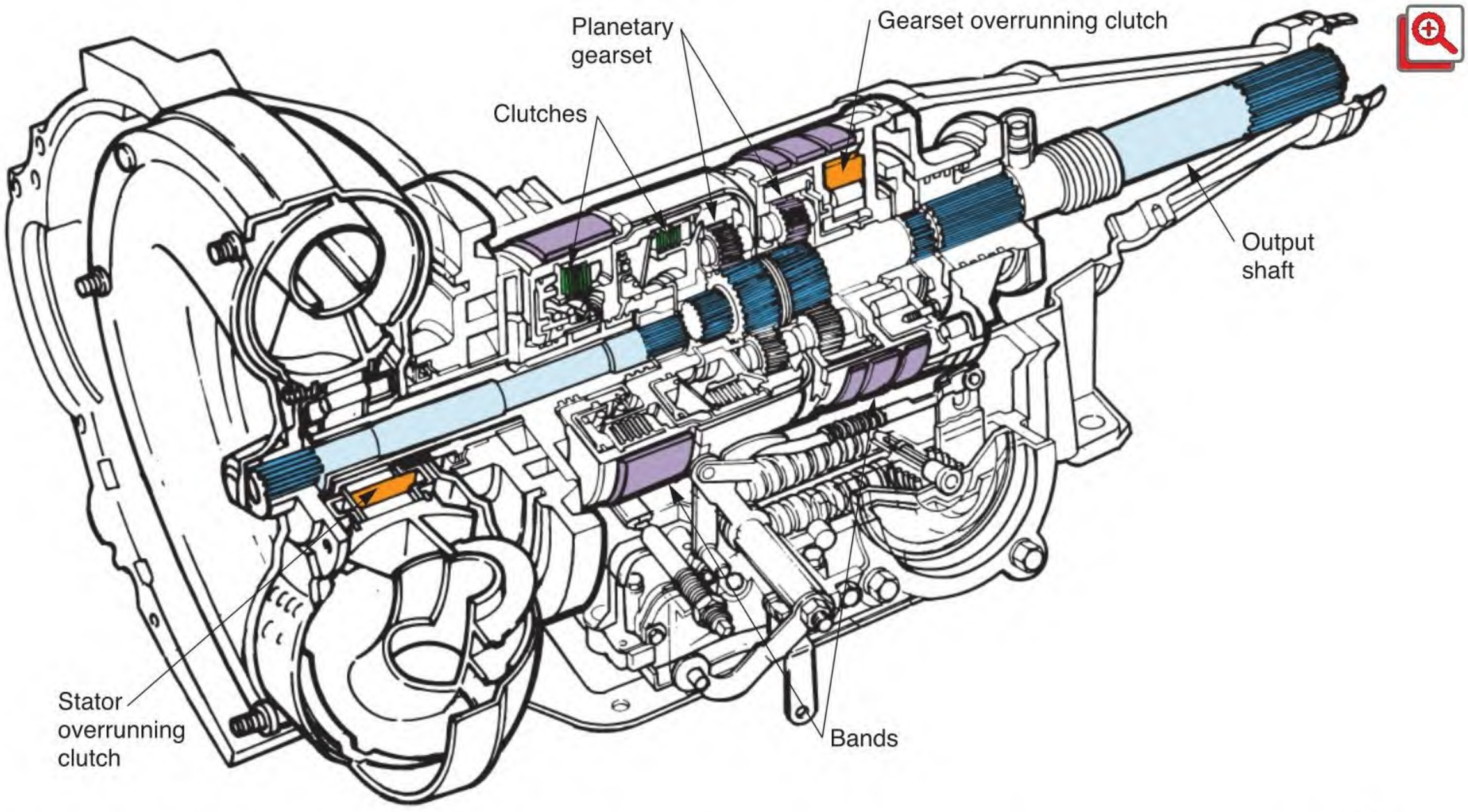
A ***multiple disc clutch*** has several clutch discs that can be used to couple (hold) planetary gearset members. The front clutch assembly usually drives a planetary sun gear. The next clutch transmits power to the planetary ring gear when engaged. This can vary, however.

A clutch assembly generally consists of a drum, a hub, an apply piston, spring(s), driving discs, driven discs, a pressure plate, and snap rings.

Clutch Construction

The ***clutch drum***, also called the ***clutch cylinder***, encloses the apply piston, pressure plate, discs, seals, and other parts of the clutch assembly, **Figure 65-15**.

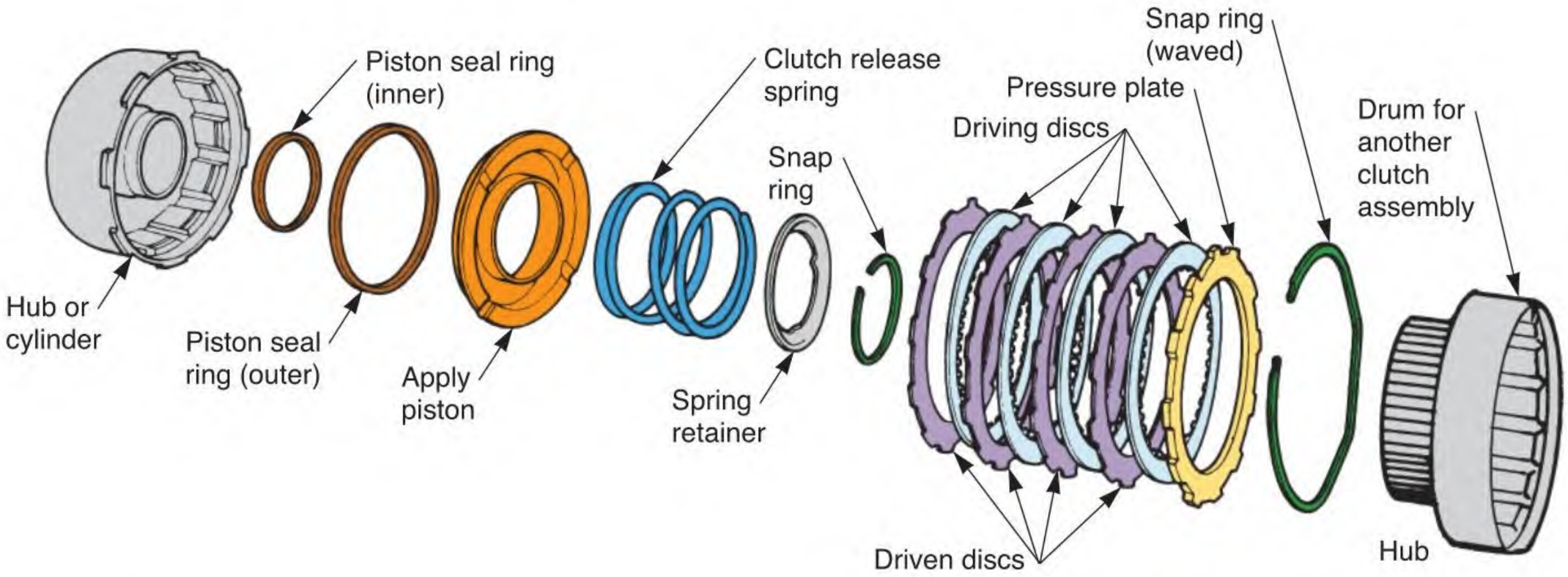
The ***clutch hub*** fits inside the clutch discs and clutch drum. It has teeth on its outer surface that



Ford

Figure 65-14. Study the location of gearsets and holding devices. Clutches, bands, and the rear one-way clutch operate the gearsets. Another one-way clutch operates the torque converter stator.

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Chrysler

Figure 65-15. Study the construction of a clutch assembly for an automatic transmission. Clutch parts fit inside the clutch drum. Note the difference in the clutch discs: driving discs are splined to hub and driven discs are locked in the drum by tabs.

engage the teeth on the driving discs. The front clutch hub is also splined to the transmission input shaft.

The ***driving discs*** are usually covered with friction lining. They have teeth on their inside diameter that engage the clutch hub.

The ***driven discs*** are steel plates with outer tabs that lock into the clutch drum. Driven discs alternate with the driving discs inside the clutch drum. This enables the hub and driving discs to turn the driven discs and drum when the clutch is activated.

The clutch ***apply piston*** slides back and forth inside the clutch drum to clamp the driving discs and the driven discs together. Seals fit on the piston to prevent fluid leakage during clutch application.

The ***pressure plate*** serves as a stop for clutch discs when the piston is applied. The piston pushes the discs against the pressure plate. Refer to **Figure 65-15**.

Clutch ***release springs*** push the apply piston away from the clutch discs during clutch disengagement.

Clutch Operation

When oil pressure is blocked from the piston, the return spring pushes the clutch discs apart. Power is no longer transferred through the clutch. The driving and driven discs are free to turn independently, **Figure 65-16A**.

During clutch engagement, oil pressure is routed into the clutch drum. Oil pressure acts on the large piston. The piston is then forced into the clutch discs. Friction locks the driving discs and driven discs together to transfer power through the clutch assembly. See **Figure 65-16B**.

Driving Shell

A ***driving shell***, or ***clutch shell***, is commonly used to transfer power to one of the planetary sun gears. The shell is a metal cylinder that connects the front clutch drum and sun gear, **Figure 65-17**.

The shell may surround the second clutch assembly and forward planetary gearset. Tabs on the shell fit into notches on the front clutch drum. This makes the shell, drum, and sun gear turn together. See **Figure 65-18**.

Bands and Servos

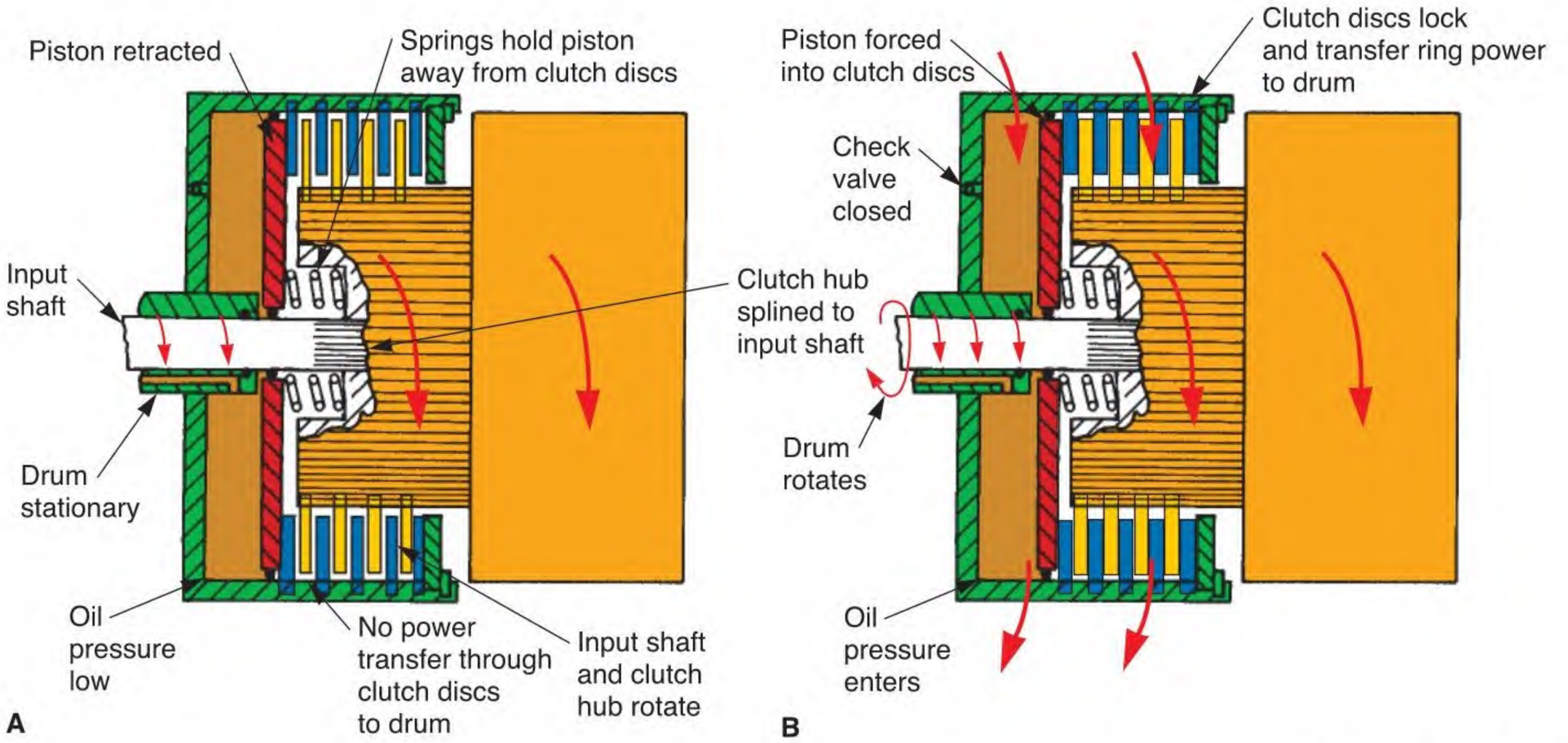
Automatic transmission bands are friction devices for holding members of the planetary gearsets. Two or three bands are commonly used in modern transmissions. ***Servos*** are apply pistons that operate the bands.

Band and Servo Construction

A band is a steel strap with a lining of friction material on its inner surface, **Figure 65-19**. The band's lining can be clamped around the clutch drum to stop drum rotation. The friction material on the inside of the band is designed to operate in automatic transmission oil. It resists the lubricating qualities of the oil.

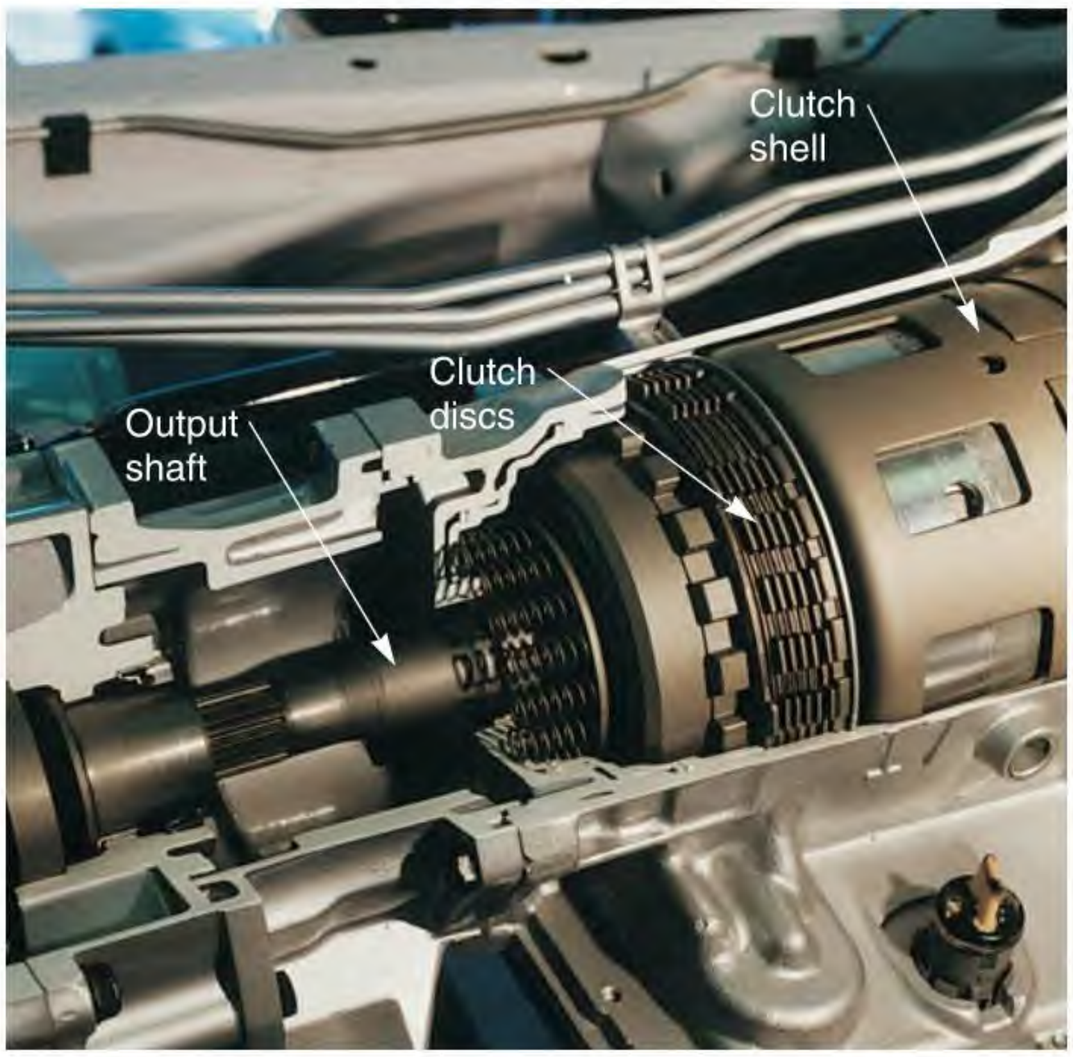
The ***servo piston*** is a metal plunger that operates in a cylinder machined in the transmission case. Rubber seals fit around the outside of the piston to prevent oil leakage. See **Figure 65-20**. A rod on the servo piston attaches to one end of the band. The other end of the band is anchored to the transmission case.

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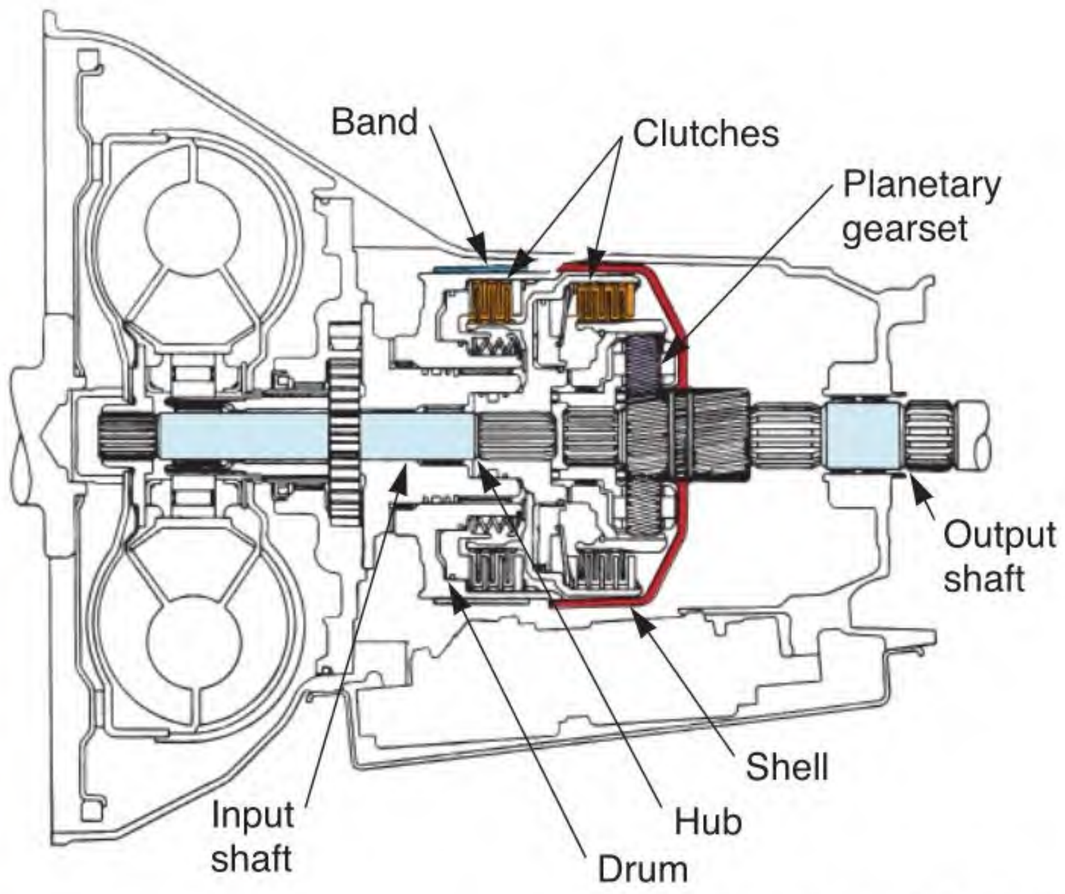
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Figure 65-16. Basic clutch operation. A—No oil pressure enters drum and springs hold the piston away from the clutch discs. The input shaft turns the clutch hub (orange) and the driving discs (yellow), but the driven discs (blue) and drum (green) remain stationary. B—Oil pressure is routed into the clutch drum and pushes the piston into the clutch discs, forcing the discs into the pressure plate. This locks the discs, hub, and drum together. Power is then transferred from the input shaft to the drum.



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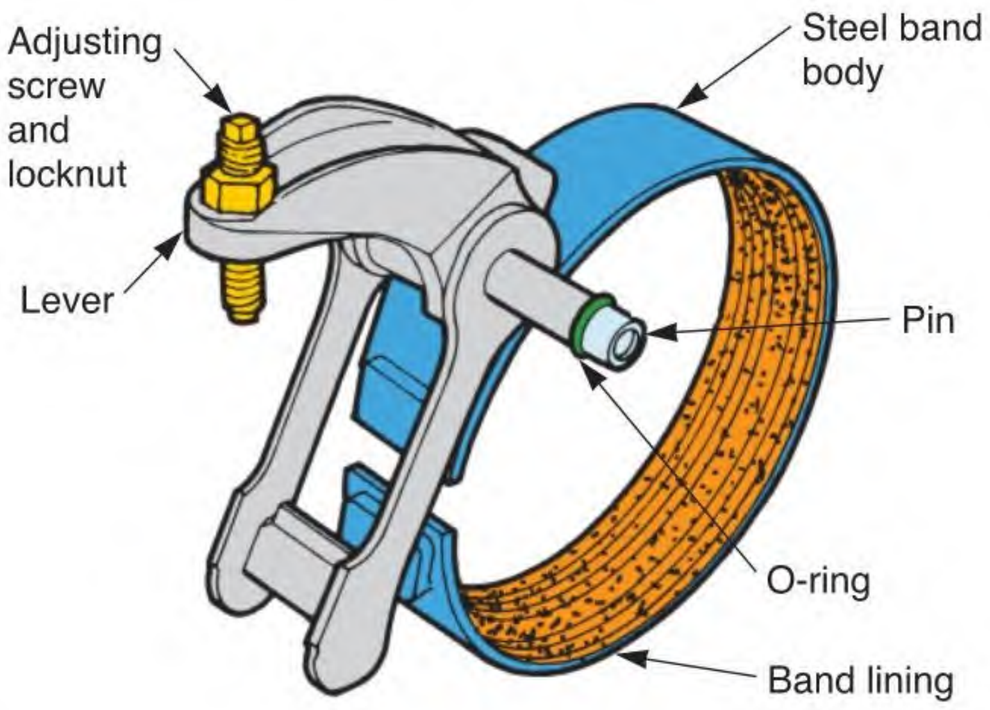
Figure 65-17. The clutch shell (driving shell) is a thin metal cylinder that transfers power.



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Figure 65-18. This driving shell connects the front drum to the sun gear. The shell surrounds the second clutch assembly and front planetary gearset. When the front clutch is locked, the shell turns the sun gear. Note the band used to hold the front drum and sun gear stationary.

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Figure 65-19. A band is a steel strap with friction lining on its inner surface. One end of the band is anchored in the case.

Subaru

Figure 65-20. This exploded view shows a band and servo assembly. Note the relationship between the parts.

A ***band adjusting screw*** provides a means of adjusting the band-to-drum clearance. It moves the band closer to the drum as the friction material wears.

Servo seals prevent oil leakage around the servo piston and cylinder. ***Snap rings*** hold the piston in its cylinder.

Transmission Band Operation

To activate a band, oil pressure is sent into the servo cylinder. Pressure acts on the servo piston. The piston then slides in the cylinder and pushes on one end of the band, as in **Figure 65-21**.

Since the other end of the band is anchored, the band tightens around the drum. The friction material rubs on the drum and stops it from turning. This keeps one of the planetary components from revolving.

When oil flow to the piston servo is blocked, the servo spring pushes on the piston. This slides the piston rod away from the band. The band then releases the drum and the planetary gearset member.

An ***accumulator*** is used in the apply circuit of a band or clutch to cushion the initial application. It temporarily absorbs some of the oil pressure to cause slower movement of the apply piston.

Overrunning Clutches

Aside from bands and clutches, an ***overrunning clutch*** can also be used to hold a planetary gearset member. It is a one-way roller clutch that locks in one direction and freewheels in the other. Refer to **Figure 65-22**.

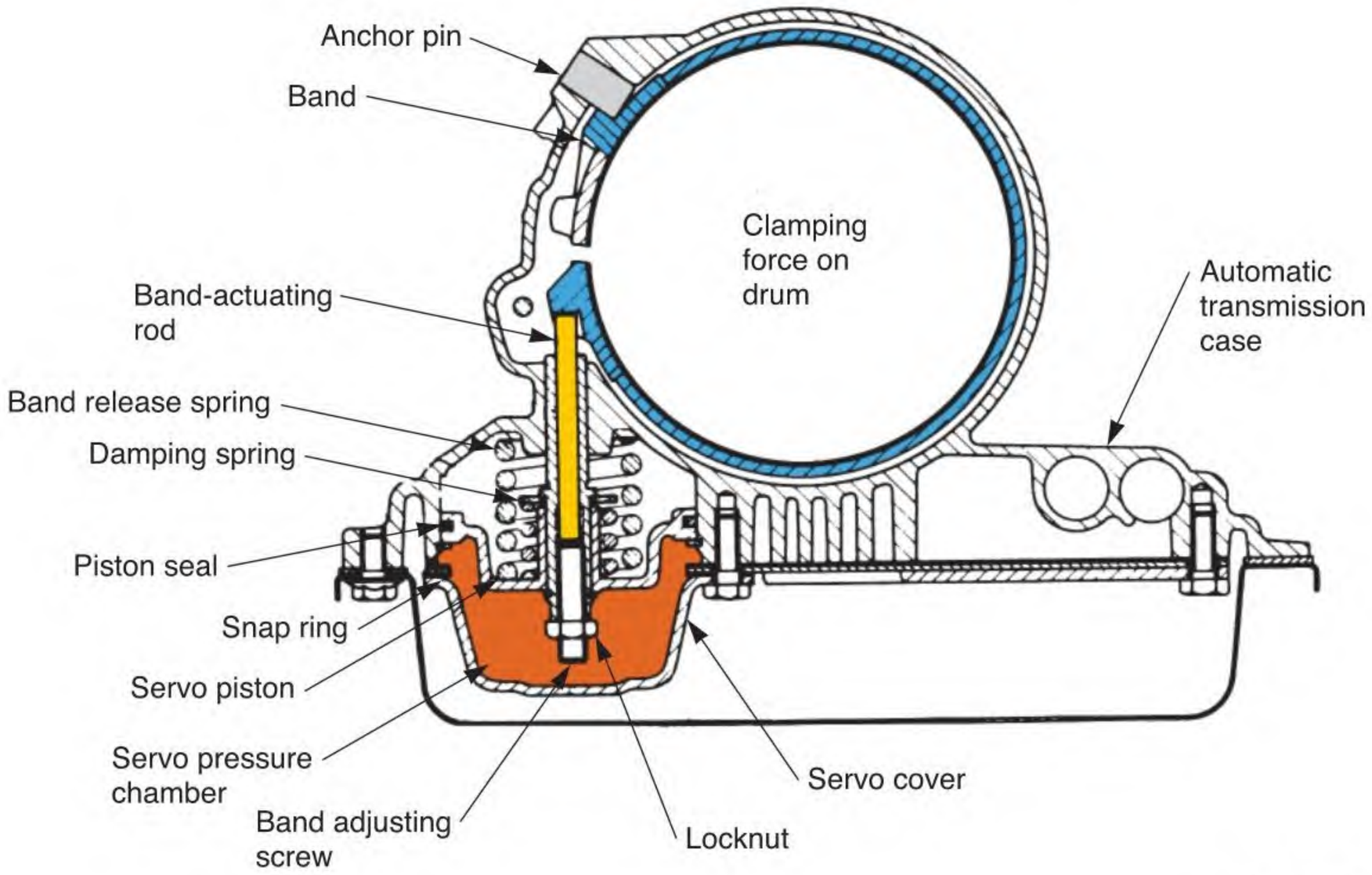
An overrunning clutch for the planetary gears is similar to the ones used in a torque converter stator or an electric starting motor drive gear. A planetary gearset overrunning clutch consists of an inner race, rollers, a set of springs, and an outer race.

Hydraulic System

The ***hydraulic system*** for an automatic transmission typically consists of the pump, pressure regulator valve, manual valve, solenoids, shift valves, servos, pistons, and valve body. See **Figure 65-23**. These parts work together to form the "muscles" (control) of the automatic transmission. The hydraulic system also forces oil to high-friction points in the transmission. This lubricates the moving parts, preventing wear and overheating.

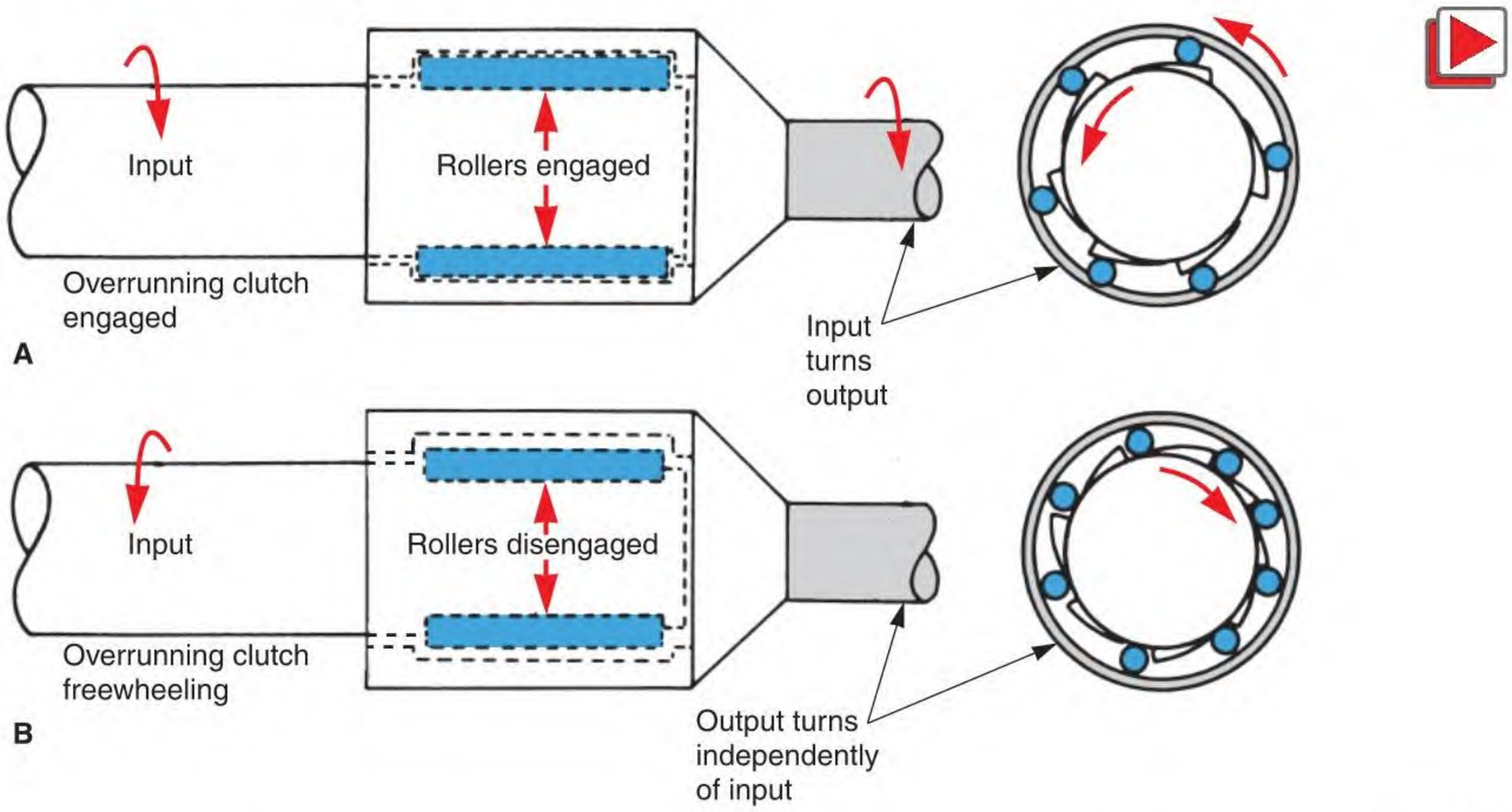
The basic action of a hydraulic valve is illustrated in **Figure 65-24**. Hydraulic valves are used to operate the band servos and clutch pistons. Transmission oil pump pressure causes oil to flow through the spool

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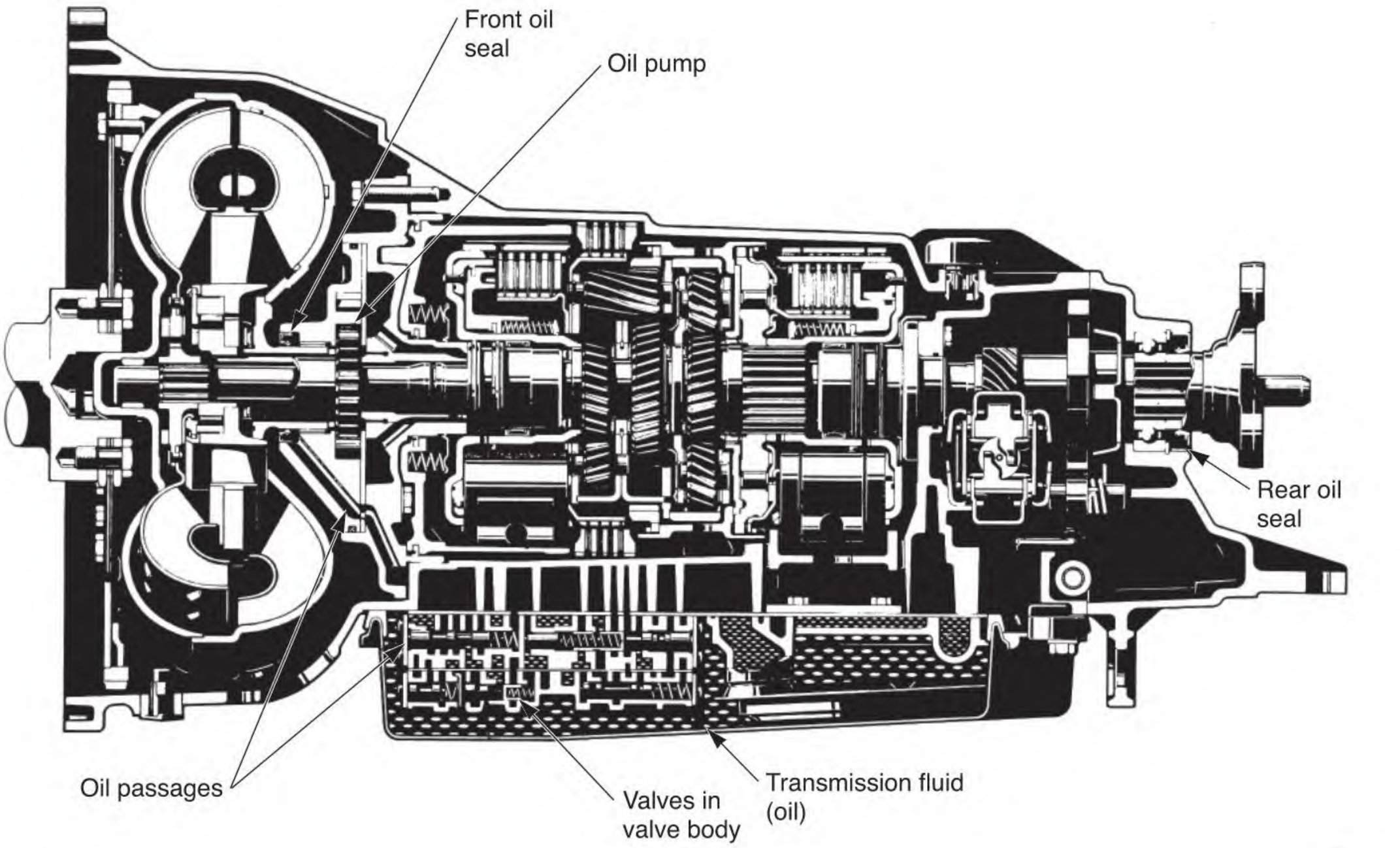
Figure 65-21. Servo piston and band action. When oil pressure enters the servo pressure chamber, the servo piston slides up in the cylinder. An actuating rod then pushes to squeeze the band inward on the drum.



Deere & Co.

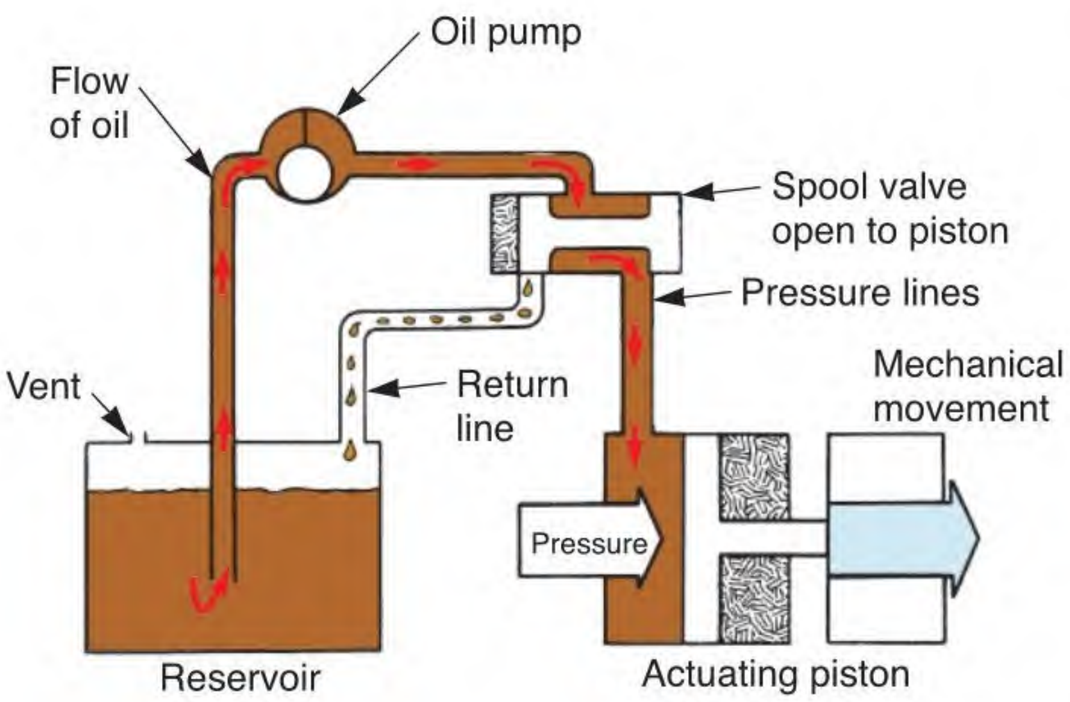
Figure 65-22. Overrunning clutch action. A—When driven in one direction, the rollers lock between the ramps on the inner race and the outer race. Both races turn together. This action can be used to stop movement of planetary member. B—When turned in the other direction, the two races are free to turn independently.

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Figure 65-23. The transmission oil pump is normally located in the front of the case. Oil is drawn out of the pan and circulated through passages to hydraulic components. Note the location of oil seals.



Chrysler

Figure 65-24. A basic hydraulic circuit. The pump draws oil out of the reservoir and forces it through a spool valve. In this position, the spool valve routes oil to the piston. The piston uses oil pressure to produce clamping pressure.

valve pressure lines to the piston cylinder. This pushes the piston. When the spool valve is moved the other way, pump pressure is not sent to the piston. The piston is then forced back into its cylinder.

A ***spool valve*** is used to redirect fluid flow to different locations in a hydraulic circuit. Several spool valves are used in an automatic transmission valve body. By sliding a spool valve sideways in its bore, pressure can be directed through aligning openings to permit oil flow. If the spool valve slides to cover a passage, it blocks fluid pressure from entering that leg of the hydraulic circuit.

Electric ***transmission solenoids*** direct oil flow to one end of the spool valve, or the electromagnet-induced plunger motion acts directly on the spool valve. Spool valves and solenoids are often provided for each forward gear ratio and reverse.

Automatic Transmission Fluid

Automatic transmission oil (fluid) has several additives that make it compatible with the friction clutches and bands in the transmission. Different

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types of automatic transmission oils are required for different transmissions. The vehicle's owner's manual lists the automatic transmission fluid type and related specification(s) recommended by the transmission manufacturer.

Caution

Accidentally installing the wrong type of fluid in a transmission can cause the transmission bands and clutches to slip within a few miles of driving. For example, a constantly variable transmission requires a special type of fluid for normal operation.

Transmission Oil Cooling

A tremendous amount of heat is developed inside an automatic transmission. When the torque converter slips, friction heats the oil. This heat must be removed, or transmission failure could result. Many transmissions have an oil cooling system that includes external oil lines and a cooling tank inside the engine radiator. Look at **Figure 65-25**.

When the engine is running, the transmission oil pump forces oil through the cooling lines and into the radiator cooler tank. Since transmission oil is hotter than the engine coolant, oil temperature drops. The cooled oil returns to the transmission through the other line.

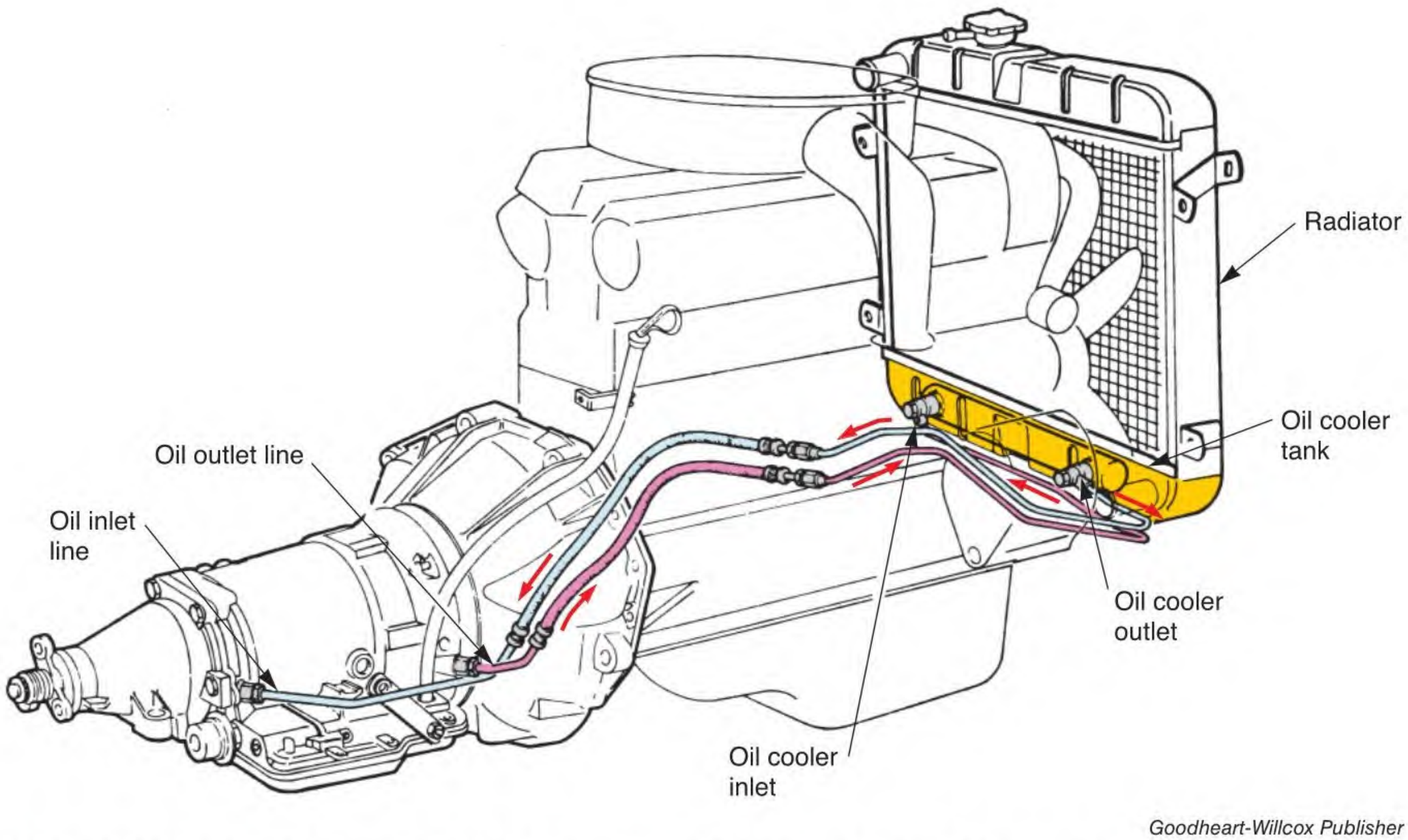
Some cars, especially those designed to pull heavy loads (trailers, boats), have an auxiliary ***transmission oil cooler***. This is a small radiator separate from the engine radiator. Air passes over the auxiliary transmission oil cooler to cool the transmission oil.

Transmission Oil Pump

The ***transmission oil pump***, also called the *oil pump*, produces the pressure to operate an automatic transmission. Automatic transmissions may have one or two pumps. The pumps are often located behind the torque converter or in the valve body. The sleeve or collar on the rear of the torque converter drives the pump. The two commonly used oil pumps are the gear type and the rotor type, **Figure 65-26**.

The transmission oil pump has several basic functions:

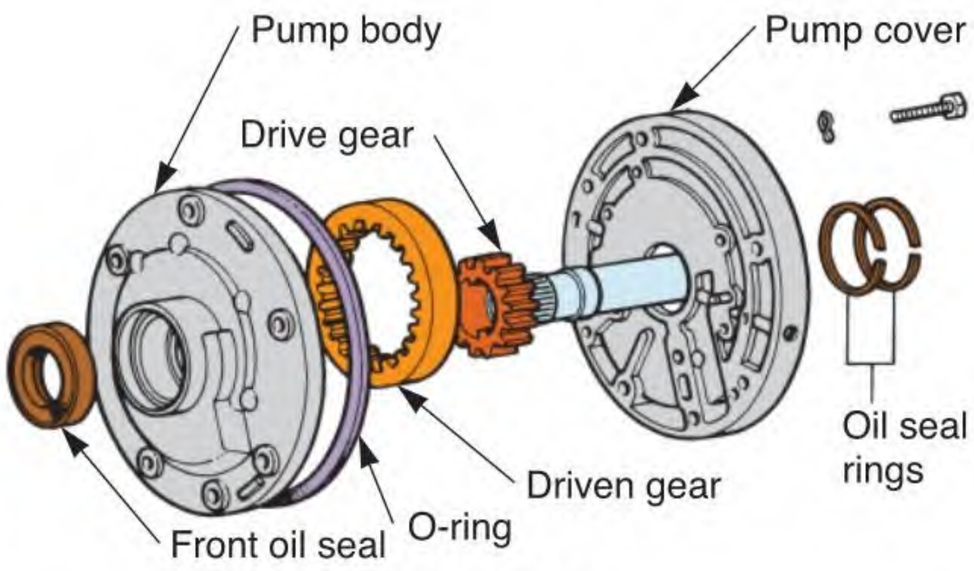
- Produce pressure to operate the clutches, bands, and gearsets.
- Lubricate the moving parts in the transmission.



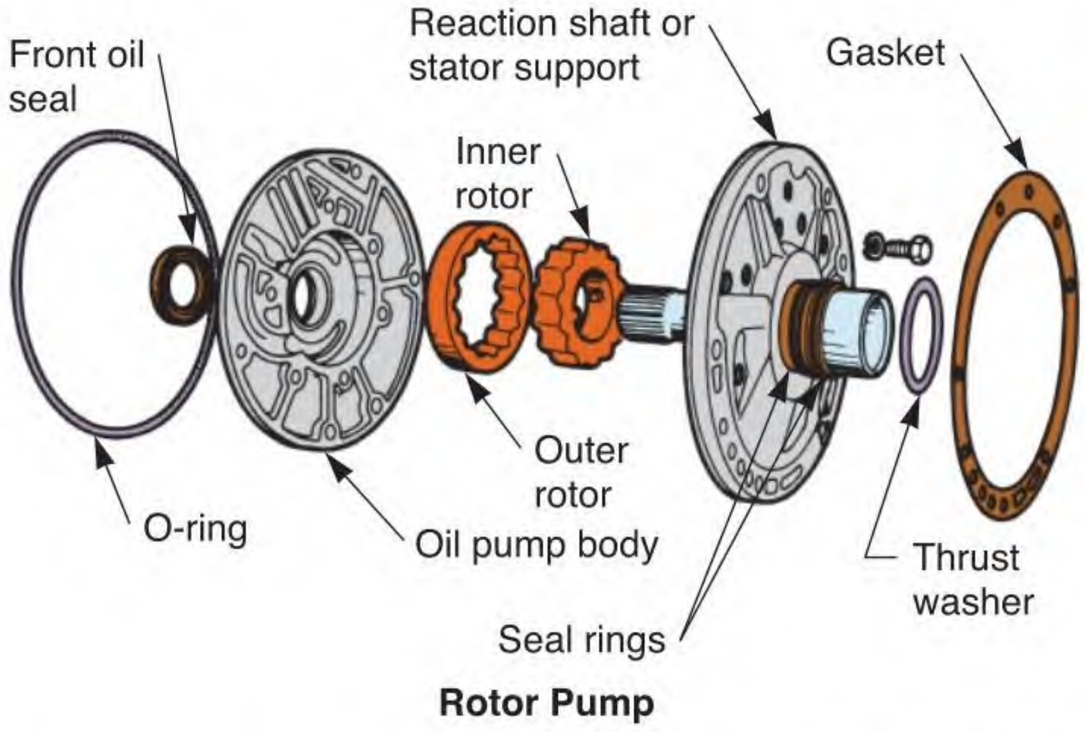
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Figure 65-25. An oil cooler tank is commonly used in transmissions. The oil pump pushes oil through lines to the cooler tank to maintain acceptable oil temperature.

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Gear Pump



Rotor Pump

Chrysler; Toyota

Figure 65-26. There are two basic types of transmission oil pumps: rotor and gear. Study the similarities and differences.

- Keep the torque converter filled with oil for proper operation.
- Circulate oil through the transmission and radiator to transfer heat.
- Operate hydraulic valves in the transmission.

When the torque converter spins the oil pump, transmission oil is drawn into the pump from the pan. The pump pressurizes the oil and forces it to the pressure regulator. This is illustrated in **Figure 65-27**.

Pressure Regulator

The ***pressure regulator*** is a spring-loaded valve that limits the maximum amount of oil pressure developed by the oil pump. Excess pump pressure is routed out of the hydraulic system to ensure proper transmission operation.

Manual Valve

A ***manual valve***, operated by the shift mechanism or shift solenoid, allows the driver to select park, neutral, reverse, or different drive ranges. When the gear shift lever is moved, the shift linkage moves the manual valve or an electrical signal to the transmission ECM causes the shift solenoid to engage drive or reverse. As a result, the valve routes oil pressure to the correct components in the transmission.

Tech Tip

The vacuum modulator valve has been phased out in electronic control systems. The manifold absolute pressure (MAP) sensor and ECM serve the same function as the vacuum modulator. Vacuum modulated operation helps you understand MAP signals and how they affect shift points with electronic controls.

Shift Valves (Balanced Valves)

Shift valves, also called ***balanced valves***, use control pressure (oil pressure from regulator, solenoid valves, throttle valve, and manual valve) to operate the bands, servos, and gearsets.

Valve Body

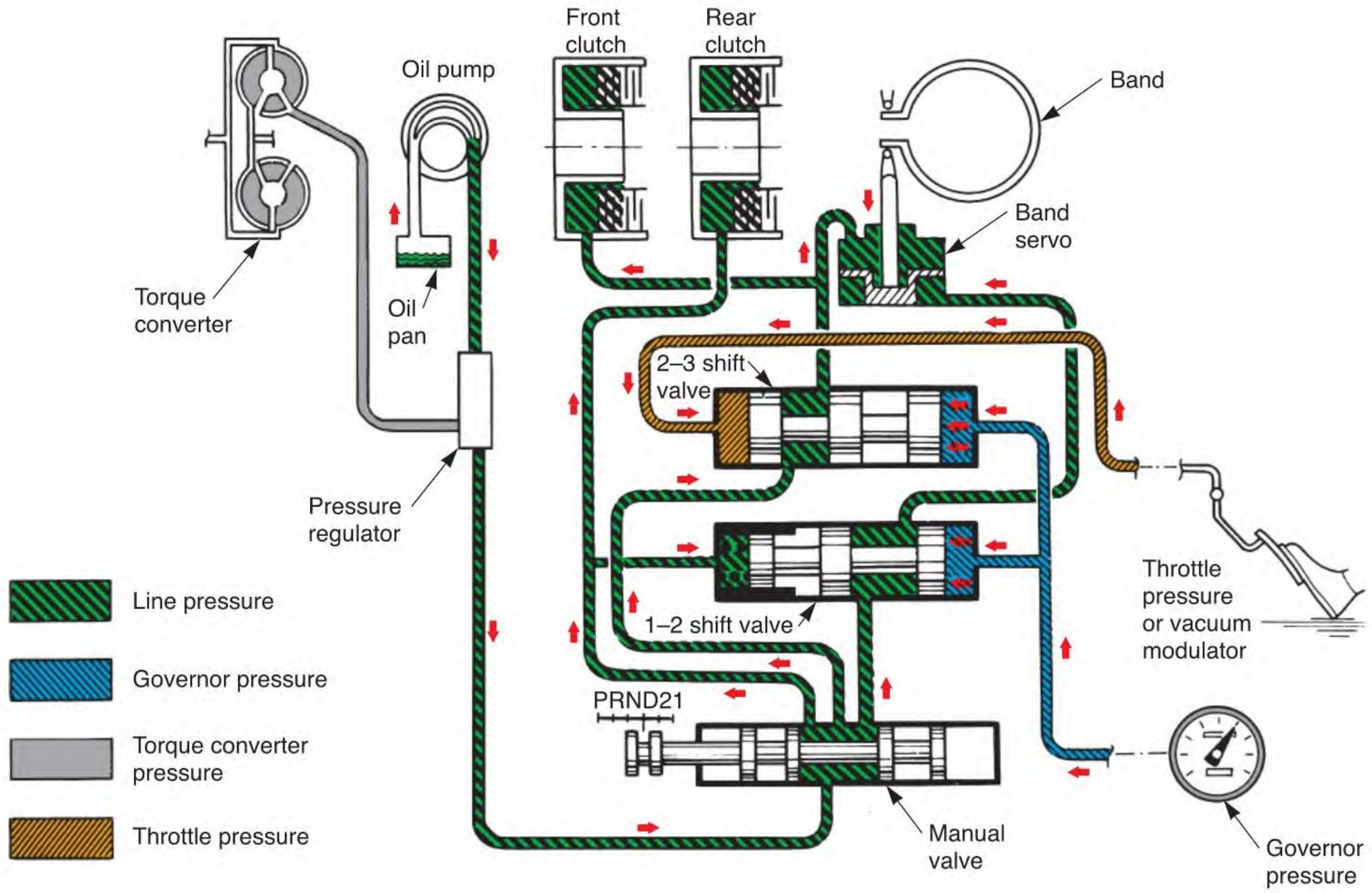
The ***valve body*** contains several electro-hydraulic spool valves (pressure-regulating valve, shift valves, manual valve, etc.) and the lever-engaged manual shift valve of an automatic transmission. See **Figure 65-28**. The valve body bolts to the bottom of the transmission case and is housed in the transmission pan. Modern transmission valve bodies also contain several shift solenoids. A filter or screen is usually attached to the bottom of the valve body.

Passages in the valve body route oil from the pump to the spool valves, and then into the transmission case. Passages in the case carry oil to the other hydraulic components.

Parking Pawl

A ***parking pawl*** is a square-cogged, gear-and-latch mechanism for locking the transmission output shaft to its case or housing, **Figure 65-29**. When the driver shifts the transmission into *Park*, the output shaft will not rotate. This keeps the car from rolling when not in use.

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Nissan

Figure 65-27. This simplified circuit shows hydraulic action in an automatic transmission. Manual valve pressure, throttle valve pressure, and governor valve pressure operate shift valves. Shift valves then direct oil pressure to correct clutch or band pistons.

Automatic Transmission Power Flow

The flow of power through an automatic transmission depends on its specific design. However, you should have a general understanding of how power is transmitted through the major parts of transmissions.

Figure 65-30 shows how torque moves from the input shaft to the output shaft in a simple transmission. Study each illustration carefully, noting which clutches, bands, and gearset members are activated.

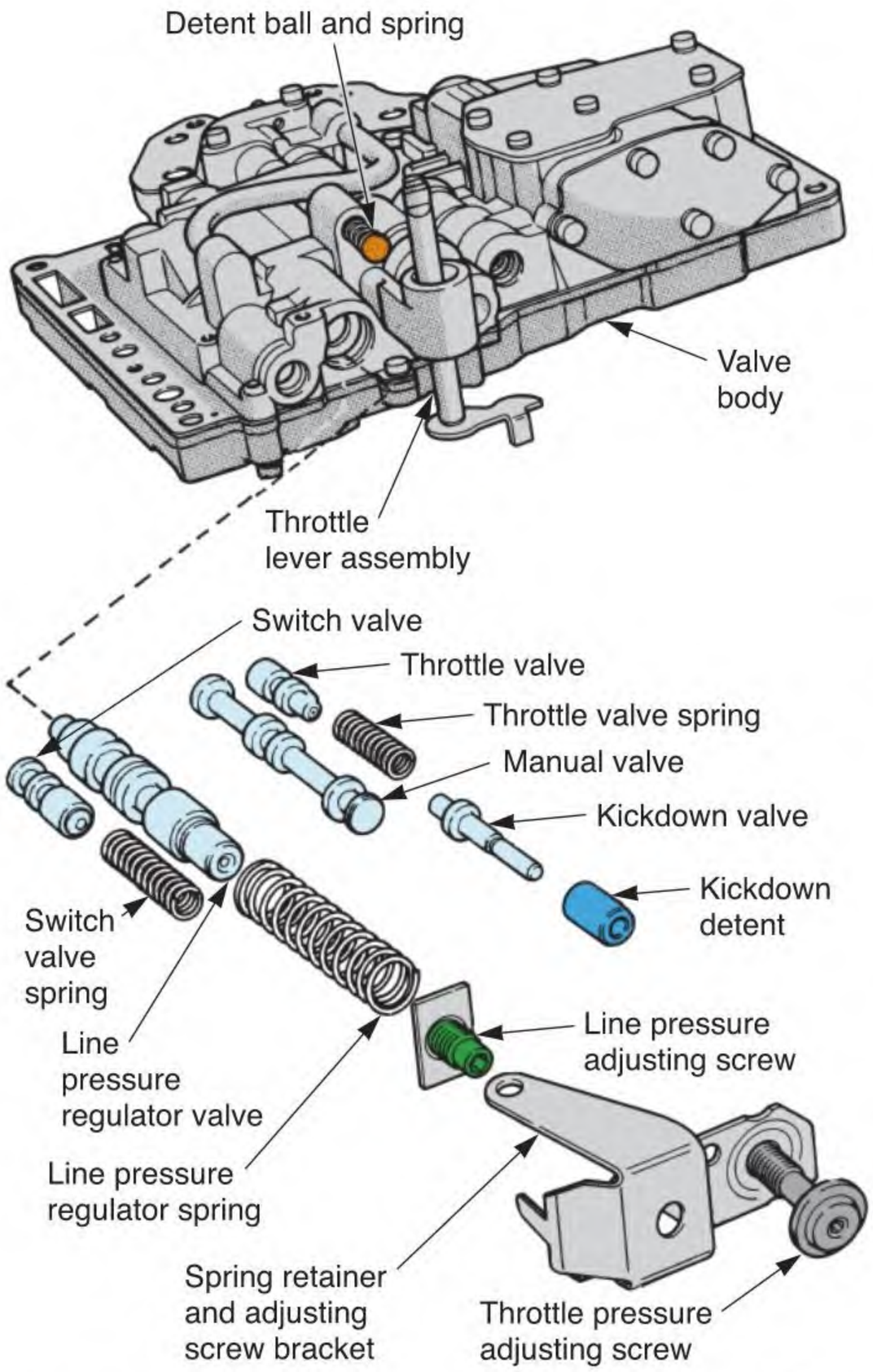
Figure 65-31 shows the power flow through a late-model, four-speed, overdrive automatic transmission in high gear. This design uses two input shafts (turbine shaft and direct input shaft). Trace the power flow and compare it to the other, more conventional transmissions covered earlier.

Electronic Transmission Control

Electronic transmission control involves using sensors, actuators, and a computer (transmission control module, or TCM) to precisely control shift points, torque converter lockup, downshifts, and other functions for more efficient operation and improved fuel economy.

A ***transmission control module*** (TCM) monitors and controls the functions of the transmission. A ***power train control module*** (PCM) monitors and controls the engine, transmission, fuel injection system, emission control system, and other units. The PCM is not as specialized as a transmission control module. The TCM exchanges data with the PCM to operate solenoids and hydraulic spool valves to control hydraulic circuit action.

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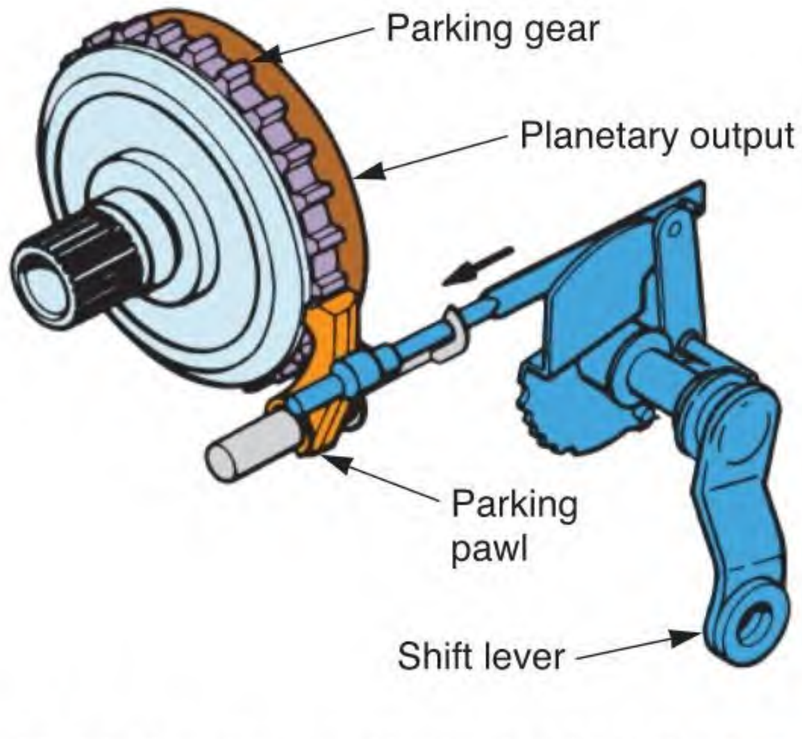


Chrysler

Figure 65-28. The valve body bolts to the bottom of the transmission case. It houses the manual valve, pressure regulator valve, kickdown valve, and other valves.

A ***shift schedule***, stored in the TCM memory, determines when an electronically-controlled transmission should change gears. The TCM uses input signals from various sensors and the shift schedule to calculate when to upshift or downshift. See **Figure 65-32**.

For example, if the driver presses down quickly on the gas pedal for rapid acceleration, the throttle position sensor sends a signal to the TCM. At the same time, the engine manifold pressure sensor reports a low-vacuum, high-load condition. The vehicle speed sensor signals low road speed, so the TCM knows to keep the transmission in first gear. This type of logic is used for precise control of automatic transmissions.



Subaru

Figure 65-29. A parking pawl is simply a latch that locks into large teeth on the parking gear. Since the pawl is mounted on the transmission case, this locks the parking gear and output shaft.

Transmission control sensors have replaced some of the mechanical components in electronically-controlled automatic transmissions. For example, the speed sensor replaces the governor, the MAP sensor replaces the vacuum modulator, and the throttle position sensor replaces the kickdown rod.

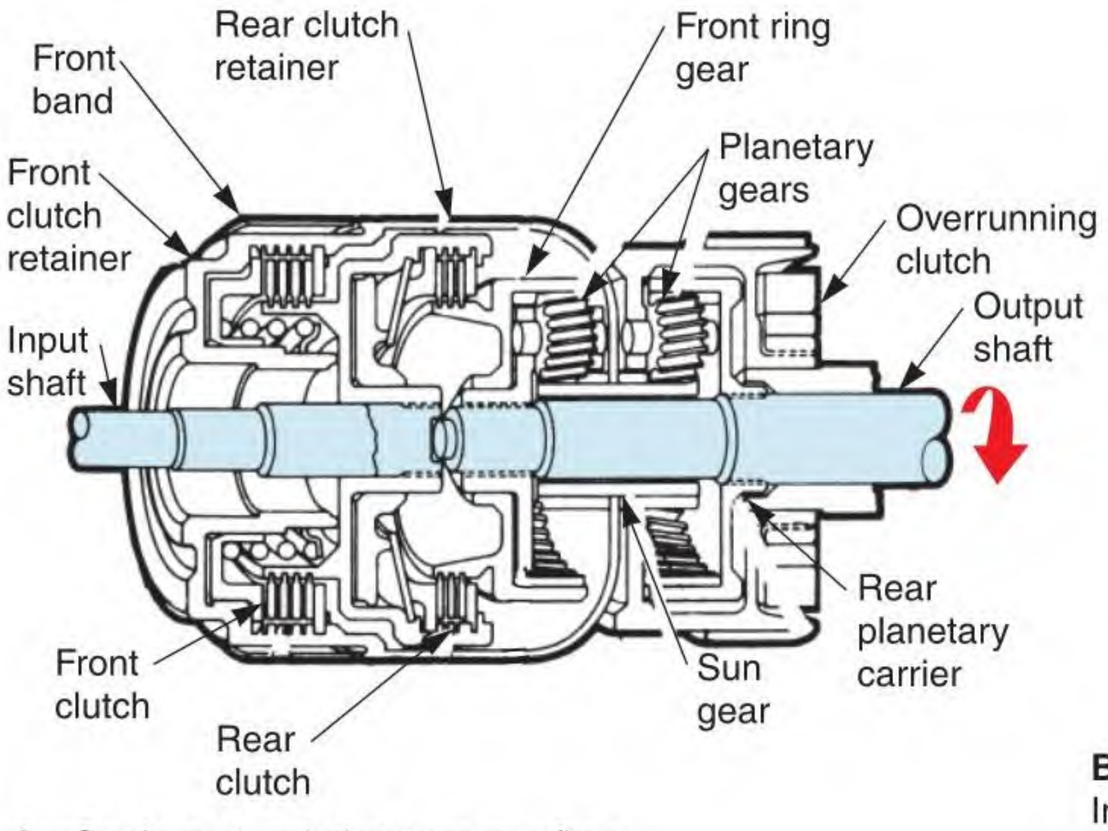
Automatic Transmission Solenoids

Transmission solenoids are actuators found on the valve body of electronically-controlled automatic transmissions, **Figure 65-33**. When the TCM sends control current through one of these solenoids, the solenoid's magnetic field acts on a control valve. In this way, the electronic system can change hydraulic pressure in the transmission to control its operation. See **Figure 65-34**. The TCM and solenoids can replace older mechanical and vacuum-operated devices, improving efficiency.

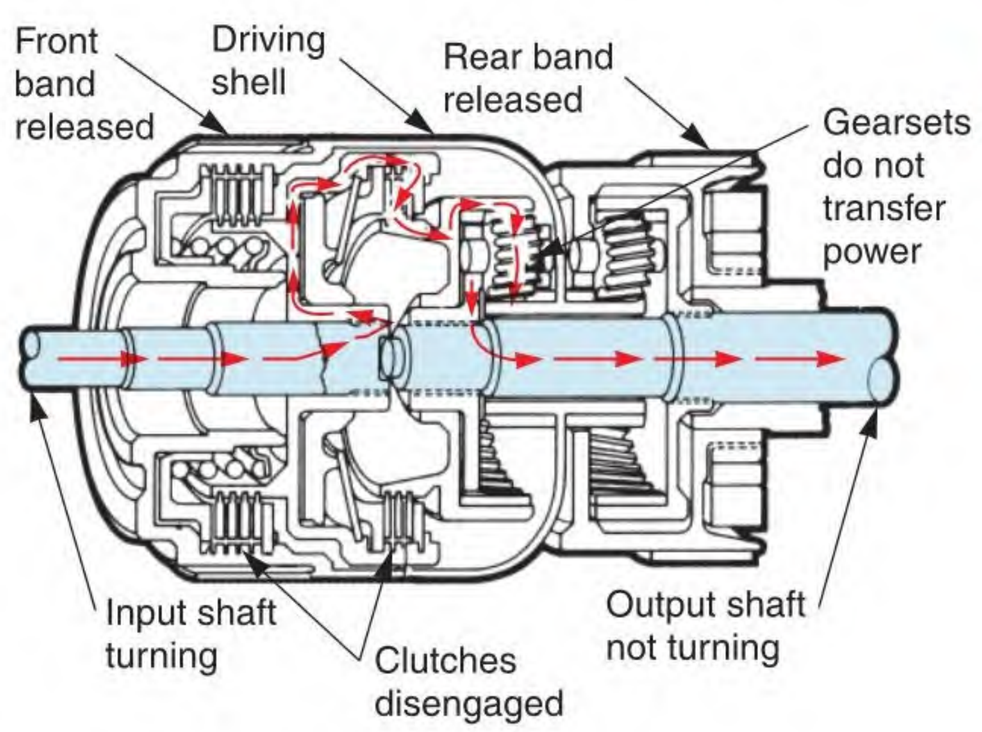
Typically, the TCM (in conjunction with the ECM) monitors engine speed, load, throttle position, transmission output shaft speed, gear shift position, and other variables. The control modules work together to control transmission shift points, torque converter lockup, ignition timing, fuel injection timing, emission control system operation, and other functions. This keeps the transmission and other engine systems functioning at maximum efficiency. The application of these solenoids varies by transmission make and model. See **Figure 65-35**.

Some transmission control systems allow for economy and sport settings. By moving a switch in the dash, the driver can set the transmission to higher shift points for better acceleration. In the economy mode, the shift points are lower to conserve fuel.

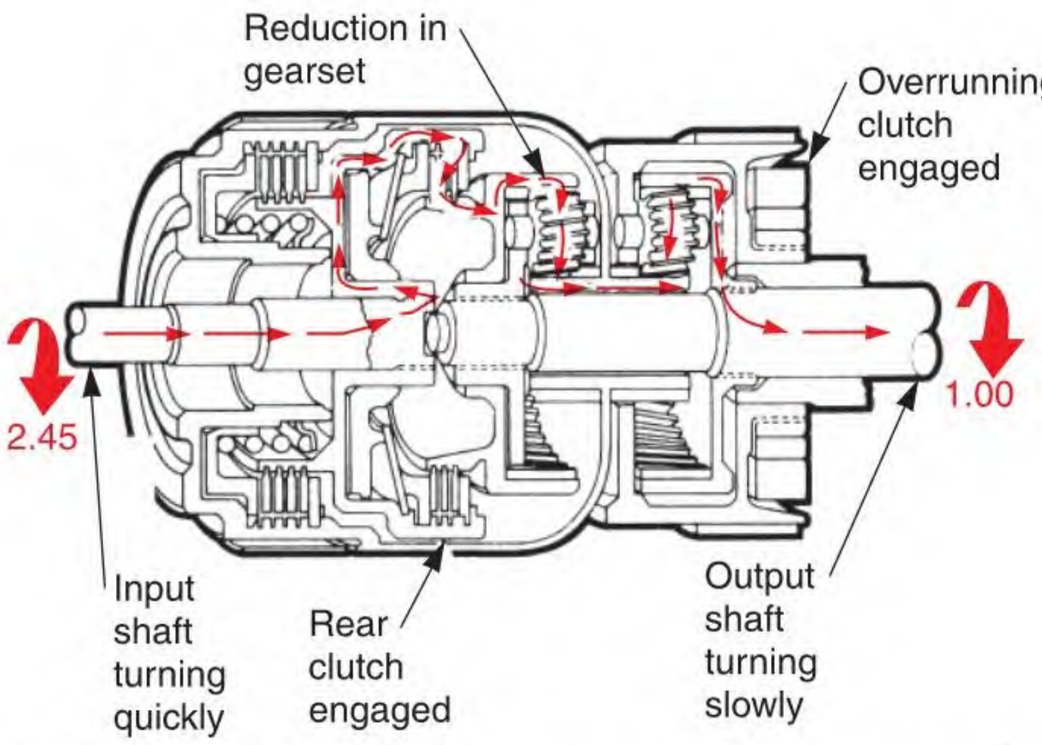
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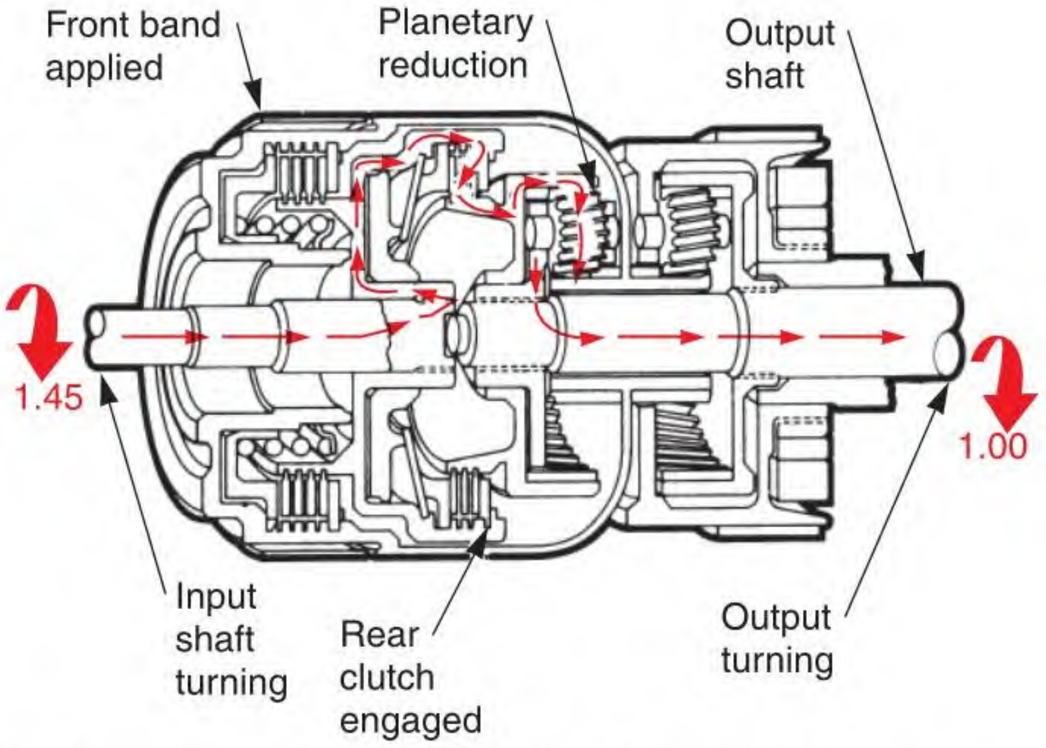
A—Study parts relating to power flow.



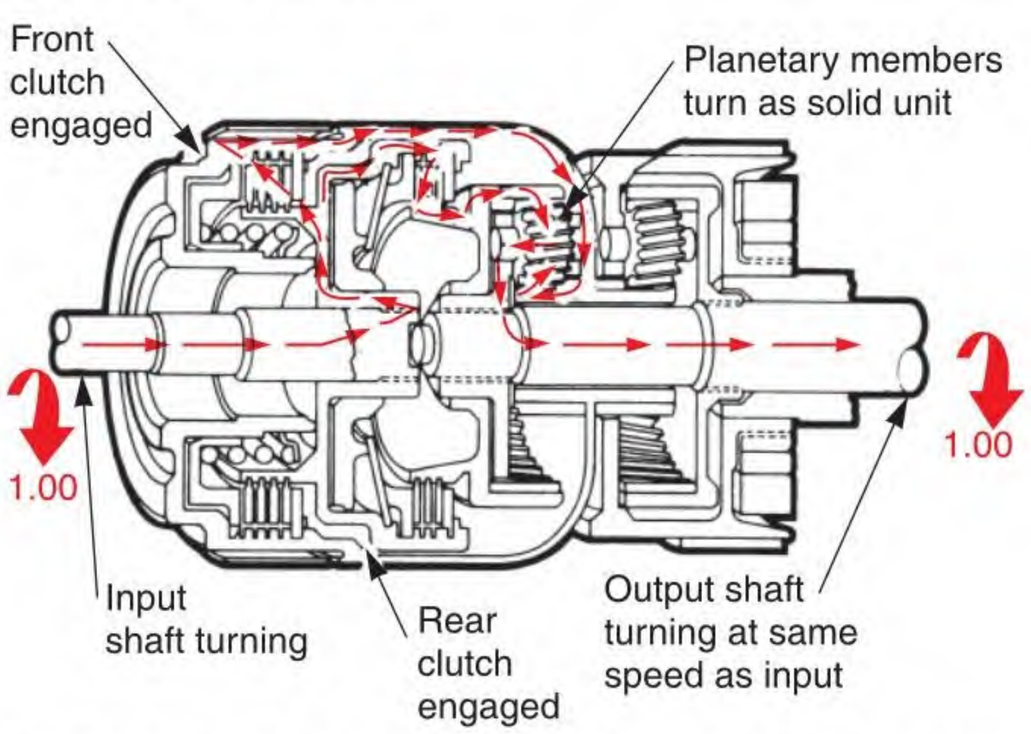
B—Neutral. Clutches and bands disengaged. Input shaft and hub turn, but power does not flow through clutches or drum. Output stationary.



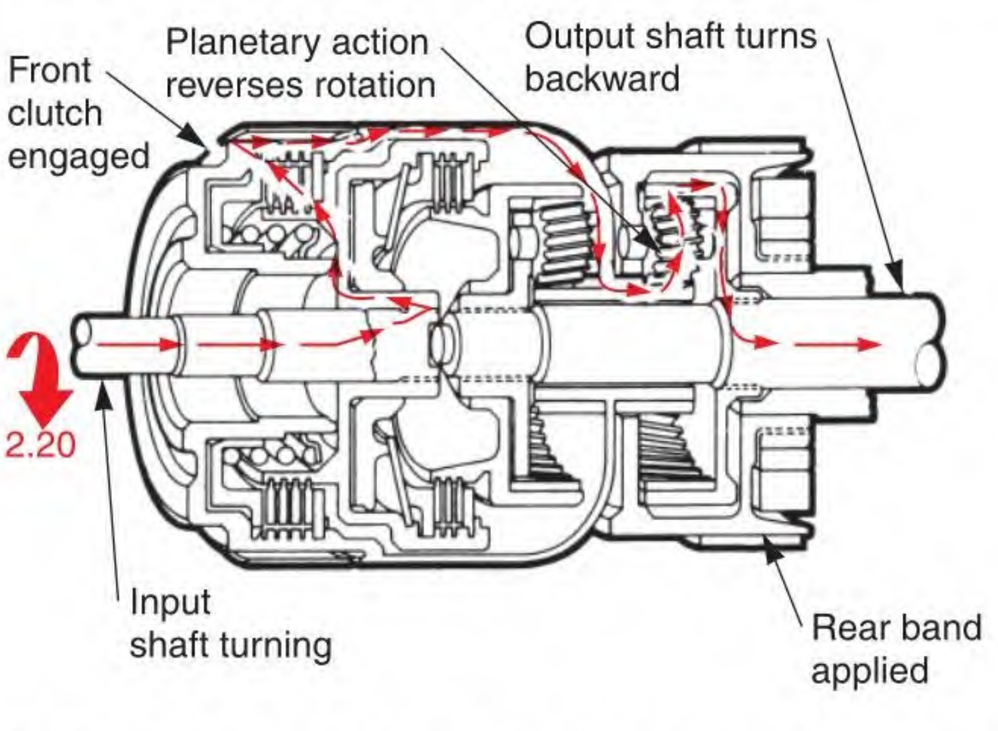
C—First gear. Rear clutch and overrunning clutch engaged. Gear reduction through planetary gearsets results in high torque output to driveline.



D—Second gear. Front band applied. Rear clutch engaged. Power flows through input, hub, clutch, drum, and front gearset to output. Less reduction results.



E—Third gear. Front and rear clutches engaged. Planetary members locked for direct drive. One-to-one ratio for higher vehicle speeds results.

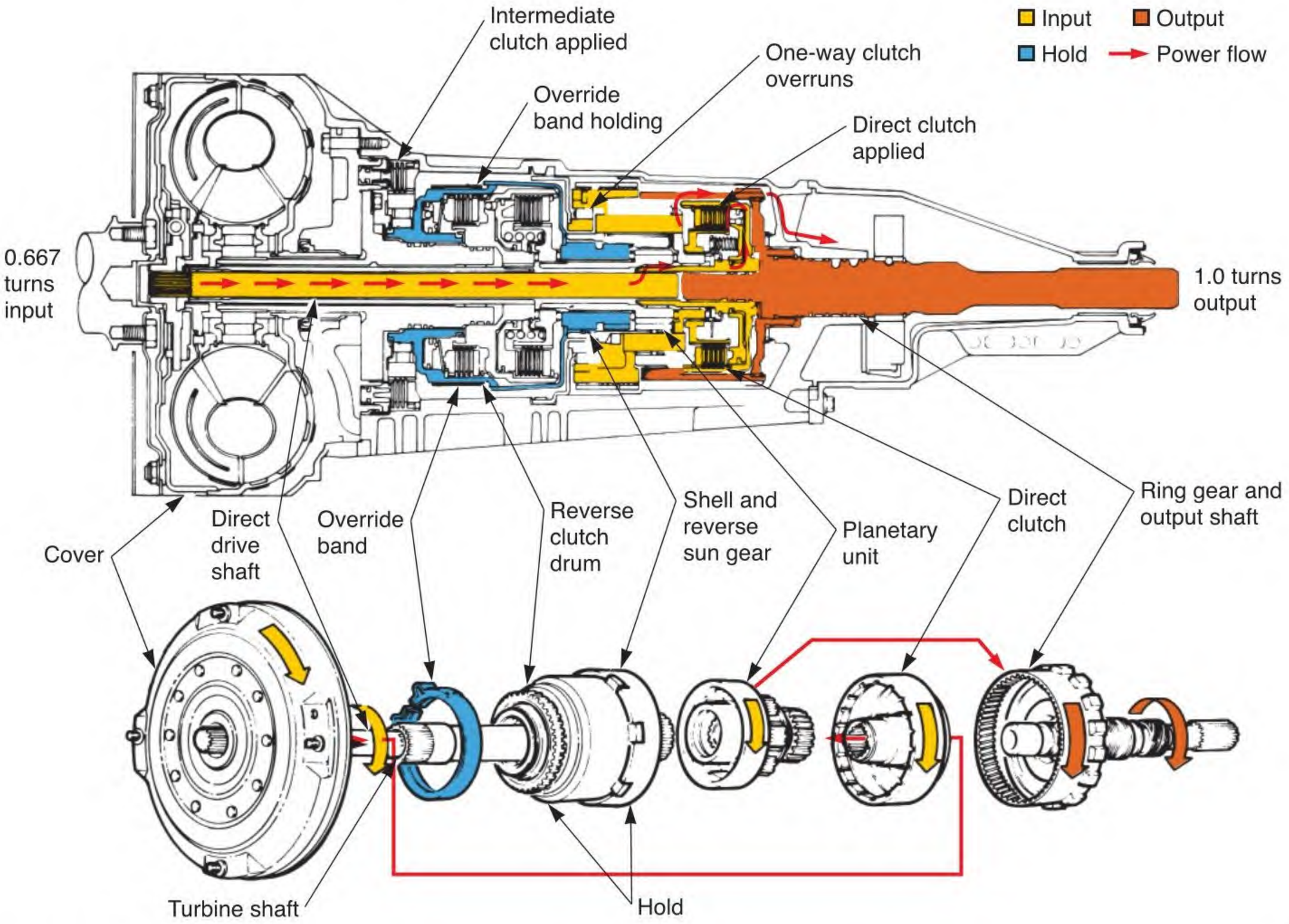


F—Reverse. Front clutch and rear band applied. Power flows through clutch, shell, and sun gear to rear planetary gearset, which reverses rotation.

Chrysler

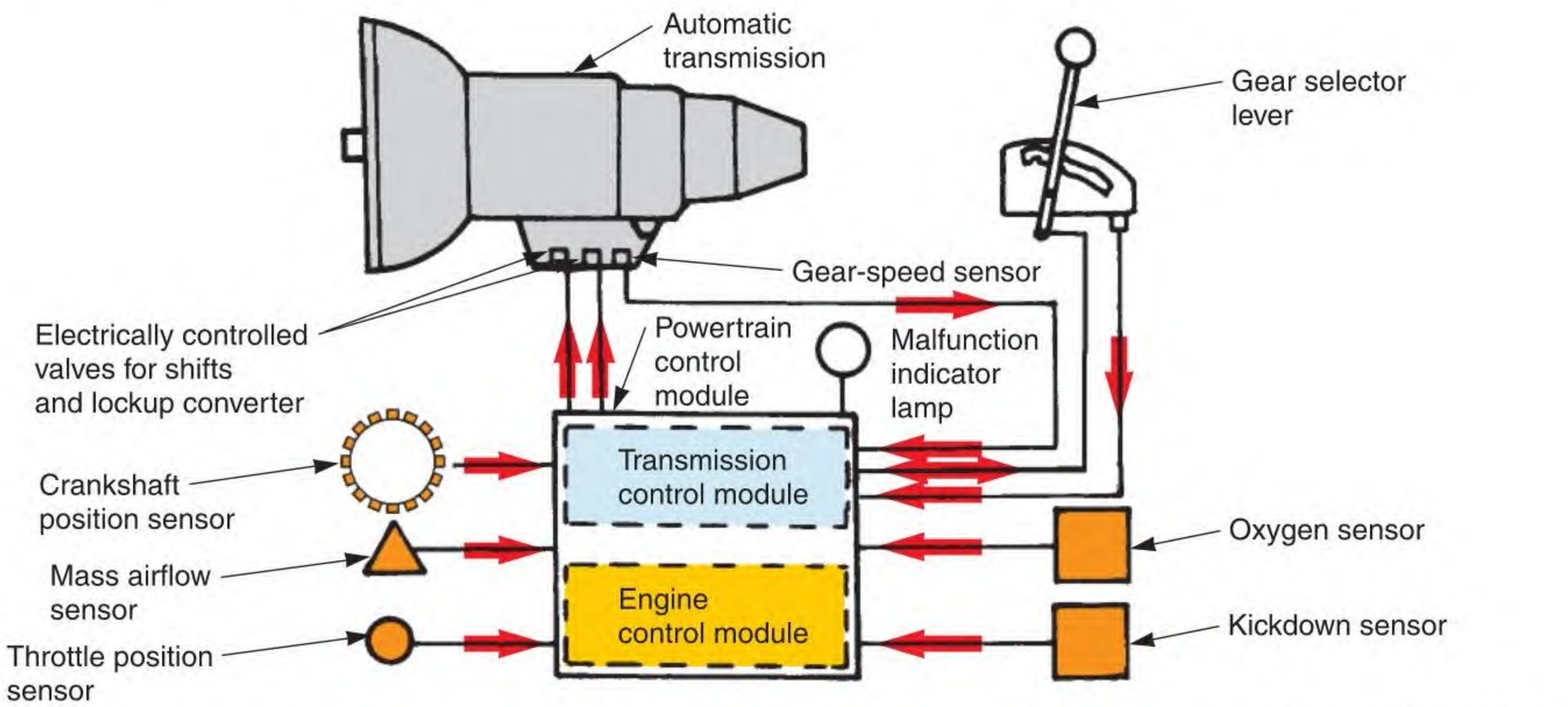
Figure 65-30. Study power flow through a typical automatic transmission.

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Ford

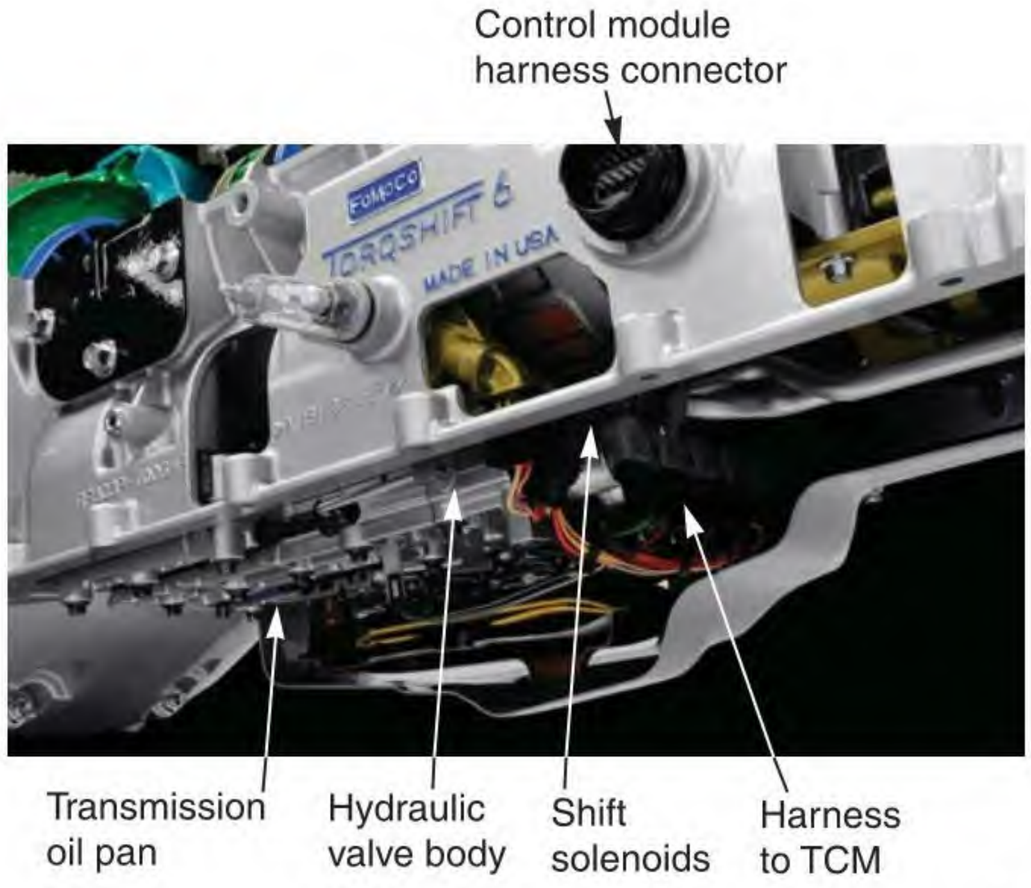
Figure 65-31. Power flow in high gear of a four-speed automatic with overdrive.



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Figure 65-32. Late-model automatic transmissions use a computer to help control shift points. Note the flow of data to and from the computer and transmission.

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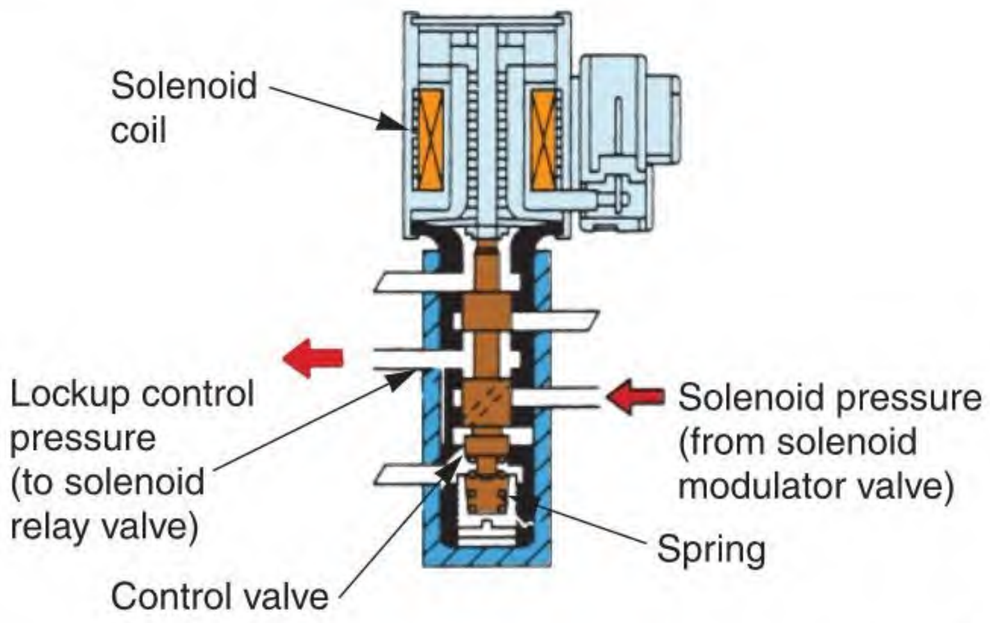


Ford

Figure 65-33. This cutaway of a transmission oil pan shows wiring leading to solenoids on the hydraulic valve body.

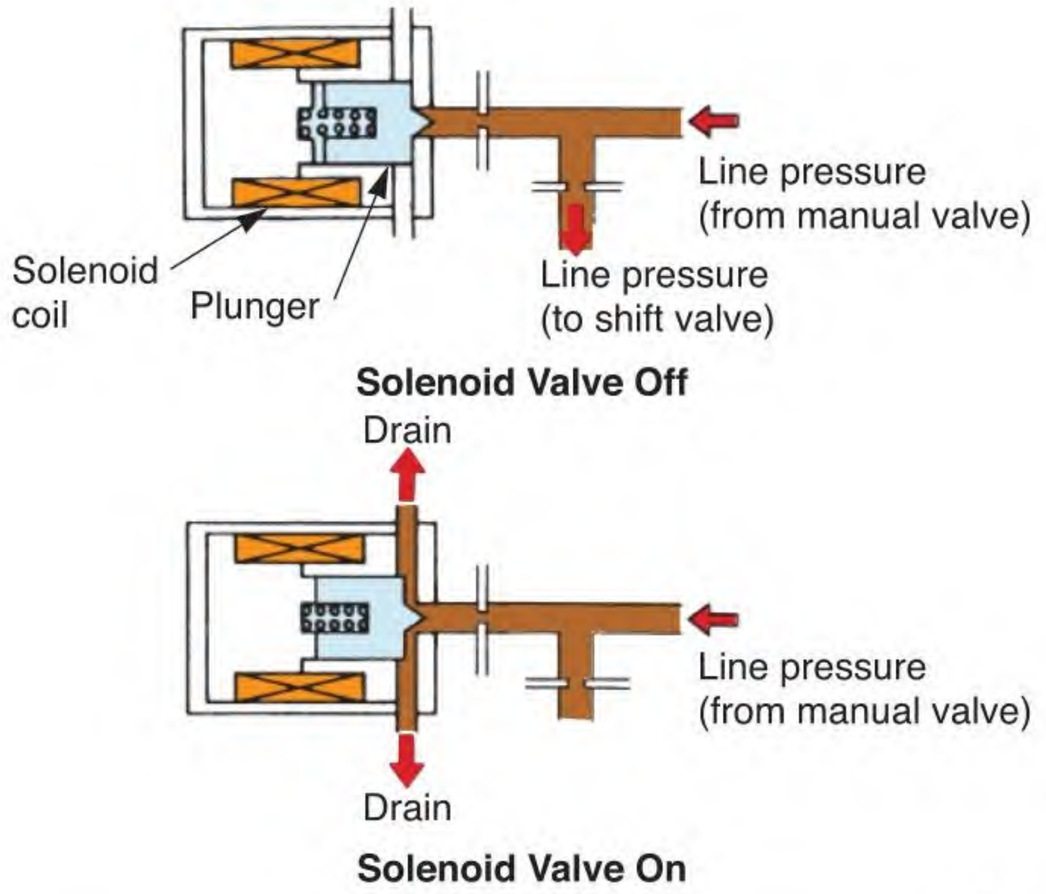
Electric shift solenoids are electromagnets with a sliding metal plunger. Electric shift solenoids on the valve body move small hydraulic spool valves. Spool valve movement directs oil pump pressure to each leg of the hydraulic circuit that feeds the hydraulic piston or servo.

A ***fixed transmission solenoid*** produces only fully "on" or "off" locations for the spool valve to open or close the fluid flow control valve. Various vehicle sensors feed data to the TCM. The TCM then uses preprogrammed data to apply voltage (or a ground) to the transmission shift solenoids and torque converter lockup solenoid. The solenoids open and close fluid pressure passages to operate the transmission or transaxles smoothly and dependably.



Lexus

Figure 65-34. When the TCM sends current through the solenoid windings, the solenoid moves a control valve to alter hydraulic pressure and flow in the transmission circuit.



Lexus

Figure 65-35. When the solenoid valve is turned off, line pressure is sent to the shift valve. When the solenoid is energized, the valve is pulled back to drain line pressure and keep pressure from acting on the shift valve.

A ***variable transmission solenoid*** can adjust the distance of spool valve opening by conducting different ECM duty cycles or signal frequencies. More ECM current flow through the solenoid windings builds a stronger magnetic field to overcome more spring tension, which allows the spool valve to be pushed or pulled even more. Hydraulic pressure changes in circuits allow for smoother transmission shifts by gradually applying the clutches and bands that shift planetary gears in an automatic transmission.

Automatic Transmission Designs

Refer to the service manual for more information on a specific automatic transmission. The manual will give hydraulic circuit diagrams, illustrations, and detailed operating and construction descriptions for the major components.

In the Rearview Mirror

General Motors was the first manufacturer to offer a fully automatic transmission on its vehicles. This transmission, dubbed the *Hydra-Matic*, was available as an option on any 1940 model for a mere $57. It provided four forward gears and true "clutchless" shifting. This was an engineering marvel for its time.

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Summary

- An automatic transmission "shifts gears" and "releases the clutch" automatically and more smoothly using a torque converter or fluid coupling.
- The basic parts of an automatic transmission include the torque converter, input shaft, transmission oil pump, valve body, shift solenoids, pistons and servos, planetary gearsets, bands and clutches, and output shaft.
- An automatic transmission uses three methods to transmit power: fluid, friction, and gears.
- An automatic transmission is normally constructed with four main components that support and enclose all the other parts in the transmission: bell housing, case, pan, and extension housing.
- The torque converter is a fluid clutch that provides a means of coupling and uncoupling the engine from the transmission.
- An automatic transmission input shaft connects the torque converter with the driving components in the transmission. The output shaft connects the driving components in the transmission with the drive shaft.
- A planetary gearset consists of a sun gear, several planet gears, a planet gear carrier, and a ring gear.
- Automatic transmission clutches and bands are friction devices that drive or lock planetary gearset members.
- Servos are apply pistons that operate the bands.
- The components of a hydraulic system (pump, pressure regulator valve, manual valve, shift valves, servos, pistons, solenoids, and valve body) work together to form the "muscles" (control) of the automatic transmission.
- Automatic transmission fluid is a special type oil with several additives that make it compatible with the friction clutches and bands in the transmission.
- Transmission oil cooling is performed by an oil cooling system that includes external oil lines and a cooling tank inside the engine radiator. Some cars have an auxiliary transmission oil cooler.
- The transmission oil pump, also called the oil pump, produces the pressure to operate an automatic transmission.
- Passages in the valve body route oil from the pump to the valves, and then into the transmission case.
- A parking pawl locks the transmission output shaft to its case or housing to keep the car from rolling when not in use.
- Electronic transmission control uses sensors, actuators (solenoids), and a computer (transmission control module, or TCM) to control shift points, torque converter lockup, downshifts, and other functions.
- A transmission solenoid is an actuator commonly found on modern electronically-controlled automatic transmissions. When energized or de-energized, they move the spool valves to control hydraulic pressure flow to the clutches and bands in the transmission.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

accumulator
apply piston
automatic transmission
automatic transmission oil (fluid)
balanced valves
band adjusting screw
bands
bell housing
clutch cylinder
clutch drum
clutch hub
clutch shell
clutches
compound planetary gearset
converter pump
driven discs
driving discs
driving shell
electric shift solenoids
electronic transmission control
extension housing
fixed transmission solenoid
hydraulic system
impeller
input shaft
lockup torque converter
manual valve
multiple disc clutch
oil pan
one-way clutch
output shaft
overrunning clutch
parking pawl
planetary gearset
power train control module
pressure plate
pressure regulator
release springs
servo piston
servo seals
servos
shift schedule
shift valves
snap rings
spool valve
stall speed
stator
stator shaft
stator support
torque converter
torque multiplication
transmission case
transmission control module
transmission control sensors
transmission oil cooler

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transmission oil pump
transmission pan
transmission solenoids
turbine
turbine shaft
valve body
variable transmission solenoid

Activities

1. Disassemble and reassemble an automatic transmission and identify the parts.
2. Demonstrate to the class how an automatic transmission works by sketching the hydraulic circuit for one gear ratio. Retrieve this information and circuit diagrams from service and repair data online, as well as on the shop's computer.

Review Questions

Answer the following questions using the information provided in this chapter.

1. List the eight major parts of an automatic transmission. Explain the function of each.
2. An automatic transmission uses the following method to transmit power:
   (A) friction.
   (B) fluid.
   (C) gears.
   (D) All of the above.
3. What are the four main components of automatic transmission construction?
4. A(n) _____ is a fluid clutch that provides a means of coupling and uncoupling the engine from the transmission.
5. Which part of a torque converter drives the turbine?
   (A) Band.
   (B) Stator.
   (C) Impeller.
   (D) None of the above.
6. Torque multiplication occurs when the impeller is spinning faster than the turbine. True or False?
7. What is the stator support?
8. Describe the movement of a planetary gearset.
9. What is the purpose of using a compound planetary gearset?
10. Solenoids and servos are friction devices that drive or lock planetary gearset members. True or False?
11. Explain the operation of a clutch apply piston.
12. During clutch engagement, oil pressure is routed into the _____.
13. What is a servo?
14. A(n) _____ is used in the apply circuit of a band or clutch to cushion initial application of oil pressure.
15. List the major parts of the hydraulic system in an automatic transmission.
16. How does the movement of a spool valve direct fluid flow in a hydraulic circuit?
17. List five basic functions of the oil pump in an automatic transmission.
18. How do the shift valves work?
19. What is the difference between a *fixed* transmission solenoid and a *variable* transmission solenoid?
20. A transmission rebuild kit costs $350 plus 7% tax. Labor for transmisssions removal, rebuilding, and installation is 7 hours at $95 per hour. What is the total cost of the repair?

ASE-Type Questions

1. Technician A says an automatic transmission's valve body connects and disconnects the engine and transmission. Technician B says an automatic transmission's torque converter connects and disconnects the engine and transmission. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Technician A says an automatic transmission's input shaft transfers power from the valve body to the gearsets. Technician B says an automatic transmission's input shaft transfers power from the gearsets to the drive shaft. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. While discussing the operation of a modern automatic transmission's valve body, Technician A says a shift lever is used to control valve body action. Technician B says valve body operation is controlled by a shift lever and sensors. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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4. Which of the following is *not* a basic component of a modern automatic transmission?
   (A) Pistons and servos.
   (B) Planetary gearsets.
   (C) Pinion seals.
   (D) Transmission bands.
5. Technician A says the oil pump in an automatic transmission is used to produce pressure to operate the transmission's hydraulic components. Technician B says an automatic transmission's oil pump is used to lubricate the transmission counter gears. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Technician A says the torque converter housing bolts to the rear of the transmission case. Technician B says the converter housing bolts to the front of the automatic transmission's extension housing. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. Technician A says an automatic transmission's oil pan is located at the bottom of the extension housing. Technician B says an automatic transmission's oil pan fits over the valve body. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. Technician A says an automatic transmission's extension housing supports the transmission input shaft. Technician B says an automatic transmission's extension housing supports the transmission output shaft. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Which of the following is another name for a torque converter impeller?
   (A) Stator.
   (B) Pump.
   (C) Turbine.
   (D) None of the above.
10. Technician A says the term "torque multiplication" refers to the ability of a torque converter to increase the amount of engine torque applied to the transmission output shaft. Technician B says the term "torque multiplication" refers to the ability of a torque converter to increase the amount of engine torque applied to the transmission input shaft. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
11. While discussing the construction of a modern automatic transmission, Technician A says the input and output shafts are the main shafts in this type of transmission. Technician B says the counter shaft and output shaft are the main shafts in an automatic transmission. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
12. Technician A says only one planetary gearset is commonly used in an automatic transmission. Technician B says an automatic transmission commonly uses two or more planetary gearsets. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
13. Technician A says a planetary gearset will act as a solid unit when two of its members are held. Technician B says a planetary gearset will act as a solid unit when one of its members is held. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
14. Technician A says bands are used in an automatic transmission to cause the gearsets to transfer power. Technician B says clutches are used in an automatic transmission to cause the gearsets to transfer power. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
15. In a modern transmission, this device senses engine load and other variables to determine when the transmission should shift to a higher gear.
    (A) Oil pump.
    (B) Transmission control module.
    (C) Pressure regulator.
    (D) None of the above.

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Chapter 66
Automatic Transmission Diagnosis, Service, and Repair

After studying this chapter, you will be able to:

- Troubleshoot an automatic transmission.
- Explain the types of problems common to an automatic transmission.
- Describe the tests needed to locate automatic transmission problems.
- Change automatic transmission oil and filter.
- Locate and repair automatic transmission leaks.
- Cite and observe safety rules while working on transmissions.
- Troubleshoot electronically controlled automatic transmissions.
- Remove and replace an automatic transmission.
- Correctly answer ASE certification test questions about automatic transmission service.

Competent automatic transmission service, diagnosis, and repair typically requires a transmission specialist. Today's computer-operated automatic transmissions use electric solenoid actuator circuits to control complex, powerful hydraulic circuits to change gear ratios and gear directions under driver control. Although automatic transmission service is usually performed by specialists, it is very important that every technician have some knowledge of basic service methods.

Problems with an automatic transmission can affect, or appear to affect, the operation of other vehicle systems. For example, a torque converter malfunction (inoperative stator or frozen lockup clutch) can appear to be an engine performance problem. The faulty converter could consume a tremendous amount of engine power or not allow engine speed to increase normally.

Tech Tip

The exact type of transmission can usually be found in the VIN (vehicle identification number) or on a number on the transmission case. You can refer to the service manual to find out what the number code says about the transmission type.

Automatic Transmission Diagnosis

The first step, as usual, is to connect a scan tool or diagnostic tablet to the vehicle's diagnostic connector. Modern vehicles can detect sticking or frozen shift solenoid valves, low hydraulic pressure, transmission slippage by comparing vehicle speed sensor data and ABS wheel speed values.

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Tech Tip

Always remember that low alternator/battery voltage can upset the operation of ECMs and cause false trouble codes. Measure battery condition with a load tester and check alternator voltage under a full load with all electrical accessories on.

Several problems are common to an automatic transmission. A few of these are illustrated in **Figure 66-1**.

Automatic transmission slippage is often caused by a low fluid level, bad, sticking shift solenoid, worn clutches or bands, or valve body problems. With partial slippage, the engine may briefly race as the transmission shifts to a higher gear. With severe slippage, the vehicle might not move.

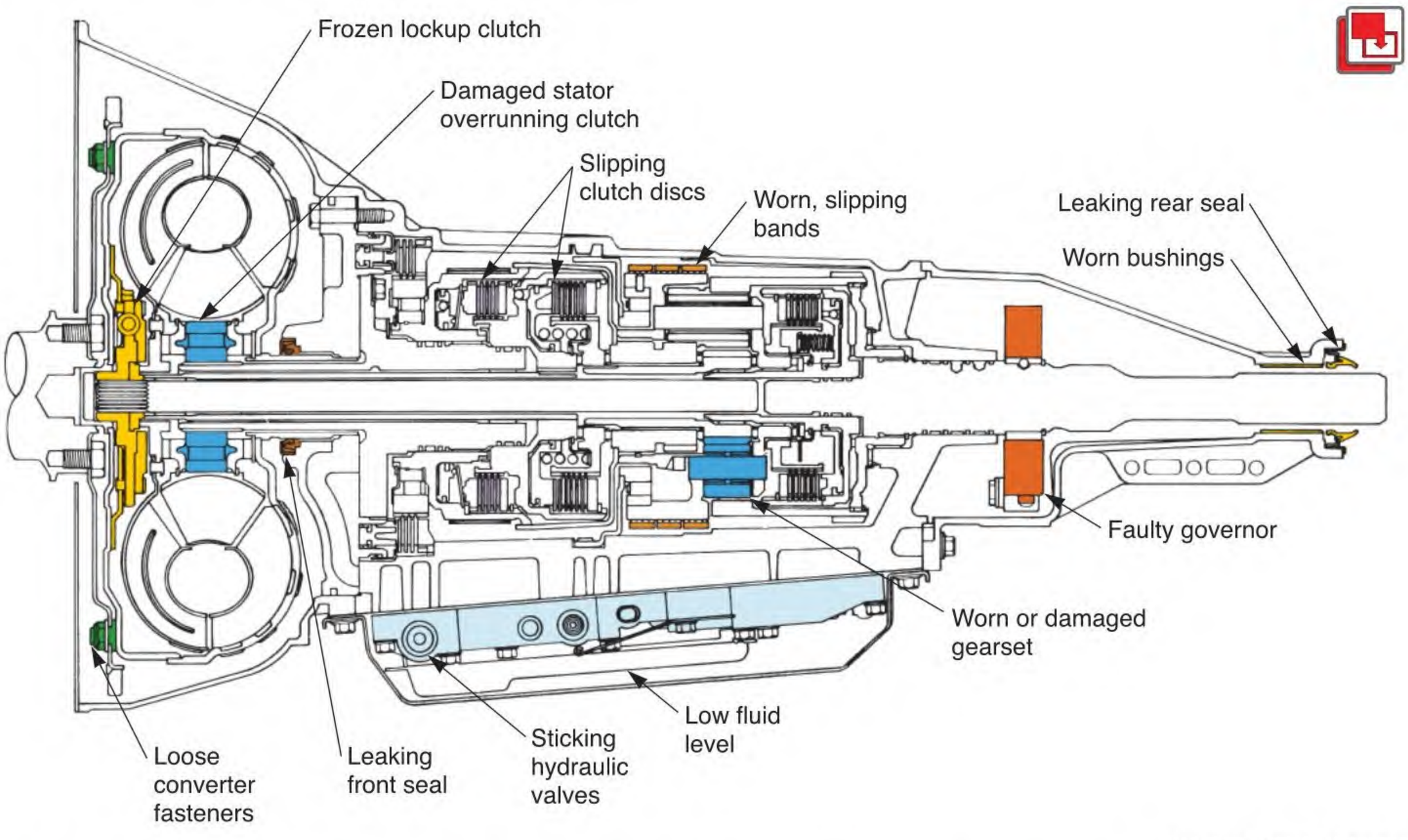
Incorrect shift points may be caused by low fluid level, a faulty MAP sensor, an engine performance problem, inoperative shift solenoids, or a bad vehicle speed sensor circuit. If incorrect shift points is the problem, the transmission might shift too soon (engine lugs in higher gear) or too late (engine races in lower gear). In some cases, it may not shift at all (locked in one gear or fails to upshift).

Mushy shifts or ***harsh shifts*** are normally caused by the same types of problems that cause slippage and incorrect shift points. A mushy shift is noticed when the transmission takes too much time changing gears. A harsh shift is just the opposite—when the transmission changes gears too quickly, causing the vehicle to jerk during shifts.

A noisy transmission (whining, whirring, grinding) might result from an improper fluid level, planetary gear troubles, damaged bearings, a faulty torque converter, or loose components.

If the abnormal sound occurs in every gear, the problem might be in the torque converter, the transmission fluid pump, or another part common to all gears. If the transmission makes the noise in only one gear, parts that operate in only that gear are at fault.

Modern vehicles produce numerous different transmission trouble codes. Your OBD scan tool will find electrical circuit problems with shift solenoids, wiring harnesses, transmission and engine sensors, etc. A few voltage and resistance measurements with your VOM will verify most automatic transmission troubles.



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Figure 66-1. Visualize the kinds of symptoms these problems could cause in an automatic transmission.

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Tech Tip

When trying to find the source of transmission noises, make sure the problem is inside the transmission before attempting transmission repairs. Worn wheel bearings, dry universal joints, and engine problems can all produce noises that appear to come from the transmission.

Follow an orderly procedure when diagnosing transmission troubles. Suspect the most common problems and causes. Begin with basic checks of the engine and transmission, and then perform the recommended shop tests. See **Figure 66-2**.

Refer to a service manual troubleshooting chart when more specific problems cannot be located. The service manual will have symptoms, part and hydraulic circuit drawings applicable to the specific transmission model.

Warning

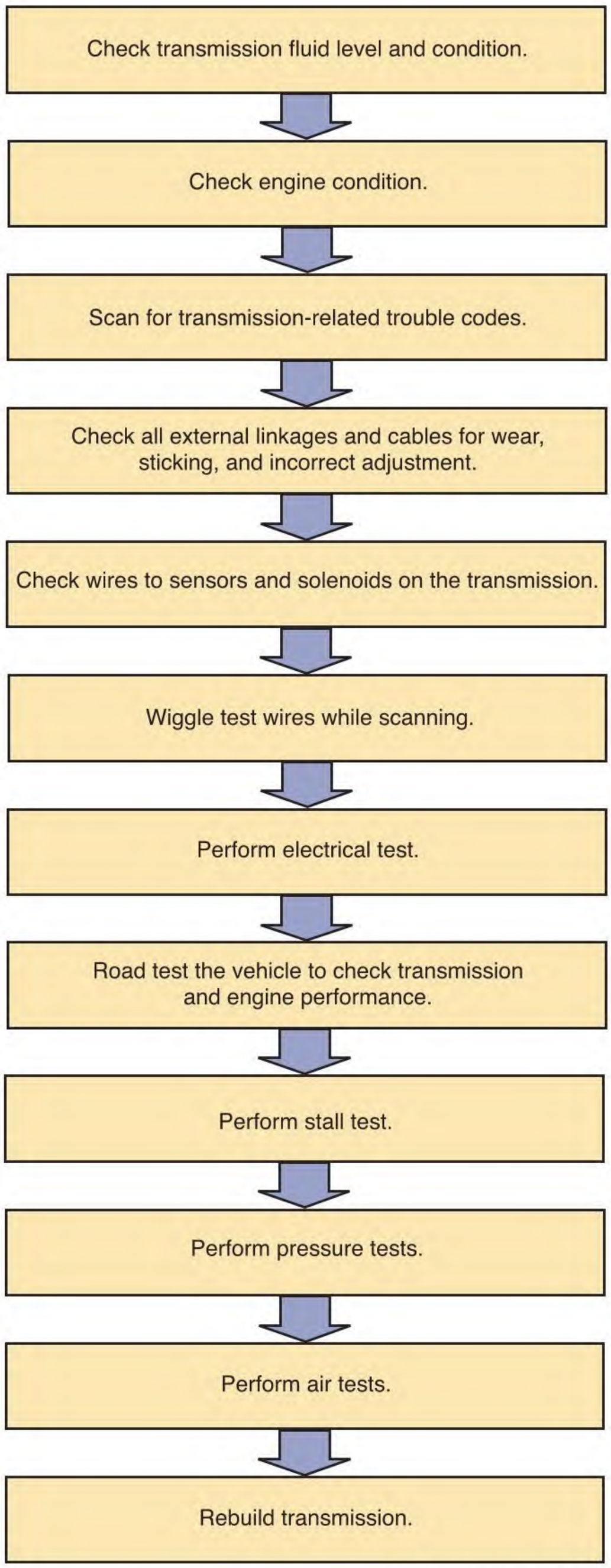
Servicing a transmission often requires the vehicle to be raised and mechanically supported. Make sure to use proper jack stands and hydraulic transmission jacks. Stay clear of drivelines when testing a transmission. Remove rings and jewelry when working. To prevent shorts, disconnect the battery when it is not needed. On an HEV, wear rubber gloves and use insulated tools.

Preliminary Checks

Before road testing the car, there are several checks you should perform, including fluid level and condition, shifter operation, and engine condition. You might find a low fluid level and fix the problem quickly.

Fluid Level

Low fluid level is normally caused by a leak and may cause the fluid pump to try to move air instead of transmission fluid. Air is compressible, but transmission fluid is not. If the transmission fluid becomes aerated, it may build pressure too slowly, causing various engagement and shifting problems. If there are air bubbles in the transmission fluid, the transmission fluid pump will produce a loud buzzing noise as



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Figure 66-2. Procedure for diagnosing automatic transmission troubles.

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voids of air move through the pressure chambers and hydraulic circuits.

A ***high fluid level*** can produce symptoms similar to those produced by a low fluid level. The transmission can churn the fluid into a foam. The air bubbles in the foam will make the fluid compressible, upsetting normal operation and causing transmission noises.

Fluid Condition

Transmission fluid condition can tell you a great deal about the internal condition of the transmission. Whenever you pull out the transmission dipstick, wipe the fluid off on your finger or a white paper towel. Inspect the fluid closely for signs of foreign matter or an unusual smell. See **Figure 66-3**.

Burned transmission fluid will be black or dark brown and will have a burned odor. The dark color is normally caused by band and clutch friction material failure—the friction material has been slipping and overheating. When you find burned transmission fluid accompanied by slipping or shifting problems, serious damage has usually occurred. Typically, the transmission will need major repairs.

Milky transmission fluid (white or nontransparent pink appearance) is normally caused by engine coolant mixing with the transmission fluid. The oil cooler in the engine radiator is leaking and allowing antifreeze to enter the transmission lines. Coolant in the transmission fluid can sometimes cause fluid seals and friction material (clutches and bands) to deteriorate. The seals can swell and leak. The clutch and band material can soften and wear quickly.

Transmission fluid varnish is evident when a light brown coating is found on the dipstick. The transmission fluid has broken down, coating the internal parts of the transmission with a sticky, glue-like substance. The fluid varnish can cause a wide range of transmission problems. It can cause hydraulic valves, servos, and pistons to stick. With an extreme case of varnish buildup, the transmission filter can clog.

With a light varnish buildup, changing the transmission fluid may prevent further problems. With a heavy varnish buildup, the transmission must often be rebuilt.



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Figure 66-3. To check fluid condition, wipe the dipstick on a clean white rag or paper towel and look for fluid discoloration and foreign matter. Also smell the fluid to check for a burned odor.

Warning

Let the vehicle cool before draining transmission fluid. Hot fluids can cause serious burns. Wear safety glasses or a face shield to protect your eyes.

Engine Condition

During your preliminary checks, always inspect the operating condition of the engine. The engine should start properly, idle smoothly, and perform normally under acceleration.

An engine problem that lowers intake manifold vacuum will trip a trouble code for the MAP sensor, engine misfire, catalytic converter, etc. The MAP sensor has replaced the vacuum modulator hydraulic valve.

Electrical Connections

Inspect any electrical connections on the transmission. Many late-model automatic transmissions have sensors and actuators on them. A poor connection can upset the operation of the transmission and related systems. Look for disconnected or frayed wires, corroded connectors, and trouble codes.

Road Testing

If you do not find the source of the transmission problem through your preliminary checks, road test the vehicle. Drive the vehicle while checking the general operation of the transmission: shift points, noises, etc. The test route should be a smooth road with little traffic. This will help reduce outside noise and distractions.

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With the transmission in drive, accelerate normally. Make sure the transmission upshifts correctly. Listen for noises in each gear and try to detect any slippage.

Then, manually shift the transmission through the gears. For example, if you think you heard a noise in second gear, manually shift into second (low 2). This will give you more time to evaluate performance in second gear.

Shop Testing

Various shop tests are used when the preliminary checks and the road test fail to locate the transmission problem. There are three main shop tests: stall test, pressure test, and air test.

Stall Test

A ***stall test*** can be used to detect transmission slippage or a malfunctioning torque converter.

Service Procedure

To perform a stall test:

1. Connect a tachometer or scan tool to measure engine speed.
2. Apply the emergency brake and press down firmly on the brake pedal.
3. Start the engine and place the transmission in low.
4. When the accelerator is slowly pressed to the floor, the engine should "stall" (stop increasing speed) at a specified rpm.

   If the tachometer does not register the specified stall speed, a problem exists inside the converter. The transmission should be tested in every gear position.
5. If the stall speed is too low, the engine might have a performance problem or the torque converter stator could be inoperative.

If engine speed is high, the transmission is slipping and could quickly overheat, burning friction material. Release the accelerator immediately to prevent further transmission damage. The problem may be low hydraulic control pressure, reducing the clamping force of the pistons and servos. Friction material could be worn down to bare metal.

Figure 66-4 shows a transmission clutch and band application chart. It can help determine which parts are faulty when a transmission slips.

Clutch and Band Application Chart

Low(D) (Breakaway) 2.74 RWD 2.69 FWD	Low(1) (Manual) 2.74 RWD 2.69 FWD	Second 1.54 RWD 1.55 FWD	Direct 1.0:1	Reverse 2.22 RWD 2.10 FWD
Rear clutch Drives front ring gear	**Rear clutch** Drives front ring gear	**Rear clutch** Drives front ring gear	**Rear clutch** Drives front ring gear	**Front clutch** Drives sun gear
Overrunning clutch Holds rear planet carrier	**Low and reverse band** Holds rear planet carrier	**Kickdown band** Holds sun gear	**Front clutch** Drives sun planet	**Low and reverse band** Holds rear carrier

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Figure 66-4. A clutch and band application chart shows which components are slipping in each gear during a stall test. It is also useful during road and pressure tests. A service manual will give a chart for the specific transmission.

Pressure Test

Pressure tests are used to determine whether fluid pressure in the various transmission circuits is normal. Plugs are provided on the outside of the transmission case for pressure tests, **Figure 66-5**.

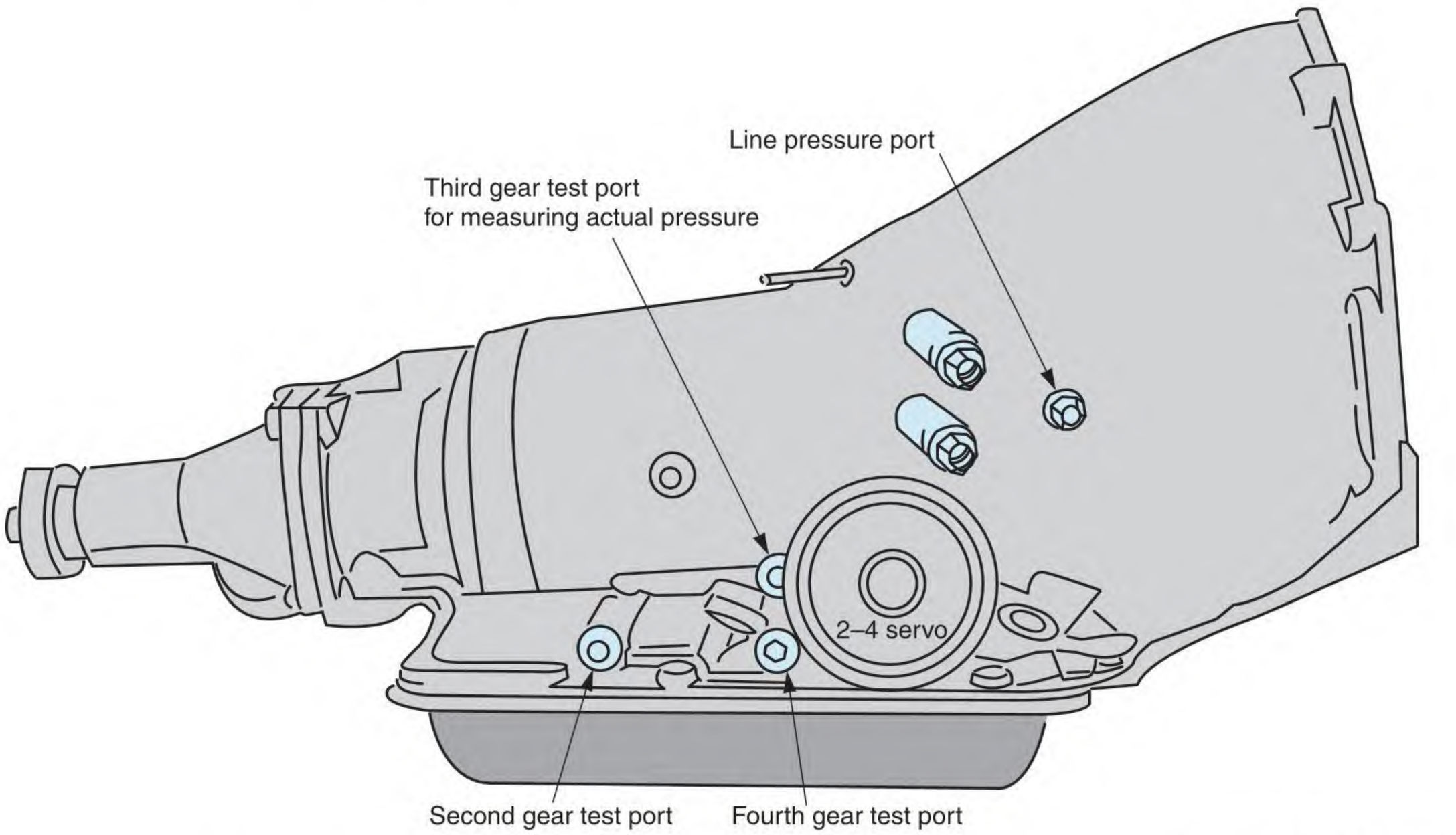
Service Procedure

To perform a pressure test:

1. Connect a 300 psi (2000 kPa) gauge to the line pressure port on the transmission. See **Figure 66-6**.
2. Run the engine until it is at operating temperature. Typically, the engine should be at curb idle.
3. While holding your foot on the brake, shift through all the gears while noting the reading on the pressure gauge.

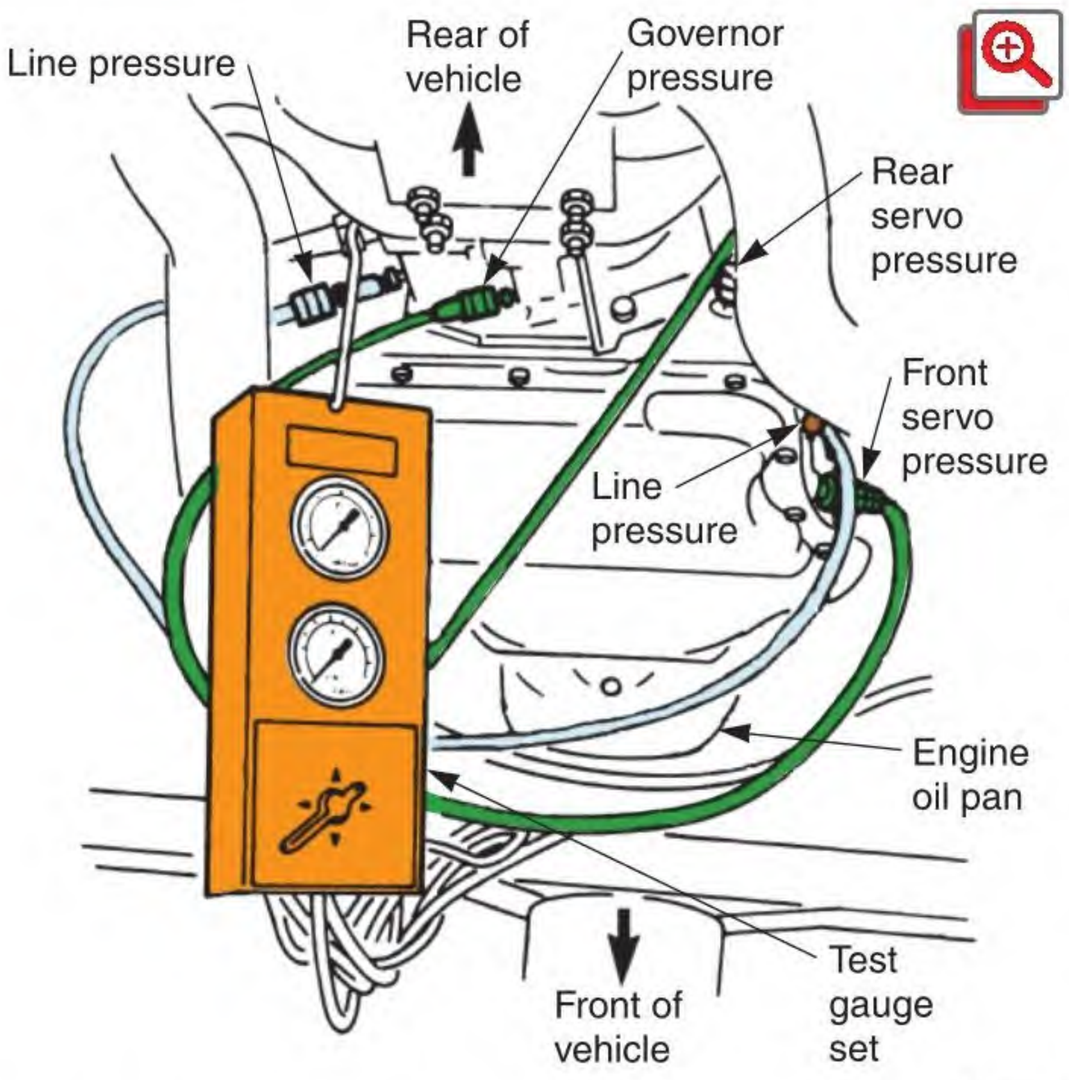
   Compare your pressure readings to those in a service manual.
4. If test pressures are low or high in one gear, suspect that shift solenoid or spool valve. The solenoid could be bad or that spool valve could be stuck.

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Figure 66-5. Plugs on the side of the transmission case cover ports to hydraulic components. To pressure test, install a pressure gauge in a port. Compare the pressure to specifications to determine the condition of various components.



Chrysler

Figure 66-6. A special gauge set like this one or pressure and vacuum gauges are connected to the transmission. Gauges can also be placed in the passenger compartment for watching pressures during a road test.

Air Test

An ***air test*** is used to further isolate problems in automatic transmission circuits. After removing the oil pan and valve body, a rubber-tipped nozzle is used to blow air pressure into the transmission passages. The air pressure used is normally 25–35 psi (170–240 kPa). Look at **Figure 66-7**. The air pressure should activate the pistons, servos, and other components. This will let you detect leaks, stuck components, bad check valves, and blocked passages.

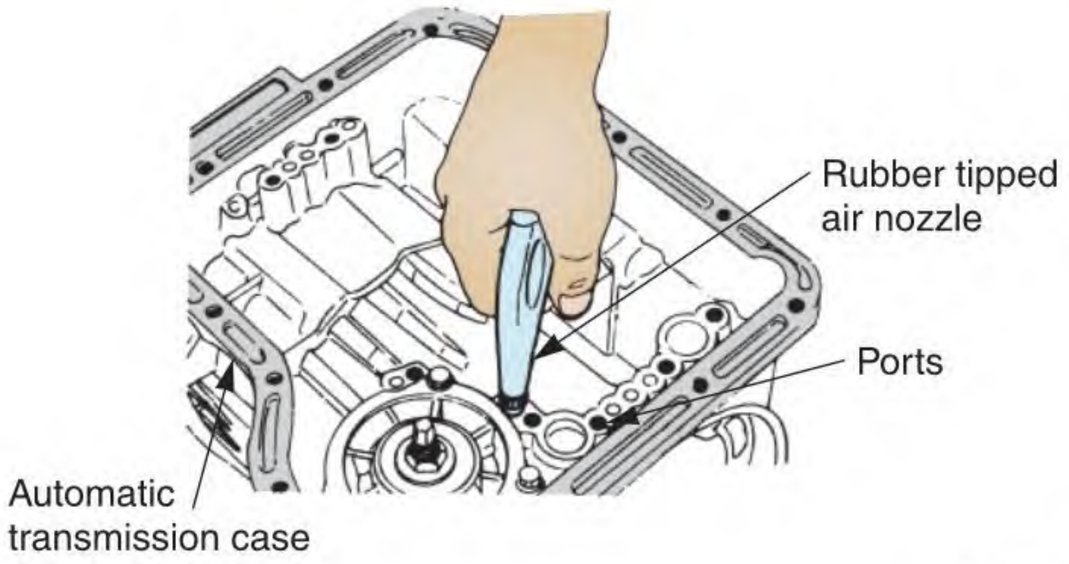
The service manual will show which transmission case passages lead to particular components. An example is shown in **Figure 66-8**.

When air pressure is blown into a piston or servo passage, a dull thud should be heard. This sound is made as the piston slides in its cylinder and bottoms. A hissing sound indicates a piston or servo leak, which would allow fluid leakage. No sound indicates a blockage or a frozen piston.

Hydraulic Circuit Diagrams

Service manuals often contain ***hydraulic circuit diagrams***, which show how the fluid passages inside an automatic transmission are connected to each

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Nissan

Figure 66-7. An air pressure test involves injecting air pressure into transmission passages. Air pressure should activate pistons and servos, making a clunking or thudding sound. Other sounds can be made when air is injected into ports to other parts. Refer to a service manual for details.

component. A hydraulic circuit diagram is frequently used when tracing hard-to-find problems or when doing pressure or air tests.

Often, a hydraulic diagram is given for each gear position. This lets you know how fluid, air, and electrical energy should flow through the transmission in each gear.

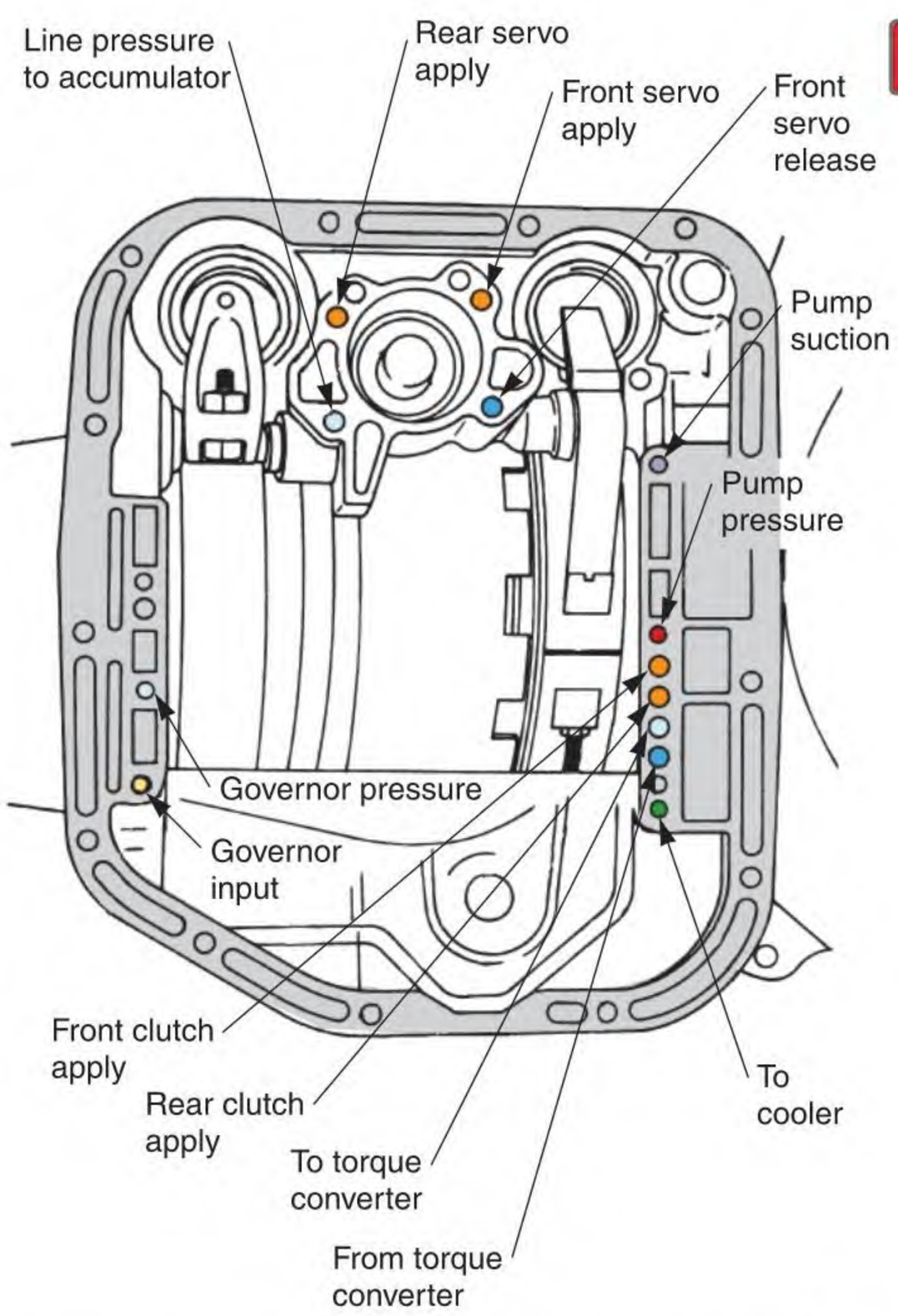
Electrical Tests

Electrical tests on an automatic transmission involve checking sensors, actuators, and wiring for basic troubles. Your scan tool will often tell you if there are problems with shift solenoids, transmission sensors, engine sensors, switches, and other transmission related components. For example, if your scan tool indicates a problem with the 1-2 shift solenoid, you would know to test this circuit first. Pulling the pan and replacing that shift solenoid may fix the transmission problem.

Automatic Transmission Maintenance

Maintenance is very important to the life of an automatic transmission. Automatic transmission fluid, just like engine oil, can become filled with foreign matter after prolonged operation. Bits of metal, friction material, water, dust, and other substances can circulate through the hydraulic system, causing premature wear.

When checking transmission fluid, apply the parking brake and block the wheels. Make sure the fluid level is between the Add and Full marks on the dipstick when the engine is running at full operating temperature. If the dipstick indicates a low level, add



Chrysler

Figure 66-8. This service manual illustration shows the function of each port in the bottom of a specific transmission case. Look up this type of illustration in the service manual when performing an air test.

more fluid. Use the transmission fluid type (Type-F, Dexron, etc.) specified in the owner's manual.

To add fluid, insert a long, clean funnel in the dipstick tube. Do not overfill the transmission—add only a partial quart if the fluid level is between the dipstick add and full marks. Add a little fluid and recheck the dipstick fluid level.

Tech Tip

Continuously variable transmissions or transaxles take a different type of fluid than conventional automatic transmissions. Use only the manufacturer-recommend type of fluid for a CVT to prevent steel belt slippage and major part damage.

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Changing Transmission Fluid

Refer to the service manual to determine when automatic transmission fluid should be changed. A typical fluid change interval is 15,000–20,000 miles (24,000–32,000 km).

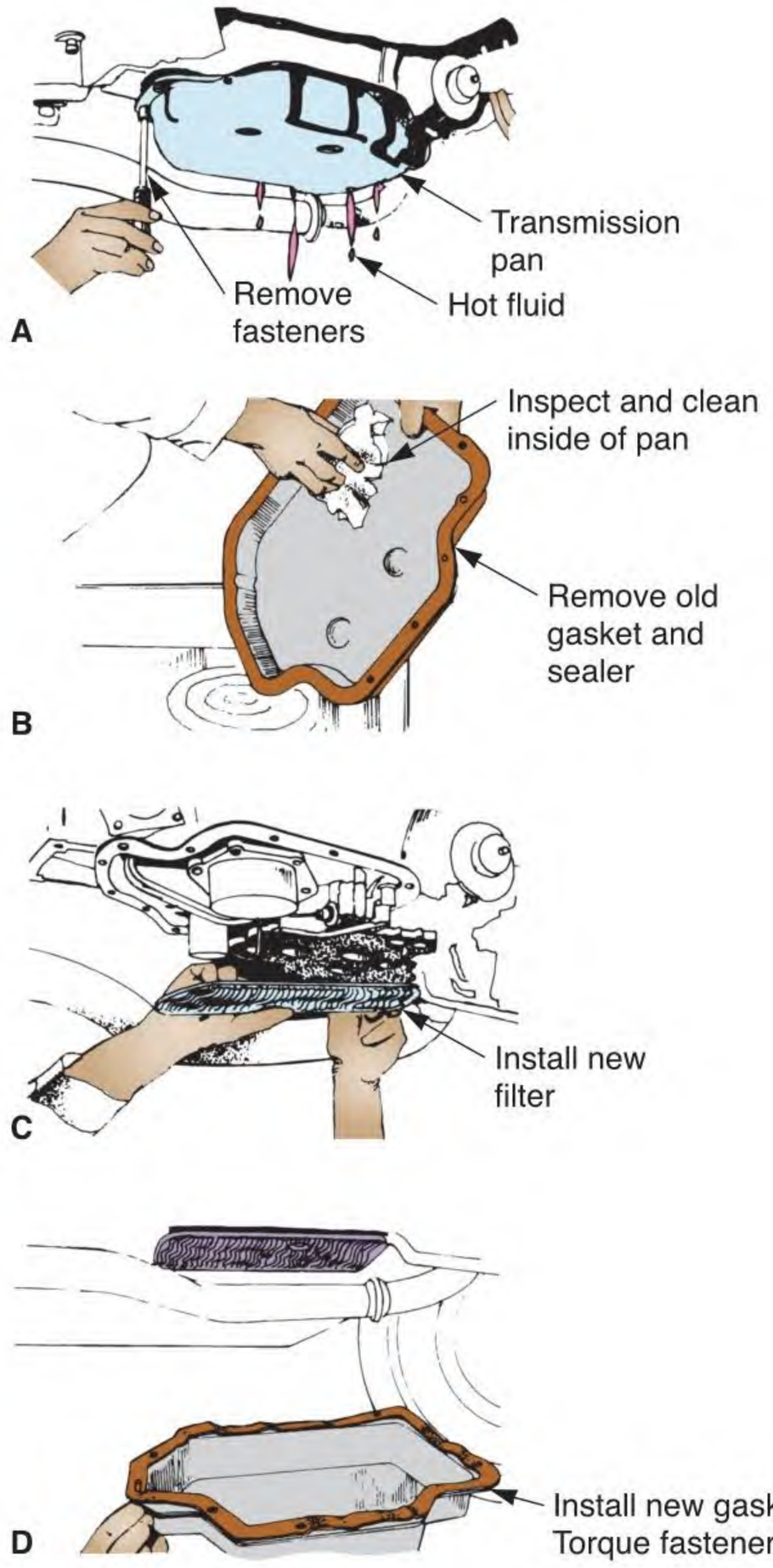
Tech Tip

If the vehicle has high mileage and very dirty transmission fluid, avoid changing the fluid, because band and clutch slippage will often result! This is especially true if the vehicle has over 100,000 on the original fluid. The dirty transmission fluid will be filled with bits of carbon, metal, friction material that will help keep worn transmission parts from slipping. To avoid the expense of a transmission rebuild and customer complaint, advise against a first-time transmission fluid change on a high mileage vehicle.

Service Procedure

To change the transmission fluid and filter:

1. Drain the fluid from the transmission pan. Be careful, the fluid may be hot!
2. On some transmissions, the torque converter must also be drained before changing the filter. Refer to the service manual for information on draining a torque converter.
3. Remove the pan. Keep it level and lower it slowly to prevent spilling.
4. Inspect the pan for debris. Bits of metal or friction material may indicate transmission problems, such as broken bands or clutch shells.
5. Clean the pan thoroughly.
6. Change the transmission fluid filter, **Figure 66-9**.
7. If sealer is used on the pan, make sure you do not use too much. If sealer is squeezed into the pan during pan installation, it may block fluid passages, cause spool valves to stick, and upset transmission operation.
8. Install the pan. Torque the pan bolts to specifications in a crisscross pattern.
9. Fill the transmission with the correct amount and type of fluid. Capacity will vary depending on whether the torque converter was drained.
10. Start the engine and shift the transmission through its gears.
11. Check for leaks and double-check fluid level.



AC-Delco

Figure 66-9. Replacing an automatic transmission filter. A—Be careful not to be burned by hot oil when removing the pan. B—Inspect the pan for debris before cleaning. C—Install a new filter. D—Install a new gasket or sealer and torque pan fasteners.

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Warning

When draining automatic transmission fluid, be careful not to be burned by hot fluid. Wearing nitrile work gloves will help prevent burns and keep your hands cleaner. Oil and grease can be difficult to remove from your hands because they can embed in the pours of your skin.

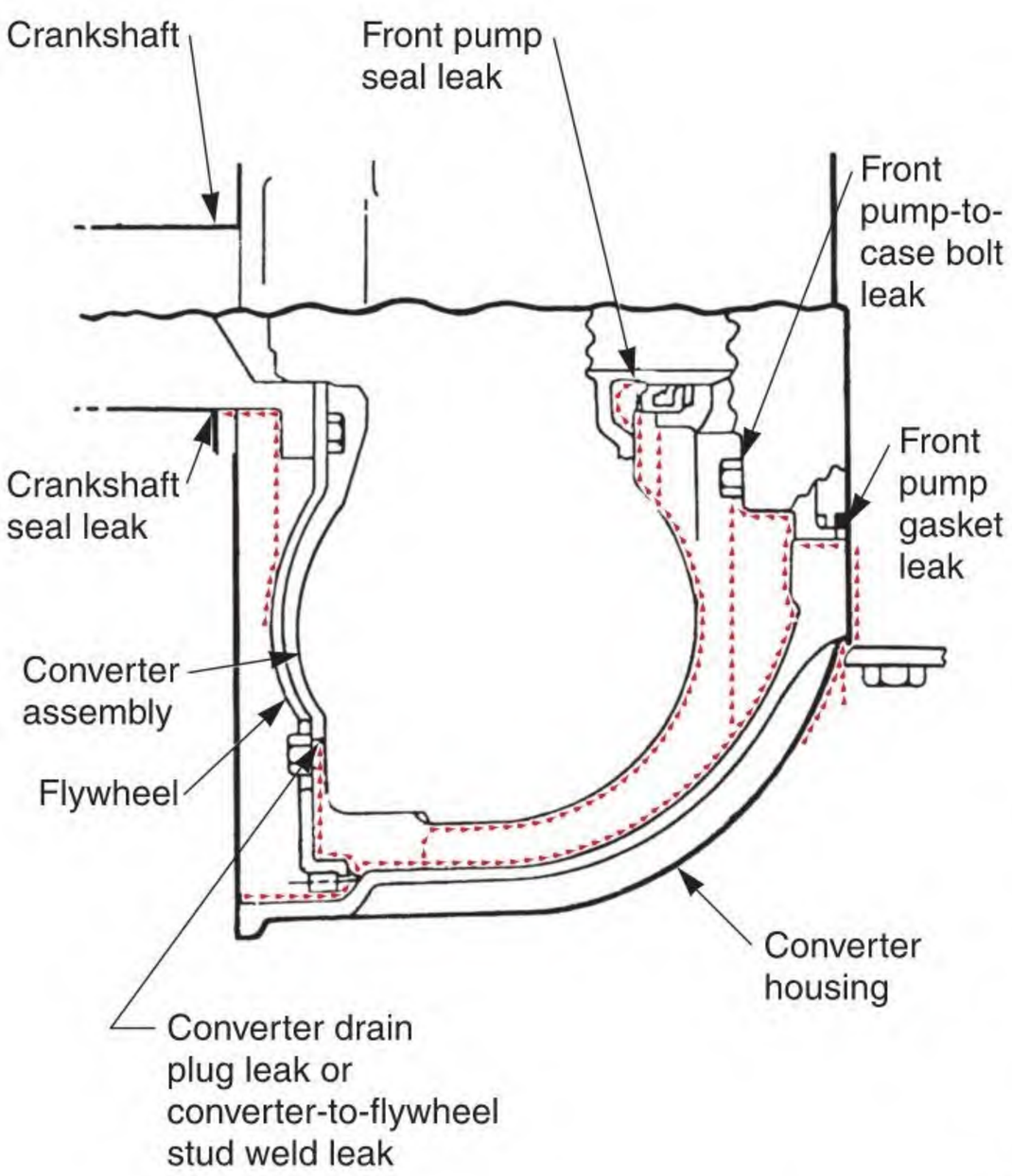
Fluid Leaks

Automatic transmission fluid leaks commonly occur at the rear seal, front seal, oil pan gasket, extension housing gasket, and shift lever shaft seal. Whenever the fluid level is excessively low, always inspect the transmission for leaks. Raise the car on a hoist and check for automatic transmission fluid, **Figure 66-10**.

Normally, the leaking transmission fluid will be cleanest near the source of the leak. The clean fluid is normally red. The leaking fluid tends to wash road dirt off the outside of the transmission case, causing it to darken as it flows along the case.

As mentioned in other chapters, you can add a leak detection dye to the transmission fluid. This will help you find a leak because of its bright color. In some cases, the dye agent will cause the transmission fluid to glow when illuminated with a black light.

If the leak is found at the rear seal, pan gasket, or extension housing, you can normally repair the leak without removing the transmission.



Ford

Figure 66-10. Diagnose automatic transmission leaks properly. Note how the engine rear main seal leak and transmission front seal leak will drip out of same location.

Seal Replacement

To remove a rear transmission seal, use a seal removing tool or hammer and chisel to drive it out of the rear housing. To install the new seal, force it into place with a seal driving tool. Drive the seal into the housing squarely until seated. The front transmission seal is usually replaced in a similar manner. However, the transmission must be removed from the vehicle to service the front seal.

Automatic Transmission Adjustments

There are several adjustments that can be made with the transmission installed in the vehicle. The most common of these are band adjustment, shift linkage adjustment, and neutral safety switch adjustment.

Band Adjustment

Band adjustment is needed to set the correct amount of clearance between the band and the drum. If the clearance is too large, the band could slip. If it is too tight, the band could drag and burn up.

To adjust a transmission band, loosen the locknut and turn the adjustment screw on the side of the transmission case. Turning the screw in (clockwise) normally tightens the band.

Typically, a service manual will require you to tighten the adjustment screw to a specific torque value. After torquing, the screw is backed off (one turn, typically) to provide band-to-drum clearance. The locknut is then tightened to lock the setting.

Many modern automatic transmissions do not need band adjustment. They have improved friction material that is extremely resistant to wear. If a band slips in a late-model transmission, major repairs are normally needed.

Shift Linkage Adjustment

Exact procedures for adjusting the shift linkage on an automatic transmission vary. Generally, make sure

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the lever going into the valve body is synchronized with the shift selector in the driver's compartment. If the selector is set to drive, the lever on the transmission must also be centered in the drive mode.

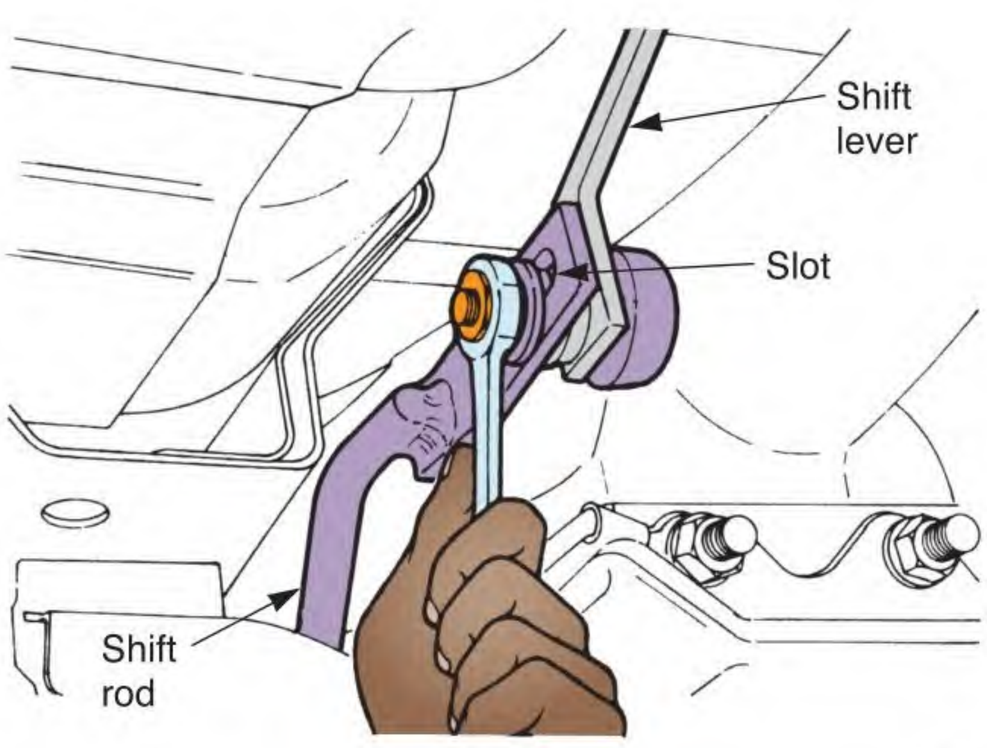
To adjust most shift linkages, a locknut is loosened on the shift rod. Then, the rod can be shortened or lengthened as needed, **Figure 66-11**.

Tech Tip

Most new cars are no longer using mechanical shift rods to move the manual spool valve. Manufacturers are transitioning to all-electronic, shift-by-wire systems. When you move the shift lever, joystick, or knob, you are sending a specific electrical signal to the transmission ECM. The transmission ECM can then energize or de-energize the correct shift solenoids to put the transmission into the desired gear.

Neutral Safety Switch Adjustment

Neutral safety switch adjustment is needed when the engine does not crank (turn over) with the shift selector in *Park*. You might have to wiggle the shifter or hold it forward before the engine cranks. Either the linkage has worn, upsetting the neutral switch setting, or the switch itself is faulty.



Chrysler

Figure 66-11. To adjust automatic transmission linkage, loosen the nut on the linkage rod. Position the driver's shift lever and the lever on the transmission in the same gear, usually park. Then tighten the nut and check.

Service Procedure

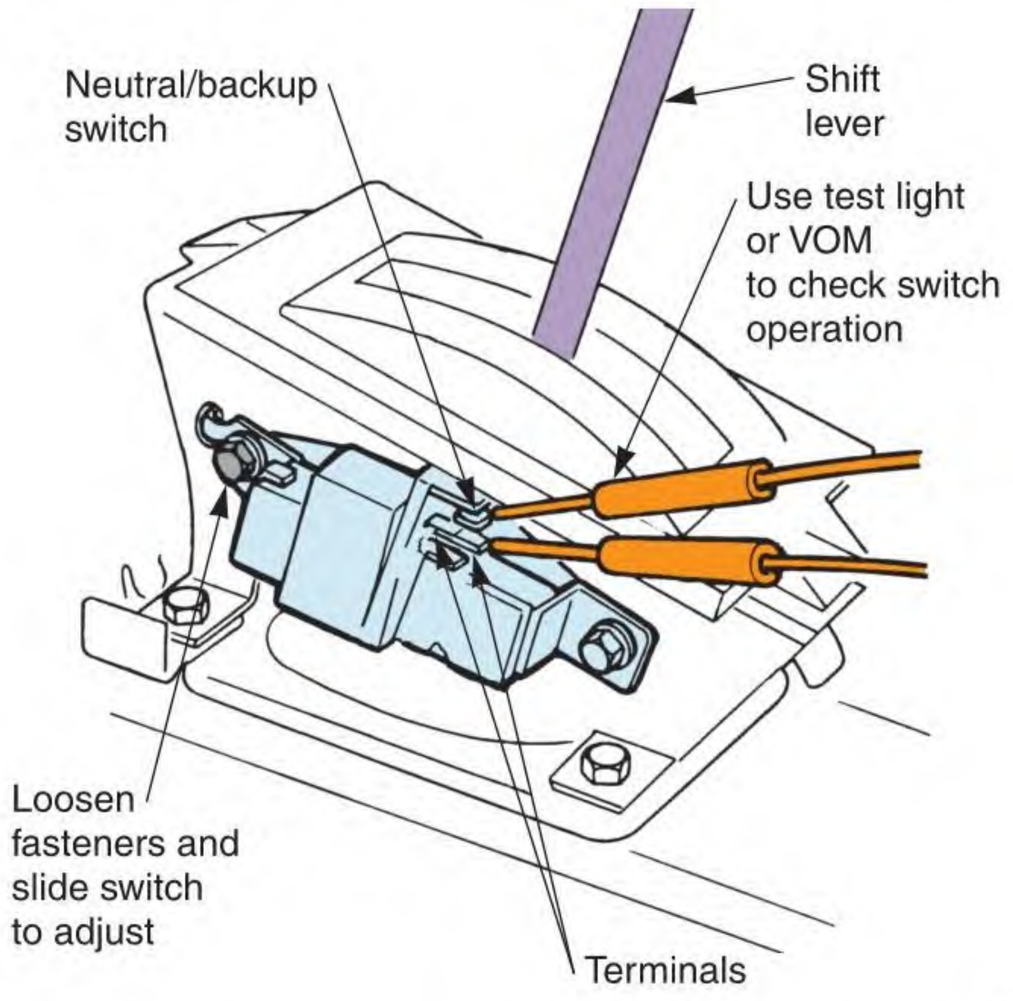
To adjust a neutral safety switch:

1. Loosen the small machine screws that hold the switch in place.
2. Position the shift selector fully into *Park*.
3. While holding the ignition key to start, slide the switch toward the *Park* position.
4. As soon as the engine begins to crank, release the key and hold the neutral safety switch in this position as you tighten it back down. Be careful not to move the switch while tightening.
5. Double-check your adjustment by starting the engine with the gear shift selector in *Park* and in *Neutral*.

Testing the Neutral Safety Switch

To check for a bad (open or shorted) neutral safety switch, connect an ohmmeter across the switch, as shown in **Figure 66-12**.

The ohmmeter should read zero ohms (closed) with the switch in *Park* and *Neutral*. It should read infinite resistance (open) in all other gear positions.



Honda

Figure 66-12. To adjust the neutral safety switch, loosen the fasteners. Turn key with transmission in park while sliding the switch forward. As soon as the engine cranks, lock down the switch. A test light or an ohmmeter can be used to check the switch while moving the shifter.

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If needed, loosen the switch mounting screws and slide the switch until the meter registers zero ohms with the shifter in *Park*. If the neutral safety switch still fails to indicate zero ohms when the shift lever is in park and neutral, replace the switch.

Backup Light Switch

Sometimes, the neutral safety switch also operates the backup lights. This side of the switch can also be checked with an ohmmeter or a test light. The backup light circuit should only have continuity (zero ohms) when the shift lever is in reverse.

Electronic Control System Service

Electronically controlled automatic transmissions can suffer conventional problems, as well as electronic problems. You must keep mechanical, hydraulic, and electrical malfunctions in mind when troubleshooting these transmissions.

A scan tool can be used to analyze late-model electronic transmissions. If the malfunction indicator light is glowing, connect the scan tool to the computer's data link connector. Check for stored trouble codes or abnormal electrical values. If the scan tool finds a circuit problem, you will need to perform specific tests to verify the exact trouble source.

To begin electronic diagnosis, mentally compare each component to its function. Try to think of which parts might be causing the trouble. For example, if the transmission does not shift from 1st gear to 2nd gear normally, consider the shift solenoid, vehicle speed sensor, MAP sensor, and throttle position sensor. All control the shift points of an electronically controlled automatic transmission.

A chart listing the function of major parts of an electronically controlled automatic transmission is given in **Figure 66-13**.

Most electronically controlled transmissions have a ***limp-in mode***, which allows the transmission to function if there is an electronic control system failure. If the TCM detects something wrong in the electronic control circuit (bad sensor, solenoids, wiring), it switches into a preprogrammed limp-in mode. In the limp-in mode, the transmission or transaxle may have only 2nd gear, *Reverse*, *Neutral*, and *Park*. However, it will work well enough to allow the vehicle to be driven to a repair facility.

Automatic transmission solenoids and sensors can be located on the side of the transmission case or on the valve body. If they are on the case, you can test and replace them without disassembly, **Figure 66-14**. If solenoids are located on the valve body, you must remove the pan to gain access to the shift solenoids, **Figure 66-15**.

For example, some modern automatic transmissions use a fluid temperature sensor. The ***fluid temperature sensor*** is used to compensate for changes in fluid viscosity to maintain normal shifting. Cold transmission fluid is thicker and affects transmission operation. The fluid temperature sensor and TCM or PCM work together to allow for good cold transmission operation.

If the transmission acts up when cold or hot only, suspect the fluid temperature sensor. If tests indicate a bad sensor, replace it. This same logic applies to other sensors and solenoids, as well. Refer to **Figure 66-16**.

Major Transmission Service

If tests point to major transmission problems, the transmission may need to be removed, repaired, and reinstalled. Transmission designs vary greatly, so transmission repair is normally performed by specialized technicians. However, a general technician may be required to remove and replace automatic transmissions.

Automatic Transmission Removal

When your tests indicate major internal problems, the automatic transmission must be removed from the car. Automatic transmission removal is similar to manual transmission removal. See **Figure 66-17**. The service manual will contain removal instructions for the specific transmission.



Service Procedure

To remove an automatic transmission:

1. Disconnect the 12-volt battery or pull the HV battery plug.
2. Raise and secure the vehicle on a four-post lift to gain access to the underside of the transmission.
3. Remove the drive shaft.
4. Remove all wires, oil lines, and cables between the transmission and the vehicle.
5. Disconnect the rear transmission mount and remove any parts that obstruct removal (front of exhaust system, for example).

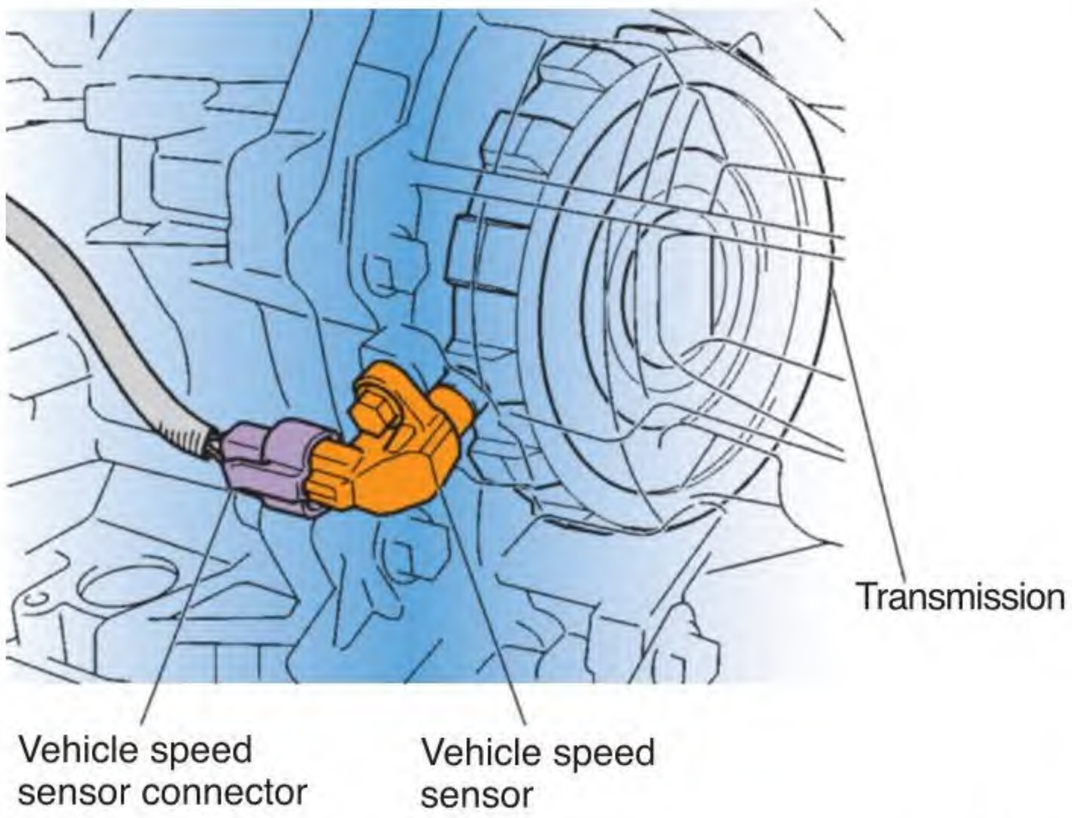
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Electronically Controlled Automatic Transmission	
Components	**Functions**
Kickdown switch	Detects the accelerator pedal position depressed beyond full throttle valve opening.
Engine speed sensor	Detects the engine speed.
Neutral safety switch	Detects the shift lever position.
OD direct clutch speed sensor	Detects OD input shaft speeds from 1st through 3rd gears.
No. 1 and No. 2 solenoid valves	Control the hydraulic pressure applied to each shift valve, and control gear shift position and timing.
Cruise control ECM	Prohibits vehicle running in OD gear and lockup control when vehicle speed drops lower than a predetermined level of the auto drive set speed.
No. 3 solenoid valve	Controls the hydraulic pressure applied to the lockup clutch and controls lockup timing.
No. 4 solenoid valve	Controls hydraulic pressure acting on accumulator back chamber during gear shifting to smoothly engage clutches and brakes.
Stoplight switch	Detects the brake pedal depression.
No. 1 and No. 2 speed sensors	Detect the vehicle speed. Ordinarily, ECT control uses signals from the No. 2 speed sensor, and the No. 1 speed sensor is used as a backup.
Pattern select switch	Selects the shift and lockup timings by the Power mode or the Normal mode.
OD OFF indicator light	Blinks and warns the driver, while the OD main switch is pushed in, when the electronic control circuit is malfunctioning.
OD switch	Prevents up shift to the OD gear if the OD switch is off.
Engine and transmission ECM	Controls the engine and transmission actuators based on signals from each sensor.
Throttle position sensor	Detects the throttle valve opening angle.
Water temperature sensor	Detects the engine coolant temperature.

Lexus

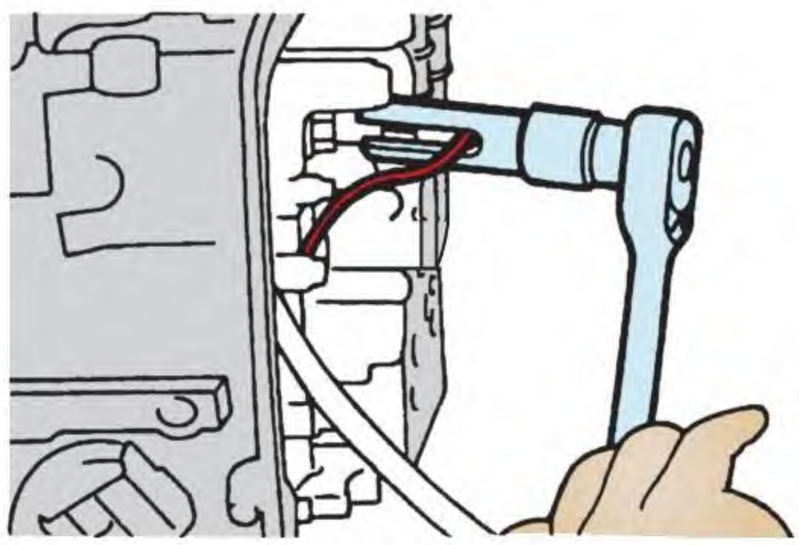
Figure 66-13. This chart shows components and their functions. If you understand what components are supposed to do, you will be able to analyze them when they fail to work.

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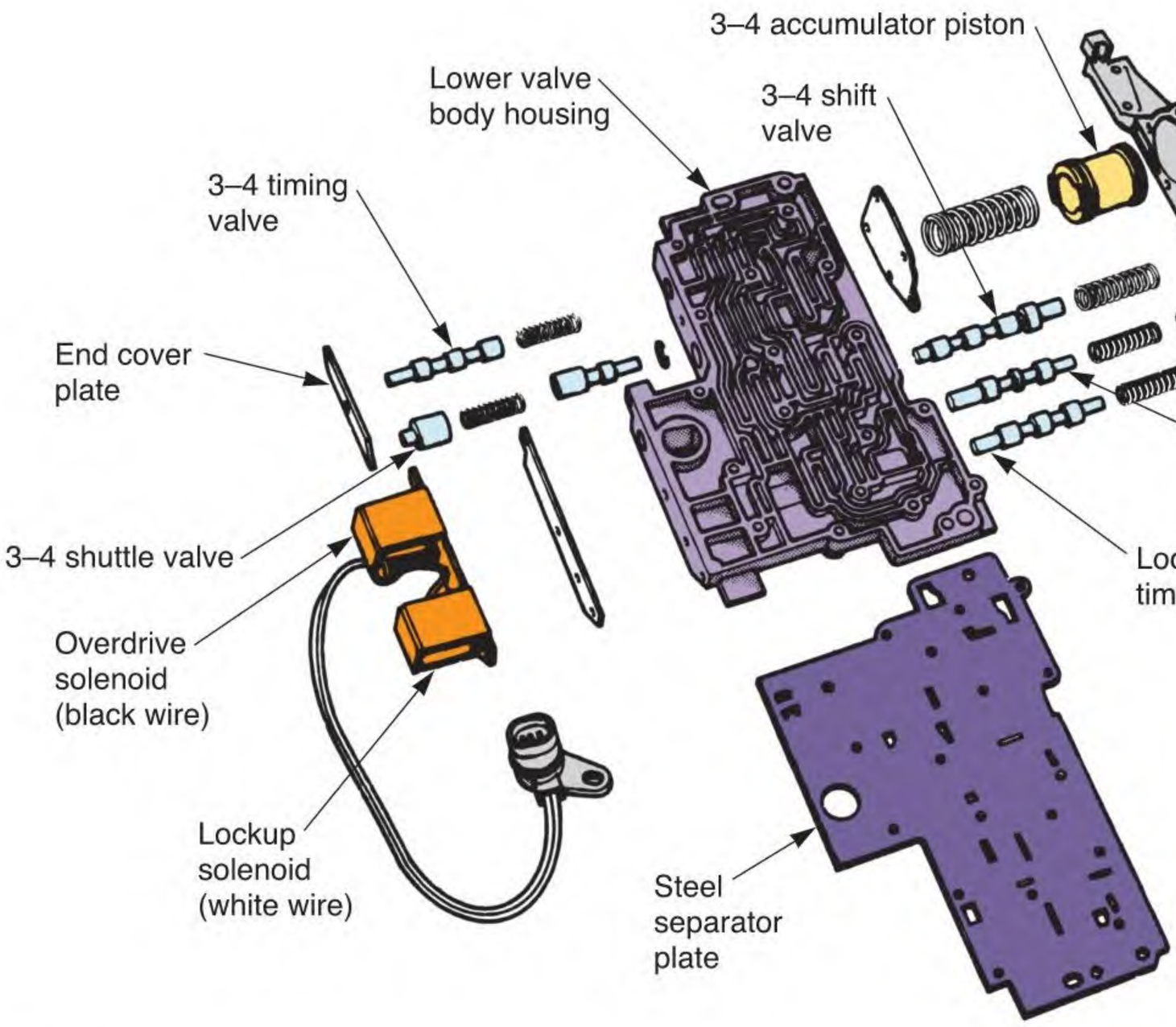
Toyota

Figure 66-14. Some electronic parts, like this vehicle speed sensor, can be serviced without transmission removal and disassembly.



Mazda

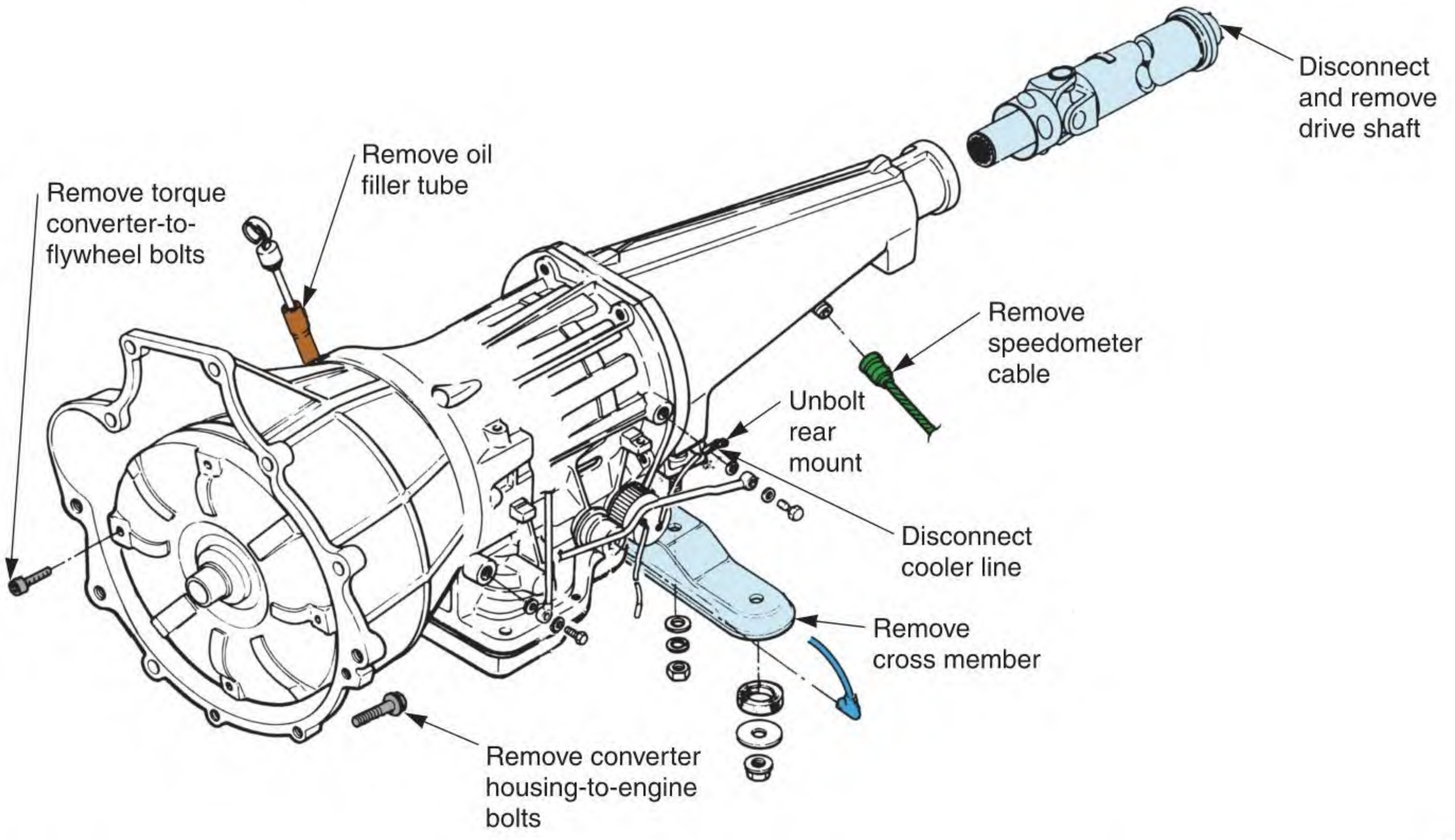
Figure 67-16. A special sensor socket is needed to remove some transmission sensors. Wires can fit through the side of this socket.



Chrysler

Figure 66-15. This transmission has overdrive and lockup solenoids mounted on the valve body. You would have to remove the pan to replace them.

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Mazda

Figure 66-17. Disconnect parts before removing an automatic transmission. The procedure is similar to the removal of a manual transmission.

6. Remove the transmission bell housing bolts that hold the transmission to the engine. The bolts along the top of the bell housing may be difficult to find and reach. A long extension with a swivel socket sometimes works well.
7. Remove the rock shield to gain access to the torque converter fasteners.
8. Remove the fasteners so the torque converter is free from the flywheel or flexplate. You can rotate the engine with a socket and breaker bar on the front crankshaft bolt.
9. Position a transmission jack under the pan and secure the transmission to the jack with holding chains or use the clamping device on the jack.
10. Raise the jack to take the weight off the rear mount.
11. Remove the rear cross member. You may want to place a screw jack under the rear of the engine to support its weight.
12. Slide the transmission straight back and lower it from the vehicle, **Figure 66-18**.

Automatic Transmission Rebuild

A general technician can remove and install a transmission, but the damaged transmission must be sent to a specialized transmission shop for repair. Normally, the transmission is rebuilt. Specialized technicians perform the work, **Figure 66-19**.

When rebuilding an automatic transmission, the technician must refer to the service manual for the necessary details and specifications.

After a transmission is rebuilt, it is sometimes tested using a transmission dynamometer, **Figure 66-20**. After testing, the transmission can be reinstalled.

Automatic Transmission Installation

Before installing an automatic transmission, make sure the torque converter is fully in place. Quite often, the converter will catch and can only be partially installed into the front pump. If you force the transmission against the engine with the mounting bolts, severe transmission front pump damage will result, **Figure 66-21**.

The transmission must be on the same plane as the engine. Raise or lower the transmission jack until the transmission centerline and crankshaft centerline appear aligned. Then, push the transmission into the

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OTC

Figure 66-18. A transmission jack will safely hold and move a heavy automatic transmission.



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Figure 66-19. A specialized technician rebuilds a transmission.

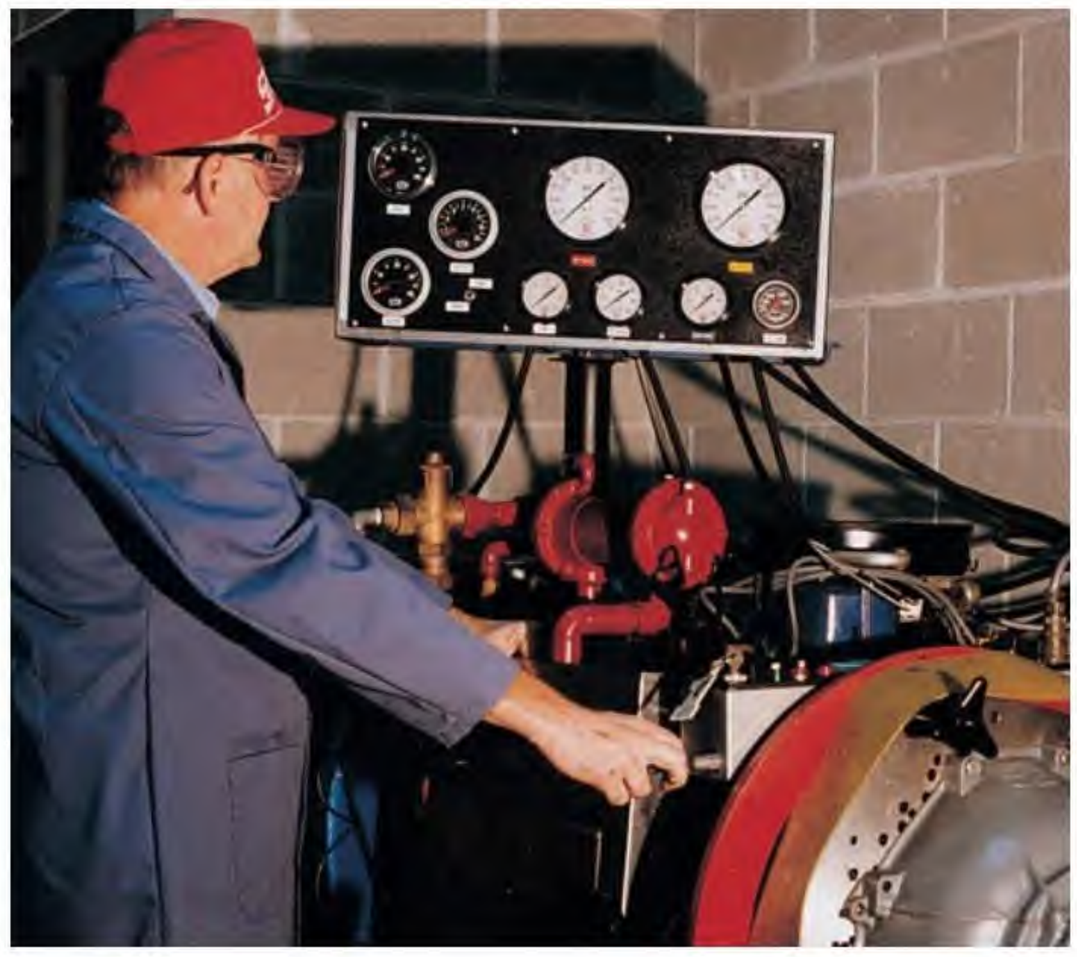
engine while wiggling the tailshaft. Make sure the torque converter studs fit through the flywheel holes.

When the transmission bell housing is touching the engine block, you can safely install the bell housing bolts and other parts.

Diagnostic Case Study

Concern: Mr. White brings his 2003 Hyundai to the shop. He complains that his automatic transmission will not shift until the engine reaches a very high speed.

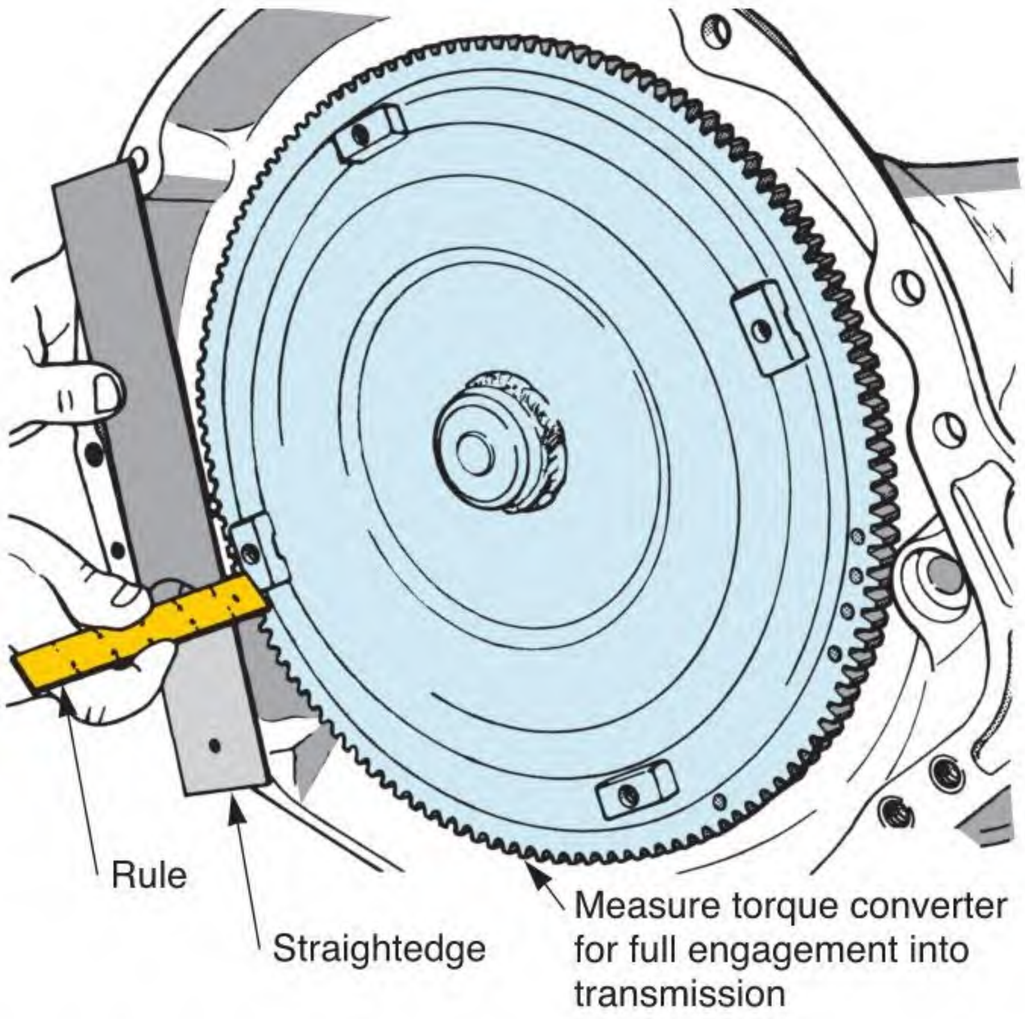
Cause: Duff performs preliminary checks. The transmission fluid level and condition are normal. No vacuum hoses are disconnected. Duff test-drives the vehicle and discovers that the transmission does not shift out of first gear at the specified shift point.



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Figure 66-20. Specialty transmission shops often have a dynamometer for testing a transmission before it is installed in a vehicle.

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Chrysler

Figure 66-21. A common, damaging mistake is to not have torque converter fully installed. Usually, the converter must slide over internal parts twice to be fully inserted. If not all the way in, the front pump and the converter can be damaged when the bell housing bolts are tightened.

Duff turns the repair over to the shop's automatic transmission specialist. The technician knows that this particular transmission uses various sensors to determine shift points. His scan tool shows a trouble code for the 1-2 shift solenoid. He checks all electrical connections to the transmissions before removing the pan for solenoid replacement.

Correction: The 1-2 shift solenoid is replaced. A new gasket and filter is installed before torquing the transmission pan to specs. The transmission fluid is changed as an added precaution. The vehicle is taken for a test-drive. The transmission shifts normally again. The vehicle is released to the customer, who is happy the transmission did not have to be rebuilt.

Summary

- Problems with an automatic transmission can affect, or appear to affect, the operation of other vehicle systems.
- Common problems related to an automatic transmission include transmission slippage, incorrect shift points, mushy or harsh shifts, and abnormal noises.
- Before road testing the car, there are several checks you should perform, including fluid level and condition, linkage operation, and engine condition.
- During the road test, check the general operation of the transmission (shift points, noises, etc.) on a route with a smooth road and little traffic.
- Three main shop tests include the stall test, pressure test, and air test.
- Electrical tests on an automatic transmission involve checking sensors, actuators, and wiring for basic troubles.
- The transmission fluid level should be between Add and Full on the dipstick when the engine is running at full operating temperature.
- Automatic transmission fluid leaks commonly occur at the rear seal, front seal, oil pan gasket, extension housing gasket, and shift lever shaft seal.
- The most common adjustments that can be made with the transmission installed in the vehicle are a band adjustment, shift linkage adjustment, and neutral safety switch adjustment.
- Consider mechanical, hydraulic, and electrical malfunctions when troubleshooting electronically controlled automatic transmissions.
- The manufacturer's service manual gives accurate instructions for transmission trouble shooting, removal, disassembly, inspection, rebuilding, and installation.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

air test
automatic transmission slippage
band adjustment
burned transmission fluid
electrical tests
fluid temperature sensor
harsh shifts
high fluid level
hydraulic circuit diagrams
incorrect shift points
limp-in mode
low fluid level
milky transmission fluid
mushy shifts
neutral safety switch adjustment
stall test
transmission fluid varnish

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Activities

1. Demonstrate the proper method of checking transmission fluid level.
2. Check and diagnose the condition of the transmission in a shop-owned or customer vehicle.
3. Demonstrate the procedure for band adjustment.

Review Questions

Answer the following questions using the information provided in this chapter.

1. Which of the following can cause automatic transmission slippage?
   (A) Low oil level.
   (B) Worn clutches or bands.
   (C) Valve body problems.
   (D) All of the above.
2. What is normally the cause of burned transmission oil?
3. Engine vacuum leaks can affect automatic transmission operation. True or False?
4. What is a stall test?
5. _____ tests are used to determine whether fluid pressure in the various circuits is normal.
6. A(n) _____ shows how the fluid passages inside an automatic transmission are connected to each component.
7. List ten steps you should carefully follow when changing the oil and filter on an automatic transmission.
8. Where do automatic transmission fluid leaks commonly occur?
9. Summarize the general adjustment of an automatic transmission band.
10. A car fails to crank (starting motor operation) when in *Park*. It will only crank when the shift lever is in *Neutral*. Technician A says that the neutral safety switch must be bad and should be replaced. Technician B says that the neutral safety switch could require adjustment. Who is correct?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

ASE-Type Questions

1. An automobile is brought into the shop with an automatic transmission "slippage" problem. Technician A checks the transmission's fluid level. Technician B inspects the condition of the transmission's valve body first. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. A car's automatic transmission shifts too soon. Technician A looks for a faulty servo. Technician B suspects a faulty MAP sensor. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. An automatic transmission is producing an abnormal sound in all gears. Technician A checks the transmission's fluid pump for problems. Technician B inspects the transmission's reverse shift fork. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. An automatic transmission has shifting problems. Technician A says low fluid level can produce this problem. Technician B says high fluid level can produce this problem. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. An automatic transmission has burned fluid and a slippage problem. Technician A believes serious transmission damage is indicated. Technician B thinks this condition requires simple band adjustment. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. An automatic transmission's fluid has a "milky" color. Technician A checks to see if engine oil is leaking into the transmission. Technician B checks to see if engine coolant is leaking into one of the transmission lines. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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7. A stall test is being performed on an automatic transmission. Technician A places the transmission in high gear during this test. Technician B places the transmission in neutral during this test. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. Pressure tests are being performed on an automatic transmission. Technician A inserts the pressure gauge in the ports located on the outside of the torque converter to perform these tests. Technician B inserts the pressure gauge in the ports located on the outside of the transmission case to perform these tests. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. The check valves in an automatic transmission are possibly malfunctioning. Technician A uses an ohmmeter to check the operation of these valves. Technician B performs an air test to check the operation of these valves. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. An automatic transmission's fluid level needs to be checked. Technician A checks the transmission's fluid level at operating temperature with the engine running in *Neutral*. Technician B checks the transmission's fluid level when the fluid is cool with the engine off and in *Neutral*. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

Automatic Transmission and Transaxle Diagnosis

Condition	Possible Causes	Correction
Fluid leaks.	1. Defective gaskets or seals. 2. Loose bolts. 3. Porous or cracked case. 4. Leaking vacuum modulator diaphragm. 5. Overfilled transmission.	1. Replace defective parts. 2. Tighten bolts. 3. Repair or replace case. 4. Replace vacuum modulator. 5. Reduce fluid level.
Slipping in gear.	1. Low fluid level. 2. Clogged filter. 3. Stuck valve. 4. Burned holding members. 5. Misadjusted bands (when used). 6. Internal leaks.	1. Add fluid and check for leaks. 2. Replace filter. 3. Remove valve body and free sticky valves. 4. Disassemble transmission, replace burned holding members. 5. Adjust bands, recheck operation. 6. Disassemble transmission and correct leaks.
No upshifts or downshifts.	1. Misadjusted linkage. 2. Stuck governor. 3. Stuck valves. 4. Defective or disconnected vacuum modulator (when used). 5. Internal leaks.	1. Readjust linkage. 2. Remove and free sticky governor or replace. 3. Remove valve body and free sticky valves. 4. Replace modulator, check lines. 5. Disassemble transmission and correct leaks.
Noises.	1. Clogged filter. 2. Pump or torque converter defective. 3. Defective gears.	1. Replace filter. 2. Replace pump or torque converter. 3. Replace gears.

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Chapter 67
Drive Shaft and Transfer Case Technology

After studying this chapter, you will be able to:

- Identify and describe the parts of a modern drive shaft assembly.
- Explain the functions of a drive shaft.
- Describe the different types of universal joints.
- List the different types of drivelines.
- Explain the basic operation of a transfer case.
- Correctly answer ASE certification test questions that require a knowledge of drive shafts and transfer cases.

The term ***driveline*** generally refers to the parts that transfer power from a vehicle's transmission to its drive wheels. Front-engine, rear-wheel-drive vehicles, such as large luxury cars, pickup trucks, and full-size vans, have a driveline that contains a drive shaft. The *drive shaft* is a long shaft that transfers power from the transmission to the rear axle assembly. The drive shaft has universal joints at its ends. Both gas-engine and hybrid cars with rear- or all-wheel drive require a drive shaft to connect the manual or auto transmission with the differential and rear axle assembly.

Front-wheel-drive and rear-engine or mid-engine vehicles do not use a transmission and a drive shaft. Instead, they use a ***transaxle*** (transmission-differential assembly) and two drive axle assemblies (swing axles). The short axle assemblies extend directly out of the transaxle to power the drive wheels.

Drive Shaft Assembly

A ***drive shaft assembly*** typically consists of the following components:

- ***Slip yoke***—The slip yoke connects the transmission output shaft to the front universal joint.
- ***Front universal joint***—The front universal joint is a swivel connection that fastens the slip yoke to the drive shaft.
- ***Drive shaft***—The drive shaft is a hollow metal tube that transfers turning power from the front universal joint to the rear universal joint.
- ***Rear universal joint***—The rear universal joint is a flex joint connecting the drive shaft to the rear yoke.
- ***Rear yoke***—The rear yoke holds the rear universal joint and transfers torque to gears in the rear axle assembly and differential.

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This drive shaft design is the most common type used on front-engine, rear-wheel-drive vehicles. See **Figure 67-1**. A few variations are sometimes used to satisfy special applications or to improve the smoothness of power transfer. These are discussed later in the chapter.

Functions of Drive Shaft Assembly

The drive shaft assembly has several important functions:

- Sends turning power from the transmission to the rear axle assembly.
- Flexes and allows vertical (up and down) movement of the rear axle assembly.
- Provides a sliding action to adjust for changes in driveline length.
- Provides smooth power transfer.

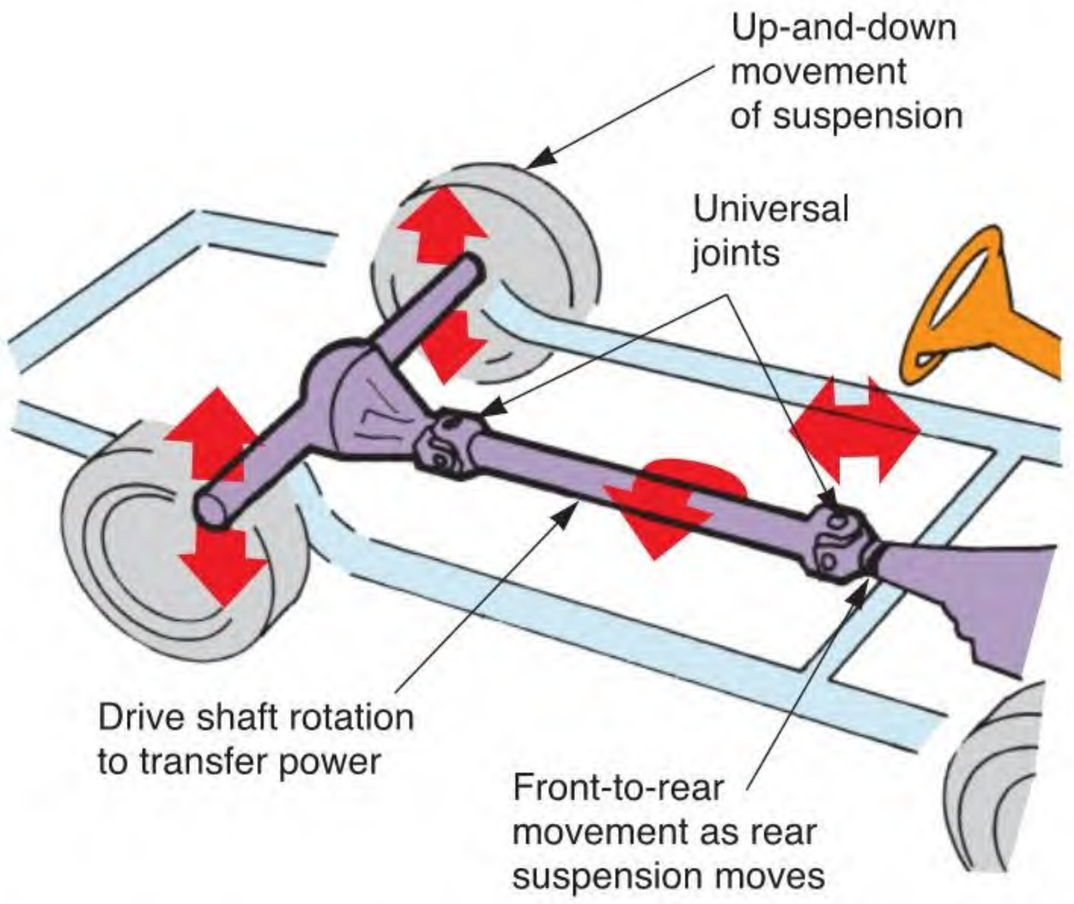
Drive Shaft Operation

When the vehicle is moving, the transmission output shaft turns the slip yoke. The slip yoke then turns the front universal joint, drive shaft, rear universal joint, and rear yoke on the differential. The differential contains gears that transfer power to the rear drive axles. The axles rotate the wheels.

Driveline Flex

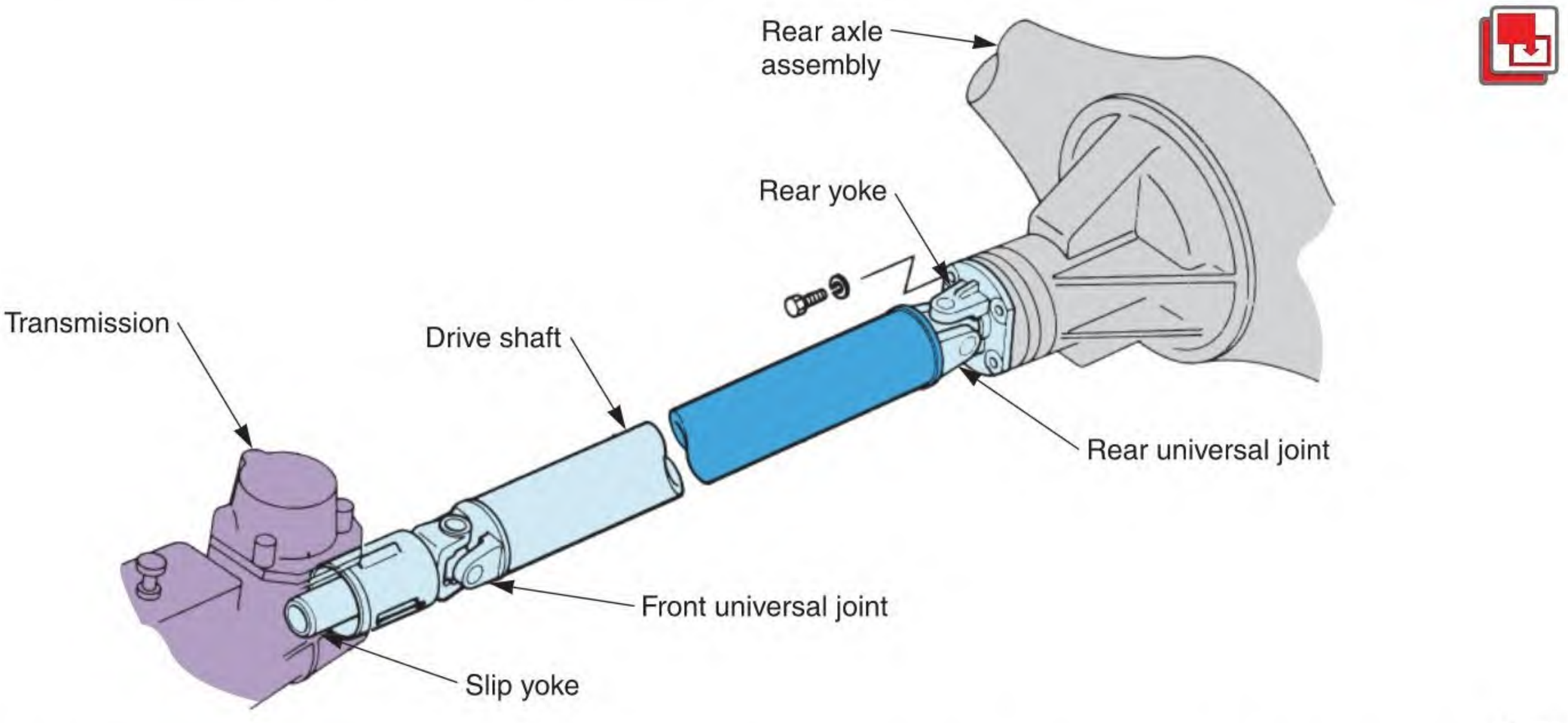
When the tires strike a bump in the road, the rear suspension moves upward and the springs are compressed. When nonindependent rear suspension is used, this pushes the rear axle upward in relation to the body.

The ***universal joints*** let the driveline flex as the rear axle moves up and down. This protects the drive shaft from damage that could be caused by the movement. Refer to **Figure 67-2**.



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Figure 67-2. The drive shaft universal joints allow the driveline to flex as the rear axle moves up and down over bumps in the road. Most types also allow for length changes to allow suspension action.



Mazda

Figure 67-1. This drive shaft assembly connects the transmission output shaft with the rear axle assembly. Note the major parts.

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Changes in Driveline Length

The movement of the rear axle assembly also changes the distance between the rear axle and the transmission. The slip yoke allows for this change of driveline length.

Slip Yoke

The slip yoke, or ***slip joint***, is splined to the transmission output shaft. It allows for changes in driveline length by sliding in and out of the transmission.

Cutaway views of a slip yoke are shown in **Figure 67-3**. Note how the inside of the slip joint has splines that fit over the transmission output shaft splines. This causes the slip joint and the output shaft to rotate together. It also permits the yoke to slide on the splines.

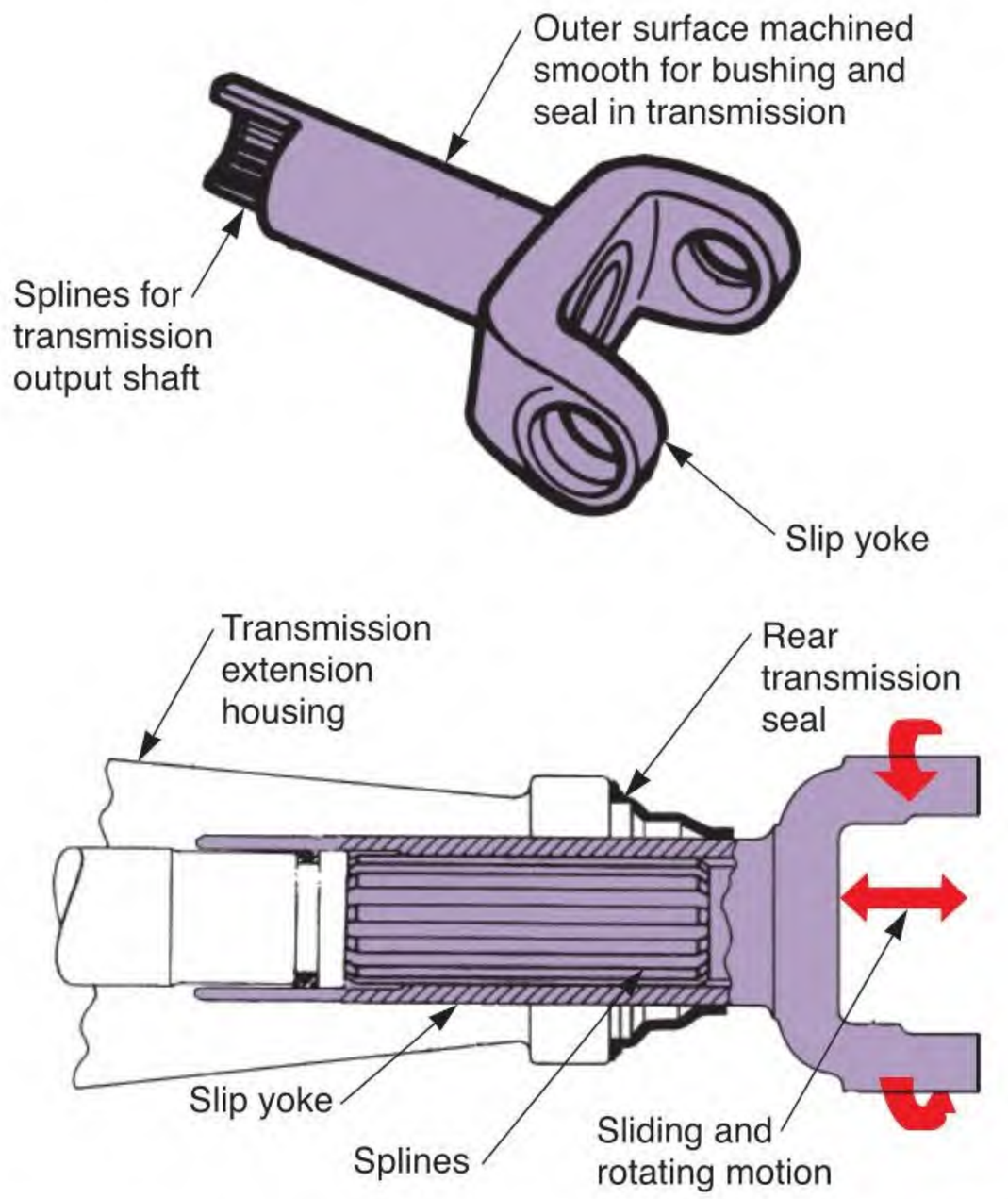
The outer diameter of the yoke is machined smooth. This smooth surface provides a bearing surface for the bushing and oil seal in the transmission. The ***extension housing bushing*** supports the slip yoke as it spins in the transmission.

The ***transmission rear seal*** rides on the slip yoke and prevents fluid leakage from the rear of the transmission. The seal also keeps road dirt out of the transmission and off the slip yoke.

Normally, the outside of the slip joint is lubricated by the transmission oil. Transmission oil prevents bushing, yoke, and seal wear. Some yokes, however, require special heavy grease on their splines. The splines are sealed from the transmission lubricant to keep the oil or fluid from washing the heavy grease off the splines.

Rear Yoke

The rear yoke is the yoke bolted to the outer end of the pinion (drive) gear on the rear axle assembly. It transfers torque to the gears in the rear axle assembly. The rear universal joint is held by this yoke.



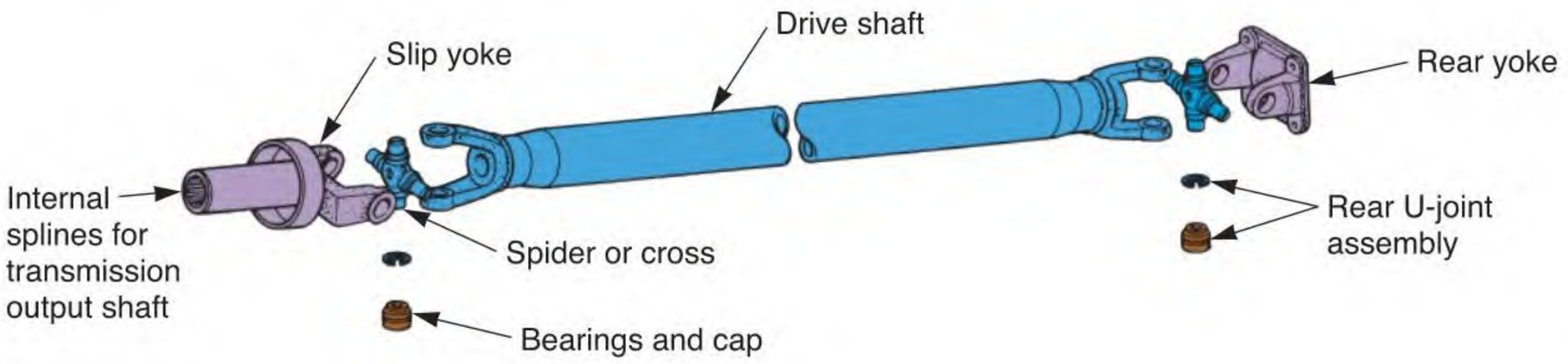
Ford

Figure 67-3. The slip yoke is splined to the transmission output shaft and fits inside the transmission extension housing. The rear transmission seal contacts the slip yoke. The yoke rides on a bushing in the extension housing. It rotates with the output shaft but is free to slide in and out of the transmission.

Drive Shaft

The drive shaft, or ***propeller shaft***, is commonly a hollow steel tube with permanent yokes welded on each end. See **Figure 67-4**.

The tubular design makes the drive shaft very strong and light. Since the drive shaft spins much faster than the wheels and tires, it must be straight and perfectly balanced.



Toyota

Figure 67-4. A typical drive shaft assembly. Note the basic components.

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As mentioned, most front-engine, rear-wheel-drive vehicles use a single, one-piece drive shaft. However, a few passenger cars and some pickup trucks have a two-piece drive shaft. This cuts down the length of each shaft, reducing driveline vibration.

Tech Tip

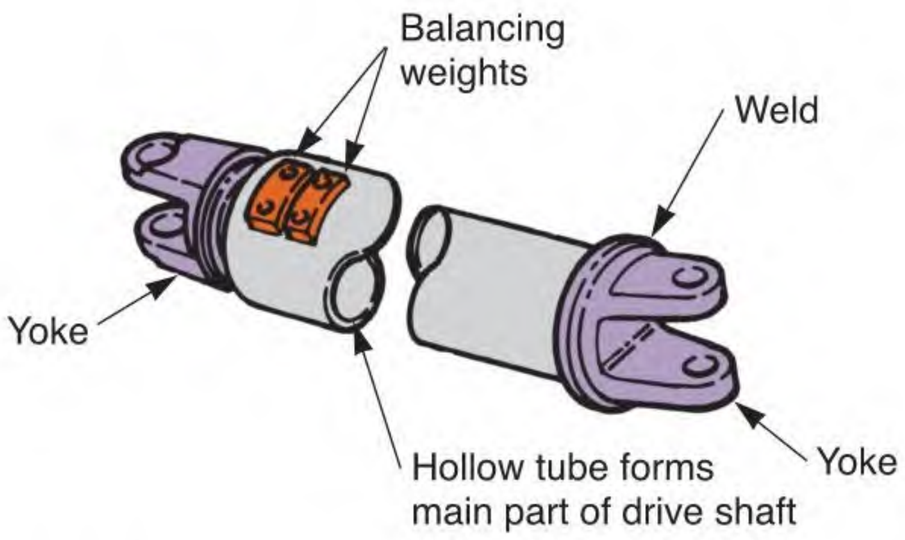
Some drive shafts are designed for increased performance. Lightweight drive shafts are made of thin-wall aluminum with longitudinally aligned graphite fibers for added strength.

Drive Shaft Balance

In high gears, the drive shaft spins at the same speed as the engine. Therefore, the drive shaft must be perfectly balanced, with its weight evenly distributed around its centerline. If the drive shaft is not balanced, the shaft could vibrate violently.

Drive shaft balancing weights are frequently welded to the shaft to reduce vibration. The drive shaft is spun on a balancing machine at the factory. If needed, small metal weights are attached to the light side of the shaft. This counteracts the heavy side to smooth operation. See **Figure 67-5**.

Sometimes, the drive shaft is equipped with a ***drive shaft vibration damper***. This is a large, ring-shaped weight mounted on rubber. The vibration damper helps keep the shaft spinning smoothly by absorbing torsional (twisting) vibration. Refer to **Figure 67-13**.



Ford

Figure 67-5. A drive shaft is normally a hollow tube with yokes welded to each end. Balancing weights are welded to the shaft to prevent vibration.

Universal Joints

A universal joint, or ***U-joint***, is a swivel connection capable of transferring a turning force between shafts at an angle to one another. A simple universal joint is made of two Y-shaped yokes (knuckles) that are connected by a cross (spider). Bearings on each end of the cross allow the yokes to swing into various angles while turning. See **Figure 67-6**.

Today, most drive shafts use two universal joints. However, extra universal joints are sometimes needed in very long drive shafts.

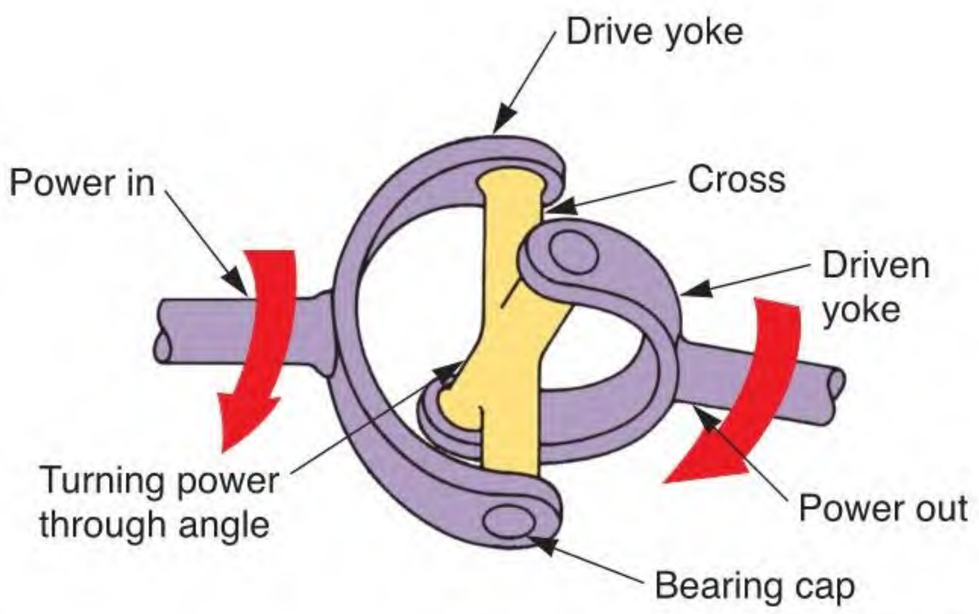
There are three common types of automotive drive shaft universal joints used on rear-wheel-drive vehicles: cross-and-roller joints (cardan joints), ball-and-trunnion joints, and constant velocity joints (double-cardan joints). Look at **Figure 67-7**.

Cross-and-Roller Universal Joint

The ***cross-and-roller joint***, also called a ***cardan universal joint***, is the most common type of drive shaft universal joint. It consists of four bearing caps, four needle roller bearings, a cross, grease seals, grease retainers, and snap rings. See **Figure 67-8**.

The bearing caps are held stationary in the drive shaft yokes. Roller bearings fit between the caps and cross to reduce friction. The cross is free to rotate inside the caps and yokes.

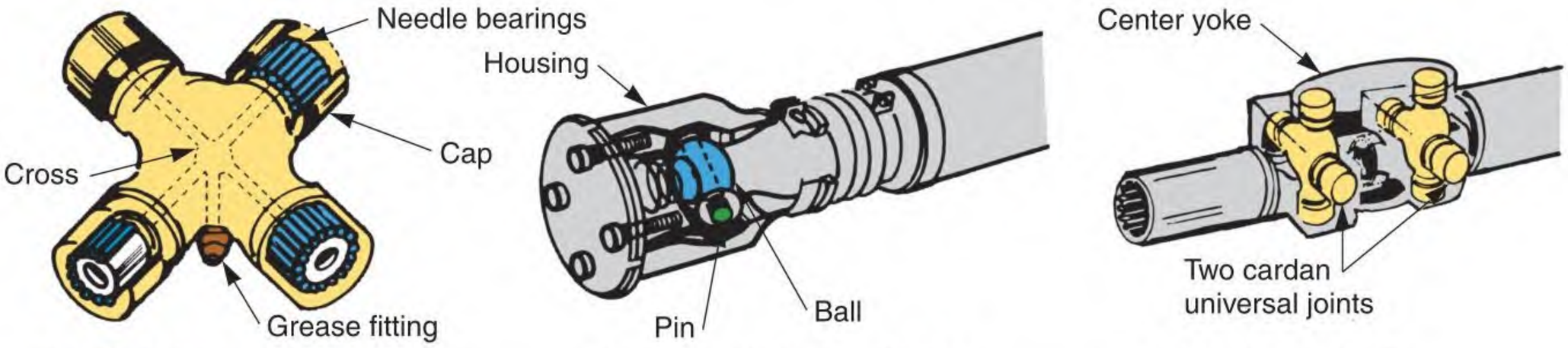
Snap rings usually fit into grooves cut in the caps or the yoke bores. There are several other methods of securing the bearing caps in the yokes. Sometimes, bearing covers, U-bolts, or injected plastic rings keep the caps and rollers from flying out of the spinning drive shaft assembly. See **Figure 67-9**.



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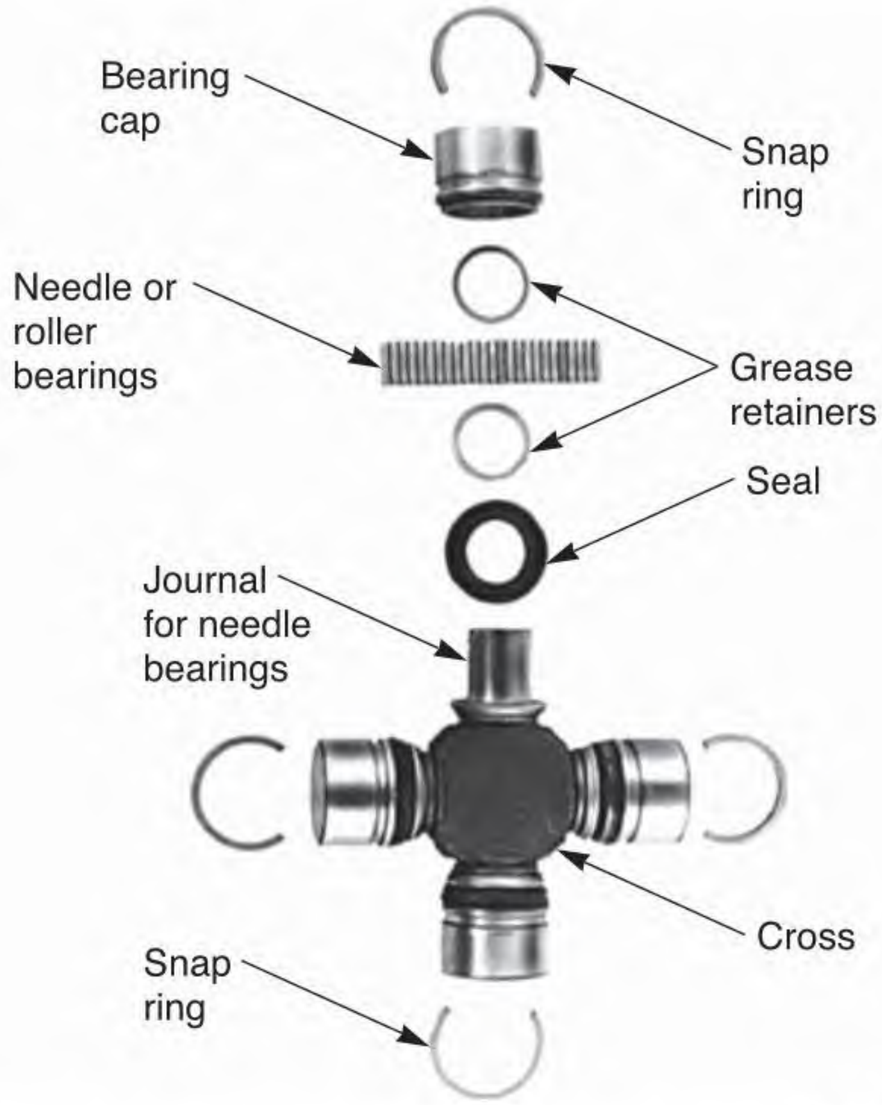
Figure 67-6. A universal joint will swivel to allow for changes in transmission-to-differential alignment. Two yokes are connected to a central cross. Needle bearings fit between the yokes and the cross. Each yoke can be swiveled in relation to the other.

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Figure 67-7. Three basic types of universal joints are used in drive shafts going to rear-axle assemblies. Other types are used in front drive axles.



General Motors

Figure 67-8. A partially disassembled view of a cross-and-roller universal joint. The needle bearings are packed with grease. The snap rings hold the bearing caps in their yokes. A rubber cup (boot) keeps grease inside the joint.

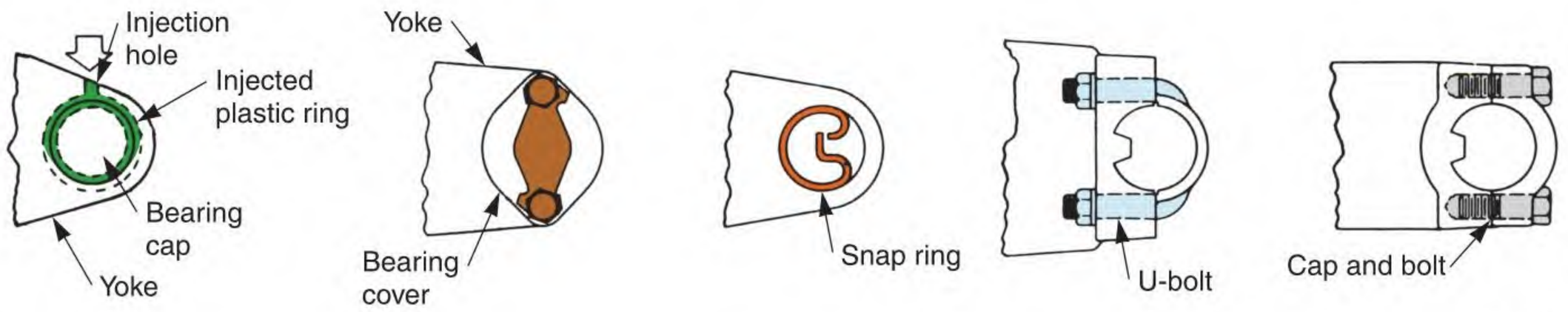
Figure 67-10 shows an exploded view of a drive shaft with cross-and-roller universal joints. Note how the universal joint components fit together.

Constant Velocity Universal Joint

When a cross-and-roller universal joint is driven at a sharp angle, its output speed tends to accelerate and decelerate during each revolution. This can set up tiny torque fluctuations and torsional vibrations. One-piece drive shaft vibration problems can be reduced by using constant velocity universal joints.

A ***constant velocity universal joint*** normally has two cross-and-roller joints connected by a centering socket and center yoke. Another name for this type of joint is the ***double-cardan joint***. See **Figure 67-11**.

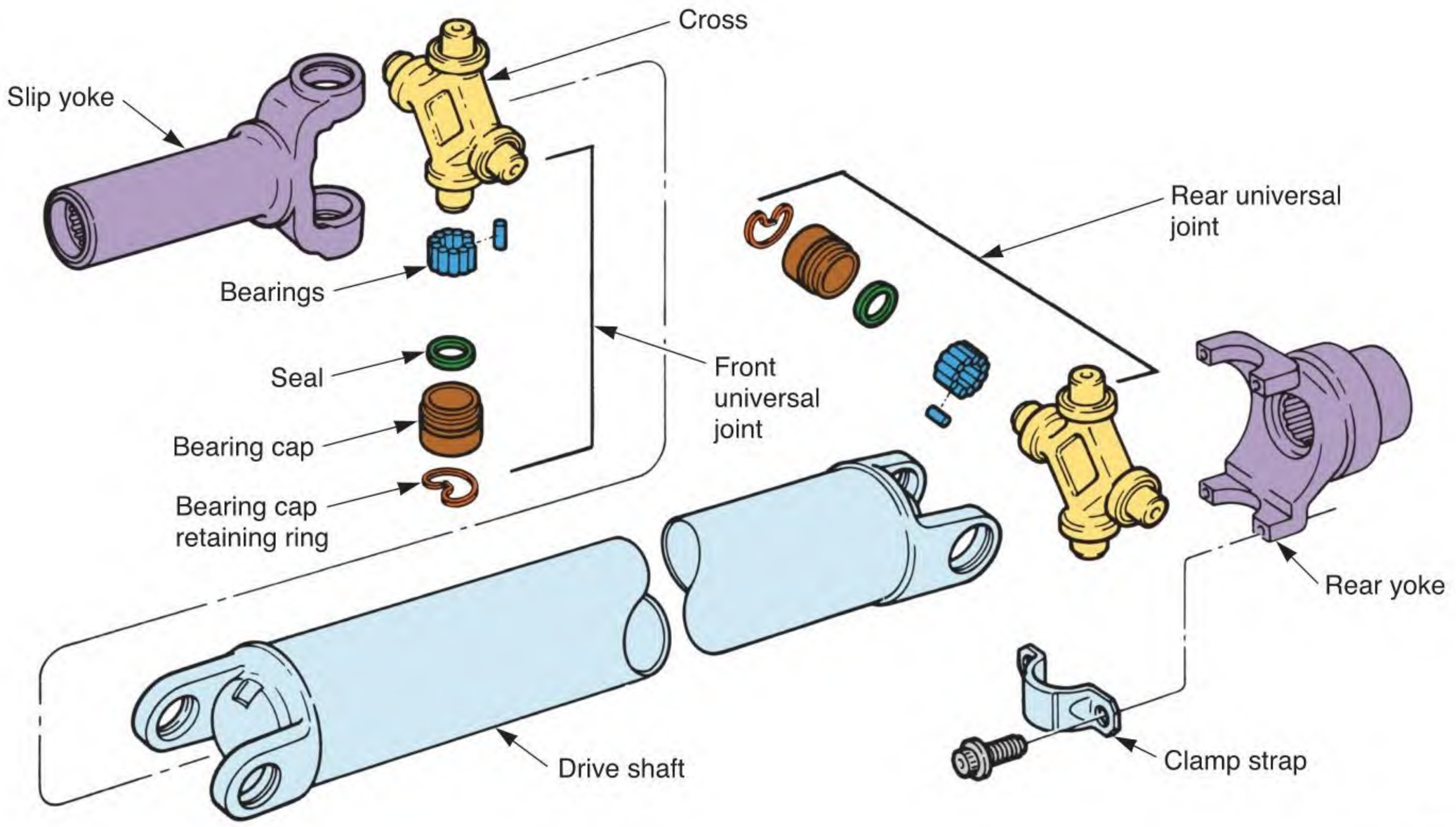
With two universal joints operating together on one end of the drive shaft, the output shaft speed fluctuations are counteracted. The action of the second joint cancels the shaft speed changes produced by the first joint. Some drive shafts use only one constant velocity universal joint. Others use more than one, **Figure 67-12**.



Dana Corp.

Figure 67-9. Several methods can be used to hold universal joint caps in the yoke.

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Chrysler

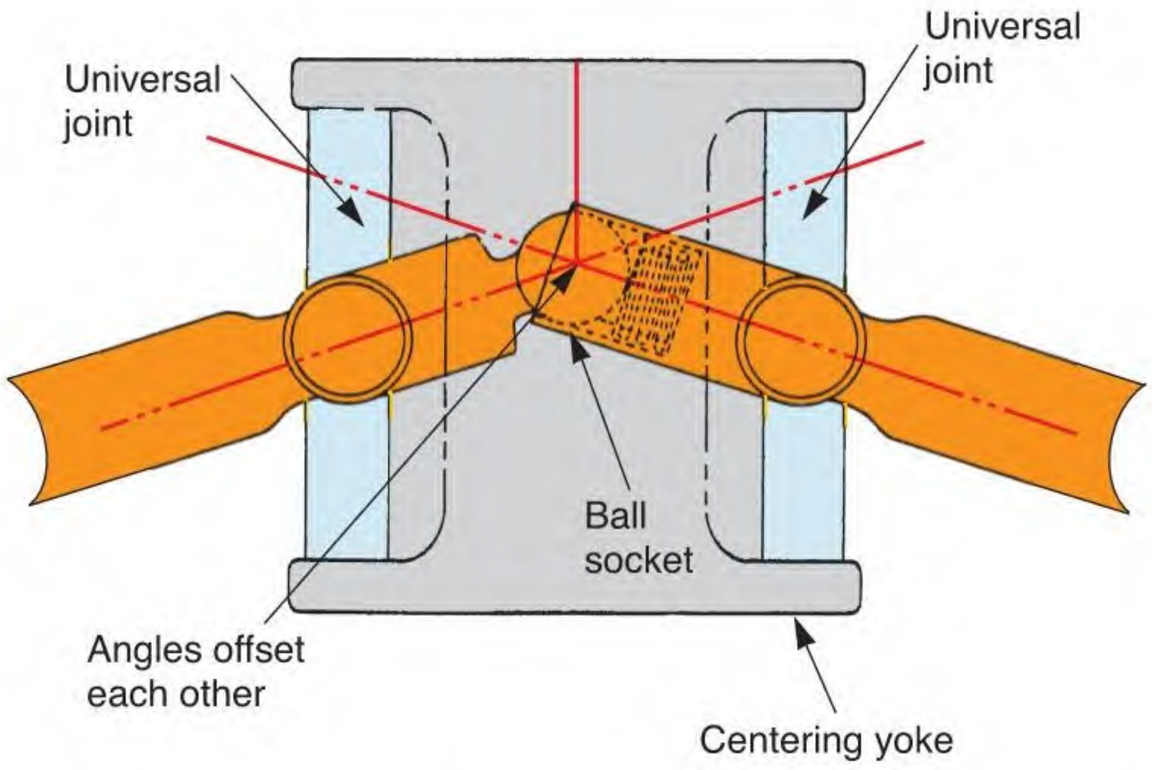
Figure 67-10. An exploded view of a drive shaft with cross-and-roller universal joints. Note how the parts fit together.

Ball-and-Trunnion Universal Joint

The ***ball-and-trunnion joint*** is another joint designed for constant velocity. It not only eliminates shaft speed fluctuations, but can also allow for slight length changes in the driveline. However, the ball-and-trunnion joint is seldom used.

Center Support Bearing

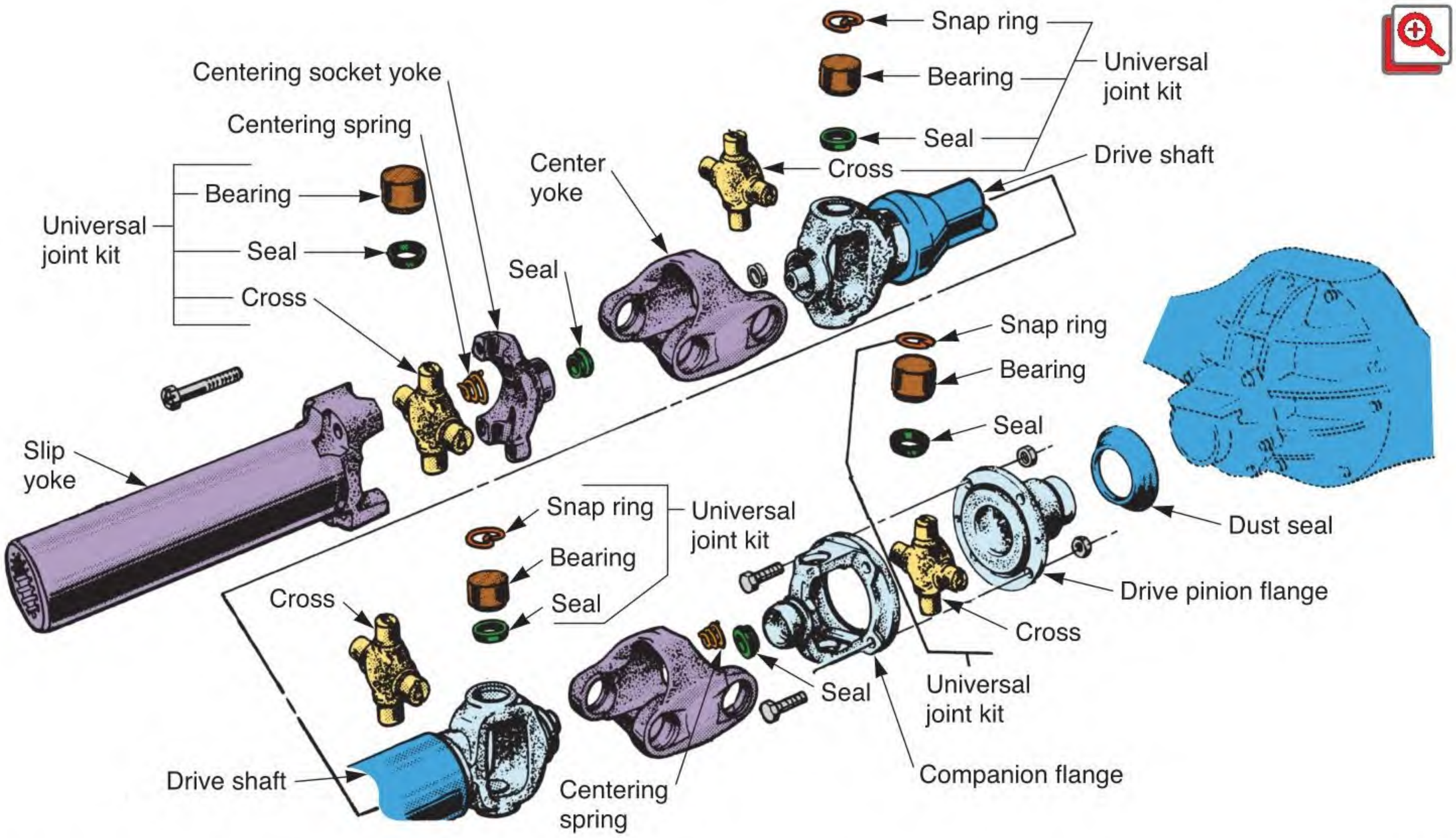
A ***center support bearing*** is needed to hold the middle of a two-piece drive shaft. The center bearing bolts to the vehicle's frame or underbody. It supports the center of the drive shaft where the two shafts come together. See **Figure 67-13**.



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Figure 67-11. Simplified illustration of a constant velocity universal joint. With two cross-and-roller joints connected to same center yoke, speed variations are counteracted. Speed changes at the output of the first joint are offset by speed changes at the other joint.

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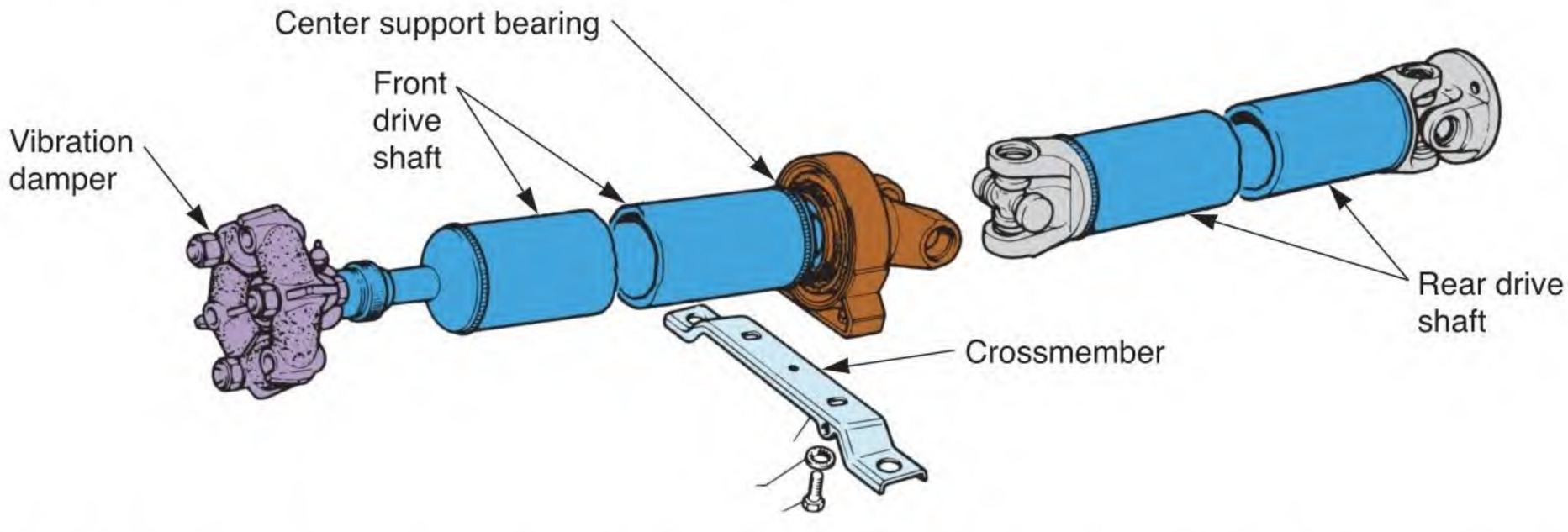
Figure 67-12. Note the construction of a drive shaft using two constant velocity universal joints. Two center yokes and four cross-and-roller joints are needed.

Pickup trucks commonly use a center support bearing. A two-piece drive shaft is required in these vehicles because of the large distance between the transmission and rear axle.

A cutaway view of a center support bearing is shown in **Figure 67-14**. A sealed ball bearing allows the drive shaft to spin freely. The outside of the ball bearing is held by a thick, rubber, doughnut-shaped mount. The rubber mount prevents noise and vibration from transferring into the driver's compartment.

Driveline Types

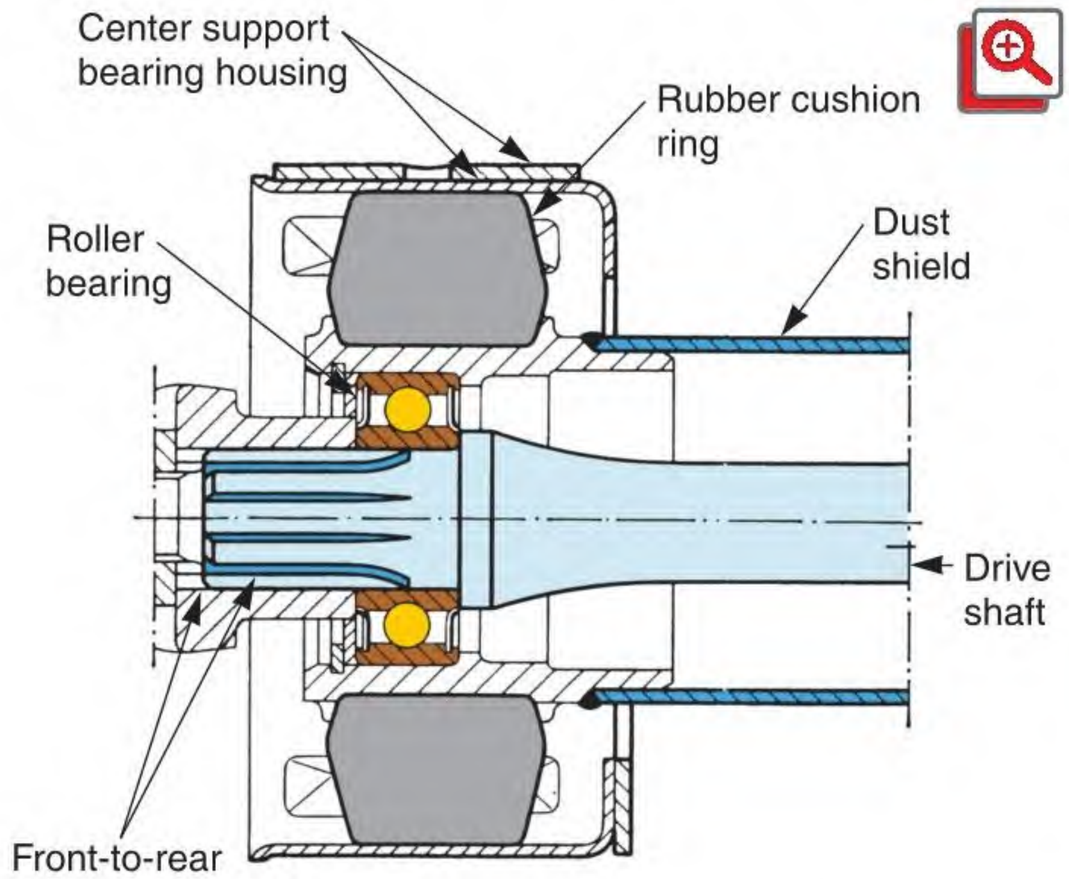
There are several variations of rear-wheel drive-lines in current use. However, most can be sorted into



Fiat

Figure 67-13. The center support bearing holds the center of a two-piece drive shaft. It is a roller bearing mounted in rubber. Also note the rubber torsion damping ring.

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Fiat

Figure 67-14. Cutaway view of a center support bearing. Study the parts.

one of two categories: Hotchkiss drivelines and torque tube drivelines.

Hotchkiss Driveline

A ***Hotchkiss driveline*** has an exposed drive shaft that operates a rear axle assembly mounted on springs. This is the most common rear-wheel driveline. It usually has cross-and-roller universal joints. A Hotchkiss driveline is pictured in **Figure 67-15**.

Torque Tube Driveline

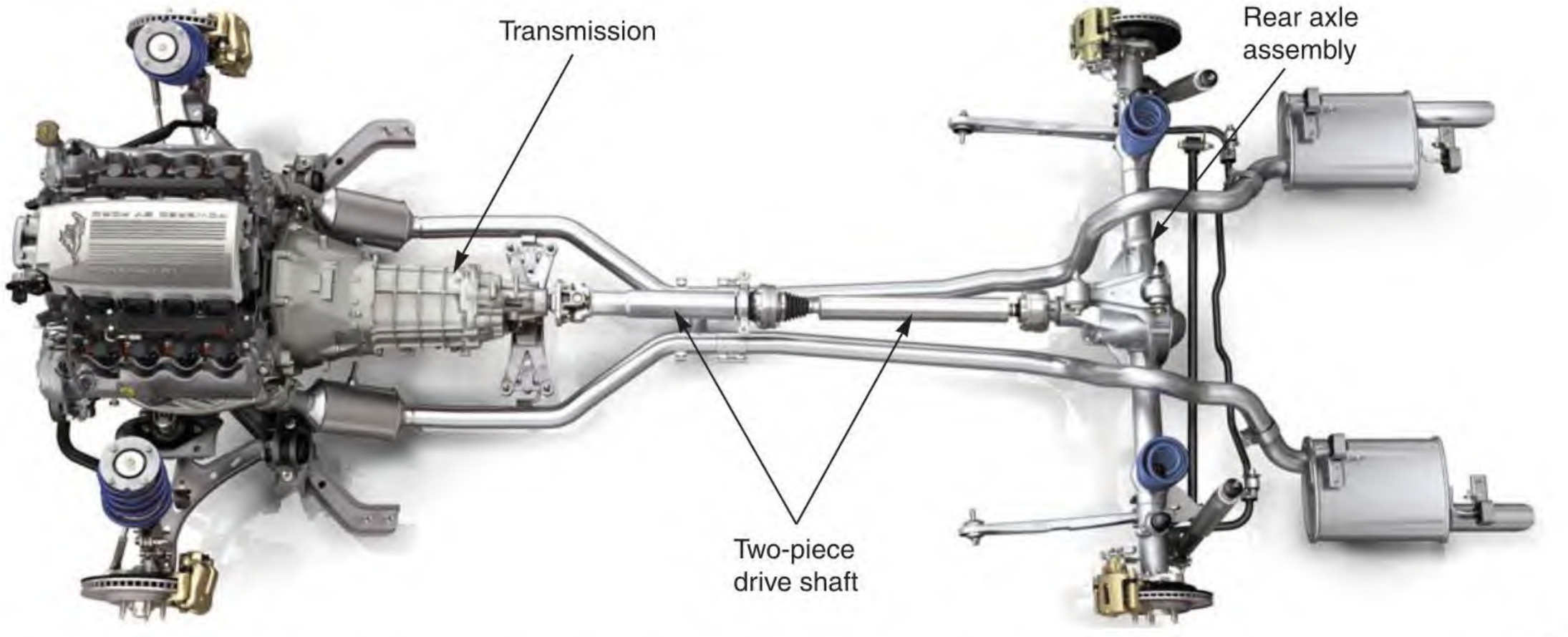
The ***torque tube driveline*** uses a solid steel drive shaft enclosed in a large hollow tube. With independent rear suspension, the drive shaft can be one piece without a universal joint. The rear of the torque tube is formed as a rigid part of the rear axle housing. This causes the transmission, drive shaft, and differential to stay in alignment without flexing when driven over rough roads. The Hotchkiss driveline has almost totally replaced the torque tube setup.

Transfer Cases

A ***transfer case*** sends power to both the front and rear axle assemblies in a four-wheel-drive vehicle. The transfer case usually mounts behind and is driven by the transmission, **Figure 67-16**. Two drive shafts normally run from the transfer case, one to each drive axle.

A transfer case is constructed something like a transmission. It uses shift forks, splines, gears, shims, bearings, and other components found in manual and automatic transmissions.

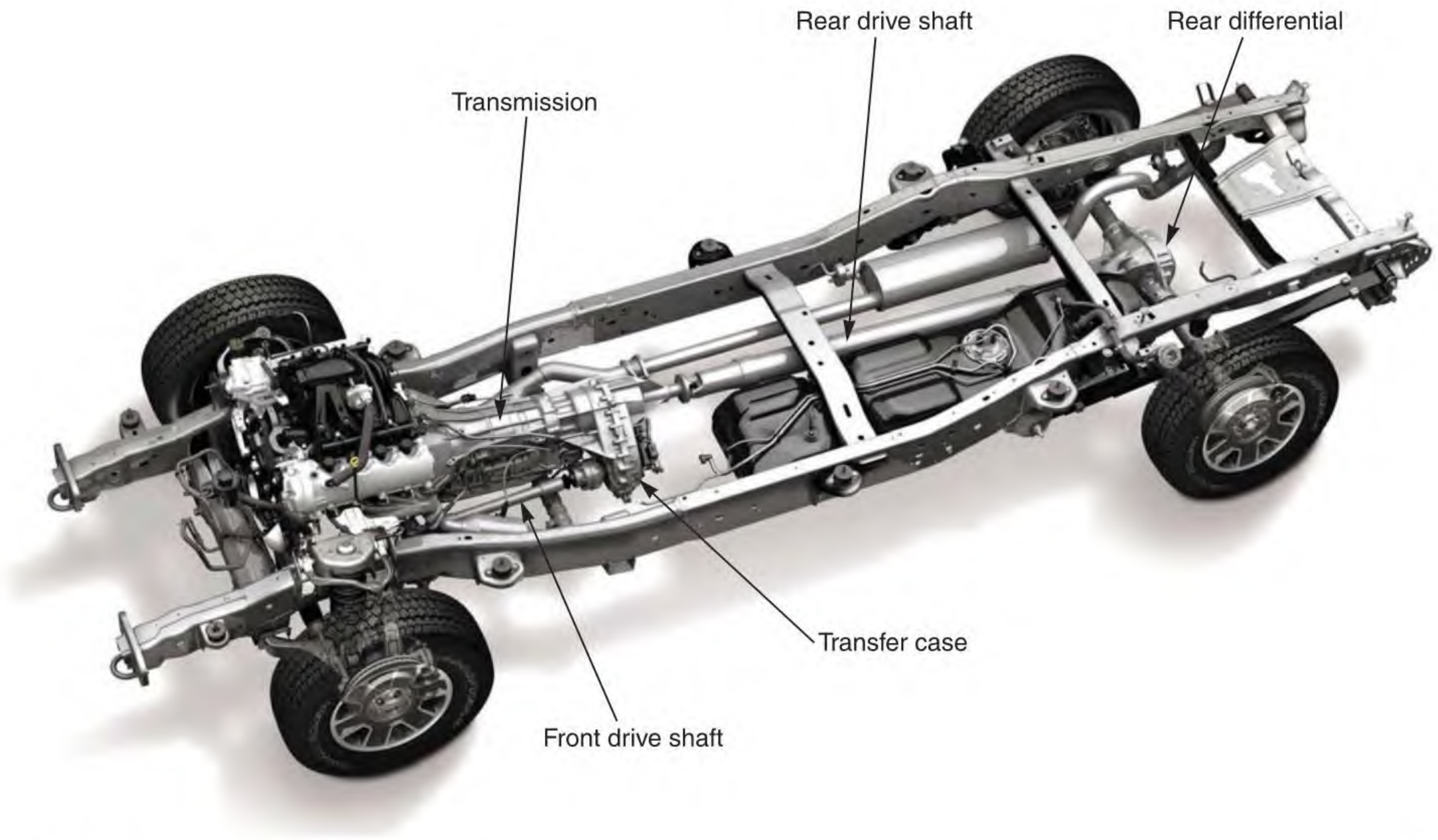
A transfer case has an outer case made of cast iron or aluminum. It is filled with lubricant (oil) that cuts friction on all moving parts. Seals hold the lubricant in the case and prevent leakage around shafts and yokes. Shims provide the proper clearances between the internal components and the case. **Figure 67-17** shows the major parts of a transfer case assembly.



Ford

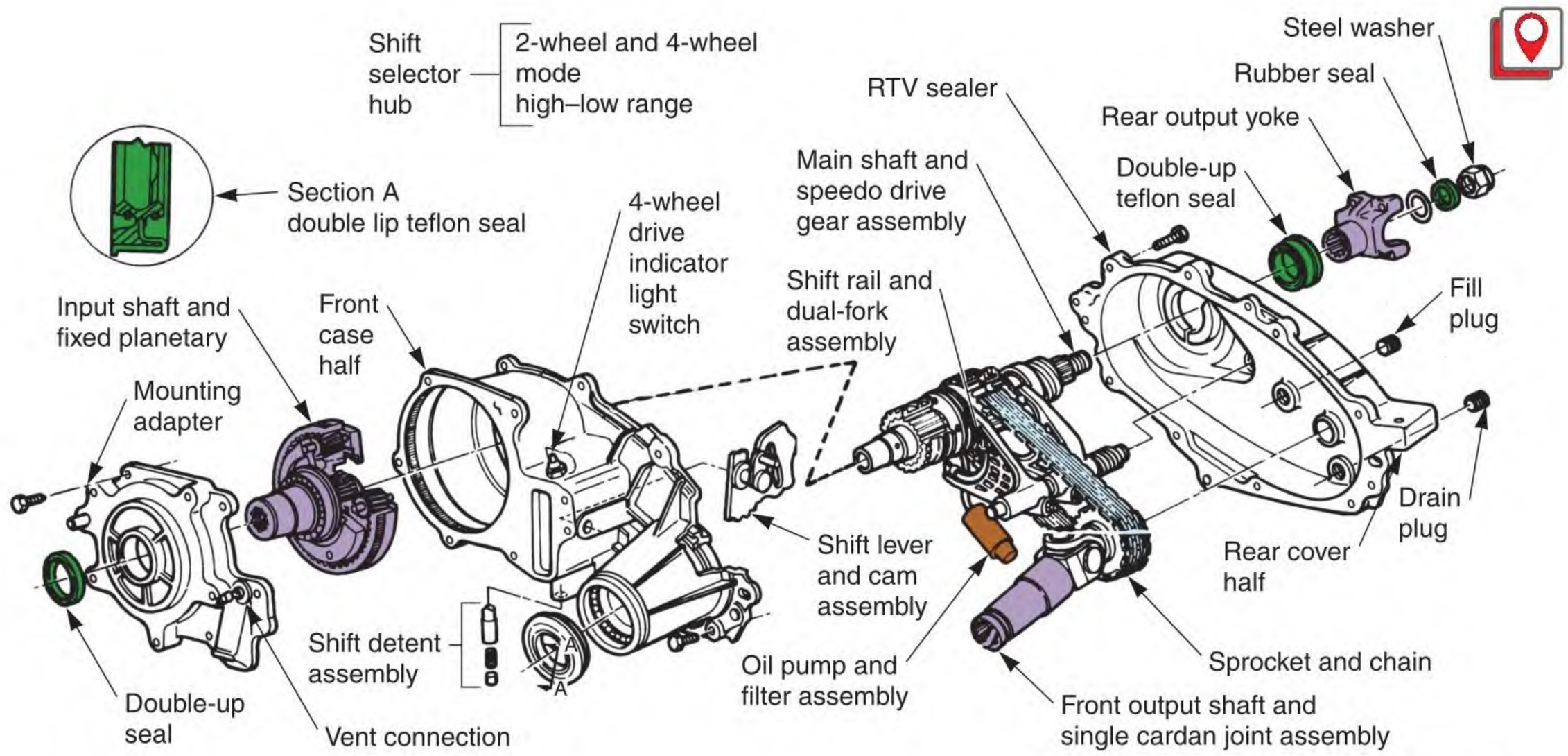
Figure 67-15. This Hotchkiss driveline has a two-piece drive shaft assembly that transfers power from the transmission to the rear axle assembly.

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Ford

Figure 67-16. Some trucks and passenger cars commonly use four-wheel drive. The transfer case is a power takeoff unit that sends power to both the front and rear drive axle assemblies. Drive shafts extend out of the front and rear of the transfer case.



Ford

Figure 67-17. Major parts of modern transfer case. The planetary gearset provides high and low ranges. The large chain sends power to the front output shaft. A shift rail and fork assembly is activated to control two-wheel-drive or four-wheel-drive mode.

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Transfer Case Ranges

Most modern transfer cases provide a two-wheel-drive, high range (2H), a four-wheel-drive, high range (4H), and a four-wheel-drive, low range (4L). High range normally has a gear ratio of 1:1. Low range typically has a gear ratio of 2:1 for climbing steep hills or pulling heavy loads. **Figure 67-18** shows how power flows through a transfer case for the different ranges.

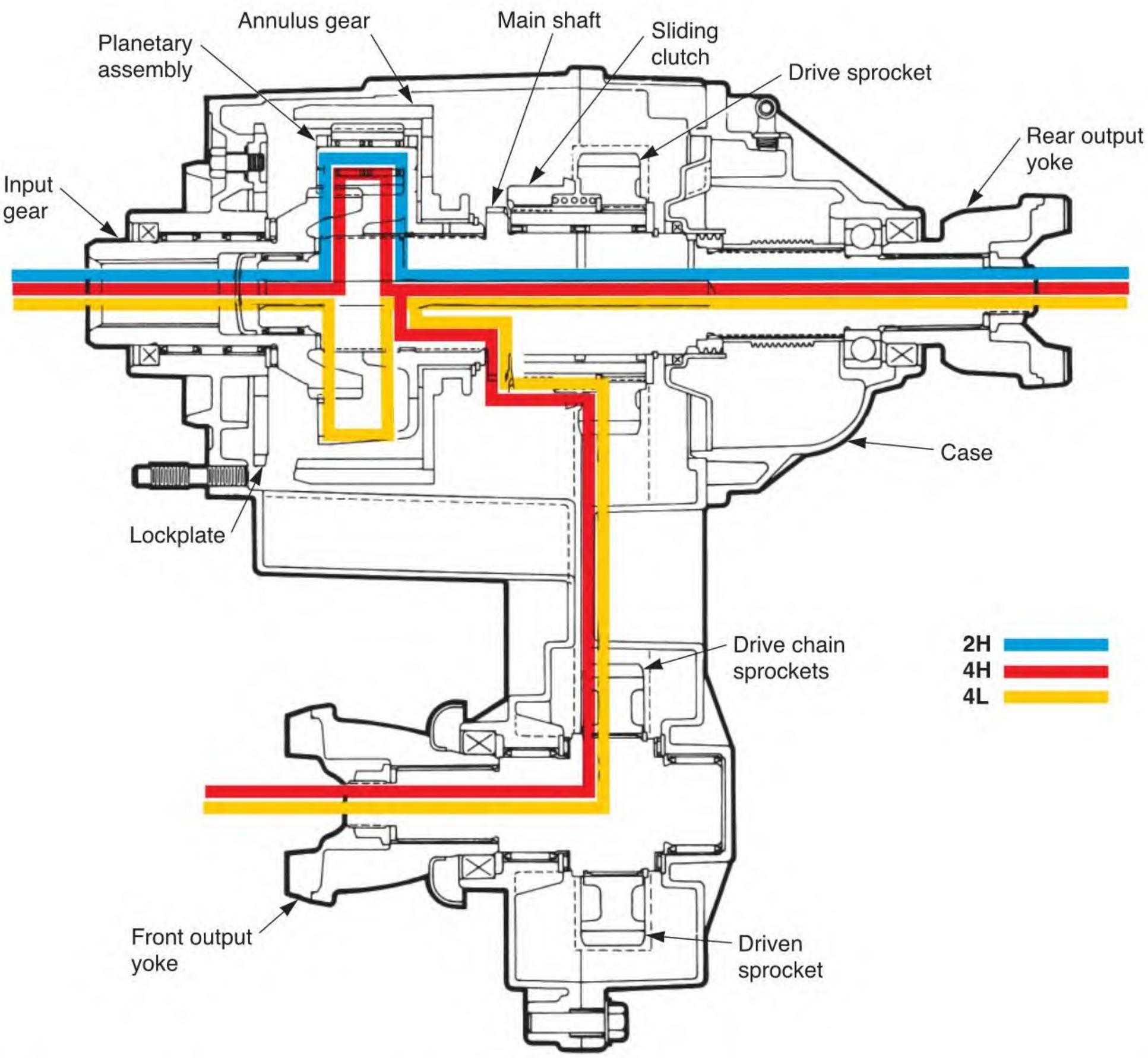
Two-Wheel-Drive, High Range (2H)

The 2H range is provided for normal driving when four-wheel-drive traction is not needed. In 2H range, torque flows from the input gear to the locked planet gears and ring gear, which rotate as a single unit. Torque is transferred to the main shaft through the planet carrier splined to the main shaft. Power finally flows out the rear yoke, through the rear drive shaft, and to the rear differential. Refer to **Figure 67-18**.

In 2H, the sliding clutch remains in the neutral position. As a result, torque is not transferred to the front axle assembly.

Four-Wheel-Drive, High Range (4H)

In 4H, torque flows through the input gear, the planet gears, and ring gear in the same fashion as in 2H. However, the sliding clutch is shifted into the main shaft clutch gear. Torque then flows through the



Chrysler

Figure 67-18. Trace power flow through a transfer case in 2H, 4H, and 4L range. Notice that this unit uses a planetary gearset to produce the two gear ratios. A hand-shifted sliding clutch regulates power transfer for two-wheel and four-wheel drive.

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drive chain, the front output yoke, and the front drive axle assembly. Both the front and rear axles drive the vehicle.

Four-Wheel-Drive, Low Range (4L)

In 4L, torque transfer is almost the same as in 4H. However, the ring gear is shifted forward into the lock plate. This holds the ring gear stationary. As a result, the planet gears walk inside the ring gear, producing a gear reduction.

All-Wheel Drive

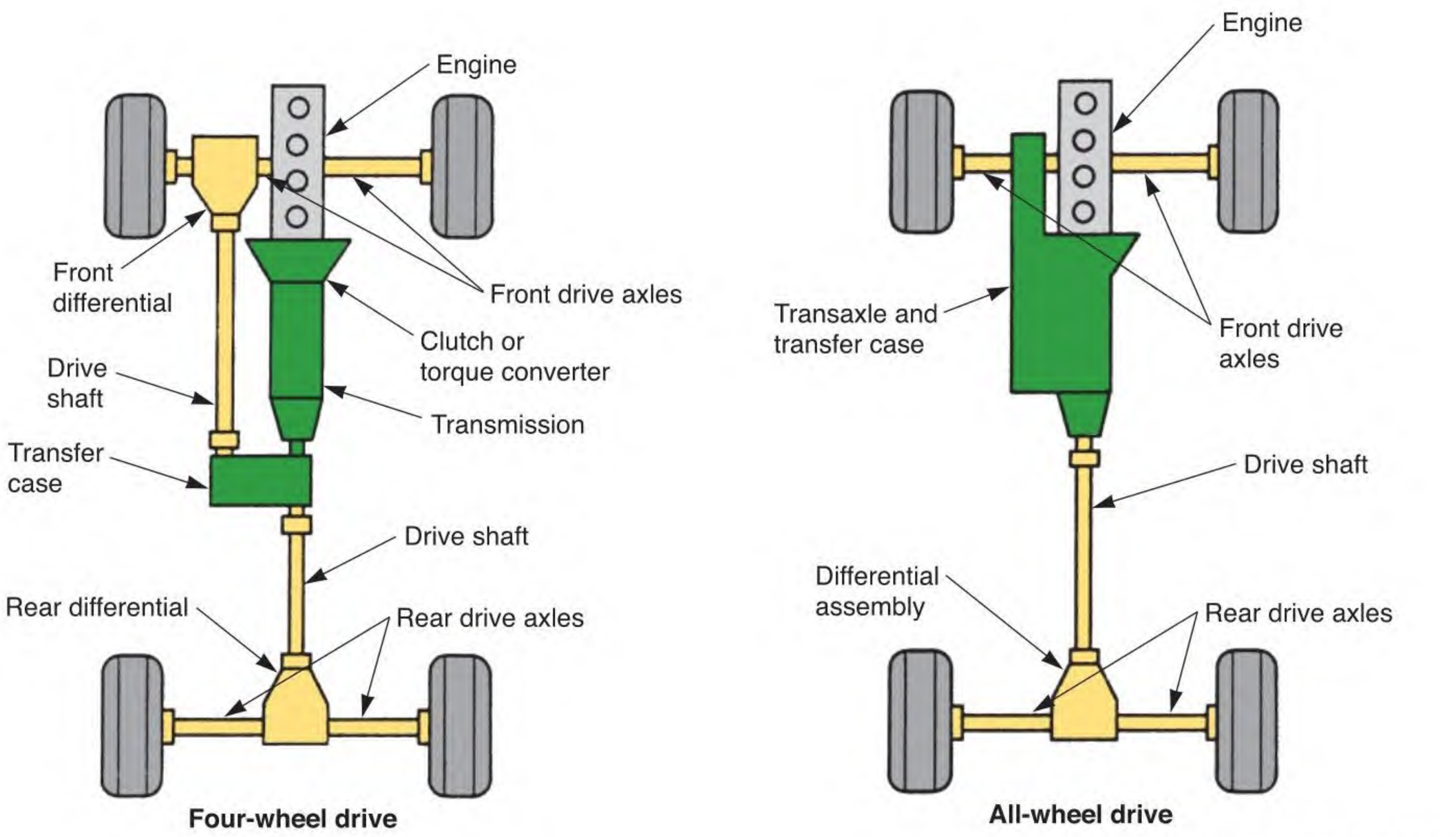
All-wheel drive refers to a four-wheel-drive system that does not use a conventional transfer case. Look at **Figure 67-19**. It is a system designed for a front-wheel-drive transaxle or a transmission.

Basically, the transmission or transaxle in an all-wheel-drive system is modified to allow power flow to the front and rear drive axles. See **Figure 67-20**.The drive shaft, drive axles, and differentials are the same as the units previously discussed.

A fluid coupling, or viscous coupling, controls the power split to the front and rear axle assemblies. Usually, more drive torque is sent to the rear wheels than to the front.

Industry Trend

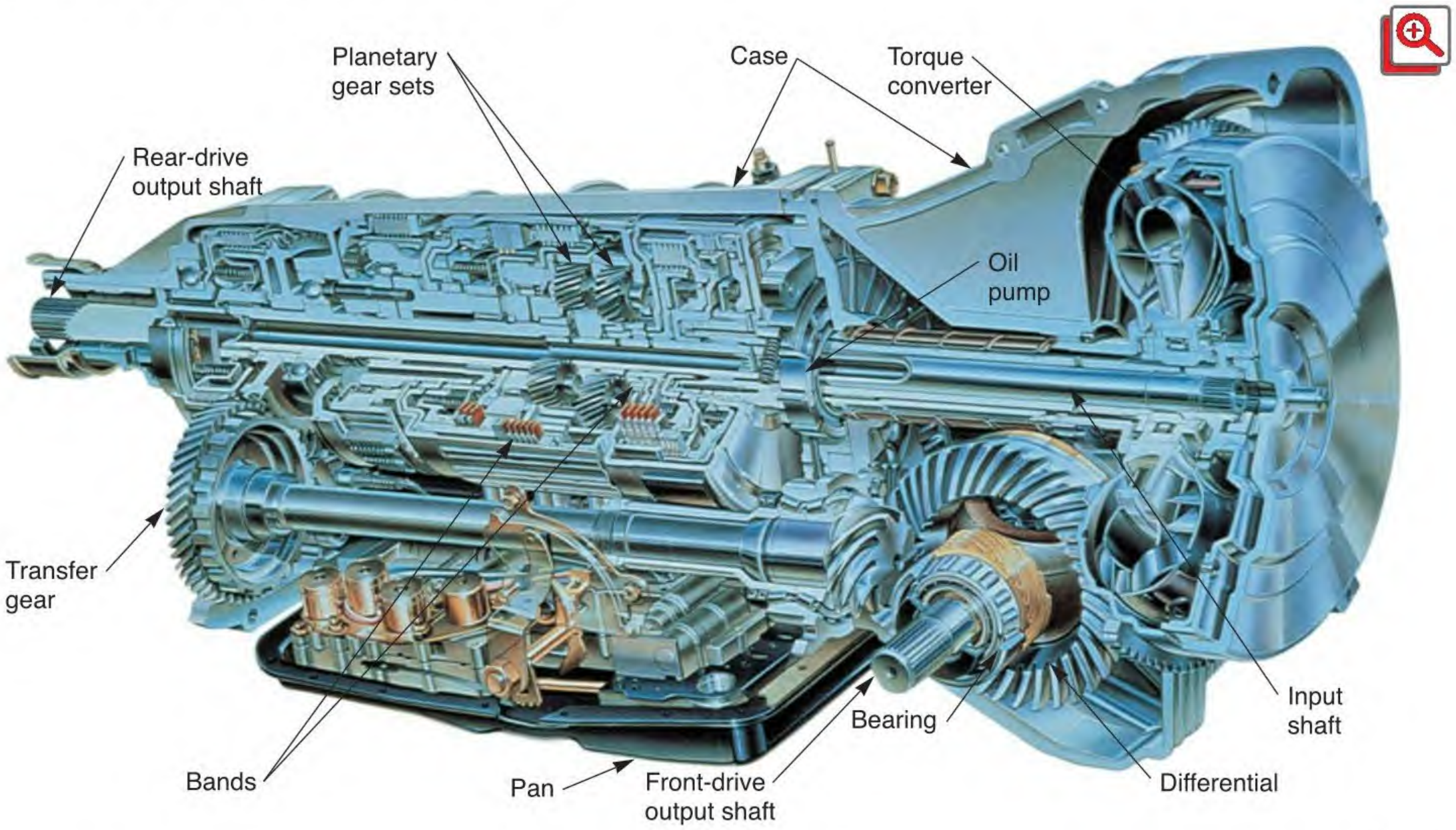
All-wheel-drive systems are equipped with a torque-sensing differential, which transfers power to the axles (front or rear) with the best traction when slippage occurs. Some late-model all-wheel-drive systems use electronic controls to deliver power to individual wheels as needed for optimum traction and control.



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Figure 67-19. This illustration shows the difference between a four-wheel-drive system and an all-wheel-drive system. A four-wheel-drive system has a transfer case that is separate from the transmission. Various drive ranges, such as 2H, 4H, and 4L, are normally provided. An all-wheel-drive system has the transfer case included as part of the transaxle.

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Subaru

Figure 67-20. Cutaway view shows the internal parts of an all-wheel-drive automatic transmission. Note that it has output shafts for front and rear wheels. A transfer gear and shaft send rear output shaft torque to the front differential.

Summary

- The term *driveline* generally refers to the parts that transfer power from the transmission to the drive wheels.
- A drive shaft is a long shaft with universal joints at both ends that transfers power from the transmission back to the rear axle assembly.
- A universal joint allows the driveline to flex as the rear axle moves up and down.
- The slip yoke, splined to the transmission output shaft, allows for any changes in driveline length by sliding in and out of the transmission.
- The extension housing bushing supports the slip yoke as it spins in the transmission.
- The transmission rear seal rides on the slip yoke and prevents fluid leakage.
- The propeller shaft is commonly a hollow steel tube with permanent yokes welded on each end.
- Drive shaft balancing weights are frequently welded to the shaft to avoid vibration.
- The cross-and-roller (cardan) universal joint is the most common type of drive shaft universal joint.
- A constant velocity joint normally has two cross-and-roller joints connected by a centering socket and center yoke.
- The ball-and-trunnion joint is designed for constant velocity.
- A center support bearing is needed to hold the middle of a two-piece drive shaft.
- A transfer case sends power to both the front and rear axle assemblies in a four-wheel-drive vehicle.
- All-wheel drive refers to a four-wheel-drive system that does not use a conventional transfer case.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

all-wheel-drive
ball-and-trunnion joint
cardan universal joint
center support bearing

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constant velocity universal joint
cross-and-roller joint
double-cardan joint
drive shaft
drive shaft assembly
drive shaft balancing weights
drive shaft vibration damper
driveline
extension housing bushing
front universal joint
Hotchkiss driveline
propeller shaft
rear universal joint
rear yoke
slip joint
slip yoke
torque tube driveline
transaxle
transfer case
transmission rear seal
U-joint
universal joints

Activities

1. Identify the components of a drive train on a vehicle in the automotive shop for service.
2. Sketch and label the parts of a universal joint.
3. Prepare an overhead transparency from the sketches made in Activity 2; use it to explain the parts of a universal joint.

Review Questions

Answer the following questions using the information provided in this chapter.

1. The term _____ generally refers to the parts that transfer power from the transmission to the drive wheels.
2. List and explain the five major parts of a drive shaft.
3. What are four functions of a drive shaft?
4. The movement of the rear axle assembly also causes the distance between the rear axle and transmission to change. True or False?
5. The _____ _____ or _____ _____ is splined to the transmission output shaft.
6. Describe the construction of a typical drive shaft, not including the universal joints or other parts.
7. Which of the following does *not* attach to an assembled drive shaft?
   (A) Balance weights.
   (B) Yokes.
   (C) Universal joints.
   (D) All of the above attach to a drive shaft.
   (E) None of the above attach to a drive shaft.
8. How does a constant velocity universal joint (double-cardan joint) work?
9. When is a center support bearing needed and why?
10. Explain the basic operation of a transfer case.

ASE-Type Questions

1. Technician A says the term *driveline* normally refers to the components that transfer power from the engine crankshaft to the drive wheels. Technician B says the term *driveline* normally refers to the parts that transfer power from the transmission to the drive wheels. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Technician A says front-wheel-drive cars use a driveline with a single, long drive shaft. Technician B says front-wheel-drive cars are usually equipped with two drive axle shafts. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. While discussing the functions of a drive shaft assembly's components, Technician A says a slip yoke connects the transmission output shaft to the front universal joint. Technician B says a slip yoke connects the transmission input shaft to the rear axle assembly. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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4. Technician A says during drive shaft assembly operation, the transmission input shaft turns the rear yoke. Technician B says during drive shaft assembly operation, the transmission output shaft turns the slip yoke. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. Technician A says a drive shaft assembly sends turning power from the transmission to the rear axle assembly. Technician B says a drive shaft assembly must flex and allow up and down movement of the rear axle assembly. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Technician A says a drive shaft assembly's rear yoke holds the rear universal joint. Technician B says a rear yoke transfers torque to gears in the rear axle assembly. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. Which of the following is *not* a drive shaft assembly component?
   (A) Universal joint.
   (B) Slip yoke.
   (C) Transmission input shaft.
   (D) Rear yoke.
8. Technician A says a drive shaft assembly's slip yoke is normally splined to the transmission output shaft. Technician B says the drive shaft assembly's slip yoke is usually bolted to the transmission output shaft. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Technician A says a rear yoke is bolted to the outer end of the rear axle assembly's ring gear. Technician B says a rear yoke is bolted to the outer end of the rear axle assembly's pinion gear. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. Technician A says a drive shaft assembly normally has one universal joint. Technician B says a drive shaft assembly is normally equipped with four universal joints. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
11. Technician A says drive shaft balancing weights are usually bolted to the drive shaft. Technician B says drive shaft balancing weights are normally welded to the drive shaft. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
12. Technician A says a cardan universal joint is the most common type of drive shaft universal joint used on rear-wheel-drive vehicles. Technician B says the ball-and-trunnion universal joint is the most common type of universal joint used on rear-wheel-drive vehicles. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
13. Technician A says a transfer case sends power to the front axles on front-wheel-drive cars. Technician B says a transfer case sends power to the rear axle assembly on rear-wheel-drive automobiles. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Chapter 68
Drive Shaft and Transfer Case Diagnosis, Service, and Repair

After studying this chapter, you will be able to:

- Troubleshoot common drive shaft problems.
- Check universal joint wear.
- Measure drive shaft runout.
- Remove and replace a drive shaft assembly.
- Replace universal joints.
- Perform basic service operations on a transfer case.
- Cite and practice good safety procedures.
- Correctly answer ASE certification test questions on the service and repair of drive shafts and transfer cases.

A drive shaft is subjected to very high loads and rotating speeds. When a vehicle is cruising down the highway, the drive shaft and universal joints may be spinning at full engine speed. They are sending high torque to the rear axle assembly.

To function properly, the drive shaft must be almost perfectly straight. The universal joints must be unworn. If any component allows the drive shaft to wobble, severe vibration, abnormal noises, and major damage can result.

Drive Shaft Problems

When driving the vehicle to verify a drive shaft–related complaint, keep in mind that other components could be at fault. A worn wheel bearing, squeaking spring, defective tire cord, transmission problems, or differential troubles could be at fault. You must use your knowledge of each system and assembly to detect which driveline part is causing the trouble. See **Figure 68-1**.

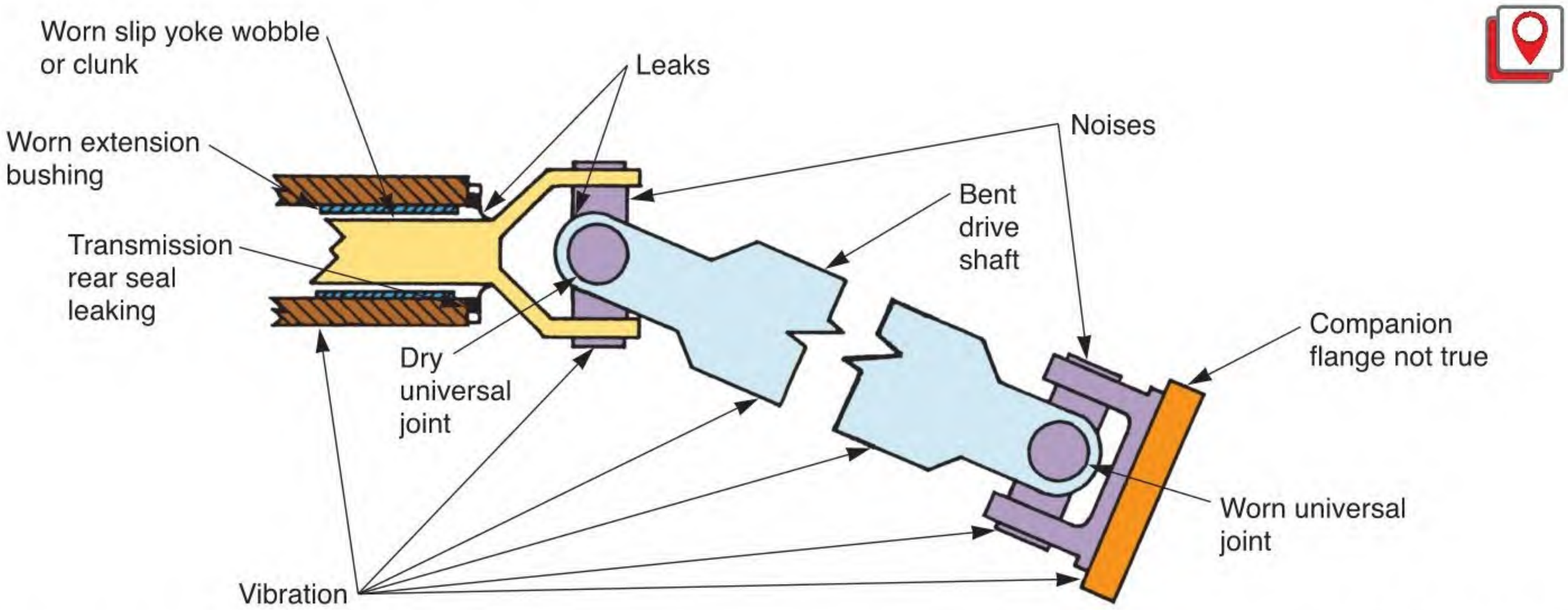
Drive shaft problems can normally be divided into two categories: drive shaft noise and drive shaft vibration.

Drive Shaft Noise

Drive shaft noise is usually caused by dry, worn universal joints, a worn slip joint and support bushing, or a faulty center support bearing.

Worn universal joints will be loose, unlubricated, and make a fairly loud noise, especially in reverse gear. If not regularly serviced with a grease gun, the steel roller bearings in the joints will become dry, causing the rollers to overheat and wear rapidly as the joint flexes when spinning at high speeds. The damaged rollers produce a grinding or squeaking sound as they operate on the badly scored universal cap and cross journal surfaces.

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Figure 68-1. A drive shaft inspection will frequently detect troubles. Wiggle joints while watching for wear and looseness at needle bearings.

Tech Tip

Use special care in diagnosing squeaking noises that seem to come from the universal joints. Wheel covers can make similar squeaking noises as barb clips around the perimeter of the wheel cover rub against the steel or aluminum wheel. Remove the wheel covers if you are uncertain of the source of the squeaking noise.

A clunking sound (deep-pitched thud) heard during acceleration or deceleration may be caused by excessive clearance between the slip yoke and transmission extension housing bushing. The slip yoke splines may be worn, which allows the yoke to flop up and down as driveline torque changes. The result is drive train play and a clunk noise when pressing or releasing the gas pedal. Worn universal joints or worn differential ring and pinion gears can also cause a clunking sound when the accelerator is released.

Dry, worn roller bearings in the center support bearing will cause a whining noise from the drive shaft. Since this bearing makes complete revolutions, it will make a different sound than a bad universal joint. A faulty center support bearing will usually produce a constant high-pitched whine.

Other abnormal sounds should be traced using your knowledge of mechanical principles, an electronic or mechanical stethoscope, and a vehicle-specific service manual troubleshooting chart.

Drive Shaft Vibration

Drive shaft vibration can be caused by any problem that affects drive shaft balance, runout (straightness), and angle. The vibration is usually more rapid than vibration caused by wheels and tires. Drive shaft vibration is similar to the vibration produced by an unbalanced clutch, flywheel, or engine crankshaft.

When test driving, drive in high gear at the engine speed that causes the most vibration. Then shift into different gears or neutral while maintaining that speed. If there is not a change, the vibration may be in the drive shaft. A vibration change indicates the engine, clutch, torque converter, or transmission is at fault. When vehicle speed remains the same, drive shaft speed remains the same.

Drive Shaft Inspection

To inspect the drive shaft, raise the vehicle on a hoist. Look for undercoating or mud on the drive shaft, which could cause vibration. Check for a sharp driveline angle, missing balance weights, cracked welds, and other drive shaft problems.

To check for worn universal joints, wiggle and rotate each universal joint back and forth while watching for side movement. Try to detect any play between the cross and yoke. If the cross moves inside the yoke, the universal joint is worn and should be replaced.

Also, wiggle the slip yoke up and down. If it moves excessively in the transmission bushing, either the yoke or the bushing is worn. Inspect the rear yoke

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bolts for tightness. Make sure the rear motor mount is not broken. Look for any condition that could upset the operation of the drive shaft.

If you fail to find a problem, you may need to measure drive shaft runout (wobble) and check balance.

Measuring Drive Shaft Runout

Drive shaft runout is caused by a bent drive shaft, damaged yokes, or worn universal joints. A dial indicator is normally used to measure drive shaft runout.

Service Procedure

To measure drive shaft runout:

1. Sand and clean around the front, center, and rear of the drive shaft. This gives the dial indicator a smooth surface for accurate measurements.
2. Mount the dial indicator perpendicular to the shaft. The indicator base must be placed on a rigid surface (differential, floor pan, transmission, or special post stand). The drive shaft must not be at a sharp angle during runout measurement. See **Figure 68-2**.
3. With the transmission in neutral, turn the drive shaft.
4. Measure runout at the front, center, and rear of the shaft.
5. Compare your measurements to specifications. Generally, drive shaft runout should not exceed 0.010″–0.030″ (0.25–0.75 mm).

If drive shaft runout is beyond specifications, try removing and rotating the shaft 180° in the rear yoke. This may shift select-fit parts back into alignment and correct the runout problem. Also, make sure the universal joints are in good condition and that the yokes are not damaged. If runout is still excessive, replace the drive shaft or send it to a machine shop for repairs. Some specialized shops can replace the center tube of the drive shaft.

Drive Shaft Balancing

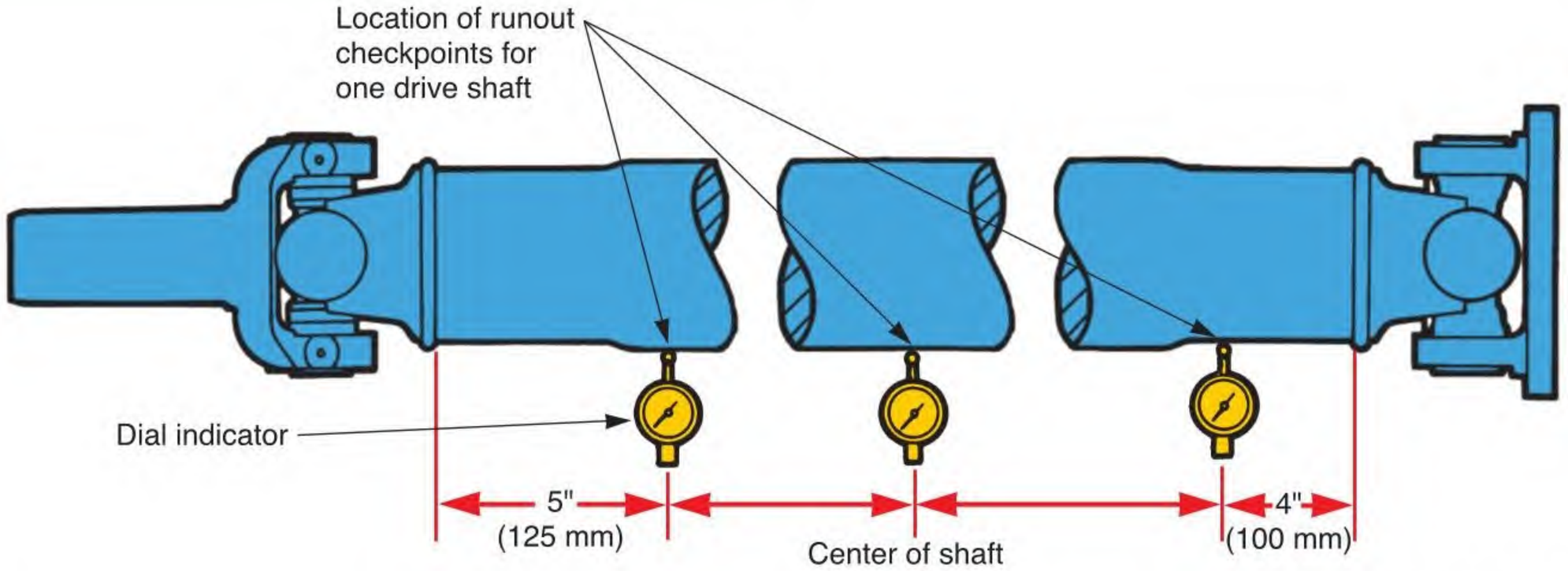
If the drive shaft is within recommended runout limits but still vibrates, it may need to be balanced. Drive shaft balancing is generally done by a machine shop that has specialized drive shaft–balancing equipment.

Measuring Driveline Angle

If your runout and balance checks fail to find a problem, you may need to check the ***driveline angle***. If the angle is too sharp, the universal joints can cause speed fluctuations and vibration.

There are various methods used to check the driveline angle. Some automakers recommend an angle gauge that reads in degrees. One is shown in **Figure 68-3**.

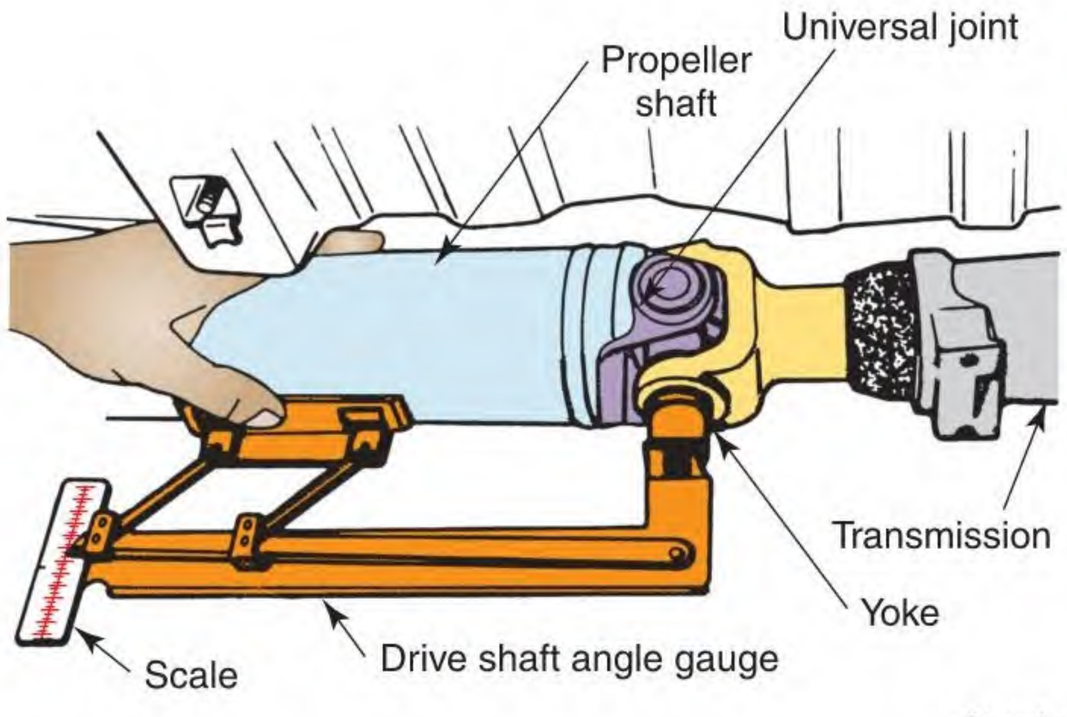
Simply place the gauge on the drive shaft (with the car in a level position and the rear axle supporting the vehicle weight) and read the driveline angle. If the angle is incorrect, you can adjust the driveline angle by placing shims under the rear axle housing



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Figure 68-2. A dial indicator can be used to measure drive shaft runout. Check in the middle and on each end of the shaft. If runout is more than specifications, the shaft is bent or yokes are damaged.

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Figure 68-3. An angle gauge, or inclinometer, can be used to check driveline alignment. Shim the rear axle or transmission, or replace springs and other parts to correct a misalignment problem. Misalignment can cause vibration and universal joint wear.

or transmission mount. Refer to a service manual for exact procedures.

Drive Shaft Maintenance

Normally, very little maintenance is required on modern drive shafts. The universal joints are usually sealed units that are filled with grease at the factory. However, some universal joints, especially aftermarket types, have grease fittings, allowing lubrication. A ***grease gun*** can be used to lubricate universal joints that have fittings. In some cases, a special needle adaptor must be mounted on the grease gun to lubricate the joint.

Drive Shaft Service

Drive shaft service requires that the drive shaft be removed for repairs. The universal joints may be worn and require replacement, or the drive shaft itself may be damaged. Although some design variations are used, general service procedures are the same for most rear-wheel-drive vehicles.

Drive Shaft Removal

Before removing the drive shaft, raise the vehicle on a hoist and scribe marks on the differential yokes and the universal joints. This will help ensure proper drive shaft balance upon reassembly.

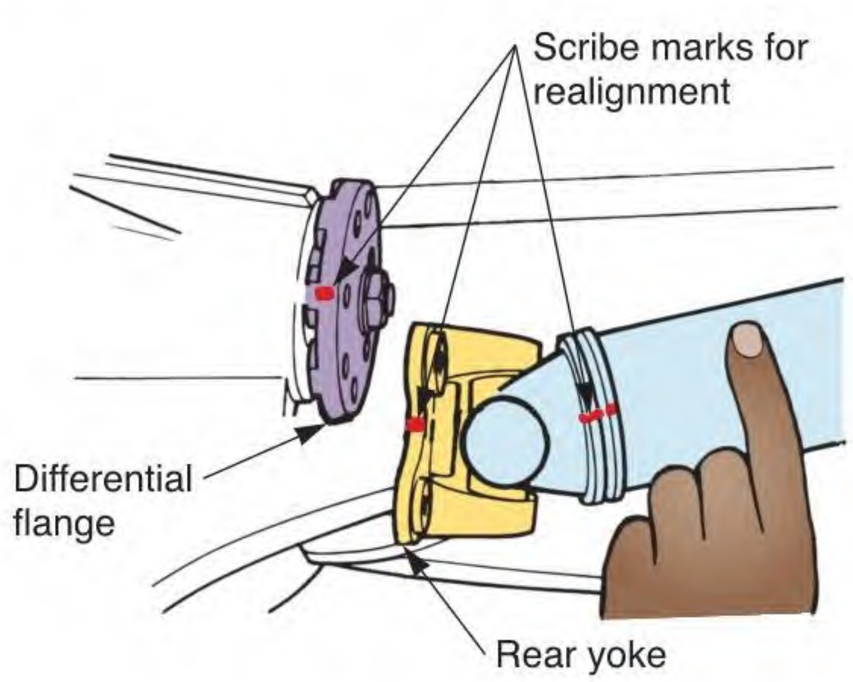
Service Procedure

To remove the drive shaft:

1. With the vehicle on a hoist, unbolt the rear joint from the differential.
2. Pry the shaft forward and lower the shaft slightly. See **Figure 68-4**.
3. Do not allow the full weight of the drive shaft to hang on the slip yoke. Support the drive shaft to prevent damage to the extension housing, rear bushing, and front universal joint.
4. Wrap tape around the two caps on the rear universal joint, if needed. This will keep the caps from falling off and spilling the small roller bearings.
5. Unbolt the center support bearing, if used.
6. Slide the drive shaft out of the transmission.
7. If transmission lubricant begins to leak out, install a plastic plug or an old slip yoke in the extension housing.

Universal Joint Service

A ***worn universal joint***, the most common drive shaft problem, can cause squeaking, grinding, clunking, or clicking sounds. The grease inside the joint can dry out. The roller bearings can then wear small indentations (dents) in the cross. When the bearings try to roll over these indentations, a loud metal-on-metal grinding or chirping sound can result.



Ford

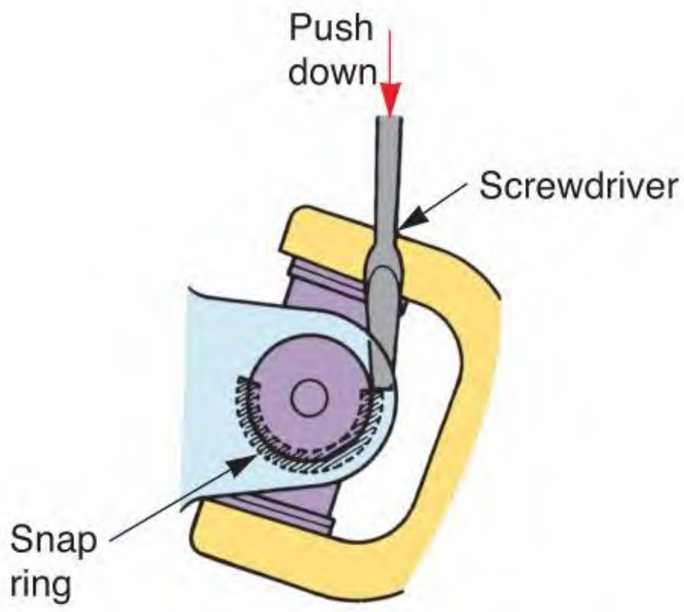
Figure 68-4. Scribe marks on the drive shaft, rear yoke, and universal joints before disassembly. This will help maintain shaft balance when reassembling.

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Quite often, a worn universal joint will be noticed when the vehicle is in reverse gear. When the car is backed up, the roller bearings are forced over the wear indentations against normal rotation. The rollers will catch on the sharp edges in the worn joint, causing an even louder sound.

Universal Joint Disassembly

Before disassembling the universal joint, scribe mark each component. The marks will show you how to reassemble the joint to avoid vibration by upsetting the factory balance.



Toyota

Figure 68-5. To disassemble a cross and roller universal joint, remove the snap rings using a screwdriver or snap ring pliers.

Service Procedure

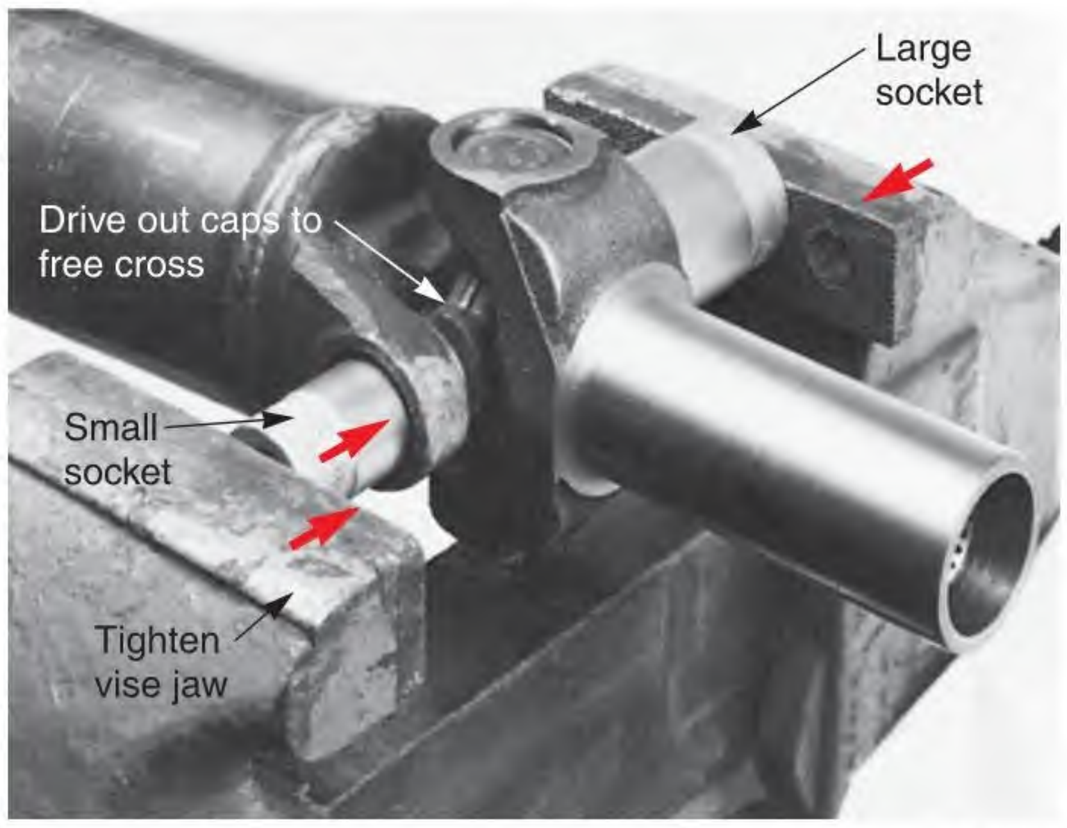
To disassemble a universal joint:

1. Clamp the drive shaft yoke in a vise. Do not clamp the weaker center section of the drive shaft or it may be bent.
2. Remove the snap rings from the universal joint caps or yokes, if used. Use a screwdriver, snap-ring pliers, or needle nose pliers to remove the rings. Look at **Figure 68-5**.

Warning

Wear safety glasses to protect your eyes in case the snap rings fly out of the joint during removal.

3. To remove the universal joint from the yokes, you can use a vise and two sockets, **Figure 68-6**.
4. Place a socket *smaller* than the bearing cap on one end of the universal joint.
5. Place a socket with an inside diameter *larger* than the bearing cap on the opposite side of the joint.
6. Fit both sockets and the universal joint inside a vise.
7. Slowly tighten the vise to force the bearing caps out of the yoke.
8. Repeat this operation on the other yoke if needed.



Chrysler

Figure 68-6. With the snap rings removed, press the cross and bearing caps out of the yokes. Use a small socket as the driver. Use a large socket to accept the bearing cap on the other side.

Special C-clamp ***universal joint tools*** are also available for pressing universal joints apart and together. These tools are used in the same way as the vise.

Tech Tip

Avoid excessive force when holding a drive shaft in a vise. If the shaft or yokes are bent, the drive shaft may vibrate when returned to service.

Universal Joint Replacement

Normally, a universal joint is replaced whenever it is disassembled. However, if the joint is relatively new, you can inspect, lubricate, and reassemble it.

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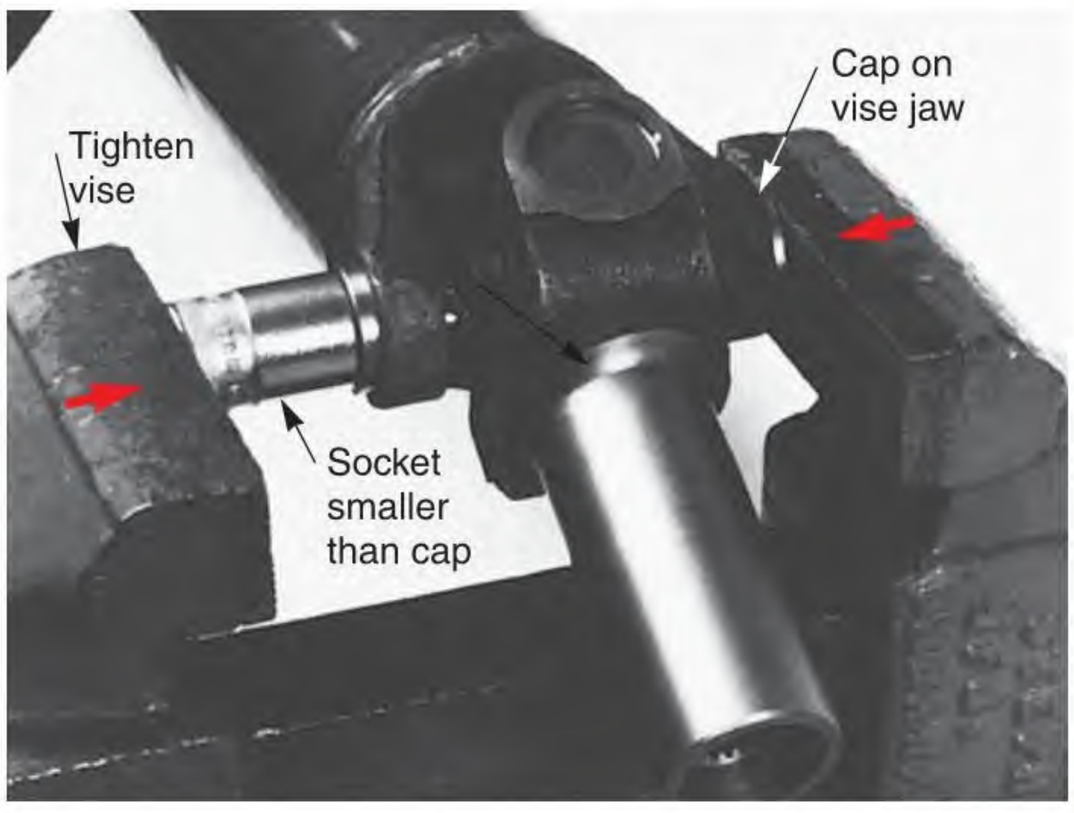
During inspection, clean the roller bearings and other parts in solvent. Then, check the cross and rollers for signs of wear. If the slightest sign of roughness or wear is found on any part, replace the universal joint.

Universal Joint Assembly

Service Procedure

To assemble a universal joint:

1. Pack the roller bearings with high-temperature grease.
2. Position the cross inside one of the yokes. Align your punch marks.
3. Fit the bearing caps into each end of the yoke. Center the cross partially into each cap to keep the roller bearings from falling out.
4. Place the assembly in a vise.
5. Tighten the vise so that the bearing caps are forced into the yoke.
6. Place a small socket on one bearing cap and tighten the vise until the cap is pushed in far enough for snap ring installation. Install the snap ring. See **Figure 68-7**.
7. With one snap ring in place, use the socket to force the other cap into place. Install its snap ring.
8. Repeat this procedure on the other universal joint and yoke, if needed. Look at **Figure 68-8**.



Chrysler

Figure 68-7. To install a universal joint, use one small socket and vise to press the caps into the yoke. Make sure the small needle bearings are in place or part damage can result. Press in until you can install one snap ring. Then, press the other cap in and install the other snap ring.

After assembly, check the action of the universal joint. Swing it back and forth into various positions. The joint should move freely, without binding. Double-check that all the snap rings have been installed properly.

Tech Tip

If the bearing cap fails to move into place with normal pressure, disassemble the joint and check the roller bearings. It is easy for a roller bearing to fall down and block cap installation. If you try to force the cap with excess pressure, the universal joint and drive shaft could be ruined.

Some caps are secured by a special plastic resin that is injected into holes in the universal joint. When dry, the plastic forms a ring to hold the joint together. Refer to a service manual for exact procedures. Allow adequate drying time before installing the drive shaft.

To service universal joints on the drive shafts of four-wheel-drive vehicles, use the general instructions provided. A four-wheel-drive system simply uses two drive shafts instead of one.

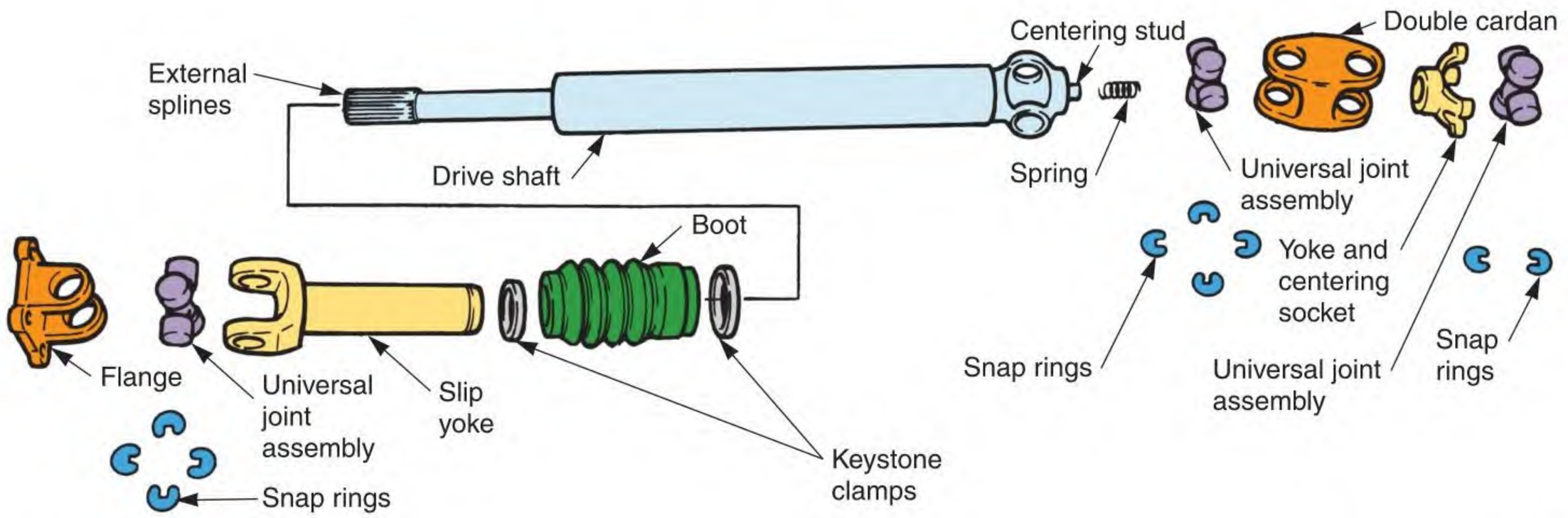
Drive Shaft Installation

Service Procedure

To install the drive shaft:

1. Wipe the slip yoke clean and place a small amount of grease on its internal splines (if recommended).
2. Align your marks and slide the yoke into the rear of the transmission.
3. Push the shaft all the way into the extension housing and position the rear joint in the differential.
4. Pull the shaft back and center the rear universal joint properly.
5. Check your rear alignment marks.
6. Install the U-bolts, bearing caps, or yoke bolts to secure the rear universal joint to the differential.
7. Lower the car to the ground.

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Ford

Figure 68-8. Inspect all drive shaft assembly components carefully. In particular, check snap ring grooves, yokes, and universal joints. Replace any part in poor condition. Also, make sure you mark position of all parts. They must be installed in the same position to prevent possible shaft vibrations.

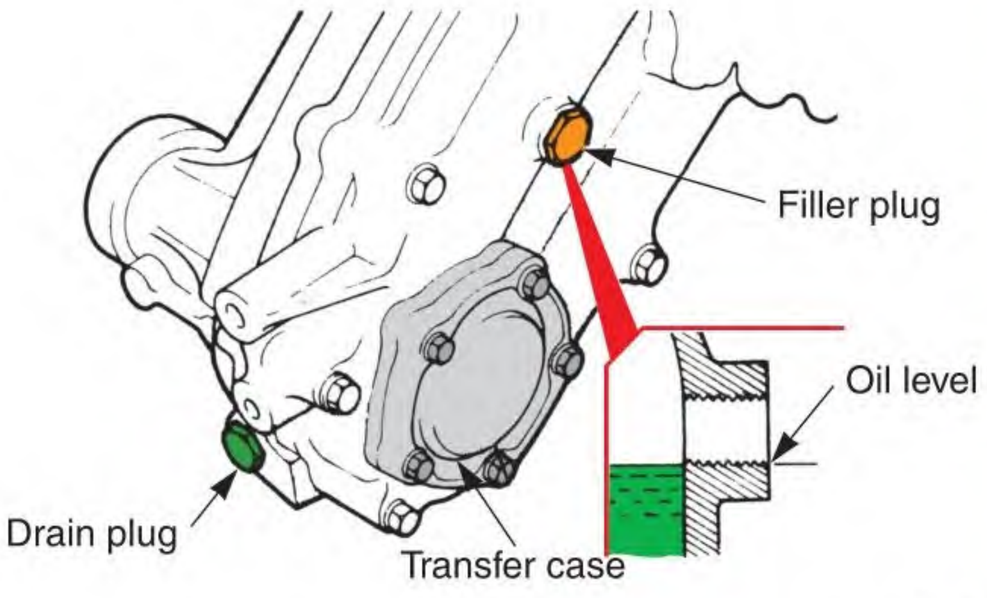
Transfer Case Service

Transfer case service is required when the unit makes abnormal noises (grinding, whining), fails to engage properly, or is locked in a range.

When diagnosing transfer case problems, check the condition and level of the oil in the unit first. See **Figure 68-9**. If the oil is dirty or contaminated with water, drain and replace it. Make sure you install the fluid type and viscosity recommended by the manufacturer.

When removing a transfer case, use a transmission jack. A transfer case is heavy and can cause injury or part damage if it is dropped.

Figure 68-10 shows the parts of a modern transfer case. To repair a transfer case, follow the make- and model-specific procedures outlined in the service manual. There are so many design variations, it is not in the scope of this book to explain the rebuilding procedures for all types of units.



Chrysler

Figure 68-9. Remove the filler plug to check the amount of oil in a transfer case. The fluid level should be about even with the filler hole.

Diagnostic Case Study

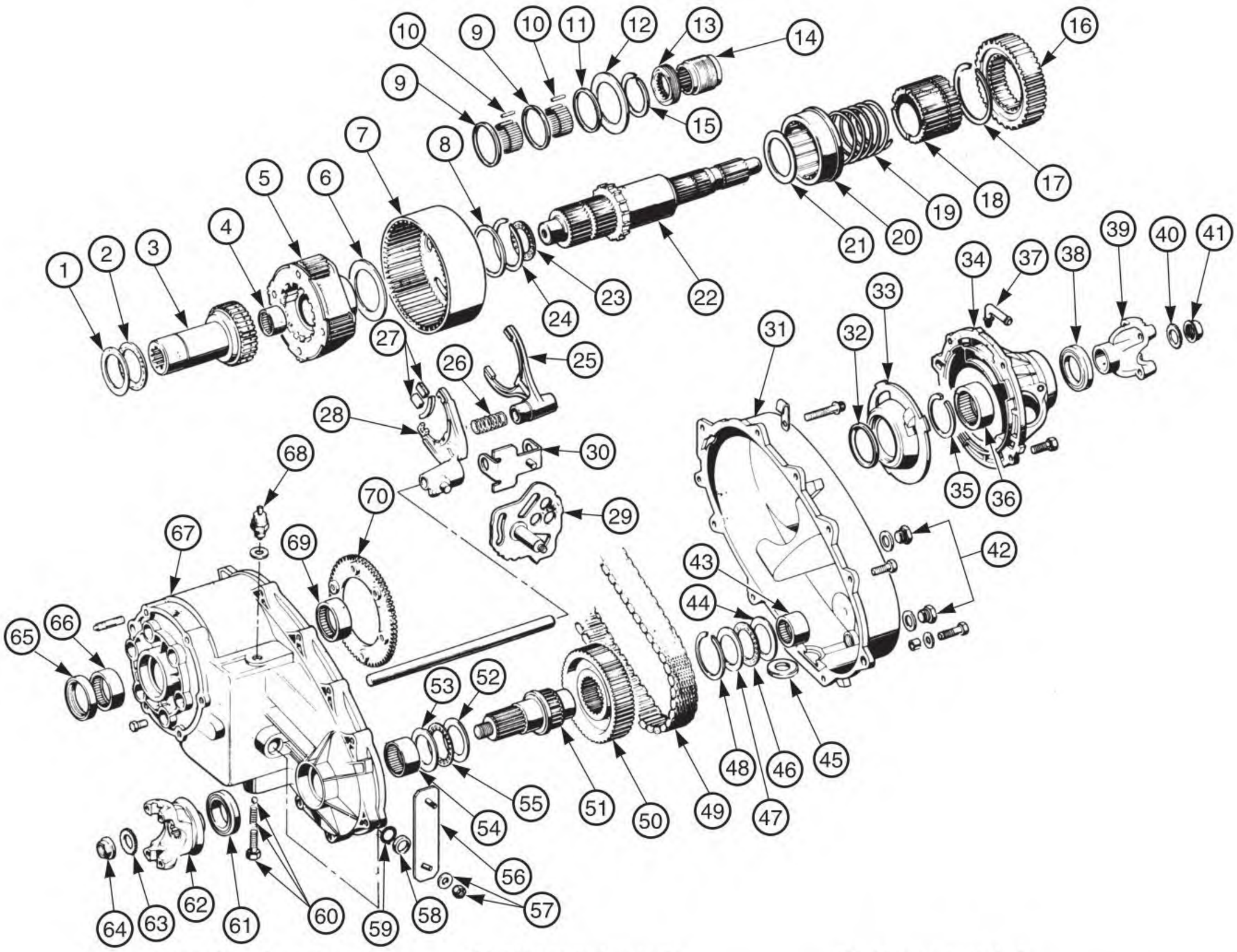
Concern: Ms. Stone brings her 2005 Ford F-150 to the shop. She complains of a chirping noise coming from the rear of her vehicle. When questioned, she said that the noise can only be heard when the car was moving, and that it seems to vary with the speed of the car.

Cause: Duff drives the car into the service bay. There is a loud metallic clunk as the car is put into gear and a cyclic chirping sound as the car moves into the garage. Duff turns the car over to one of the shop's drive train technicians.

The technician raises the vehicle on the lift and inspects the drive shaft. He finds play inside the rear universal joint when the drive shaft is wiggled up and down. He marks the drive shaft for realignment and then removes it. He disassembles the rear universal joint and inspects it for wear and damage. Because of a lack of grease, the needle bearings have dried out, causing excessive joint wear.

Correction: The technician replaces the rear universal joint. He also disassembles and inspects the front universal joint. Since the front universal joint is not worn, he packs it with grease and reassembles it. After reinstalling the drive shaft, the technician test drives the vehicle and then releases it to the customer.

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1. Input gear thrust washer
2. Input gear thrust bearing
3. Input gear
4. Main shaft pilot bearing
5. Planetary assembly
6. Planetary thrust washer
7. Annulus gear
8. Annulus gear thrust washer
9. Needle bearing spacers
10. Main shaft needle bearings (120)
11. Needle bearing spacer
12. Thrust washer
13. Oil pump
14. Speedometer gear
15. Drive sprocket retaining ring
16. Drive sprocket
17. Sprocket carrier stop ring
18. Sprocket carrier
19. Clutch spring
20. Sliding clutch
21. Thrust washer
22. Main shaft
23. Main shaft thrust bearing
24. Annulus gear retaining ring
25. Mode fork
26. Mode fork spring
27. Range fork inserts
28. Range fork
29. Range sector
30. Mode fork bracket
31. Rear case
32. Seal
33. Pump housing
34. Rear retainer
35. Rear output bearing
36. Bearing snap ring
37. Vent tube
38. Rear seal
39. Rear yoke
40. Yoke seal washer
41. Yoke nut
42. Drain and fill plugs
43. Front output shaft rear bearing
44. Front output shaft rear thrust bearing race (thick)
45. Case magnet
46. Front output shaft rear thrust bearing
47. Front output shaft rear thrust bearing race (thin)
48. Driven sprocket retaining ring
49. Drive chain
50. Driven sprocket
51. Front output shaft
52. Front output shaft front thrust bearing race (thin)
53. Front output shaft front thrust bearing race (thick)
54. Front output shaft front thrust bearing
55. Front output shaft front bearing
56. Operating lever
57. Washer and locknut
58. Range sector shaft seal retainer
59. Range sector shaft seal
60. Detent ball, spring, and retainer bolt
61. Front seal
62. Front yoke
63. Yoke seal washer
64. Yoke nut
65. Input gear oil seal
66. Input gear front bearing
67. Front case
68. Lock mode indicator switch and washer
69. Input gear rear bearing
70. Lockplate

Chrysler

Figure 68-10. During transfer case repairs, refer to instructions and illustrations in the service manual. It will give details of the particular unit being serviced. Study the construction of this transfer case.

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Summary

- To function properly, the drive shaft must be straight and its universal joints must be unworn.
- Drive shaft noises are usually caused by worn universal joints, slip joint wear, or a faulty center support bearing.
- Grinding and squeaking from the drive shaft is frequently caused by worn universal joints.
- A clunking sound during acceleration or deceleration may be caused by excessive clearance between the slip yoke and transmission extension housing bushing.
- A whining noise from the drive shaft is sometimes caused by a dry, worn center support bearing.
- Drive shaft vibration can be caused by any problem that affects drive shaft balance, runout, and angle.
- To check for worn universal joints, wiggle and rotate each universal joint back and forth while watching for side movement.
- If the drive shaft is within recommended runout limits and still vibrates, the drive shaft may need to be balanced.
- Be extremely careful not to let any part of your body come in contact with the spinning drive shaft or rear wheels.
- If your runout and balance checks fail to find a problem, you may need to check the driveline angle.
- A grease gun can be used to lubricate universal joints that have fittings.
- A worn universal joint, the most common drive shaft problem, can cause squeaking, grinding, clunking, or clicking sounds.
- Wear safety glasses to protect your eyes in case the snap rings fly out of the joint during removal.
- If the bearing cap fails to press into place with normal pressure, disassemble the joint and check the roller bearings.
- When diagnosing transfer case problems, check the condition and level of oil.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

drive shaft noise
drive shaft vibration
drive shaft runout
driveline angle
grease gun
worn universal joint
universal joint tools

Activities

1. Inspect a universal joint on a vehicle in the shop. State its condition and indicate if replacement is required.
2. Explain and demonstrate a procedure for checking runout on a drive shaft.
3. Replace a universal joint using the appropriate procedure.
4. Demonstrate the proper technique for removing and replacing a drive shaft.

Review Questions

Answer the following questions using the information provided in this chapter.

1. Drive shaft problems can normally be classified into two categories: drive shaft _____ and drive shaft _____.
2. What are some common causes of drive shaft noise?
3. Grinding or squeaking from the drive shaft is frequently caused by:
   (A) worn slip joint.
   (B) bent drive shaft.
   (C) worn, dry universals.
   (D) None of the above.
4. List three common causes of drive shaft vibration.
5. How do you check for worn universal joints?
6. How do you check drive shaft runout?
7. What should you do if the drive shaft is within recommended runout limits but still vibrates?
8. What is used to check driveline angle?
9. Summarize the procedure for assembly of a universal joint.
10. A transmission jack is commonly used when removing a transfer case. True or False?

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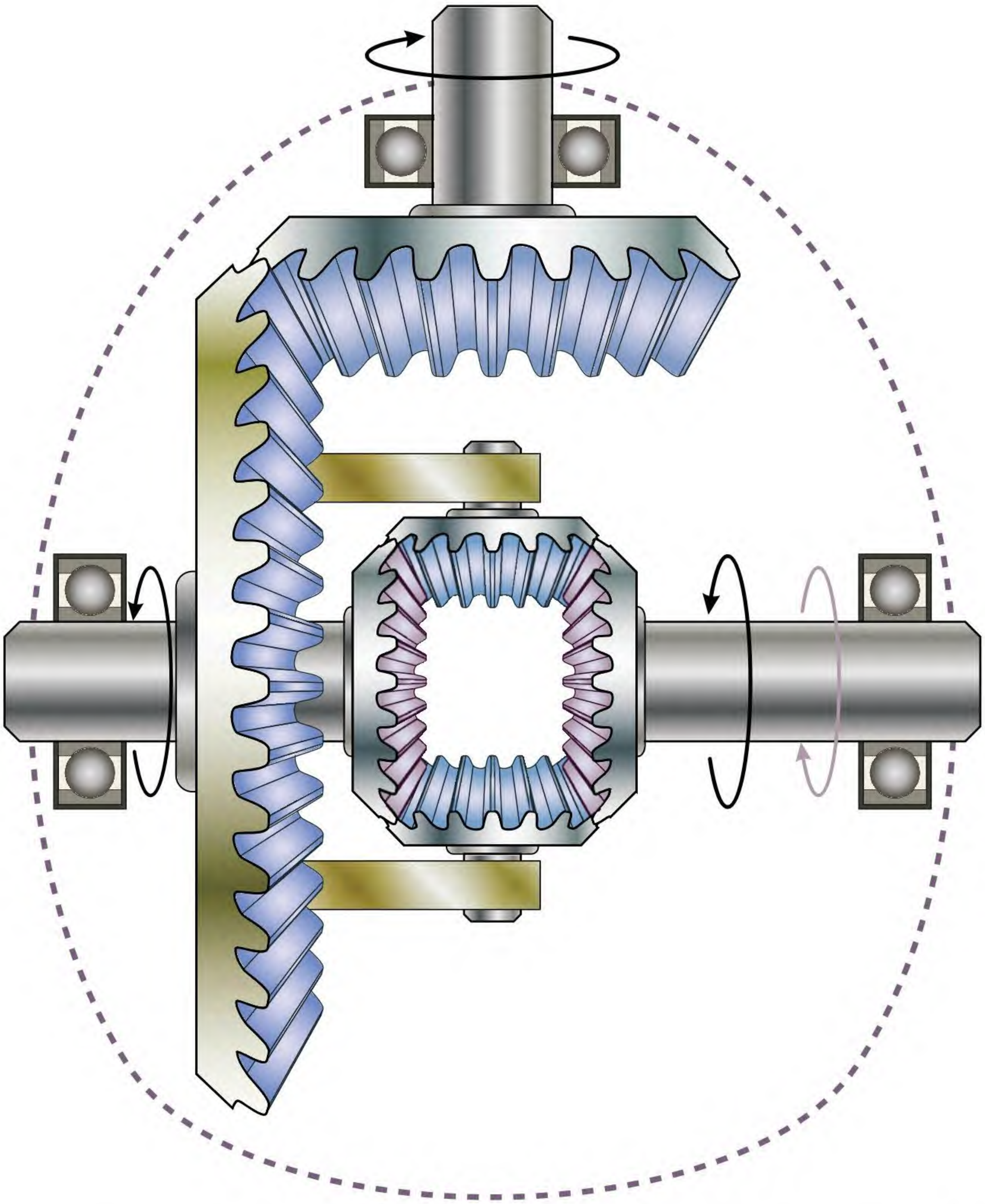
ASE-Type Questions

1. A grinding sound is coming from an automobile's drive shaft assembly. Technician A inspects the condition of the slip yoke. Technician B checks for a bad universal joint. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. A squeaking noise is believed to be coming from underneath an automobile. Technician A says this noise may indicate a bad universal joint. Technician B says the car's wheel covers may be producing this noise. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. A whining noise is coming from an automobile's drive shaft assembly. Technician A says this problem is the result of a bad transmission input shaft bushing. Technician B looks for a worn center support bearing. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. A customer complains that a vibration-type noise is coming from the bottom of his/her car. Technician A checks the drive shaft for runout. Technician B inspects the condition of the universal joint. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. Vibration is coming from underneath an automobile. Technician A checks the condition of the drive shaft. Technician B checks for an unbalanced engine flywheel. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. All of the following are common drive shaft problems, *except*:
   (A) drive shaft warpage.
   (B) worn universal joint.
   (C) damaged center support bearing.
   (D) carrier warpage.
7. A car's drive shaft needs to be inspected for problems. Technician A inspects the balance weights. Technician B inspects the condition of the rear yoke bolts. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. A car's drive shaft needs to be checked for runout. Technician A is going to use an inside micrometer to perform this task. Technician B is going to use a dial indicator to perform this task. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. A car is brought into the shop to have the drive shaft inspected. Technician A places the transmission in neutral when measuring for shaft runout. Technician B places the transmission in park when measuring for shaft runout. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. An automobile's drive shaft has excessive runout. Technician A believes a bent drive shaft may have caused this problem. Technician B thinks a damaged slip yoke could have caused this problem. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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11. Drive shaft runout on a particular automobile measures 0.050". Technician A says this measurement indicates that runout is still within specifications. Technician B says this measurement indicates that runout is beyond specifications. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
12. An automobile is brought into the shop with an incorrect drive shaft angle. Technician A adjusts the drive shaft angle by placing shims under the rear axle housing. Technician B adjusts the drive shaft angle by placing shims under the transmission mount. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
13. A customer wants his/her automobile's universal joints greased. Technician A tells the customer that certain modern universal joints are normally sealed units that are filled with grease at the factory. Technician B tells the customer that some universal joints have grease fittings that allow for lubrication. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
14. A drive shaft needs to be removed from a vehicle. To begin this procedure, Technician A removes the drive shaft's slip yoke mounting bolts. To begin this procedure, Technician B unbolts the center support bearing. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
15. A transfer case's problem is being diagnosed. Technician A checks the lubricant to determine if it is dirty or contaminated. Technician B removes the transfer case by using a transfer jack. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Fouad A. Saad

A differential gearset performs multiple functions. It increases torque, supplies power to both drive axles, and allows each drive axle to turn at a different speed.

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Chapter 69
Differential and Rear Drive Axle Technology

After studying this chapter, you will be able to:

- Identify the major parts of a rear drive axle assembly.
- List the functions of a rear axle assembly.
- Describe the operation of a differential.
- Relate rear axle ratios to vehicle performance.
- Explain differential design variations.
- Describe the principles of a limited-slip differential.
- Compare different types of axles.
- Explain electro-hydraulic differentials.
- Correctly answer ASE certification test questions requiring a knowledge of differential and rear drive axle fundamentals.

Many new cars and most trucks use a front-engine, rear-wheel-drive setup. After engine power flows through the transmission and drive shaft, it enters the rear axle assembly. The rear axle assembly's differential and axle shafts then transfer torque to the rear drive wheels. Cars equipped with all-wheel drive require two differentials to power four-wheel drive axles and wheels.

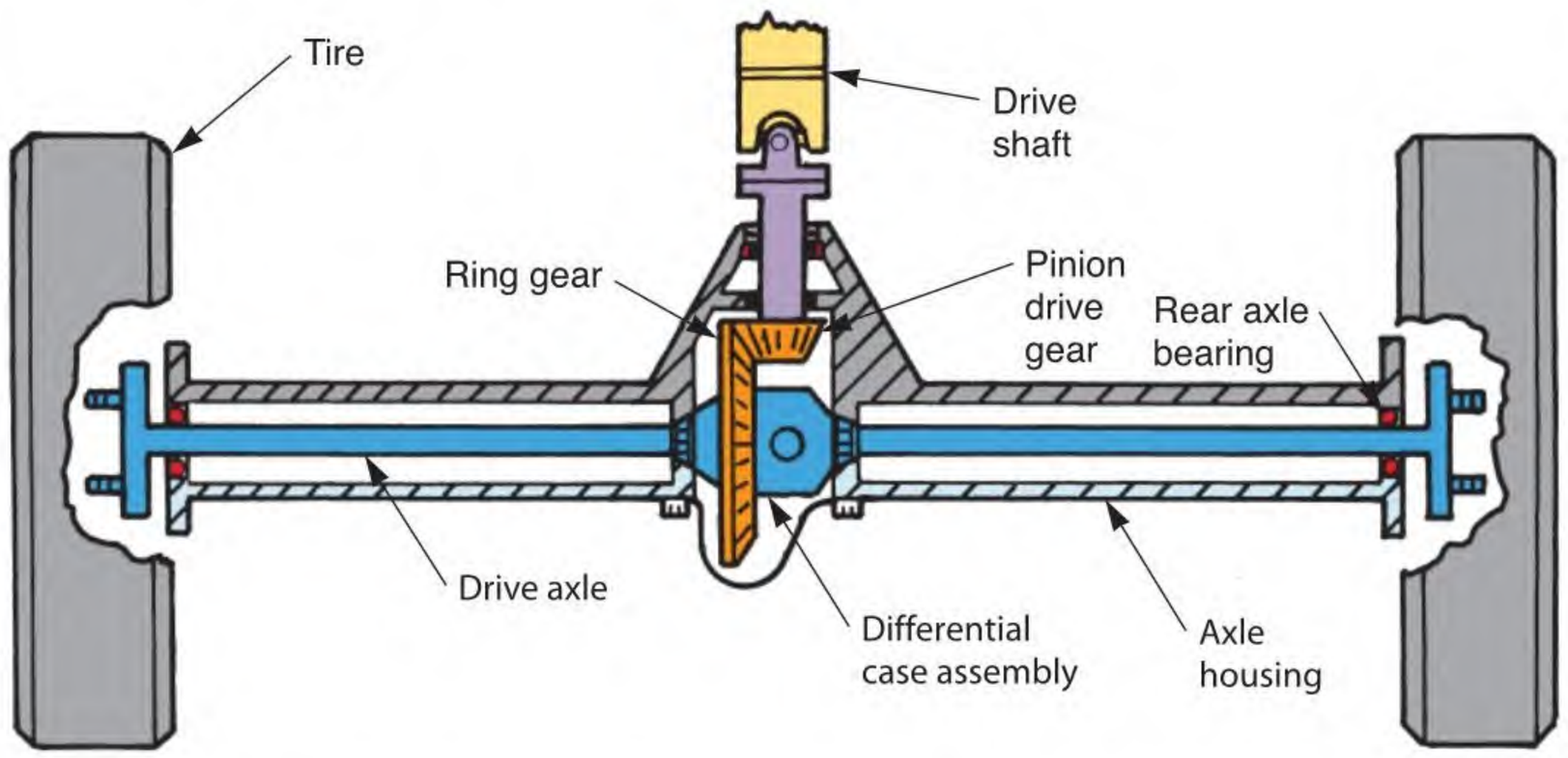
As you will learn in later chapters, front-engine, front-wheel-drive vehicles also use a differential, but it is located inside the transaxle. This chapter will prepare you to understand transaxles and front-wheel-drive systems.

Basic Rear Drive Axle Assembly

A simple ***rear drive axle assembly*** is shown in **Figure 69-1**. It consists of the following parts:

- ***Pinion gear***—The differential pinion gear transfers power from the drive shaft to the ring gear.
- ***Ring gear***—The differential ring gear transfers turning power to the differential case assembly.
- ***Differential case***—The differential case, or ***differential housing***, holds the ring gear and spider gears that drive the rear axles.
- ***Rear drive axles***—Rear drive axles are steel shafts that transfer torque from the differential assembly to the drive wheels.
- ***Rear axle bearings***—Rear axle bearings are ball or roller bearings that fit between the axles and the inside of the axle housing.
- ***Axle housing***—The axle housing is a metal body that encloses and supports parts of the rear axle assembly.

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Figure 69-1. Note the basic parts of this simplified rear drive axle assembly. The drive shaft turns the pinion gear. The pinion gear turns the ring gear and differential case assembly. The differential transfers power to the drive axles and wheels.

Rear Axle Power Flow

Power enters the rear axle assembly from the drive shaft. The drive shaft spins the pinion gear. The pinion gear turns the larger ring gear to produce a gear reduction.

The ring gear is bolted to the differential case, so the case rotates with the ring gear. Small gears inside the differential case send torque to each axle.

The axles extend beyond the axle housing. The axles normally hold and turn the rear wheels to propel the vehicle.

Functions of a Rear Drive Axle

A rear drive axle assembly has several functions. These include:

- Sending power from the drive shaft to the rear wheels.
- Providing a final gear reduction.
- Transferring torque through a 90° angle.
- Splitting the amount of torque going to each wheel.
- Allowing the wheels to rotate at different speeds in turns.
- Supporting the rear axles, brake assemblies, suspension components, and chassis.

Differential Construction

A ***differential assembly*** uses drive shaft rotation to transfer power to the axle shafts. The differential must be capable of providing torque to both axles, even when they are turning at different speeds (when the vehicle is turning a corner, for example).

Pinion Gear and Ring Gear

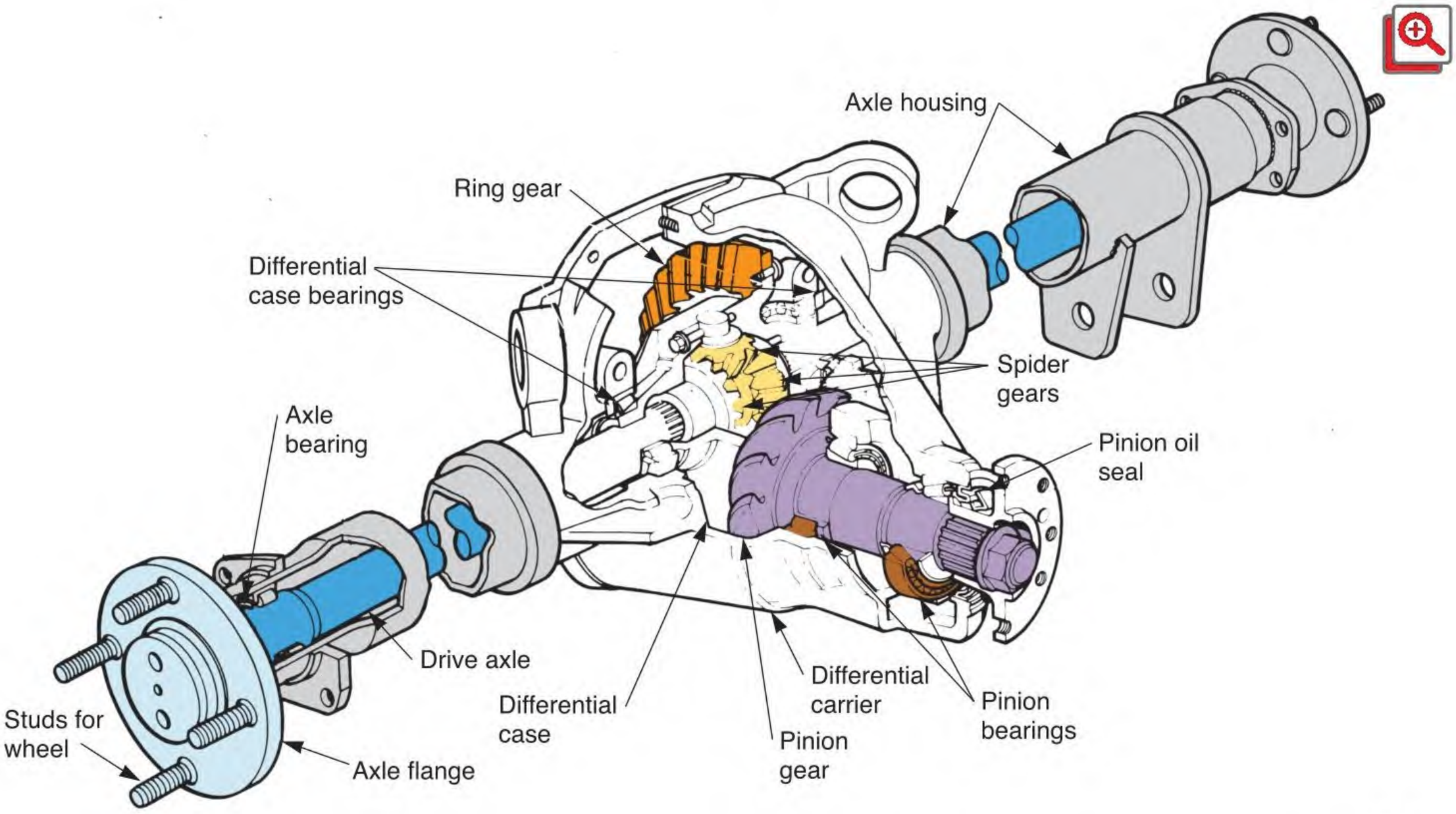
The pinion gear turns the ring gear when the drive shaft is rotating. See **Figure 69-2**. The outer end of the pinion drive gear is splined to the rear universal joint companion flange or yoke. The inner end of the pinion gear meshes with the teeth on the ring gear. The pinion gear is normally mounted on tapered roller bearings. They allow the pinion gear to revolve freely in the carrier. Either a crushable sleeve or shims are used to preload the pinion gear bearings. ***Gear preload*** is a small amount of pressure applied to the bearings to remove play and excess clearance.

With some differentials, the extreme inner end of the pinion gear is supported by a pinion pilot bearing. This is a straight roller bearing. The ***pinion pilot bearing*** helps the two tapered roller bearings support the pinion gear during periods of heavy load or rapid vehicle acceleration. See **Figure 69-3**.

The ring gear is driven by the pinion gear and transfers rotating power through an angle change of 90°. The ring gear has more teeth than the pinion gear. Bolts hold the ring gear securely to the differential case. Refer to **Figure 69-4**.

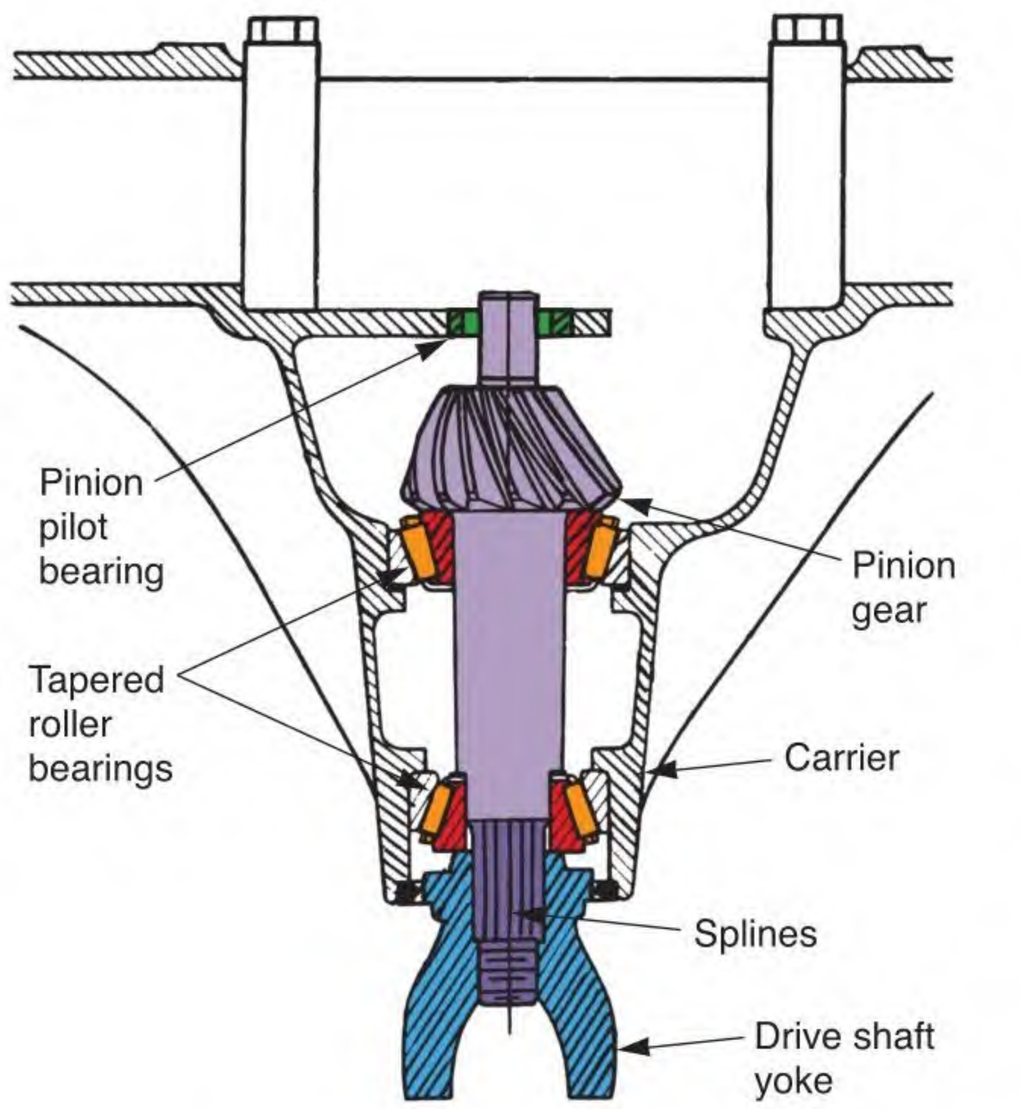
The ring gear and pinion gear are commonly a matched set. This set is ***lapped*** (meshed and spun together with abrasive compound on their teeth) at the factory. Then, one tooth on each gear is marked to show the correct tooth engagement. Lapping produces quieter operation and ensures longer gear life.

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Ford

Figure 69-2. This cutaway shows a detailed view inside the axle housing. Note the relationship of parts. The axle housing fastens to suspension components.



Ford

Figure 69-3. The pinion gear is mounted on tapered roller bearings and sometimes a pinion pilot bearing. The drive shaft yoke is splined to the pinion gear.

Hunting and Nonhunting Gears

A ***hunting gearset*** does not mesh the same gear teeth during each revolution of the ring gear. The number of teeth on the pinion compared to the number of teeth on the ring gear causes different teeth to mesh.

A ***nonhunting gearset*** meshes the same gear teeth over and over during gearset operation. Most ring and pinion gears are nonhunting types. They will have markings that must be aligned during assembly.

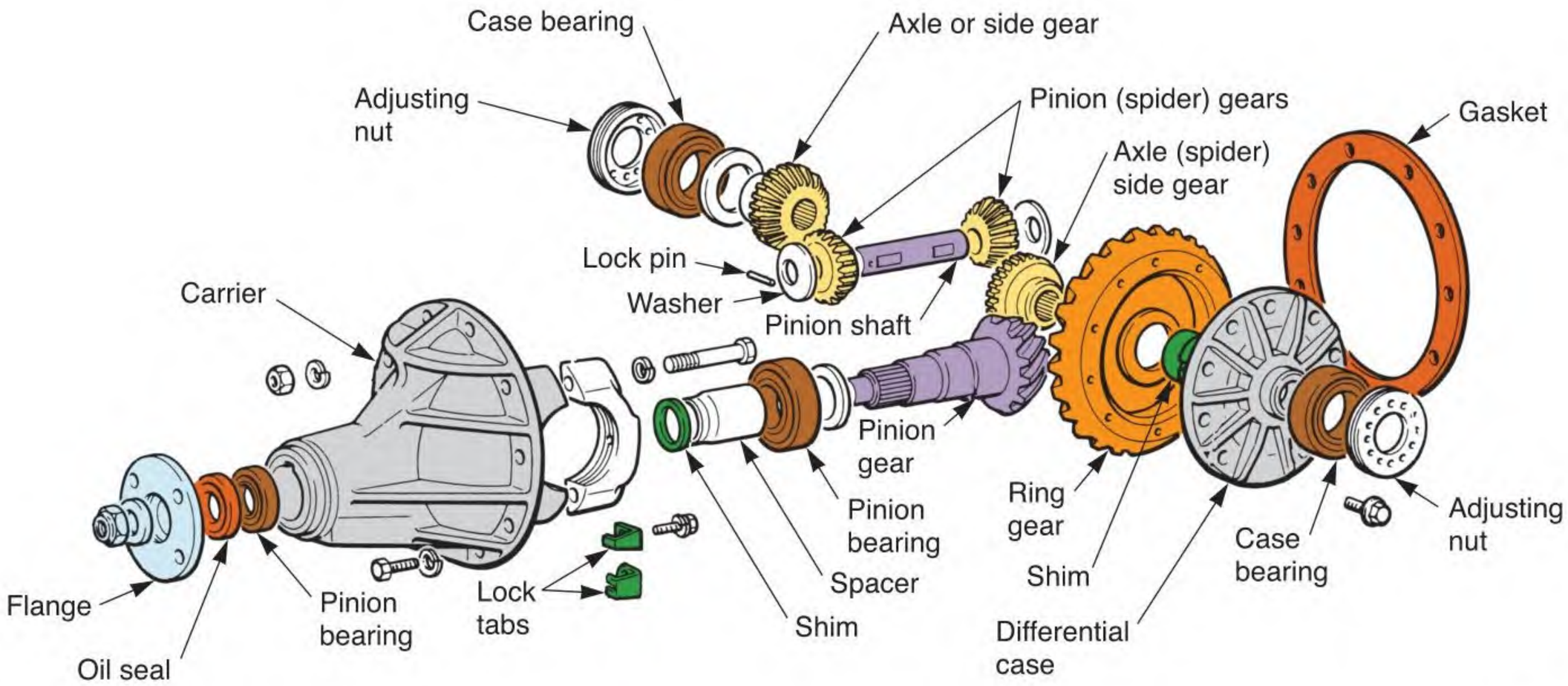
Hypoid and Spiral Bevel Gears

Hypoid gears have the driving pinion centerline offset, or lowered, from the centerline of the ring gear. Modern differential ring and pinion gears are hypoid type. Refer to **Figure 69-5**.

Spiral bevel gears have curved gear teeth with the pinion and ring gears on the same centerline. This type of gear setup is no longer used.

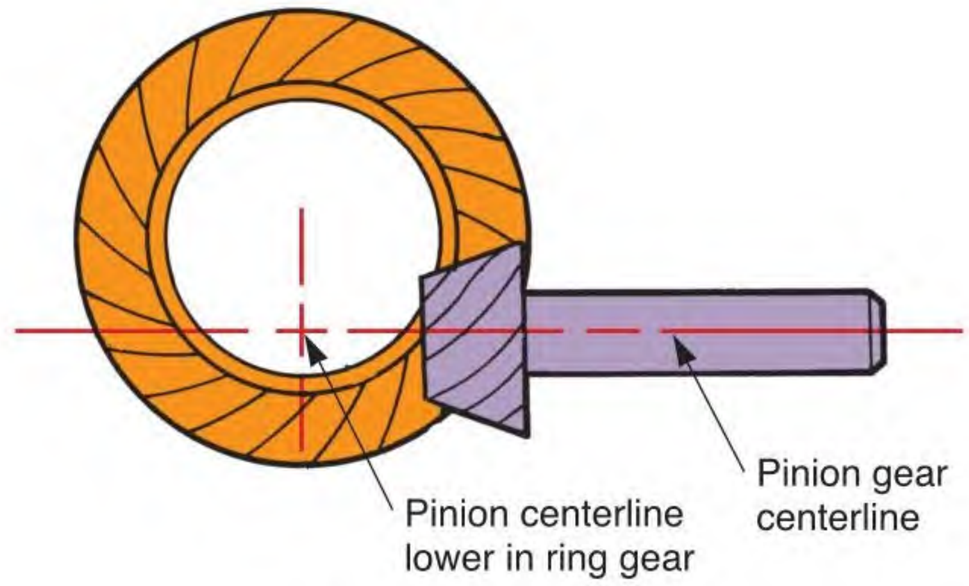
Hypoid gears have replaced spiral bevel gears because they allow for a lower hump in the vehicle floor and improve gear meshing action. Hypoid gears have a larger gear tooth contact area than spiral bevel gears. This helps increase gear life and reduce gear noise.

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Chrysler

Figure 69-4. This exploded view shows all the major parts of a differential assembly. The ring gear bolts to the differential case. The case mounts in bearings, which are adjusted using large nuts. Study the part names and how they fit together.



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Figure 69-5. Modern ring and pinion gears are hypoid type. Note how hypoid lowers the centerline of the pinion gear. This improves gear tooth contact and lowers the drive shaft hump in the floor of the vehicle.

Rear Axle Ratio

Rear axle ratio, or ***differential ratio***, is the ratio of ring gear teeth to pinion gear teeth. To calculate rear axle ratio, count the number of teeth on each gear. Then, divide the number of ring gear teeth by the number of pinion teeth. For example, if the ring gear has 30 teeth and the pinion gear has 10 teeth, the rear axle ratio would be 3:1 (30 divided by 10).

Generally, automakers use a rear axle ratio that provides a compromise between performance and economy. An average ratio is 3.50:1.

A higher axle (numerical) ratio, 4.11:1 for instance, increases acceleration and pulling power, but decreases fuel economy. The engine has to run at a higher speed to maintain an equal cruising speed. A 4.11:1 ratio might be found in a full-size pickup truck.

A lower rear axle ratio, such as 3:1, reduces acceleration and pulling power, but increases fuel economy. The engine runs at a lower speed while maintaining a constant vehicle speed.

Tech Tip

Do not become confused about the terms "rear axle ratio" and "final drive ratio." Rear axle ratio is the ratio between the differential pinion and ring gears. Final drive ratio, or overall drive ratio, includes the axle ratio and the transmission/transaxle high-gear ratio.

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Differential Carrier

The ***differential carrier*** provides a mounting place for the pinion gear, differential case, and other differential components. There are two basic types of differential carriers: the removable carrier and the integral (unitized) carrier.

A ***removable carrier*** bolts to the front of the axle housing. Stud bolts are installed in the housing to provide proper carrier alignment, **Figure 69-6A**. A gasket fits between the carrier and the housing to prevent oil leakage.

An ***integral carrier*** is constructed as part of axle housing. A stamped metal or cast aluminum cover bolts to the rear of the integral carrier, **Figure 69-6B**.

Differential Case

The differential case holds the ring gear, spider gears, and inner ends of the axles. It mounts and rotates in the carrier. See **Figure 69-7**. ***Case bearings***, also called ***carrier bearings***, fit between the outer ends of the differential case and the carrier.

Spider Gears

The ***spider gears***, or ***differential gears***, include two ***axle gears*** (differential side gears) and two pinion gears (differential idler gears). The spider gears are small bevel gears that mount inside the differential case. Refer again to **Figure 69-4**.

A ***pinion shaft*** passes through the two pinion gears and the case. The two axle gears are splined to the inner ends of the axles.

Differential Lubricant

Differential lubricant, usually SAE 80W-90 gear oil, is used to reduce friction between the moving parts in the rear axle assembly. Ring gear rotation splashes the oil on all moving parts to prevent wear. Without proper lubricant, a differential will usually overheat and lock up very quickly.

Tech Tip

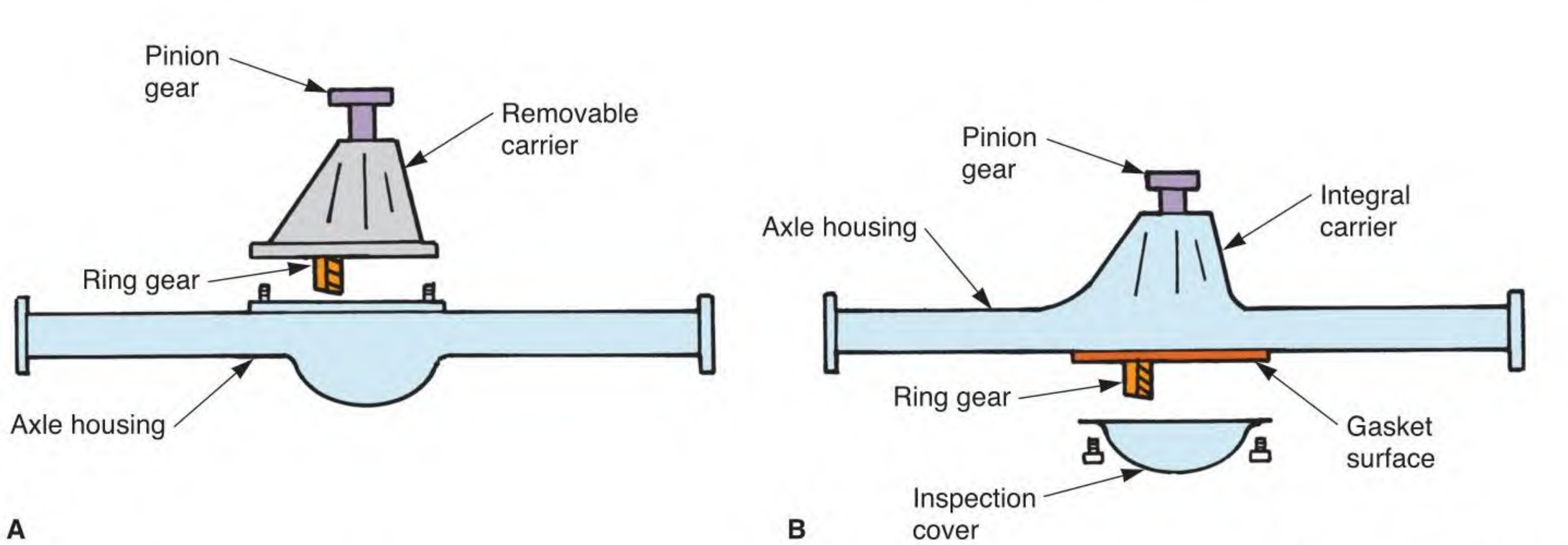
A clutch-type limited-slip differential usually requires a special gear lubricant for the clutch pack. The friction discs will not function properly with regular gear oil.

Differential Action

The rear wheels of a car do not always turn at the same speed. When the car is turning or when tire diameters differ slightly, the rear wheels must rotate at different speeds.

If there were a solid connection between each rear axle and the differential case, the tires would tend to slide, squeal, and wear whenever the vehicle turned. A differential is designed to prevent this problem.

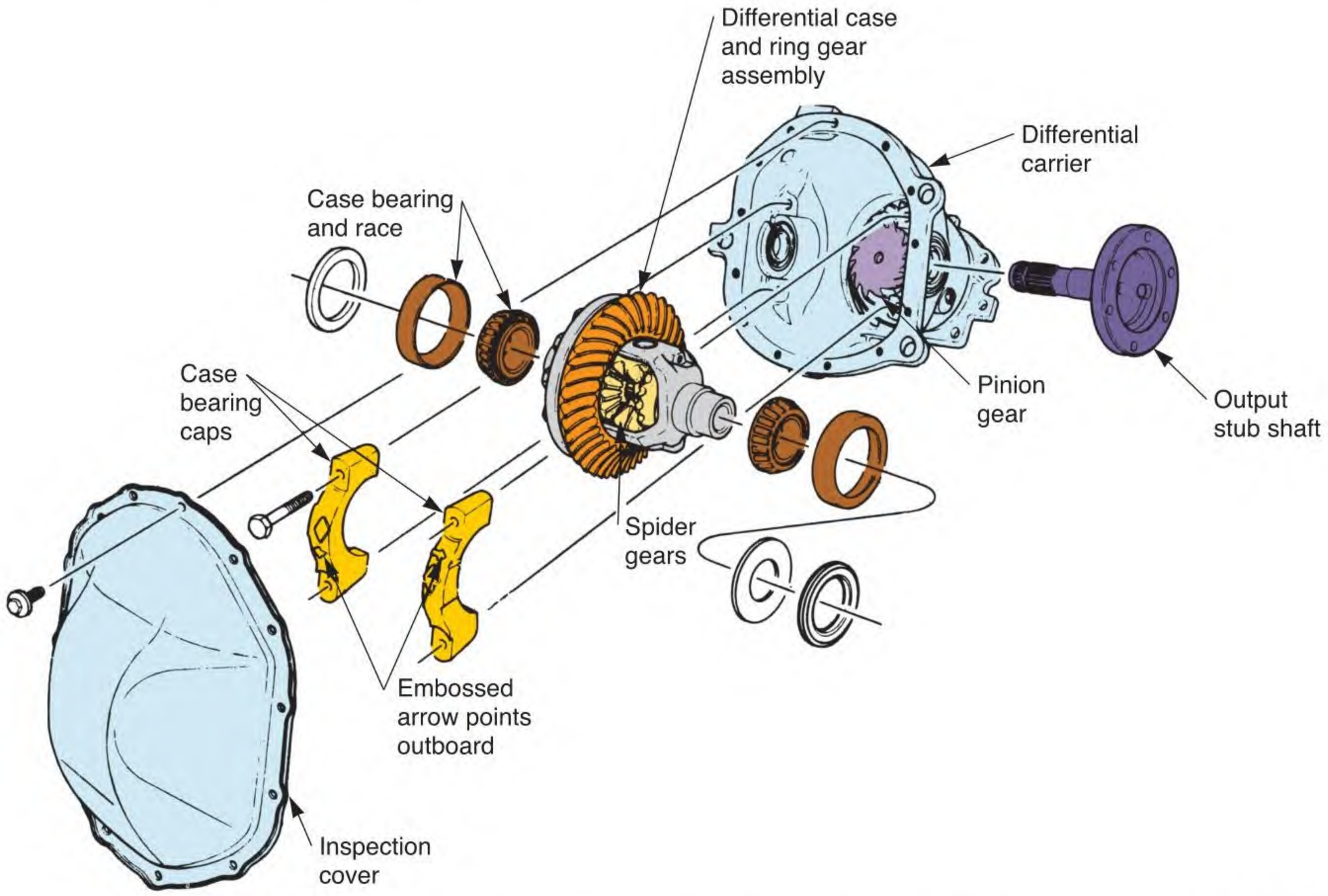
When driving straight, both rear wheels turn at the same speed. The spinning case and pinion shaft rotate the differential pinion gears. The teeth on the pinion gears apply torque to the axle gears and axles. Balanced forces make the differential appear to be locked. Look at **Figure 69-8A**.



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Figure 69-6. Two basic types of solid rear axle carriers. A—A removable carrier is handy because it can be serviced at a workbench. B—An integral, or unitized, carrier is formed as part of the axle housing.

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Subaru

Figure 69-7. The differential case mounts in the carrier on tapered roller bearings. Races fit between the bearings and the carrier. Large caps secure bearing assemblies.

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Figure 69-8. Differential action allows wheels to turn at different speeds. A—Vehicle traveling straight. The differential spider gears are inactive. Spider gears seem to be locked. B—With the car turning a corner, the outer wheel must travel farther and turn faster than the inner wheel. Pinion spider gears rotate on their shaft, allowing axle side gears to turn at different speeds.

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When the vehicle is turning a corner, the outer wheel turns faster than the inner wheel. The outer wheel must travel farther than the inner wheel. See **Figure 69-8B**.

The action of the spider gears allows each axle to change speed while still transferring torque to propel the car. Without a differential, you could break an axle or wear out tires because of the different turning speeds of the rear wheels.

Limited-Slip Differentials

With an ***open differential***, there may not be adequate traction on slippery pavement, in mud, or during rapid acceleration. When one rear wheel on a vehicle with an open differential lacks traction (on ice, for example), the other wheel cannot propel the vehicle. Torque flows through the spider gears and to the axle that turns easiest.

A ***limited-slip differential*** provides driving force to both rear wheels at all times. It transfers a portion of the driving torque to both the slipping wheel and the driving wheel. This helps prevent the vehicle from becoming stuck in mud or snow.

Other names for a limited-slip differential are *positraction*, *sure-grip*, *equal-lock*, and *no-spin*.

Clutch Pack Differential

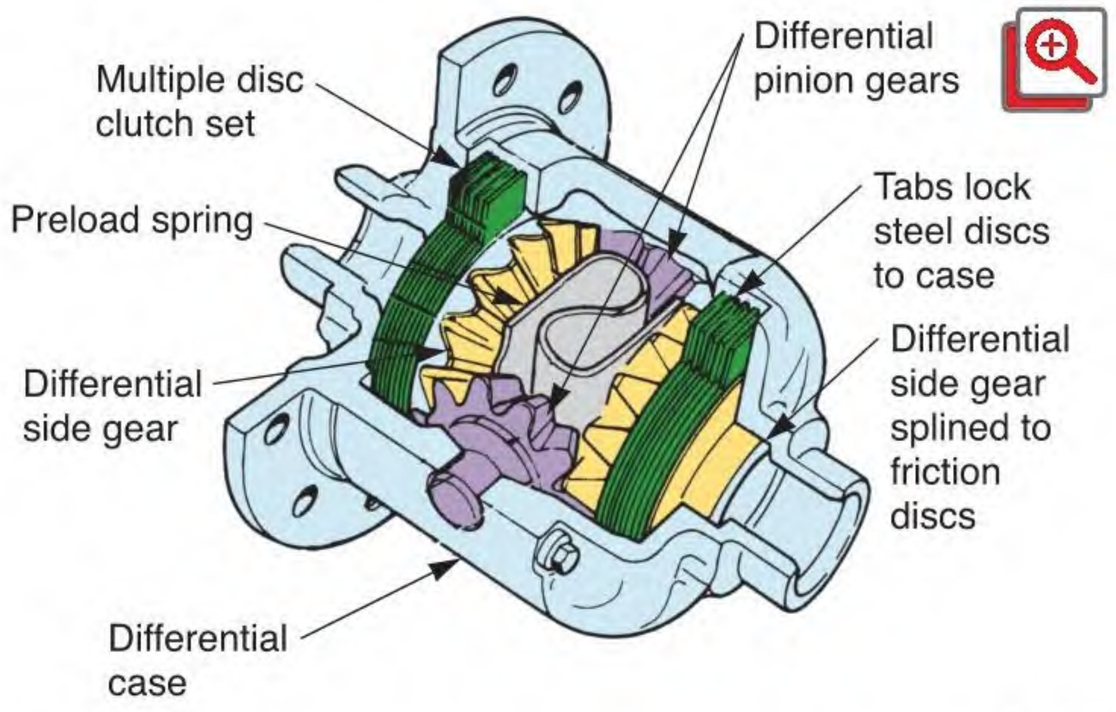
The most popular type of limited-slip differential uses a ***clutch pack*** (set of friction discs and steel plates). The friction discs are sandwiched between the steel plates inside the differential case. See **Figure 69-9**.

The friction discs are usually splined to the differential side gears. The steel plates have tabs that lock into notches in the differential case. The friction discs turn with the axle side gears. The plates turn with the case, **Figure 69-10**.

Springs (belleville springs, coil springs, or a leaf spring) force the friction discs and steel plates together. As a result, both rear axles try to turn with the differential case.

The thrust action of the spider gears normally helps the clutch spring(s) apply the clutch pack. Under high-torque conditions, the rotation of the differential pinion gears pushes out on the axle side gears. The axle side gears then push on the clutch discs. This action helps lock the discs and keeps both rear wheels turning.

However, when driving normally, the vehicle can turn a corner without both wheels rotating at the same speed. The clutch pack will slip in turns, **Figure 69-11**.



Ford

Figure 69-9. This section view of a limited-slip differential shows how clutch discs and spider gears fit in the case. A spring pushes the side gears and clutch discs together. This produces friction, causing both axles to drive the vehicle.

Cone Clutch Differential

A ***cone clutch differential*** uses the friction produced by cone-shaped axle gears to provide improved traction. See **Figure 69-12**. Springs are used to force the cones against the ends of the differential case. With the axles splined to the cone gears, the axles tend to rotate with the case.

Under rapid acceleration, the differential pinion gears push outward on the cone gears. This increases friction between the cones and differential case, and the drive wheels are turned with even greater torque.

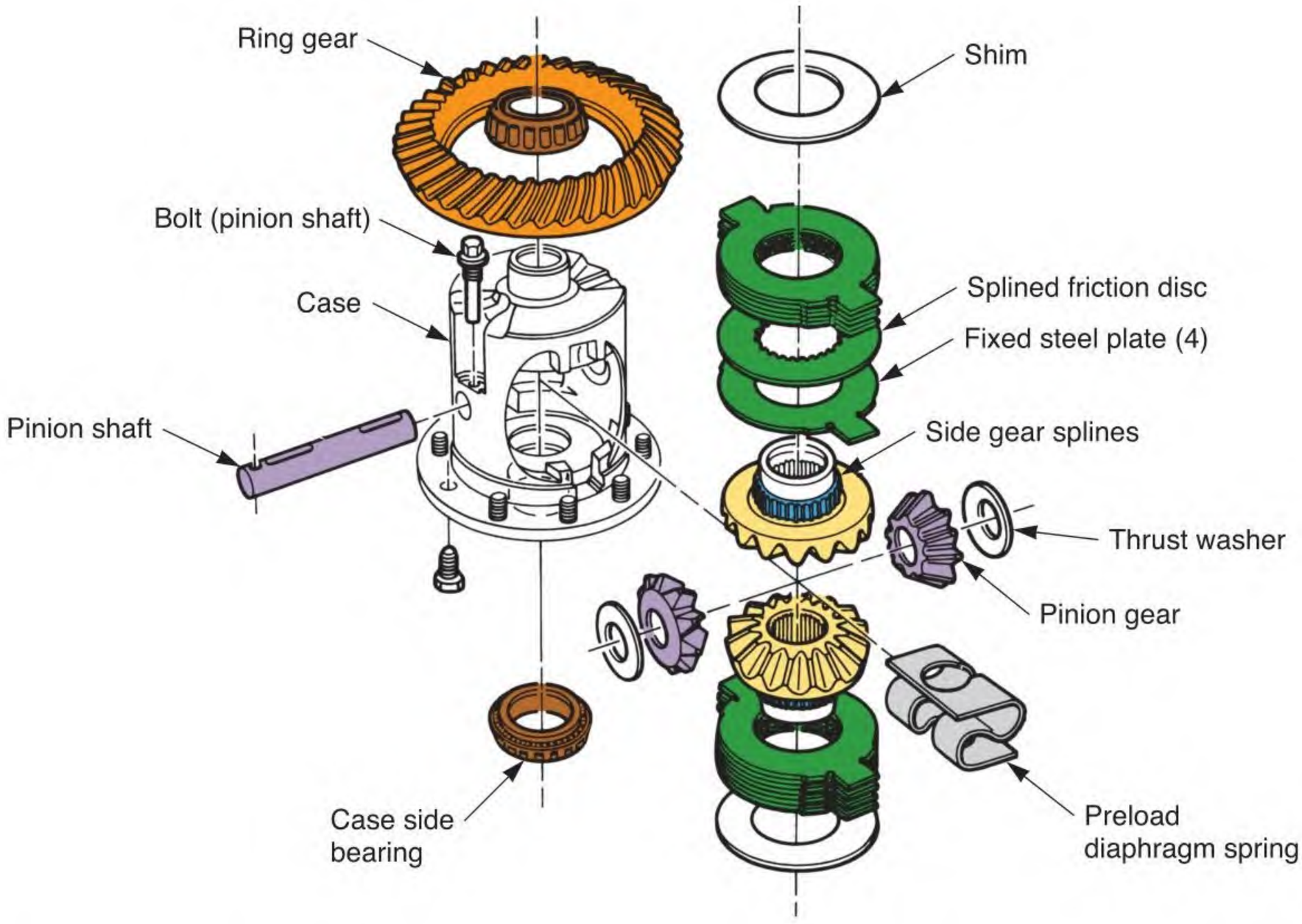
Ratchet Differential

A ***ratchet differential***, also called a ***Detroit locker***, uses a series of cams and ramps to direct torque to the drive axle with the most traction. Its operation is derived from relative wheel speed, rather than traction. The ratchet differential sends power through sets of teeth (***dog clutch***) that can engage and disengage to keep torque applied to the slowest turning axle. The operation of a ratchet differential is illustrated in **Figure 69-13**.

Torsen Differential

A ***Torsen® differential*** is a locking differential that uses complex worm gearsets. The gearsets include worms (drive gears) and worm wheels (driven gears). The basic principle behind this differential design is that worm gears can drive other gears but cannot be driven. The construction of a Torsen differential is shown in **Figure 69-14**.

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Chrysler

Figure 69-10. This limited-slip differential uses belleville or diaphragm springs to preload the clutch discs. The friction discs are splined to the axle side gears. Steel discs are locked to the case by large tabs.

Rear Drive Axles

The rear drive axles connect the differential side gears to the drive wheels. They normally support the weight of the vehicle. Rear axles are usually induction-hardened for increased strength. There are several types of rear axle designs: semifloating, three-quarter floating, full-floating, and swing axles, **Figure 69-15**.

Modern cars normally use semifloating and swing axles. Four-wheel-drive vehicles and some pickup trucks use three-quarter and full-floating axles. Compare the construction of the axle types in **Figure 69-16**.

A ***semifloating axle*** turns the drive wheel and supports the weight of the car. It is the most common type of axle found on automobiles.

A ball or roller bearing fits between the axle shaft and the axle housing. Splines on the inner end of the axle fit into matching splines in the differential side gears. A flange is usually machined on the outer end of the axle shaft. A collar may be used to hold the axle bearing on the axle.

The ***rear wheel bearings*** reduce friction between the axle and axle housing. They allow the axle to turn freely. The inner bearing race fits against the axle. The outer bearing race fits into the machined end of the axle housing. Ball or roller bearings can be used.

The ***rear axle seals*** usually press into the axle housing. The seal lips contact the axle or axle collar to prevent lubricant leakage from the housing.

Axle retainer plates can bolt to the outside of the axle housing to keep the axles from sliding out. They are normally used with a removable carrier differential. See **Figure 69-17**.

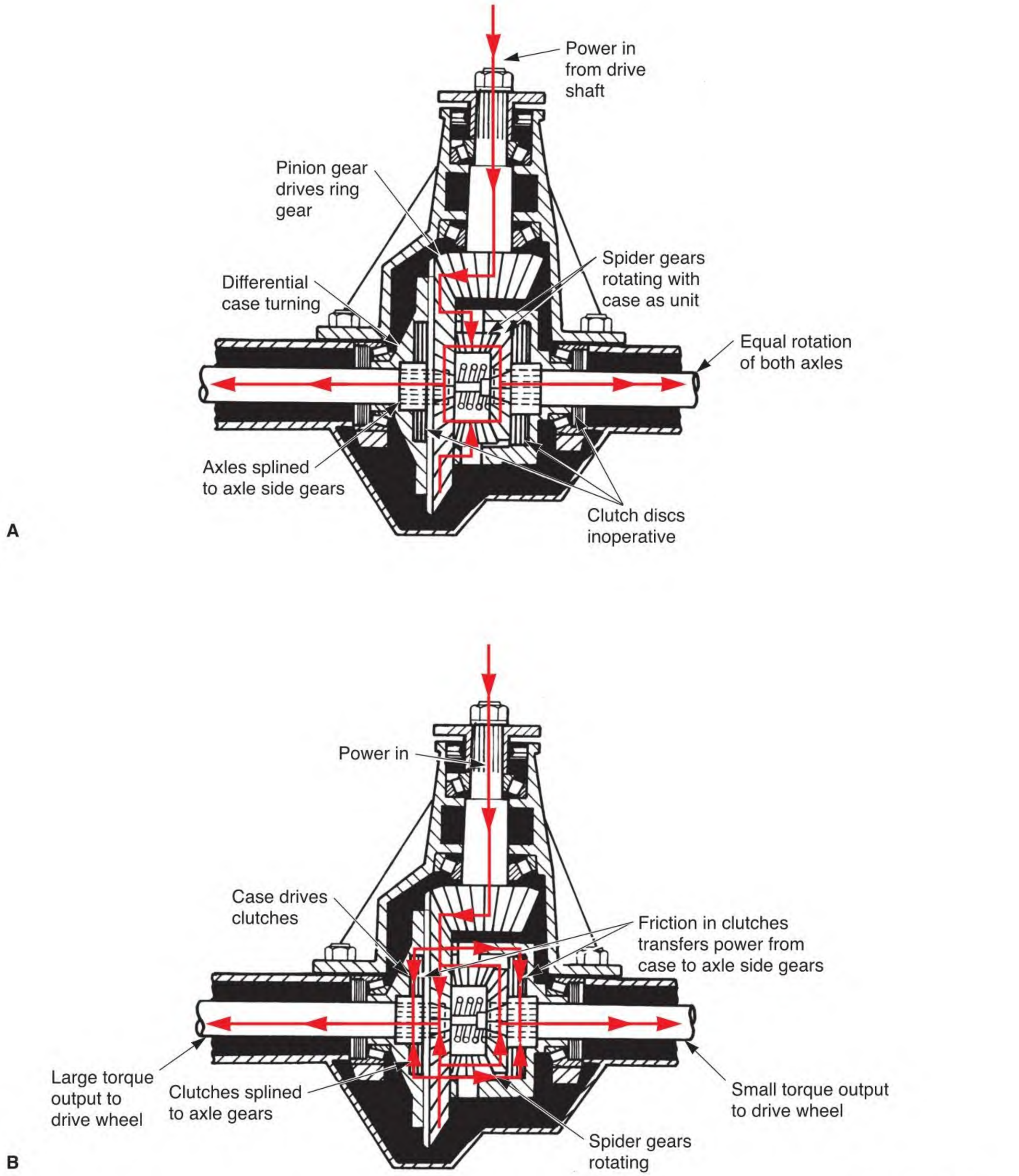
Special bolts usually fit through holes in the housing flange and retainer. Nuts screw on these bolts to secure the axle into the housing.

Axle shims are frequently used between the axle retainer plate and the housing to limit axle end play. The thinner the shim, the greater the end play. Refer to **Figure 69-18**.

Swing Axles

Swing axles are used when the differential is rigidly mounted on the car's frame. Universal joints in the axles allow for up and down suspension action. **Figure 69-19** illustrates front and rear drive axle assembly with swing axles.

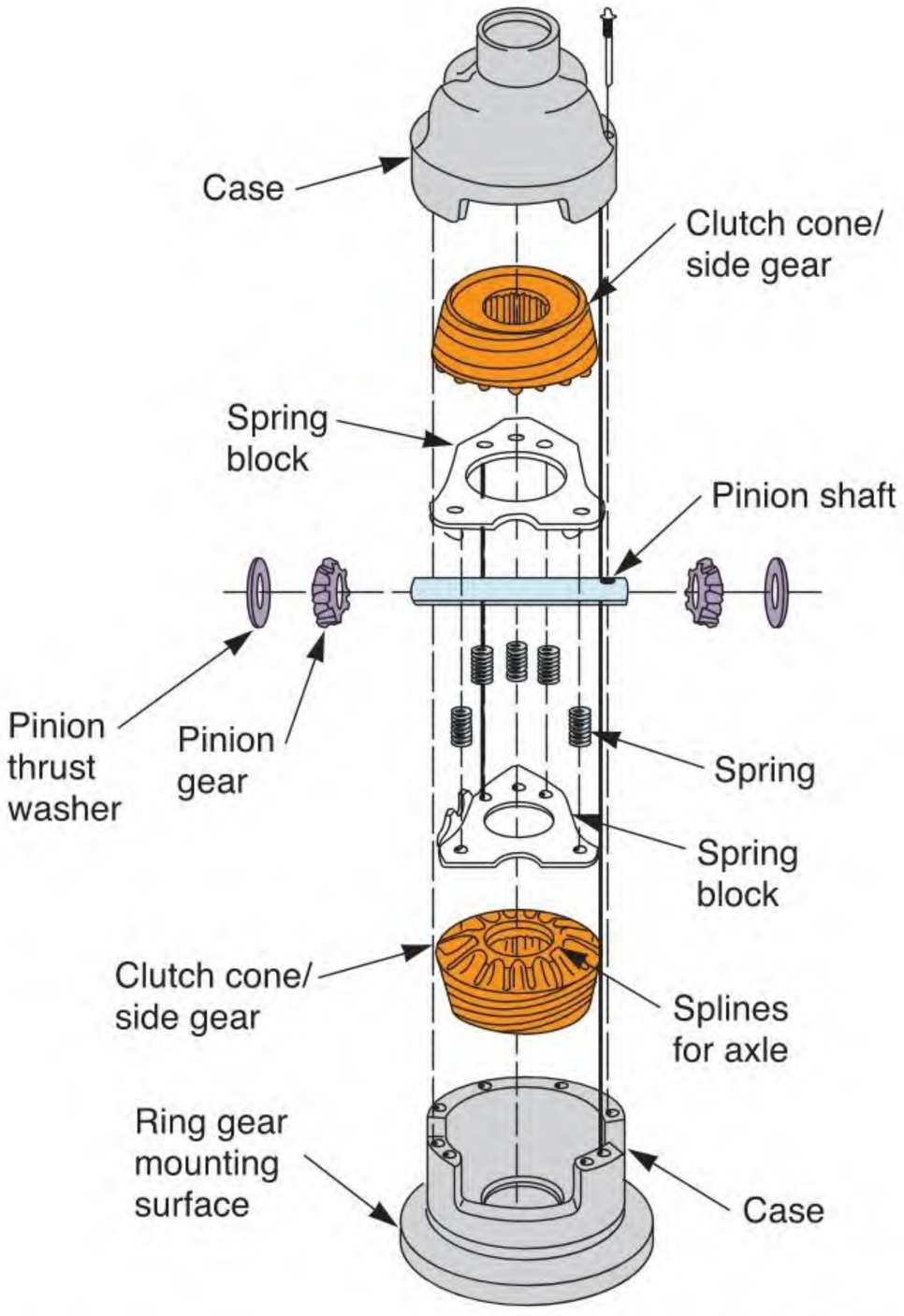
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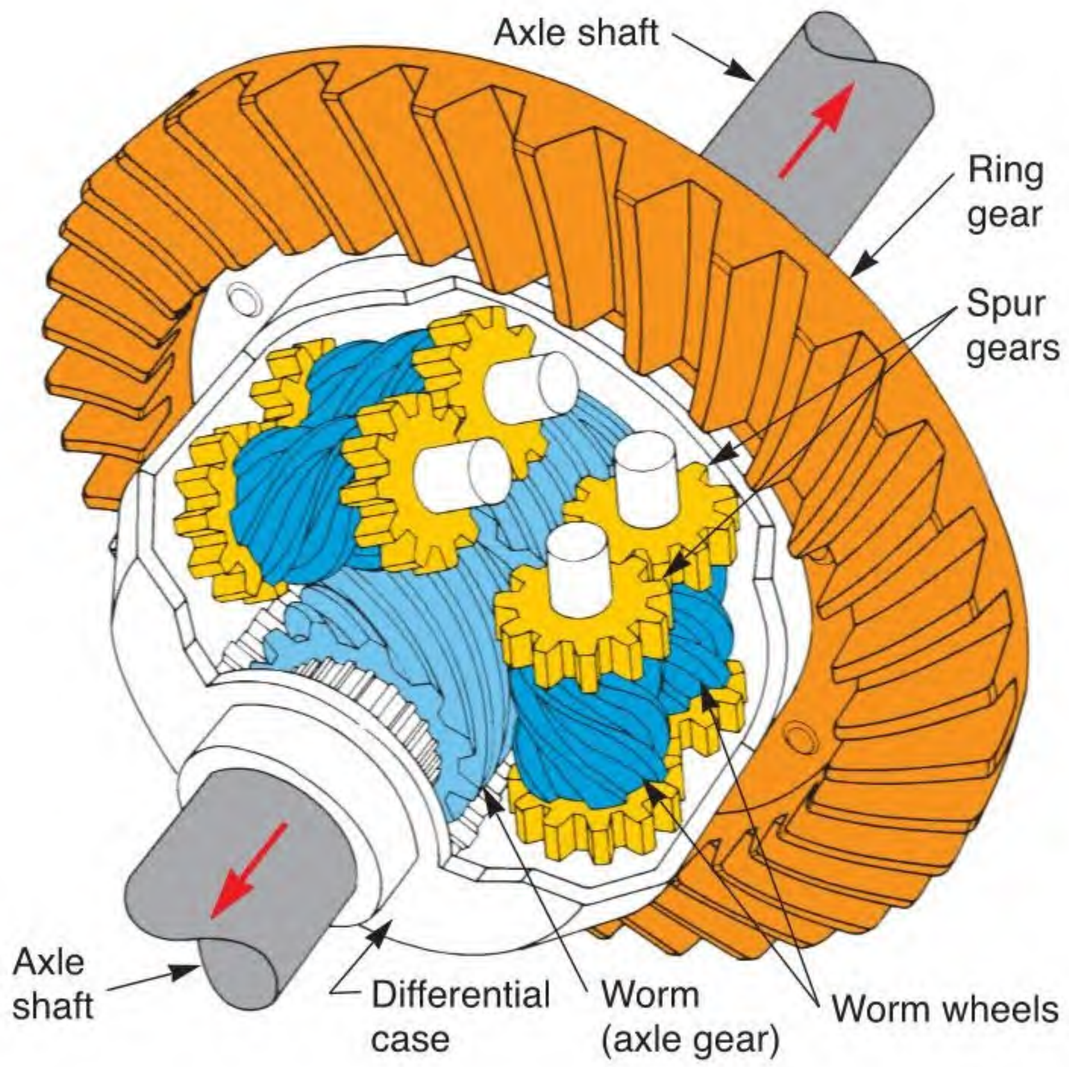
Figure 69-11. Power flow through a limited-slip or posi-traction differential. A—Car is traveling straight ahead and on dry pavement. Spider gears transfer power normally. Clutch discs turn together and do not slip. B—One wheel spins on slippery pavement. Friction between clutches still transfers torque to the other axle. This gives the vehicle more traction than with a conventional differential.

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Figure 69-12. A cone clutch limited-slip differential. The cone surface on the axle side gears serves as friction surface to drive both axles. Increased engine torque pushes the side gears and cones outward to lock the axles. In turns, the side thrust on axles helps release one axle.

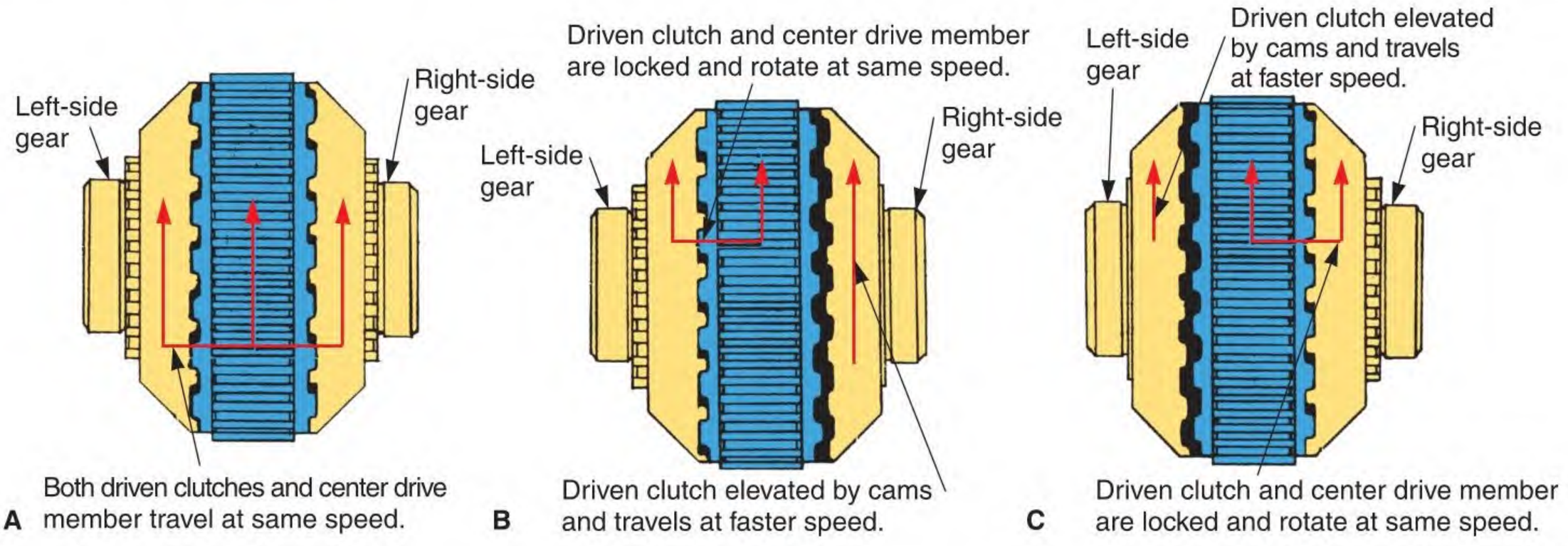


Torsen

Figure 69-14. A Torsen® differential uses a complex series of gears to send the required torque to both drive axles. This differential is used in some exotic, high-priced production vehicles.

The differential works like a conventional unit. However, the drive axles are not solid steel shafts. They are flexible. Each has two universal joints, one U-joint mounted on each end.

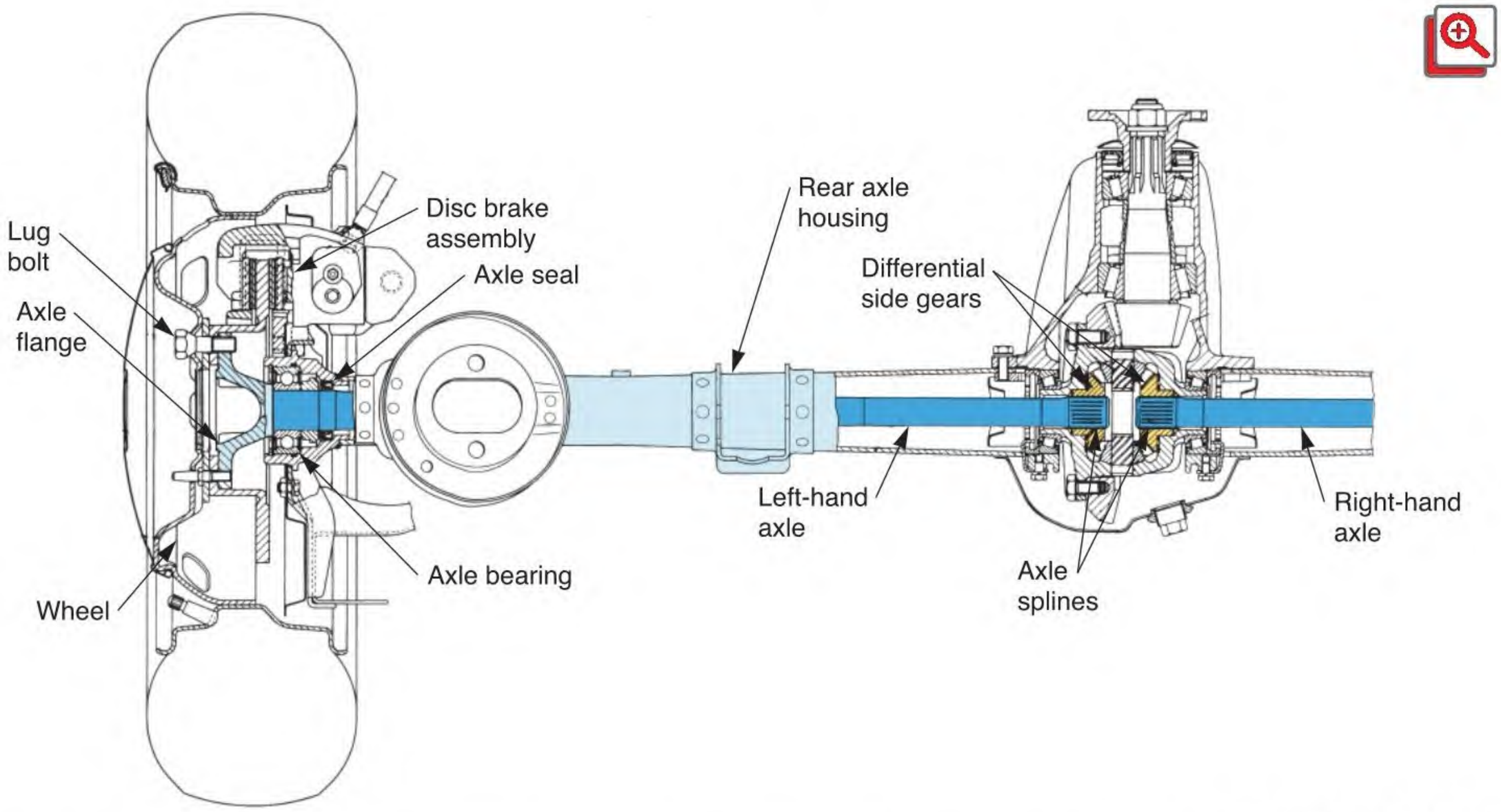
Modern passenger vehicles use swing axles, or CV axles, to transfer differential output power



Ford

Figure 69-13. A ratchet differential. A—During straight-ahead operation, teeth are engaged on both sides of the case. Power is transferred equally to each wheel. B—When making a left turn, the greater speed of the right wheel causes the internal cam on the right side of the case to disengage the right-side teeth. All power goes through the left axle and wheel. C—When making a right turn, the left-side cam disengages the left-side teeth.

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Figure 69-15. A solid steel, case-hardened rear drive axle extends beyond the differential to the outside of the axle housing. The case and side gear support the inner end of the axle. The rear wheel bearing supports the outer end of the axle. Also note the flange on the axle for the wheel.

to the wheel hubs and tires for propulsion. See **Figure 69-20**. Large trucks still use more heavy-duty, solid rear axle assemblies with solid steel axles.

Differential Breather Tube

A ***differential breather tube*** vents pressure or vacuum in or out of the rear axle housing as temperature changes occur.

Without a breather tube, pressure could build as the differential lubricant warmed to operating temperature. Lubricant could blow out the axle seals or pinion drive gear seal.

Front Drive Axle—Four-Wheel-Drive Vehicles

The ***front drive axle*** used in four-wheel-drive systems is similar to a rear drive axle assembly. However, provisions must be made for steering the front wheels. The outer ends of the axles have universal joints, which let the front wheels and hubs swivel while still transferring driving power to the hubs and wheels.

Locking hubs transfer power from the driving axles to the driving wheels on a four-wheel-drive vehicle. There are three basic types of locking hubs:

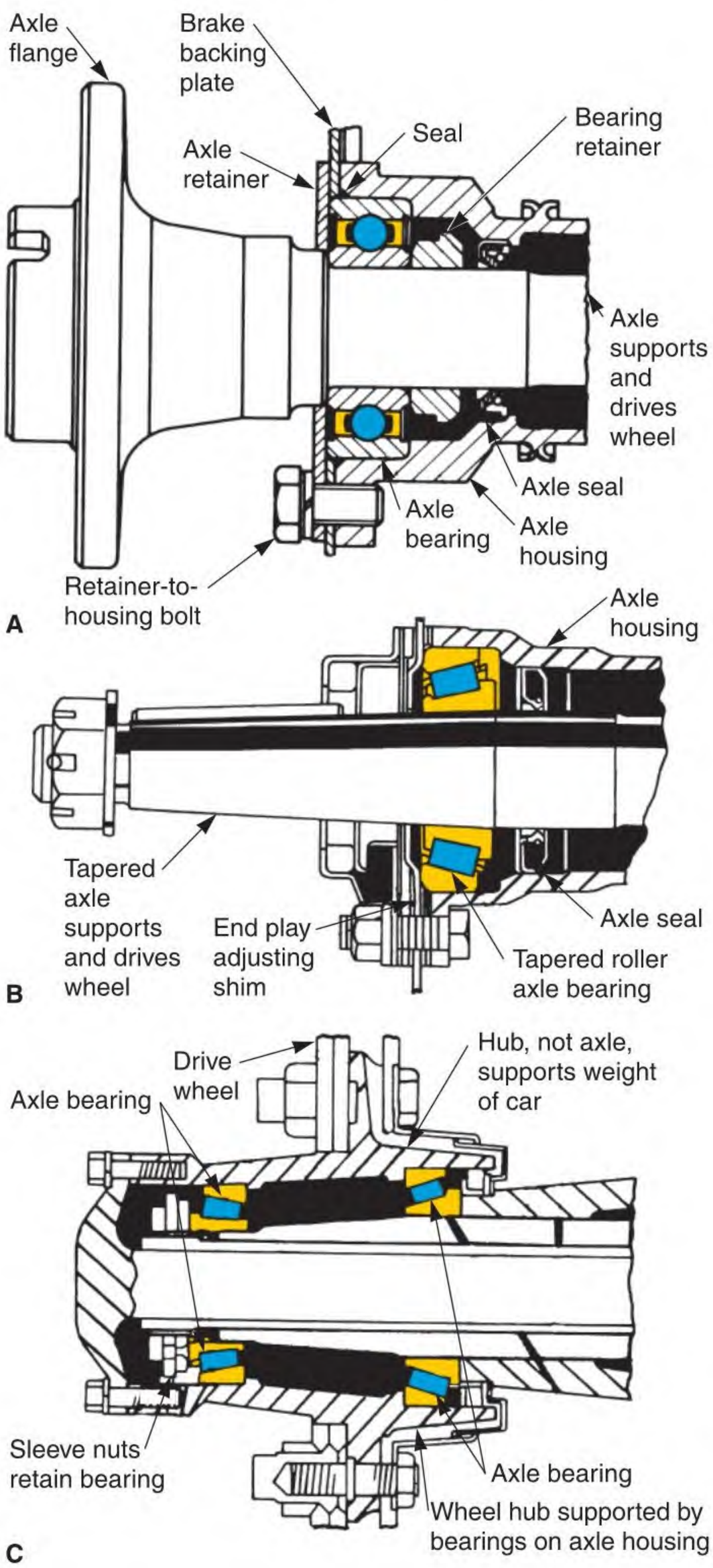
- ***Manual locking hub***—A manual locking hub requires that the driver turn a latch on the hub to lock it into four-wheel drive.
- ***Automatic locking hub***—An automatic locking hub electrically locks the hubs at the front wheels to axles when the driver shifts into four-wheel drive.
- ***Full-time hub***—A full-time hub is always locked to drive front wheels.

Manual and automatic locking hubs are common. Used with part-time four-wheel drive, they enable the driveline to be in two-wheel drive for vehicle use on dry pavement. When the hubs are unlocked, the front wheels turn without turning the front axles. This increases fuel economy and reduces driveline wear.

Electro-Hydraulic Differential

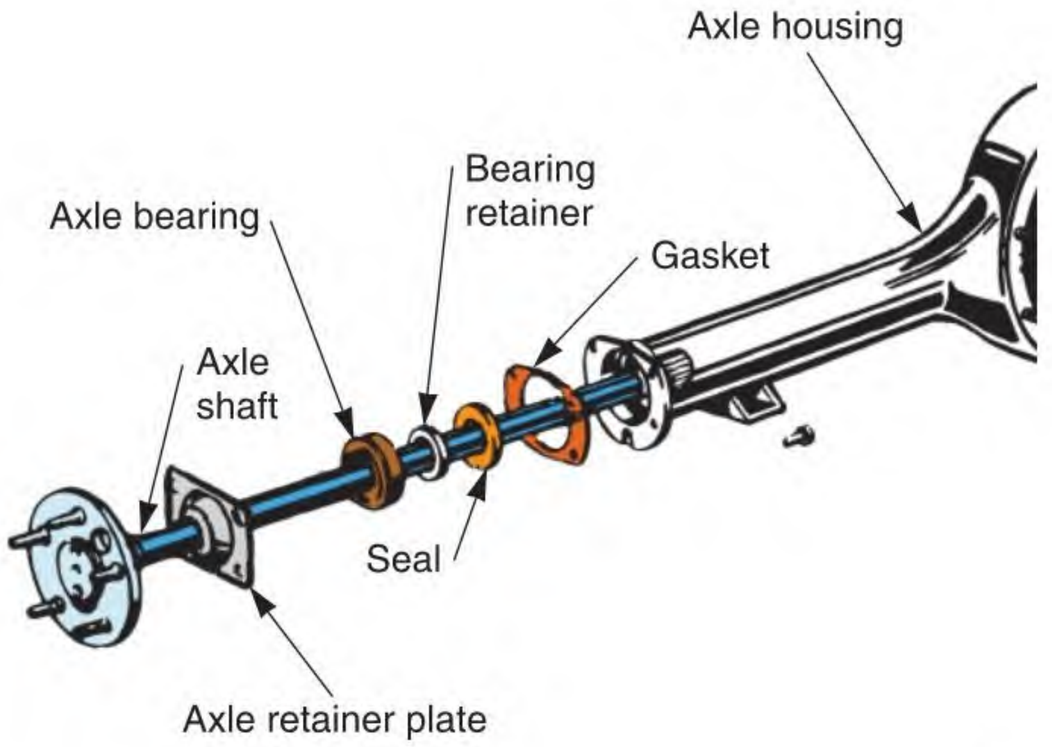
An ***electro-hydraulic differential*** can gradually apply torque to each driving axle to reduce wheel spin during rapid acceleration. It can also improve handling

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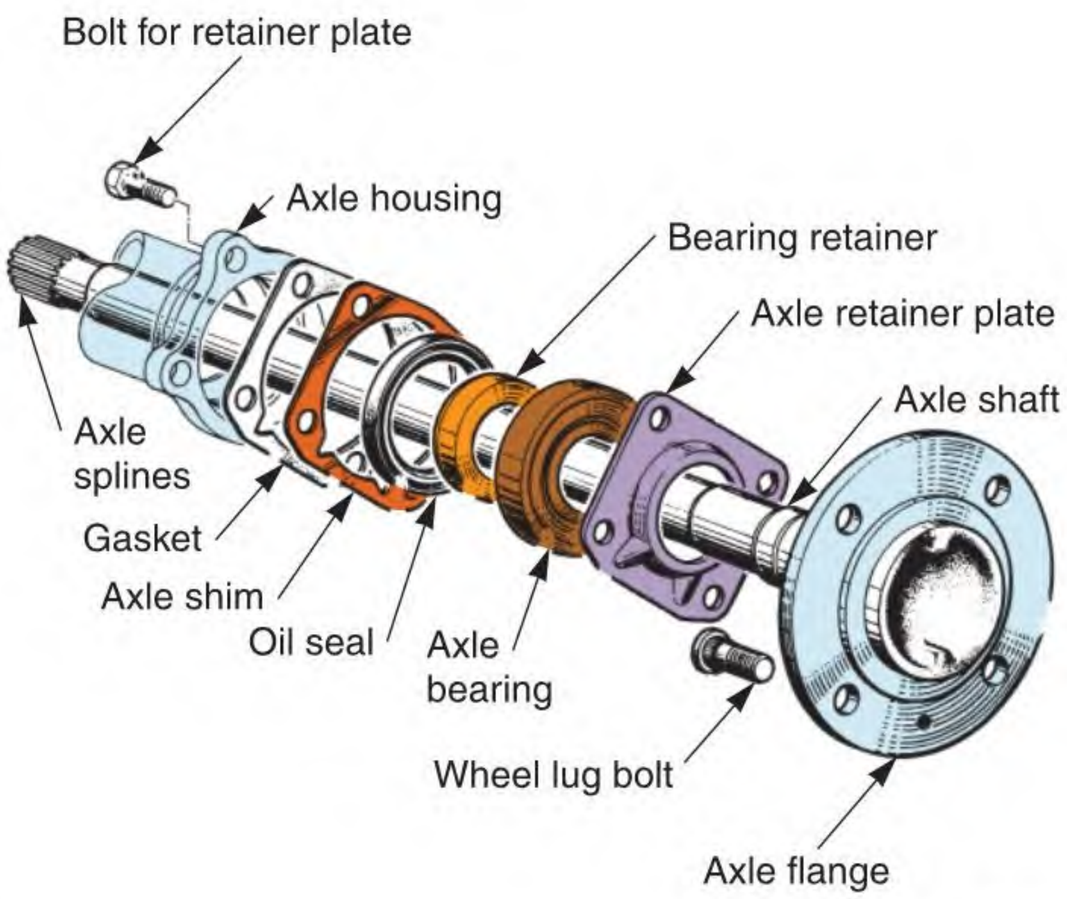
Fiat and Deere & Co.

Figure 69-16. Three common rear wheel bearing variations. A—Semifloating, ball bearing type is used on small cars. B—Semifloating, roller bearing type is often used on midsize and full-size cars. C—Full-floating axle, used on heavy-duty, pickup truck, and large truck applications.



Ford

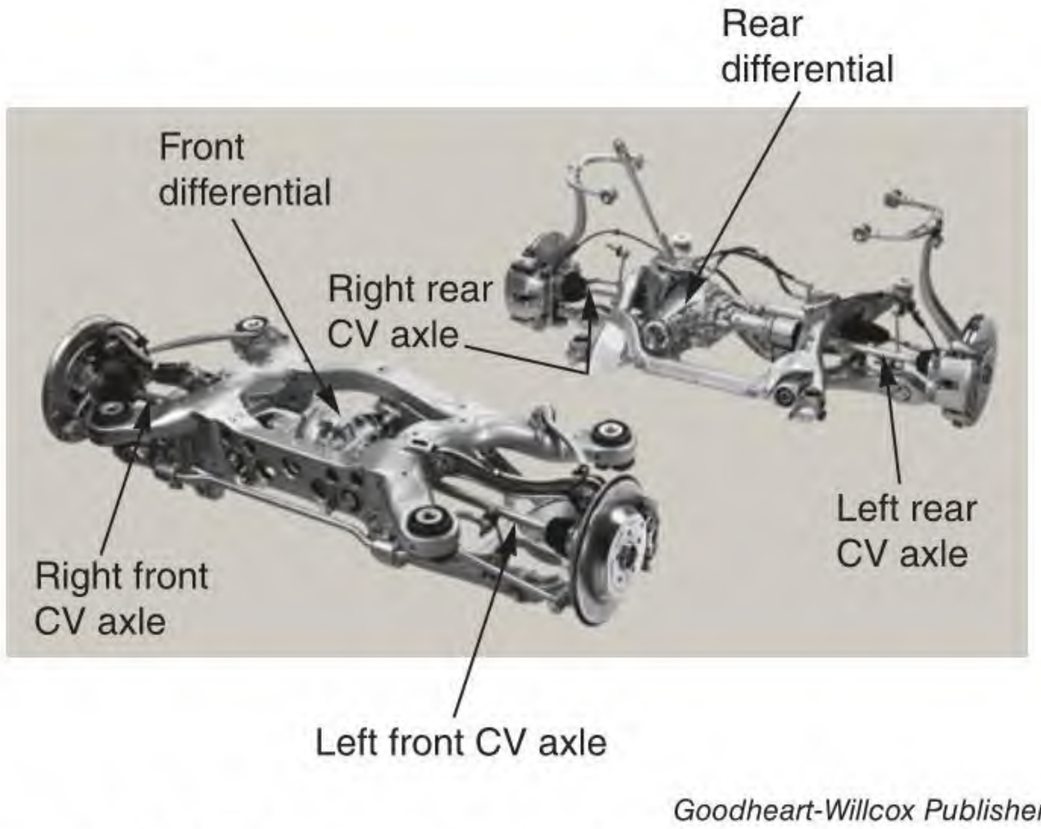
Figure 69-17. This rear axle assembly has a removable carrier, semifloating axles, and conventional differential.



Toyota

Figure 69-18. Most rear axles with removable carriers have an axle retainer plate that bolts to the axle housing. Shims are used to adjust axle end play. A gasket and oil seal prevent leakage of differential oil.

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Figure 69-19. A swing axle has the differential assembly mounted on a frame member. Constant velocity universal joints allow the axles and wheels to move up and down with suspension action.

during high-speed cornering by controlling torque application to each drive axle. Study **Figure 69-21**.

The following are major parts of an electro-hydraulic differential:

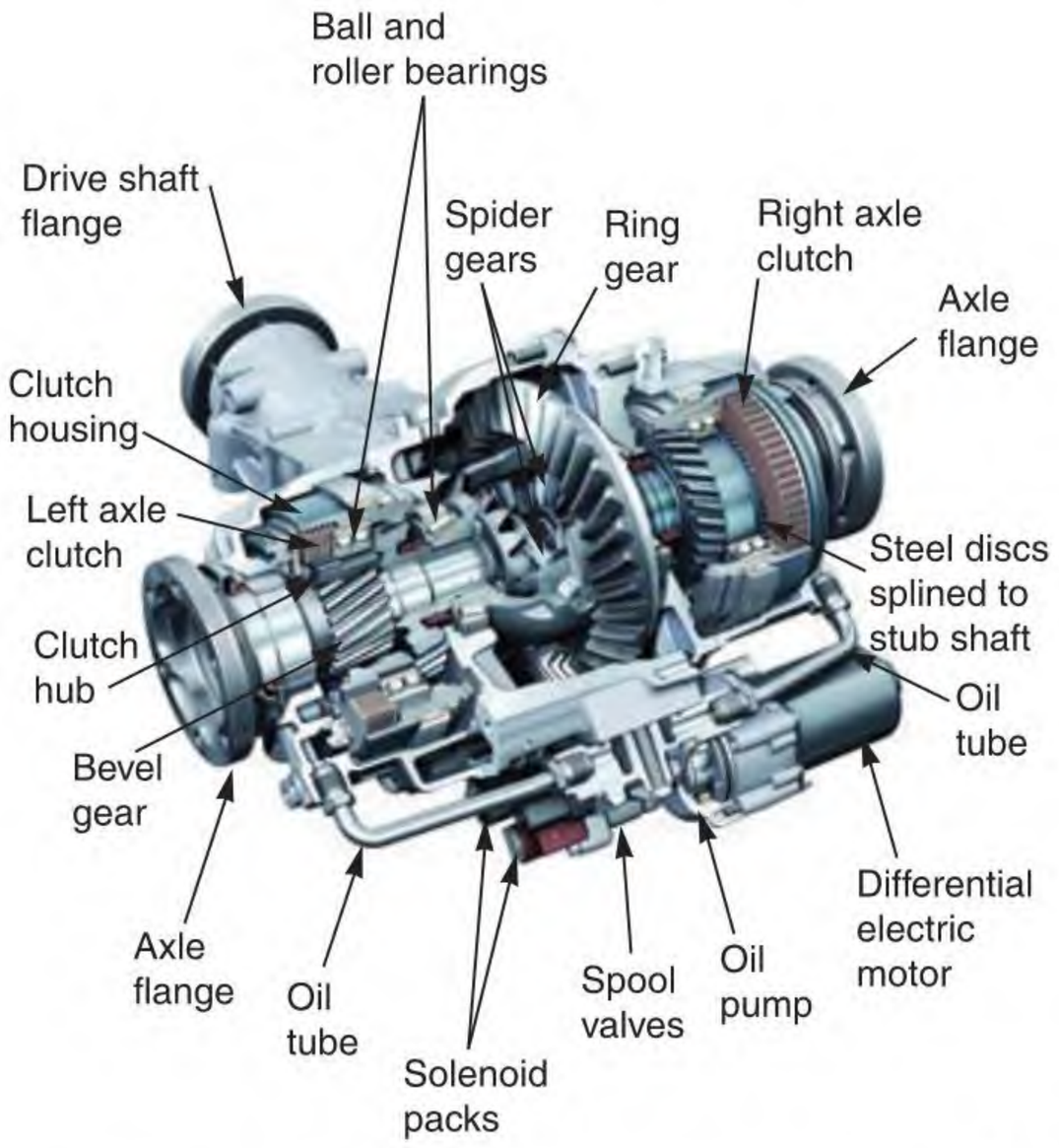
- **Differential housing**—The differential housing (or case) is normally a cast aluminum enclosure for the gears, case, and bearings.
- **Ring and pinion gears**—Ring and pinion gears transfer drive shaft torque from the engine and/or motor-generator to the axle shafts.
- **Spider gears**—Spider gears transfer ring gear torque to the axle flanges or hubs in the differential.
- ***Electric oil pump*** or ***mechanical oil pump***—These pumps provide hydraulic pressure for clutch application to lock each drive flange to the ring gear.



Mazda

Figure 69-20. Most late-model passenger cars use an independent rear suspension, with the differential mounted solidly to the frame. CV axles transfer power to the drive wheels while allowing for suspension action. How many parts of this drive train can you identify?

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Audi

Figure 69-21. The internal parts of an electro-hydraulic differential. The electric solenoids on the bottom of the unit operate the hydraulic spool valves to control oil pump pressure applied to each differential clutch set. This allows the drive train ECM to instantly lock or unlock the axle for maximum traction under any driving condition.

- **Hydraulic spool valves**—Located on the differential, the hydraulic spool valves adjust oil flow to each clutch pack by reacting to solenoid movement.
- ***Differential solenoid valves***—The solenoid valves operate the hydraulic spool valve that adjusts the amount of clamping force applied to each axle clutch set.
- **Hydraulic lines and hydraulic passages**—Located in the differential housing, the hydraulic lines and hydraulic passages carry oil pressure to each clutch piston.
- ***Differential clutch pistons***—Two differential clutch pistons apply clamping force to the clutch friction discs.
- ***Differential friction discs***—The differential friction discs are covered with a synthetic fiber or ceramic coating to increase surface friction. Each is separated by steel clutch discs to make a clutch set.
- ***Stub axle***—Stub axles are short splined shafts with a flange on one end to transfer torque to the CV axles extending from the differential housing.

An electro-hydraulic differential uses solenoid packs to operate hydraulic spool valves. The spool valves direct oil flow to wet clutch packs to engage each axle when needed. The drive train ECM can clamp or release the wet clutch packs that lock and unlock each drive axle.

To control differential lockup, all engine, transmission, suspension, and driveline ECMs sense engine power output, vehicle speed, wheel speed, transmission speed, gear position, engine throttle position, motor-generator torque output and torque consumption, and other variables. With variable solenoid application, the spool valves can be adjusted to meter the exact amount of clutch pressure needed to limit tire slip or skid on the road surface. Study **Figure 69-22**.

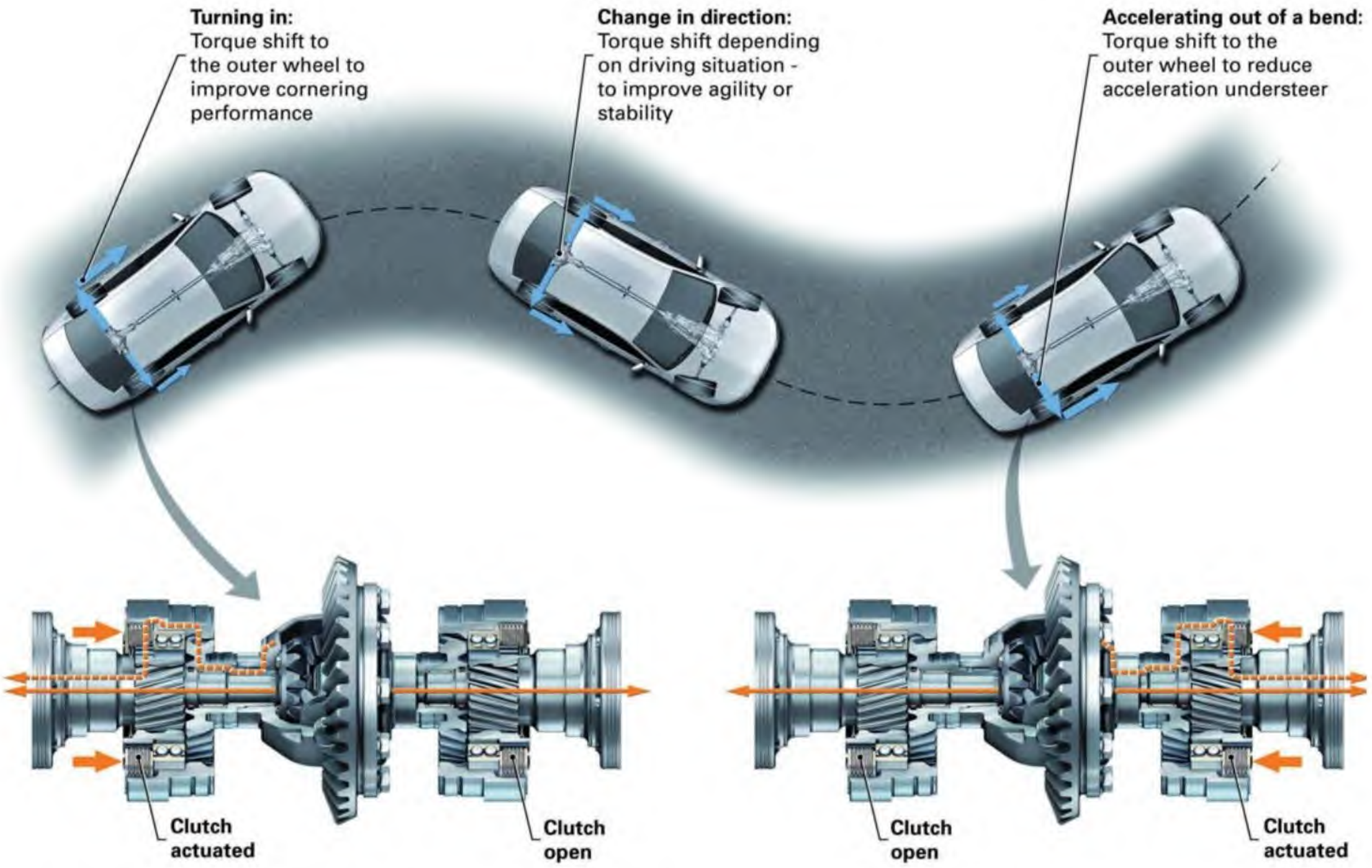
For example, if the driver floors the engine for a "jack rabbit start," the ECM controlling the differential might energize both solenoids on the differential. This would slide the hydraulic spool valves fully open for complete lockup of both axles for full positive traction.

As soon as the ECM detects too much wheel spin from either wheel (brake system wheel speed sensor signal frequency is too low or slowed), it would send a shorter pulse width to partially close the solenoid and spool valve. This partially releases that clutch to avoid excess tire spin in order to gain tire-to-road surface traction.

All-Wheel-Drive Differential

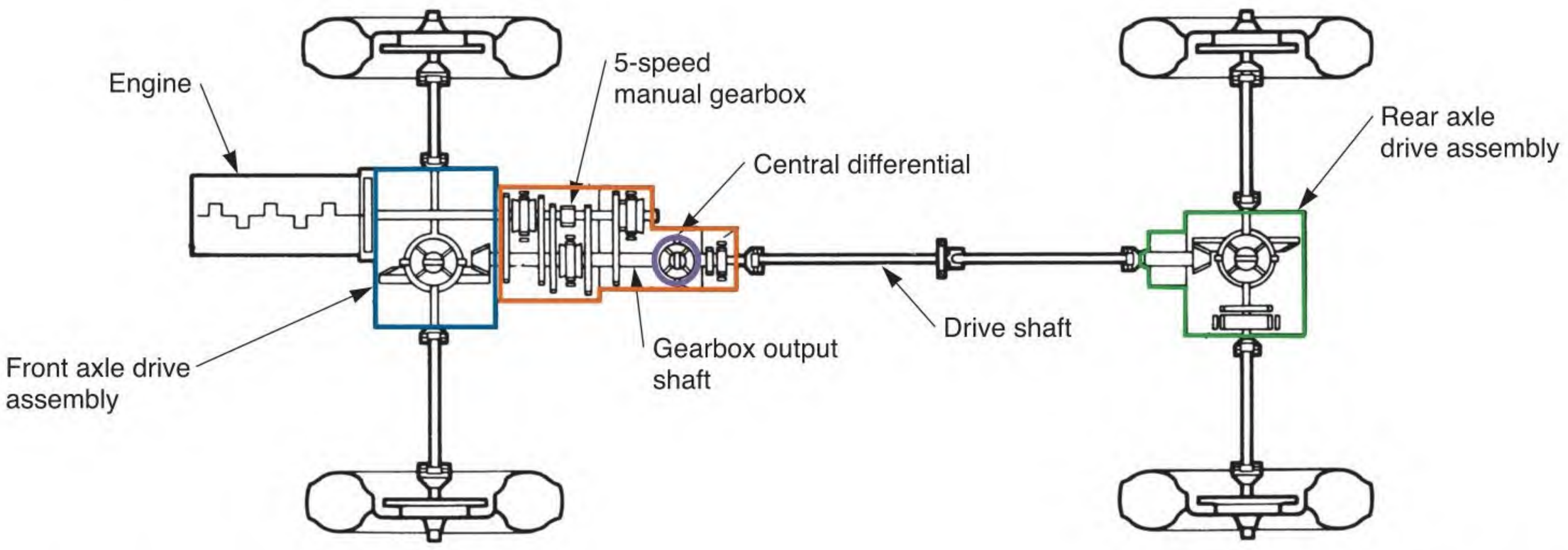
Differentials for all-wheel-drive vehicles are similar in construction and operation to those on truck four-wheel drive configurations. However, the front differential is constructed inside the transmission to produce a transaxle (transmission and differential combined). Study the modern all-wheel-drive configuration in **Figure 69-23**.

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Audi

Figure 69-22. The operation of an electro-hydraulic differential as a car swerves on a curvy road.



Porsche-Audi

Figure 69-23. This all-wheel-drive system uses three differentials.

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Workplace Skills

Remember that safety is one of the most important skills you can develop as an automotive technician. If you constantly break safety rules while working, you or someone around you will likely be injured on the job.

Summary

- Power enters the rear axle assembly from the drive shaft. The drive shaft spins the pinion drive gear.
- The ring gear is driven by the pinion gear; it transfers rotating power through an angle change of 90°.
- Hypoid gears have the driving pinion centerline offset, or lowered, from the centerline of the ring gear.
- Rear axle ratio is the ratio of ring gear teeth to pinion gear teeth.
- The differential carrier provides a mounting place for the pinion gear, differential case, and other differential components.
- A removable carrier bolts to the front of the axle housing. An integral carrier is constructed as part of the axle housing.
- The spider gears include two axle gears and two pinion gears.
- A limited-slip differential provides driving force to both rear wheels at all times.
- The most popular type of limited-slip differential uses a clutch pack (set of friction discs and steel plates).
- A cone clutch limited-slip differential uses the friction produced by cone-shaped axle gears to provide improved traction.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

automatic locking hub
axle gears
axle housing
axle retainer plates
axle shims
carrier bearings
case bearings
clutch pack
cone clutch differential
Detroit locker
differential assembly
differential breather tube
differential carrier
differential case
differential clutch pistons
differential friction discs
differential gears
differential housing
differential lubricant
differential ratio
differential solenoid valves
dog clutch
electric oil pump
electro-hydraulic differential
front drive axle
full-time hub
gear preload
hunting gearset
hypoid gears
integral carrier
lapped
limited-slip differential
locking hubs
manual locking hub
mechanical oil pump
nonhunting gearset
open differential
pinion gear
pinion pilot bearing
pinion shaft
ratchet differential
rear axle bearings
rear axle ratio
rear axle seals
rear drive axle assembly
rear drive axles
rear wheel bearings
removable carrier
ring gear
semifloating axle
spider gears
spiral bevel gears
stub axle
swing axles
Torsen® differential

Activities

1. Using a mock-up of a differential provided by your instructor, identify its various parts.
2. Count the number of teeth on a ring gear and on its mating pinion gear. Write down these numbers and then determine the gear ratio.
3. Demonstrate to the rest of the class how power is transmitted from the drive pinion through the rest of the differential to the drive wheels.

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Review Questions

Answer the following questions using the information provided in this chapter.

1. Which of the following is *not* a basic part of the rear axle assembly?
   (A) Differential case assembly.
   (B) Axle housing.
   (C) Pinion drive gear.
   (D) Gudgeon pin.
2. The purpose of the pinion gear is to transfer power from the ring gear to the axle. True or False?
3. The _____ must be capable of providing torque to both axles when turning corners.
4. Explain the difference between a hunting gearset and a nonhunting gearset.
5. Rear axle ratio is determined by comparing the number of teeth on the _____ gear to the number of teeth on the _____ gear.
6. An integral carrier is constructed as part of the axle housing. True or False?
7. What major problem is a differential designed to prevent?
8. A limited-slip differential usually uses 80W-90 gear oil as a lubricant. True or False?
9. Which of the following statements best describes a clutch pack for a limited-slip differential?
   (A) Set of friction discs and steel plates usually splined to the differential side gears.
   (B) Friction-producing cone shaped axle gears that are splined to the axles.
10. Swing axles are found on a differential that is rigidly mounted on the auto frame. True or False?

ASE-Type Questions

1. Technician A says an automobile's rear axles transfer torque to the differential pinion gear. Technician B says an automobile's rear axles transfer torque to the rear wheels. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Technician A says a rear drive axle assembly's pinion drive gear transfers power from the transmission input shaft to the ring gear. Technician B says the pinion drive gear transfers power from the drive shaft to the ring gear. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. Technician A says an automotive differential's ring gear transfers turning power to the differential case assembly. Technician B says the ring gear transfers turning power to the drive shaft's rear yoke. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. Which of the following is *not* considered an automotive rear drive axle component?
   (A) Spider gears.
   (B) Pilot shaft.
   (C) Drive axle.
   (D) Rear axle bearing.
5. Technician A says a rear drive axle assembly's ring gear is bolted to the rear axle flange. Technician B says the ring gear is bolted to the differential case. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Technician A says a rear drive axle assembly splits the amount of torque going to each wheel. Technician B says a rear drive axle assembly transfers torque through a 90° angle. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. Technician A says a differential's pinion gear is normally mounted on tapered roller bearings. Technician B says a differential's pinion gear is normally mounted on the differential case. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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8. Technician A says a differential's ring and pinion drive gears are never manufactured as a matched set. Technician B says a differential's ring and pinion gears are commonly manufactured as a matched set. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Technician A says a hunting gearset meshes the same gear teeth over and over during operation. Technician B says a hunting gearset does not mesh the same gear teeth during operation. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. Technician A says most ring and pinion gears are classified as a hunting gearset. Technician B says most ring and pinion gearsets are nonhunting types. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
11. Technician A says modern differential ring and pinion gears are hypoid type. Technician B says modern differential ring and pinion gears are classified as a spiral bevel gearset. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
12. Which of the following is a major part of a differential assembly?
   (A) Inboard universal joint.
   (B) Outer race.
   (C) Carrier.
   (D) Slip disc.
13. Technician A says rear axle ratio is determined by comparing the number of teeth on the spider gears and the ring gear. Technician B says rear axle ratio is determined by comparing the number of teeth on the pinion drive gear and the ring gear. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
14. All of the following are other names for a limited-slip differential, *except*:
   (A) Posi-traction.
   (B) Sure-grip.
   (C) Equal-lock.
   (D) Spin-free.
15. Technician A says several modern automobiles use the semifloating rear axle design. Technician B says several modern automobiles use the swing-type rear axle design. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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Chapter 70
Differential and Rear Drive Axle Diagnosis, Service, and Repair

After studying this chapter, you will be able to:

- Diagnose common differential and rear drive axle problems.
- Check and replace rear axle lubricant.
- Remove and replace axles, axle bearings, and seals.
- Explain the basic service and repair of a differential assembly.
- Adjust ring and pinion gears.
- Describe limited-slip differential testing and service.
- Cite safety rules and practice safe work habits.
- Correctly answer ASE certification test questions on differential and rear drive axle repairs.

Differentials and rear drive axles are normally very dependable. However, if operated dry (without lubricant), abused (dropping the clutch at high speed, for example), or used for prolonged service, the ring and pinion gears, spider gears, shafts, and bearings can wear and fail. This chapter will introduce the most important steps for diagnosing and repairing a differential and solid rear axle assembly.

Tech Tip

Much of the information in this chapter will help you when studying about the service of a transaxle, which also contains a differential.

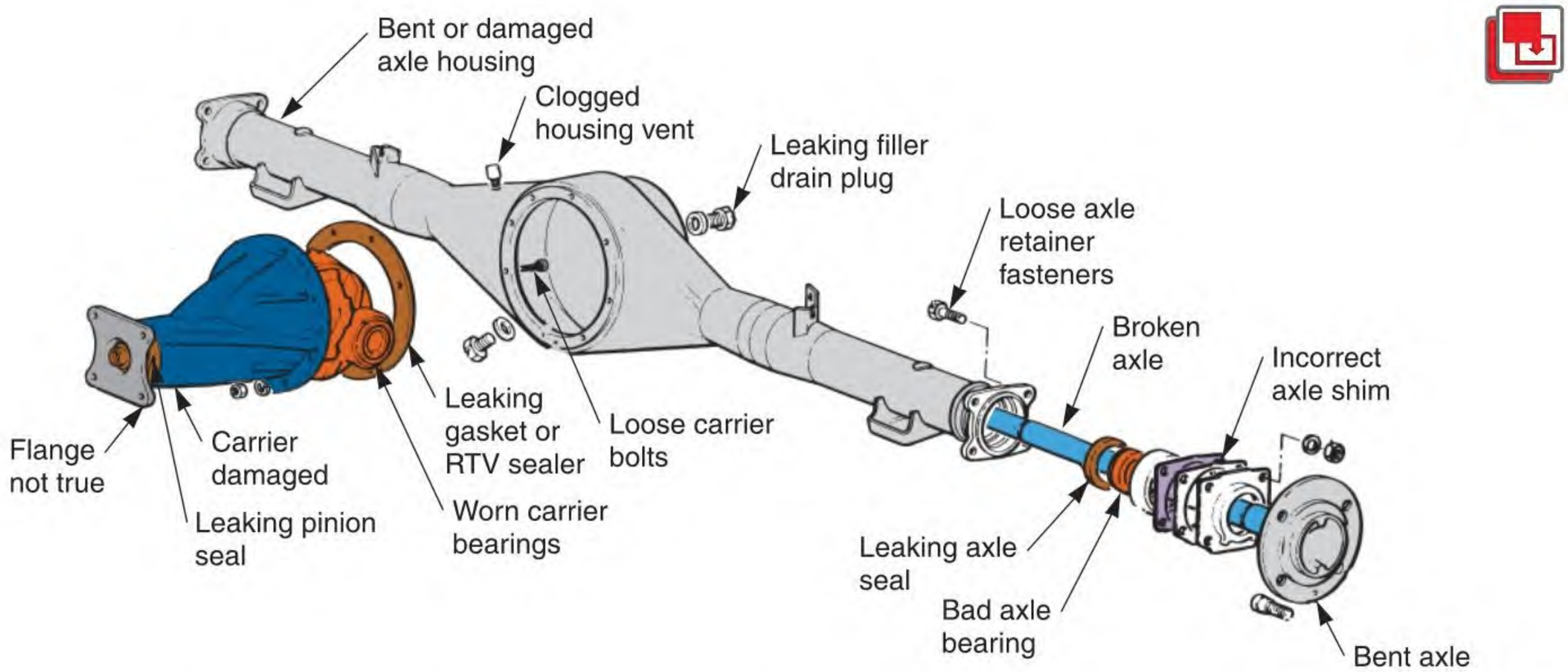
Rear Axle Problem Diagnosis

Rear end (rear drive axle assembly) problems usually show up as abnormal noises. It is critical that correct procedures be used when trying to find the source of these noises. Other problems (worn wheel bearings, universal joints, or transmission gears) can produce symptoms similar to those caused by faulty rear drive axle components.

To begin diagnosis, gather information. Determine when the noise or condition occurs—when accelerating, coasting at certain speed, or rounding corners. Use common sense and your understanding of the drive axle's operating principles to narrow down the possible sources.

Road test the vehicle on a smooth road surface. Listen for changes in the noise under different driving conditions. **Figure 70-1** lists some typical problems you might find.

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Figure 70-1. These are typical problems that can develop in a rear axle assembly.

Eliminate other Problem Sources

After your road test to verify the complaint, use your knowledge of noise diagnosis to determine which components should be checked further. If the noise could possibly be tire related, increase inflation pressure in the tires as described in a service manual. If the abnormal noise changes, the tires may be at fault.

If the sound originates from the middle or front of the car, listen for noises in the transmission or transaxle. Also check for dry, noisy front wheel bearings.

Problem Isolation

A ***stethoscope*** (listening device) can often be used to isolate the source of a differential or rear axle bearing problem. Raise the vehicle on a lift. Ask another technician to start the engine, place the transmission in gear, and accelerate to 30 mph (48 km/h).

Touch your stethoscope on the ends of the axle housing and on the housing near the carrier bearings. The area producing the loudest noise contains the faulty parts.

Warning

When using a stethoscope to listen for rear axle noise, stay away from the spinning tires and driveline. Serious injury could result if you touch these parts.

Common Rear Axle Assembly Problems

Rear axle assemblies are normally very dependable units. However, with abuse or prolonged use, gear teeth can wear, bearings can fail, and seals can leak.

As you will learn, precision assembly methods are required to rebuild and adjust a new ring and pinion gearset. Incorrect differential repair methods will result in a loud ring and pinion gear whine when driving.

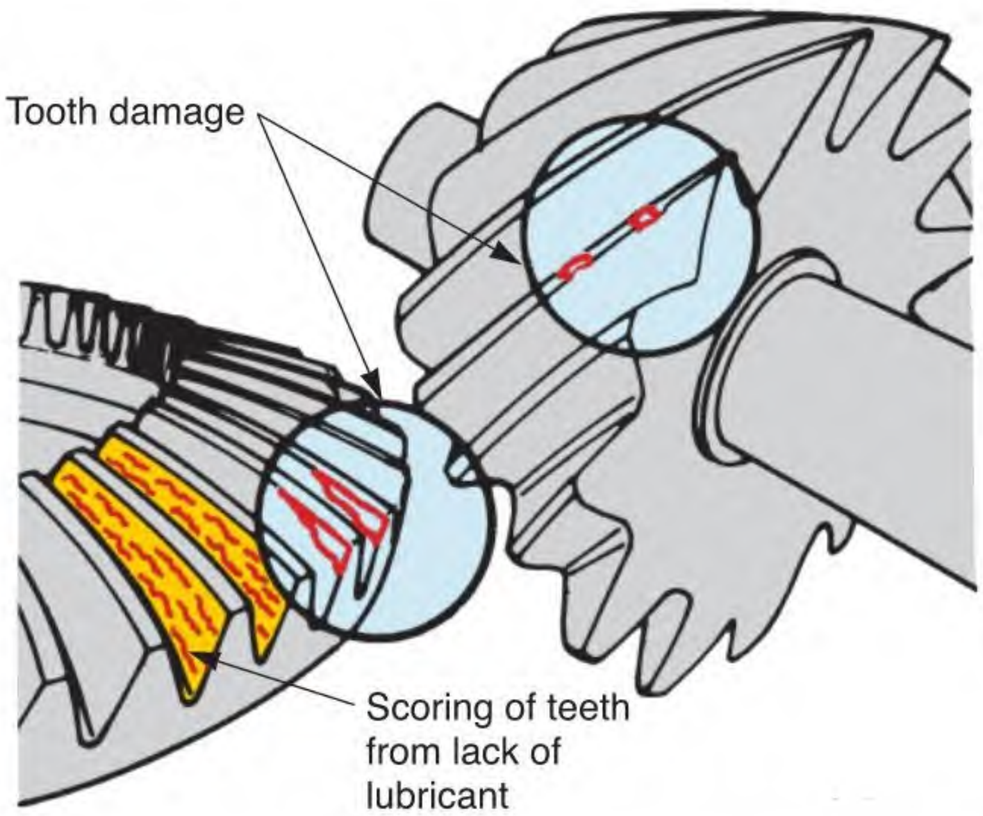
Ring and Pinion Problems

Ring and pinion problems usually show up as a howling or whining noise that changes when going from acceleration to deceleration. Since the ring gear and pinion gear transfer engine power through a 90° angle, they are very sensitive to load. The sound of bad ring and pinion gears usually changes pitch (noise frequency or tone) as you press and release the accelerator while driving.

The ring and pinion gears can become worn, scored, out of adjustment, or damaged. These problems can result from prolonged service, fatigue, and lack of lubricant. You need to inspect the differential to determine whether adjustment or part replacement is required. See **Figure 70-2**.

If the backlash (clearance) between the ring and pinion is too great, a clunking sound can be produced by the gears. For example, when an automatic

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Ford

Figure 70-2. Damaged pinion and ring gear teeth cause abnormal noise that can be affected by load. Check each tooth closely during inspection.

transmission is shifted into drive, the abrupt rotation of the drive shaft could bring the gears together with a loud thump or mechanical clunk sound.

Rear Axle Leaks

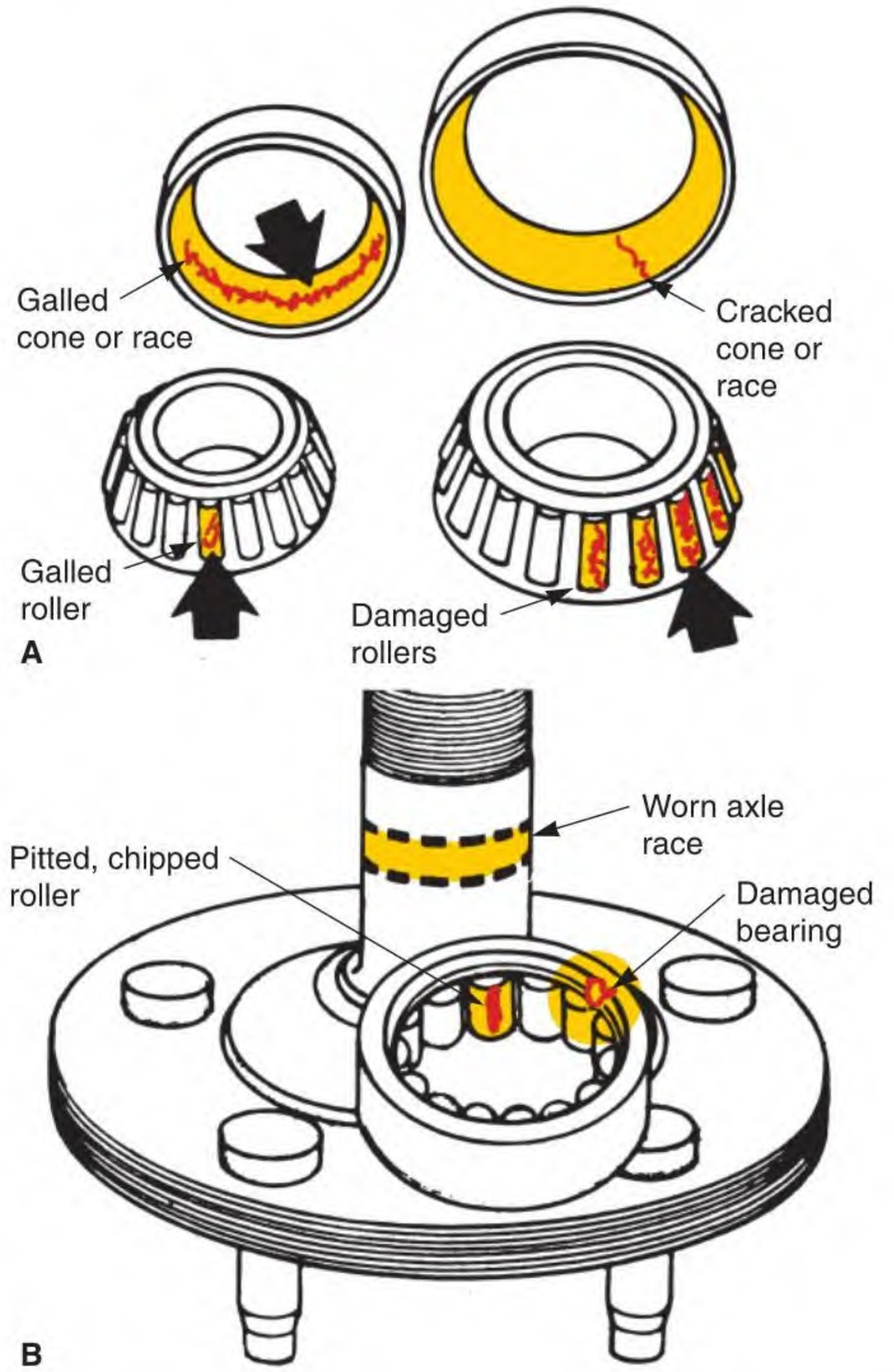
Rear axle lubricant leaks can occur at the pinion gear seal, the carrier or inspection cover gaskets, and the two axle seals. A leak will show up as an oily or dirty area below the pinion gear, under the carrier, or on the inside of the wheel and brake assembly.

Always make sure that a possible axle seal leak is not a brake fluid leak. Touch and smell the wet area to determine the type of leak.

Axle and Carrier Bearing Problems

Worn or damaged bearings in the carrier or on the axles often produce a constant whirring or humming sound. When bad, these bearings make about the same sound whether accelerating, decelerating, or coasting.

Figure 70-3 shows some typical bearing failures. These apply to both differential and axle bearings.



Ford

Figure 70-3. Bearing problems usually produce noise that does not change very much with load. A—Pinion gear and case bearings can fail from prolonged service or lack of lubricant. B—Axle bearings are a common source of trouble. They are not as well lubricated as bearings in the carrier.

Service Procedure

When diagnosing and repairing bearing failures:

1. Check the general condition of all parts during disassembly, not just the most badly worn or damaged parts.
2. Compare the failure to any information in the service manual and your knowledge of component operation.
3. Determine the cause of the part failure. This helps ensure that the problem does not reoccur.
4. Make all repairs following manufacturer's recommendations and specifications.

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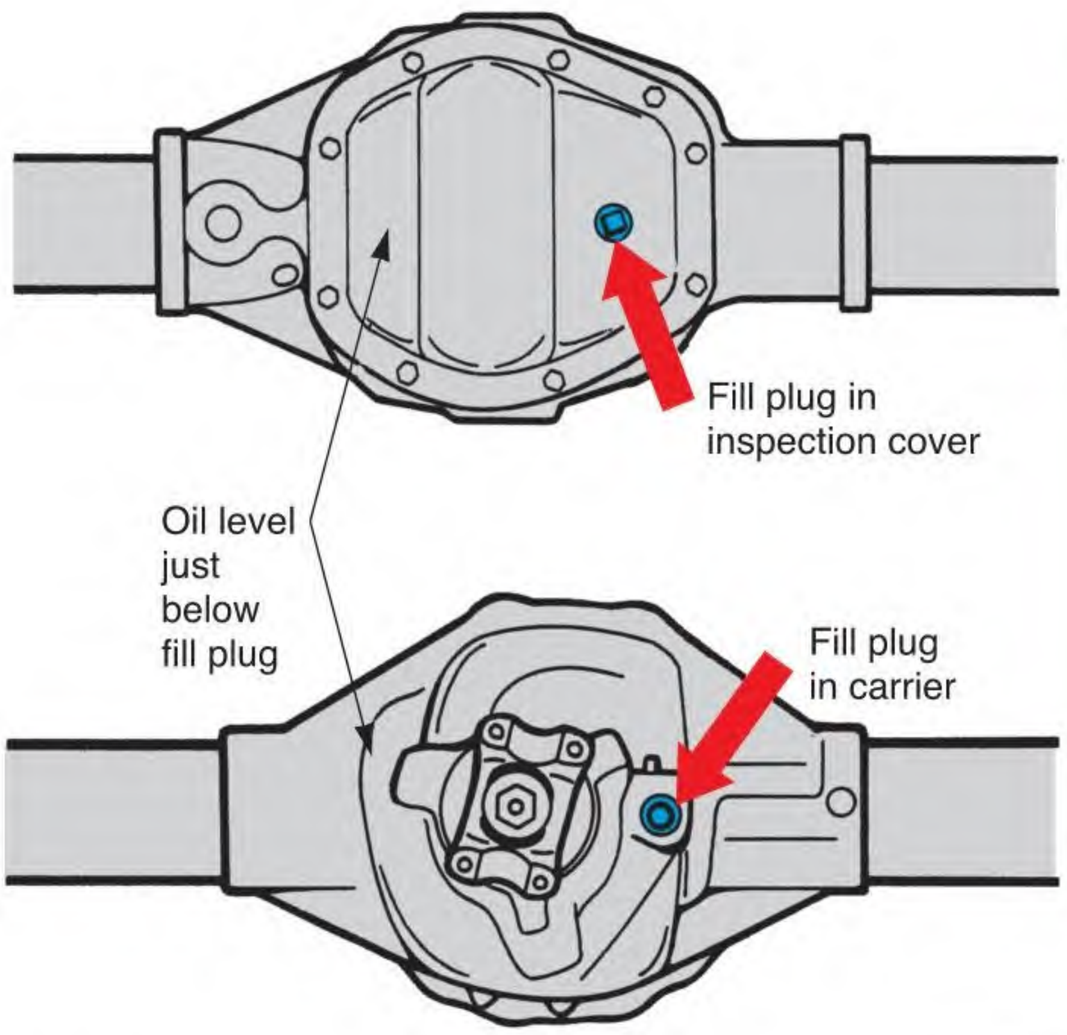
Differential Case Problems

Differential case problems frequently show up when rounding a corner. With the rear wheels turning at different speeds, any problem (damaged spider gears or a grabbing limited-slip clutch pack, for example) will usually show up as an abnormal sound (clunking or clattering) from the rear of the vehicle.

A limited-slip differential (clutch-type) can sometimes make a chattering sound when turning a corner. The clutches are sticking to each other and then releasing. Many automakers recommend that the differential fluid be drained and replaced when this occurs.

Differential Maintenance

Many automobile manufacturers recommend that the differential fluid be checked or replaced at specific intervals. See **Figure 70-4**. If not contaminated with water or leaking out of a seal, differential gear fluid can last hundreds of thousands of miles or the service life of the vehicle.



Chrysler

Figure 70-4. Check the oil level when you detect problems in the rear drive axle assembly. Lubricant should be almost even with the fill hole when the oil is warm. If a drain plug is not provided, you must remove the cover or carrier or use a suction gun to remove the old oil.

Tech Tip

Always install the correct type of differential fluid. Limited-slip differentials often require a special type of gear fluid with friction additives intended for the wet clutch packs in modern differentials.

Rear Axle Service

Rear axle service is needed when an axle bearing is noisy; when an axle is broken, bent, or damaged; or when an axle seal is leaking. As you will learn later, the rear axles must also be removed to allow removal and repair of the differential assembly.

Solid Axle Removal

Generally, two methods are used to hold solid axles in their housing: a retainer plate on the outside of the housing or C-clips on the inner ends of the axles. A ***retainer plate type axle*** is commonly used with a removable carrier. A ***C-clip type axle*** is frequently used with an integral carrier.

Service Procedure

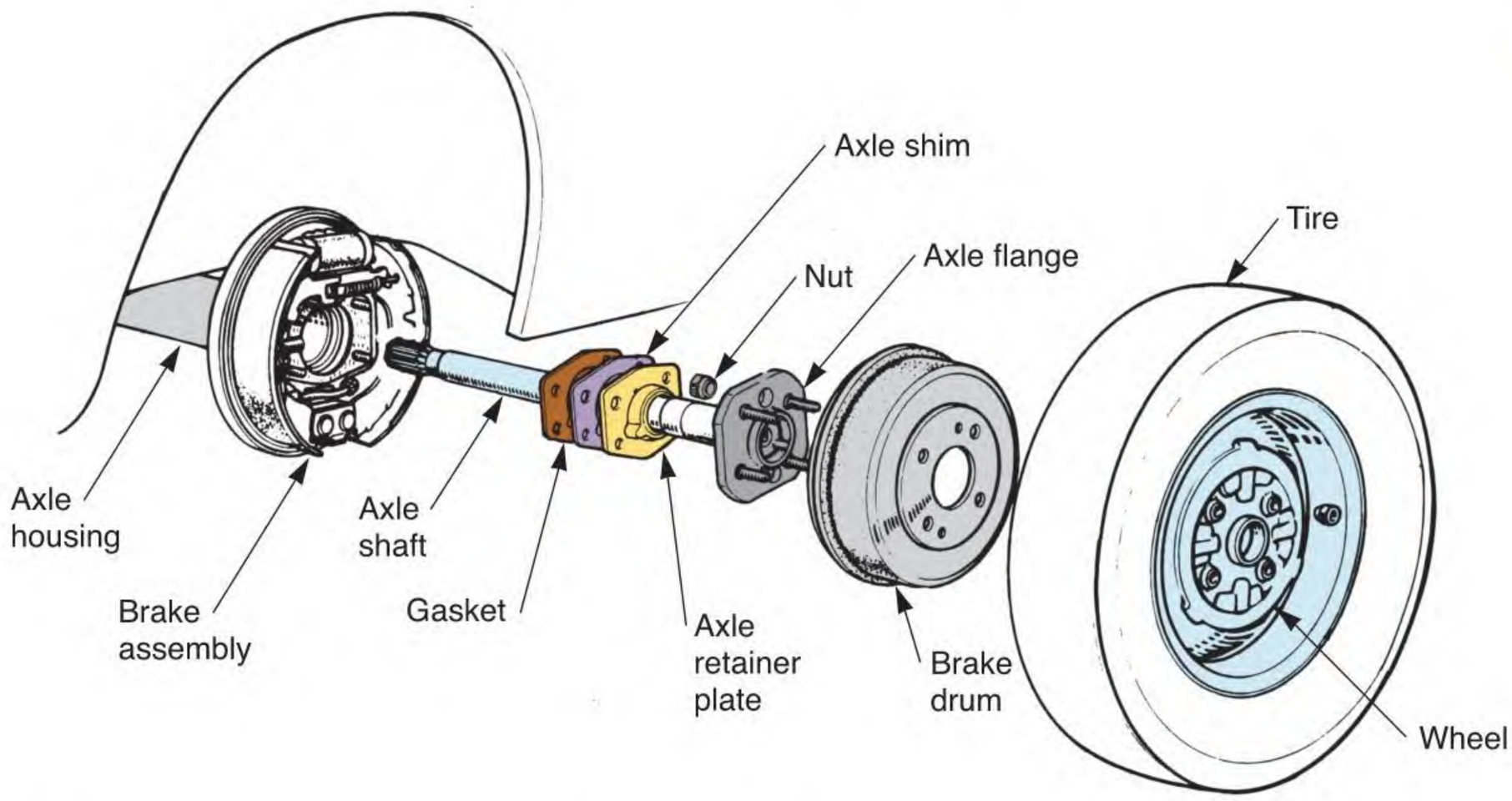
To remove an axle that is secured with a retainer plate, **Figure 70-5**:

1. Support the car on jack stands.
2. Unbolt the rear wheel and slide off the brake drum.
3. Unscrew the nuts on the ends of the axle housing. A socket, extension, and ratchet can normally be used to reach through a hole in the axle flange. You may need to install a slide hammer puller on the axle studs, **Figure 70-6**.
4. Tap the axle out of the housing. Repeat on the other axle if needed.

Caution

While pulling an axle, be careful not to pull the brake backing plate off with the axle. If the backing plate is pulled off, you could bend and damage the brake line.

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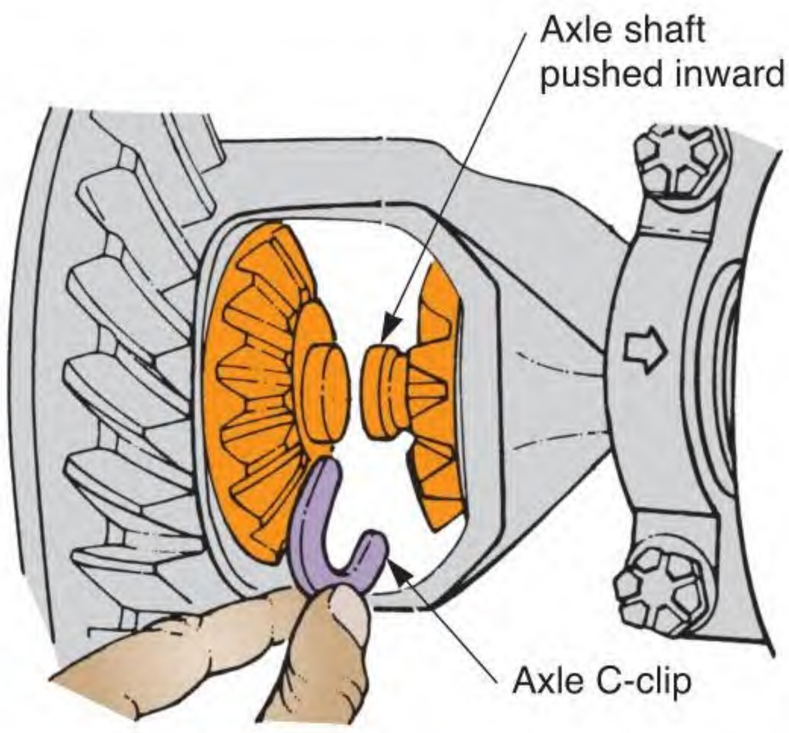
Toyota

Figure 70-5. To remove an axle with a retainer plate, remove the four nuts on the plate and end of housing. Reach through the axle flange with a socket and extension to loosen the fasteners. Pull the axle out without moving the brake backing plate assembly.

Service Procedure

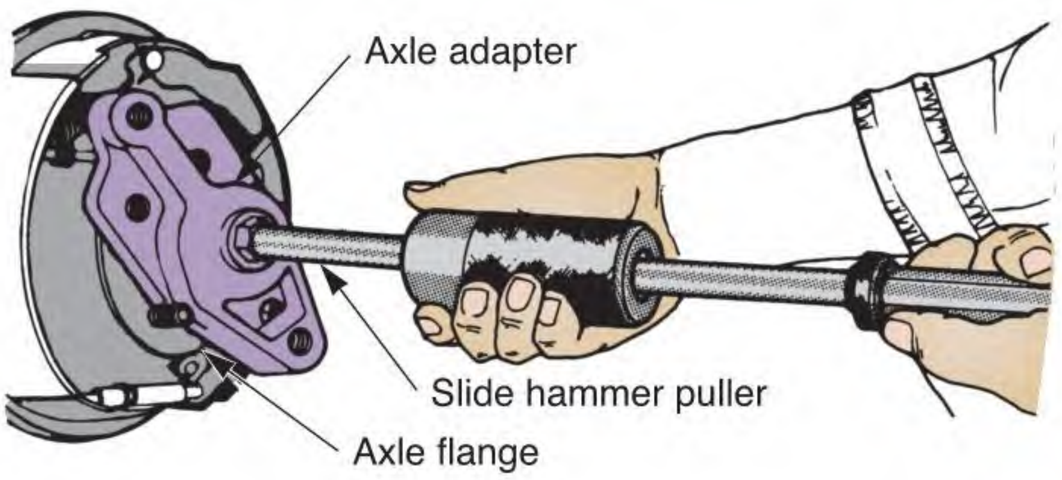
To remove a solid axle that is held in place with a C-clip:

1. Drain the axle lubricant.
2. Unbolt the cover on the rear of the axle housing.
3. Remove the pinion shaft bolt and pinion shaft, if necessary.
4. Slide the axle inward.
5. Remove the C-clip from the groove in the axle end, **Figure 70-7**.
6. Slide the axle out of the housing.



Ford

Figure 70-7. With many integral carriers, you must remove the pinion shaft bolt and pinion shaft. Then slide axle inward and remove the C-clip. This will let you pull the axle out of the housing.



Chrysler

Figure 70-6. If the axle is stuck in the housing, use a slide hammer puller as shown.

With the axle removed, inspect the bearings and splines for damage. Rotate the bearings by hand while feeling for roughness. Some vehicles use axles with tapered ends. This type of axle may require a puller for removal of the hub. Refer to a service manual for details.

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Axle Bearing Service

When an axle bearing is faulty, it must be removed from the axle or housing carefully and a new bearing must be installed. Most axle bearings are press-fit on the axle. A collar may also be pressed on the axle to help secure the bearing. To remove this type of axle bearing, carefully cut the collar off with a grinder and sharp chisel. See **Figure 70-8**.

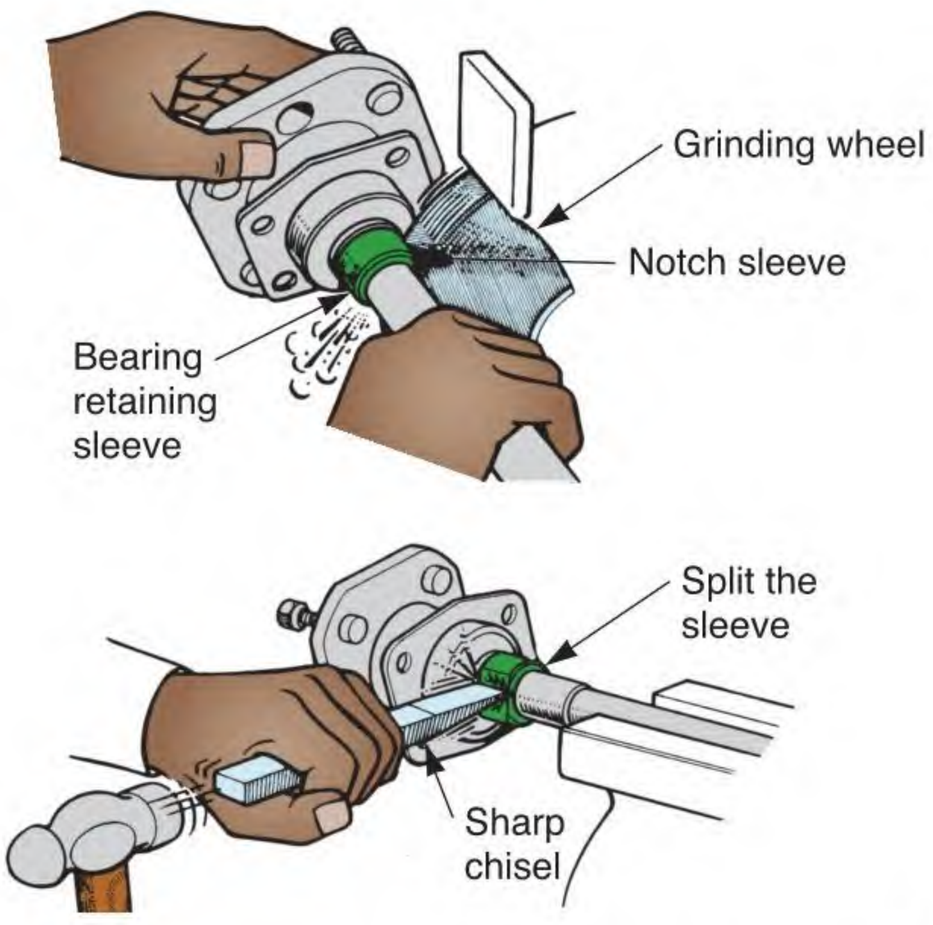
Caution

Do *not* use a cutting torch to remove an old collar and axle bearing. The heat can weaken and ruin the axle.

With the collar cut off, place the axle in a hydraulic press, as shown in **Figure 70-9**. The driving tool should be positioned so that it contacts the *inner* bearing race. Never press a bearing off using the outer race surface—bearing damage will result.

Warning

Wear eye and face protection when pressing a bearing on or off an axle. The tremendous pressure could cause the bearing to shatter and fly into your face with deadly force.



Toyota

Figure 70-8. To prepare for axle bearing removal, grind a notch in the bearing retainer. Then, split the retainer with a sharp chisel. Remember to wear safety glasses because bits of steel can fly out of the cut.

To install the new bearing, slide the retainer and bearing onto the axle. Make sure the bearing is facing in the proper direction. Sometimes, a chamfer on the inner bearing race must face the axle flange. Refer again to **Figure 70-9**.

Applying force on the inner bearing race, press the bearing fully into place. Then, if needed, press the bearing collar or retaining ring onto the axle.

Caution

Do not attempt to press the bearing and collar on at the same time. Bearing or collar damage could result.

Rear Axle Seal Service

Any time the axle is removed for service, it is wise to install a new axle seal. The axle seal is normally press-fit in the end of the axle housing.

To remove a housing-mounted seal, use a slide hammer puller equipped with a hook nose. Place the hook on the metal part of the seal. Jerk outward on the puller slide to pop out the seal. A large screwdriver will also work. Be careful not to scratch the bearing bore in the axle housing, **Figure 70-10**.

Make sure that you have the correct new seal. Its outside and inside diameters must be the same as the old seal. A part number is normally stamped on the side of a seal. This number and the name of the seal manufacturer may help when ordering the replacement.

Before installing the new seal, coat its outer surface with nonhardening sealer. Coat the inside of the seal with lubricant. With the seal facing in the proper direction (sealing lip toward the inside of the housing), drive the seal squarely into place. Use a seal driving tool, **Figure 70-10**.

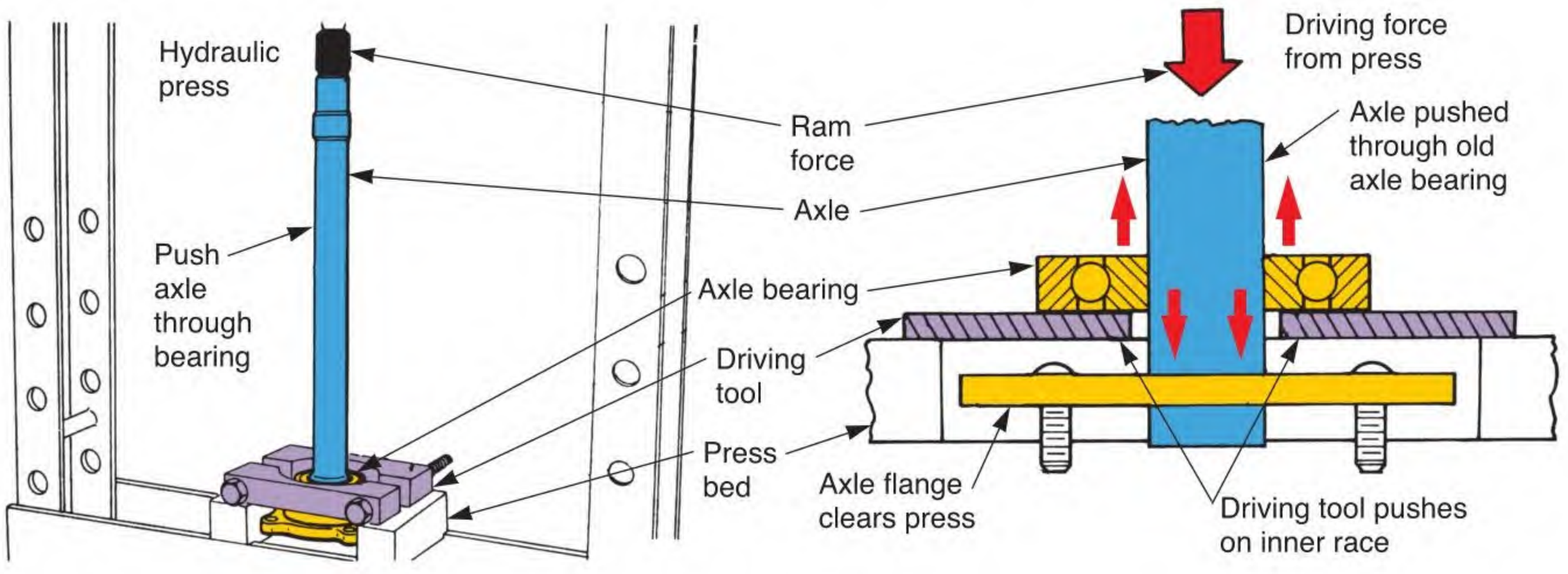
Caution

When installing an axle seal, be careful not to bend the metal seal housing or a leak could result. Make sure the seal is fully seated.

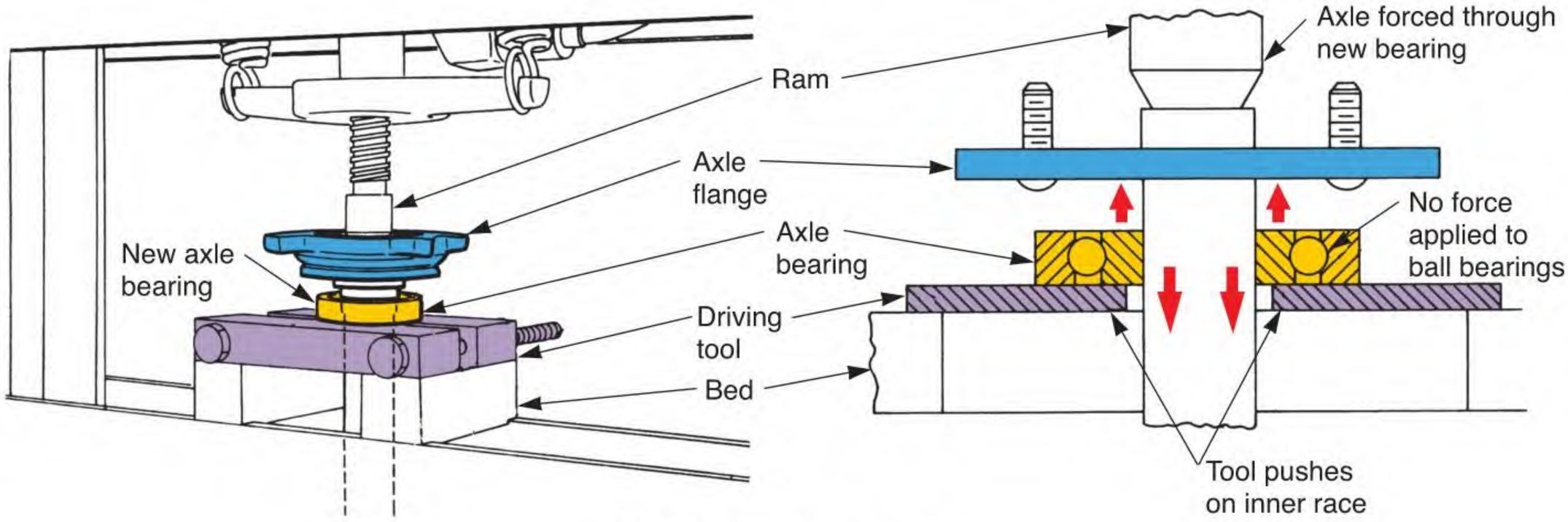
Axle Stud Service

Before installing the axle, make sure that the lug studs on the flange are in good condition. If the threads are damaged or the lugs are loose, install new

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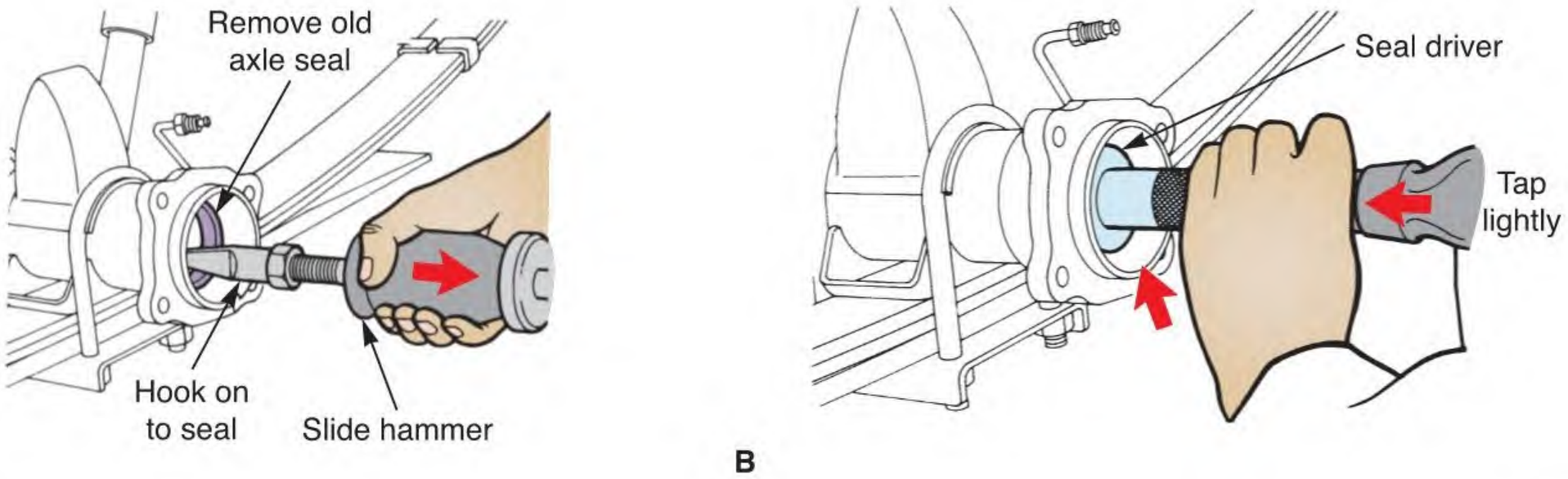
Axle bearing removal



Axle bearing installation

Chrysler

Figure 70-9. Axle bearing removal and installation. When removing a bearing, position the driving tool so it contacts the inner bearing race. Push the axle through the bearing. When installing a bearing, again position the tool to contact the inner race. Press the axle back through the bearing. Wear a face shield and do not exceed recommended ram pressure.



Chrysler

Figure 70-10. Replacing an axle seal. A—Use a hook-nose adapter on a slide hammer to remove the old seal. B—Tap gently on the seal driver to force the new seal into the housing. Be careful not to damage the housing bore, bearing, or seal.

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lugs. Use a hydraulic press to force out the damaged studs. Then, press new wheel studs into the axle flange from the rear of the flange.

Rear Axle Installation

Before installation, wipe the axle clean. Then, carefully slide the axle into the housing.

To prevent seal damage, support the weight of the axle as it slides over the seal. Do not allow the axle to rub on the new seal, or the seal could be ruined.

Wiggle the axle up and down and move it around until its splines fit into the splines in the differential side gear. Align the axle bearing and push the axle fully into place.

If the axle has a retainer, tighten the retainer nuts. Install the brake drum and wheel. If the axle has C-clips, fit the clips over the inner axle ends. Then, install the pinion shaft and differential cover. Fill the differential with lubricant.

Measuring Axle End Play

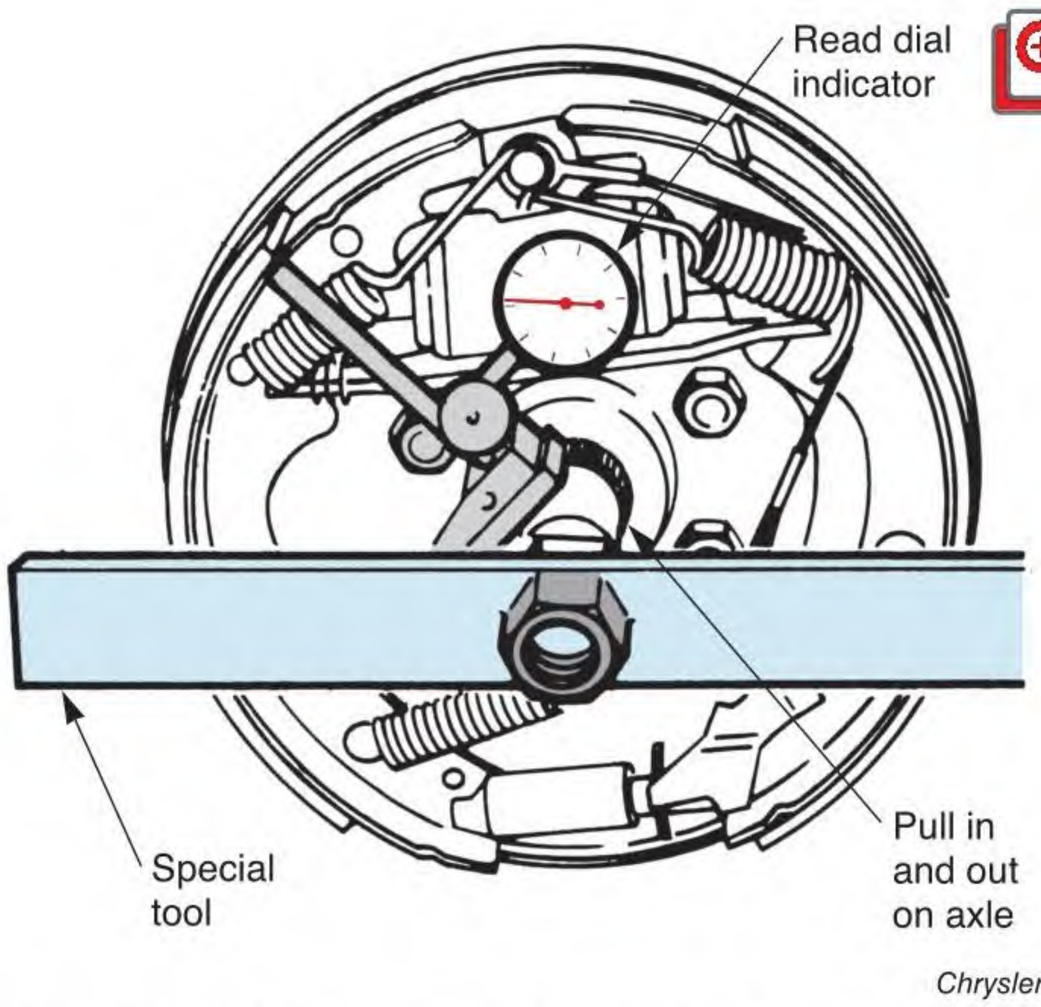
Excessive ***axle end play*** can cause a clunking sound as the vehicle rounds a corner. The axle can slide one way and then the other, producing an audible clunk or knock. Insufficient end play can result in axle bearing, retainer, or differential side gear failure.

To measure axle end play, mount the indicator so that the indicator plunger is parallel with the axle centerline. Set the indicator needle on zero. Pull the axle in and out while watching the indicator. Compare the readings to factory specifications. A special adapter is sometimes installed on the axle when taking end play measurements. See **Figure 70-11**.

If there is too much end play, you may need to add shims next to the axle retainer plate. If the end play is too small, install thinner shims. With a C-clip type axle, you need to replace parts or install shims behind the side gears in the differential to adjust axle end play. Check a service manual for details.

CV Axle Service

Swing axle, or CV axle, operation and repair information is given in the next two chapters. Front-wheel drive axles are identical to modern rear-drive independent suspension systems. The rear differential housing is bolted to the frame so it cannot move up and down with the suspension. Flexible, constant velocity universal joints are needed to transfer power out to the wheel hubs.



Chrysler

Figure 70-11. Many automakers recommend measurement of axle end play. Mount the adapter over the axle. Then use a dial indicator to measure in and out movement of the axle. Add or remove shims or replace parts as needed to correct end play.

Differential Service

When symptoms point to differential troubles, remove the differential carrier or rear inspection cover. Inspect the ring gear, pinion drive gear, bearings, and spider gears.

A ***differential ID number*** (identification number) is provided to show the exact type of differential for ordering parts and looking up specifications. The number may be on a tag under one of the carrier or inspection cover fasteners. It may also be stamped on the axle housing or carrier. Use the ID number to find the axle type, axle ratio, make of unit, and other information.

Differential Removal

Service Procedure

To remove a separate carrier differential:

1. Remove the drive shaft.
2. Unbolt the nuts around the outside of the carrier.
3. Place a drain pan under the differential.
4. Force the differential away from the housing.
5. Drain the lubricant into the pan.
6. Slowly slide the heavy differential off of its studs and place it on your workbench.

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Warning

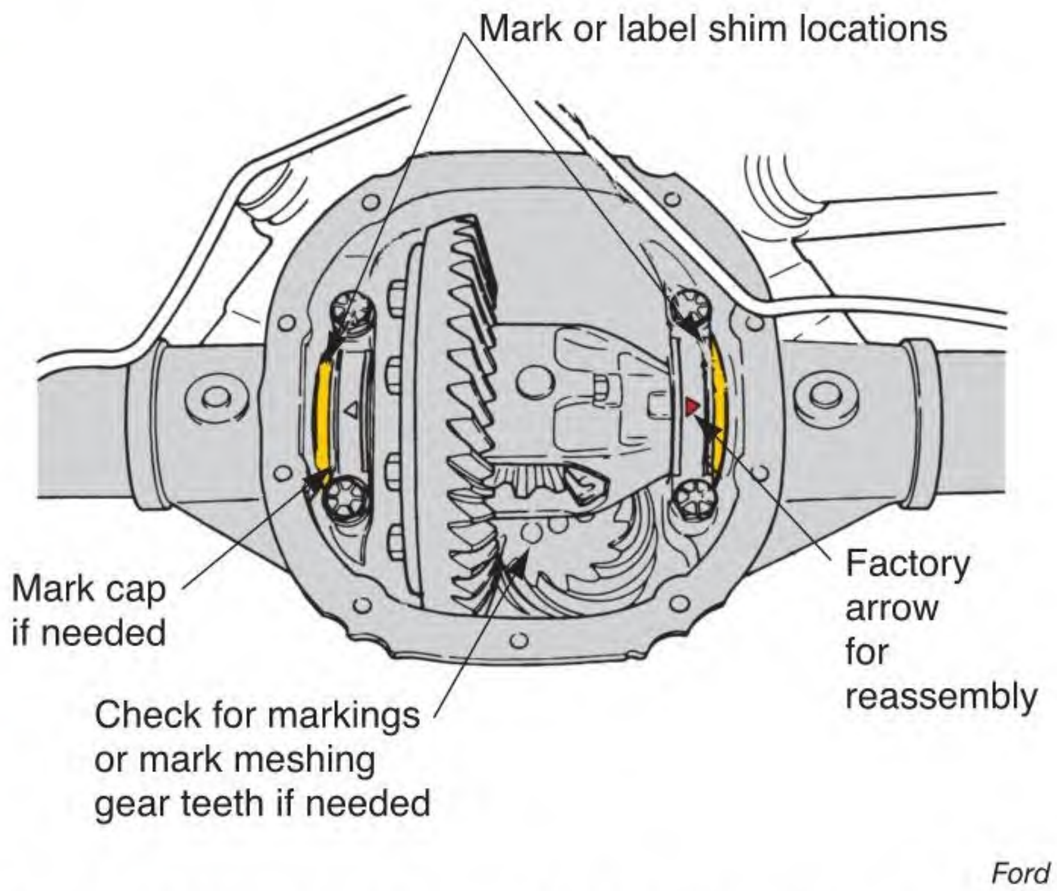
A differential carrier can be surprisingly heavy. Grasp it securely during removal. A carrier can cause painful injuries if dropped.

To remove an integral differential, remove the cover on the rear of the axle housing. Drain the lubricant. With the cover off, inspect and mark the individual components as they are removed. Look at **Figure 70-12**.

Differential Disassembly and Reassembly

The procedures for repairing a differential vary with the particular unit. However, the following service rules relate to almost all types of differentials:

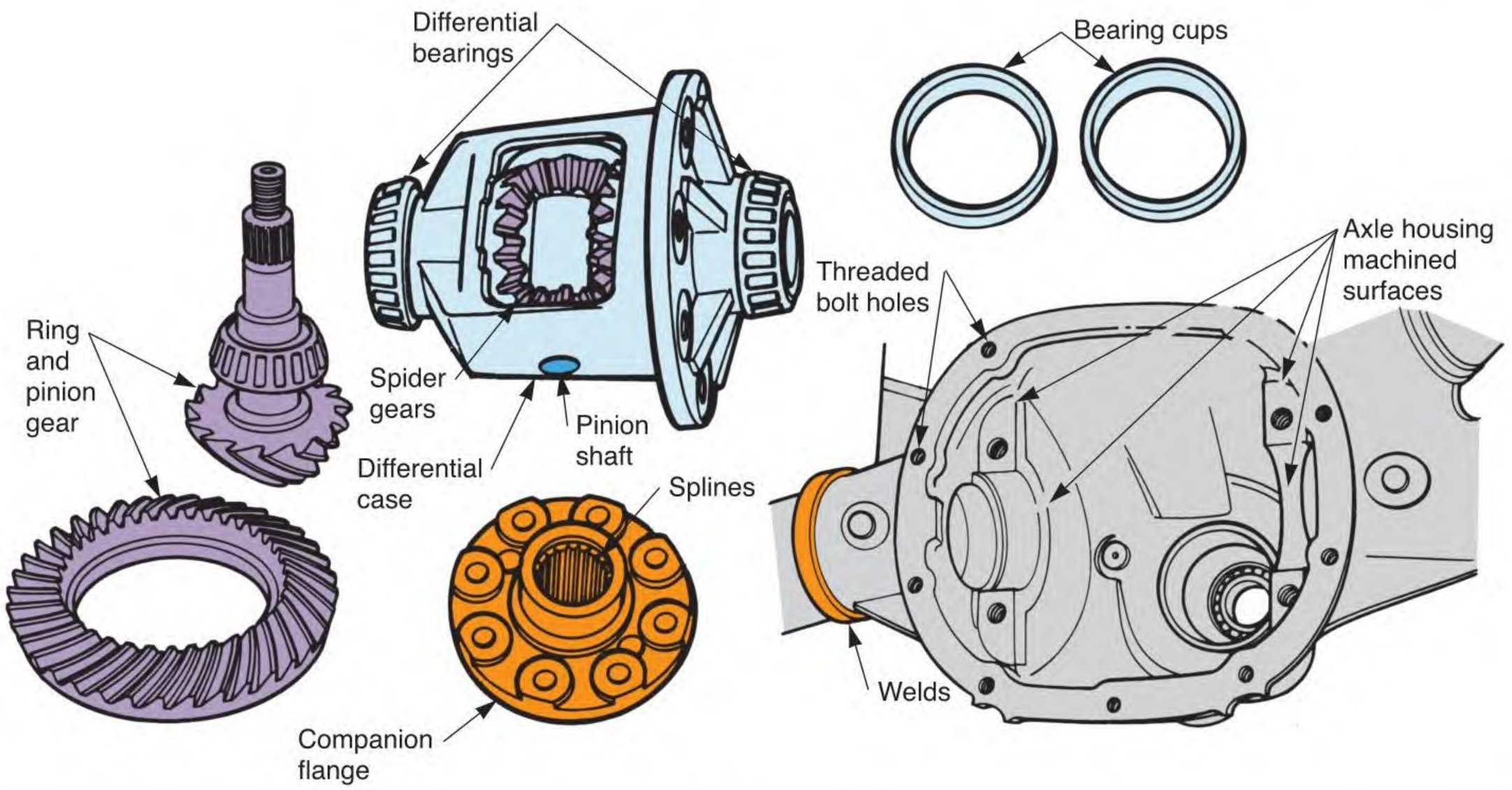
- Check for markings before disassembly. Carrier caps, adjustment nuts, shims, ring and pinion gears, spider gears, and the pinion yoke and flange should be reinstalled exactly as they are removed. If needed, punch mark, label, or scribe these components so they can be reassembled properly.
- Clean all parts carefully. Then, inspect them closely for wear or damage. **Figure 70-13** shows the most important parts needing inspection.



Ford

Figure 70-12. As you disassemble the differential, make sure you check markings and mark critical components. Most parts must be installed in the same location during reassembly. Note the markings on this unit.

- Use a holding fixture for the differential, if available. It will make your work easier.
- Rotate the pinion and case bearings by hand while checking for roughness. Inspect each roller and race. Replace the bearing and race as a set



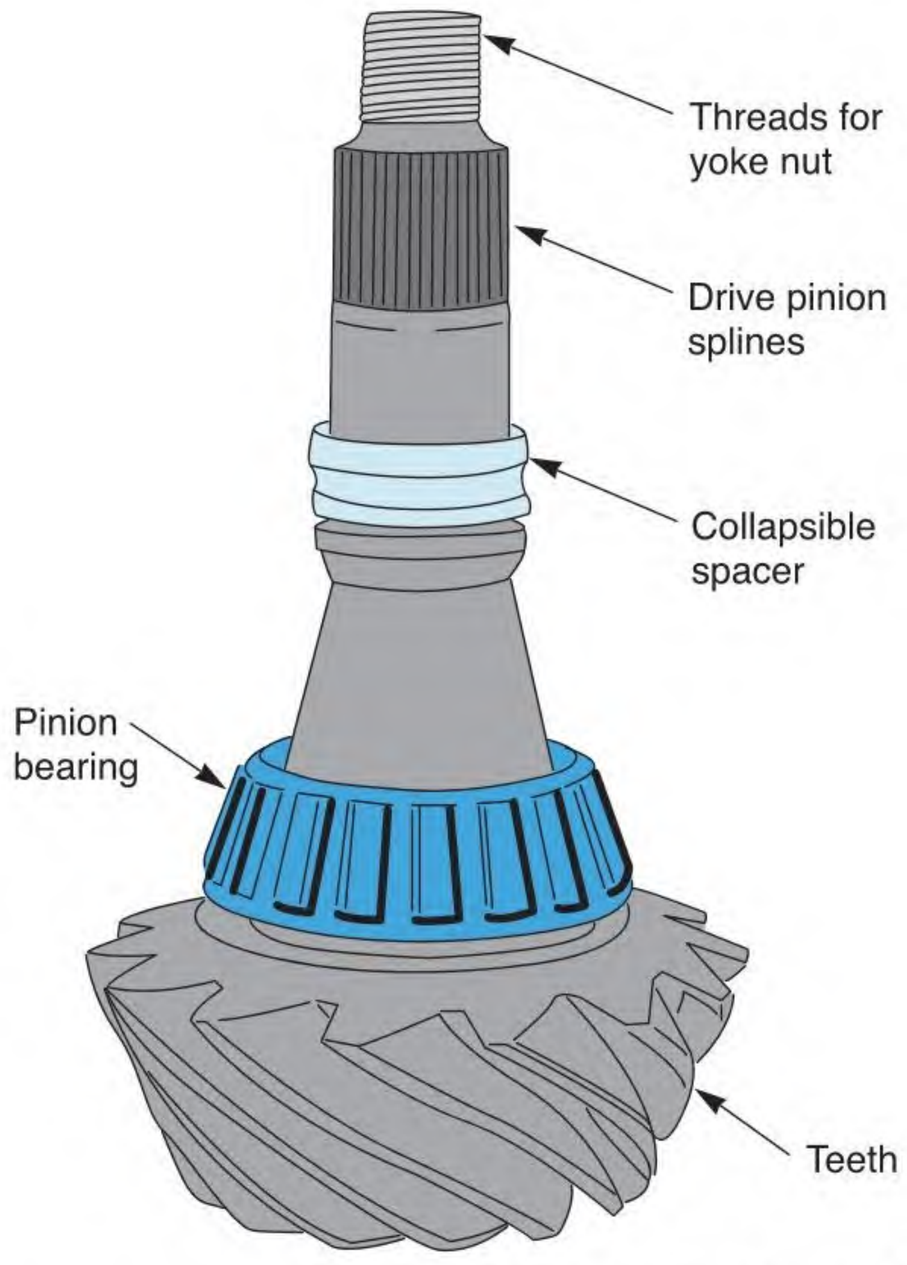
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Figure 70-13. Inspect all differential components carefully. If you overlook even one bad part, your repair could fail.

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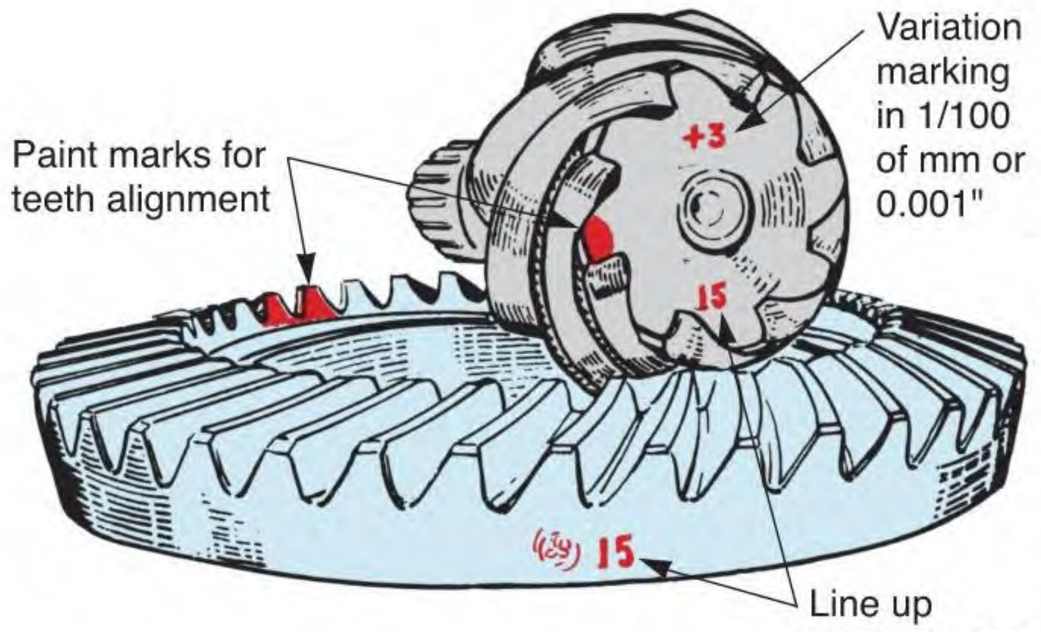
if faulty. To install new bearings, use a press or a puller, if required.

- If the pinion gear has a collapsible spacer (device for preloading the pinion bearings), always replace it. See **Figure 70-14**.
- Coat the outside of all seals with nonhardening sealer. Lubricate the seal's inside surface. Make sure the sealing lip faces the inside of the differential. To avoid seal damage, use a seal driver to install the seals.
- When tightening the pinion yoke nut, clamp the yoke in a vise or use a special holding bar.
- Replace the ring and pinion gears as a set. Mesh or align the gear timing markings (painted lines or other marks) on the ring and pinion gears (if used). This will properly match the teeth, which have been lapped together at the factory, **Figure 70-15**.
- Torque all fasteners to specifications. Refer to the service manual for torque values.
- Use new gaskets and approved sealer.



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Figure 70-14. If the pinion gear uses a collapsible spacer, install a new one any time the bearings are disassembled. If an old spacer is used, the bearing preload cannot be accurately attained.



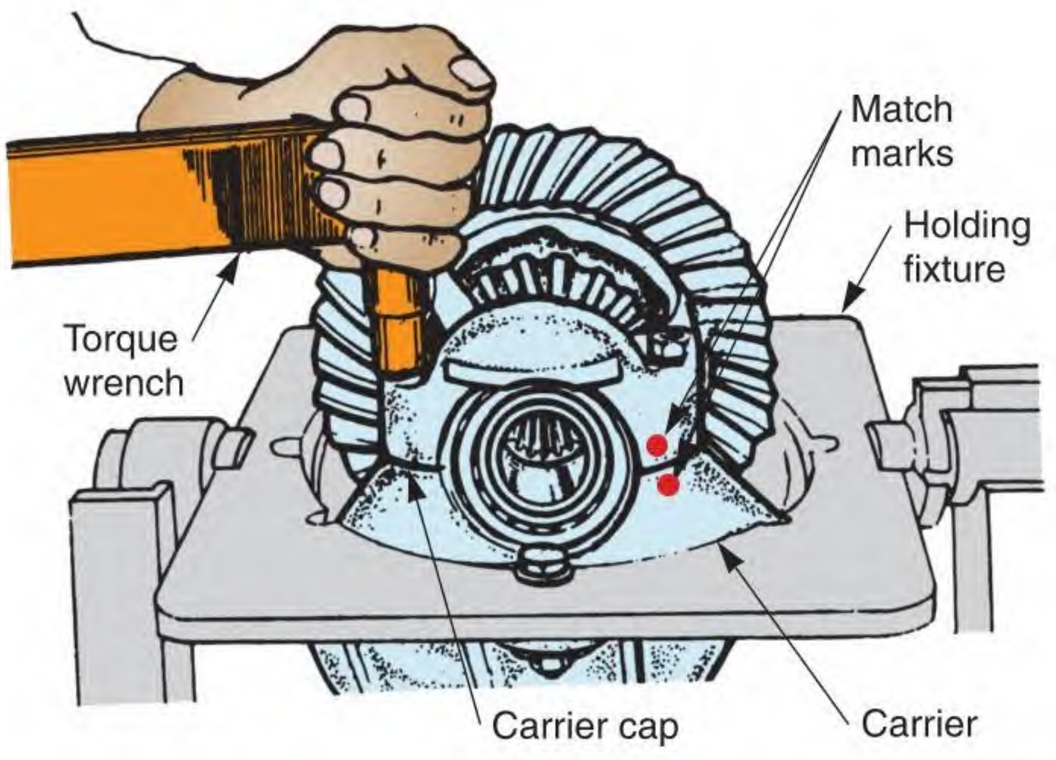
Chrysler

Figure 70-15. Always replace ring and pinion gears as a set. Note the markings. Some give information for adjustment. Others show which teeth must be meshed together during installation.

- Align all markings during reassembly. If you install the carrier caps backward, for example, the caps could crush and damage the bearings and races. The differential could fail as soon as it is returned to service, **Figure 70-16**.
- Differential designs and repair procedures vary, **Figure 70-17**. Special tools and methods are frequently needed. Refer to a shop manual for detailed instructions.

Limited-Slip Differential Service

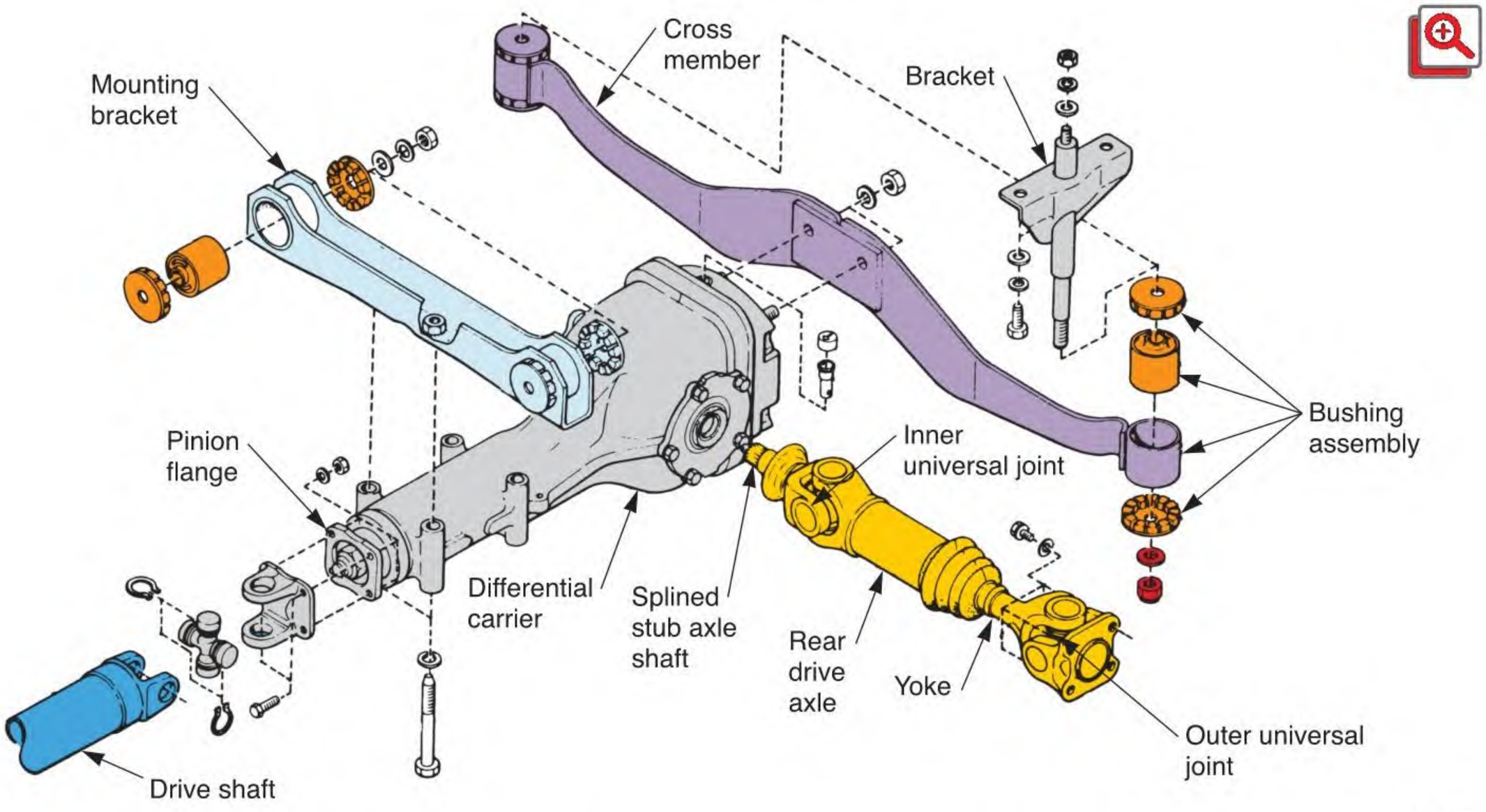
Limited-slip differential repair may be required after prolonged service or after damage from abuse or



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Figure 70-16. Make sure you align markings during assembly and torque all fasteners to specifications.

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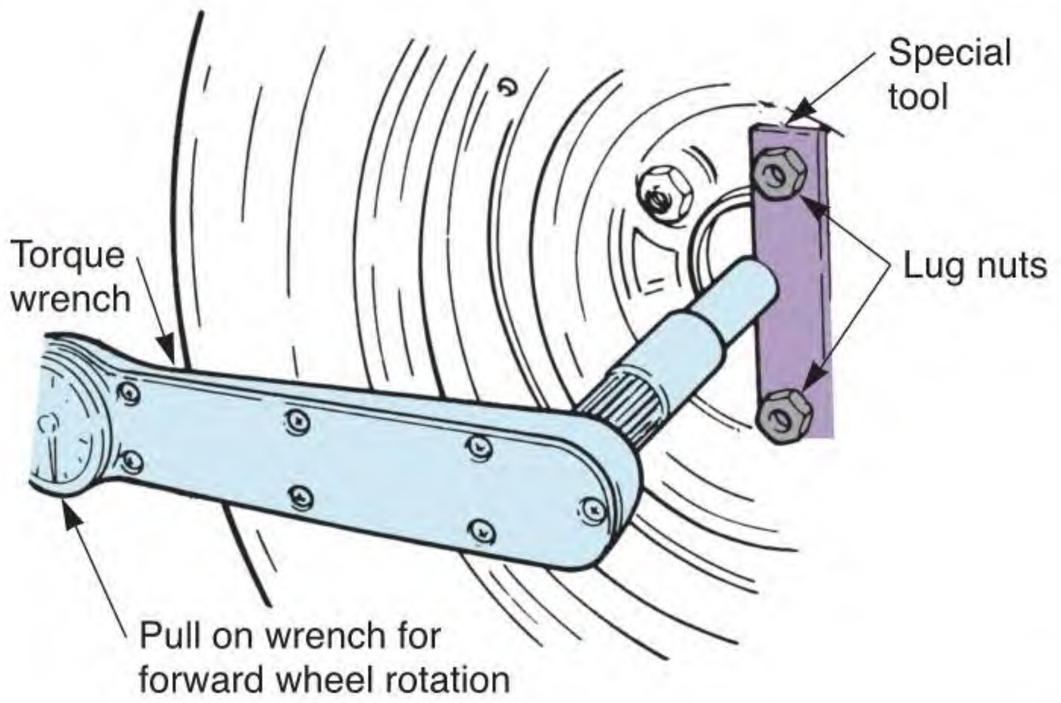
Figure 70-17. If a vehicle has swing axles or CV axles, service is similar to repairs made on a drive shaft.

lack of maintenance. The clutch discs can wear, losing much of their frictional quality. This can make the differential act like a conventional unit.

Service Procedure

To test a limited-slip differential (clutch and cone types):

1. Bolt a special tool to the wheel. The tool mounts over the lug studs so that a torque wrench can be used to rotate the axle.
2. Raise the tire off the shop floor.
3. Place the transmission in neutral.
4. Turn the wheel and axle with a torque wrench. Note the torque reading when the wheel begins to turn. This is the clutch pack or cone break-away torque, **Figure 70-18**.



Ford

Figure 70-18. To check most clutch-type limited-slip differentials, measure the break-away torque. With the test wheel off the ground and the other on the ground, mount the tool on the wheel. Then, measure how much torque is needed to turn the wheel and slip clutches. Compare the measurement to specifications.

Break-away torque is the amount of torque needed to make one axle or differential side gear rotate the limited-slip differential clutches. If the break-away torque is too low (worn clutches or cones, weakened clutch or cone springs, or part damage) or too high (shimmed improperly, part damage), repairs are needed.

If a limited-slip differential needs to be serviced, replace the clutch discs and springs.

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Differential Measurements and Adjustments

There are several measurements and adjustments that must be made when assembling a differential. When "setting up" (measuring and adjusting) a differential, correct bearing preloads and gear clearances are extremely critical.

The most important differential measurements and adjustments include:

- Pinion gear depth.
- Pinion bearing preload.
- Case bearing preload.
- Ring gear runout.
- Ring and pinion backlash.
- Ring and pinion contact pattern.

Pinion gear depth refers to the distance the pinion gear extends into the carrier. Pinion gear depth affects where the pinion gear teeth mesh with the ring gear teeth. Pinion gear depth is commonly adjusted by varying shim thickness on the pinion gear and bearing assembly. **Figure 70-19** illustrates how shims affect pinion gear depth in both removable and integral carriers.

Pinion bearing preload is frequently adjusted by torquing the pinion nut to compress a collapsible spacer. The more the pinion nut is torqued, the more the spacer compresses to increase the preload (tightness) of the bearings.

When a solid spacer is used, ***pinion gear shims*** commonly control pinion bearing preload. The pinion nut is usually torqued to a specific value.

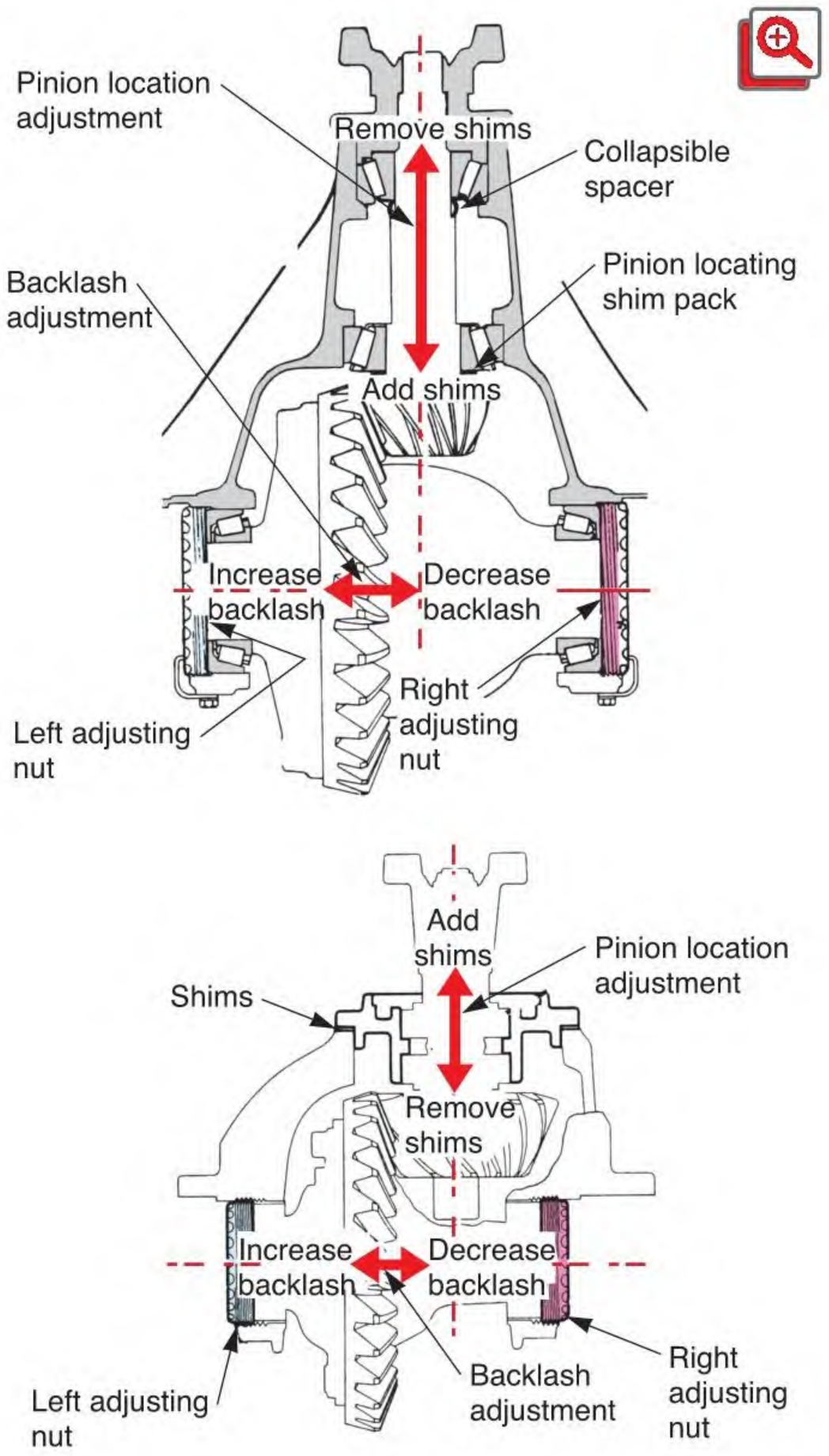
To set pinion gear or bearing preload, a holding tool is used to keep the pinion gear stationary. Then, a breaker bar or torque wrench is used to tighten the pinion nut.

With a collapsible spacer, only tighten the nut in small increments. Then, measure pinion preload by turning the pinion nut with a torque wrench. See **Figure 70-20**.

Case bearing preload is the amount of force pushing the differential case bearings together. As with pinion bearing preload, it is critical.

If the case bearing preload is too low (bearings too loose), differential case movement and ring and pinion gear noise can result. If preload is too high (bearings too tight), bearing overheating and failure can result.

When adjusting nuts are used to set case bearing preload, the nuts are typically tightened until all the play is out of the bearings. Then, each nut is tightened a specific portion of a turn to preload the bearings. This is done when adjusting backlash (covered shortly).



Ford

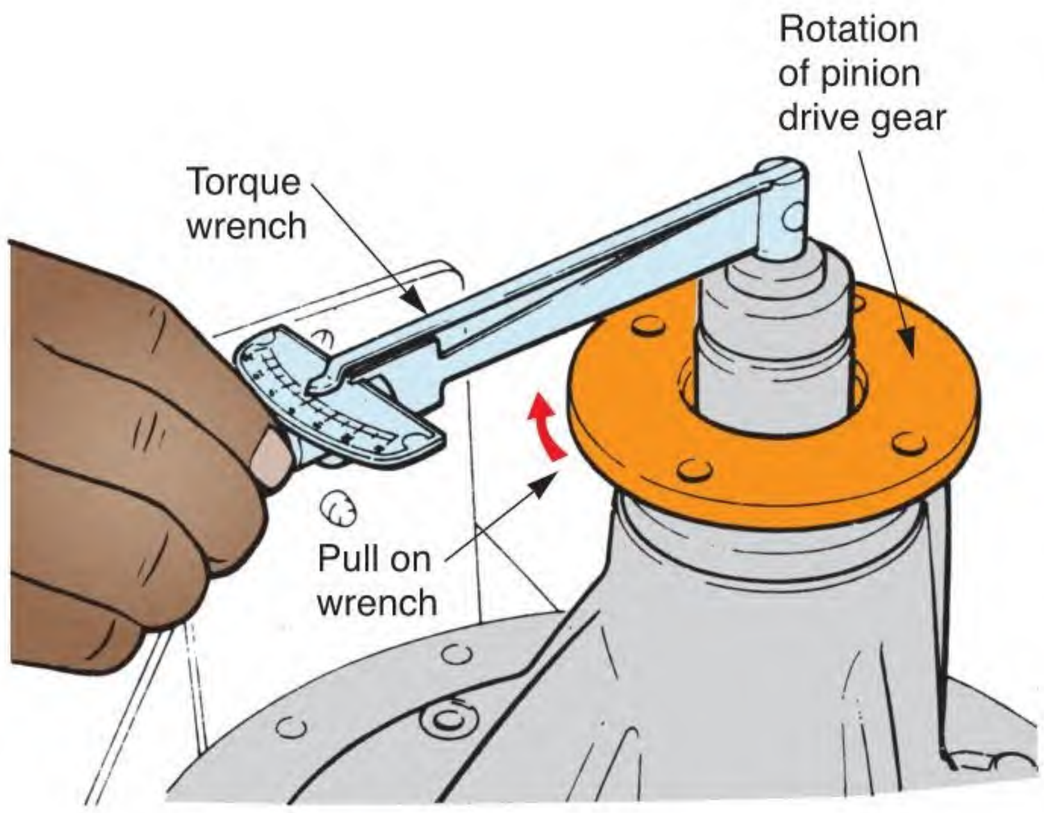
Figure 70-19. Study how the movement of the pinion and ring gears adjusts differentials. Shim thickness change affects each differently.

When shims are used to adjust preload, you may need to use a feeler gauge to check side clearance between the case bearing and carrier. This allows you to calculate the correct shim thickness to preload the case bearings. Refer to a shop manual for specific adjustment procedures.

Ring gear runout is the amount of wobble (side-to-side movement) produced when the ring gear is rotated. Ring gear runout must be within specifications.

To measure ring gear runout, mount a dial indicator against the back of the ring gear. The indicator stem should be perpendicular to the ring gear surface.

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Figure 70-20. Measure pinion bearing preload with a small torque wrench. Compare the measurement to specifications and adjust using service manual directions.

Then, turn the ring gear and note the indicator reading. See **Figure 70-21**.

If ring gear runout is excessive, check the ring gear mounting and the differential case runout. If the ring gear mounting is not a problem, replace either the ring gear (and pinion) or the case as needed.

Ring and pinion backlash refers to the amount of space between the meshing teeth of the gears. Backlash is needed to allow for heat expansion and lubrication.

As the gears operate, they produce friction and heat. This makes the gears expand, reducing the clearance between meshing teeth. Without sufficient backlash, the ring and pinion teeth could jam into each other as they reach operating temperature. The gears could fail in a short time. Too much ring and pinion backlash could cause gear noise (whirring, roaring, or clunking).

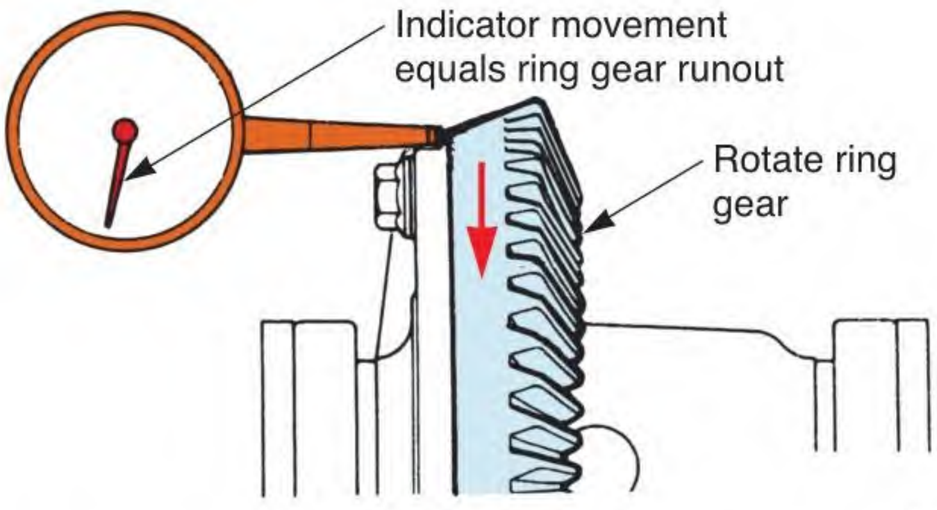
To measure ring and pinion backlash, mount a dial indicator as shown in **Figure 70-22**. Position the indicator stem on one of the ring gear teeth. Then, while holding the pinion gear stationary, wiggle the ring gear back and forth. Needle movement on the dial indicator reveals gear backlash. Compare your measurement to specifications and adjust backlash as needed.

To increase backlash, move the ring gear away from the pinion gear. To decrease backlash, move the ring gear toward the pinion gear. Refer to **Figure 70-19**. With some differentials, ring gear position is controlled by the case bearing nuts. In others, shims are used to move the ring gear.

A check of the ***ring and pinion contact pattern*** is used to double-check the gear adjustment. Wipe white grease or hydrated ferric oxide (yellow oxide of iron) on the teeth of the ring gear. This is illustrated in **Figure 70-23**.

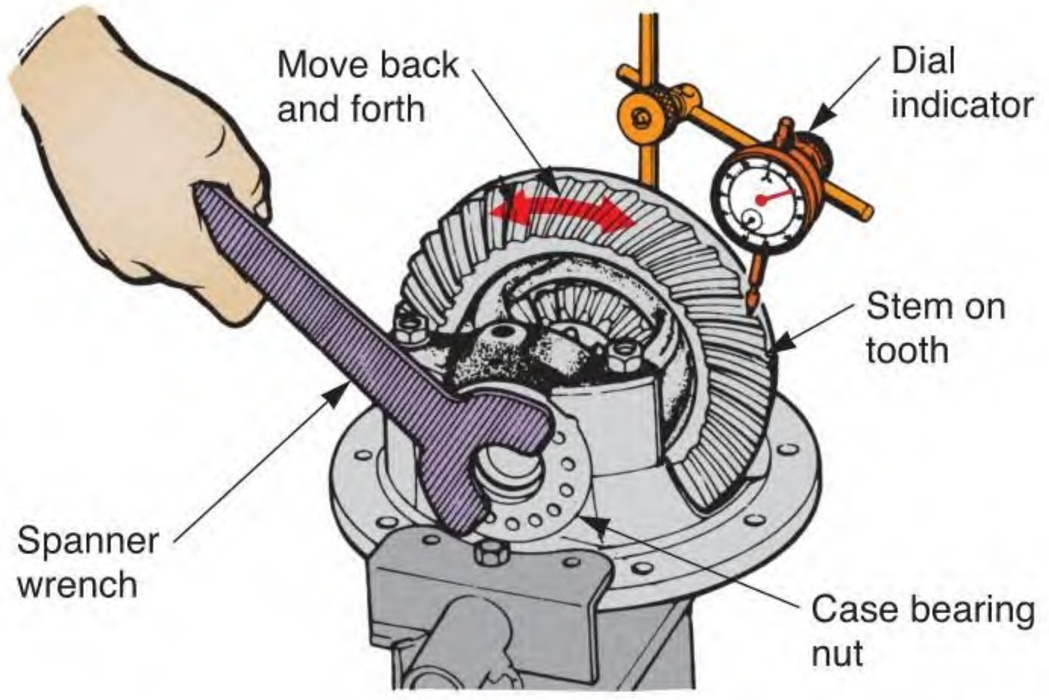
Spin the ring gear one way and then the other. Carefully note the contact pattern, which shows up on the teeth where the grease has been wiped off. A good contact pattern is located in the center of the gear teeth. Also, note the names of the areas on the ring gear teeth shown in **Figure 70-24**. These include:

- Toe—The toe is the narrow part of the gear tooth.
- Heel—The heel is the wide part of the gear tooth.



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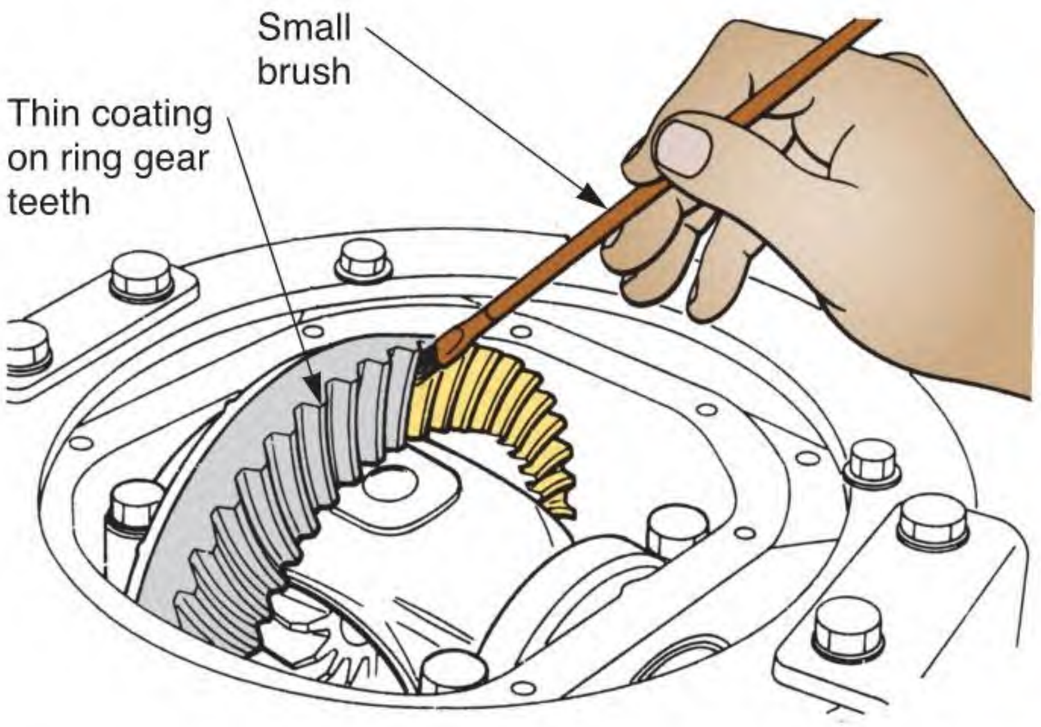
Figure 70-21. If gears seem to tighten up and loosen when turned, measure ring gear runout. Indicator needle movement equals runout.



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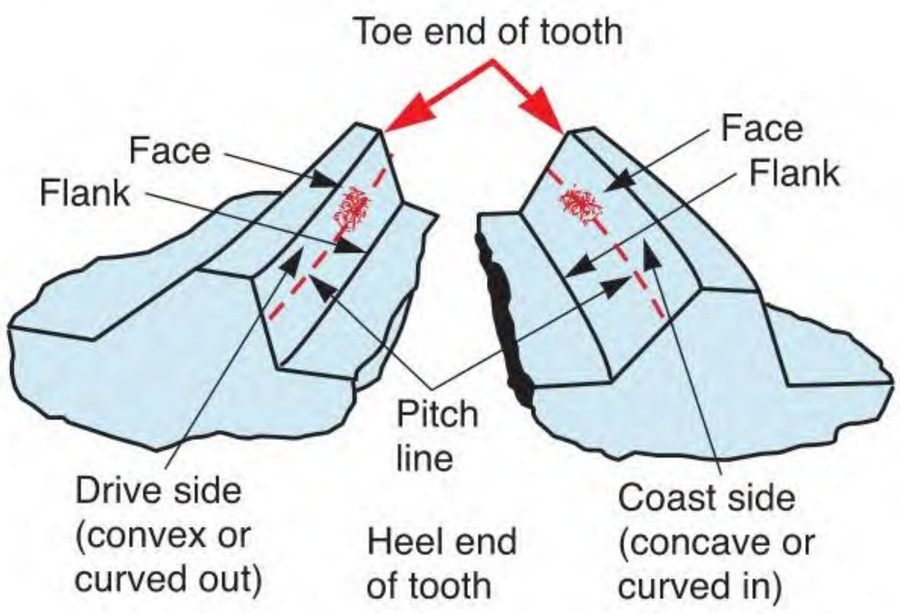
Figure 70-22. After setting pinion bearing preload and depth, adjust backlash and case bearing preload. This unit is adjusted by turning nuts. The indicator is mounted with the direction of gear rotation, touching the outer end of the tooth. Hold the pinion stationary and move the ring gear back and forth while watching the indicator.

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Figure 70-23. To check contact between the pinion gear and ring gear, coat the ring gear teeth with an approved substance: white grease, hydrated ferric oxide, etc. Turn the ring gear one way and then the other to rub the teeth together, producing the contact pattern.



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Figure 70-24. Ring gear teeth nomenclature. Study the names. They are needed when reading or interpreting gear contact patterns.

- Pitch line—The pitch line is an imaginary line along the center of the tooth.
- Face—The face is the area on the tooth above the pitch line.
- Flank—The flank is the area on the tooth below the pitch line.
- Drive side—The drive side is the convex side of the tooth.
- Coast side—The coast side is the concave side of the tooth.

Figure 70-25 shows several ring and pinion gear contact patterns. Study each and note the suggested correction for the faulty contact.

Diagnostic Case Study

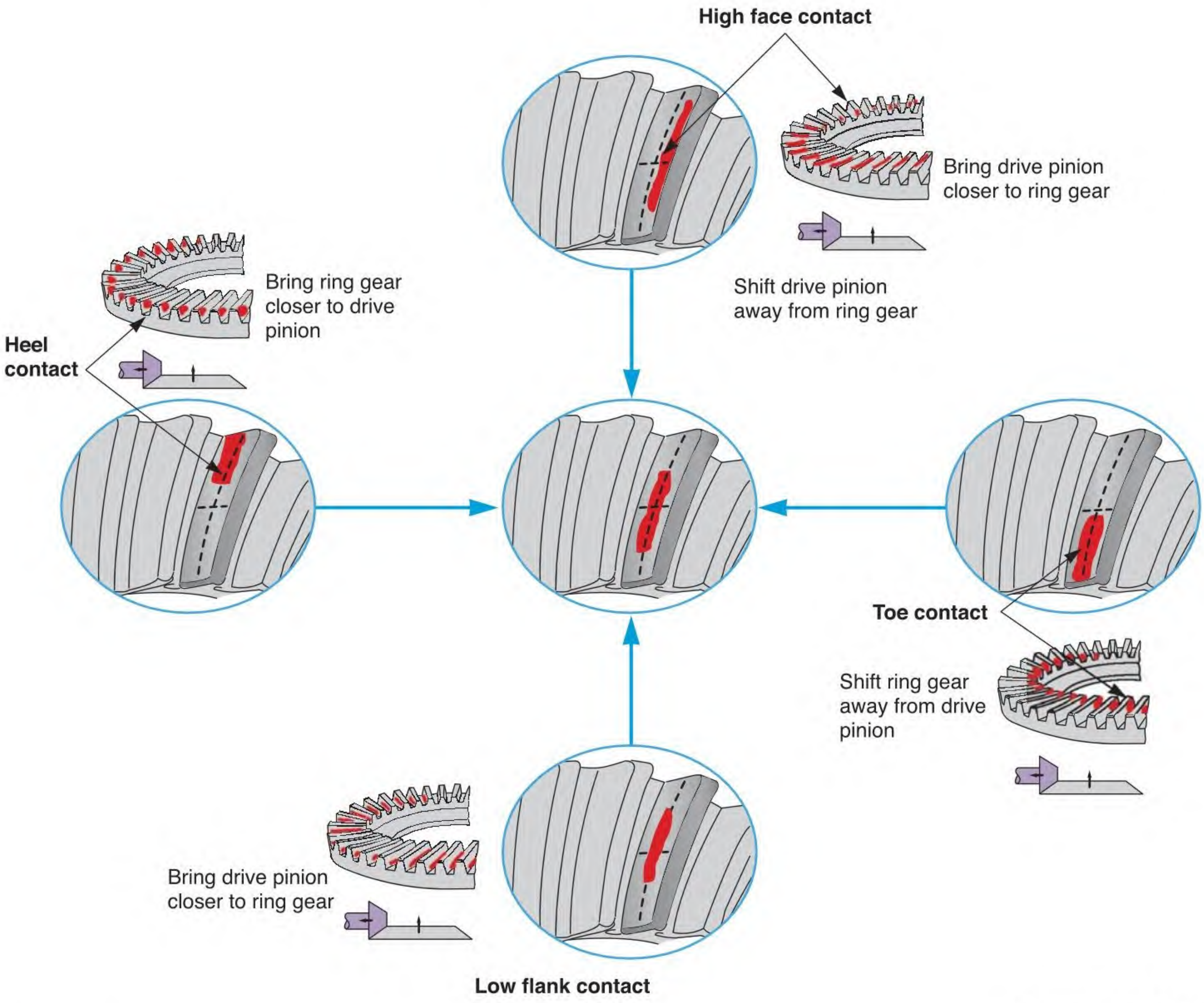
Concern: Mr. Jenson brings his 2001 Viper to the shop. He complains that during hard acceleration, only one tire spins.

Cause: Duff looks up the differential type in the service literature and finds that the car is equipped with a clutch-type, limited-slip differential. Suspecting that the clutch plates are worn, Duff turns the car over to the shop's driveline technician. The technician raises one rear tire off the shop floor. He uses an axle adapter plate and torque wrench to rotate one axle. He finds that the amount of torque required to rotate the axle is significantly less than the specifications call for.

The technician removes the drive shaft and differential from the vehicle. Next, he removes the differential case and then removes the ring gear assembly from the housing. When differential is disassembled, he sees that the clutch plates are badly worn.

Correction: The technician installs new clutch plates and shims into the differential case. He then reinstalls the ring gear and differential case into the housing. The ring gear backlash is adjusted using dial indicator. The differential is reinstalled and the drive shaft is reconnected. Once again, one rear wheel is lifted above the shop floor and the amount of torque required to turn the axle is measured. It is within the specifications. The vehicle is then taken for a test-drive to make sure the differential is operating correctly. Both rear tires are getting equal traction during acceleration and there is no differential binding or noise when the vehicle is turning. Confident the problem has been solved, the technician releases the vehicle to the owner.

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Figure 70-25. The area where grease is rubbed off the ring gear indicates contact point. It must be centrally located on the teeth. Note typical methods of correcting patterns.

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Summary

- Differentials and rear drive axles are normally very dependable. However, if operated dry (without lubricant), abused, or used for prolonged service, parts can wear and fail.
- Ring and pinion problems usually show up as a howl or whining noise that changes when going from acceleration to deceleration.
- A stethoscope can often be used to isolate the source of a differential or rear axle bearing problem.
- Rear axle lubricant leaks can occur at the pinion gear seal, carrier or inspection cover gaskets, and at the two axle seals.
- Worn or damaged bearings in the carrier or on the axles often produce a constant whirring or humming sound.
- Differential case troubles frequently show up when rounding a corner. With the rear wheels turning at different speeds, any problem will usually show up as an abnormal sound from the rear of the vehicle.
- Many automobile manufacturers recommend that the differential fluid be checked or replaced at specific intervals.
- A retainer plate–type axle is commonly used with a removable carrier. A C-clip–type axle is frequently used with an integral carrier.
- Wear eye and face protection when pressing a bearing on or off an axle.
- Excessive axle end play can cause a clunking sound as the car rounds a corner.
- Insufficient axle end play can result in axle bearing, retainer, or differential side gear failure.
- Break-away torque is the amount of torque needed to make one axle rotate the limited-slip differential clutches.
- Pinion gear depth refers to the distance the pinion gear extends into the carrier.
- Pinion gear preload is frequently adjusted by torquing the pinion nut to compress a collapsible spacer. When a solid spacer and pinion nut torque is used, pinion gear shims commonly control pinion bearing preload.
- Case bearing preload is the amount of force pushing the differential case bearings together.
- Ring gear runout is the amount of wobble produced when the ring gear is rotated.
- Ring and pinion backlash refers to the amount of space between the meshing teeth of the gears.
- A check of the ring and pinion contact pattern is used to double-check the gear adjustment.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

axle end play
break-away torque
case bearing preload
C-clip type axle
differential ID number
pinion bearing preload
pinion gear depth
pinion gear shims
rear end
retainer plate type axle
ring and pinion backlash
ring and pinion contact pattern
ring gear runout
stethoscope

Activities

1. Check out a rear axle assembly on a shop vehicle and report on its condition.
2. Remove an axle of the retainer-plate type.
3. Remove an axle of the C-clip type.
4. Clean a differential and replace the fluid.

Review Questions

Answer the following questions using the information provided in this chapter.

1. A(n) _____ is a listening device that can be used to isolate differential and axle noises.
2. Describe ring and pinion noise.
3. Excess ring and pinion backlash can cause a "clunk" sound when the transmission is placed in drive. True or False?
4. Worn or damaged bearings in the carrier or on the axles produce a humming sound that changes with load. True or False?
5. List four points to consider when diagnosing bearing failures.

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6. _____ _____ often require a special type of gear fluid with friction additives intended for the wet clutch packs in modern differentials.
7. Explain the two methods commonly used to hold a rear drive axle in its housing.
8. How do you measure axle end play?
9. List twelve service rules for differentials.
10. Which of the following is *not* a common differential adjustment?
    (A) Pinion gear depth.
    (B) Pinion bearing preload.
    (C) Case bearing preload.
    (D) Ring and pinion preload.

ASE-Type Questions

1. An automobile rear drive axle assembly needs to be road tested for diagnostic purposes. Technician A road tests the car on a smooth road surface. Technician B road tests the vehicle rounding corners. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Noise is coming from a car's rear drive axle assembly. Technician A checks for broken pinion gear teeth. Technician B inspects the condition of the ring gear. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. A whining noise is coming from a car's differential case when driving straight. Technician A inspects the ring and pinion gear for problems. Technician B replaces the axle shims. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. A customer wants to know what caused his/her car's ring and pinion gears to malfunction. Technician A says prolonged service may have caused this problem. Technician B says low differential lubricant level may have caused this problem. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. A customer complains of a lubricant leak near the rear axle assembly. Technician A checks the housing's axle seals. Technician B checks to see if it is brake fluid. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. A rear axle is leaking lubricant. Technician A checks the pinion gear seal. Technician B checks the drive shaft slip yoke seal. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. A humming sound is coming from a car's rear axle's carrier when driving straight ahead. Technician A wants to replace the carrier bearings. Technician B wants to replace the spider gears. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. The bearings in a rear axle assembly need replacing. Before performing this task, Technician A checks the condition of all axle assembly parts. Before performing this task, Technician B wants to determine the cause of the original bearing failure. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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9. The lubricant in a limited-slip differential needs changing. Technician A tells the owner of the vehicle that all differential lubricant is the same. Technician B tells the owner of the car that certain limited-slip differentials require a special type of lubricant. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. A rear axle must be removed from its housing. Technician A says a retainer plate may be used to hold this axle in its housing. Technician B says a C-clip may be used to hold this particular axle in its housing. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
11. An automobile's retainer plate–type axle needs replacing. Technician A begins this repair procedure by disassembling the differential carrier. Technician B begins this procedure by removing the spider gears. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
12. A press-fit rear axle bearing must be removed and replaced. Technician A wants to use a cutting torch to remove the bearing. Technician B wants to use a grinder, chisel, and hydraulic press to remove this bearing. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
13. Noise is coming from a car's differential case in turns. Technician A looks for damaged spider gears. Technician B inspects the condition of the axle mounting plates. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
14. A rear axle assembly differential is being serviced. Technician A checks pinion gear depth during this service procedure. Technician B checks ring gear runout during this service procedure. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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Rear Axle Diagnosis

Condition	Possible Causes	Correction
Noise during straight ahead driving.	1. Insufficient lubricant. 2. Worn or improper lubricant. 3. Differential case bearings worn. 4. Worn drive pinion shaft bearings. 5. Worn ring and pinion. 6. Excessive backlash. 7. Insufficient backlash. 8. Excessive ring and pinion backlash. 9. Insufficient ring and pinion backlash. 10. Pinion shaft or differential case bearings improperly preloaded. 11. Excessive ring gear runout. 12. Loose ring gear fasteners. 13. Unmatched ring and pinion. 14. Loose differential case bearing cap fasteners. 15. Warped housing. 16. Loose pinion shaft companion flange retaining nut. 17. Incorrect tooth (ring and pinion) contact pattern. 18. Loose wheel. 19. Wheel hub loose on tapered axle. 20. Wheel hub key (on tapered axle) sheared. 21. Worn wheel (axle) bearing. 22. Bent axle. 23. Worn wheel hub or axle keyway. 24. Dry pinion shaft seal. 25. Loose universal joint retainers. 26. Damaged universal joint. 27. Worn or broken front-wheel drive front suspension parts. 28. Worn or broken transaxle unit.	1. Fill housing to correct level. 2. Drain. Flush and fill with correct lubricant. 3. Replace bearings. 4. Replace pinion bearings. 5. Replace ring and pinion. 6. Adjust backlash. 7. Adjust backlash. 8. Adjust backlash. 9. Adjust backlash. 10. Preload as specified by the manufacturer. 11. Remove ring, clean, and check flange runout. Reinstall and check runout. Replace ring or case as needed. 12. Torque fasteners. 13. Install a matched ring and pinion set. 14. Torque fasteners. 15. Replace housing. 16. Torque flange nut. 17. Adjust as needed. 18. Tighten wheel lugs. 19. Inspect, if not damaged, torque retaining nut. 20. Install new key. 21. Replace axle bearing and seal. 22. Replace axle. 23. Replace axle or hub as needed. 24. Replace pinion shaft seal. 25. Tighten universal joint retainers. 26. Replace universal joint. 27. Repair or replace as necessary. 28. Repair or replace as needed.
Noise when rounding a curve.	1. Worn or broken differential pinion gears. 2. Worn differential pinion shaft. 3. Worn or broken axle side gears. 4. Excessive axle side gear or pinion gear end play. 5. Excessive axle end play. 6. Improper type of lubricant. 7. Loose or broken suspension parts (front-wheel drive). 8. Loose or broken universal joints.	1. Replace gears. 2. Replace pinion shaft. 3. Replace side gears. 4. Install new thrust washers or replace case and/or gears. 5. Adjust end play. 6. Drain. Flush and fill with correct lubricant. 7. Repair or replace parts as needed. 8. Tighten or replace universal joints.

(Continued)

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Rear Axle Diagnosis

Condition	Possible Causes	Correction
Clunking sound when engaging clutch, accelerating, or decelerating.	1. Excessive ring and pinion backlash. 2. Excessive end play in pinion shaft. 3. Worn axle side gears and pinions. 4. Worn differential bearings. 5. Worn side gear thrust washers. 6. Differential pinion shaft loose in case or pinions. 7. Worn axle shaft splines. 8. Worn wheel hub or axle keyway. 9. Loose wheel or hub. 10. Loose or broken universal joints.	1. Adjust backlash. 2. Preload bearings. 3. Replace worn gears. 4. Replace bearings. 5. Replace thrust washers. 6. Replace pinion shaft, gears, or differential case. 7. Replace axle. 8. Replace hub or axle. 9. Tighten fasteners. 10. Tighten or replace universal joints.
Axle leaking lubricant.	1. Clogged breather. 2. Worn seals. 3. Loose carrier-to-housing or inspection cover fasteners. 4. Carrier or inspection cover gasket damaged. 5. Lubricant level too high. 6. Wrong type of lubricant. 7. Porous housing (standard and transaxle). 8. Stripped fill plug threads. 9. Cracked housing (standard and transaxle).	1. Open breather. 2. Install new seals. 3. Tighten fasteners. 4. Install new gasket or sealer. 5. Drain lubricant to proper level. 6. Drain. Flush and install correct lubricant. 7. Repair or replace housing. 8. Repair or replace as needed. 9. Repair or replace housing.
Noises that may be confused with drive axle assembly.	1. Low air pressure in tires. 2. Road surface. 3. Transmission. 4. Bent propeller shaft. 5. Loose U-joints. 6. Engine. 7. Front wheel bearings. 8. Tire tread. 9. Dragging brakes. 10. Excessive front wheel end play.	1. Inflate tires to proper pressure. 2. Test on several different road surfaces. 3. Check transmission. 4. Replace shaft. 5. Tighten or replace U-joints. 6. Check engine. 7. Replace bearings. 8. Inflate temporarily to 50 psi (34.5 kPa) for road test only. 9. Adjust brakes. 10. Adjust wheel bearings.
Rear axle overheating.	1. Wrong type of lubricant. 2. Insufficient lubricant. 3. Overloading (pulling heavy trailer). 4. Worn gears. 5. Excessive bearing preload. 6. Insufficient backlash between ring and pinion.	1. Drain, flush, and fill with correct lubricant. 2. Fill lubricant to proper level. 3. Reduce vehicle load. Advise driver. 4. Replace gears. 5. Adjust preload. 6. Adjust backlash.

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Chapter 71
Transaxle and Front Drive Axle Technology

After studying this chapter, you will be able to:

- Identify the major parts of a transaxle assembly.
- Explain the operation of a manual transaxle.
- Explain the operation of an automatic transaxle.
- Trace the flow of power through manual and automatic transaxles.
- Describe design differences in transaxles.
- Identify the parts of constant velocity drive axles.
- Compare design differences in CV joints.
- Correctly answer ASE certification test questions requiring a knowledge of transaxle and front drive axle designs.

This chapter describes the construction and operating principles of modern transaxle designs and front drive, CV axle assemblies. It relies and builds on the information given in previous chapters on clutches, gearsets, manual transmissions, automatic transmissions, and differentials.

Tech Tip

In this chapter, the term *front drive axle assembly* refers to a transaxle differential and CV axles going to the front wheel hubs. Vehicles with modern independent rear suspensions use similar rear swing axles with CV joints to allow the axles to flex with suspension movement.

Transaxle

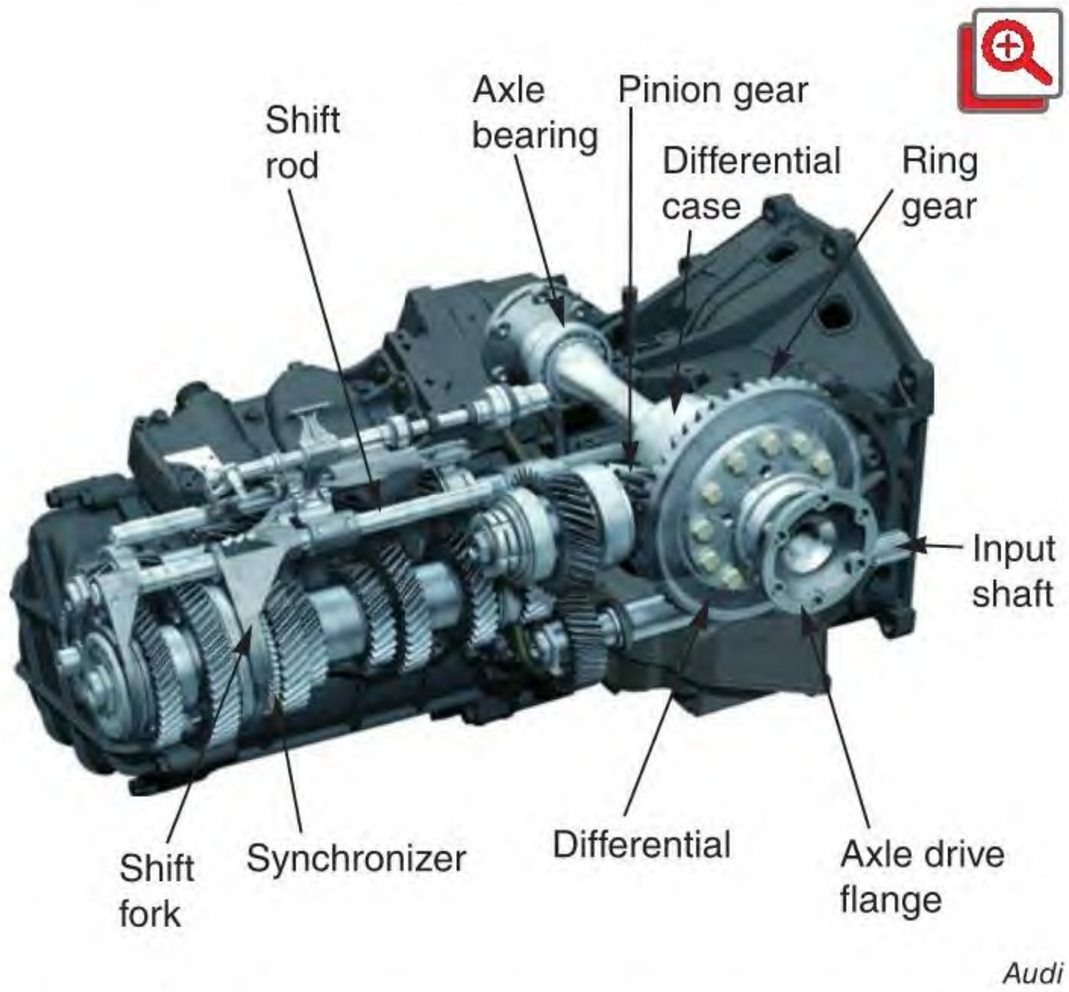
A ***transaxle*** is a transmission and a differential combined in a single assembly. Short drive axle assemblies can be used to connect the transaxle output to the hubs and drive wheels. See **Figure 71-1**.

A transaxle is commonly used in late-model, front-wheel-drive cars. However, a few rear-engine or mid-engine sports cars and some older rear-engine economy cars also use a transaxle.

Compared to a front-engine vehicle with rear-wheel drive, a front-engine vehicle with a transaxle and front-wheel drive has several advantages:

- Reduced drive train weight and improved efficiency.
- Improved traction on slippery pavement because of more weight on the drive wheels.
- Increased passenger compartment space (no hump in the floor for the drive shaft).

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Audi

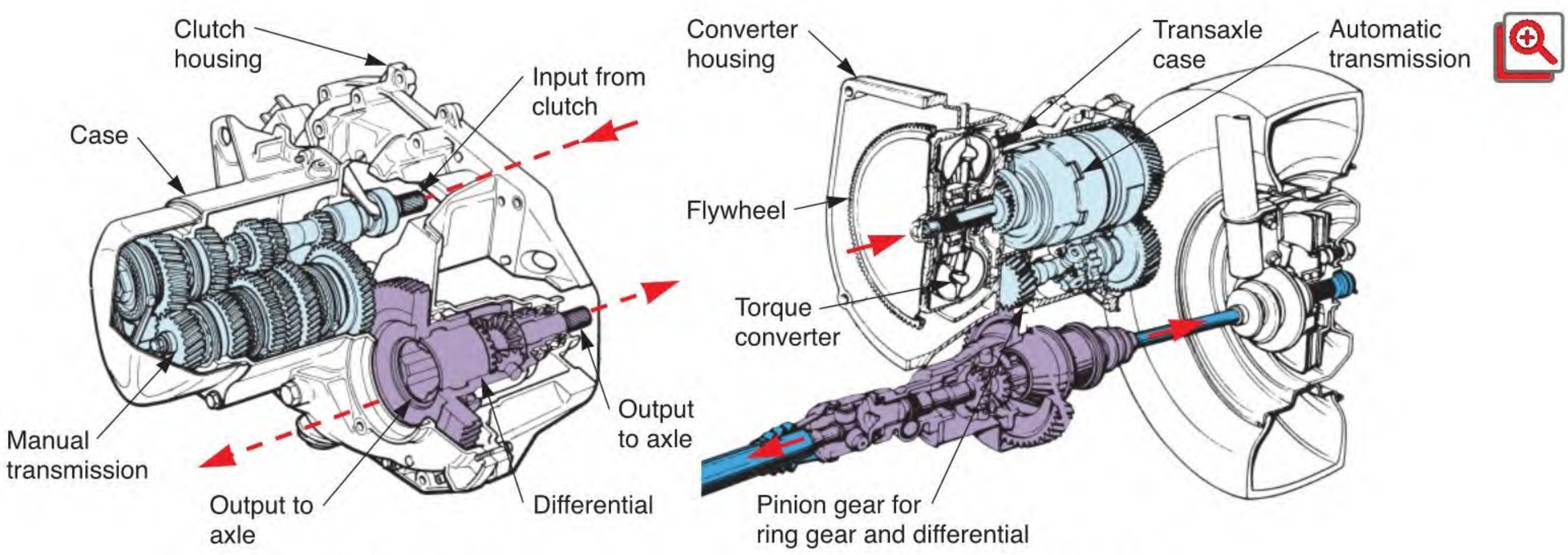
Figure 71-1. A transaxle combines a transmission and differential (large ring and pinion gears) to transfer power to the axles, hubs, wheels, and tires for vehicle propulsion.

- Smoother ride because of less unsprung weight (weight that must move with suspension action).
- Quieter operation because engine and drive train noise is centrally located in the engine compartment (no transmission, drive shaft, and rear axle under passenger compartment).
- Improved safety because of increased mass in front of passengers.

However, a front-wheel-drive vehicle also has some disadvantages:

- ***Torque steer*** causes the front wheels to pull to one side when engine power acts on the steering system through the front drive axles. Upon rapid acceleration, the vehicle tends to steer to one side of the road.
- Loss of directional control under hard acceleration. If the front wheels spin, the vehicle can skid out of control, especially when turning while accelerating.
- Less steering wheel feel of road because steering system must overcome torque steer. ***Steering feel*** is the feedback of road imperfections that is sent into the steering wheel.
- Loss of traction during acceleration on dry pavement—especially in vehicles with high-performance engines. Upon acceleration, vehicle weight transfers to the rear wheels, which lifts weight off the front drive wheels and tires. Drag race cars are usually rear-wheel-drive for this reason.

Both manual and automatic transaxles are available. A manual transaxle uses a friction clutch and a standard transmission gearbox. An automatic transaxle commonly uses a torque converter and a hydraulic system to control gear engagement. Compare the manual and automatic transaxles shown in **Figure 71-2**.



Manual transaxle **Automatic transaxle**

Renault; Chrysler

Figure 71-2. A manual transaxle is a helical gear transmission and a differential in a single assembly. An automatic transaxle is a planetary gear transmission and differential combined.

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Transverse Engine Transaxle

Most transaxles are designed so that the engine can be ***transverse*** (sideways) in the engine compartment. The engine crankshaft centerline points at both drive wheels. See **Figure 71-3**. The transaxle bolts to the rear of the engine. This produces a very compact lightweight, power-efficient drive unit.

Engine torque enters the clutch and transmission. The transmission transfers power into the differential. Then, the differential turns the drive axles, which rotate the front drive wheels.

Longitudinal Engine Transaxle

A few transaxles are made so that the engine is mounted ***longitudinally*** (lengthwise). The crankshaft centerline points toward the front and rear of the vehicle. Look at **Figure 71-4**.

A transaxle for a longitudinally mounted engine frequently uses a more conventional differential with helical ring and pinion gears.

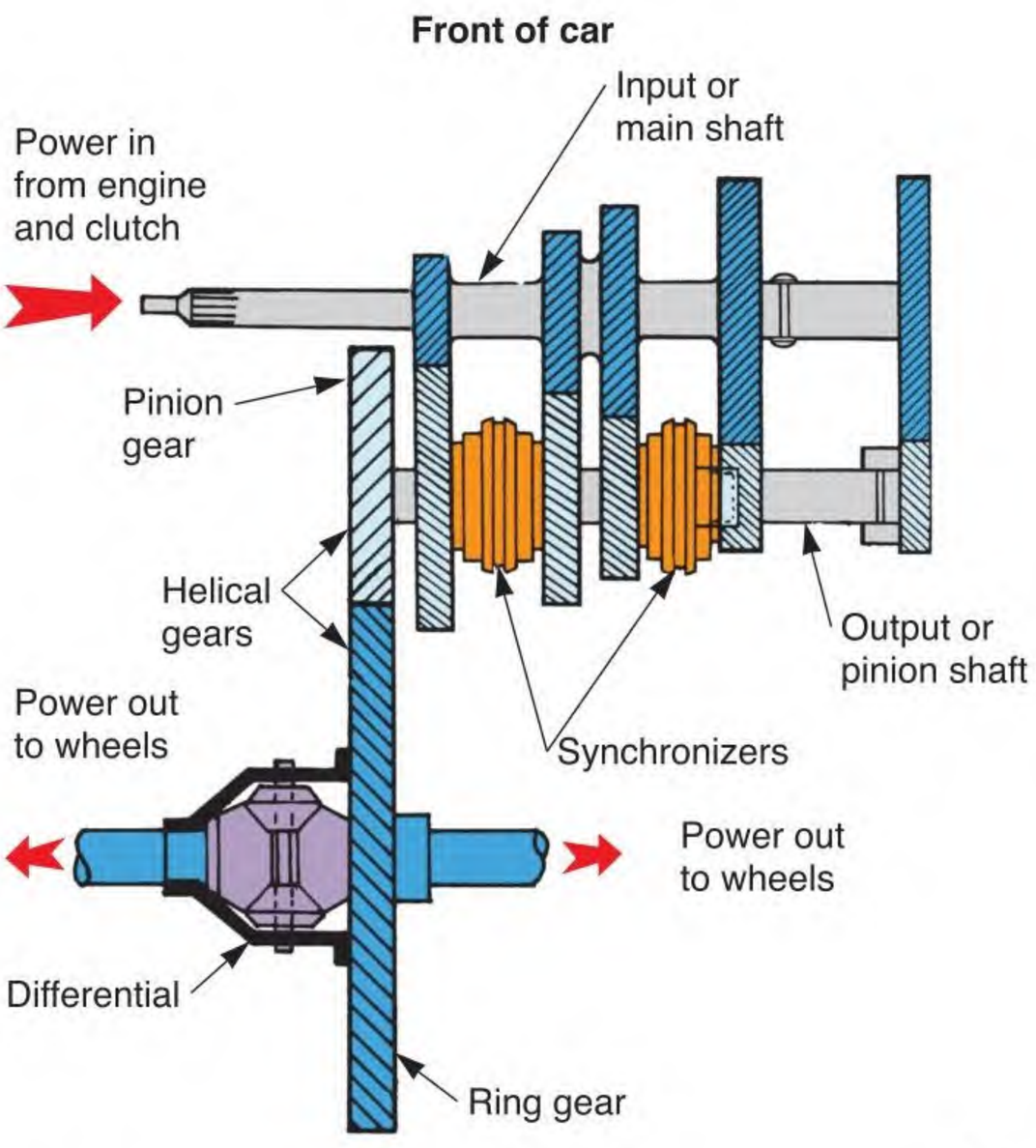
The flow of engine torque must be changed 90° in order to turn the drive axles. This type of transaxle uses the same principles as a conventional transmission and rear drive axle assembly. However, the parts are arranged differently.

Manual Transaxle

A ***manual transaxle*** uses a manual clutch and transmission. A foot-operated clutch engages and disengages the engine and transaxle. A hand-operated shift lever allows the driver to change gear ratios.

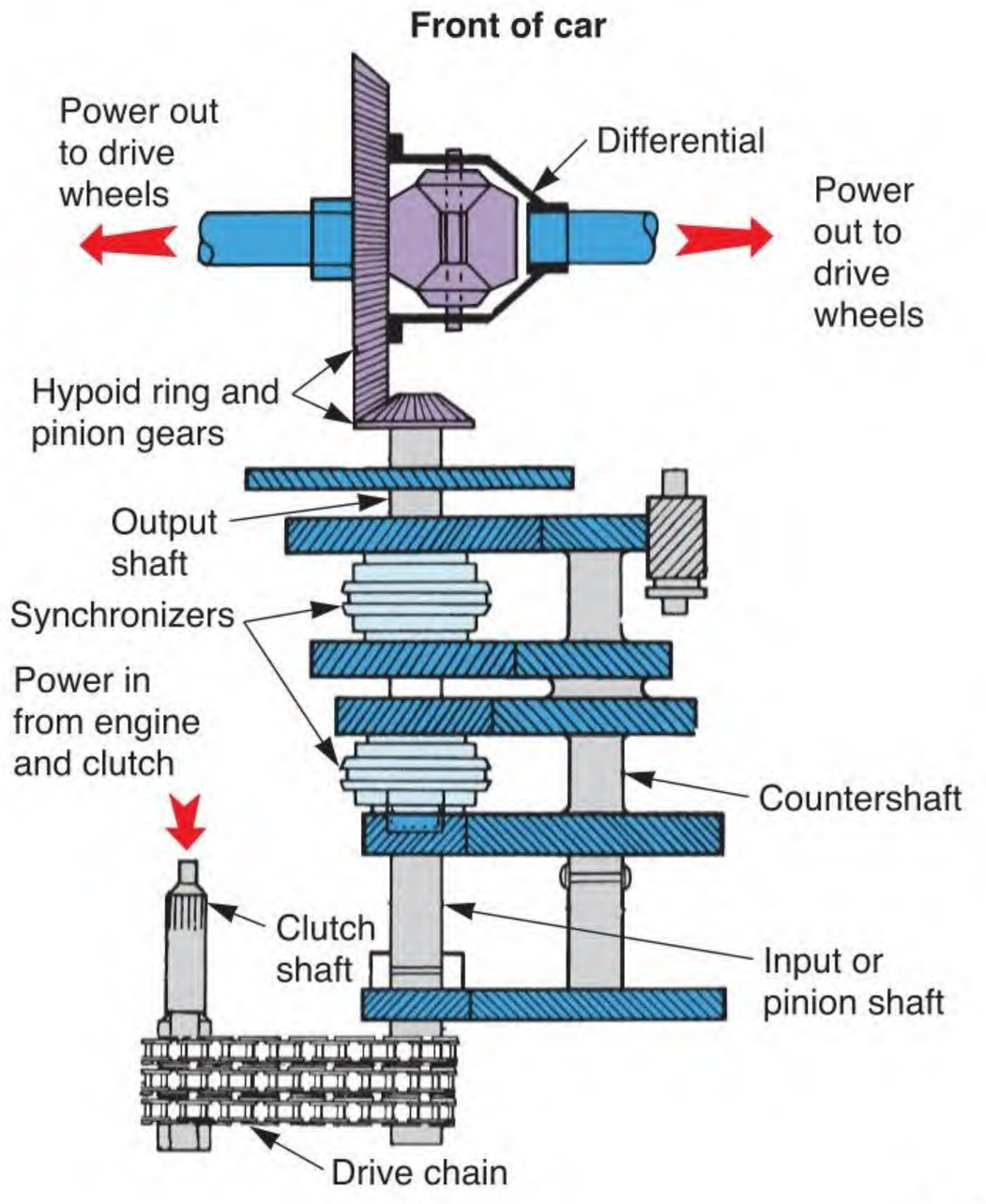
As the basic parts related to a manual transaxle are introduced, refer to **Figure 71-5**.

- ***Input shaft***—The input shaft is the main shaft splined to the clutch disc. It turns gears in the transaxle.
- ***Input gears***—Input gears are either freewheeling or fixed gears on the input shaft. They mesh with output gears.
- ***Output gears***—Output gears are either freewheeling or fixed gears driven by input gears.
- ***Output shaft***—The output shaft is a pinion shaft that transfers torque to the differential ring and pinion gears.



Saab

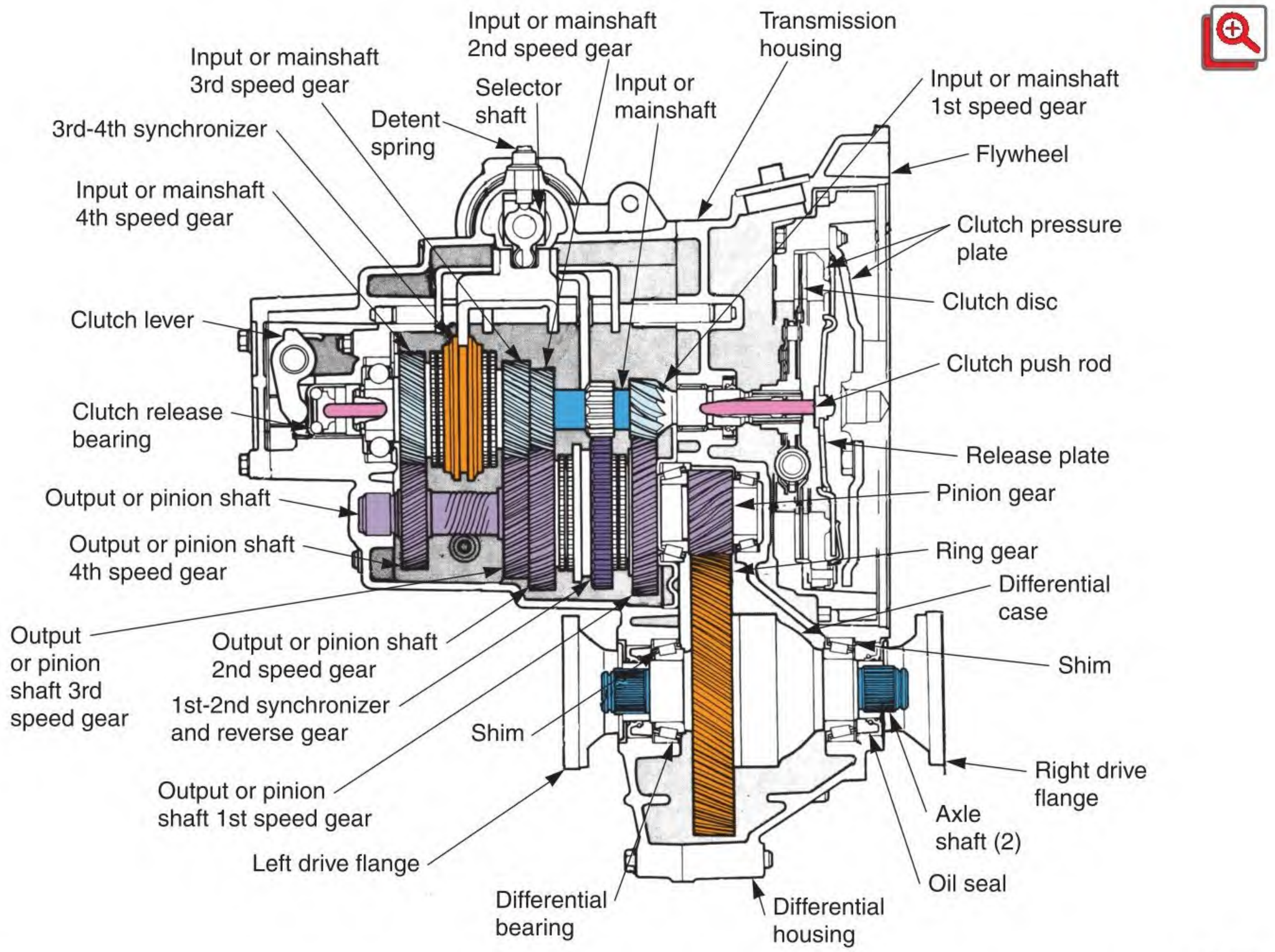
Figure 71-3. In a transaxle used with a transverse engine, the pinion and ring gears are helical. They are positioned in the same direction as transmission gears.



Saab

Figure 71-4. In a transaxle used with a longitudinal engine, the differential uses hypoid gears to change the direction of output. The drive chain transfers power from the crankshaft and clutch to the input shaft.

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Chrysler

Figure 71-5. This detailed view shows all major parts of a manual transaxle. Study the names and locations carefully. In this transaxle design, a long push rod extends through the center of the input shaft to actuate clutch.

- ***Synchronizers***—Synchronizers are splined hub assemblies that can be used to lock freewheeling gears to their shafts for engagement.
- ***Differential***—The differential transfers gear box torque to driving axles and allows axles to turn at different speeds.
- ***Transaxle case***—The transaxle case is an aluminum housing that encloses and supports the parts of the transaxle.

Manual Transaxle Clutch

A ***manual transaxle clutch*** is almost identical to the clutch used with a manual transmission for a rear-wheel-drive vehicle. It uses a friction disc and a spring-loaded pressure plate bolted to a heavy flywheel.

Some transaxles use a conventional clutch release mechanism (throw-out bearing and fork). Others use a long push rod that passes through the input shaft.

Drive Chain

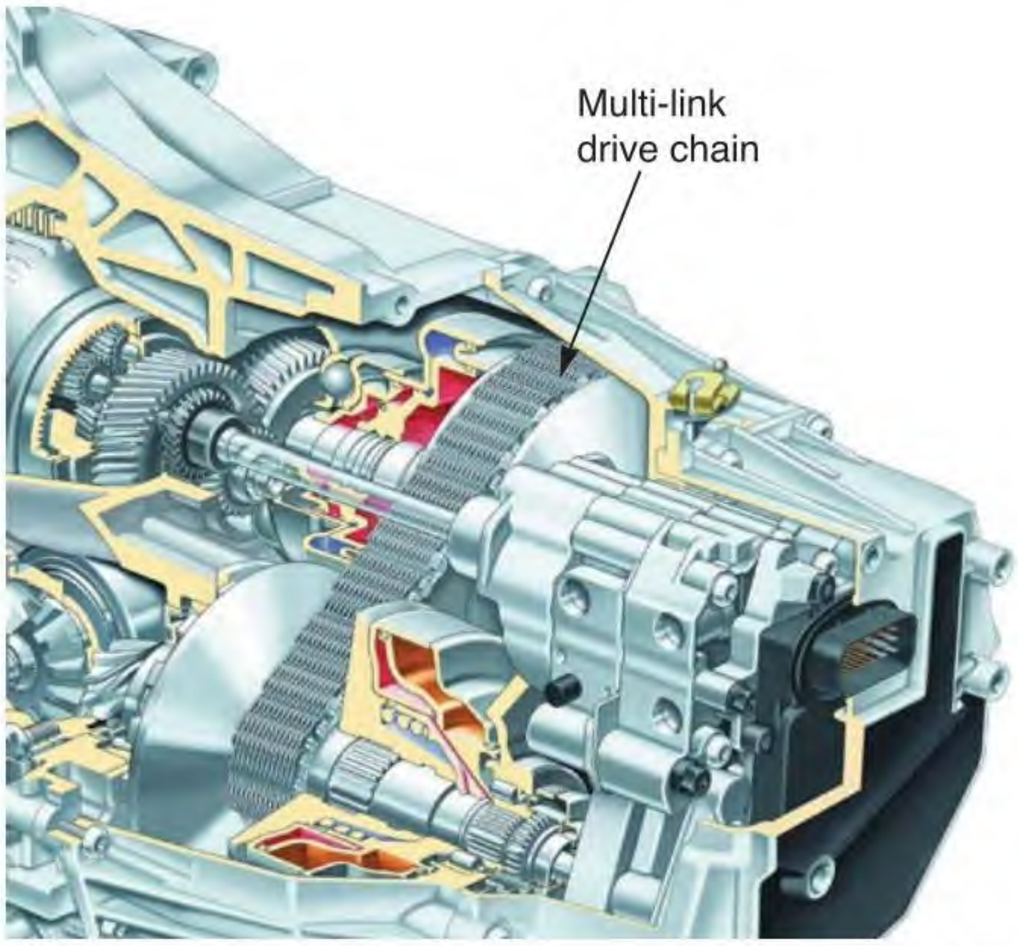
A ***drive chain***, or ***drive link***, is sometimes used to transfer crankshaft power to the transaxle gearbox, or transmission. It is used with longitudinal engines and some transverse engines. See **Figure 71-6**.

One sprocket is mounted on a shaft connected to the engine crankshaft. The other sprocket drives the transaxle input shaft. This allows the transaxle to be located below and to one side of the engine. The differential and drive axles are almost directly below the center of the engine.

Manual Transaxle Transmission

A ***manual transaxle transmission*** provides several (usually four or five) forward gear ratios and reverse. Sometimes, high gear can provide an overdrive ratio for increased fuel economy.

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Figure 71-6. This electro-hydraulic automatic transaxle uses a multi-link drive chain.

As you read service manuals, you will find that the names of the shafts, gears, and other transaxle parts will vary. The naming depends on the location and function of the components.

The input shaft is sometimes called the ***main shaft***. The output shaft is often called the ***pinion shaft*** because it drives the ring and pinion gears.

Sometimes, the input or output shaft gears are called the ***cluster gear assembly*** or the ***countershaft gear assembly***. Like a manual transmission countershaft gear, several gears in the transaxle can be machined together as a unit.

The ***transaxle shafts*** are normally mounted in either tapered roller bearings or ball bearings. The shaft bearings fit into the transaxle case. The output shaft usually has a gear or sprocket for driving the differential ring gear.

The ***transaxle synchronizers*** are almost identical to those used in many manual transmissions. The inside hub of the synchronizer is splined to a transaxle shaft. The outer sleeve is free to slide on the hub.

When a shift fork moves a synchronizer into one of the freewheeling gears, the outer sleeve (ring) of the synchronizer meshes with the small, outer teeth on the gear. This locks the gear to the shaft.

Transaxle Differential

A ***transaxle differential***, like a rear axle differential, transfers power to the axles and wheels while allowing one wheel to turn at a different speed than the other. A small pinion gear on the output shaft turns the differential ring gear. Look at **Figure 71-7**.

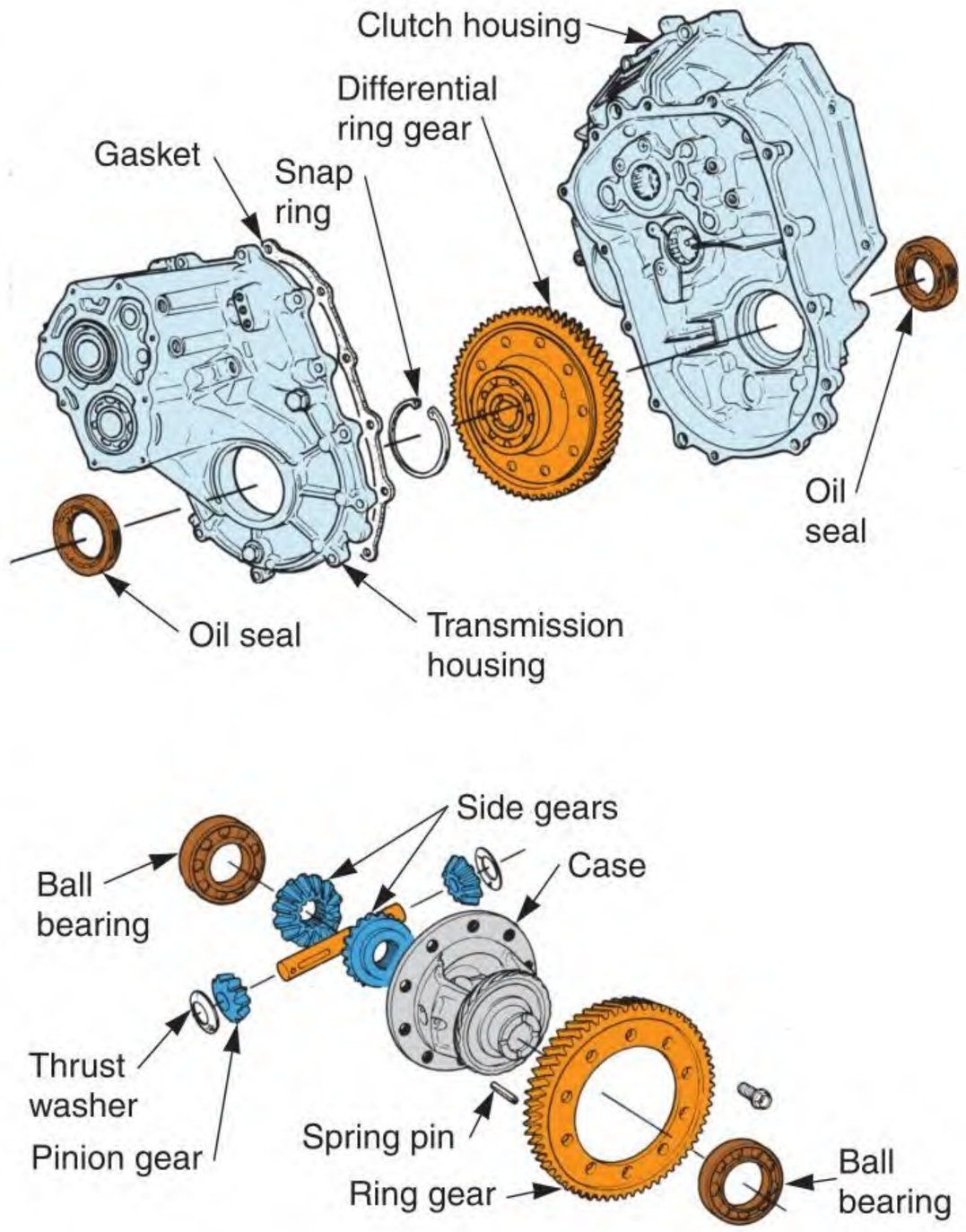
The differential ring gear is fastened to the differential case. The case holds the spider gears (pinion gears and axle side gears) and a pinion shaft. The axle shafts are splined to the differential side gears.

When the gearbox spins the differential ring gear and case, the pinion shaft and pinion gears also revolve. The pinion gear teeth transfer power to the side gears. This causes the axle shafts to rotate.

The transaxle case is normally made of cast aluminum. The shaft and differential bearing races are press-fit into the case. The case also has provisions for mounting the shift forks and other components.

Manual Transaxle Power Flow

To be able to quickly diagnose manual transaxle problems, you must be able to visualize power flow through the unit. See **Figure 71-8**. For example, if a



Chrysler

Figure 71-7. The transaxle differential also uses spider gears, a pinion shaft, and ring gear to transfer torque to both axles. Note that this unit for a transverse engine uses helical ring and pinion gears, rather than hypoid gears.

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noise develops in only one gear position, you can picture which parts might be causing the trouble.

Transaxle in Neutral

With the transaxle in neutral, the engine spins the input shaft. However, since the synchronizers do not lock any gears to the output shaft, power is not transferred to the differential. See **Figure 71-8A**.

Transaxle in First Gear

When the driver shifts the transaxle into first gear, a shift fork slides the first-second synchronizer into mesh with first gear. This locks the synchronizer teeth with the small teeth on the side of first gear. The first gear is now locked to its shaft.

Power flows through the input shaft first gear, output shaft first gear, pinion gear, ring gear, and differential spider gears to the drive axles, **Figure 71-8B**.

Since the input shaft first gear is much smaller than the output shaft first gear, a gear reduction is produced. Torque is increased because the engine must rotate several times to produce one axle shaft rotation.

Transaxle in Second Gear

When the transaxle is shifted into second gear, the first-second synchronizer is moved into mesh with second gear on the input shaft. The second gear can no longer freewheel on its shaft. Power then flows through the second gear and into the differential. From the differential, power flows to the axle shafts and drive wheels. Refer to **Figure 71-8C**.

Transaxle in Third Gear

With the transaxle in third gear, the first-second synchronizer is shifted into neutral so that the first and second gears freewheel. At the same time, the third-fourth synchronizer is slid into mesh with third gear. Third gear is then locked to its shaft. Power flows through the transaxle as shown in **Figure 71-8D**.

Transaxle in Fourth Gear

When the transaxle is in fourth gear, the third-fourth synchronizer is moved into contact with fourth gear. Power flows through the fourth gears, into the differential, and to the front wheels. **Figure 71-8E**.

Since the fourth gear on the input shaft and the fourth gear on the output shaft are the same size, the gear ratio is 1:1. Compared to its rotation in the other gears, the engine turns slowly while the differential case and axles spin at a relatively high speed. This allows the vehicle to cruise at highway speeds with the engine running at low speeds.

Transaxle in Reverse

When the transaxle is shifted into reverse, the reverse idler gear is moved into mesh with the reverse gears on the input shaft and output shaft. The idler gear reverses the direction of rotation. As a result, the differential and axle shafts are turned backward and the car moves in reverse. Look at **Figure 71-8F**.

Automatic Transaxle



An ***automatic transaxle*** is a combination of an automatic transmission and a differential. See **Figure 71-9**. An automatic transaxle consists of seven main components:

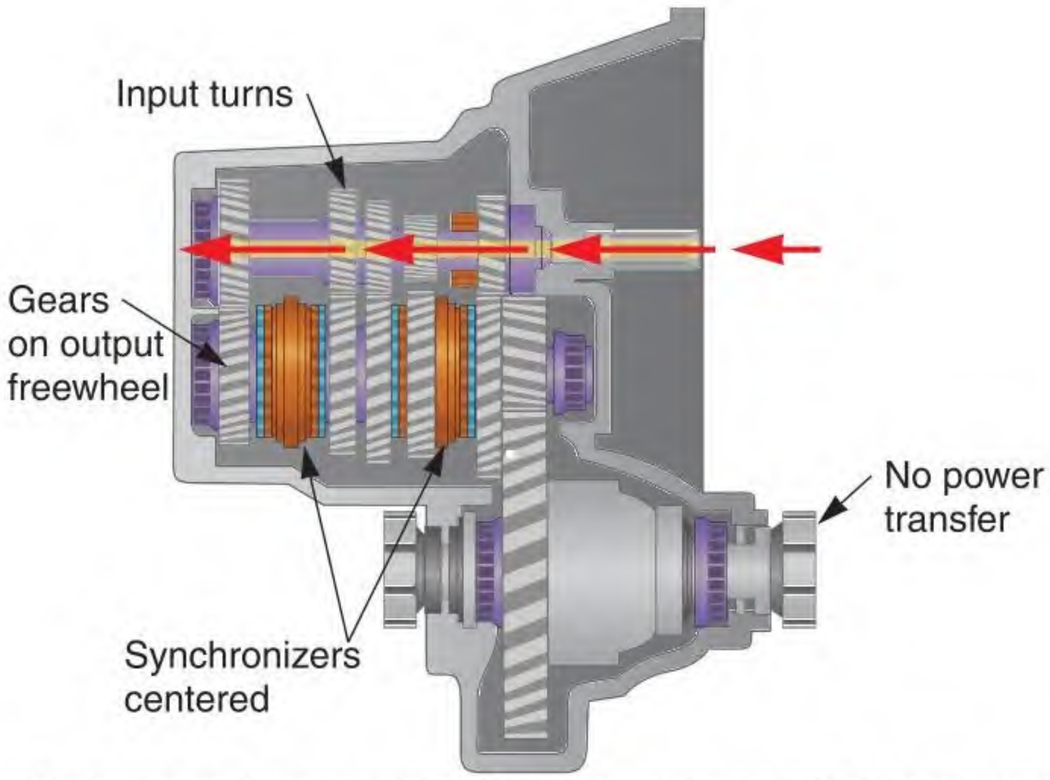
- ***Torque converter***—The torque converter is a fluid-type clutch that slips at low speeds, but locks up and transfers full engine power at a predetermined speed. It couples the engine crankshaft to the transaxle input shaft and gear train.
- ***Oil pump***—The oil pump produces hydraulic pressure to operate, lubricate, and cool the automatic transaxle. The pressure it produces activates the pistons and servos.
- ***Valve body***—The valve body controls oil flow to pistons and servos in the transaxle. It contains hydraulic valves that are operated by shift linkage, engine speed, and load-sensing devices.
- ***Pistons and servos***—Pistons and servos operate clutches and bands, and are activated by oil pressure from the valve body.
- ***Bands and clutches***—Bands and clutches apply planetary gears in the transaxle. Different bands and clutches can be activated to operate different units in gearsets.
- ***Planetary gearsets***—Planetary gearsets provide different gear ratios and the reverse gear.
- Differential—The differential transfers power from the transmission to the axle shafts.

Automatic Transaxle Power Flow

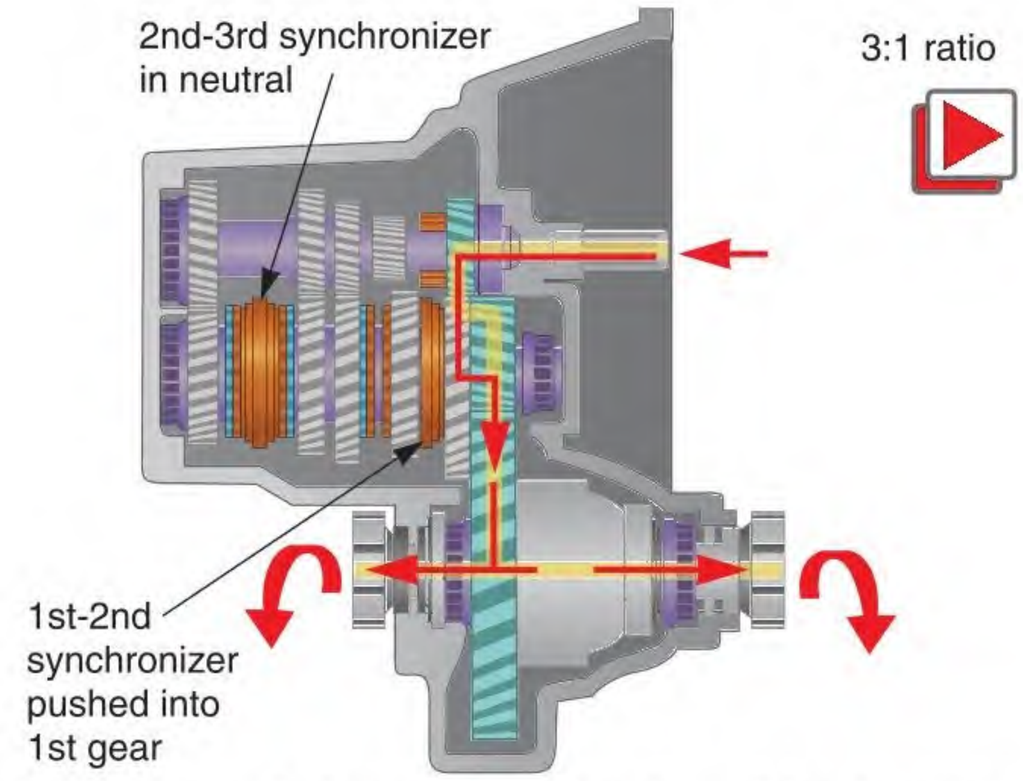
The flow of power through an automatic transaxle is similar to power flow through an automatic transmission. Engine torque enters the torque converter. The torque converter then turns the input shaft and planetary gearsets.

Depending upon which bands and clutches hold the gearset members, power flows through the planetary gearsets to the ring and pinion gears. The differential powers the axle shafts and front wheels, **Figure 71-10**.

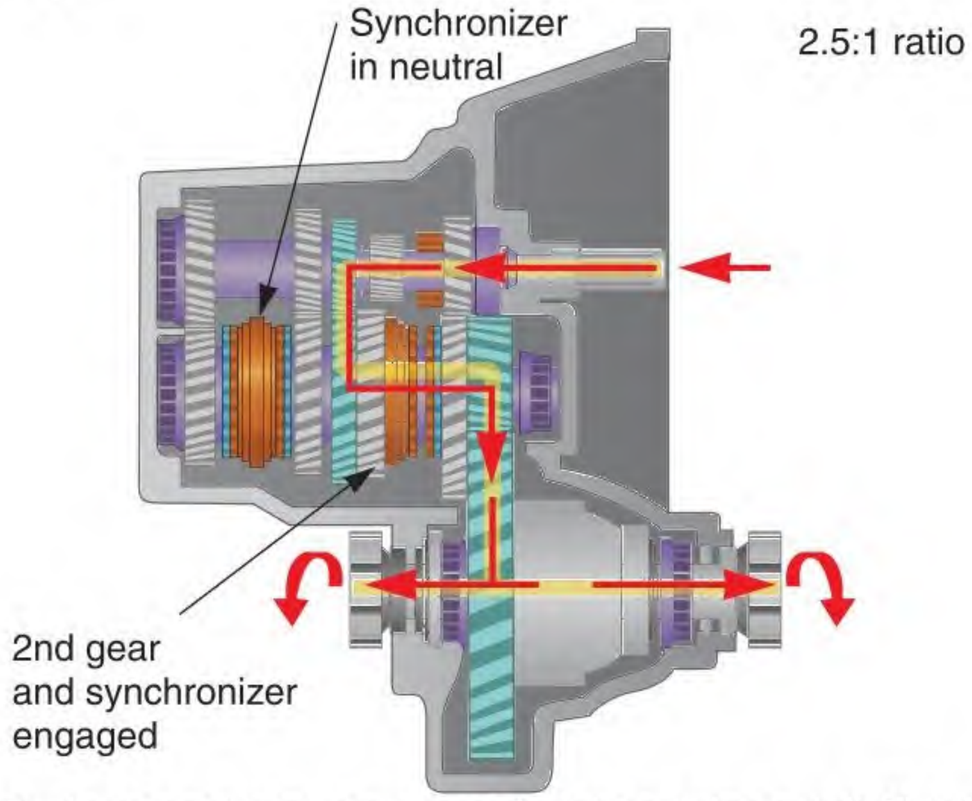
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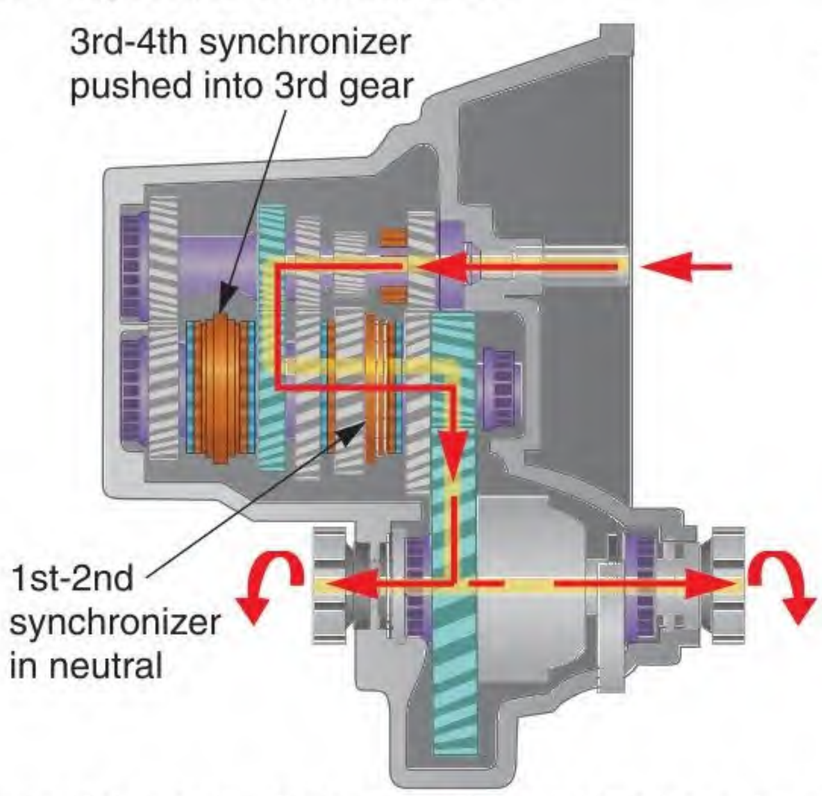
A—In neutral, no synchronizers are engaged with gears. Input shaft spins but gears freewheel and do not transfer power to output.



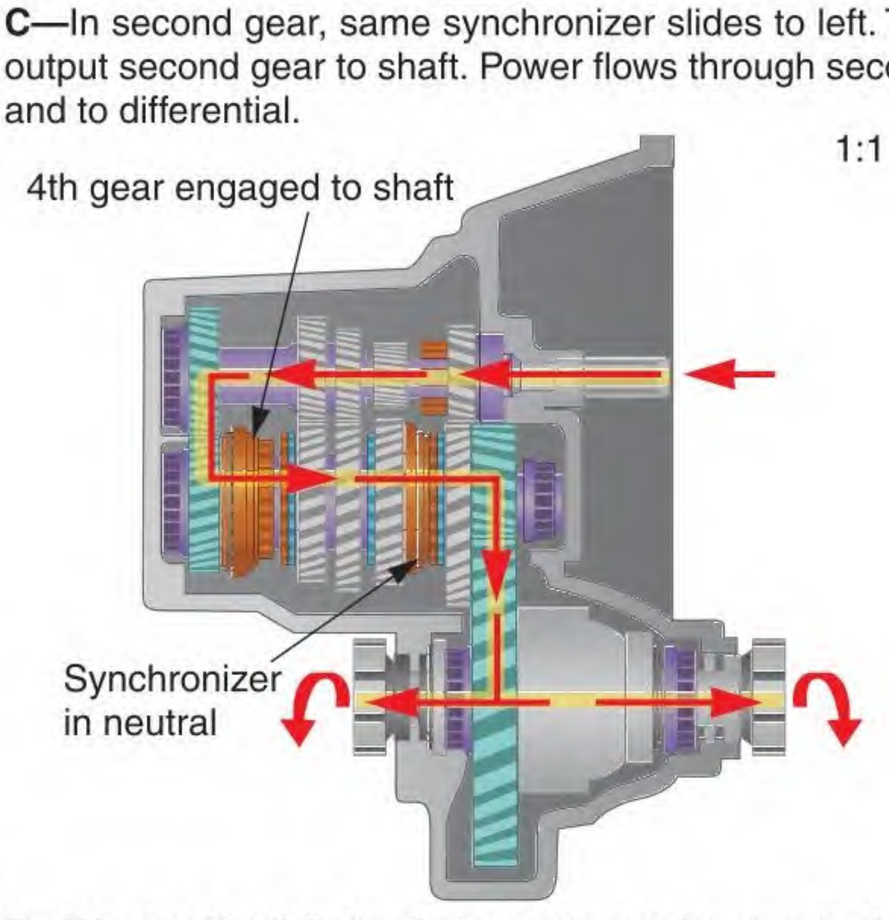
B—In first gear, first-second synchronizer slides to right, engaging first output gear. This locks gear to shaft and power flows to output shaft and differential.



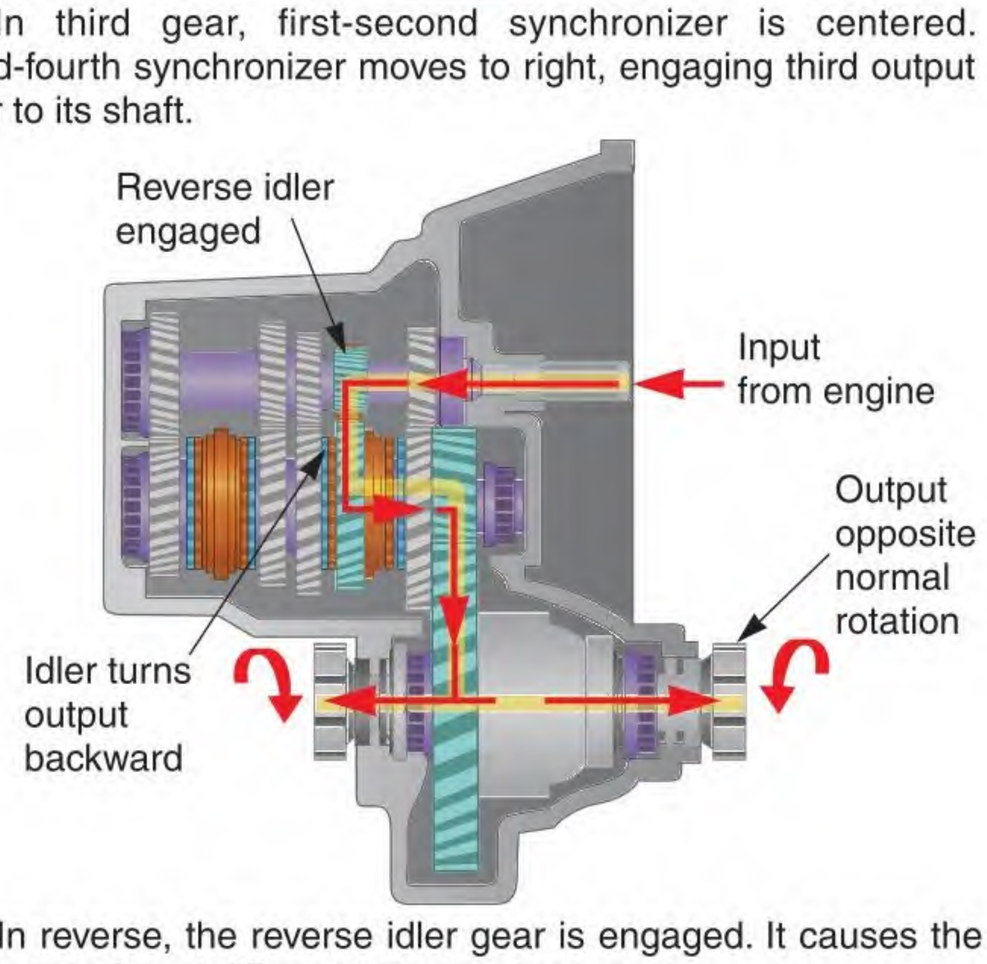
C—In second gear, same synchronizer slides to left. This locks output second gear to shaft. Power flows through second gears and to differential.



D—In third gear, first-second synchronizer is centered. Third-fourth synchronizer moves to right, engaging third output gear to its shaft.



E—When shifted into fourth, the same synchronizer is slid the other way. Fourth output gear is locked to shaft and transmits power.

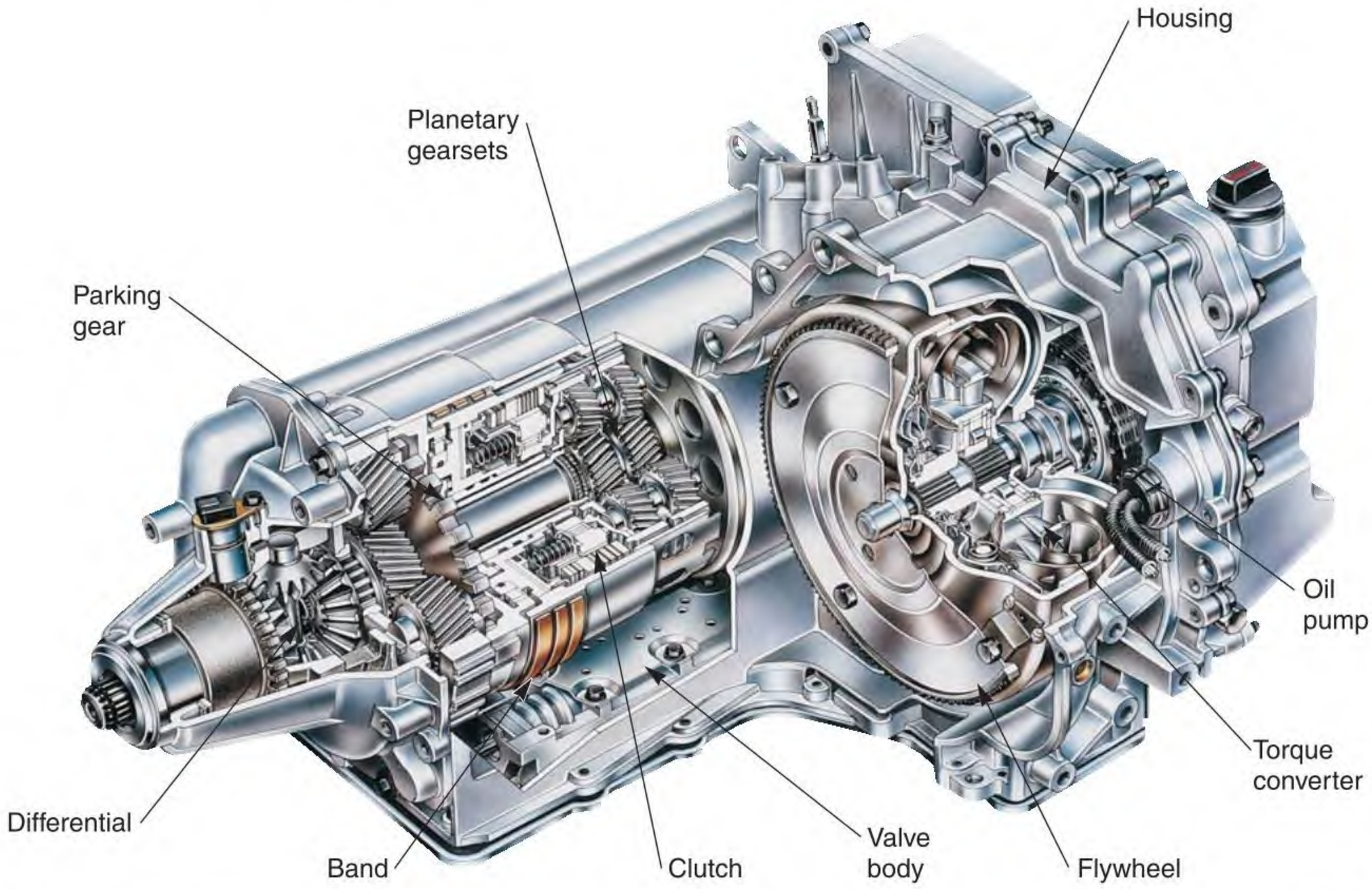


F—In reverse, the reverse idler gear is engaged. It causes the output shaft and differential to turn backward.

Ford

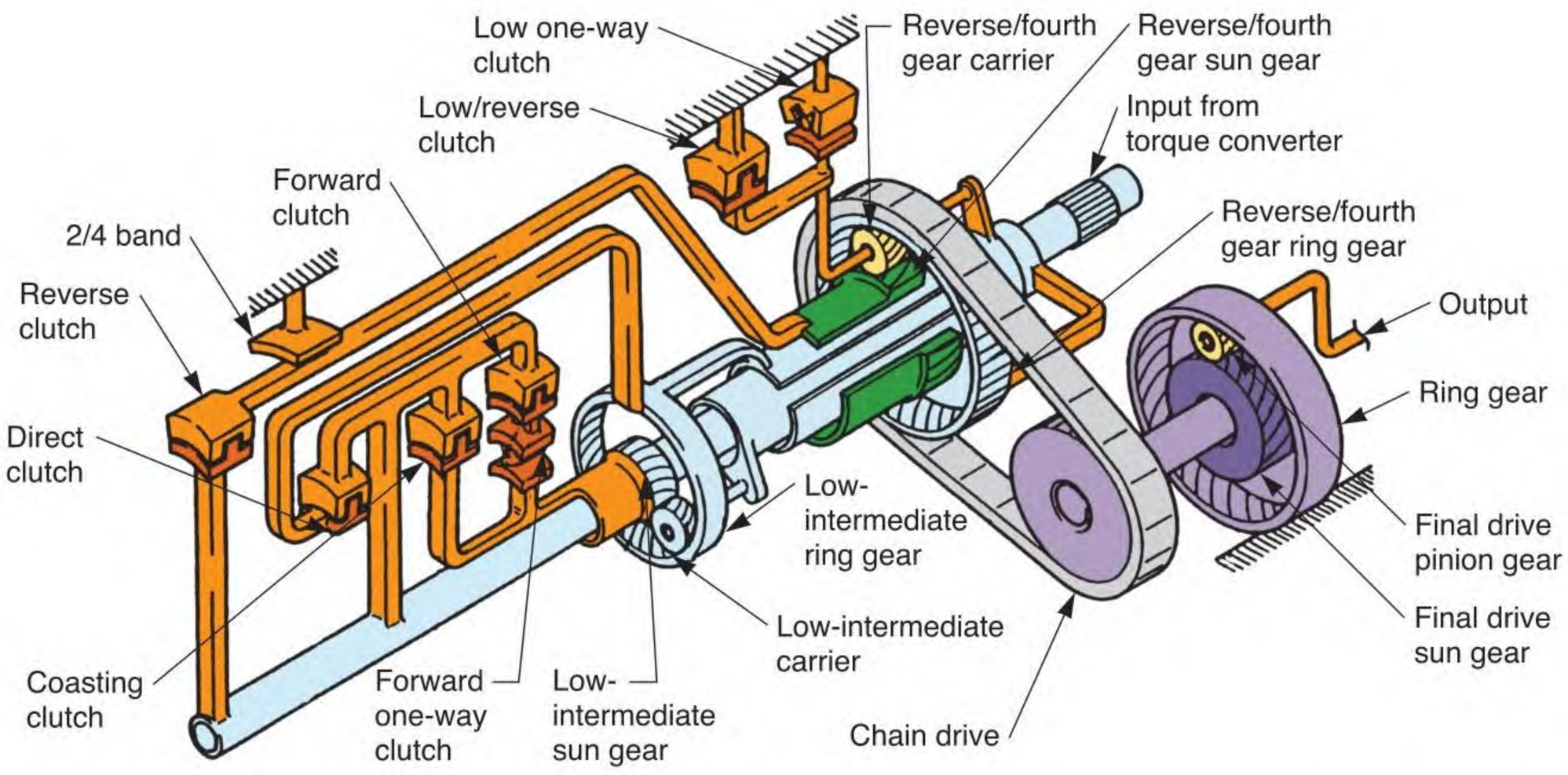
Figure 71-8. Trace the power flow through a typical manual transaxle.

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General Motors

Figure 71-9. Study the basic parts of an automatic transaxle. It uses many of the same parts as an automatic transmission.



Mazda

Figure 71-10. This illustration shows the major parts that transfer power through one automatic transaxle design. Note the drive chain, which transfers power from the planetary gearset to the final drive gears.

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Figure 71-11 shows the power flow through one make of automatic transaxle. In **Figure 71-11A**, the transaxle is in first gear. The band holds the forward sun gear. The one-way clutch sends turbine shaft torque to the low-reverse sun gear. This produces a gear reduction in the planetary gearset for initial acceleration.

In **Figure 71-11B**, the transaxle is in second gear. The band remains applied and holds the forward sun gear. The intermediate clutch is applied, locking the intermediate shaft to the ring gear. This causes slightly less gear reduction than first gear.

In **Figure 71-11C**, the transaxle is in third gear. Both clutches are applied. This locks both members of the planetary gearset, and the unit turns as a single member for direct drive to the differential.

In **Figure 71-11D**, the transaxle is in reverse. The reverse clutch holds the planetary ring gear stationary. The direct clutch locks the turbine shaft to the low-reverse sun gear. The one-way clutch allows the

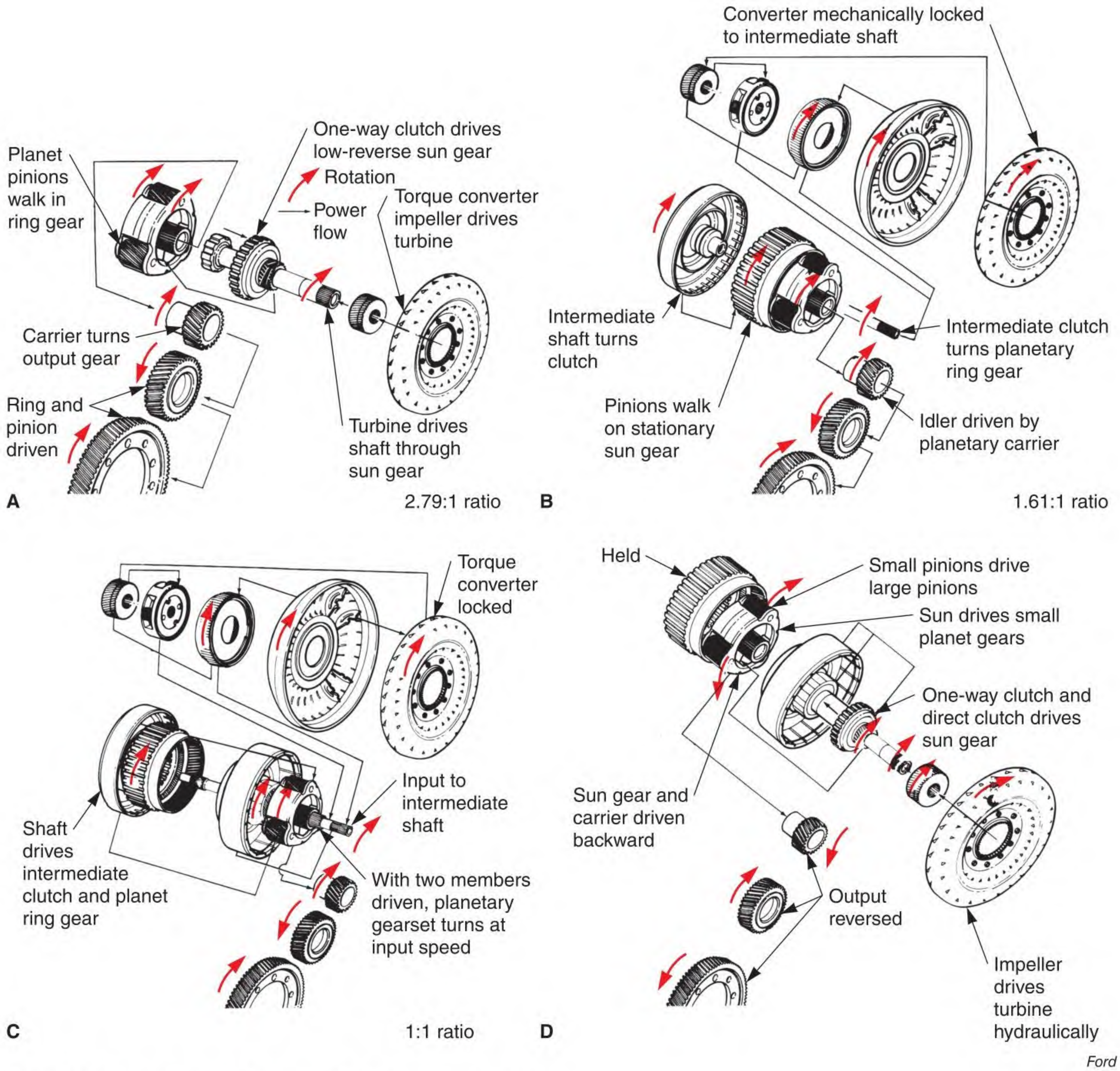


Figure 71-11. Basic power flow through an automatic transaxle.

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turbine shaft to turn the low-reverse sun gear clockwise. Then, the output from the planetary gearset is reversed.

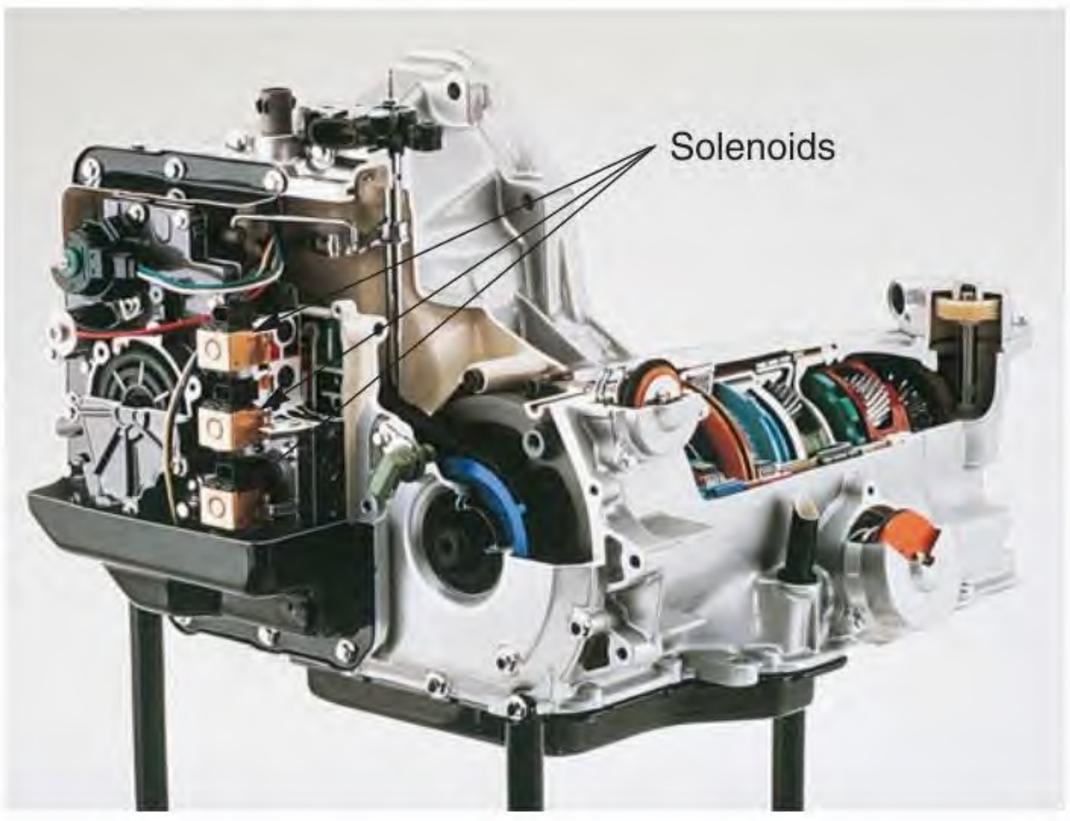
Transaxle Electronic Controls

Modern transaxles use computer control to increase efficiency. The powertrain control module can monitor various vehicle functions to better control shift points and torque converter lockup. This increases fuel economy and saves energy. Refer to **Figure 71-12**.

A basic transaxle electronic control system includes the following elements:

- Electronic control module—The transaxle ECM is a small computer that uses sensor signals to adjust output voltages to operate the transaxle actuators.
- Transmission sensors—These sensors provide input signals that represent various transmission shaft and gear positions.
- Transmission actuators—These solenoids alter hydraulic pressure to shift gears using clutches and bands. Oil pressure is also used to engage or operate the lockup torque converter.

Some vehicles use a separate transaxle control module to analyze sensor inputs and determine the outputs needed to operate the automatic transaxle. Others use a power train control module, which controls the functions of both the engine and transaxle. Look at **Figure 71-13**.



Ford

Figure 71-12. This photo shows a modern electronically-controlled automatic transaxle. Solenoids on the hydraulic valve body provide an interface between the computer's electronic circuits and transmission's hydraulic circuits.

An electronically-controlled transaxle uses solenoids to alter hydraulic pressure to each circuit. Sensors on the transaxle provide feedback concerning fluid temperature, transaxle speed, vehicle speed, and other variables.

Electronic controls can also be used on transaxles using manual-type gearsets. The solenoids move the synchronizers to shift gears. See **Figures 71-14** and **71-15**.

Continuously Variable Transaxle

A ***continuously variable transaxle*** (CVT) has an infinite number of driving ratios, rather than three, four, or five forward speeds. A CV transaxle uses spring-loaded, two-piece pulleys that have variable diameters. The parts of the pulleys can be moved closer together to make the effective pulley diameter larger. See **Figure 71-16**. The pulley halves can also be pulled wider to make a smaller pulley diameter surface. A flexible, segmented, steel drive-belt runs between the pulley sets, **Figure 71-17**. This arrangement takes the place of the planetary gearsets or helical manual transmission gearsets. The ratio produced by the two pulleys can be changed to control vehicle road speed without changing engine or motor-generator speed.

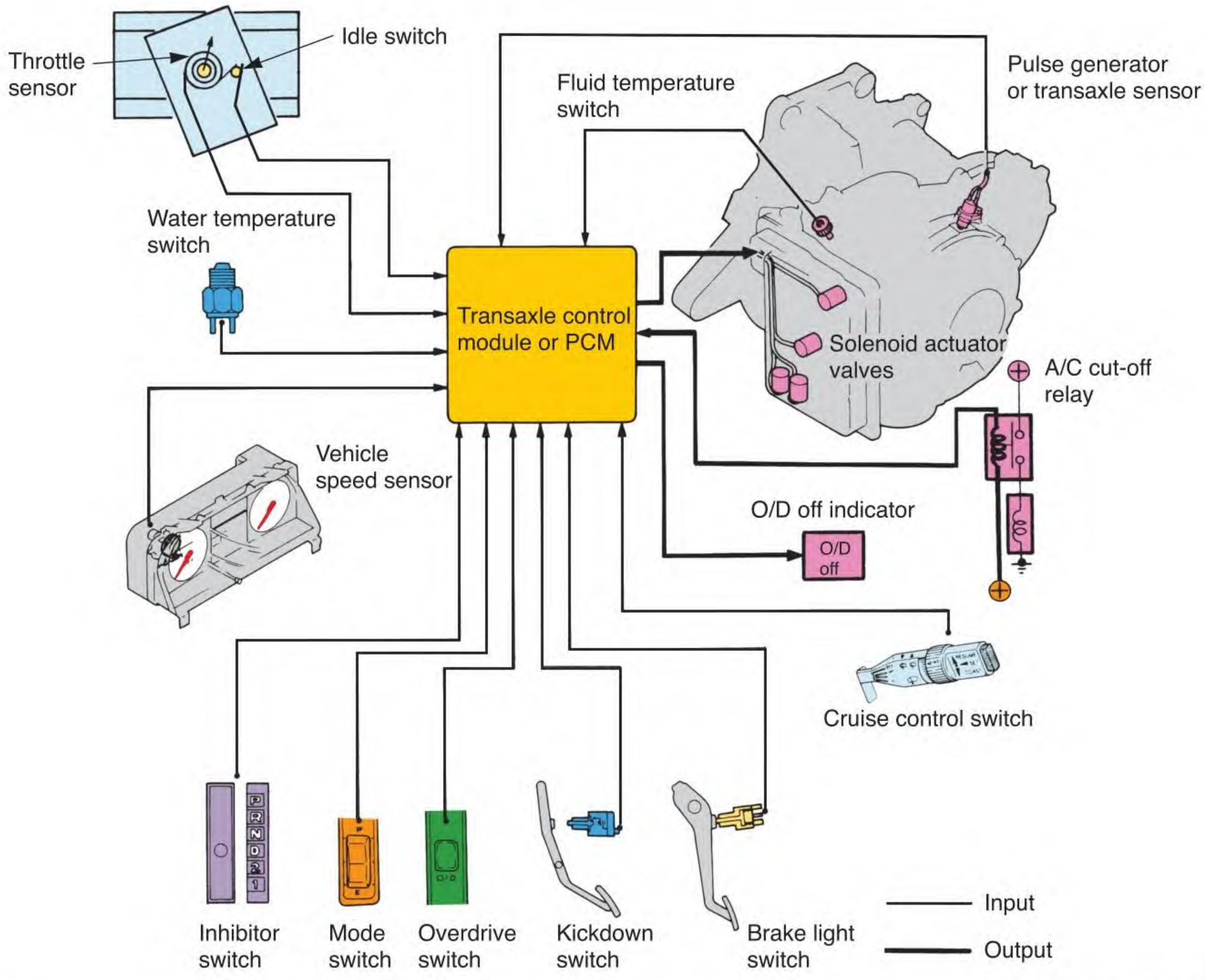
Some continuously variable transmissions use a planetary gearset arrangement to provide seamless drive ratio changes. The transmission's electronically controlled hydraulic system governs the operation of the planetary gearset through a system of wet clutches and friction bands applying different transmission shafts.

A CVT is capable of increasing fuel economy by approximately 25% because it keeps the engine at its most efficient operating speed at all times. Because the engine does not have to accelerate through each gear, a relatively constant engine speed is maintained. The result is an almost perfectly smooth increase in vehicle speed. See **Figure 71-18**.

Independent Drive Axle Assembly

An ***independent drive axle assembly*** transfers power (torque or horsepower) from the differential to the hubs and drive wheels of the vehicle. Study **Figure 71-19**. Most modern CV drive axle assemblies consist of two or three separate shafts and two universal joints. Since the differential or transaxle is bolted solid on the vehicle frame or crossmember, lightweight

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Figure 71-13. Note how the control module serves as the "brain" to determine shift points. Various sensors feed data to the module, which uses programmed shift schedules to control when power is sent to each shift solenoid. When the shift solenoid is energized, it opens or blocks hydraulic pressure to change transaxle gear ratios.

(but strong) swing axles can smoothly transfer power to the wheel hubs. The spinning outer ends of the CV axles can then move up and down over bumps in the road without vibration. The front drive axles must also allow for smooth power transfer while flexing from right to left when cornering the vehicle. The outer ends of the CV axles must transfer torque smoothly while flexing into compound angles.

CV axles turn much slower than long drive shafts used on rear-wheel-drive vehicles. They turn about one-third the speed of rear-drive shafts and are therefore less prone to high-speed vibration. Modern all-wheel-drive vehicles use transaxles and CV axles in the front, and independent rear-drive axles in the rear.

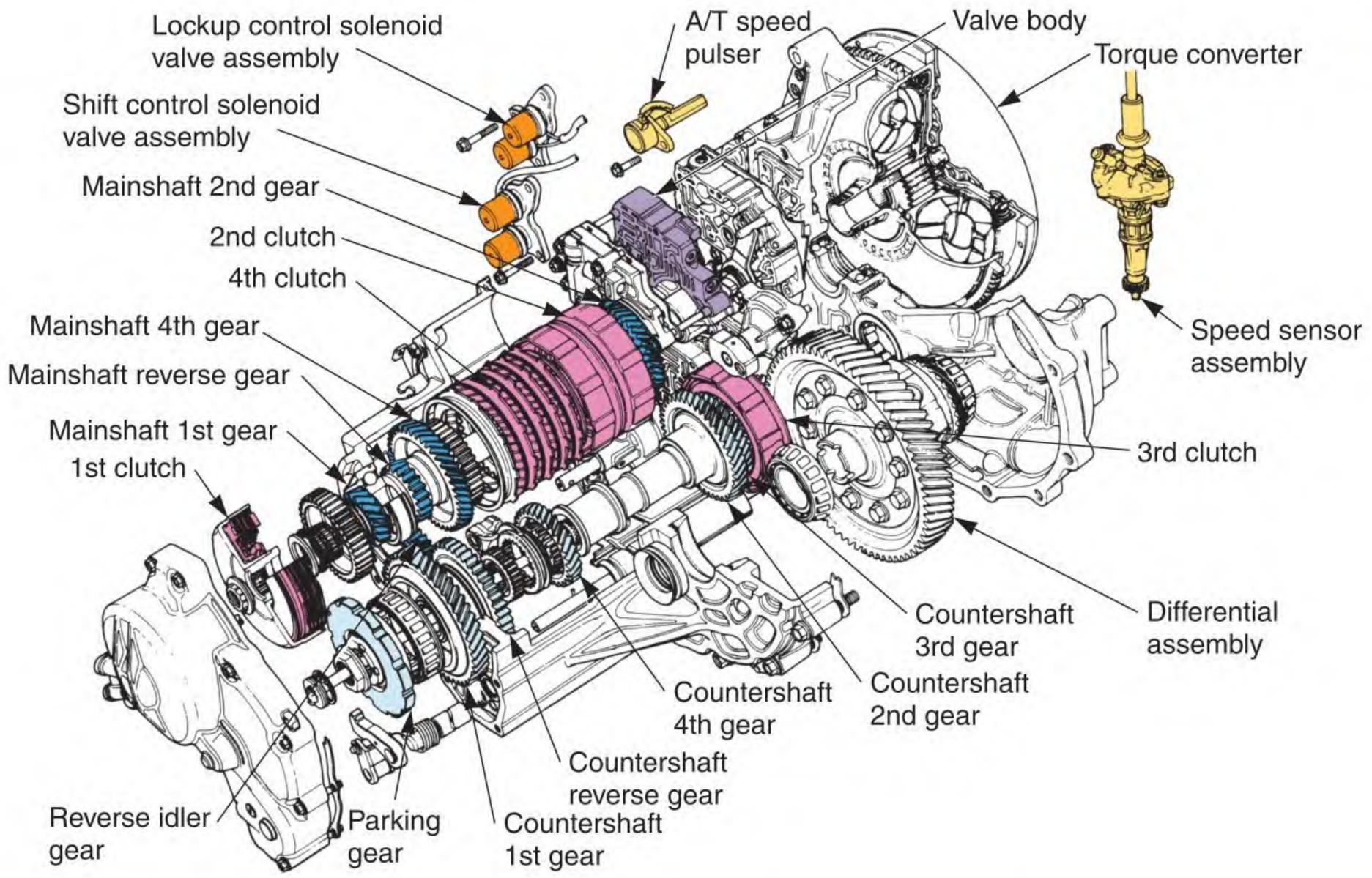
CV Axle Shafts

Three ***axle shafts*** are typically used in a drive axle assembly:

- ***Inner stub shaft***—The inner stub shaft is a short shaft splined to the side differential gear and connected to the inboard (inner) CV joint.
- ***Outer stub shaft***—The outer stub shaft is a short shaft connected to the outboard (outer) CV joint and front wheel hub.
- ***Interconnecting shaft***—The interconnecting shaft is the center shaft that fits between the two CV joints.

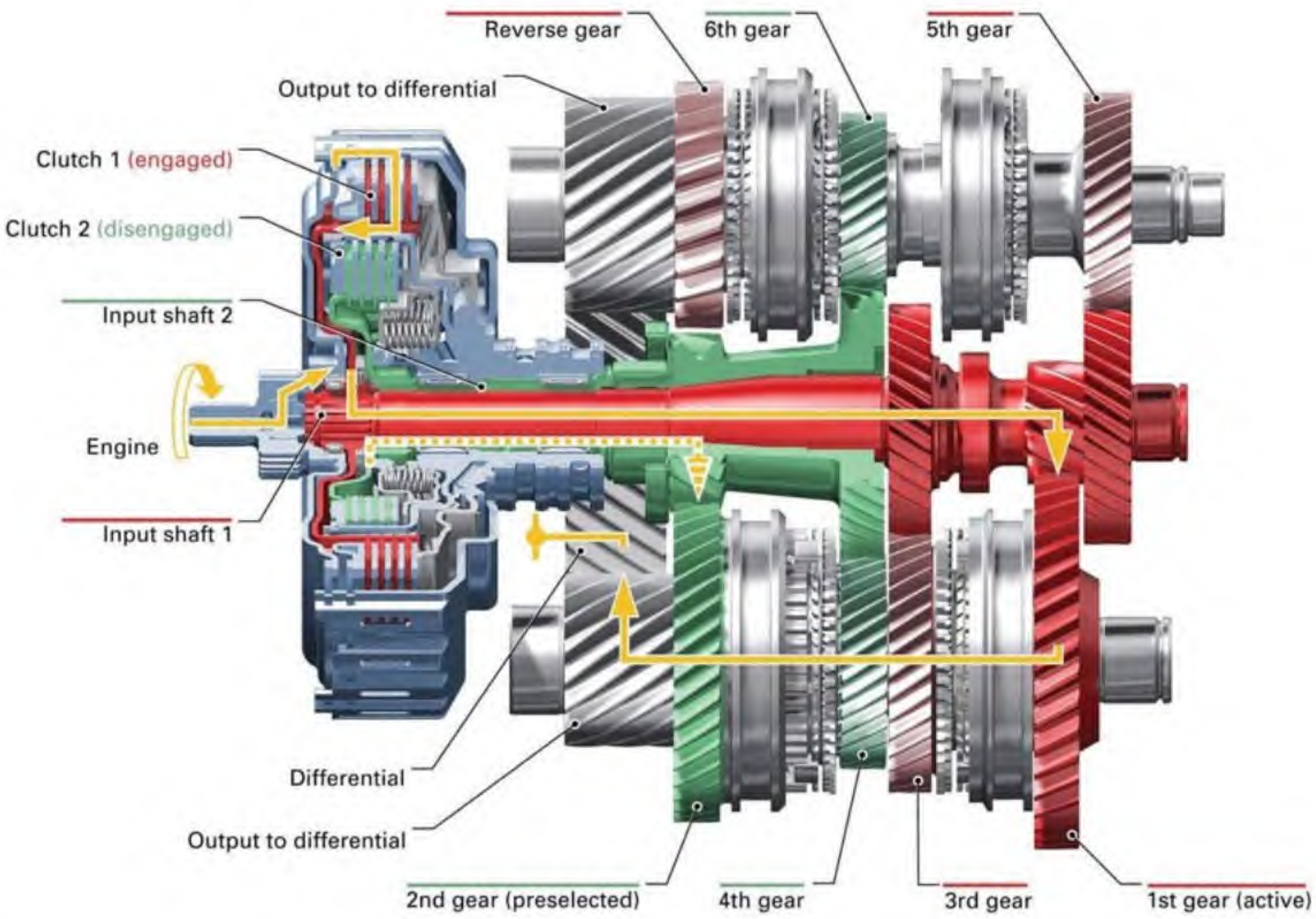
The outer ends of each shaft are machined and may have splines for meshing with the splines on

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Honda

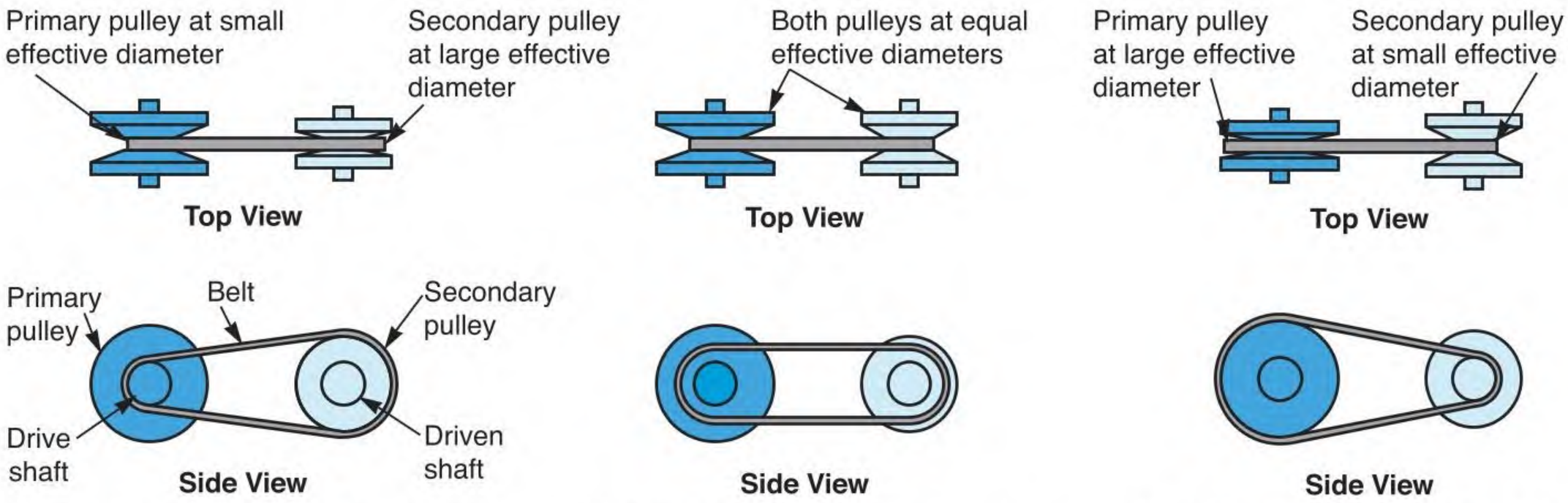
Figure 71-14. This exploded view shows the unique construction of this automatic transaxle. It uses solenoids to shift helical gears and lock torque converter clutch. Conventional automatic-type clutches are also used in this design.



Audi

Figure 71-15. Power flow through a modern wet clutch and helical gearset transaxle. The engine can send torque through the transaxle without interrupting power on gear changes or upshifts. This provides faster acceleration while consuming less fuel or HV battery energy.

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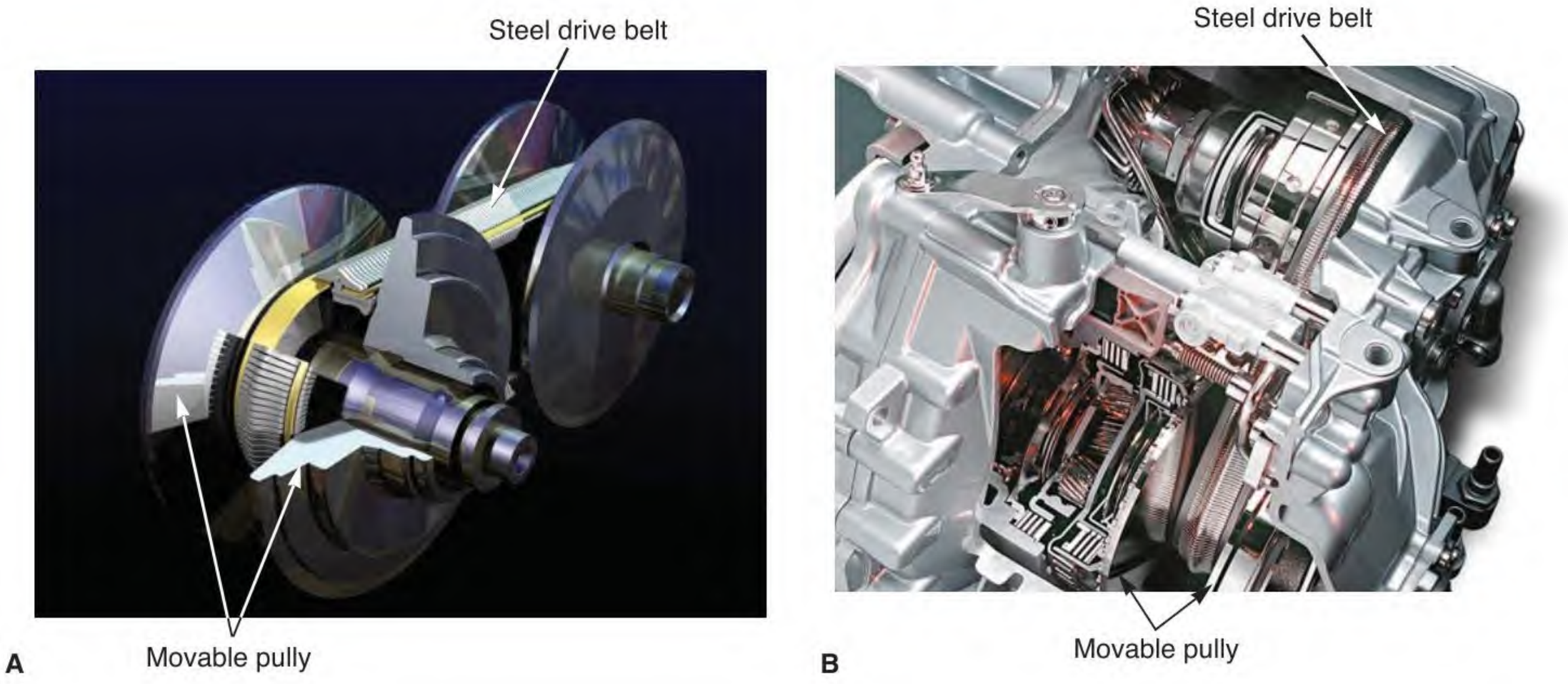
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Figure 71-16. Changing a pulley's effective diameter changes the position of the belt on the pulley. This, in turn, changes the ratio between the drive pulley and the driven pulley.

mating parts. See **Figure 71-20**. A portion of a CV joint may be machined as an integral part of the shaft. Grooves are also cut in the shafts for snap rings, boots, and other components.

CV Joints

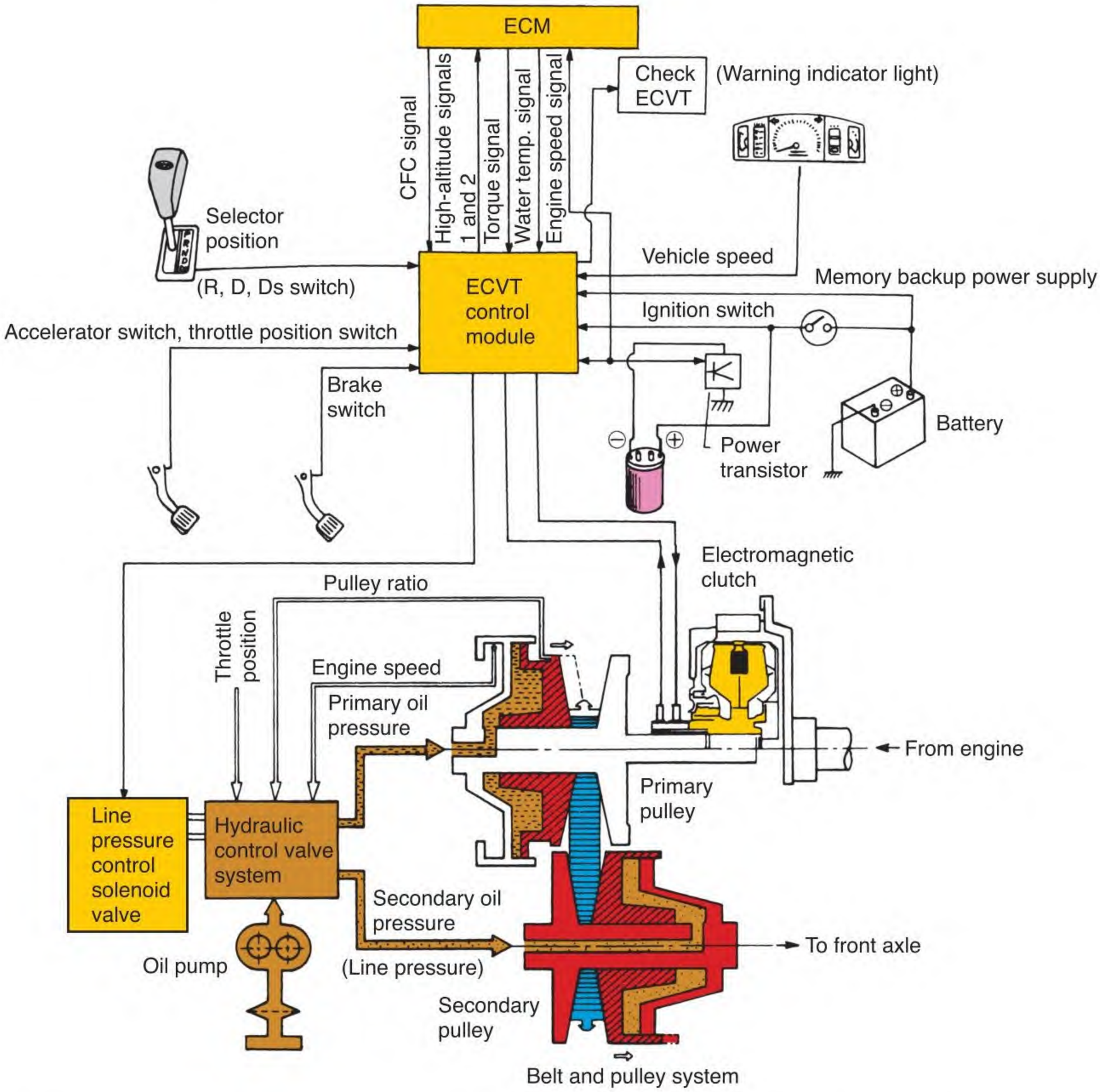
CV joints are used in independent drive axle assemblies to allow the shafts to transfer torque through an angle smoothly. Normally, either Rzeppa (ball-and-cage) or tripod (ball-and-housing) CV joints are used in these axle assemblies.



Ford; Nissan

Figure 71-17. The steel drive belt and movable pulleys in a continuously variable transaxle. A—The steel drive belt is flexible and its ends are shaped to ride inside the smooth metal pulleys. B—As the pulley halves are pushed together, the belt is pinched and moves up to ride near the top (larger diameter area) of the pulley to change effective gear ratios.

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Subaru

Figure 71-18. This diagram shows the basic operation of a computer-controlled CVT. Trace the flow of data to and from the control modules. Also note how the line pressure control solenoid provides an interface between the control module and the hydraulic control valve system. An electromagnetic clutch replaces the conventional torque converter.

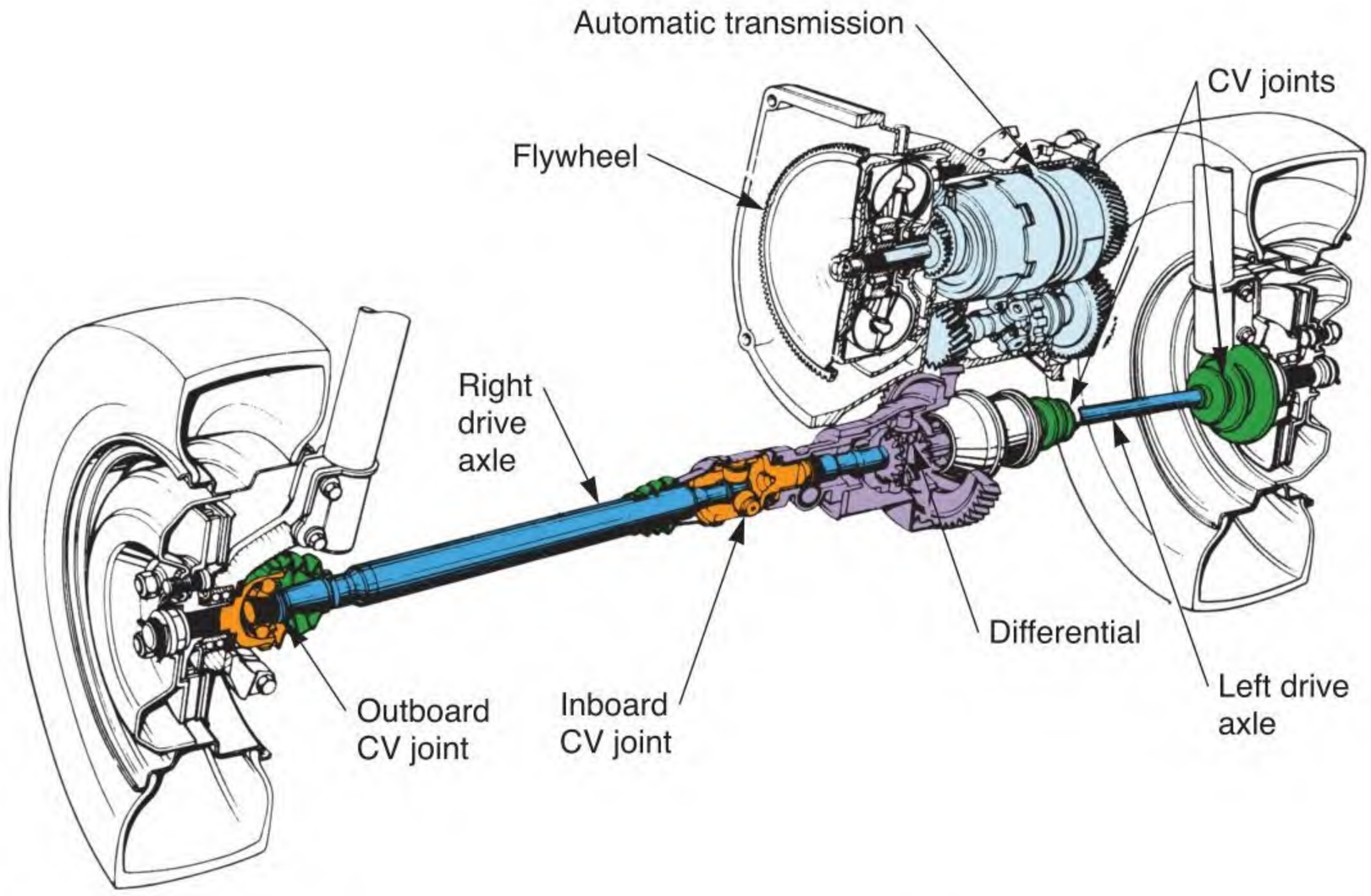
Tech Tip

Double-cardan (cross-and-roller) universal joints are no longer used in independent drive axle assemblies.

The ***inboard CV joint*** is commonly a plunging (sliding) tripod joint. It acts like a slip joint in a drive shaft for a rear-wheel-drive vehicle. As the front wheels move up and down over bumps in the road, the operating length of the drive axle assembly must increase with extreme suspension movement. The plunging action of the inboard CV joint allows for a change in distance between the transaxle and the wheel hub.

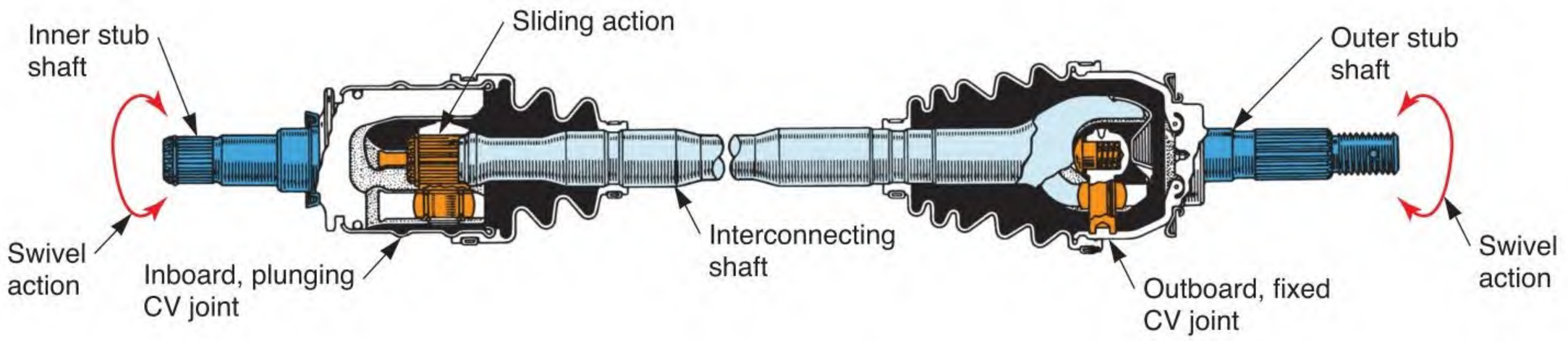
The ***outboard CV joint*** is normally a fixed (non-sliding) Rzeppa joint. Sometimes it is a fixed tripod joint. The outboard CV joint transfers rotating power from the axle shaft to the hub assembly. Look at **Figure 71-21**.

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Figure 71-19. Front drive axles connect the differential side gears to wheel hubs. When differential side gears turn, the axles rotate the hubs and front wheels to propel the vehicle.



Toyota

Figure 71-20. This is a three-piece drive axle. Note the inner stub shaft, intermediate shaft, and outer stub shaft. The universal joints, or CV joints, allow the drive axle to swivel into various angles. The inboard CV joint is normally a sliding joint to allow for the length changes caused by suspension and steering action.

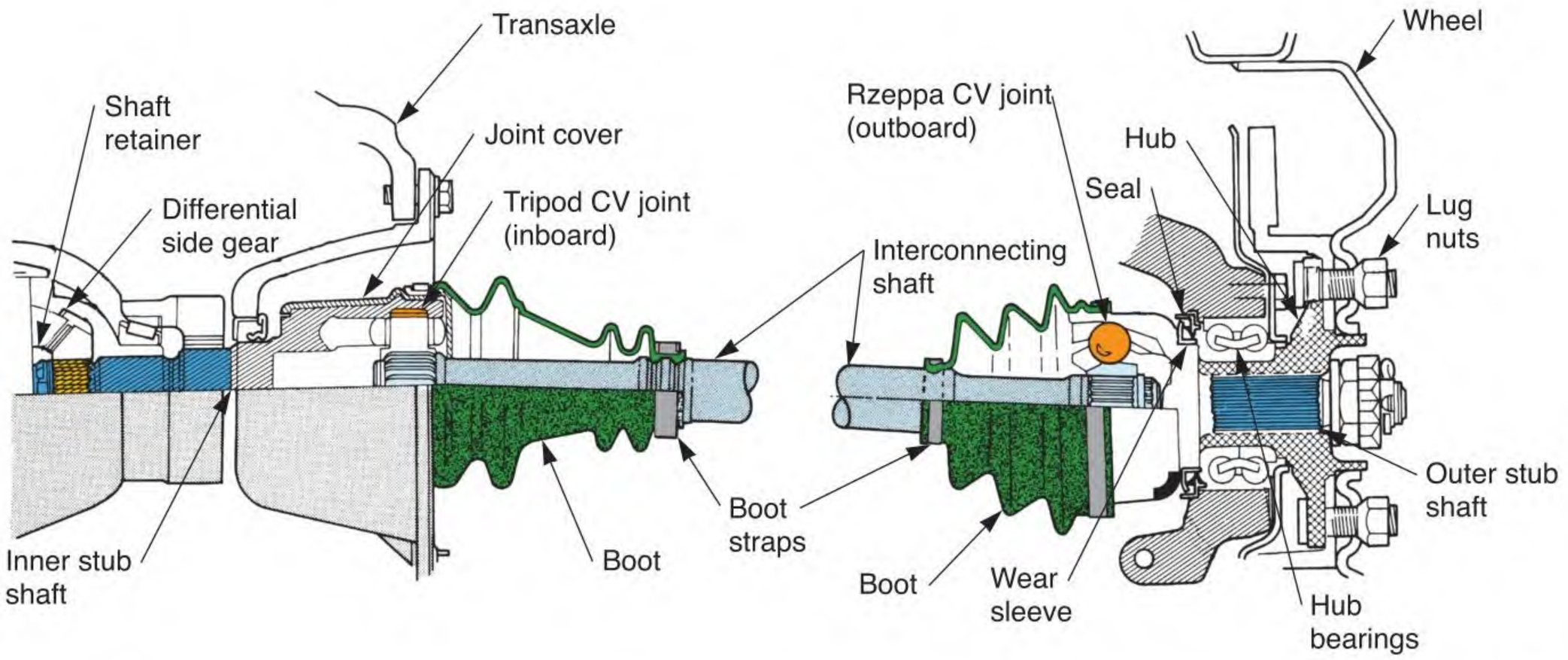
CV Joint Construction

A ***Rzeppa CV joint*** consists of a star-shaped inner race, several ball bearings, a bearing cage, an outer race or housing, and a rubber boot. Refer to **Figure 71-22**. The inner race is normally splined to the axle shaft. Ball bearings fit between the inner and outer races. When the axle turns, power is transferred through the inner race, ball bearings, and outer race to the wheel hub.

A ***tripod CV joint*** consists of a spider, needle bearings, balls (usually three), an outer yoke, and a boot. See **Figure 71-23**. The inner spider is normally splined to the axle shaft. The needle bearings and three balls fit around the spider. The yoke, or housing, then slides over the balls. Slots in the yoke allow the balls to slide in and out and swivel.

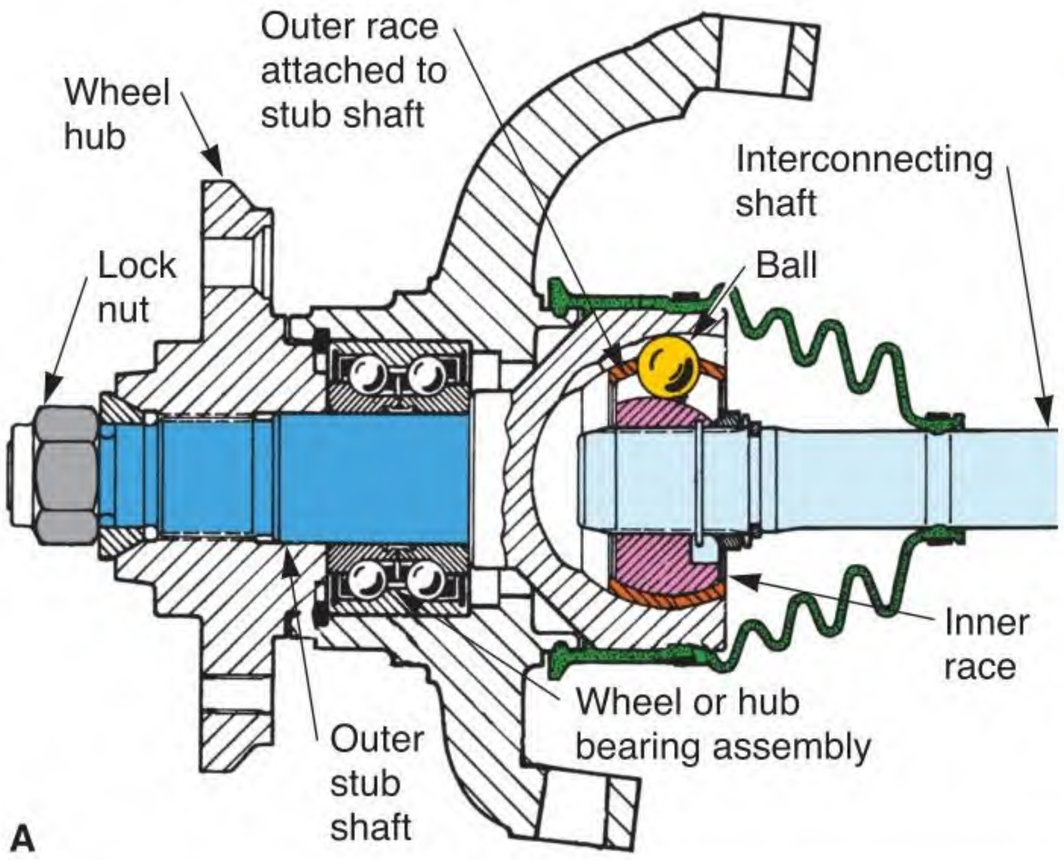
During operation, the yoke is driven by the transaxle. This causes the balls, the spider, and the interconnecting shaft to transfer motion to the outer CV joint. Since the balls ride in grooves cut into the yoke, they are free to slide in and out to allow for changes needed in CV axle assembly length as the vehicle steers or travels over road irregularities.

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Figure 71-21. The outboard CV joint of this assembly is a fixed Rzeppa joint. The inboard CV joint is a plunging tripod type. Notice that the inner stub shaft is splined to the side differential gear. The outer stub shaft is splined to front wheel hub.



Saab; Dana Corp.

Figure 71-22. Study the construction of a common Rzeppa CV joint. A—The drive axle turns the inner race. The inner race turns the balls. The balls transfer turning force to the outer race and hub, rotating the wheels. B—In the exploded view of a Rzeppa CV joint, notice how the parts fit together. A plunging joint is used inboard; a fixed joint is used outboard.

CV Joint Boots

CV joint boots are flexible synthetic rubber balloon seals that keep road dirt out of the bearings in the CV joint. They also prevent the loss of lubricant (heavy, high-temperature grease) when high rotating speeds and high centrifugal force try to sling the grease out of the joint. The rubber fabric of the boot is pleated (accordion-shaped) and tapered to flex with movement of the CV axle.

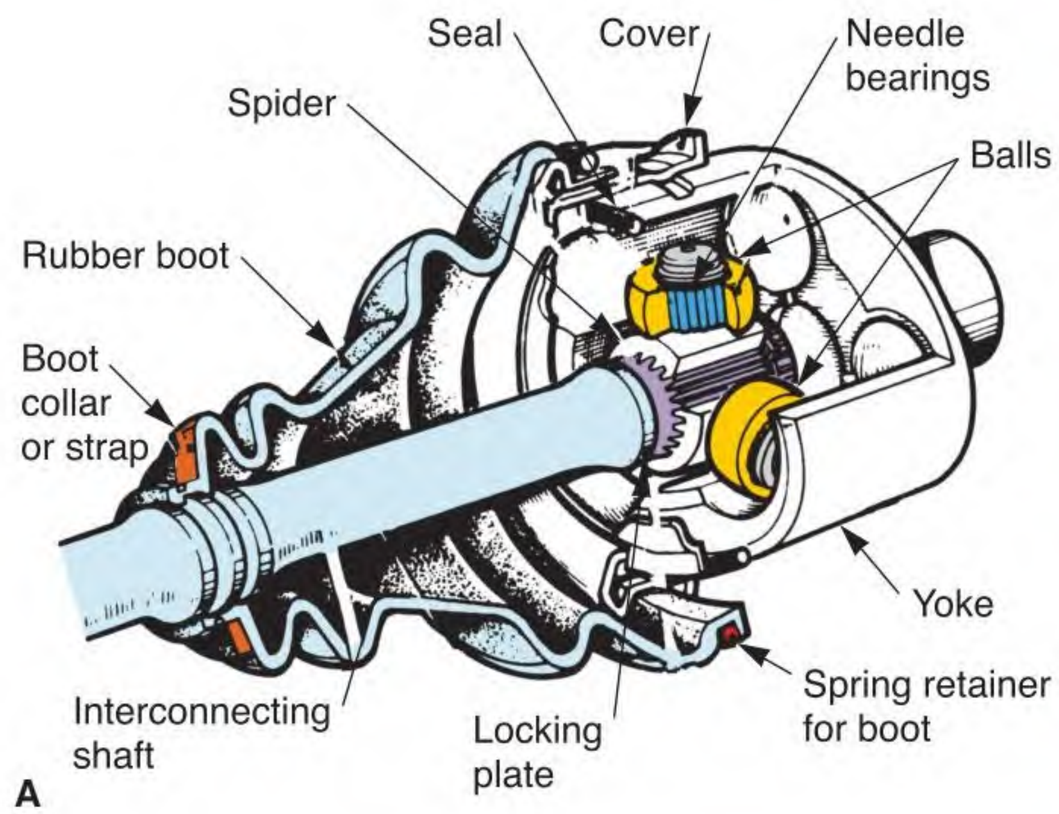
CV joint boot ***retaining collars*** or ***straps*** secure the CV joint boots to the drive axle and universal joint housing. They are usually plastic straps or metal crimp clamps that hold the ends of the boot, providing a tight seal, but not completely airtight. Each axle boot provides a dust, water, and grease seal, and is very important to the longevity of the U-joint. Refer to **Figure 71-23**.

Industry Trend

Many late-model vehicles are equipped with continuously variable transmissions (CVTs). Discussed earlier in this chapter, a CVT constantly adjusts to provide the most efficient drive ratio for the operating conditions. This helps improve vehicle performance and fuel economy. However, it is important to note that a vehicle with a CVT will exhibit different operating characteristics than a vehicle with a standard automatic

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transmission or transaxle. For example, you cannot feel or hear the gear changes in a CVT-equipped vehicle. Additionally, engines in CVT-equipped vehicles tend to rev higher under heavy acceleration than those in vehicles with conventional transmissions or transaxles.



Dana Corp.

Figure 71-23. Tripod CV joint construction. A—Cutaway view shows how a tripod joint fits together. The interconnecting shaft is splined to the spider. The spider rotates the balls and housing. Balls turn on needle bearings to allow swiveling action. B—Exploded view of tripod joint. Inboard joints are sliding tripods. Outboard joints are fixed tripods. Tripod joints are commonly used as inboard plunging joints.

Summary

- A transaxle is a transmission and a differential combined in a single assembly.
- Most transaxles are designed so that the engine can be transverse in the engine compartment. However, a few transaxles are made so that the engine is mounted longitudinally.
- A manual transaxle uses a manual clutch and standard transmission-type gearbox.
- The basic parts of a manual transaxle include an input shaft, input gears, output gears, output shaft, synchronizers, differential, and transaxle case.
- An automatic transaxle is a combination of an automatic transmission and a differential.
- An automatic transaxle consists of seven main components: a torque converter, oil pump, valve body, pistons and servos, bands and clutches, planetary gearsets, and differential.
- Modern transaxles use computer control to increase efficiency.
- A continuously variable transaxle (CVT) has an infinite number of driving ratios which controls vehicle road speed without changing engine or motor-generator speed.
- An independent drive axle assembly transfers power from the differential to the hubs and drive wheels of the vehicle.
- Three axle shafts are typically used in a drive axle assembly: an inner stub shaft, outer hub shaft, and interconnecting shaft.
- Universal joints in front drive axle assemblies allow the shafts to operate through an angle without damage.
- CV joint boots keep road dirt out of the CV joints and prevent the loss of lubricant.

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Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

automatic transaxle
axle shafts
bands and clutches
cluster gear assembly
continuously variable transaxle
countershaft gear assembly
CV joint boots
CV joints
differential
drive chain
drive link
inboard CV joint
independent drive axle assembly
inner stub shaft
input gears
input shaft
interconnecting shaft
longitudinally
main shaft
manual transaxle
manual transaxle clutch
manual transaxle transmission
oil pump
outboard CV joint
outer stub shaft
output gears
output shaft
pinion shaft
pistons and servos
planetary gearsets
retaining collars
Rzeppa CV joint
steering feel
straps
synchronizers
torque converter
torque steer
transaxle
transaxle case
transaxle differential
transaxle shafts
transaxle synchronizers
transverse
tripod CV joint
valve body

Activities

1. Identify the major parts of a transaxle chosen by your instructor.
2. Identify the various parts of front drive axle assembly.
3. Compare two different designs of front drive axle CV joints.

Review Questions

Answer the following questions using the information provided in this chapter.

1. What is a transaxle?
2. List six possible advantages of a front-wheel-drive vehicle with a transaxle over a rear-wheel-drive vehicle with a transaxle.
3. A manual transaxle uses a friction clutch and a standard transmission gearbox. True or False?
4. Summarize the differences in design between transaxles for transverse mounted engines and longitudinally mounted engines.
5. Name the seven major parts of a manual transaxle. Explain the function of each.
6. Which of these parts is *not* found in a manual transaxle?
   (A) Synchronizers.
   (B) Differential.
   (C) Transmission.
   (D) Fluid coupling.
7. A drive chain is sometimes used to send crankshaft power to the transaxle with a(n) _____ mounted engine.
8. List the seven main components of an automatic transaxle. Explain the function of each.
9. Explain how a continuously variable transaxle can increase fuel economy.
10. Which of the following is *not* part of a front drive axle assembly?
    (A) Boots.
    (B) CV joints.
    (C) Pivot shaft.
    (D) Interconnecting shaft.
11. The _____ shaft is the center shaft that fits between the two CV joints.
12. CV joint boot straps provide an airtight seal on the end of the CV joint boot. True or False?

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ASE-Type Questions

1. Technician A says transaxles are used only on front-wheel-drive cars. Technician B says transaxles are used on front-wheel-drive cars and certain types of rear-engine cars. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Technician A says one possible advantage of a front-wheel-drive car equipped with a transaxle is that it improves traction on a slippery pavement. Technician B says one possible advantage of a front-wheel-drive vehicle equipped with a transaxle is that it improves the safety of the passengers because there is increased mass in the front of the car. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. Technician A says cars equipped with a transaxle can use either a manual transmission or automatic transmission. Technician B says cars equipped with a transaxle can only use manual transmissions. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. Technician A says if an engine is mounted in an automobile longitudinally, the crankshaft centerline points to the front and rear of the vehicle. Technician B says if an engine is mounted longitudinally in an automobile, the crankshaft centerline points to both front drive wheels. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. All of the following are basic components of an automatic transaxle, *except*:
   (A) Torque converter.
   (B) Pinion gear.
   (C) Transaxle case.
   (D) Rzeppa joint.
6. Technician A says during transaxle operation, the differential transfers power into the transmission. Technician B says during transaxle operation, the transmission transfers power into the differential. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. Technician A says the input shaft on a manual transaxle turns the gears in the transaxle. Technician B says the input shaft on a manual transaxle powers the torque converter. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. Technician A says all manual transaxles use a throw-out bearing and fork to release the clutch. Technician B says all manual transaxles use a push rod mechanism to release the clutch. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Technician A says manual transaxle transmission's shafts are normally mounted in tapered roller bearings. Technician B says manual transaxle transmission's shafts are normally mounted in ball bearings. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. Technician A says a manual transaxle transmission is always driven by a drive shaft powered by the engine's crankshaft. Technician B says a manual transaxle transmission is sometimes driven by a chain link powered by the engine's crankshaft. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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11. Which of the following is *not* a component of an automatic transaxle?
    (A) Valve body.
    (B) Oil pump.
    (C) Synchronizers.
    (D) Planetary gearsets.
12. Technician A says that screws are normally used to secure front drive axle CV joint boots. Technician B says that straps are normally used to secure front drive axle CV joint boots. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Chapter 72
Transaxle and Front Drive Axle Diagnosis and Repair

After studying this chapter, you will be able to:

- Diagnose common transaxle and drive axle problems.
- Adjust transaxle shift linkage.
- Complete maintenance operations on a transaxle.
- Remove and install a transaxle assembly.
- Remove and install a front drive axle.
- Replace CV joints on front drive axles.
- Correctly answer ASE certification test questions about the diagnosis and repair of manual and automatic transaxles.

Vehicles are commonly equipped with front-wheel drive, so it is very important for you to understand the basic service and repair of transaxles and front drive axles. Transaxles and CV axles suffer from the same kinds of problems as transmissions and differentials. The gears, shafts, bearings, seals, and other parts wear and fail after prolonged use. Because the drive axles follow the movement of the steering and suspension systems, they too can wear and become damaged after extended service.

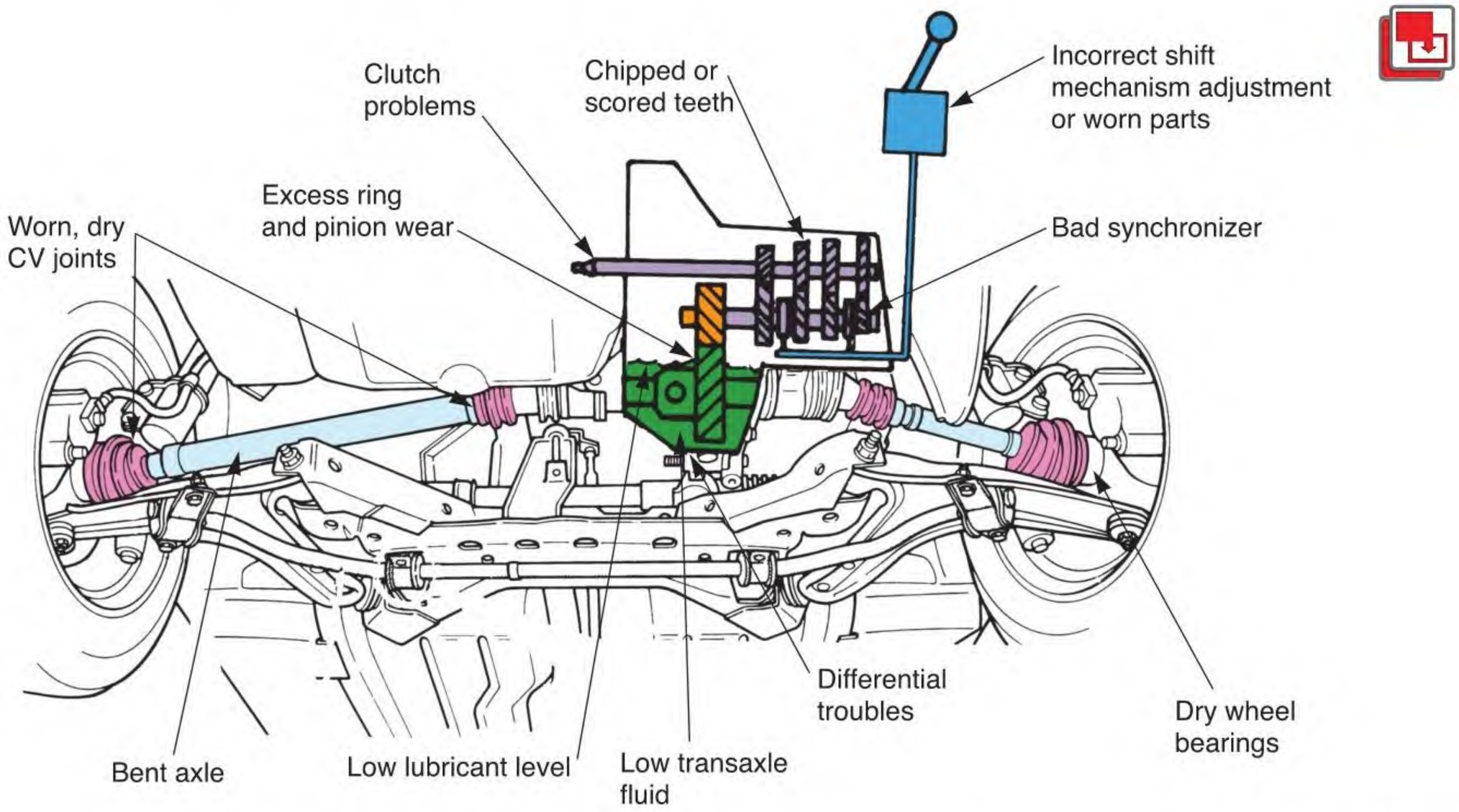
Transaxle Problem Diagnosis

Correct diagnosis of transaxle and front drive axle problems can require a great deal of care. With the engine, clutch, transmission, differential, and drive axles close together in the engine compartment, noises and other symptoms can be difficult to pinpoint. However, if you use your knowledge of component operation and basic troubleshooting techniques, transaxle problems can be isolated without too much trouble.

Test-drive the vehicle to verify the customer's complaint. Shift into each gear while accelerating, decelerating, coasting, and cruising at a constant speed. Check for abnormal noises and vibration under each driving condition.

Use your understanding of CV joints, gears, bearings, shafts, synchronizers, and shift mechanisms to decide what might be the trouble. Approach diagnosis of a transaxle as you would problems in a transmission or a differential. See **Figure 72-1**.

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Chrysler

Figure 72-1. When diagnosing transaxle and drive axle problems, visualize the operation of all components. Compare this information to the symptoms.

On-Board Diagnostics

Late-model vehicles often use on-board diagnostic (OBD) systems to monitor and control transaxle operation. With OBD systems, many transaxle problems will trip a diagnostic code and illuminate the dash trouble light.

A scan tool will quickly read diagnostic trouble codes and provide operating values of the transaxle electric circuits. If transaxle trouble codes or abnormal operating parameters are indicated, use pinpoint tests to find the actual source of the transaxle trouble. See **Figure 72-2**.

Manual Transaxle Problems

Manual transaxle problems include abnormal bearing and gear noises (whirring, howling, whining), shifting problems (hard to shift into gear, grinds when shifted, will not shift, pops out of gear), and fluid leaks (ruptured gasket or RTV sealer, damaged seal).

If the transaxle is noisy, find out when the abnormal sounds occur. For example, if the transaxle is noisy in only second gear, the input second gear or the output second gear might be at fault.

If a transaxle noise occurs in all gears and under all driving conditions, a common problem exists (bad shaft bearings or scored ring and pinion gears, for example). Use this elimination technique to narrow down the possible sources of trouble.

A manufacturer's diagnosis chart may also be helpful in determining what parts are causing the symptoms. Use a chart that is written for the exact make and model of transaxle being serviced.

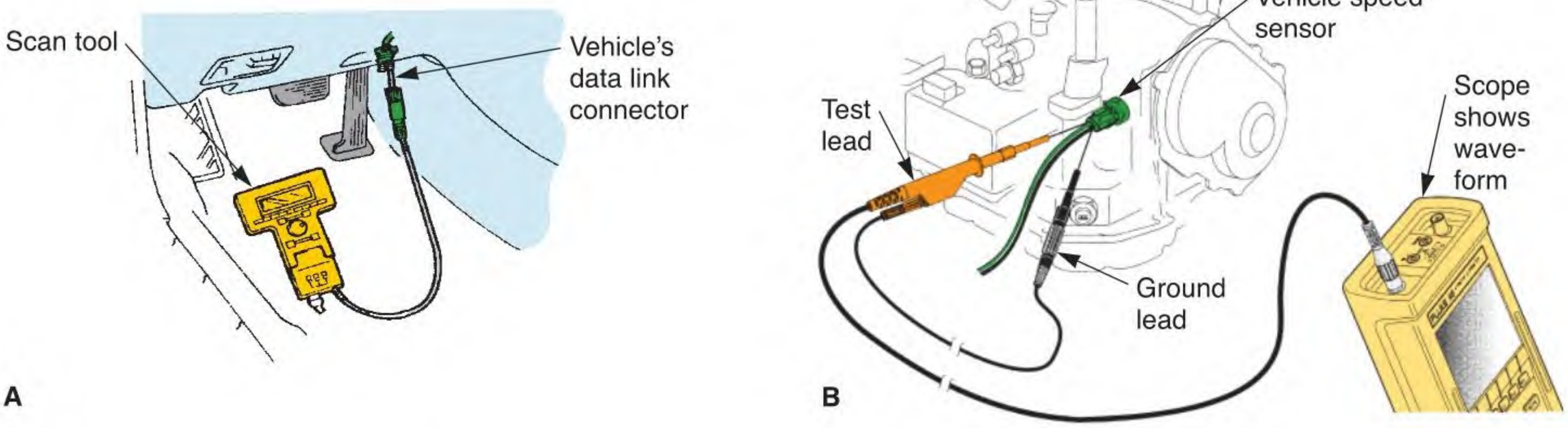
Automatic Transaxle Problems

Automatic transaxle problems, like automatic transmission problems, show up as slipping in gear (low fluid level, worn bands or clutches, low system pressure), abnormal noises (damaged planetary gears, bad bearings, air in the system), and fluid leaks.

If the test-drive or the preliminary inspection does not pinpoint the trouble, you may need to perform a stall test, pressure tests, or air tests. Look at **Figure 72-3.**

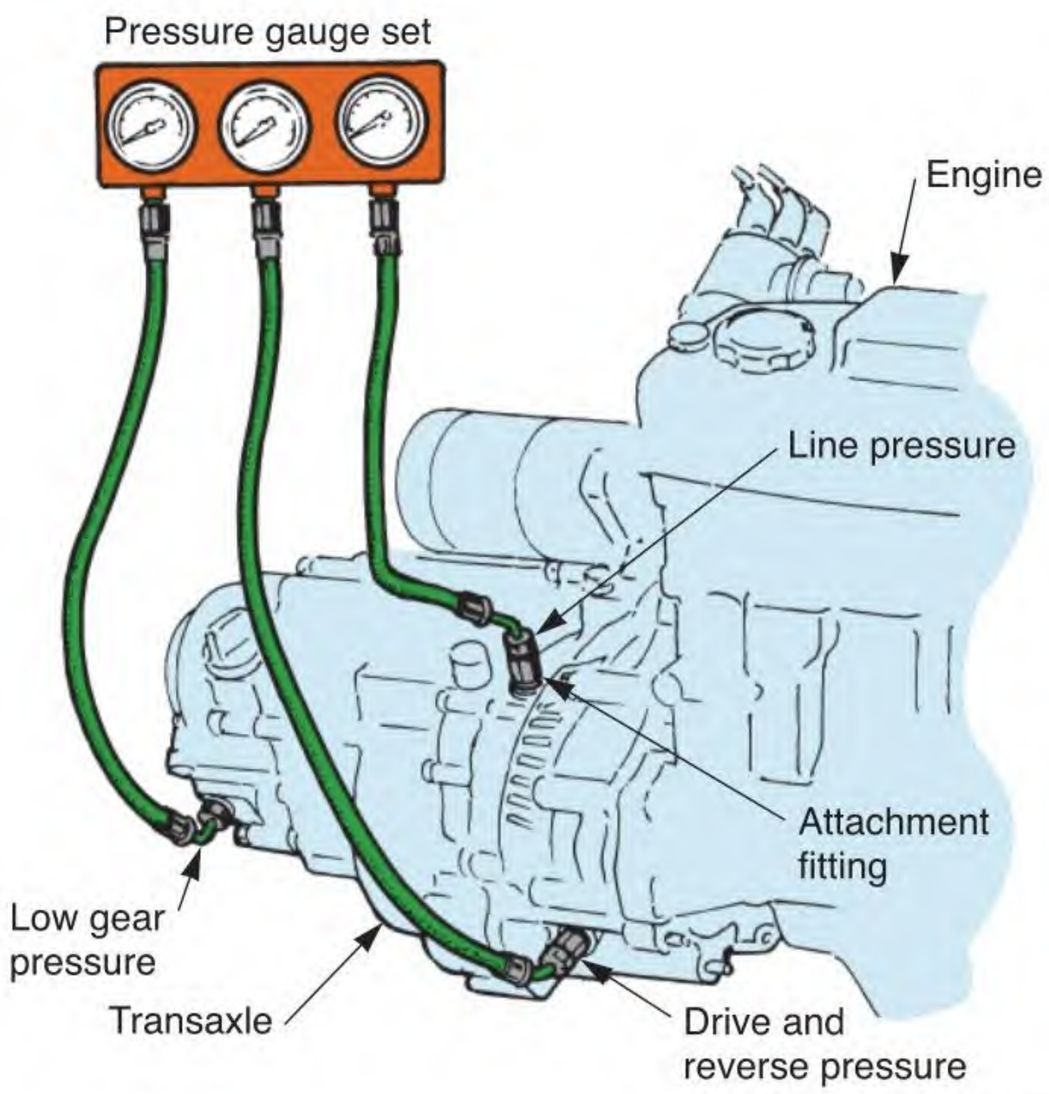
A manufacturer's diagnosis chart and hydraulic schematics are very helpful in determining which transaxle parts are causing the symptoms. Use a chart that is written for the exact make and model of transaxle being serviced.

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Mazda; Fluke

Figure 72-2. With OBD vehicles, the ECM monitors and controls most transaxle functions. A—If the MIL light is on, use a scan tool to retrieve stored trouble codes. The scan tool also gives other operating values, which can aid diagnosis. B—If the scan tool indicates a bad sensor or circuit, perform a pinpoint test to verify the source of trouble. Here, a handheld scope checks the signal from the vehicle speed sensor on the transaxle.



Honda

Figure 72-3. As with an automatic transmission, pressure gauges are used to measure oil pressure in each gear position to determine the condition of automatic transaxle components.

Front Drive Axle Problems

Front drive axle problems are usually noticed as abnormal noises (clicking, grinding, clunking, humming), vibration, or excessive play in the universal joints. Drive axles are under stress from high engine torque being transmitted at various angles through the driveline. This can cause the CV joint bearings and races to fail after prolonged service. If the rubber boot around a CV joint is ruptured, road dirt and water will enter and wash the grease out of the joint. A damaged boot seal also allows lubricant to escape from the joint. Contamination and lubricant loss will quickly cause joint wear and failure.

Tech Tip

To check for bad front drive axles, drive the vehicle in reverse with the steering wheel turned sharply to the right and then to the left. This can be done in an empty parking lot. With the windows down, you will be able to hear the noise from worn CV joints.

When symptoms point to possible drive axle troubles, raise the vehicle on a lift. Inspect the axle shafts. Make sure the CV joint rubber boots are not torn or cracked. Wiggle and rotate the joints to check for excessive play and wear. Twist one axle shaft one way and the next shaft the other way, and look for movement and play in the bearings.

Warning

Do *not* operate the engine and transaxle with the suspension system hanging unsupported on a lift. The CV joints may be bent at a sharp angle. When spun, the joints could bind and fly apart with lethal force.

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Transaxle Maintenance

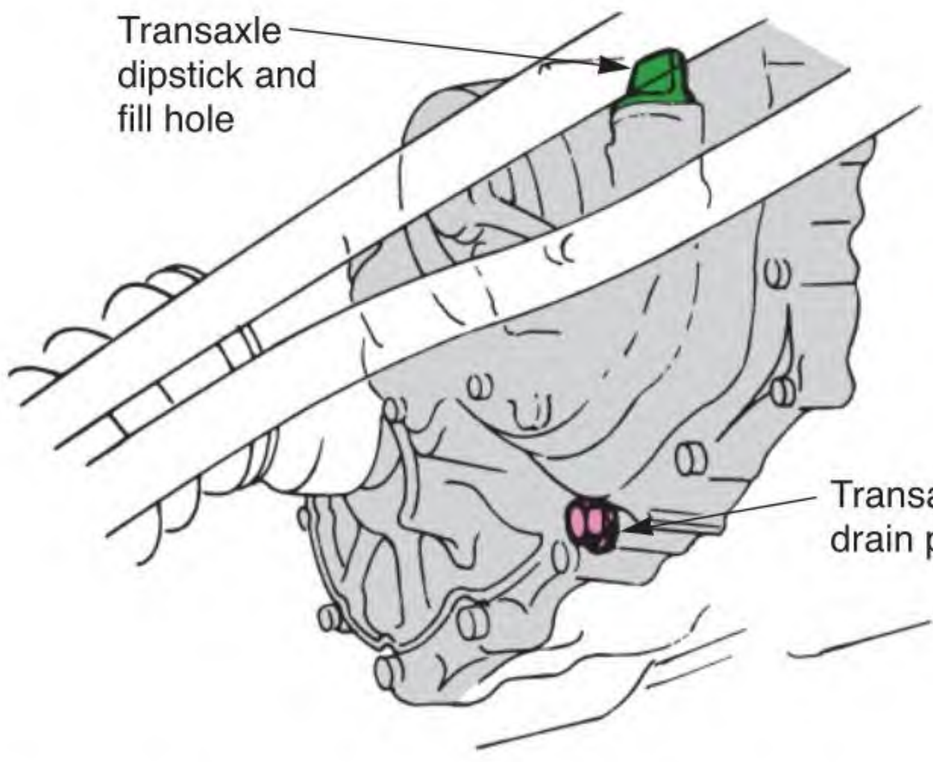
Proper maintenance is very important to the service life of a transaxle. If the transaxle lubricant is not changed at recommended intervals, abnormal part wear and failure can result. The clutch, shift linkage, and bands must be adjusted periodically if the transaxle is to provide dependable operation.

Checking Transaxle Lubricant

You should check the lubricant level in both a manual and automatic transaxle at regular intervals. See **Figure 72-4**.

An automatic transaxle normally has a dipstick for checking lubricant level. Normally, the transaxle should be at operating temperature with the engine running and the shift selector in *Park*. If the lubricant level is low, add the recommended type of fluid.

A manual transaxle has a fill hole or dipstick for checking lubricant level. Some manufacturers recommend checking manual transaxle lubricant with the unit at room temperature. Others require that the lubricant be warmed to operating temperature. The lubricant should be almost even with the fill hole or between the prescribed lines on the dipstick.



Honda

Figure 72-4. Check transaxle oil level using the dipstick (if provided) or at the fill hole. Use the manufacturer's recommended checking and changing procedures and the correct type of lubricant.

Caution

Some manual transaxles use automatic transmission fluid, while others use manual transmission gear oil. Always refer to a service manual when in doubt. The incorrect type of lubricant could cause severe transaxle damage.

Changing Transaxle Fluid

Service Procedure

To change the transaxle fluid:

1. Warm the transaxle fluid to full operating temperature by running the engine.
2. Raise and secure the vehicle in a level position.
3. Locate and remove the transaxle drain plug, **Figure 72-4**.
4. If a drain plug is not provided, unbolt and remove the sump pan (in an automatic transaxle). Pan removal is also needed if you are going to replace the automatic transaxle filter.

Warning

When at operating temperature, transaxle fluid can cause painful burns. Do not allow hot fluid to run down your arm when draining.

5. If you removed the sump pan, clean off the sealing surfaces on the pan and the transaxle case. Wipe them dry with a clean rag and solvent.
6. Install a new filter, if needed.
7. Install a new gasket or RTV sealer on the pan.
8. Bolt the pan to the transaxle. Tighten the pan bolts to specifications in a crisscross pattern.
9. Using a funnel, fill the transaxle with the correct type and amount of fluid. A shop manual will indicate how much fluid the transaxle will hold.
10. Lower the vehicle and start the engine.
11. Shift the transaxle through each gear.
12. Check under the vehicle for lubricant leaks.

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External Transaxle Adjustments

Some automakers recommend clutch and shift linkage adjustments at regular intervals. Transaxle shift linkage or cables are adjusted using procedures similar to those for transmissions. Check that the shift arms on the transaxle are in the proper position in relation to the driver's shift lever. Some transaxles require a special linkage holding fixture for adjustment.

Adjusting a manual transaxle clutch is similar to adjusting the clutch linkage on a manual transmission. Make sure the clutch pedal has the correct free play and applied height.

A few automatic transaxle bands have an adjusting screw inside the pan. By loosening the locknut, the screw can be turned to set the band-to-drum clearance. Normally, the screw is turned in until it bottoms at a specific torque. Then, the screw is turned out a specified number of turns and the locknut is tightened.

Front Drive Axle Service

Normally, when you find problems with a front drive axle assembly, it must be removed for service. Refer to **Figure 72-5**. The most common front drive axle problem is worn, dry CV joints.

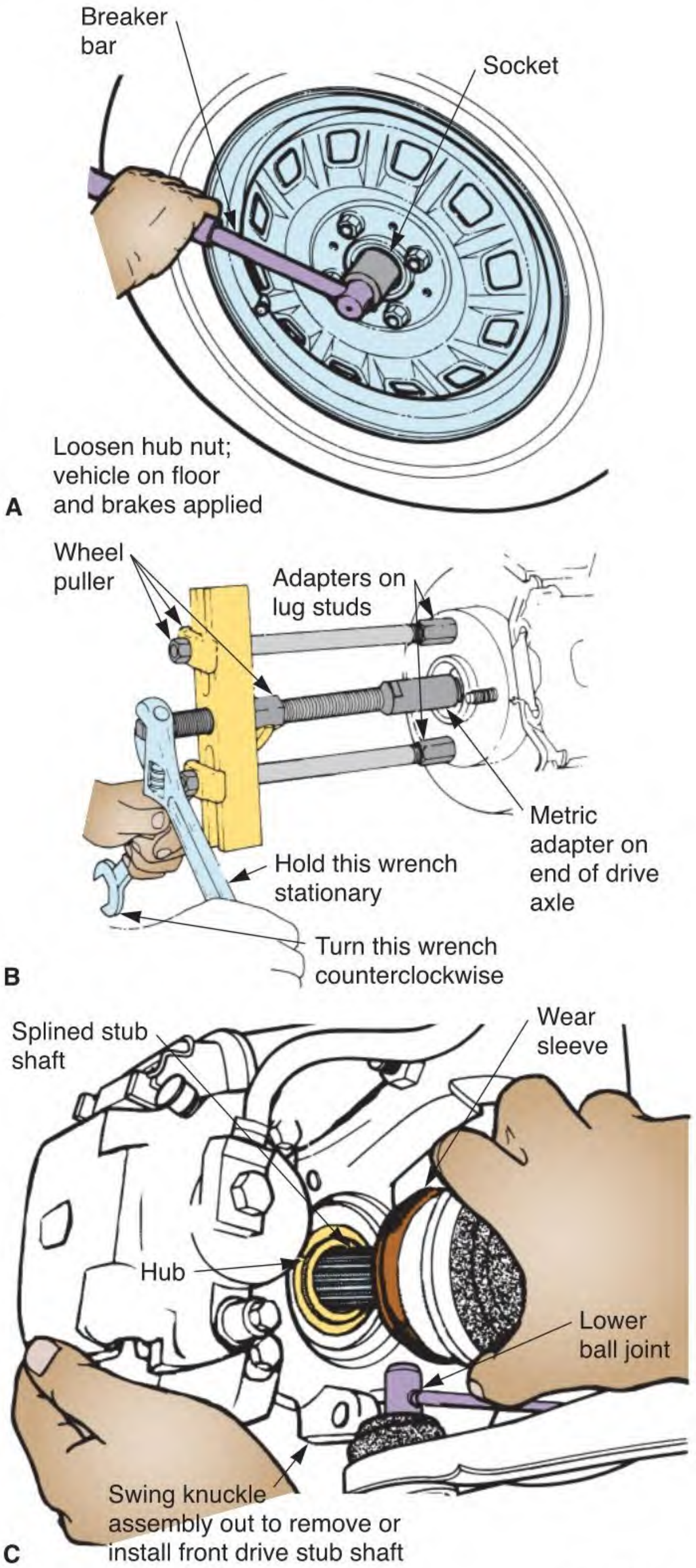
Front Drive Axle Removal

Before removing the front drive axle assembly, disconnect the battery to avoid accidental engine cranking and startup. Then, remove the wheel and tire of the axle to be serviced and remove the hub nut. Either leave the vehicle on the ground or hold the brake disc with a large screwdriver. This allows you to turn the nut without turning the hub and brake disc, **Figure 72-5A**.

On some cars, a puller must be used to free the outer stub shaft from the hub. The puller grasps the hub's lug studs and pushes in on the axle shaft. See **Figure 72-5B**.

Frequently, you must remove the lower ball joint before the drive axle will slide out of the transaxle. The stub axle shaft will not slide out far enough unless the steering knuckle is free to swing away from the transaxle, **Figure 72-5C**.

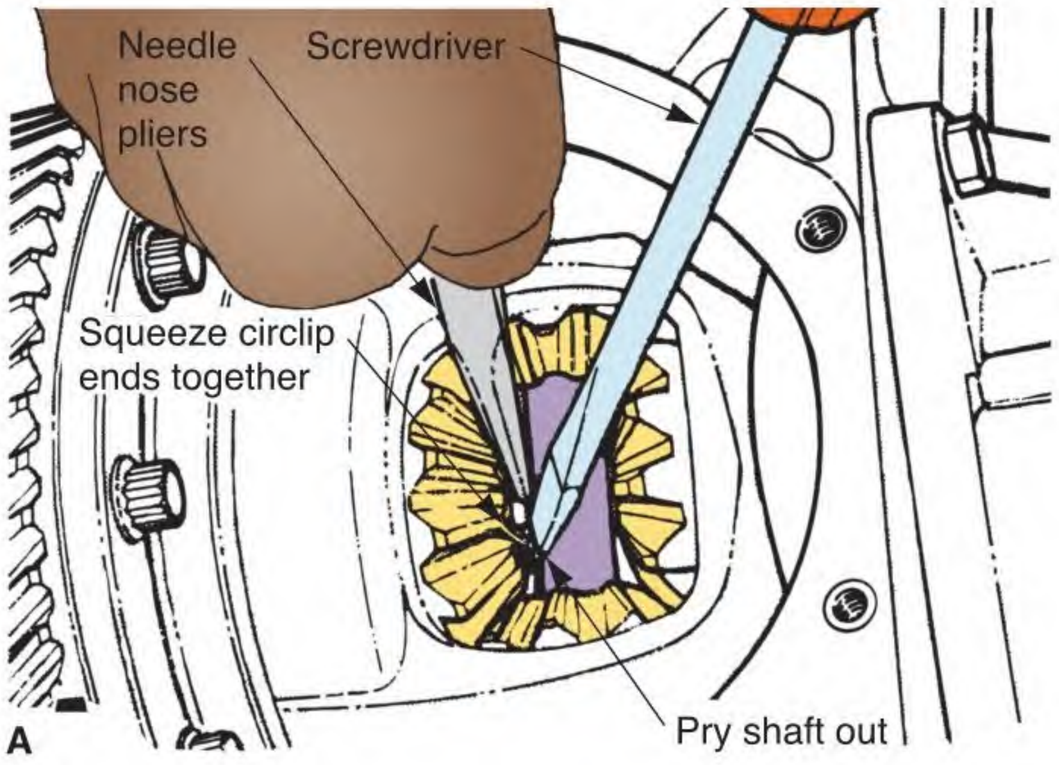
With some transaxles, the inner stub shaft is held in place by snap rings or circlips, **Figure 72-6A**. To access these rings or clips, the transaxle differential cover must be removed. The snap rings or circlips can then be removed from the grooves in the stub shafts, and the axles can be pulled out of the transaxle.



Ford; Chrysler

Figure 72-5. Typical method for disconnecting the outer end of a front drive axle assembly. A—With the vehicle on the ground, loosen hub nut with a breaker bar and socket. B—A puller is sometimes needed to force the outer stub shaft splines from the hub. Make sure you have removed the ball joint, lower control arm fastener, sway bar, and any other obstructing parts. C—With the lower ball joint removed, swing the steering knuckle outward so axle splines will slide out. Support the axle.

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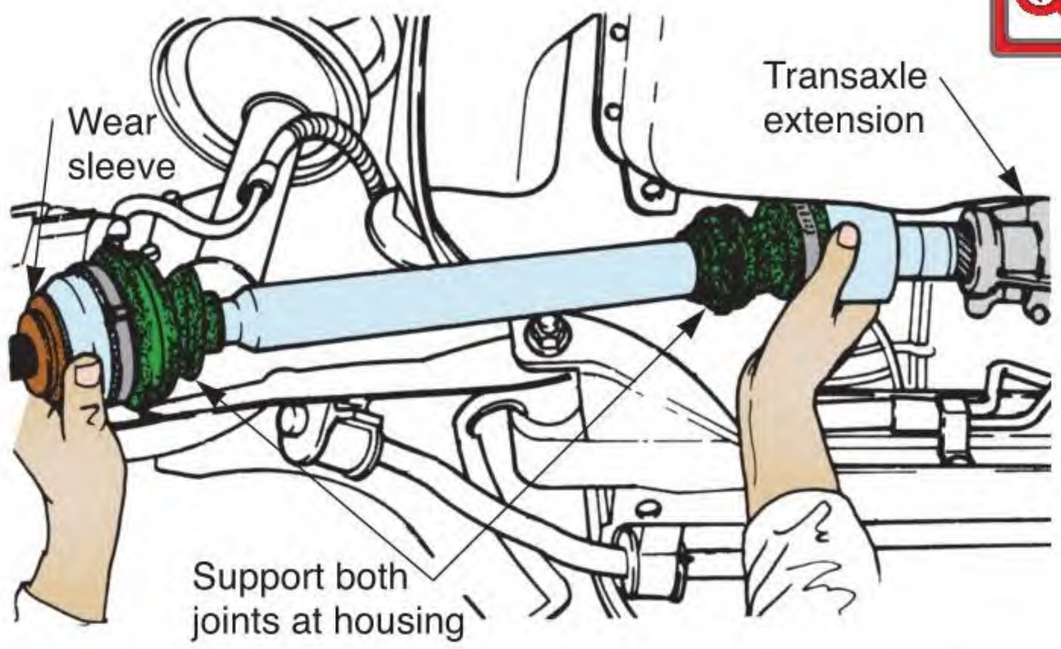
Chrysler

Figure 72-6. Inner stub shafts are commonly connected by snap rings or bolts. A—The snap ring must be removed from its groove before the shaft can be removed. B—When the inner axle flange is bolted to the drive flange, remove the fasteners so the shaft can be removed.

With other designs, the inner axle flange must be unbolted before removing the stub shaft, **Figure 72-6B**. If required, use a slide hammer to pull the shaft from the transaxle. While holding the axle assembly together, pull it out or off the transaxle as illustrated in **Figure 72-7**.

Transaxle CV Joint Replacement

In most cases, the entire drive axle assembly is replaced when a faulty CV joint is found. However, the CV joint can be replaced, if desired. A ***CV joint kit*** usually includes new joint components, grease, a boot, and boot straps. To replace CV joints, mount the drive axle assembly in a vise, **Figure 72-8**. If you have a tubular, or hollow, axle shaft (interconnecting shaft), be careful not to bend or dent the shaft. The slightest dent could cause vibration.



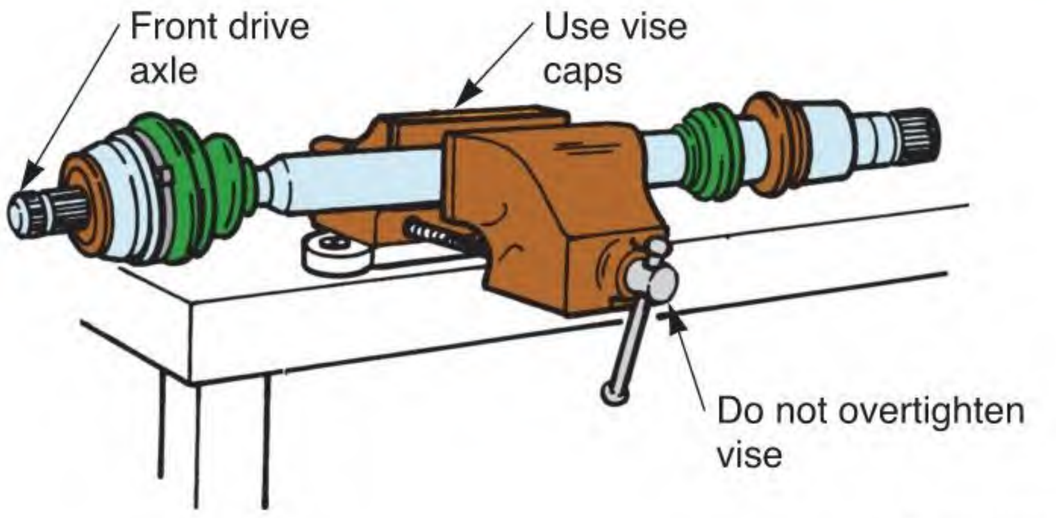
Chrysler

Figure 72-7. When removing the front drive axle assembly, support both ends and hold the plunging joint together. Never let the axle hang unsupported, as joint or boot damage can result.

Service Procedure

To service a tripod CV joint:

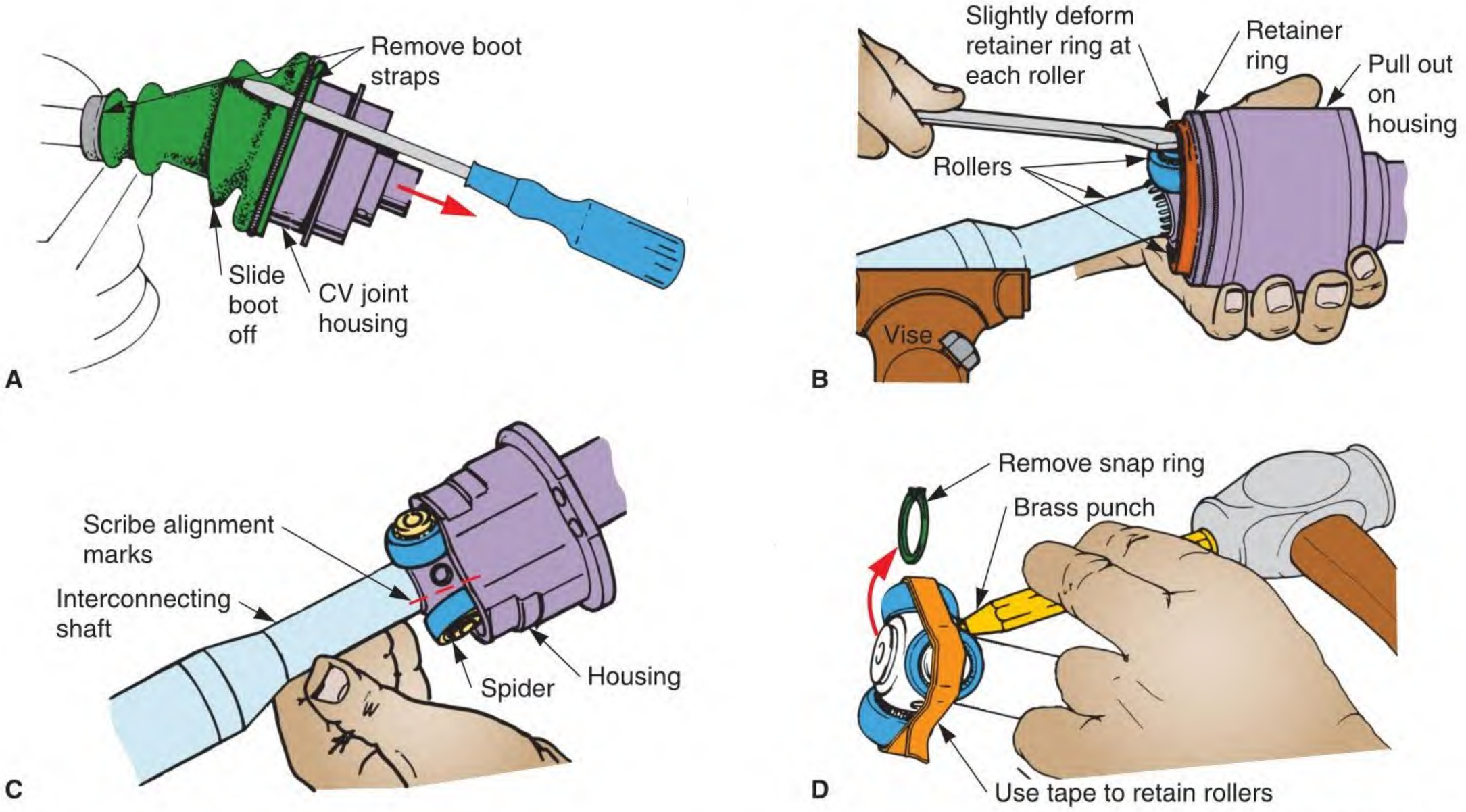
1. Remove the straps or clamps holding the boot around the joint. Cut the plastic type or carefully pry off the spring type because they can be reused. See **Figure 72-9A**.
2. Separate the tripod from the housing, **Figure 72-9B**.



Dana Corp.

Figure 72-8. To service CV joints, mount the axle in a vise. With hollow drive axles, be extremely careful not to bend or dent the shaft. This could cause shaft vibration.

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Chrysler; Dana Corp.

Figure 72-9. Basic steps for disassembling a tripod CV joint. A—Remove the straps or clamps holding the boot around the joint. B—Slide the spider out of the housing. If needed, flex the retainer ring out of the way. C—If any joint components are to be reused, mark their alignment during disassembly. D—Remove the snap ring holding the spider on the axle splines and drive off the old spider. Tape is used to keep rollers and needles from falling off.

3. Scribe mark the housing and interconnecting shaft to ensure proper alignment during reassembly, **Figure 72-9C**.
4. To remove the spider from the interconnecting shaft, remove the snap ring in the end of the shaft. Then, use a brass drift or punch to push the spider off the axle. See **Figure 72-9D**.
5. Slide the new rubber boot onto the interconnecting shaft.
6. Inspect the axle shaft splines and snap ring grooves. Make sure the spider is fitted on splines correctly. The chamfer may have to face a certain direction. Install a new snap ring to hold the spider on the axle.
7. Grease the spider and the housing.
8. Place the recommended amount of grease in the boot.
9. Fit the spider and housing together. Make sure that the scribed lines on the interconnecting shaft and the housing align.
10. Fit the boot over the housing and install the boot straps. See **Figure 72-10**.

Caution

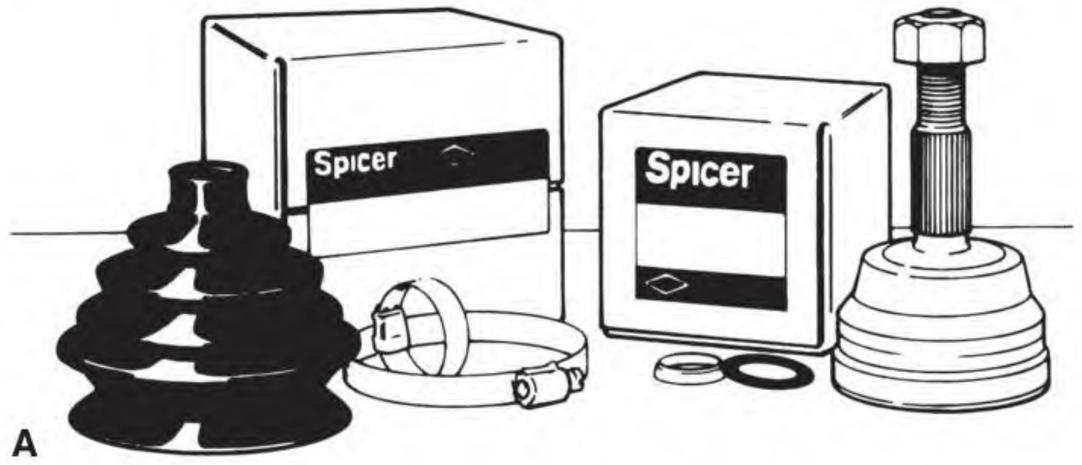
Always use the recommended type of grease on a CV joint. Quality CV joint kits provide the correct type and amount of grease. The wrong type of grease can cause boot deterioration and joint failure.

Service Procedure

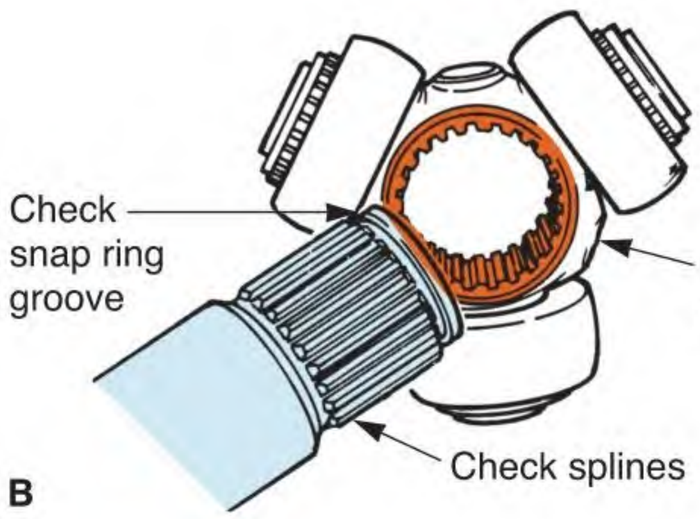
To service a Rzeppa CV joint:

1. Remove the boot straps.
2. Slide the boot back and remove the retaining ring.
3. Remove the joint from its shaft.
4. Tilt the cage and inner race using thumb pressure, **Figure 72-11A**. In some cases, light taps with a hammer and wooden dowel may be required to tilt the cage, **Figure 72-11B**. With the cage tilted, remove the balls from the cage. Tilt the cage in different directions to free each ball, **Figure 72-11C**.

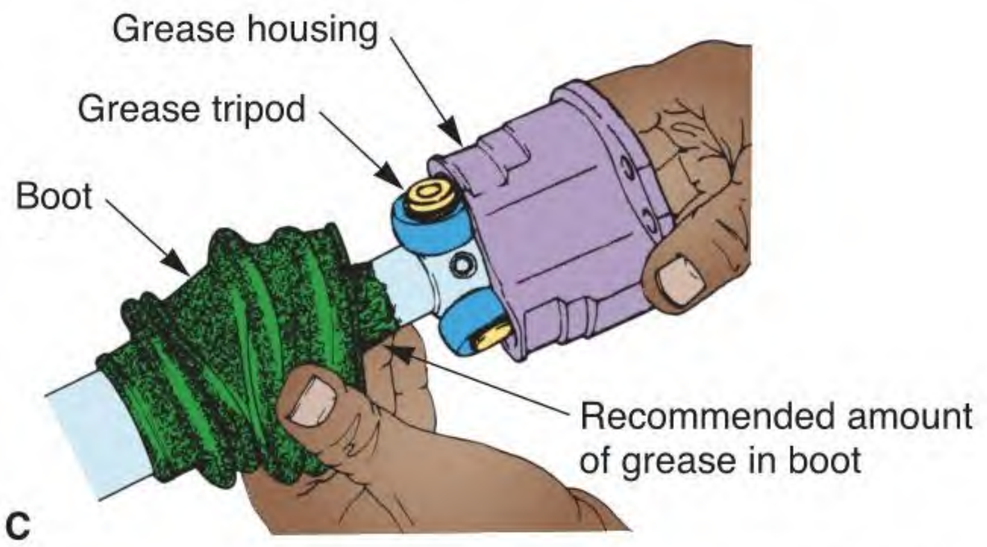
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A



B



C

Dana Corp.; Chrysler

Figure 72-10. Fundamental steps for rebuilding a tripod CV joint. A—A CV joint kit normally contains a new joint spider, boot, rollers, needle bearings, snap rings, and boot straps. B—Place the new spider on its interconnecting shaft splines and install the snap ring in place. C—Grease the spider and the housing. Place the recommended amount of grease in the boot.

Tech Tip

If a hammer and dowel are used to tilt the cage when removing the balls, do not use a metal dowel. The housing could be damaged.

5. Swivel the cage and inner race and remove them from the housing, **Figure 72-11D**.
6. Rotate the inner race and remove it from the cage, **Figure 72-11E**.
7. Clean and inspect the parts to be reused.
8. Obtain the correct CV joint repair kit.
9. Grease the inner race and fit it into the cage.
10. Install the cage and inner race into the joint housing, **Figure 72-12A**.
11. Tilt the cage and position each ball, **Figure 72-12B**. With a sliding Rzeppa joint, the balls, cage, and inner race will slide into the housing as a unit.
12. Assemble the joint on the axle shaft. Make sure all snap rings are in good condition. Sometimes, a press is needed to force the joint over its splines.
13. After reassembly, thoroughly grease all moving parts of the joint. If recommended, place extra grease in the boot for added lubrication.
14. Fit the boot over the joint, **Figure 72-12C**. Make sure the boot ends fit into their grooves.
15. Install the boot straps. Do not overtighten the straps. You may cut the boot or break the strap.

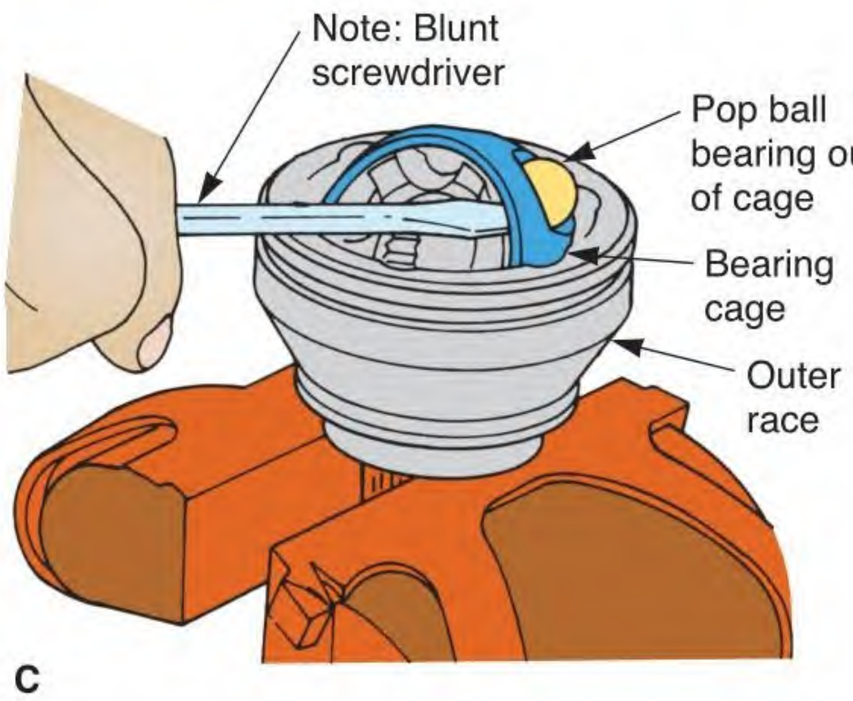
    Figure 72-13 shows two typical front drive axle assemblies. Note how both have sliding inboard CV joints. One is a Rzeppa joint and the other is a tripod joint. Both axles have fixed outer Rzeppa joints.

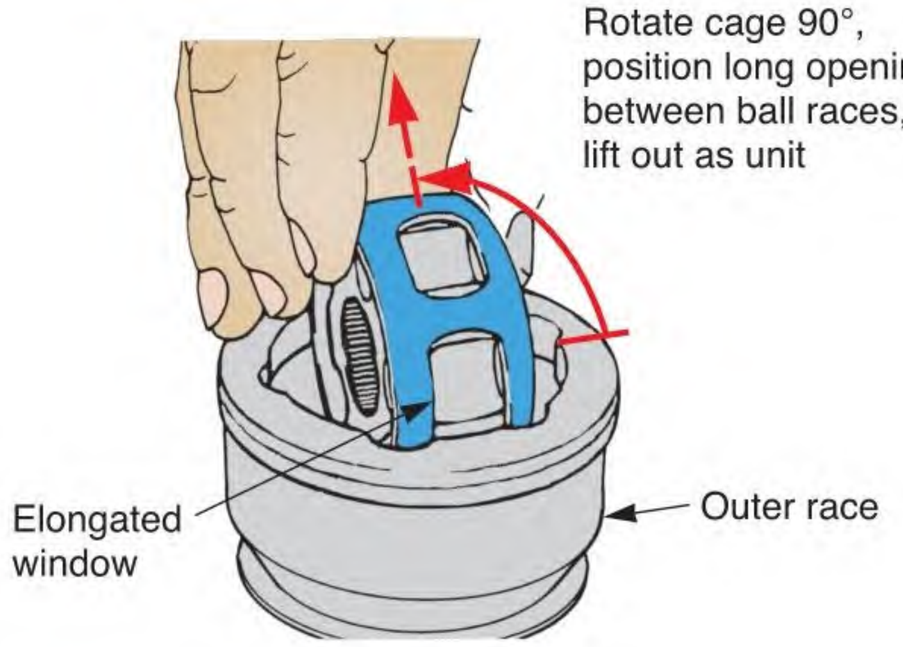
Refer to a service manual when servicing either type of CV joint. The manual provides special, detailed directions and a list of special tools required for the repair.

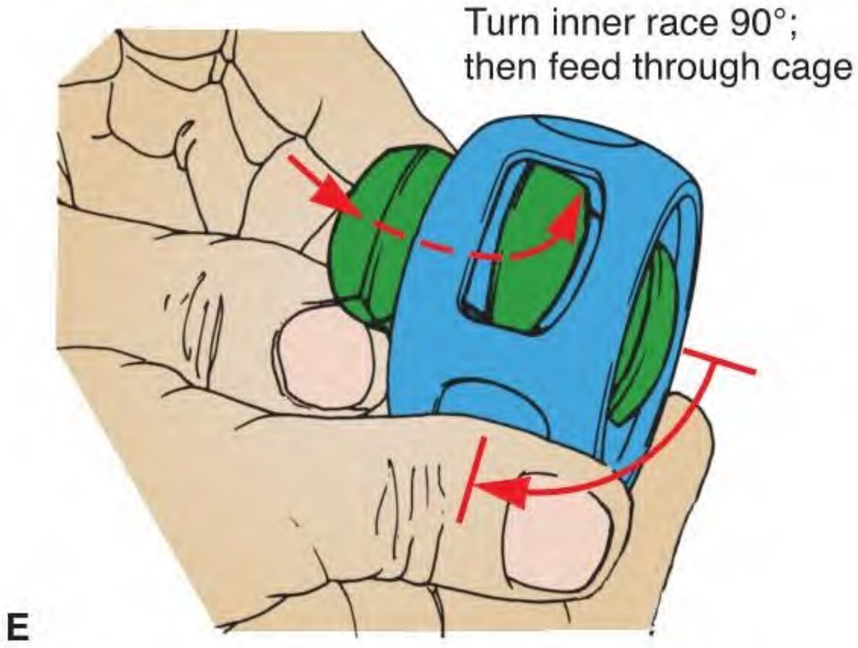
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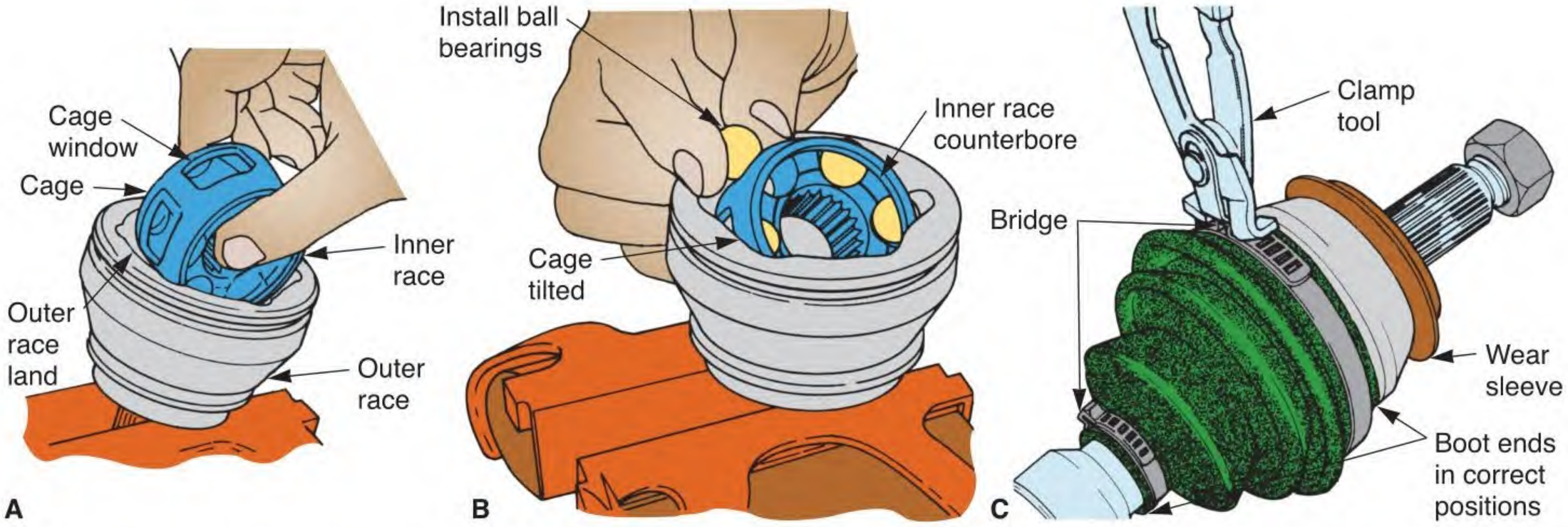




Ford; Chrysler

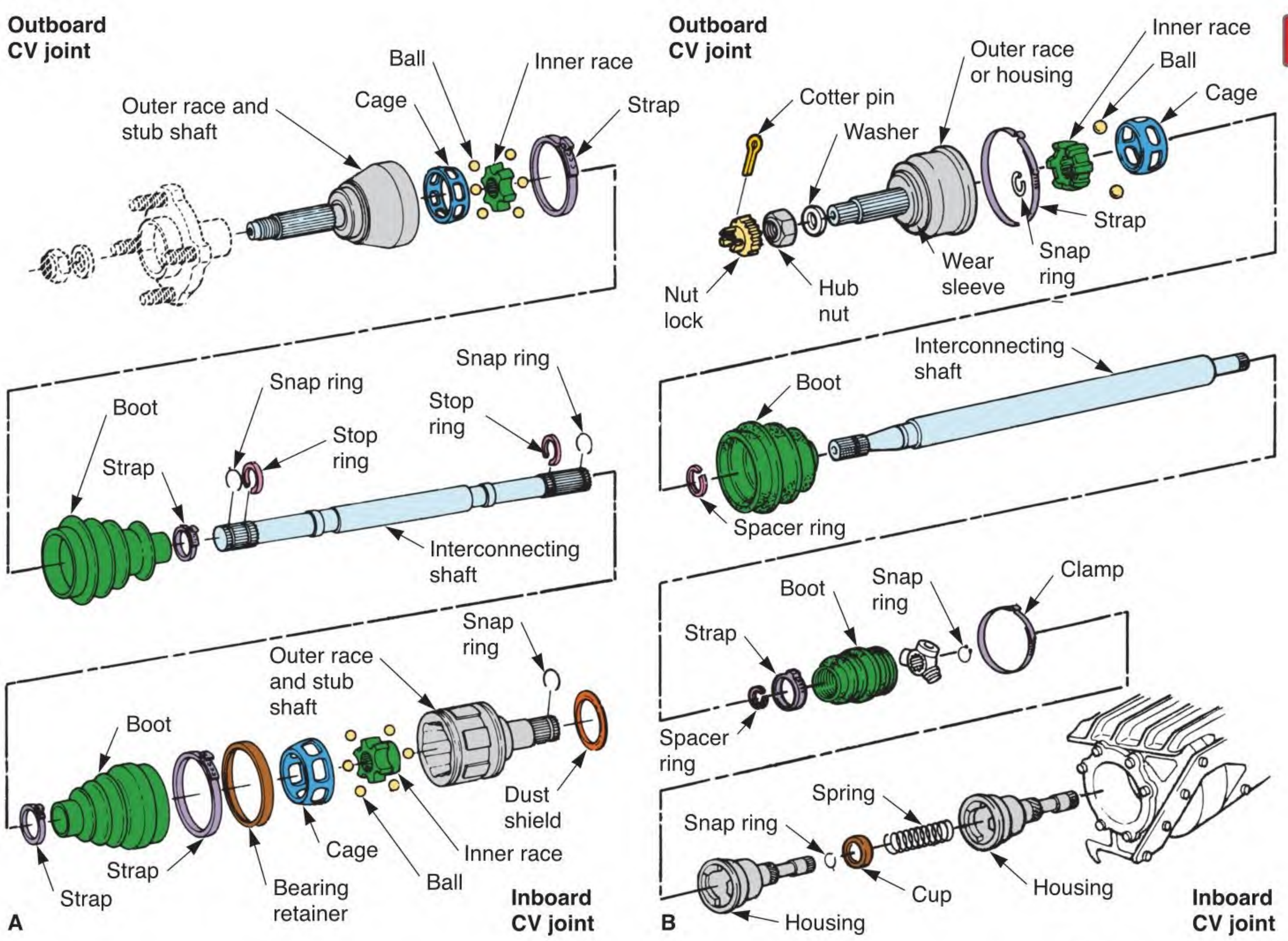
Figure 72-11. General procedures for disassembling a Rzeppa CV joint. A—Use thumb pressure to tilt the cage so the balls can be removed. B—You may need to use hammer and wooden dowel. C—Remove the balls with a dull-tip screwdriver. D—Swivel the cage and inner race 90° and remove it from the housing. E—Rotate the inner race to remove it from the cage.

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Ford; Chrysler

Figure 72-12. Reassembly steps for a Rzeppa or ball and cage CV joint. A—Install the cage and inner race inside the housing. B—Tilt the cage and install the balls one at a time. C—Install the boot and boot straps. Note the use of special pliers designed for boot installation.



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Figure 72-13. Exploded view of two typical CV axle designs. A—This axle has two Rzeppa joints. The outboard CV joint is fixed. The inboard Rzeppa joint is sliding. B—This axle has a fixed Rzeppa outboard and a sliding tripod joint inboard.

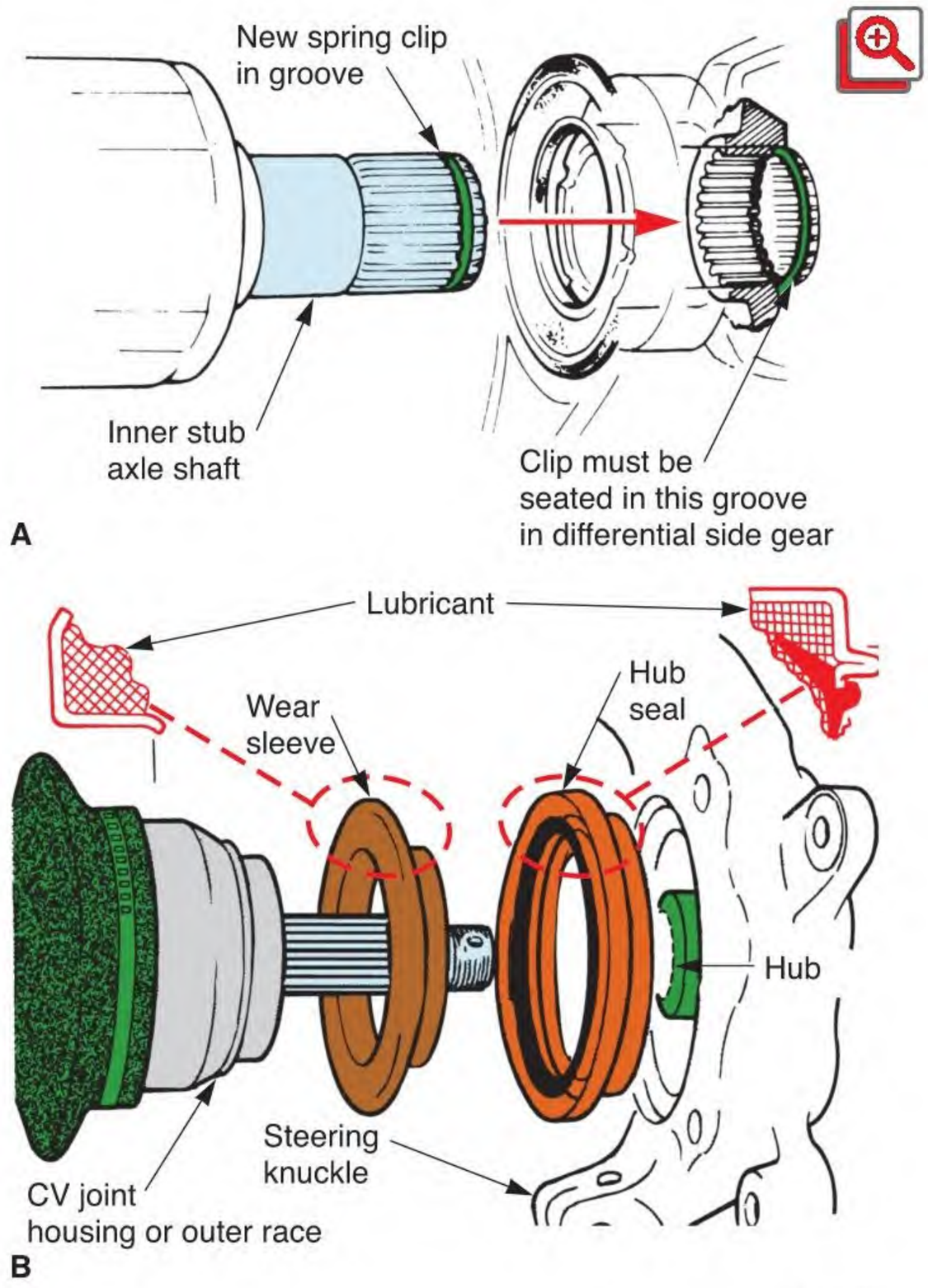
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Installing a Front Drive Axle

Service Procedure

To install a front drive axle, you basically reverse the directions used in axle removal.

1. Fit or slide the inner end of the axle on or into the transaxle. The shaft may slide easily into the transaxle, or you may need to use light taps with a hammer and driving tool.
2. If used, make sure the snap ring or spring clip locks in the differential by pulling on the joint, **Figure 72-14A**.
3. Reinstall any bolts or other parts removed during disassembly.
4. Replace and lubricate the hub seal, or grease seal.
5. Lubricate the ***wear sleeve*** (bushing between axle and seal), if used. See **Figure 72-14B**.
6. Hub seal replacement is normally recommended during front drive axle service.
7. Slide the outer end of the axle into the hub. You may need to use a puller to force the axle through the hub splines.
8. If needed, reinstall the lower ball joint.
9. Screw on the spindle nut and torque it to specifications.
10. If you had to remove the snap rings on the inner ends of the axle shafts and the differential cover, make sure the snap rings are reinstalled properly.
11. Clean the differential cover.
12. If recommended, adhere the new gasket to the cover.
13. If RTV sealer is to be used, coat the differential cover with an even bead of sealer, **Figure 72-15**.
14. Bolt the cover to the transaxle and torque the bolts to specifications in a crisscross pattern.
15. Fill the transaxle with the correct type and amount of lubricant.
16. Install the front wheels and axle nuts.
17. Lower the vehicle to the ground.
18. Torque the lug nuts to specifications.
19. Test-drive the vehicle.



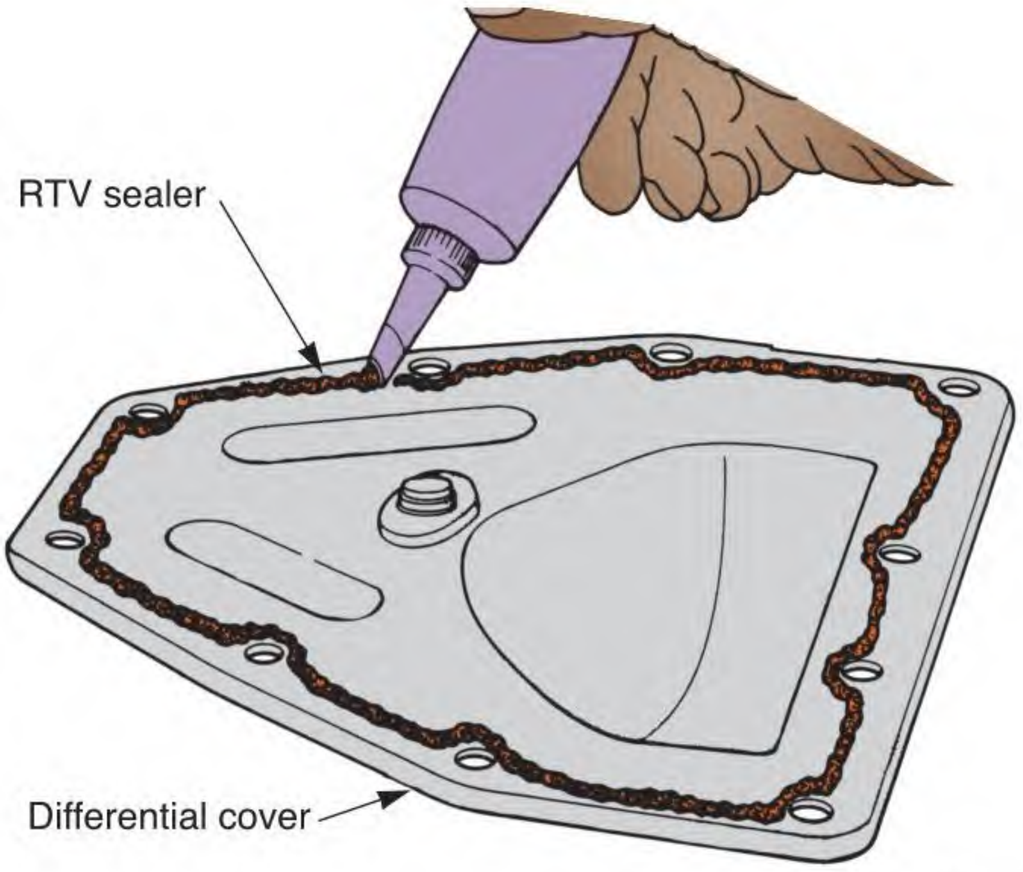
Chrysler

Figure 72-14. Front drive axle installation. A—If a snap ring or spring clip holds the inner stub shaft in the differential, make sure it snaps into place. B—Lubricate parts as recommended. Note how this axle design requires grease on both the wear sleeve and seal.

Transaxle Removal

The specific procedures for removing a transaxle from a vehicle vary. Sometimes the engine and transaxle must be removed together through the top of the engine compartment. However, with most front-wheel-drive vehicles, the transaxle can be separated from the engine and removed from the bottom of the engine compartment.

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Chrysler

Figure 72-15. If the differential cover was removed, clean and apply gasket or RTV sealer to the cover.



OTC

Figure 72-16. Note the holding fixture on this vehicle supporting the weight of the engine. The engine must not hang from the motor mounts.

Service Procedure

To remove a transaxle:

1. Disconnect the negative battery cable.
2. Remove all parts connected between the transaxle and vehicle.
3. Remove the clutch cable, speedometer cable, shift cables or rods, sensor or switch wiring connectors, cooler lines, starting motor, and upper engine-to-transaxle bolts.
4. If recommended, mount an engine holding fixture on the vehicle. It is needed to keep the engine from dropping as you remove the transaxle, **Figure 72-16**.
5. Raise the vehicle on a hoist and remove the front wheels.
6. Place a transmission jack under the transaxle, **Figure 72-17**.
7. If a ***cradle*** (engine-supporting subframe) or a crossmember is used, it may have to be removed to gain access to the transaxle.
8. Drain the fluid from the transaxle and then remove both drive axles.
9. Remove the remaining engine-to-transaxle bolts. It may also be necessary to remove one or more motor mounts.
10. Force the transaxle away from the engine.
11. Slowly lower the jack while watching for any components still connected.



OTC

Figure 72-17. Note the large saddle on the transmission jack. It safely secures and holds the transaxle during removal.

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Transaxle Service

When repairing or rebuilding a transaxle, follow the detailed procedures given in a service manual.

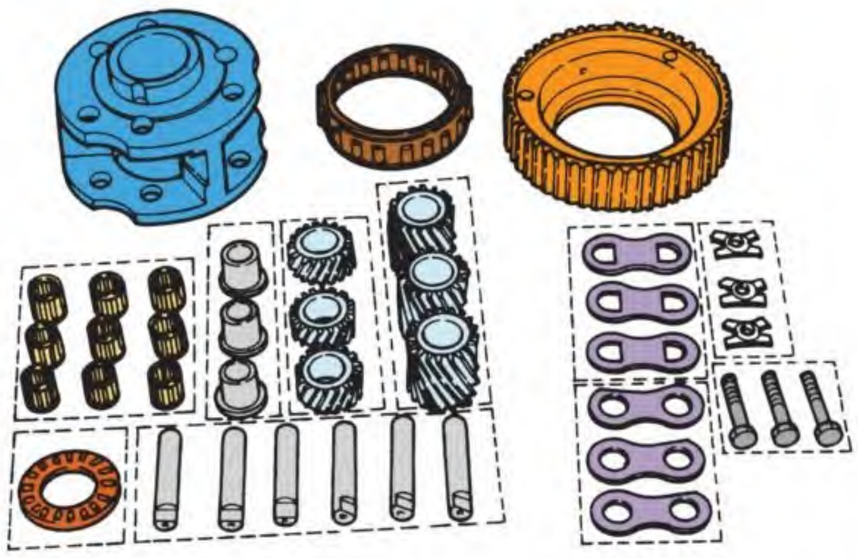
The following are a few general rules to remember:

- Do not dent or nick the gasket sealing surfaces during disassembly or cleaning.
- Keep all parts organized so that used parts can be returned to their original positions, **Figure 72-18**.
- Clean all parts and closely inspect them for damage. Replace any parts that show wear.
- Replace all gaskets and seals.
- Use special tools when needed.
- During reassembly, measure all gears, shafts, bearings, and other critical components as described in a service manual, **Figure 72-19**.
- Measure bearing preload as described in the service manual, **Figure 72-20**.
- Make sure all snap rings, shims, and other parts are installed correctly.
- Torque all bolts to specifications. Most transaxles have aluminum cases that are very sensitive to bolt torque.

Transaxle Installation

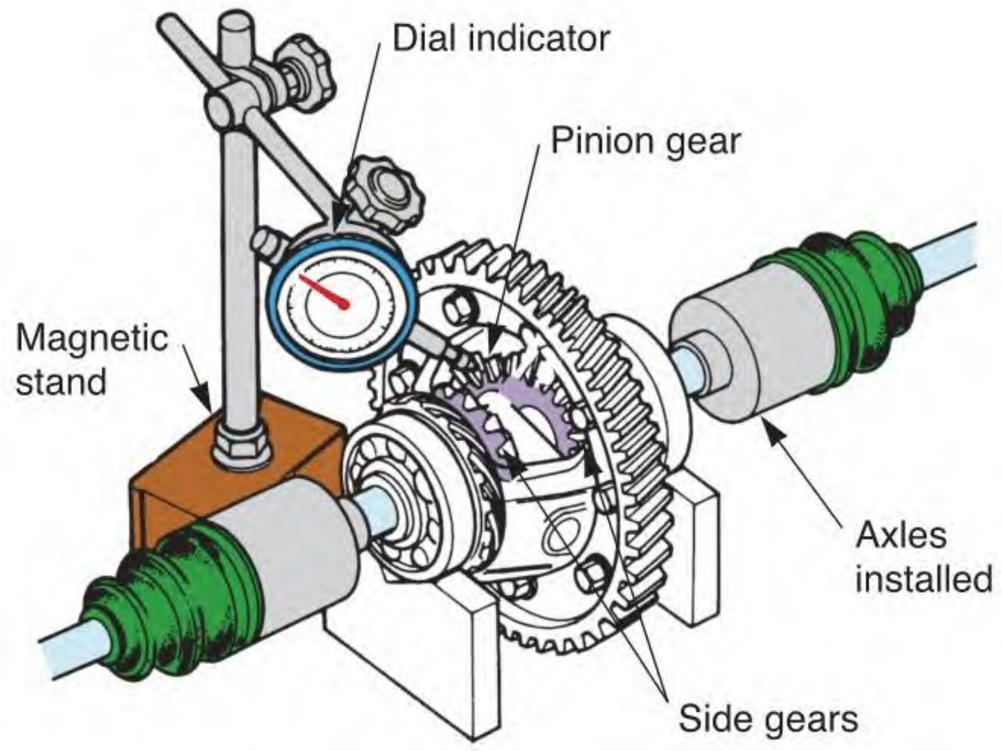
Install a transaxle in the reverse order of removal. Use a jack to position the transaxle behind the engine. Align the engine crankshaft centerline with the transaxle input shaft centerline.

On a manual transaxle, make sure the throw-out bearing is new or in good condition. Make sure it is installed correctly.



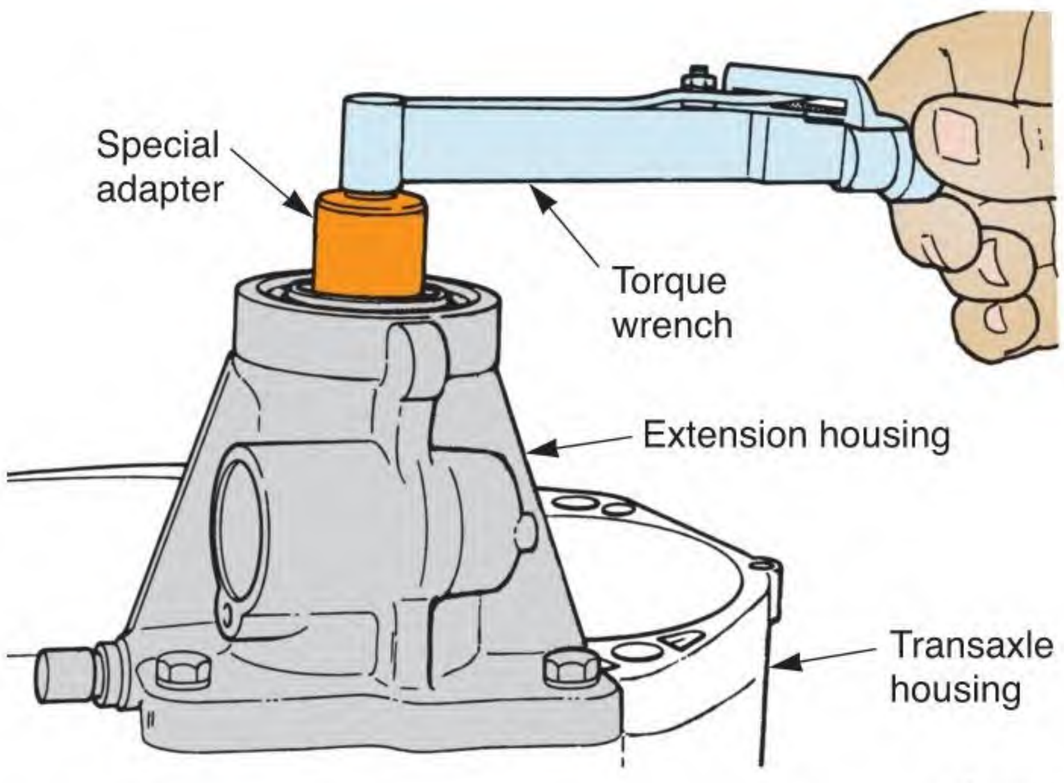
Subaru

Figure 72-18. Clean and inspect all components very carefully. If you overlook just one problem, your repair may fail. Keep parts organized to simplify reassembly.



Honda

Figure 72-19. This illustrates how to measure differential pinion gear backlash. Many other measurements are also essential.



Chrysler

Figure 72-20. As with a rear axle differential, a torque wrench can be used to measure transaxle differential case bearing preload. Compare reading to specifications.

Slowly push the transaxle against the engine. Make sure the studs on the engine fit into the holes in the transaxle bell housing. On an automatic transaxle, you may also have to align the torque converter bolts with the flywheel while fitting the transaxle.

Caution

As with a transmission, double-check that the torque converter is correctly installed. If the converter is not fully into position, part damage could result when you tighten the bolts holding the transaxle to the engine.

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Start and torque the engine-to-transaxle bolts. Then, install the other components (cradle, starter, mounts, etc.). Fill the transaxle with lubricant and test-drive the car.

Transaxle Solenoid Service

Modern transaxles are electro-hydraulic—they use electric and electronic components to control hydraulic circuits that operate the clutches and gearsets in the transaxle. A scan tool will indicate a trouble code when shift or pressure solenoids have failed (open or high resistance circuit to any sensor, solenoid, or servo motor).

A bad transaxle solenoid can cause a wide range of transaxle performance problems, such as slipping, failure to shift gears, and inability to drive or reverse.

A pressure solenoid controls the pressure applied by the hydraulic pistons and servo to the clutches and bands. A bad pressure solenoid can cause slippage or gear disengagement if the bands and clutches are not clamped together with enough force. The lockup torque converter may slip if it does not get enough oil pressure from the solenoid-controlled hydraulic circuit.

A bad shift solenoid affects when and how well the specific gear change or gear ratio shift is completed. For example, if the transaxle shifts fine into 2nd gear but does not upshift into 3rd or 4th gears, suspect the 3rd gear shift solenoid. It may not be moving its 3rd gear hydraulic spool valve, or the valve may be dirty and sticking.

A transaxle's solenoid can usually be replaced without removing the transaxle from the vehicle. By removing the transaxle pan or cover over the solenoid, the solenoid can be removed and replaced easily.

Diagnostic Case Study

Concern: Mr. Smith brings his 2005 Camry to the shop. He complains of an odd, clunking sound coming from the front of the vehicle when he turns corners or pulls into his driveway. He says the sound seems to be coming from the front of the vehicle.

Cause: Duff test-drives the car in the parking lot. When turning the car sharply while backing up, a knocking or clunking sound can be heard.

Duff gives the car to one of the shop's master technicians. The technician raises the car on a lift and inspects the front drive axles. When he wiggles the right front axle shaft, the technician notices excessive movement. He also finds rips in the rubber boots over both CV joints.

Correction: The technician replaces both front drive axles with new units. After the new axles are installed, the vehicle is briefly test-driven and released to the customer.

Summary

- Transaxles suffer from the same kinds of problems as transmissions and differentials. The gears, shafts, bearings, seals, and other parts can wear and fail.
- With the engine, clutch, transmission, differential, and drive axles close together in the engine compartment, noises and other symptoms can be difficult to pinpoint.
- With OBD systems, many transaxle problems will trip a diagnostic code and illuminate the dash trouble light. Use pinpoint tests to find the actual source of the trouble.
- Manual transaxle problems include abnormal bearing and gear noises, shifting problems, and fluid leaks.
- Automatic transaxle problems show up as slipping in gear, abnormal noises, and fluid leaks.
- A manufacturer's diagnosis chart may be helpful in determining what parts might be causing the transaxle symptoms.
- Front drive axle assembly problems are usually noticed as abnormal noises (clicking, grinding, clunking, humming), vibration, or excessive play in the universals.
- Changing the transaxle lubricant at recommended intervals is very important to the service life of a transaxle.
- Some automakers recommend clutch and shift linkage adjustments at regular intervals.
- The most common front drive axle problem is worn, dry CV joints.
- When repairing or rebuilding a transaxle, follow the detailed procedures given in a service manual.
- A scan tool will indicate a trouble code when shift or pressure solenoids have failed.

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Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

cradle

CV joint kit

wear sleeve

Activities

1. Show the proper diagnosing procedure for a transaxle provided by your instructor.
2. Remove, disassemble, and replace a CV joint.
3. Change the transaxle lubricant in a unit assigned by your instructor.
4. Given a flat rate manual, a list of parts to be replaced, and a parts catalog, prepare a repair estimate for replacing CV joints on a transaxle. Use an hourly rate suggested by your instructor.

Review Questions

Answer the following questions using the information provided in this chapter.

1. What are three typical symptoms of manual transaxle problems?
2. What are three typical symptoms of automatic transaxle problems?
3. Describe three symptoms of front drive axle troubles.
4. What are the two types of lubricant commonly used in manual transaxles?
5. How do you check the oil or lubricant level in automatic and manual transaxles?
6. Which of the following is *not* an adjustment related to an automatic transaxle?
   (A) Clutch fork.
   (B) Bands.
   (C) Shift cable.
   (D) All of the above.
7. The most common problem with a front drive axle is worn CV joints. True or False?
8. What components are normally included in a CV joint kit?
9. Explain how to remove the spider from the interconnecting shaft when servicing a tripod CV joint.
10. Always reuse the old hub seal when replacing a front drive axle. True or False?
11. Name five general rules to remember when servicing a transaxle.
12. Describe the malfunctions that may occur if a pressure solenoid goes bad.

ASE-Type Questions

1. A customer complains that her automatic transaxle-equipped vehicle is making an odd noise. Technician A asks the customer to identify which gear or what conditions the noise is present. Technician B test-drives the car in all gears at different speeds. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. A car's manual transaxle produces a noise in every gear. Technician A inspects the condition of the valve body. Technician B checks the condition of the transaxle's shaft bearings. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. A manual transaxle is noisy in second gear. Technician A checks the condition of the input second gear. Technician B inspects the condition of the output second gear. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. An automatic transaxle slips when placed in gear. Technician A checks for worn bands. Technician B checks the transaxle's fluid level. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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5. A customer wants to know what caused the car's CV joints to fail. Technician A says CV joints can fail after prolonged service. Technician B says CV joint failure can result from ruptured CV joint boots. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. A manual transaxle's lubricant level needs to be checked. Technician A looks for the transaxle's dipstick or fill hole. Technician B says all manual transaxles use a dipstick for checking lubricant level. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. A customer wants the car's manual transaxle lubricant level checked. Technician A tells the customer that the lubricant levels of certain manual transaxles should be checked with the lubricant at room temperature. Technician B tells the customer that the lubricant levels of all manual transaxles should be checked with the lubricant at operating temperature. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. A manual transaxle's lubricant level is low. Technician A says that all manual transaxles use manual transmission gear oil. Technician B checks the manual to see if this transaxle uses automatic transmission fluid or manual transmission gear oil for lubrication. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. A tripod type CV joint must be replaced. Before installing the new CV joint, Technician A inspects the axle shaft splines. Before installing the new CV joint, Technician B checks the condition of the axle shaft snap ring groove. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. The transaxle on a front-wheel-drive car must be removed for major repairs. Technician A says that on most front-wheel-drive cars, the transaxle can be disconnected from the engine and removed from the bottom of the engine compartment. Technician B says that on any front-wheel-drive car, the transaxle and engine must be removed together through the top of the engine compartment. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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Automatic Transmission and Transaxle Diagnosis		
Condition	**Possible Causes**	**Correction**
Delayed engagement from neutral to drive.	1. Hydraulic pressure too low. 2. Valve body malfunction. 3. Low fluid level. 4. Incorrect gearshift linkage adjustment. 5. Oil filter clogged. 6. Faulty oil pump. 7. Worn input shaft seal rings. 8. Aerated fluid. 9. Engine idle speed too low. 10. Worn or faulty rear clutch.	1. Check fluid pressure at ports and repair as necessary. 2. Inspect valve body and repair. 3. Fill transaxle to proper level. 4. Adjust gearshift linkage. 5. Replace oil filter. 6. Replace oil pump. 7. Replace input shaft seal rings. 8. Replace transaxle fluid. 9. Check engine. Adjust as necessary. 10. Replace discs and seals at rear clutch.
Delayed engagement from neutral to reverse.	1. Low/reverse band misadjusted. 2. Hydraulic pressures too low. 3. Low reverse band worn out. 4. Valve body malfunction. 5. Low/reverse band, servo or linkage malfunction. 6. Low fluid level. 7. Incorrect gearshift linkage adjustment. 8. Oil filter clogged. 9. Faulty oil pump. 10. Worn input shaft seal rings. 11. Aerated fluid. 12. Engine idle speed too low. 13. Worn reaction shaft support seal rings. 14. Worn or faulty front clutch.	1. Adjust bands to specifications. 2. Check fluid pressure at ports and repair as necessary. 3. Replace low/reverse band. 4. Inspect valve body and repair. 5. Repair low/reverse servo. Adjust reverse band and linkage. 6. Fill transmission to level. 7. Adjust gearshift linkage. 8. Replace oil filter. 9. Replace oil pump. 10. Replace input shaft seal rings. 11. Replace transmission fluid. 12. Set up engine to specifications. 13. Inspect and replace reaction shaft support seal rings. 14. Replace discs and seals at front clutch.
Harsh engagement from neutral to drive.	1. Engine idle speed too high. 2. Valve body malfunction. 3. Hydraulic pressure too high. 4. Worn or faulty rear clutch. 5. Rear clutch spring load high. 6. Engine performance.	1. Check engine curb idle speed. Correct as necessary. 2. Inspect valve body and repair. 3. Check fluid pressure at ports and repair as necessary. 4. Replace discs and seals at rear clutch. 5. Replace rear clutch spring. 6. Check engine. Adjust as necessary.
Harsh engagement from neutral to reverse.	1. Low/reverse band misadjusted. 2. Engine idle speed too high. 3. Low/reverse band worn out. 4. Low/reverse band, servo or linkage malfunction. 5. Hydraulic pressure too high. 6. Worn or faulty rear clutch. 7. Engine performance.	1. Adjust band to specifications. 2. Set up engine to specifications. 3. Replace low/reverse band. 4. Repair low/reverse servo. Adjust band and linkage. 5. Check fluid pressure at ports and repair as necessary. 6. Replace discs and seals at rear clutch. 7. Check engine. Adjust as necessary.

(Continued)

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Automatic Transmission and Transaxle Diagnosis		
Condition	**Possible Causes**	**Correction**
Runaway upshift.	1. Hydraulic pressures too low. 2. Valve body malfunction. 3. Low fluid level. 4. Oil filter clogged. 5. Aerated fluid. 6. Incorrect throttle linkage. 7. Worn reaction shaft support seal rings. 8. Governor malfunction. 9. Kickdown band, servo or linkage malfunction. 10. Worn front clutch.	1. Check fluid pressure at ports and repair as necessary. 2. Inspect valve body and repair. 3. Fill transmission to level. 4. Replace oil filter. 5. Replace transmission fluid. 6. Adjust throttle linkage. 7. Replace reaction shaft support seal rings. 8. Inspect and repair governor. 9. Inspect and repair kickdown band, servo, or linkage. 10. Replace discs and seals at front clutch.
No upshift.	1. Hydraulic pressure too low. 2. Valve body malfunction. 3. Low fluid level. 4. Incorrect gearshift linkage adjustment. 5. Incorrect throttle linkage adjustment. 6. Governor support seal rings worn. 7. Worn reaction shaft support seal rings. 8. Governor malfunction. 9. Kickdown band, servo or linkage malfunction. 10. Worn front clutch. 11. Engine performance.	1. Check fluid pressure at ports and repair as necessary. 2. Inspect valve body and repair. 3. Fill transmission to proper level. 4. Adjust gearshift linkage. 5. Adjust throttle linkage. 6. Replace governor support seal rings. 7. Replace reaction shaft support seal rings. 8. Inspect and repair governor. 9. Inspect and repair kickdown band, servo, or linkage. 10. Replace discs and seals at front clutch. 11. Set up engine to specifications.
Kickdown runaway.	1. Hydraulic pressure too low. 2. Valve body malfunction. 3. Low fluid level. 4. Aerated fluid. 5. Incorrect throttle linkage adjustment. 6. Kickdown band out of adjustment. 7. Governor support seal rings worn. 8. Kickdown band, servo or linkage malfunction. 9. Worn front clutch.	1. Check fluid pressure at ports and repair as necessary. 2. Inspect valve body and repair. 3. Fill transmission to proper level. 4. Replace transmission fluid. 5. Adjust throttle linkage. 6. Adjust kickdown band. 7. Replace governor support seal rings. 8. Inspect and repair kickdown band, servo or linkage. 9. Replace discs and seals at front clutch.
No kickdown or normal downshift.	1. Valve body malfunction. 2. Incorrect throttle linkage adjustment. 3. Governor malfunction. 4. Kickdown band, servo or linkage malfunction.	1. Inspect valve body and repair. 2. Adjust throttle linkage. 3. Inspect and repair governor. 4. Inspect and repair kickdown band, servo, or linkage.

(Continued)

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Automatic Transmission and Transaxle Diagnosis

Condition	Possible Causes	Correction
Erratic shifts.	1. Hydraulic pressure too low. 2. Valve body malfunction. 3. Low fluid level. 4. Incorrect gearshift linkage adjustment. 5. Oil filter clogged. 6. Faulty oil pump. 7. Aerated fluid. 8. Incorrect throttle linkage adjustment. 9. Governor support seal rings worn. 10. Worn reaction shaft support seal rings. 11. Governor malfunction. 12. Kickdown band, servo or linkage malfunction. 13. Worn front clutch. 14. Engine performance.	1. Check fluid pressure at ports and repair as necessary. 2. Inspect valve body and repair. 3. Fill transmission to level. 4. Adjust gearshift linkage. 5. Replace oil filter. 6. Replace oil pump. 7. Replace transmission fluid. 8. Adjust throttle linkage. 9. Replace governor support seal rings. 10. Replace reaction shaft support seal rings. 11. Inspect and repair governor. 12. Inspect and repair kickdown band, servo, or linkage. 13. Replace discs and seals at front clutch. 14. Set up engine to specifications.
Slips in forward drive positions.	1. Hydraulic pressure too low. 2. Valve body malfunction. 3. Low fluid level. 4. Incorrect gearshift linkage adjustment. 5. Oil filter clogged. 6. Faulty oil pump. 7. Worn input shaft seal rings. 8. Aerated fluid. 9. Incorrect throttle linkage adjustment. 10. Overrunning clutch not holding. 11. Worn rear clutch. 12. Overrunning clutch worn, broken, or seized.	1. Check fluid pressure at ports and repair as necessary. 2. Inspect valve body and repair. 3. Fill transmission to proper level. 4. Adjust gearshift linkage. 5. Replace oil filter. 6. Replace oil pump. 7. Replace input shaft seal rings. 8. Replace transmission fluid. 9. Adjust throttle linkage. 10. Inspect and repair overrunning clutch. 11. Replace discs and seals at rear clutch. 12. Replace overrunning clutch assembly.
Slips in reverse only.	1. Low/reverse band misadjusted. 2. Hydraulic pressure too low. 3. Low/reverse band worn out. 4. Valve body malfunction. 5. Low/reverse band, servo or linkage malfunction. 6. Low fluid level. 7. Incorrect gearshift linkage adjustment. 8. Faulty oil pump. 9. Aerated fluid. 10. Worn reaction shaft support seal rings. 11. Worn front clutch.	1. Adjust low/reverse band. 2. Check fluid pressure at ports and repair as necessary. 3. Replace low/reverse band. 4. Inspect valve body and repair. 5. Repair low/reverse servo. Adjust reverse band and linkage. 6. Fill transmission to level. 7. Adjust gearshift linkage. 8. Replace oil pump. 9. Replace transmission fluid. 10. Replace reaction shaft support seal rings. 11. Replace discs and seals at front clutch.

(Continued)

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Automatic Transmission and Transaxle Diagnosis		
Condition	**Possible Causes**	**Correction**
Slips in all positions.	1. Hydraulic pressure too low. 2. Valve body malfunction. 3. Low fluid level. 4. Oil filter clogged. 5. Faulty oil pump. 6. Worn input shaft seal rings. 7. Aerated fluid.	1. Check fluid pressure at ports and repair as necessary. 2. Inspect valve body and repair. 3. Fill transmission to level. 4. Replace oil filter. 5. Replace oil pump. 6. Replace input shaft seal rings. 7. Replace transmission fluid.
No drive in any position.	1. Hydraulic pressure too low. 2. Valve body malfunction. 3. Low fluid level. 4. Oil filter clogged. 5. Faulty oil pump. 6. Planetary gearsets broken or seized.	1. Check fluid pressure at ports and repair as necessary. 2. Inspect valve body and repair. 3. Fill transmission to level. 4. Replace oil filter. 5. Replace oil pump. 6. Replace planetary gearsets.
No drive in forward drive positions.	1. Hydraulic pressure too low. 2. Valve body malfunction. 3. Low fluid level. 4. Worn input shaft seal rings. 5. Overrunning clutch not holding. 6. Worn rear clutch. 7. Planetary gearsets broken or seized. 8. Overrunning clutch worn, broken, or seized.	1. Check fluid pressure at ports and repair as necessary. 2. Inspect valve body and repair. 3. Fill transmission to level. 4. Replace input shaft seal rings. 5. Inspect and repair overrunning clutch. 6. Replace discs and seals at rear clutch. 7. Replace planetary gearsets. 8. Replace overrunning clutch assembly.
No drive in reverse.	1. Hydraulic pressure too low. 2. Low/reverse band worn out. 3. Valve body malfunction. 4. Low/reverse band, servo or linkage malfunction. 5. Incorrect gearshift linkage adjustment. 6. Worn reaction shaft support seal rings. 7. Worn front clutch. 8. Worn rear clutch. 9. Planetary gearsets broken or seized.	1. Check fluid pressure at ports and repair as necessary. 2. Replace low/reverse band. 3. Inspect valve body and repair. 4. Repair low/reverse servo. Adjust reverse band and linkage. 5. Adjust gearshift linkage. 6. Replace reaction shaft support seal rings. 7. Replace discs and seals at front clutch. 8. Replace discs and seals at rear clutch. 9. Replace planetary gearsets.
Drives in neutral.	1. Valve body malfunction. 2. Incorrect gearshift linkage adjustment. 3. Insufficient clutch plate clearance. 4. Worn rear clutch. 5. Rear clutch dragging.	1. Inspect valve body and repair. 2. Adjust gearshift linkage. 3. Check and adjust clutch plate clearance. 4. Replace discs and seals at rear clutch. 5. Inspect and repair rear clutch.
Drags or locks.	1. Low/reverse band worn out. 2. Kickdown band adjustment too tight. 3. Planetary gearsets broken or seized. 4. Overrunning clutch worn, broken or seized.	1. Replace low/reverse band. 2. Adjust kickdown band. 3. Replace planetary gearsets. 4. Replace overrunning clutch assembly.

(Continued)

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Automatic Transmission and Transaxle Diagnosis

Condition	Possible Causes	Correction
Grating, scraping, or growling noise.	1. Low/reverse band worn out. 2. Kickdown band out of adjustment. 3. Replace drive shaft bushing. 4. Planetary gearsets broken or seized. 5. Overrunning clutch worn, broken, or seized.	1. Replace low/reverse band. 2. Adjust kickdown band. 3. Drive shaft bushing damaged. 4. Replace planetary gearsets. 5. Replace overrunning clutch assembly.
Buzzing noise.	1. Valve body malfunction. 2. Low fluid level. 3. Aerated fluid. 4. Overrunning clutch inner race damaged.	1. Inspect valve body and repair. 2. Fill fluid to level. 3. Replace transmission fluid. 4. Replace overrunning clutch assembly.
Hard to fill, oil blows out filler hole.	1. Oil filter clogged. 2. Aerated fluid. 3. High fluid level.	1. Replace oil filter. 2. Replace transmission fluid. 3. Adjust fluid level to specifications.
Transaxle overheats.	1. Stuck cooler flow switch valve. 2. Engine idle speed too high. 3. Hydraulic pressures too low. 4. Low fluid level. 5. Incorrect gearshift linkage adjustment. 6. Faulty oil pump. 7. Kickdown band adjustment too tight. 8. Faulty cooling system. 9. Insufficient clutch plate clearance.	1. Replace switch valve behind oil pump housing. 2. Adjust engine idle to specifications. 3. Check fluid pressure at ports and repair as necessary. 4. Fill transmission to level. 5. Adjust gearshift linkage. 6. Replace oil pump. 7. Adjust kickdown band. 8. Check cooling system temperature and repair as needed. 9. Check and adjust clutch plate clearance.
Harsh upshift.	1. Hydraulic pressures too low. 2. Incorrect throttle linkage adjustment. 3. Kickdown band out of adjustment. 4. Hydraulic pressure too high. 5. Engine performance.	1. Check fluid pressure at ports and repair as necessary. 2. Adjust throttle linkage. 3. Adjust kickdown band. 4. Check fluid pressure at ports. 5. Set up engine to specifications.
Delayed upshift.	1. Incorrect throttle linkage adjustment. 2. Kickdown band out of adjustment. 3. Governor support seal rings worn. 4. Worn reaction shaft support seal rings. 5. Governor malfunction. 6. Kickdown band, servo or linkage malfunction. 7. Worn front clutch. 8. Engine performance.	1. Adjust throttle linkage. 2. Adjust kickdown band. 3. Replace governor support seal rings. 4. Replace reaction shaft support seal rings. 5. Inspect and repair governor. 6. Inspect and repair kickdown band, servo, or linkage. 7. Replace discs and seals at front clutch. 8. Set up engine to specifications.
No torque converter clutch application.	1. Stuck cooler flow switch valve. 2. Hydraulic pressures too low. 3. Low fluid level. 4. Faulty oil pump. 5. Worn input shaft seal rings. 6. Aerated fluid.	1. Replace switch valve behind oil pump housing. 2. Check fluid pressure at ports and repair as necessary. 3. Fill transmission to level. 4. Replace oil pump. 5. Replace input shaft seal rings. 6. Replace transmission fluid.

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Section 12

Suspension and Steering Technology

Chapter 73
Tire, Wheel, and Wheel Bearing Fundamentals

Chapter 74
Tire, Wheel, and Wheel Bearing Diagnosis and Repair

Chapter 75
Suspension System Technology

Chapter 76
Suspension System Diagnosis and Repair

Chapter 77
Steering System Technology

Chapter 78
Steering System Diagnosis and Repair

Chapter 79
Wheel Alignment

The suspension and steering systems literally "take a pounding" during the life of a motor vehicle. The suspension will travel over thousands of bumps and holes in the road surface. The steering system is also subjected to this pounding and constant motion while responding to driver control.

Section 12 details the operation, construction, service, and repair of everything from tires to four-wheel alignment. It contains information that will make you a better chassis technician. This section will also help you pass ASE certification test A4, *Suspension and Steering*.





Chapter 73
Tire, Wheel, and Wheel Bearing Fundamentals

After studying this chapter, you will be able to:

- Identify the parts of a tire and wheel assembly.
- Describe different methods of tire construction.
- Explain types and sizes of tires.
- Describe tire ratings and designations.
- Describe different types of wheels.
- Define valve stems, valve cores, lug nuts, lug studs, and lug bolts.
- Identify the parts of driving and nondriving hub and wheel bearing assemblies.
- Correctly answer ASE certification test questions requiring a knowledge of tires, wheels, hubs, and wheel bearings.

This chapter introduces the various tire, wheel, and hub designs used on modern passenger vehicles and light trucks. It explains how tires and wheels are constructed to give safe and dependable service. The chapter also covers hub and wheel bearing construction for both rear- and front-wheel-drive vehicles. As a result, you will be better prepared to study later chapters on brakes, suspension systems, and wheel alignment.

Tires

Automobile ***tires*** perform two basic functions: they act as a soft *cushion* between the road and the metal wheel, and they provide adequate *traction* (friction) with the road surface.

Tires must transmit driving, braking, and cornering forces to the road in both good and bad weather. At the same time, they should resist punctures and wear.

The tires used on early vehicles were solid natural rubber. Today's automotive tires are ***pneumatic***, which means they are filled with air. Internal air pressure pushes out on the inside of the tire to support the weight of the vehicle. Refer to **Figure 73-1**.

Today's vehicles use ***tubeless tires***, which do *not* have a separate inner tube. The tire and wheel form an airtight unit. Older vehicles used ***inner tubes*** (soft, thin, leakproof rubber liners) that fit inside the tire and wheel assemblies.

Parts of a Tire

Although there are several tire designs, all tires have the same basic parts, **Figure 73-2**:

- ***Beads***—The beads are two rings made of steel wire that are encased in rubber. They hold the tire sidewalls snugly against the wheel rim.

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Mini Cooper

Figure 73-1. The basic parts of tire and wheel assembly.



Goodyear

Figure 73-2. The basic parts of a tire.

- ***Body plies***—Body plies are rubberized fabric and cords wrapped around the beads. They form the carcass, or body, of the tire.
- ***Tread***—Tread is the outer surface of the tire that contacts the road.
- ***Sidewall***—The sidewall is the outer part of the tire that extends from the bead to the tread. Markings on the sidewall provide information about the tire.
- ***Belts***—Belts may be used to strengthen the body plies and stiffen the tread. They lie between the tread and plies.
- ***Liner***—The liner is a thin layer of rubber that is bonded to the inside of the plies. It provides a leakproof membrane for the modern tubeless tire.

Tire Construction

There are many construction and design variations in tires: different number of plies may be used, the plies may run at different angles, and different materials may be used.

Tire ***rolling resistance*** is a measurement of the amount of friction produced as the tire operates on the road surface. A high rolling resistance increases fuel consumption and wear. Typically, rolling resistance is reduced by higher inflation pressure, proper tire design, and lower vehicle weight.

Three types of tires found in use today are the bias ply tire, belted bias tire, and radial tire. All American passenger cars manufactured since the early 1980s have been factory equipped with radial tires. Bias ply and belted bias tires can still be found on off-road vehicles and on antique cars.

Bias Ply Tire

In a ***bias ply tire***, the plies run at an angle from bead to bead. The angle is reversed from ply to ply. The tread is bonded directly to the top ply. See **Figure 73-3A**.

A bias ply tire is one of the oldest designs, and it does *not* use belts. The position of the plies in a bias ply tire allows the body of the tire to flex easily. This tends to improve cushioning action. A bias ply tire provides a very smooth ride on rough roads.

One disadvantage of the bias ply tire is the weakness of the plies and tread, which reduces traction at high speeds and increases rolling resistance.

Belted Bias Tire

A ***belted bias tire*** is a bias ply tire with belts added to increase tread stiffness. The plies and belts normally run at different angles. The belts do *not* run around to the sidewalls—they lie under the tread area only. Usually, two stabilizer belts and two or more plies are used to improve tire performance. Look at **Figure 73-3B**.

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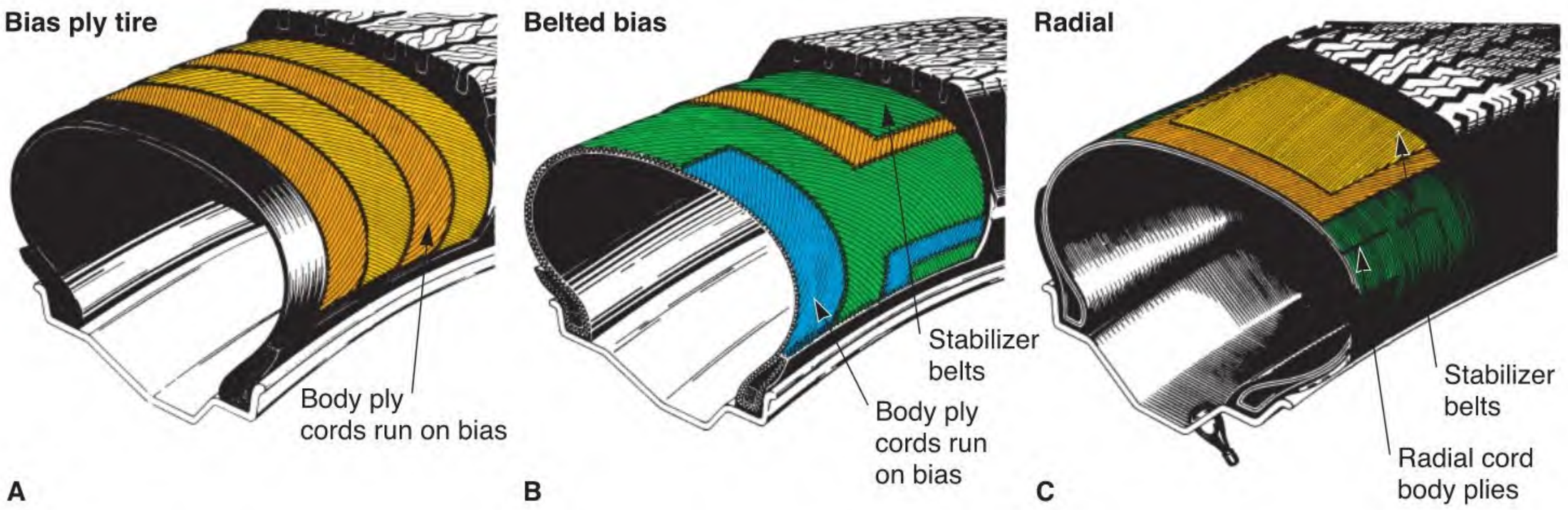


Figure 73-3. There are three basic tire types. A—Bias ply tire. B—Belted bias tire. C—Radial ply tire.

A belted bias tire provides a smooth ride and good traction. It also offers some reduction in rolling resistance over a bias ply tire.

Radial Ply Tire

A ***radial ply tire*** has plies running straight across from bead to bead, with stabilizer belts directly beneath the tread. The belts can be made of steel, flexten, fiberglass, or other materials. A typical radial tire is illustrated in **Figure 73-3C**.

A radial tire has a very flexible sidewall *and* a stiff tread, giving it a very stable ***footprint*** (shape and amount of tread touching road surface). This improves safety, cornering, braking, and wear.

One possible disadvantage of a radial tire is that it may produce a harder, or harsher, ride at low speeds. The stiff tread area does *not* give or flex as much on rough roads.

Tire Markings

Tire markings on the sidewall of a tire give information about tire size, tire model, load-carrying ability, inflation pressure, number of plies, speed rating, manufacturer, etc. It is important that you understand these tire markings. Refer to **Figure 73-4**.

Tire Size

Tire size is given on the sidewall as a letter-number sequence. There are two common size designations: alpha-numeric (conventional measuring system) and P-metric (metric measuring system).

The ***P-metric*** size designation is the newest tire identification system. It uses metric values and international standards. Look at **Figure 73-5A**. The letter "P" indicates that the tire is designed for use on a passenger car. The first number, 155, gives section width in millimeters. The second number, 80, is the aspect ratio (height-to-width ratio). The R indicates radial (B means belted bias and D means bias ply). The last number, 13, shows the rim diameter in inches (not metric values).

The ***alpha-numeric*** (alphabetical-numerical) tire size designation uses letters and numbers to denote tire size in inches and its load-carrying capacity in pounds. An example is given in **Figure 73-5B**. The first letter, G, indicates the load and size relationship. The higher the letter, the larger the size and load-carrying ability of the tire. G is smaller than H, for example. The second letter, R, means that the tire is a radial. Bias and belted bias tires do not have a second letter. The first number, 78, is the aspect, or height-to-width, ratio. The last number, 15, is the rim diameter in inches.

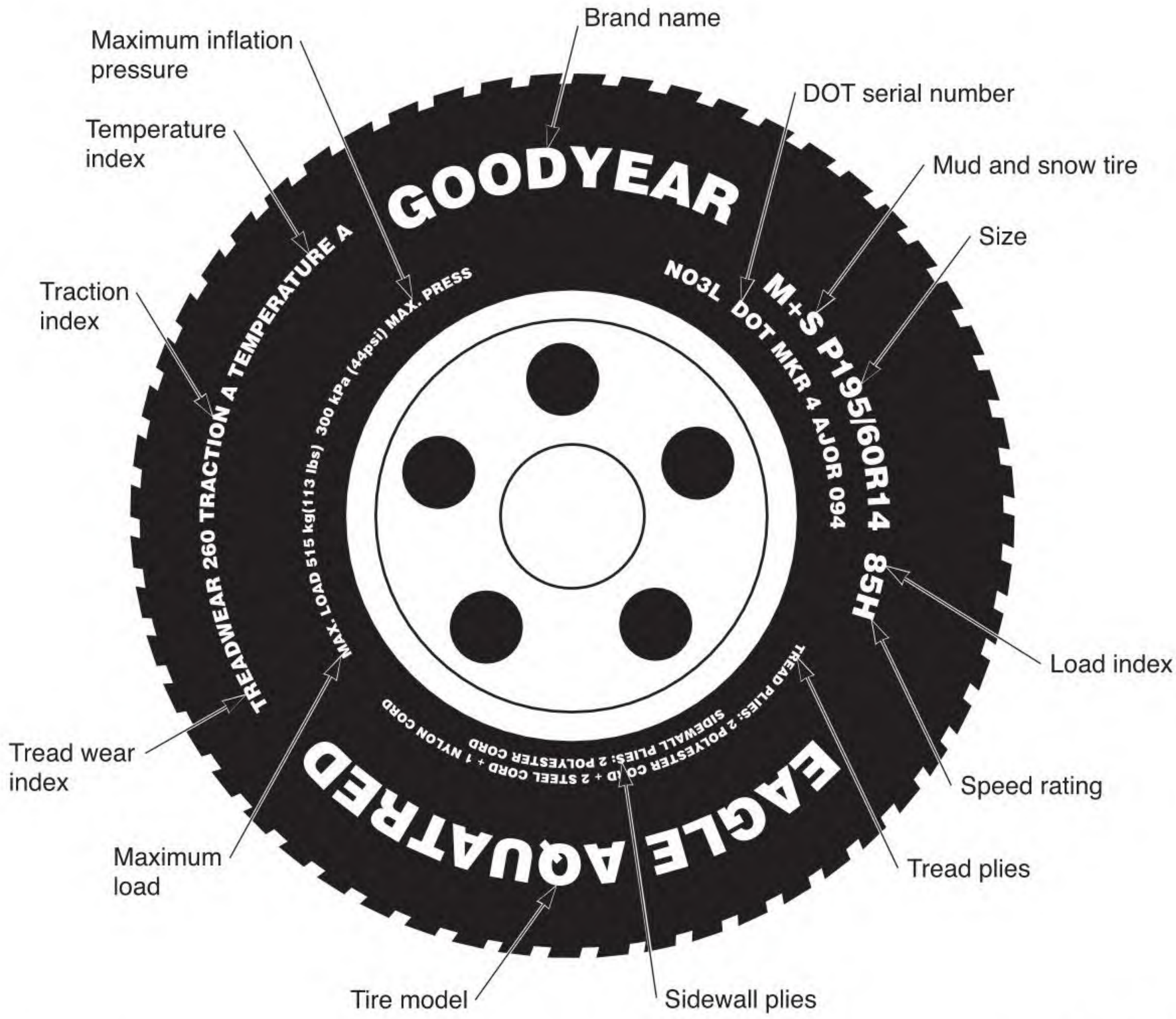
The points of measure for a tire are given in **Figure 73-6**.

Aspect Ratio

The ***aspect ratio***, or height-to-width ratio, in the tire size designation is the most difficult value to understand. See **Figure 73-7**. Note that, as the number becomes smaller, the tire becomes more ***squat*** (wider and shorter). The aspect ratio is the comparison of the tire's height (bead-to-tread distance) and width (sidewall-to-sidewall distance).

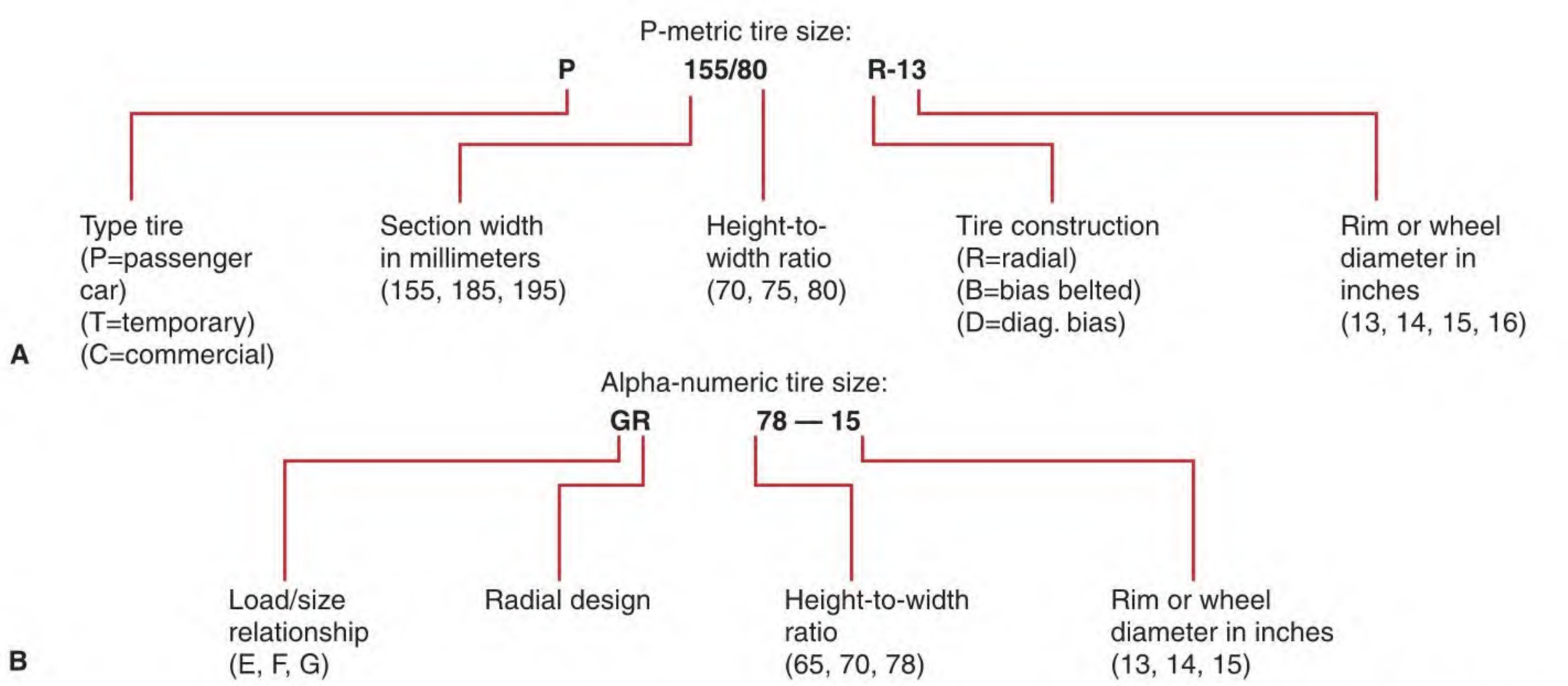
A 70-series tire, for example, has an aspect ratio of 70—the height of the tire is 70 percent of the width. A 60 series tire would be "short" and "fat." A 78 tire would be "narrow" and "tall."

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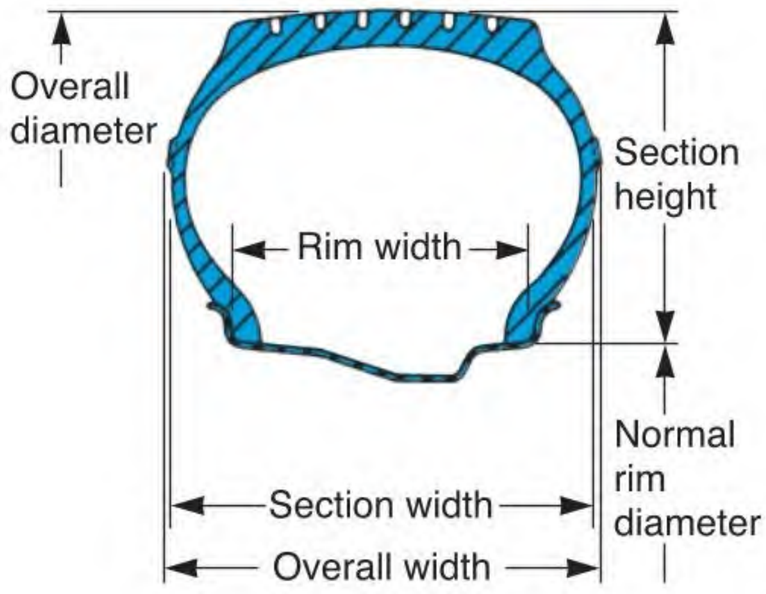
Figure 73-4. Sidewall markings contain information about a tire. Study the sidewall markings on this tire.



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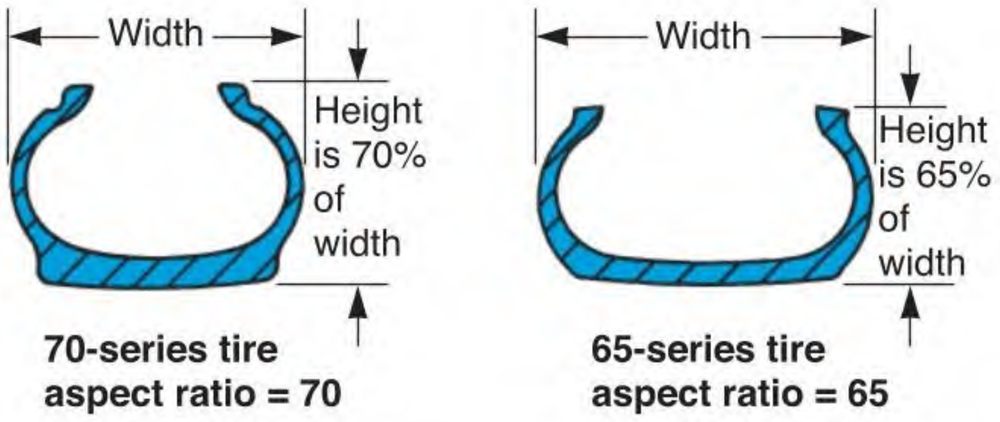
Figure 73-5. Note the two tire size designations. A—P-metric designation. B—Alpha-numeric designation.

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B.F. Goodrich

Figure 73-6. Points of measurement on a tire. These dimensions are important when ordering new tires or wheels.



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Figure 73-7. The aspect ratio is the height-to-width ratio of tire. Note that a 65 series tire is wider and shorter than a 70 series tire.

Maximum Load Rating

The ***maximum load rating*** of a tire indicates the amount of *weight* the tire can carry at the recommended inflation pressure. The maximum load value (1500 pounds, for example) is printed on the sidewall.

With P-metric tire designations, the load rating is simply given in kilograms and pounds. The alpha-numeric load rating is indicated by a letter. Most alpha-numeric size tires are load range B. They are restricted to the load specified at 32 psi (220 kPa). Where a greater load carrying ability is needed, load range C or D tires are used.

Maximum Inflation Pressure

The ***maximum inflation pressure*** is the highest air pressure that should be pumped into the tire. Many tires have a maximum recommended inflation pressure of 32 psi (220 kPa). However, tires with higher load ranges can hold higher pressures and carry more weight.

Tread Plies

The tire sidewall also includes information on the number of plies and ply rating. For example, the tire may be a 2-ply tire, a 2-ply with a 4-ply rating (plies made stronger than normal), or a 4-ply tire. A greater number of plies or a higher ply rating generally indicates a greater load-carrying ability.

Sidewall Plies

The number of sidewall plies is also shown on the tire sidewall.

DOT Serial Number

DOT stands for *Department Of Transportation*. When you see "DOT" on the tire sidewall, the tire has passed prescribed safety tests.

Following the letters DOT is the ***DOT serial number***, which identifies the particular tire manufacturer, plant location, construction, and date of manufacture. The DOT serial number is stamped into the tire sidewall.

Tire Grades

Tread wear, traction, and temperature grades are normally shown on the tire sidewall according to the Uniform Tire Quality Grading System.

Tread wear is given as a number. Tread wear ratings range from 100 to 500. The higher the number, the more resistant the tire is to wear.

Tire traction is given an A, B, or C rating. A tire with an "A" rating would provide the most traction, while a tire with a "C" rating would provide the least traction.

Tire temperature resistance is also given as an A, B, or C rating. A tire with an "A" rating resists a temperature buildup better than a tire with a "B" or "C" rating.

Speed Rating

A ***tire speed rating*** is the maximum allowable sustained road speed a tire can safely withstand without failure. Speed ratings range from B (31 mph or 50 km/h) to Z (149 mph or 238 km/h).

It is important that the speed rating of a tire be higher than the speed at which the vehicle will be driven. If too low a speed rating is used, the tire could fail and cause a fatal accident. This is extremely important if the vehicle is to be driven in areas where there is no speed limit (some states and foreign countries).

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Special Tires and Tire Features

You should be familiar with several types of special tires and tire features. The automotive technician will encounter compact spare tires, self-sealing tires, retreads, and run-flat tires.

Asymmetric Tires

Asymmetric tires have a different tread pattern on the inner edge than the outer edge. See **Figure 73-8**. The outer tread pattern is designed to improve cornering on dry surfaces. The inner tread pattern is designed to improve traction on wet surfaces. An asymmetric tire must be mounted so the proper edge faces the outside of the wheel. This type of tire is generally marked with the word *outside* to indicate which way it should be mounted on the wheel.

Directional Tires

Directional tires are high-performance tires designed to rotate in a specific direction to minimize hydroplaning. ***Hydroplaning*** is a loss of control that occurs when a layer of water prevents the tire tread from contacting the road surface. Directional tires have an arrow and the word *rotation* molded onto their sidewalls. Mount directional tires on their wheels so that the sidewall directional arrow faces the front of the vehicle when at the top. It must face the direction of the tire rotation when the vehicle is traveling forward.



Goodyear

Figure 73-8. Note the asymmetrical tire tread pattern.

Spare Tires

A ***spare tire***, or spare, is an extra wheel and tire assembly that can be installed if the vehicle has a flat tire. The spare can be a full-size tire or a compact tire.

A ***full-size spare*** is a tire of the same size and type used on the other four wheels of the vehicle. It can be mounted and used like any other tire. It is being replaced by compact, lighter spare tires.

Most new cars use a ***compact spare tire***, or ***space saver spare***, which is much smaller than the normal tire used on the vehicle. It saves space in the trunk or storage area.

A ***high-pressure spare*** is a compact spare tire that holds higher-than-normal air pressure (typically about 60 psi). It is inflated when in the trunk and is ready for use.

Some spare tires are *not* inflated when in storage. A small bottle of compressed air may be used to inflate the tire, when needed.

A ***lightweight spare tire*** has very thin sidewall and tread construction. Being light, it is more easily picked up and mounted on the vehicle. However, the driving range and maximum speed rating of a lightweight spare are generally lower than those for a compact spare.

Tech Tip

Most modern spare tires are designed for *temporary use only*. Refer to the manufacturer's specifications on inflation pressure, maximum driving speed, and the number of miles that can be driven. Most compact spares should not be used at speeds over 50 mph and will last only a few thousand miles.

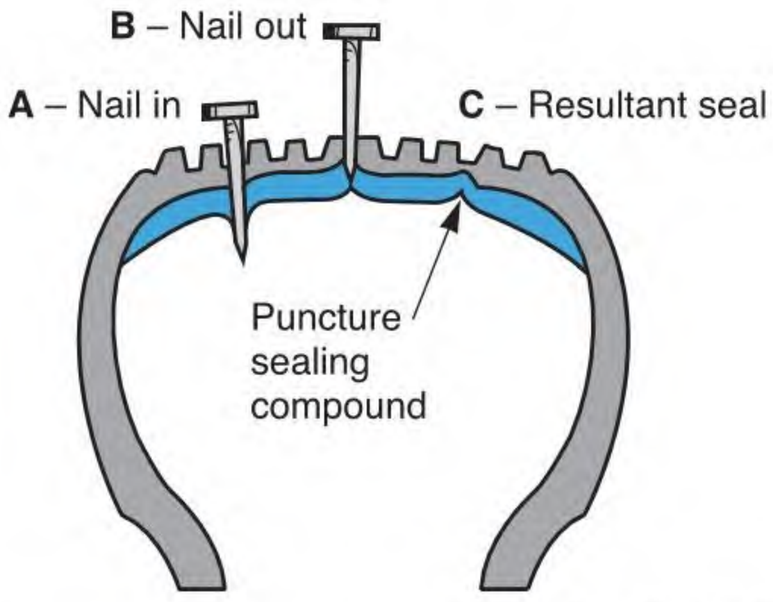
Self-Sealing Tires

Some tires are ***self-sealing*** (seal small punctures). These tires have a coating of sealing compound applied to their liners. If a nail punctures a self-sealing tire, air pressure will push the soft compound into the hole to stop air leakage. Refer to **Figure 73-9**.

Retreads

Retreads are used tires that have had a new tread vulcanized (applied using heat and pressure) to the old carcass, or body. Retreads, also called recaps, are seldom used on passenger cars. However, large truck tires are frequently recapped because of the high cost of new truck tires.

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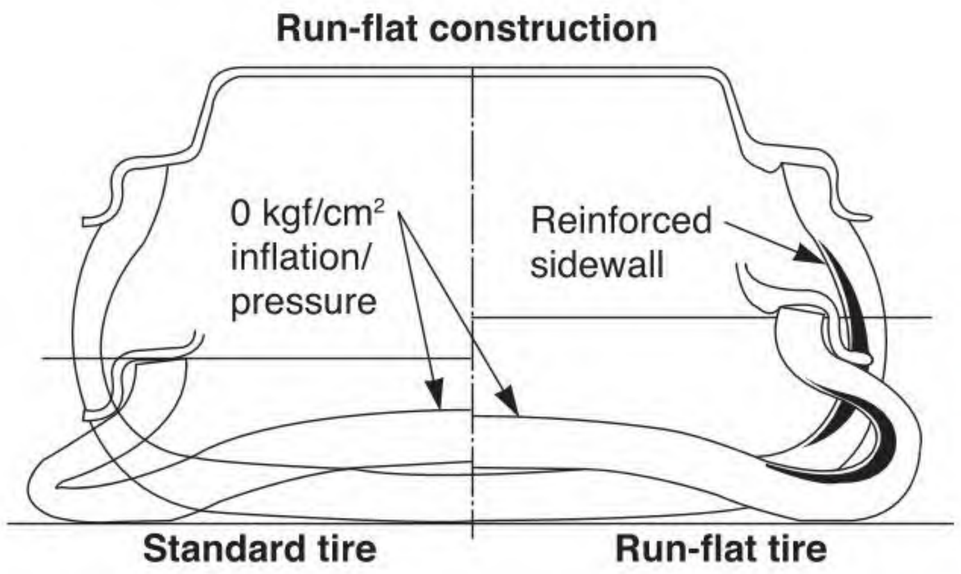
Figure 73-9. Self-sealing tire action. A—Nail punctures the tire. B—Nail is pulled out. C—Sealing compound flows into the hole to prevent air from leaking out.

Run-Flat Tires

Run-flat tires have an extremely stiff sidewall construction so that they are still usable with a loss of air pressure. If the tire leaks, you can drive the vehicle to a repair shop without tire and wheel damage. The tire will retain most of its shape because the sidewall is strong enough to support vehicle weight. See **Figure 73-10**. The tire uses a special rubber compound and a thick rubber sidewall support insert that helps support the weight of the vehicle.

Wear Bars

Wear bars are used to indicate a critical amount of tread wear. When too much tread has worn from the tires, solid rubber bars will show up across the tread. This tells the customer and the technician that tire replacement is needed. Look at **Figure 73-11**.



Bridgestone

Figure 73-10. Compare the construction of a run-flat tire to that of a conventional tire.



Goodyear

Figure 73-11. When the tread has worn even with the wear bar, the tire is worn enough to be unsafe and should be replaced.

Tire Pressure Monitoring Systems

Many late-model vehicles are equipped with ***tire pressure monitoring systems***, which alert the driver if one or more of the vehicle's tires is underinflated. There are two types of tire inflation systems used in late-model vehicles: direct systems and indirect systems.

Direct tire pressure monitoring systems use a pressure sensor/transmitter mounted at each wheel. In some cases, these sensors are attached to the tire valves. In other designs, the sensors are held to the wheel with a metal or plastic strap. See **Figure 73-12**.

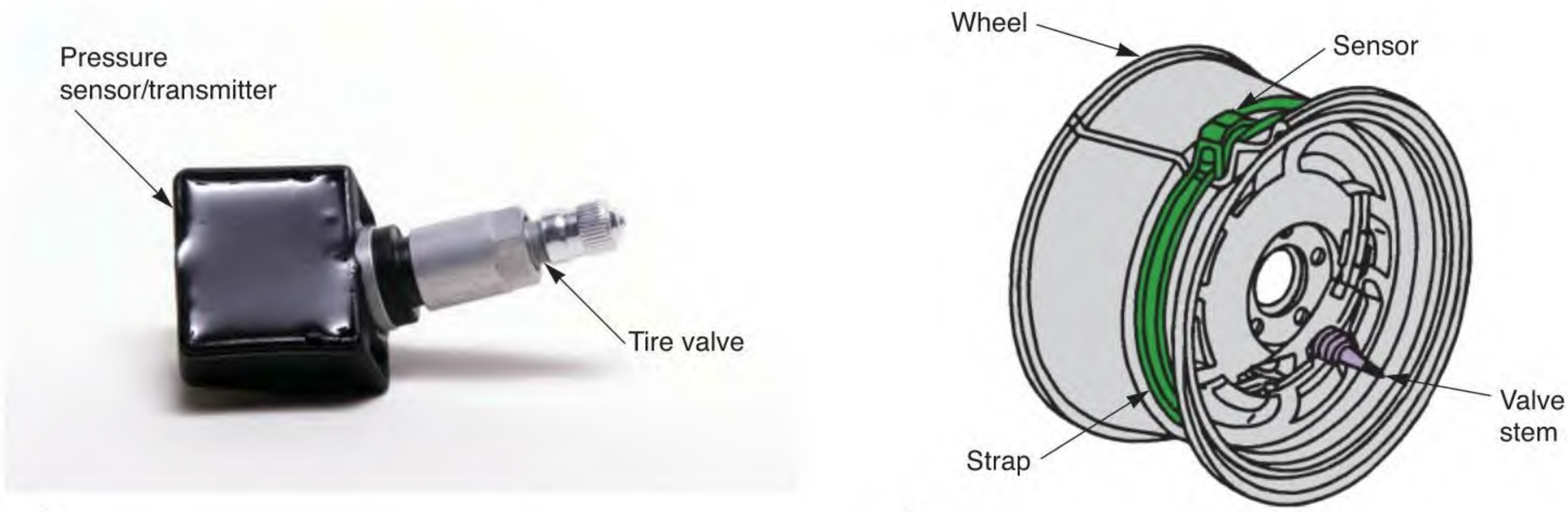
If the tire pressure drops below a predetermined value, the sensor on the corresponding wheel will send a signal to a small receiver mounted in the passenger compartment. The receiver then turns on a dash warning light to inform the driver of the inflation problem. See **Figure 73-13**.

In an indirect tire pressure monitoring system, the anti-lock brake system components are used to monitor tire pressure. When pressure in a tire drops, the tire's circumference is reduced. This causes the wheel and tire assembly to spin faster than the other tires. The computer interprets the speed sensor signal from the affected wheel as a drop in tire pressure and triggers a warning light.

Tech Tip

All vehicles with a gross vehicle weight rating of less than 10,000 lbs. sold on or after September 1, 2007, are equipped with a tire pressure monitoring system.

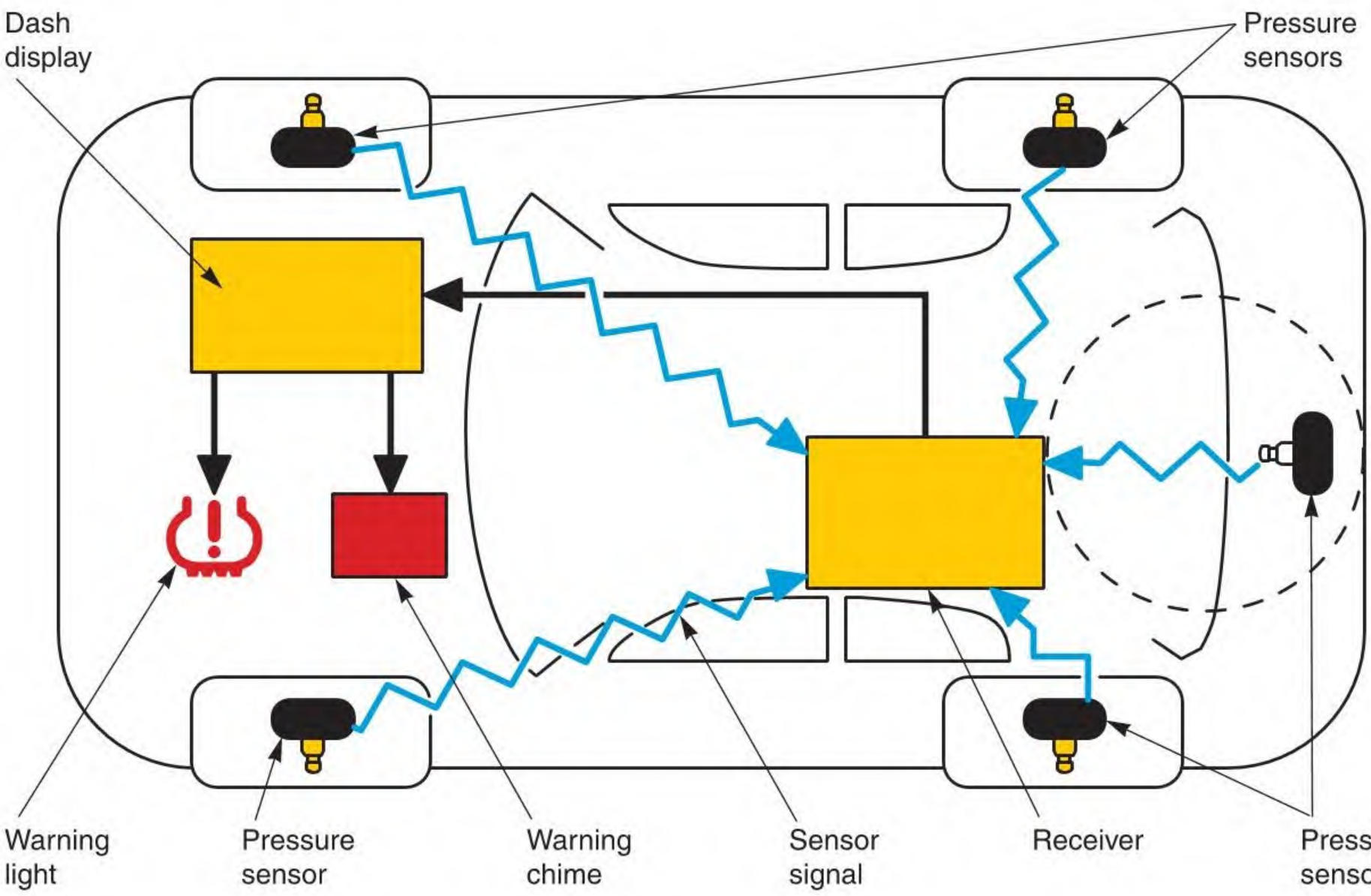
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A **B**

Ford

Figure 73-12. Some tire pressure monitoring systems use a pressure sensor/transmitter mounted at each wheel. A—Valve-mounted sensor. B—This sensor is strapped to the inside of the wheel.



Toyota

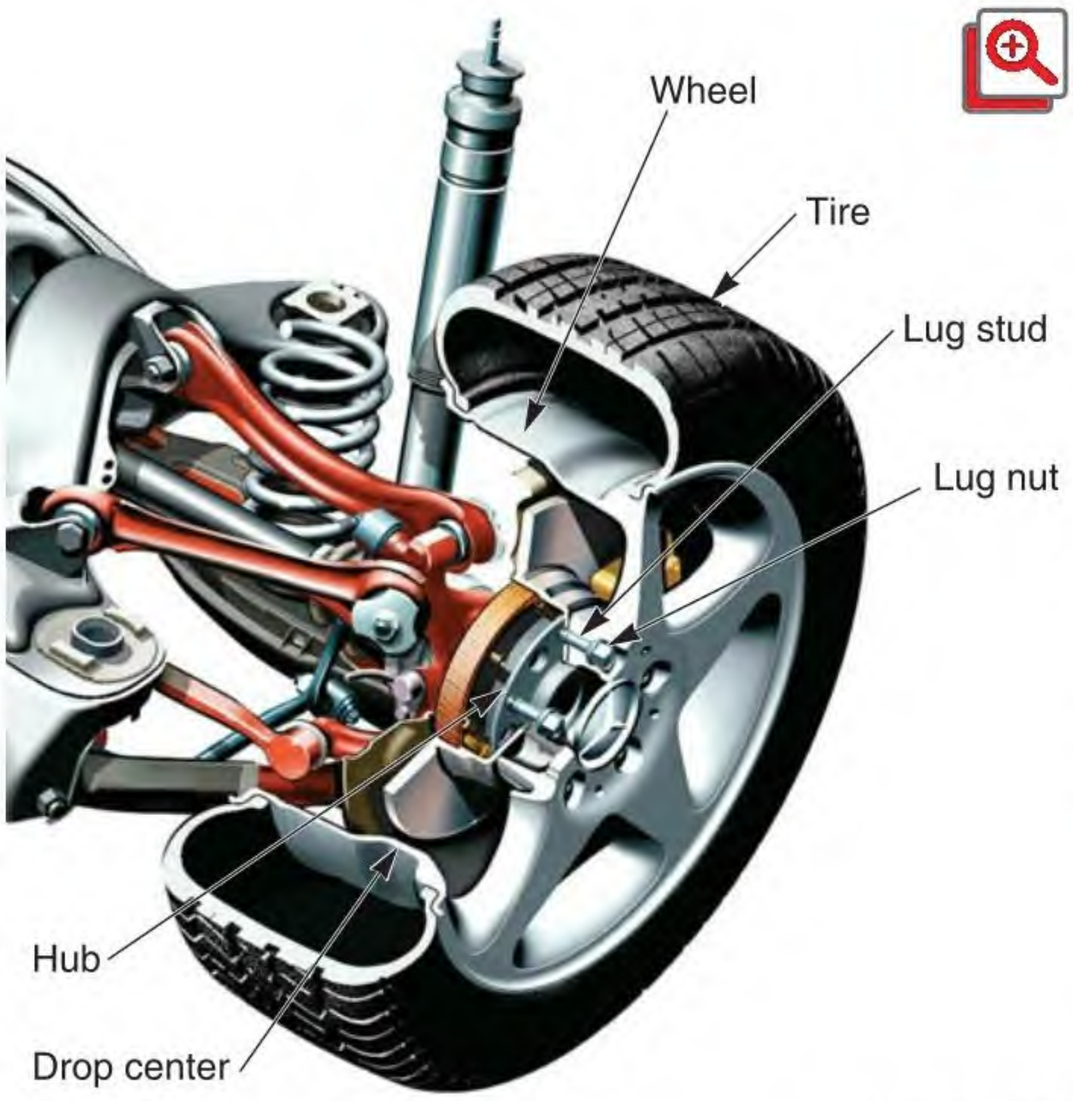
Figure 73-13. If one of the pressure sensor/transmitters detects low tire pressure, it will produce a radio signal. A receiver in the passenger compartment detects the signal and triggers a warning light in the dash.

Wheels

Wheels are designed to support the tire while withstanding loads from acceleration, braking, and cornering. Refer to **Figure 73-14**. Most wheels are made of steel. A few optional types are cast aluminum or magnesium. ***Mag wheels***, or ***mags***, is a nickname for aluminum or magnesium wheels. These wheels do not need wheel covers.

A ***drop-center wheel*** is commonly used on passenger vehicles because it allows for easier installation and removal of the tire. Since the center of the

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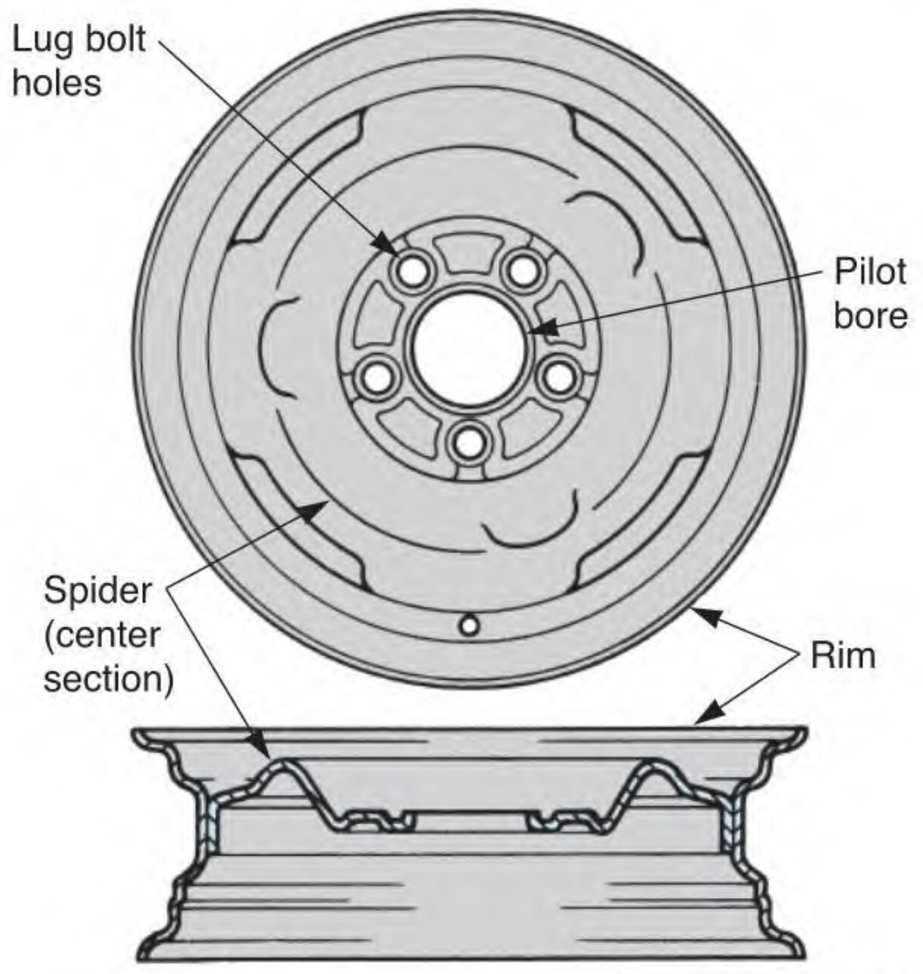
Mercedes Benz

Figure 73-14. This cutaway shows many of the components relating to a wheel and tire.

wheel is smaller in diameter (dropped) than the rim, the tire bead can fall into the recess. Then, the other side of the tire bead can be forced over the rim for removal. See **Figure 73-15**.

A standard wheel consists of the ***rim*** (outer lip that contacts tire bead) and the ***spider*** (center section that bolts to vehicle hub). Normally, the spider is welded to the rim.

The various dimensions of a wheel are illustrated in **Figure 73-16**.



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Figure 73-15. Study the parts of a conventional drop-center wheel.

Safety Rims

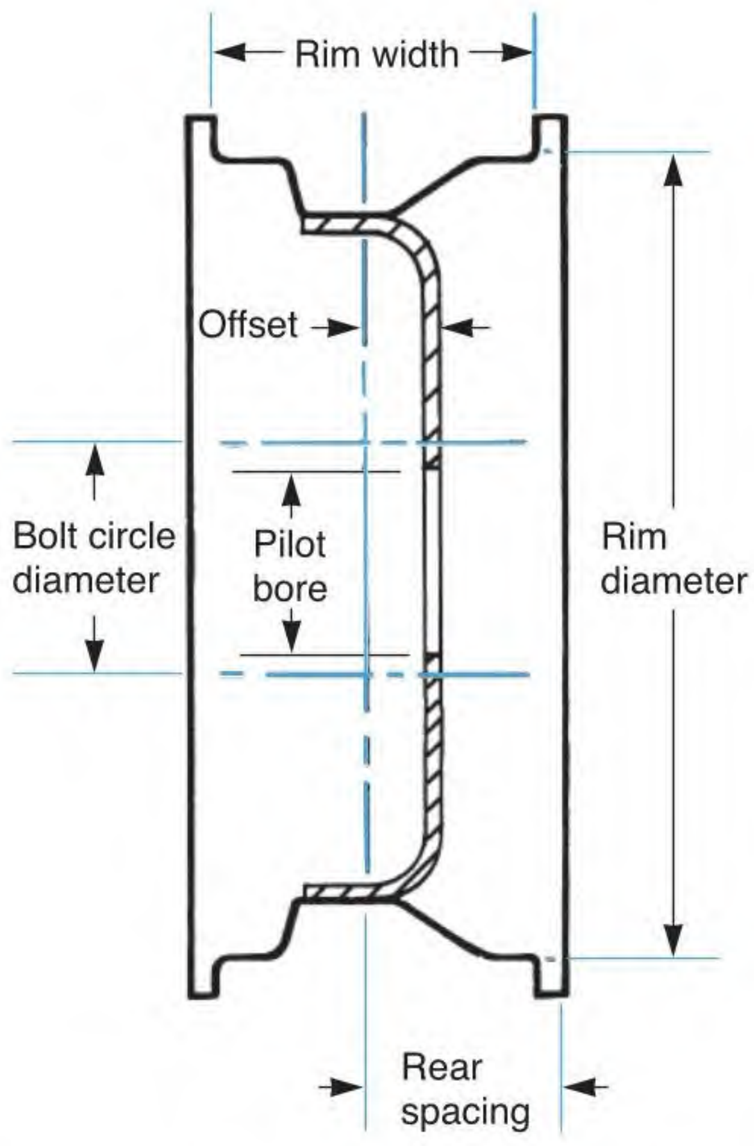
A ***safety rim*** has small ridges that hold the tire beads on the wheel during a tire ***blowout*** (instant rupture and air loss) or a ***flat*** (slow leak reduces inflation pressure).

Small raised lips around the rim keep the tire beads from sliding into the drop-center section. This improves safety by keeping the tire from coming off the wheel. See **Figure 73-17**.

Valve Stems and Cores

A ***valve stem*** is pressed into a hole in the wheel of a tubeless tire to allow inflation and deflation. The stem is made of rubber. A threaded metal tube is formed in the end of the stem. See **Figure 73-18**.

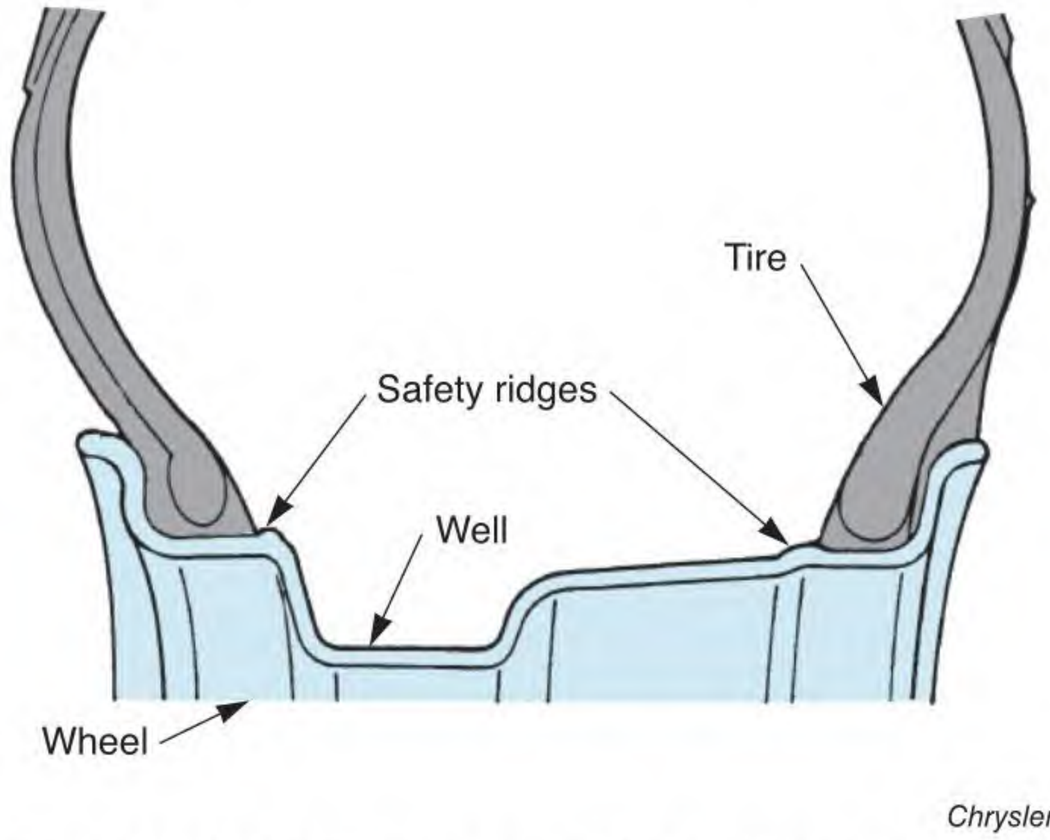
The ***valve core*** is a spring-loaded air valve that is threaded into the valve stem. The valve core allows air to be added to the tire when an ***air chuck*** (tool for filling tire with air) is placed over the valve stem. When the air chuck is removed from the valve stem, the spring pushes the valve closed to prevent air leakage.



Goodyear

Figure 73-16. Study the basic dimensions of a wheel.

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Chrysler

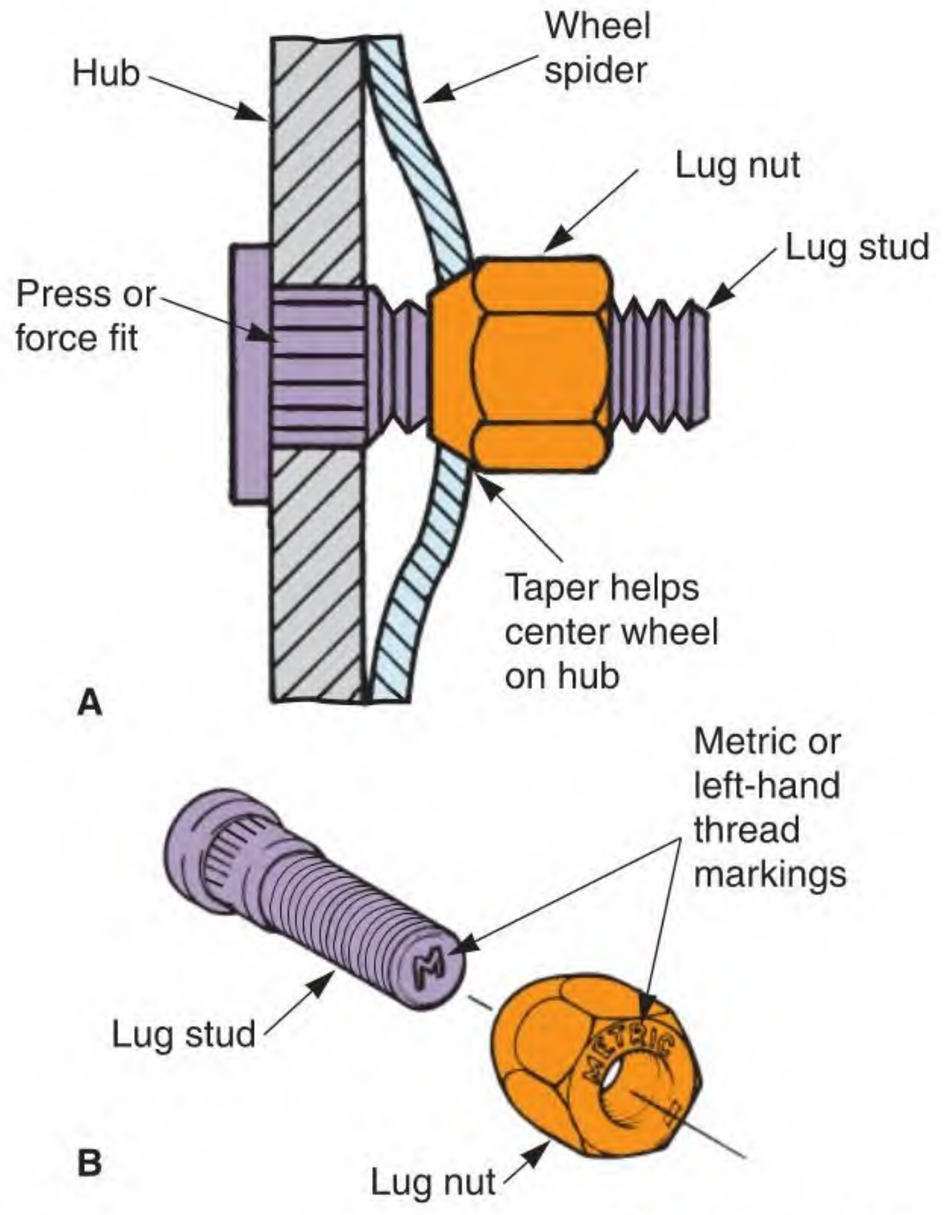
Figure 73-17. Safety ridges prevent the tire from dropping into the center well in the event of a flat or a blowout.

To remove air from the tire, push the center of the valve core inward. The valve will open, allowing air to escape. A ***valve stem cap*** screws over the threaded valve stem to protect the air valve and stem threads from dirt, moisture, and damage. It also helps prevent accidental depression of the valve and the resulting loss of air pressure.

Lug Nuts, Studs, and Bolts

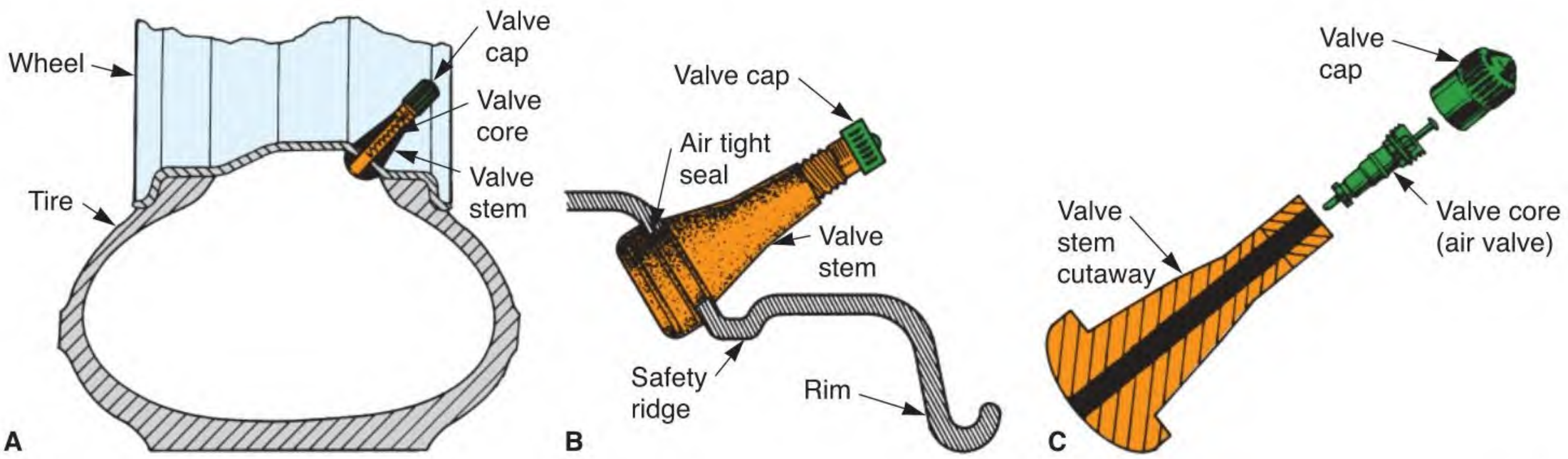
Lug nuts hold the wheel and tire assembly on the vehicle. They fasten to special studs. The inner face of the lug nut is tapered to help center the wheel on the hub. Refer to **Figure 73-19A**. ***Lug studs*** are the special studs that accept the lug nuts. The studs are pressed through the back of the hub or axle flange.

Normally, the lug nuts and studs have right-hand threads (turn clockwise to tighten). When left-hand



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Figure 73-19. A—The lug nut screws onto a lug stud to secure the wheel to the hub. The tapered end of the nut must contact the wheel. The stud is pressed into the hub. B—If metric or left-hand threads are used, markings will normally be given on the nut or stud.



Toyota

Figure 73-18. Note how the valve stem assembly mounts in a wheel. A—Valve stem snaps into a hole in the wheel. B—The press fit between the stem and the wheel forms an airtight seal. C—The valve core is an air valve that screws into the valve stem body. The valve cap screws over the end of the stem.

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threads are used, the nut or stud will be marked with an "L." Metric threads will be identified with an "M" or the word "Metric." See **Figure 73-19B**.

A few cars use ***lug bolts*** instead of lug nuts. The bolts screw into threaded holes in the hub or axle flange.

Wheel Weights

Wheel weights are small lead weights that are attached to the wheel rim to balance the wheel-and-tire assembly, preventing vibration. The weights are used to offset a heavy area of the wheel and tire.

Clip-on lead weights can be hammered over the wheel lip of steel wheels, but will damage aluminum wheels. Aluminum wheels require stick-on lead weights with an adhesive backing. Stick-on wheel weights are applied to the inner wheel surface so they cannot be seen.

Hub and Wheel Bearing Assemblies

Wheel bearings allow the wheel to turn freely around the spindle, in the steering knuckle, or in the bearing support. Most wheel bearings are either tapered roller bearings or ball bearings, **Figure 73-20**.

The wheel bearings are lubricated with heavy, high-temperature grease. This lets the elements (rollers or balls) operate with very little friction and wear.

The basic parts of a wheel bearing are:

- ***Outer race*** —The outer race is a steel cup or cone pressed into the hub, steering knuckle, or bearing support.
- ***Balls*** or ***rollers*** —Balls and rollers are antifriction elements that fit between inner and outer races.
- ***Inner race*** —The inner race is another steel cup or cone that rests on spindle or drive axle shaft.

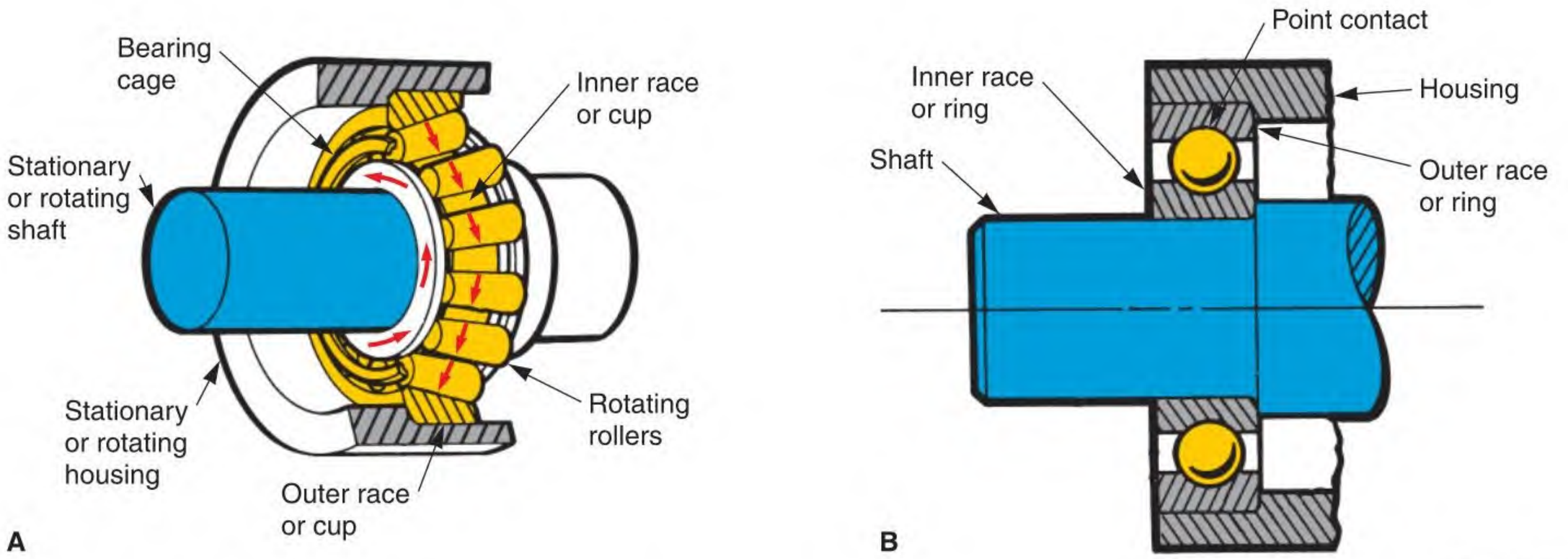
There are two basic ***hub and wheel bearing assembly*** designs: those with tapered roller bearings and those with ball or straight roller bearing assemblies.

Hub and Wheel Bearing Assembly: Tapered Roller Bearings

Tapered roller bearings can be used on both driving and non-driving wheels. See **Figures 73-21** and **73-22**.

The basic parts of a hub and tapered roller bearing assembly for a vehicle's non-driving wheels include:

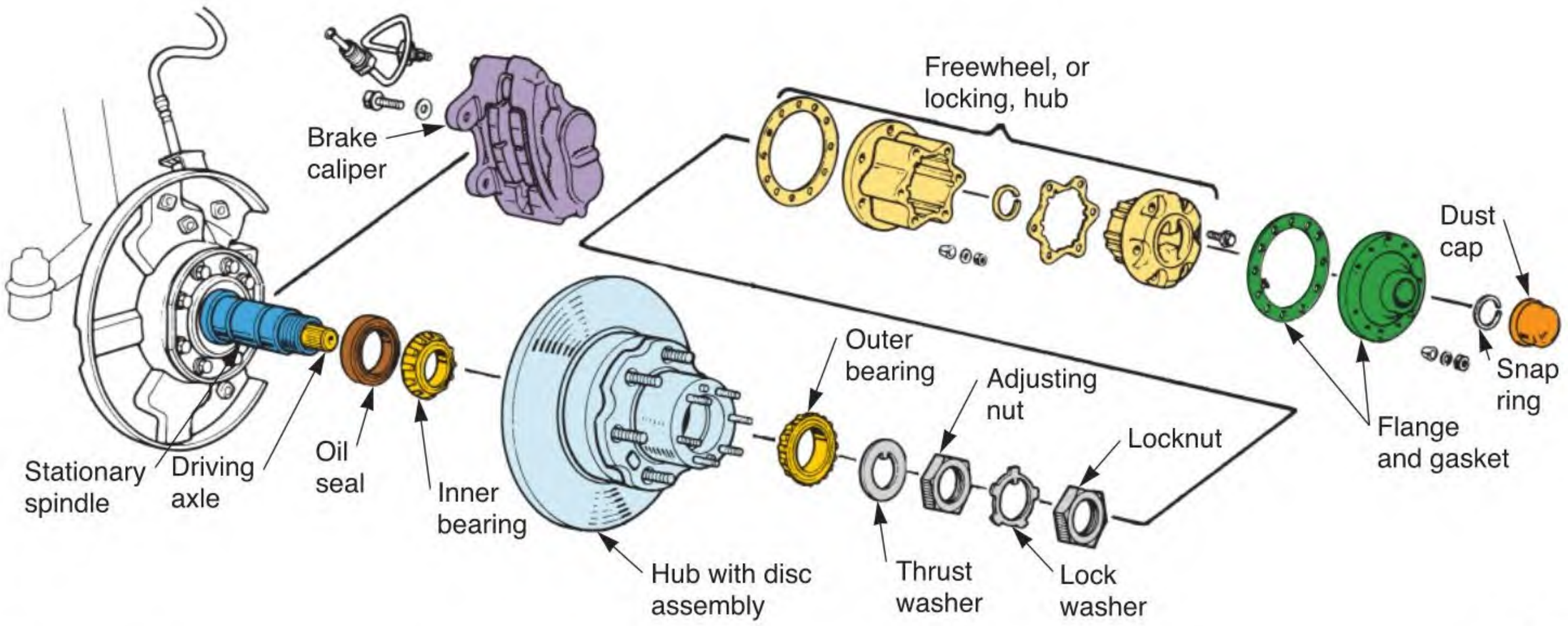
- ***Spindle*** —The spindle is a stationary shaft extending outward from the steering knuckle or the suspension system.
- ***Wheel bearings*** —Wheel bearings are tapered roller bearings mounted on the spindle and in the wheel hub.
- ***Hub*** —The hub is the outer housing that holds the brake disc or drum, front wheel, grease, and wheel bearings.



Federal Mogul

Figure 73-20. Two basic wheel bearing configurations. A—A tapered roller bearing has cylindrical rollers that operate between inner and outer races. If the shaft is stationary, the bearing will allow the outer housing or hub to turn. If outer bearing mount is stationary, the shaft or axle can turn in the bearing. B—Ball bearings are also used as wheel bearings, especially on a vehicle's driving wheels. The balls allow parts to rotate with a minimum amount of friction and wear.

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Toyota

Figure 73-21. This front hub and wheel bearing assembly is used in a four-wheel-drive vehicle. Note how the drive axle sticks through a stationary spindle. An adjustable hub allows the drive axle to be connected and disconnected from the hub and wheel assembly for two- or four-wheel-drive operation.

- ***Grease seal***—The grease seal prevents the loss of lubricant from the inner end of the spindle and hub.
- ***Safety washer***—The safety washer is a flat washer that keeps the outer wheel bearing from rubbing on and turning the adjusting nut.
- ***Spindle adjusting nut***—The spindle adjusting nut is threaded on the end of the spindle for adjusting the wheel bearing.
- ***Nut lock***—The nut lock is a thin, slotted nut that fits over the spindle adjusting nut.
- ***Cotter pin***—The cotter pin is made of soft metal. It fits through a hole in the spindle, adjusting nut, and nut lock to keep the adjusting nut from turning in service.
- ***Dust cap***—The dust cap is a metal cap that fits over the outer end of the hub to keep grease in and road dirt out of bearings.

Since this hub and wheel bearing assembly does not transfer driving power, the spindle is stationary. It simply extends outward and provides a mounting place for the wheel bearings, hub, and wheel. When the vehicle is moving, the wheel and hub spin on the bearings and spindle. The hub simply freewheels. The hub is partially filled with grease to lubricate the bearings.

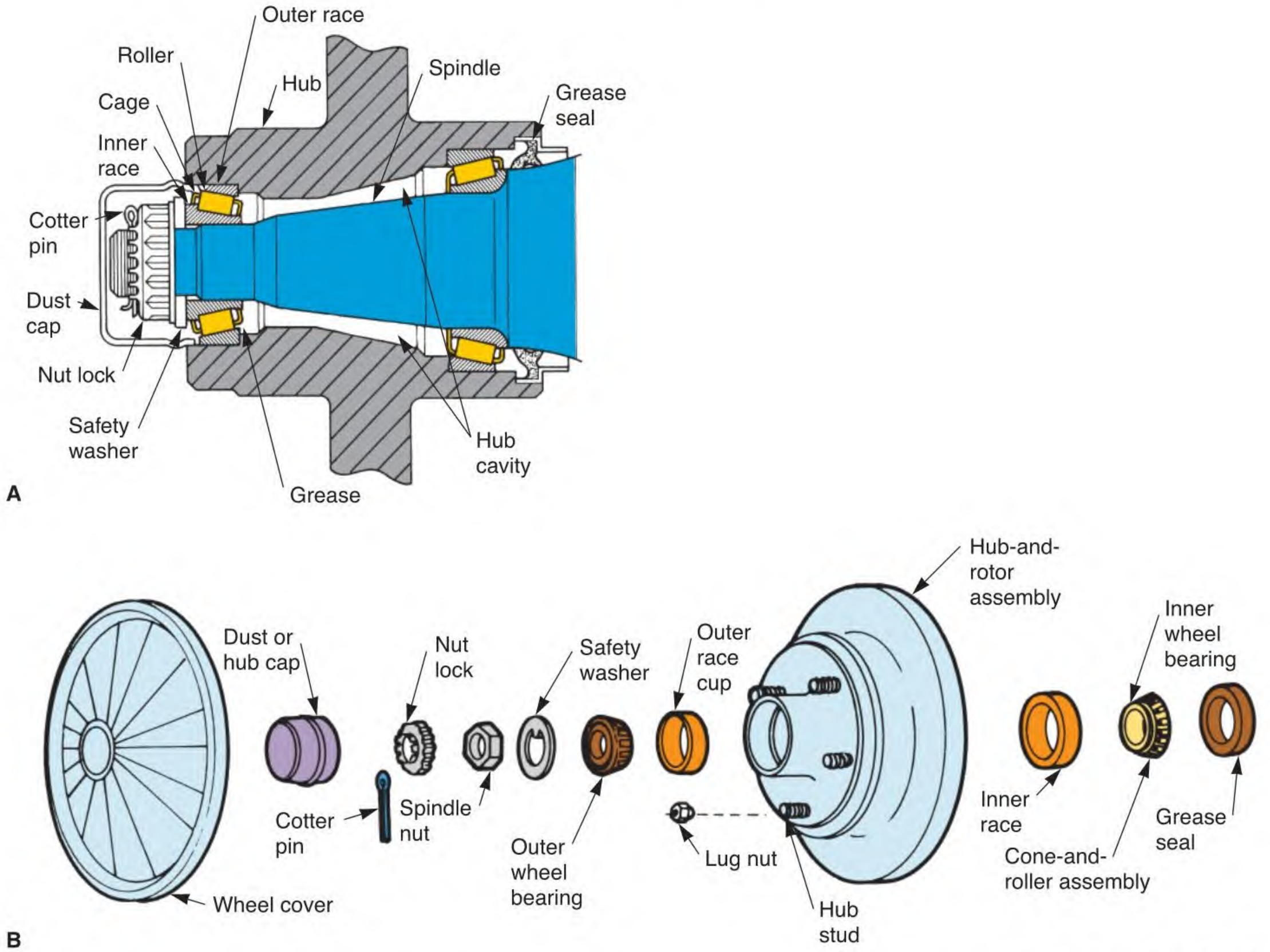
Hub and Wheel Bearing Assembly: Ball or Straight Roller Bearings

Ball bearings and straight roller bearings are often used at both driving and non-driving wheels. In most cases, the bearings are part of an assembly that includes the inner and outer races. The assembly is pressed into the steering knuckle or support.

Figure 73-23 illustrates the basic parts found in a hub and wheel bearing assembly for the driving wheel of a front-wheel-drive vehicle. These parts include:

- ***Outer drive axle***—The outer drive axle is a stub axle shaft that extends through the bearings and is splined to the hub.
- ***Ball bearings***—Ball bearings are antifriction elements that allow the drive axle to turn in the steering knuckle or bearing support.
- ***Steering knuckle*** or ***bearing support***—The steering knuckle or bearing support is a steering or suspension component that holds the wheel bearings, axle stub shaft, and hub.
- ***Driving hub***—The driving hub is a mounting surface for the wheel. It transfers driving power from the stub axle to the wheel.
- ***Axle washer***—The axle washer is a special washer that fits between the hub and locknut.

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Chrysler; Florida Dept. of Voc. Ed.

Figure 73-22. Typical non-driving hub and wheel bearing assembly. A—Two tapered roller bearings allow the hub and wheel to revolve around the stationary spindle. Grease partially fills the hub and is contained by an inner seal. A nut on the end of the spindle allows adjustment of the bearing preload. B—Disassembled view of a non-driving hub and wheel bearing assembly. Note the part names and relationships.

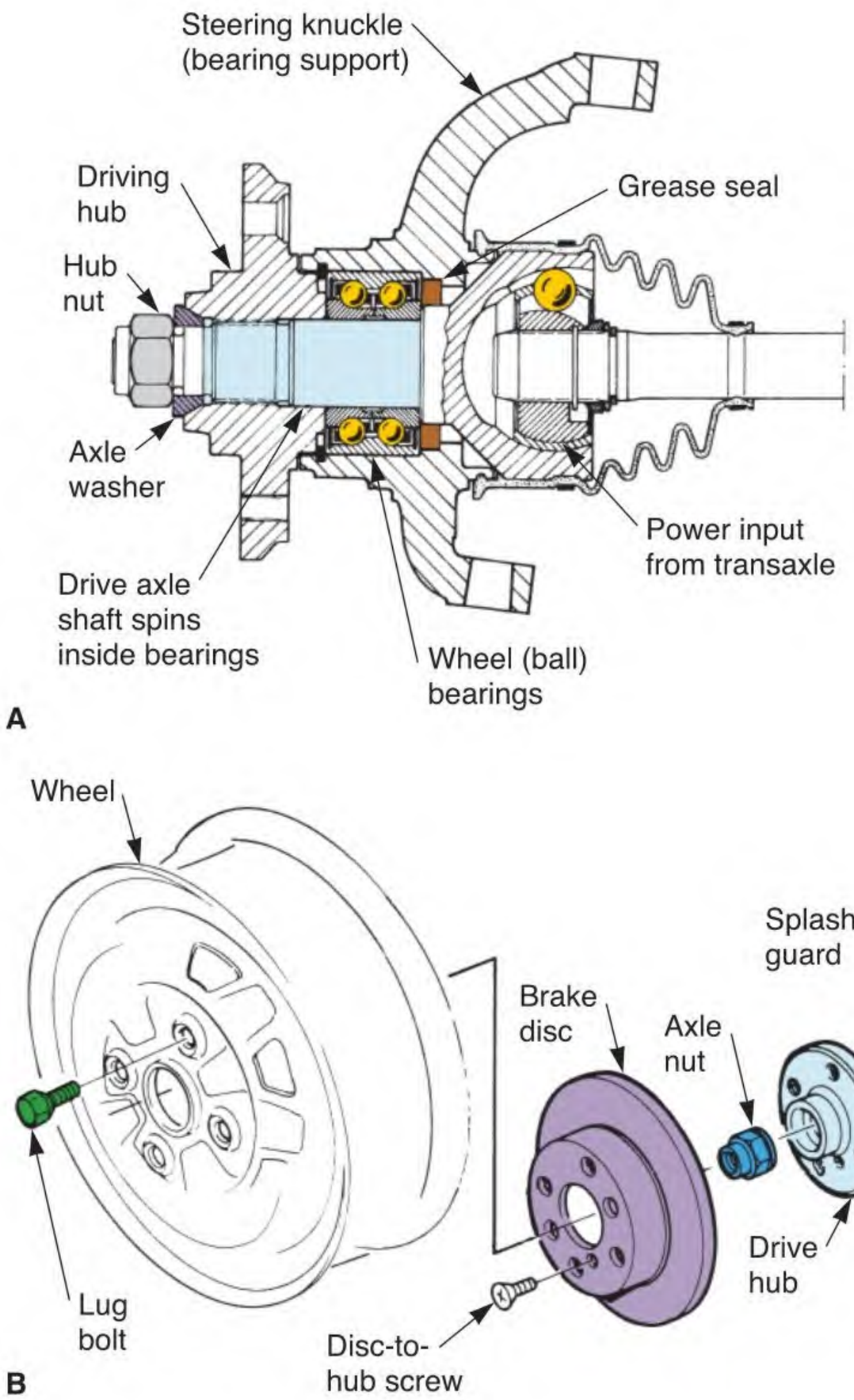
- ***Hub locknut*** or ***axle locknut***—This locknut screws on the end of the drive axle stub shaft to secure the hub and other parts of assembly.
- ***Grease seal***—The grease seal prevents lubricant loss between the inside of the axle and the knuckle or bearing support.

Other Hub and Wheel Bearing Assemblies

Modern vehicles use a wide variation of hub and wheel bearing assemblies. For example, many late-model vehicles use a sealed hub and bearing assembly that contains ball bearings, straight roller bearings, or tapered roller bearings. These self-contained units are not serviceable. In most cases, they are bolted to the knuckle or support. A few are press fit into the knuckle.

When you need more information on a specific vehicle, always refer to the factory service manual. It will explain and illustrate the hub and wheel bearing assembly clearly. Most designs, however, will be similar.

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Honda

Figure 73-23. The basic parts of a driving hub and wheel bearing assembly. A—Bearings are mounted in a stationary steering knuckle or a bearing support. The drive axle shaft fits through the center of the bearings. The hub is splined to axle shaft. B—Disassembled view of a driving hub and wheel bearing assembly. Study the names of the parts.



Green Tech

Tires

Used tires are a large source of waste in the automotive industry. Since so many tires are disposed of, they can fill landfills very quickly if they are thrown out. Used tires should not be burned because the smoke given off by the oil in the tires will pollute the air. Because tires are made to be very strong and long-lasting, they can be difficult to recycle. However, tires that are taken to recycling facilities can be broken down and used to make new tires. This saves both energy and materials that would be used to produce new tires, as well as protects the environment from air pollution.

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Summary

- Automobile tires perform two basic functions: they act as a soft *cushion* between the road and the metal wheel. Tires must also provide adequate *traction* (friction) with the road surface.
- Car tires are pneumatic, which means they are filled with air.
- Today's vehicles use tubeless tires, which do *not* have a separate inner tube. The tire and wheel form an airtight unit.
- Tire rolling resistance is a measurement of the amount of friction produced as the tire operates on the road surface.
- A bias ply tire has plies running at an angle from bead to bead.
- A belted bias tire is a bias ply tire with belts added to increase tread stiffness.
- A radial ply tire has plies running straight across from bead to bead, with stabilizer belts directly beneath the tread.
- Tire markings on the sidewall of a tire give information about tire size, tire model, load-carrying ability, inflation pressure, number of plies, speed rating, manufacturer.
- Tire size is given on the sidewall as a letter-number sequence.
- The aspect ratio, or height-to-width ratio, is a comparison of the tire's height and width.
- The maximum load rating of a tire indicates the amount of *weight* the tire can carry at recommended inflation pressure.
- The maximum inflation pressure is the highest air pressure that should be pumped into the tire.
- A tire speed rating is the maximum allowable sustained road speed the tire can safely withstand without failure.
- Some tires are self-sealing (seal small punctures) because of a coating of sealing compound applied to the tire liner.
- Retreads are used tires that have had a new tread vulcanized (applied using heat and pressure) to the old carcass, or body.
- Run-flat tires have an extremely stiff sidewall construction so that they are still usable with a loss of air pressure.
- A tire pressure monitoring system alerts the driver if one or more of the vehicle's tires is underinflated.
- A drop-center wheel is commonly used on passenger vehicles because it allows for easier installation and removal of the tire.
- A valve stem is pressed into a hole in the wheel of a tubeless tire to allow inflation and deflation.
- Lug nuts hold the wheel-and-tire assembly on the vehicle.
- Wheel weights are small lead weights attached to the wheel rim to balance the wheel-and-tire assembly, preventing vibration.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

air chuck
alpha-numeric
aspect ratio
asymmetric tires
axle locknut
axle washer
ball bearings
balls
beads
bearing support
belted bias tire
belts
bias ply tire
blowout
body plies
compact spare tire
cotter pin
directional tires
DOT serial number
driving hub
drop-center wheel
dust cap
flat
footprint
full-size spare
grease seal
high-pressure spare
hub
hub and wheel bearing assembly
hub locknut
hydroplaning
inner race
inner tubes
lightweight spare tire
liner
lug bolts
lug nuts
lug studs
mag wheels
mags
maximum inflation pressure
maximum load rating
nut lock
outer drive axle
outer race
P-metric

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pneumatic
radial ply tire
retreads
rim
rollers
rolling resistance
run-flat tires
safety rim
safety washer
self-sealing
sidewall
space saver spare
spare tire
spider
spindle
spindle adjusting nut
squat
steering knuckle
tire markings
tire pressure monitoring systems
tire size
tire speed rating
tire temperature resistance
tire traction
tires
tread
tread wear
tubeless tires
valve core
valve stem
valve stem cap
wear bars
wheel bearings
wheel weights
wheels

Activities

1. Using a section of an old worn tire, prepare a cutaway teaching aid showing the different parts and layers of the tire.
2. Prepare an overhead transparency that explains tire and wheel sizes and tire ratings.
3. As a classroom demonstration, disassemble and identify the parts of a hub.

Review Questions

Answer the following questions using the information provided in this chapter.

1. What are the two basic functions of a tire?
2. Car tires are _____, which means that they are filled with air.
3. List and explain the six major parts of a tire.
4. Tire _____ _____ is a measurement of the amount of friction produced as the tire operates on the road surface.
5. Which of the following is *not* a type of tire used on passenger cars?
   (A) Radial.
   (B) Bias ply.
   (C) Lateral ply.
   (D) Belted bias.
6. What information is commonly given on the tire sidewall?
7. Many tires have a maximum recommended inflation pressure of 22 psi (152 kPa). True or False?
8. How does a self-sealing tire work?
9. A(n) _____ _____ has small ridges that hold the tire on the wheel during a tire blowout.
10. Explain why a valve core is needed.
11. _____ _____ are attached to the rim to balance the wheel-and-tire assembly and prevent vibration.
12. Name and describe the basic parts of a wheel bearing.
13. List and explain the nine basic parts of a hub and tapered roller bearing assembly.
14. List and explain the seven basic parts of a hub and ball bearing assembly.
15. A sealed hub and bearing assembly is not serviceable. True or False?

ASE-Type Questions

1. Technician A says one of the functions of an automotive tire is to provide a cushion between the road and the metal wheel. Technician B says one of the functions of an automotive tire is to provide adequate traction with the road surface. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Technician A says automotive tires are pneumatic. Technician B says modern automotive tires are not pneumatic. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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3. Technician A says older vehicles used tires equipped with inner tubes. Technician B says vehicles always came from the factory equipped with tubeless tires. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. Technician A says an automotive tire's beads are used to stiffen the tire treads. Technician B says an automotive tire's beads are used to hold the sidewalls against the wheel rim. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. Technician A says an automotive tire's body plies provide a leakproof membrane for modern tubeless tires. Technician B says an automotive tire's liner provides a leakproof membrane for modern tubeless tires. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Technician A says an automotive tire's belts form the body of the tire. Technician B says an automotive tire's belts are sometimes used to strengthen the plies and stiffen the treads. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. Technician A says tire "rolling resistance" is normally reduced by lower inflation pressure. Technician B says tire "rolling resistance" is normally reduced by higher inflation pressure. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. Technician A says "belted bias" tires provide a smooth ride and good traction. Technician B says "radial" tires have a very stable footprint. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Technician A says a "bias ply tire" is one of the newest tire designs and is equipped with belts. Technician B says a "bias ply tire" is one of the oldest tire designs and does not use belts. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. Technician A says a radial ply tire's belts are sometimes made of steel. Technician B says a radial ply tire's belts are sometimes made of fiberglass. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
11. Technician A says tire markings on the sidewall of a tire give information about tire load-carrying ability. Technician B says tire markings on the sidewall of a tire provide the maximum recommended inflation pressure. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
12. Technician A says most automotive wheels are made of steel. Technician B says most automotive wheels are made of aluminum. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
13. Technician A says wheel bearings in several car models are the tapered roller bearing type. Technician B says wheel bearings in certain car models are the ball bearing type. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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14. While discussing the basic parts of an automotive wheel bearing, Technician A says the bearing's outer race is sometimes pressed into the automobile's steering knuckle. Technician B says a wheel bearing's outer race is sometimes pressed into the hub. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
15. Technician A says a steering knuckle is a basic component in a driving hub and wheel bearing assembly. Technician B says an inner drive axle is a basic component in a driving hub and wheel bearing assembly. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Chapter 74
Tire, Wheel, and Wheel Bearing Diagnosis and Repair

After studying this chapter, you will be able to:

- Diagnose common tire, wheel, and wheel bearing problems.
- Describe tire inflation and rotation procedures.
- Measure tire and wheel runout.
- Explain static and dynamic wheel balance.
- Summarize different methods of balancing wheels and tires.
- Use safe practices while servicing tires and wheels.
- Replace and reprogram tire pressure sensors.
- Explain service procedures for wheel bearings.
- Correctly answer ASE certification test questions requiring a knowledge of the service and repair of tires, wheels, and wheel bearings.

Tires are a common source of trouble. Normal wear, impact damage from road debris, and improper inflation pressure commonly result in tire failures. Wheels and tires can be damaged by impact with curbs, large potholes, and other objects, causing vibration or tire deflation.

Wheel bearings can wear and fail when operated without grease or after several hundred thousand miles of normal operation. Worn wheel bearings increase play in the steering and suspension. Complete wheel bearing failure can cause the tire and wheel to actually fall off while driving.

Tire, Wheel, and Wheel Bearing Diagnosis

Tire problems usually show up as vibrations, abnormal tread wear patterns, steering wheel pull, abnormal noises, and other symptoms. In some cases, you may need to test drive the vehicle to verify the customer complaint. Make sure the symptoms are *not* being caused by steering, suspension, or front wheel alignment problems.

Closely inspect the tires. Check for bulges, splits, cracks, chunking, cupping of the tread, and other signs of damage or abnormal wear. Look closely at the outer sidewall, the tread area, and the inner sidewall. If problems are found, determine what caused the damage before replacement or repair.

Tire tread measuring less than about 1/8″ (3.175 mm) is considered worn. See **Figure 74-1**. If any part of the tread is worn down more than this, the tread grooves are too shallow, and the tire is not safe. Both dry and wet stopping distances are increased with tread this shallow. On slippery pavement, worn tire tread gains very little traction, which reduces the ability of the vehicle to stop suddenly.

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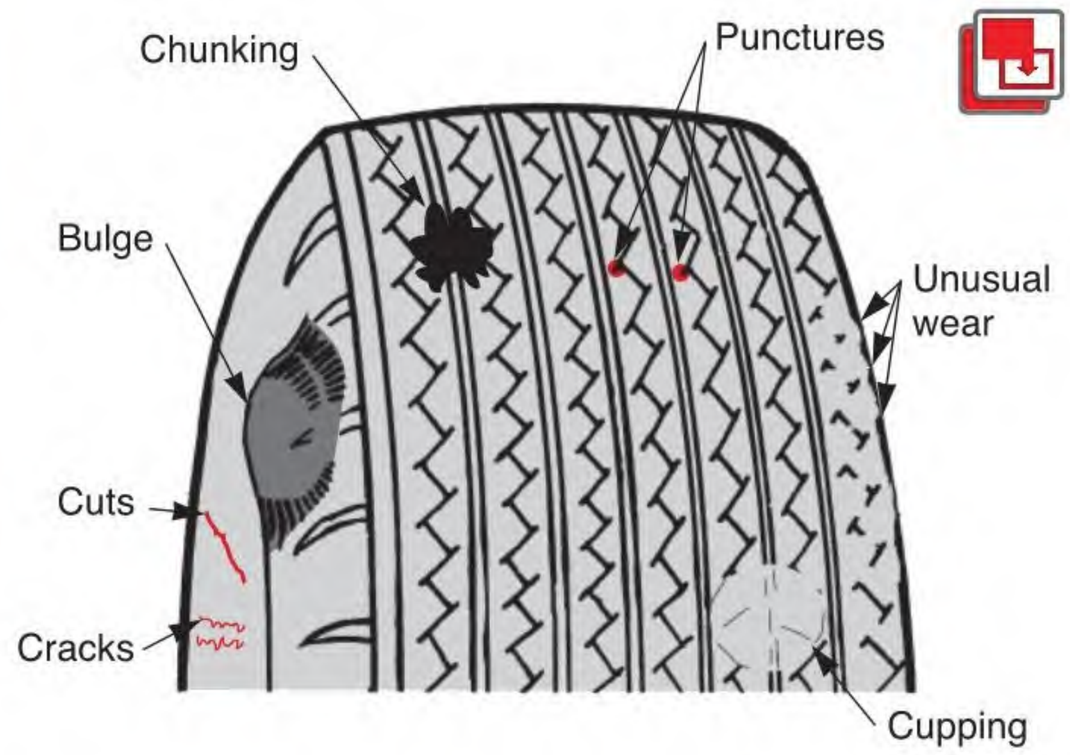


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Figure 74-1. Tire service normally begins with a thorough inspection. Look for damage and wear on all surfaces of the tire. A—Insert a penny into a groove in the tire tread. If you can see the very top of President Lincoln's head, the tire tread is too worn and the tire should be replaced. B—A tire depth gauge can be used to measure the actual tread depth. If the tread depth is less than 1/8″ (3.175 mm), the tire may be unsafe and should be replaced.

Tire Impact Damage

Tire impact damage, also termed ***road damage***, includes punctures, cuts, tears, and other physical tire injuries. Drivers often run over road debris, potholes, hit curbs, and impact other objects that cause premature tire failures. Small air leaks can usually be repaired. However, even minor tire damage, cuts, air bubbles, and wear patterns require that the tire be replaced to be considered safe to drive. Some examples of tire failure are illustrated in **Figure 74-2**.



Florida Dept. of Voc. Ed.

Figure 74-2. These are typical types of damage found on used tires.

Tire Wear Patterns

A ***tire wear pattern*** (area of tread worn *off*) can usually be studied to determine the cause of the abnormal wear. Look at **Figure 74-3**.

Improper tire inflation, ply separation, incorrect wheel alignment, lack of periodic tire rotation, and an out-of-balance condition can cause excessive tire wear. By carefully inspecting the tire tread, a technician can identify worn steering and suspension parts that should be repaired before tire replacement.

Tire Inflation Problems

Correct tire inflation pressure is important to the service life of a tire. Proper inflation is needed so the full tire tread contacts the road, **Figure 74-4**.

Underinflation (low air pressure) is a common and destructive problem that wears the outer corners of the tread area. The low pressure allows the tire sidewalls to flex, building up heat during operation. The center of the tread flexes upward and does *not* wear.

Underinflation can cause rapid tread wear, loss of fuel economy, and possibly ***ply separation*** (plies tear away from each other). Ply separation causes the tire sidewalls to bulge outward and form an air bubble in the sidewall.

Overinflation (too much air pressure) causes the center area of the tread to wear. The high pressure

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A–Feathering. This is caused by erratic scrubbing against road when tire is in need of toe-in or toe-out alignment correction.



B–Overinflation. Overinflation can cause fast centerline wear in bias and bias belted tires. In this case, center ribs get more contact with road than they should and wear much faster than outer ribs.



C–Underinflation. When a tire is underinflated, most of its contact with road is on outer tread rib, or shoulder, causing faster wear here than in middle. Be sure to check tire's air pressure.



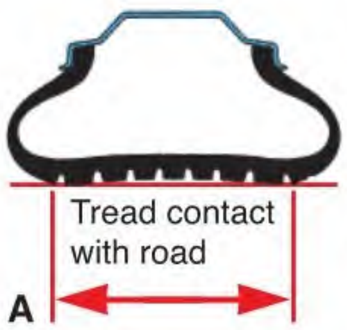
D–One-side wear. Here's another type of alignment problem–excessive camber, which means tire is leaning too much to inside or outside of tread, and placing all work on one side of tire.



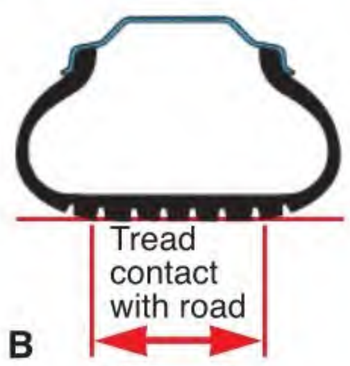
E–Cupping. This means the car may need wheels balanced, or possibly new shock absorbers or ball joints, or both.

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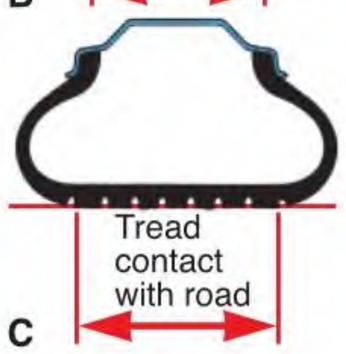
Figure 74-3. Tire tread wear patterns will help you identify the cause of rapid or abnormal wear. Study the patterns and the causes.



Underinflation–Causes excessive tire flex and heat buildup, risking failure. It also causes excessive wear on outer tread ribs.



Overinflation–Causes tires to ride hard and makes them more vulnerable to impact damage and weakening of tire body.



Proper Inflation–Correct profile for uniform contact with road which results in good tire performance.

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Figure 74-4. Tire inflation pressure is critical to tire life, vehicle handling, and ride.

causes the body of the tire to stretch outward. This pushes the center of the tread against the road surface, but lifts the outer edges of the tread off the road.

An overinflated tire produces a rough or hard ride. It is also more prone to impact damage. Use a tire pressure gauge to check inflation pressure if you suspect high or low tire air pressure.

Tech Tip

Remember that the tire inflation pressure on the sidewall is the maximum recommended pressure. The ideal tire pressure at a specific temperature is given in the owner's manual. This pressure depends on several variables, such as tire temperature, vehicle curb weight, suspension stiffness, and intended use.

With a properly inflated tire, the full tread area of the tire touches the road. The tire will wear evenly across the tread. This increases tire life and improves handling and safety.

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Steering wheel pull can be caused by uneven tire inflation. For example, if the left front tire (driver's side) is underinflated, the car will pull to the left. The partially deflated tire has greater rolling resistance, pulling the steering wheel away from the normally inflated tire, which consumes more energy.

Tech Tip

Keep tires inflated properly on every car you work on. Low tire pressure increases tire rolling resistance, fuel consumption, and tire wear. Low pressure is not always obvious, especially with modern carbon fiber sidewalls and run-flat tires. The sides do not bulge out when underinflated like conventional tires. You must use a pressure gauge to verify inflation pressure with modern high-performance tire designs.

Tire Vibration Problems

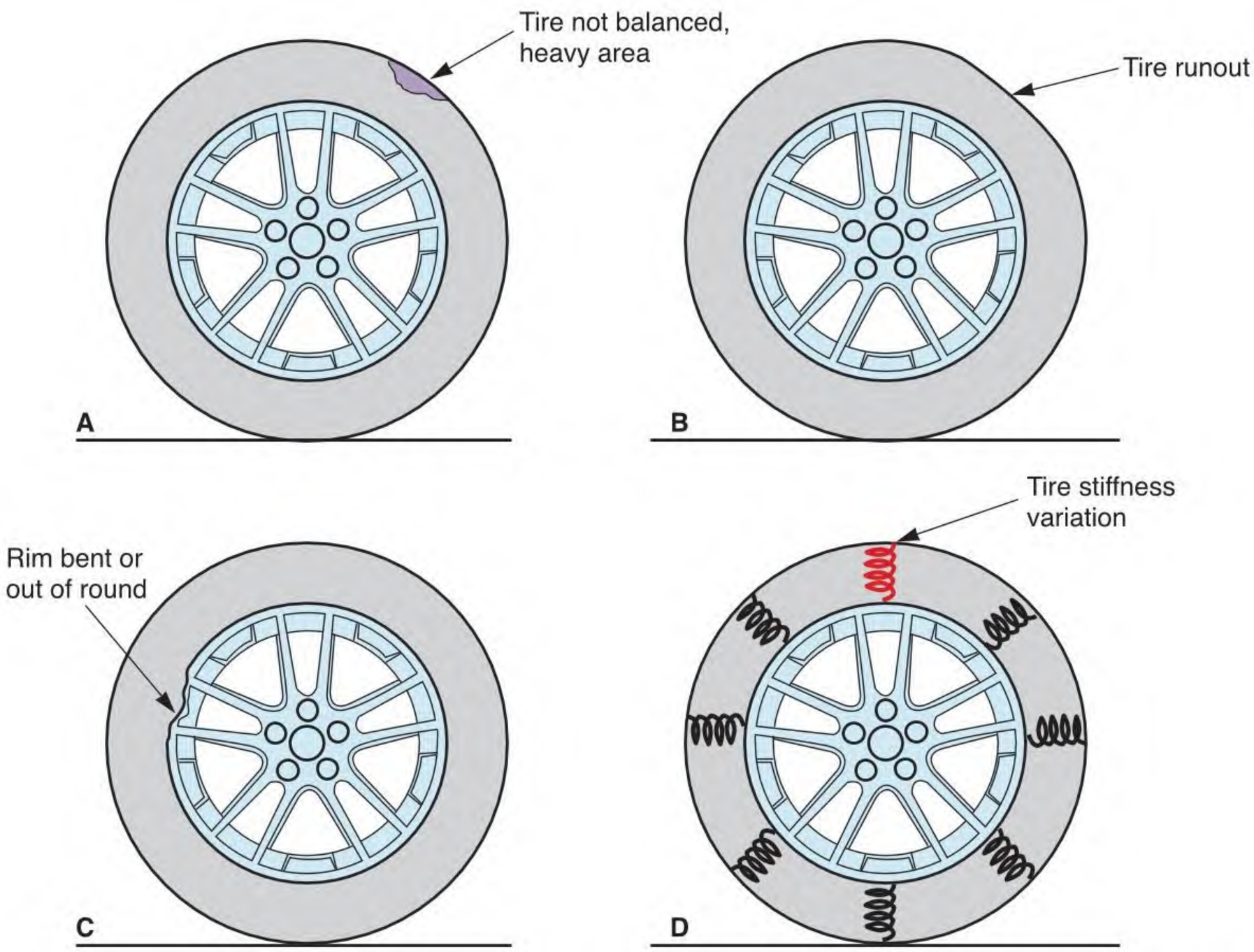
Tire vibration is commonly caused by an out-of-balance condition, ply separation, excessive tire runout, a bent wheel, tire stiffness variation, or tire cupping. Refer to **Figure 74-5**.

When one of the *front* tires is vibrating, it can usually be felt in the *steering wheel*. When one of the *rear* tires is vibrating, the vibration will be felt in the *center* and *rear* of the car.

Tire and Wheel Bearing Noise

Tire noise usually shows up as a thumping sound caused by ply separation or as a whine due to abnormal tread wear. Inspect the tire for an out-of-round condition or tread cupping. Tire replacement is needed to correct these problems.

Wheel bearing noise is normally produced by a dry, worn, or damaged wheel bearing. The balls or rollers are damaged from lack of lubrication and are no longer smooth and round. The weight of the vehicle



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Figure 74-5. Four common causes of tire-related vibration. A—Wheel-tire assembly not balanced. B—Excessive tire runout. C—Bent rim or excessive rim runout. D—Stiffness variation in rubber.

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pressing down on the chipped, pitted bearings causes them to emit a noticeable humming or growling sound.

Tech Tip

If overheated enough, wheel bearings can gall, glow red hot, and then seize together before bearing parts shatter. Total wheel bearing failure often causes the wheel and hub to fall off while cornering. This can be very dangerous to anyone near the self-destructing wheel bearing and out-of-control vehicle.

To check for a worn or loose wheel bearing, raise and secure the vehicle. Rotate the tire by hand while listening to it with a stethoscope. Feel and listen carefully for bearing roughness. Also, wiggle the tire back and forth to check for bearing looseness. You may have to disassemble the wheel bearing to verify the problem.

Wheel Cover and Cap Service

A ***wheel cover*** is the large metal or plastic decorative cover for the wheel. It is press-fit over the wheel rim to hide the lug nuts, dust cap, and other parts. Sometimes the lug nuts hold the plastic wheel cover in place. The plastic wheel cover will lift off easily once the lug nuts are removed.

To remove a barbed wheel cover, use the flat end of a lug wrench or a large screwdriver. Working carefully, pry between the wheel and cover at four alternating points. To install a barbed wheel cover, use a rubber hammer. Hold the wheel cover snugly in place with the valve stem aligned and sticking through the cover. Tap in a circular or alternating pattern.

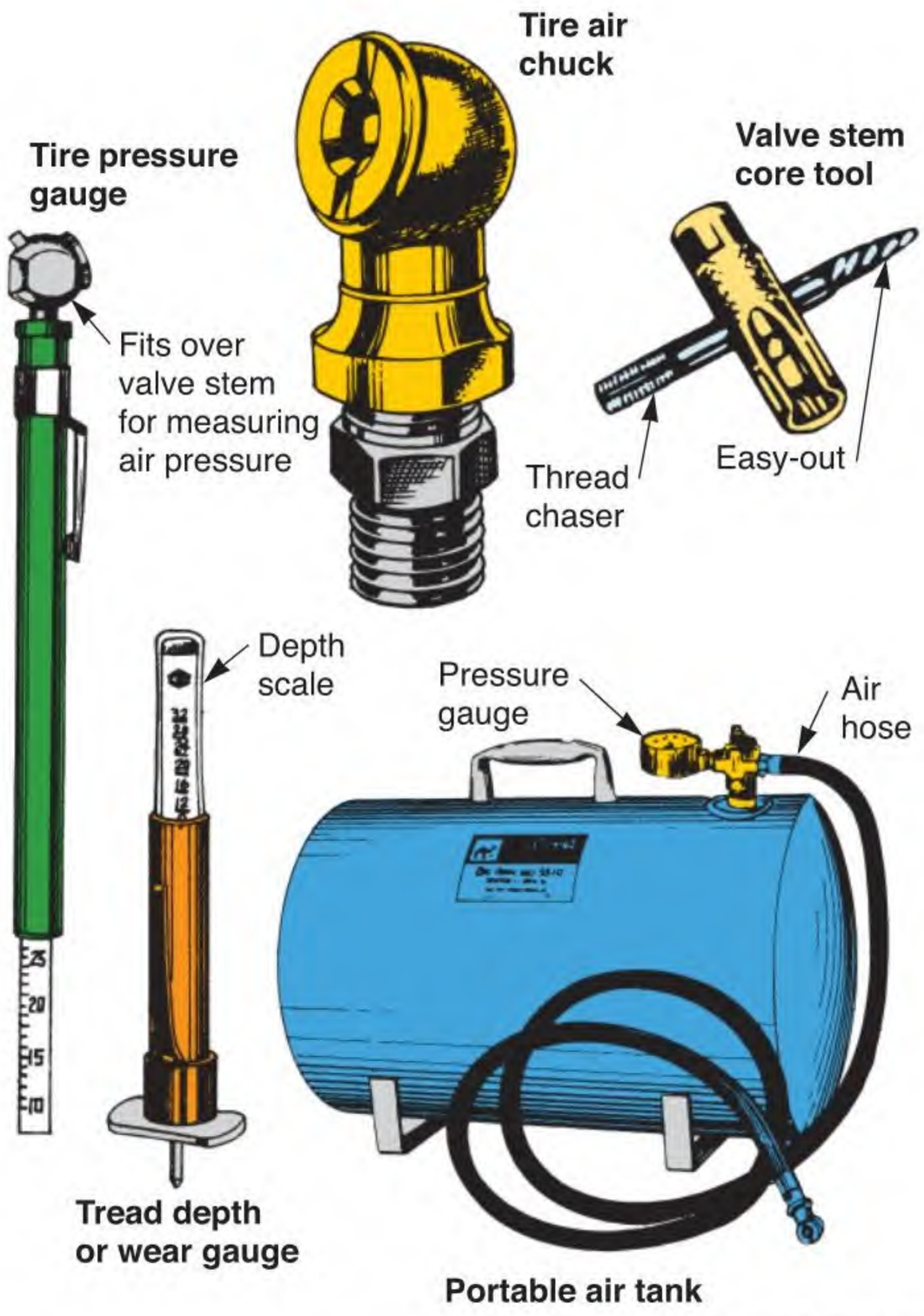
A ***wheel cap*** is a small metal or plastic cover in the center of a wheel. It is commonly used on aluminum wheels to hide the spindle nut and cap. Like a wheel cover, it usually snaps into place in the center of the wheel.

Tire Maintenance

Tire maintenance involves periodic inspection, checking of inflation pressure, and rotation. These preventive maintenance steps will help ensure vehicle safety and longer tire life. **Figure 74-6** shows some of the tools used during tire maintenance and service procedures.

Periodic Inspection

Periodic tire inspection involves visually checking the condition of the tires. Look for anything that could affect the dependability of the tires—tread wear, cracks, cuts, tears, etc. Raise the vehicle on a lift so you can inspect the inside sidewalls and tread all the way around each tire. Most tire damage and normal wear is on the inner edge of the tread, which is impossible to see with the vehicle on the ground.



Camel; Snap-on

Figure 74-6. Common tire service tools: Pressure gauge to accurately measure tire inflation. Depth gauge will accurately check tread depth and wear. Tire air chuck for filling tire with air. Portable air tank for filling car tire in remote areas. Core tool for removing and installing core in valve stem.

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Checking Tire Inflation Pressure

Service Procedure

To measure tire inflation pressure:

1. Unscrew and remove the valve stem cap.
2. Press the ***tire pressure gauge*** squarely over the valve stem. See **Figure 74-7**. Use your fingers to hold the tool square as you push down to compress the valve core spring.
3. Read the air pressure indicated on the gauge.
4. Compare your reading to the recommended maximum tire pressure printed on the tire's sidewall or given by the vehicle manufacturer.
5. If the tire pressure is low, add air. If the pressure is high, press in on the valve core pin to release air from the tire.
6. Recheck tire pressure and add or release air as necessary.
7. Reinstall the valve stem cap snugly.

Most tire manufacturers recommend a cold inflation pressure that is 1 to 3 psi (21 kPa) below the maximum listed air pressure. This allows for tire heating, air expansion, and pressure increase without exceeding the maximum pressure limits.

Tech Tip

A ***tire load index number*** represents the weight (in pounds or kilograms) the tire can carry without failure. For example, a load index number of 91 means the tire can carry a maximum load of 1356 pounds (610 kilograms) at its highest rated speed. This index number, as well as the tire's load-carrying ability, is molded on the side of the tire for easy reference.

Rotating Tires

Tire rotation involves changing the location of the tires on the vehicle to ensure maximum tire life. Normally, the front or rear tires wear differently. Rotation helps even out tire wear and prevents premature failure of any one tire. For example, a front-wheel-drive car will wear out its front tires more quickly than its rear tires. On rear-wheel-drive vehicles, the rear tires will wear more quickly. Generally, tires should be rotated at intervals suggested by the tire manufacturer (typically every 3000 miles or 4827 km) or sooner, if irregular wear develops. See **Figure 74-8**.

Tech Tip

Many high performance cars come equipped with a different size tire on the front compared to the rear. Tire rotation is not practical with different size tires.

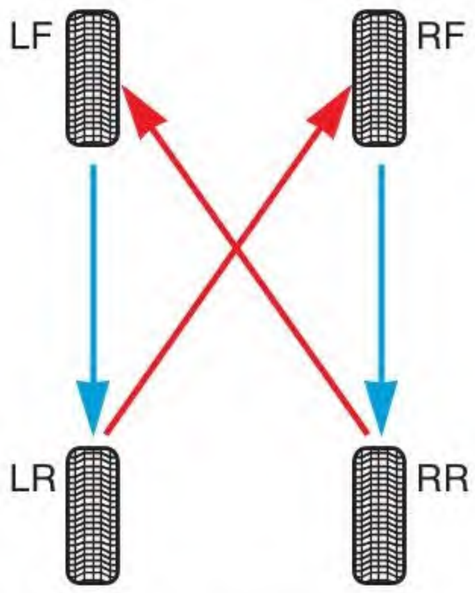


A B

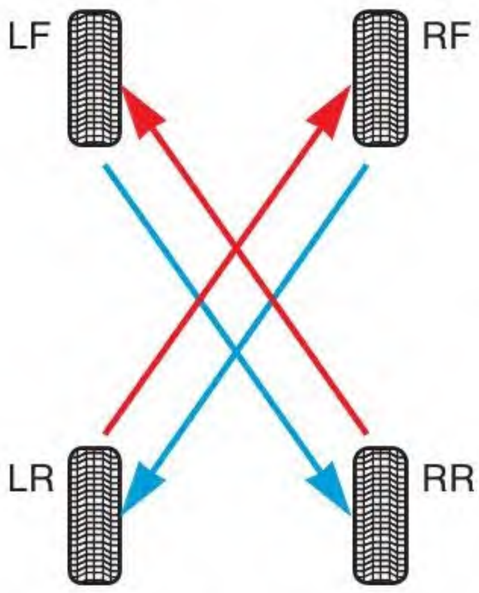
Goodyear

Figure 74-7. A quality tire pressure gauge can be used to obtain accurate pressure readings. A—Position your fingers to hold the tool square while pushing it straight down over the stem fitting. B—When adding air, hold the tire inflator tool square on the stem as you press down. This will avoid air leakage around fitting.

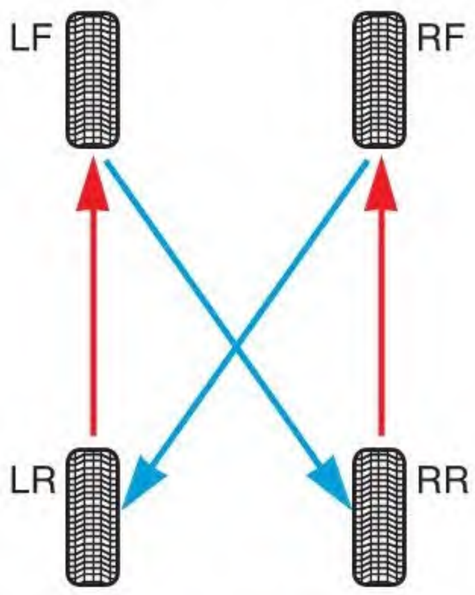
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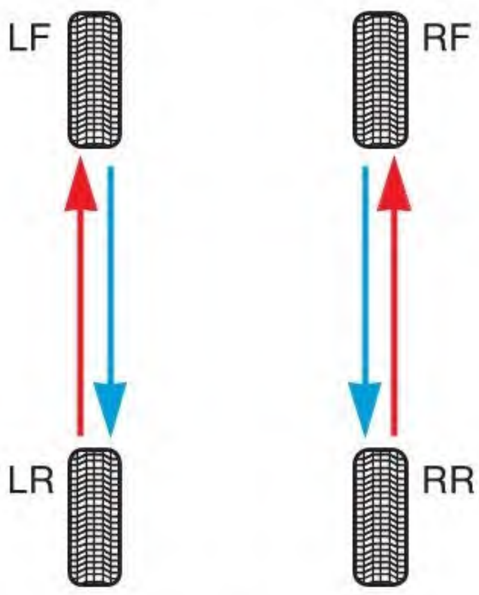
Front-wheel-drive vehicles—primary pattern



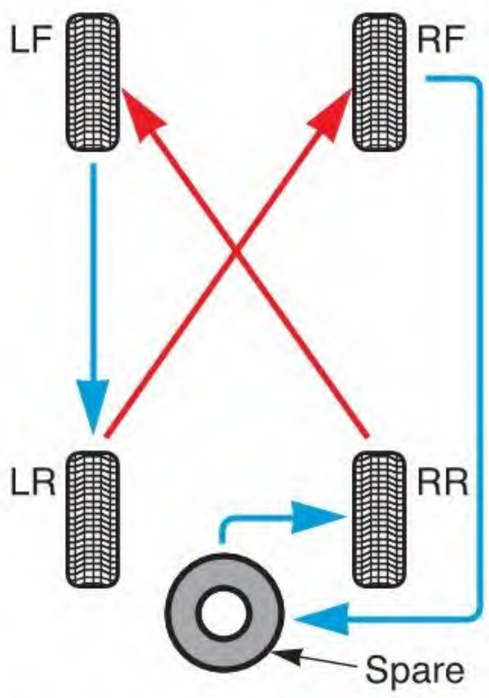
Front-wheel-drive vehicles—alternate pattern



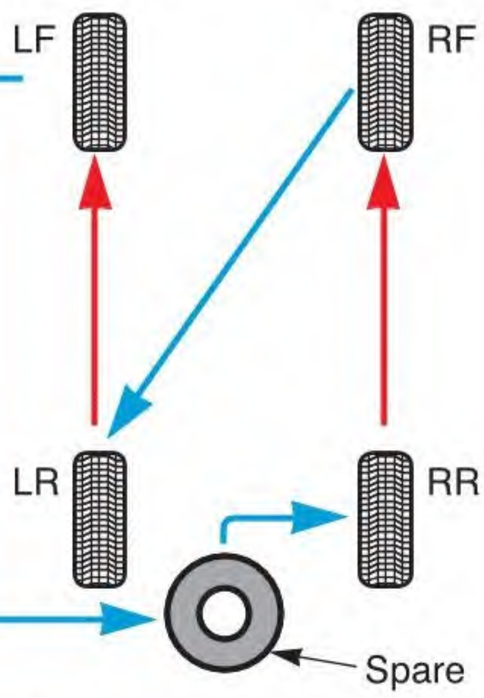
Rear- and four-wheel-drive vehicles



Vehicles with directional tires of the same size



Front-wheel-drive vehicles with a full-size matching spare



Rear- and four-wheel-drive vehicles with a full size matching spare

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Figure 74-8. Study the typical tire recommendations for various vehicle and tire types.

Torquing Lug Nuts

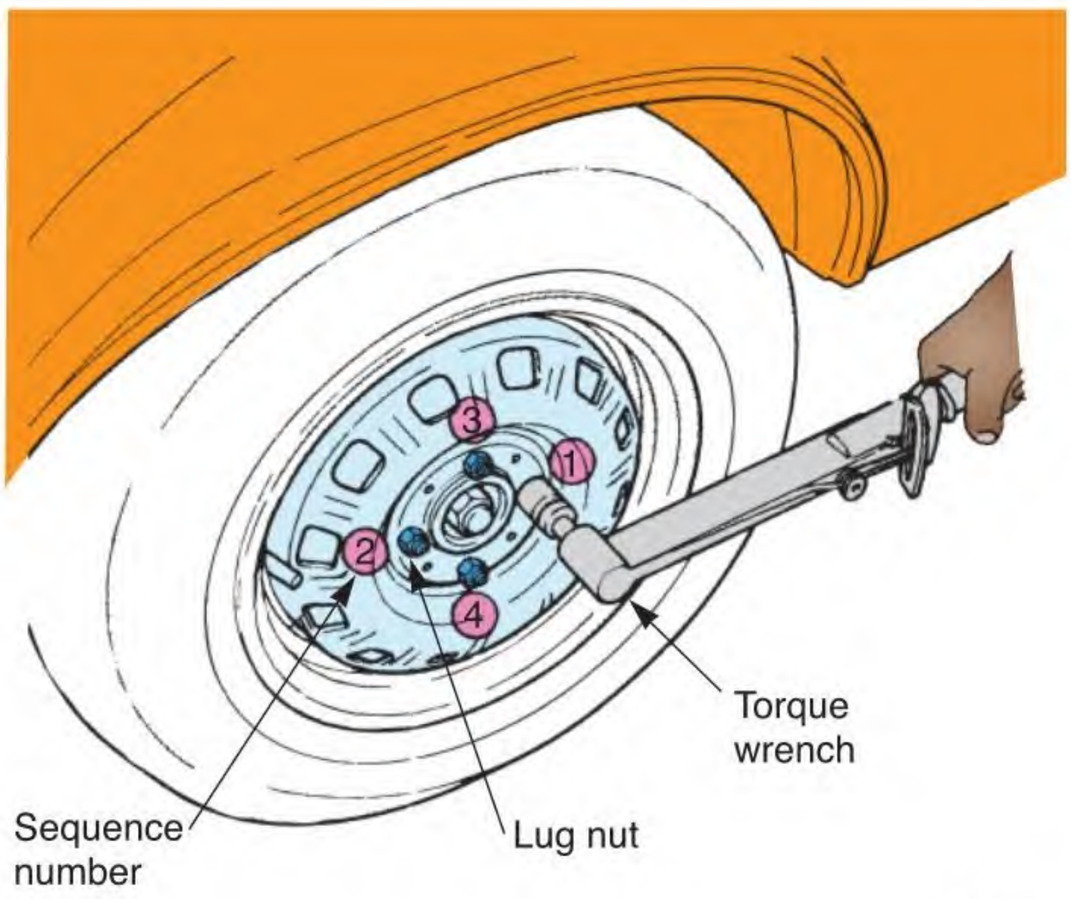
Lug nut torque (tightening force) is very important, especially on vehicles equipped with mag wheels and lightweight hubs. Overtorquing can cause wheel or hub distortion, excessive runout, and vibration. Undertorquing might allow the lug nuts to loosen and the wheel to fall off.

Automakers suggest that lug nuts be tightened to specifications with a torque wrench. Tighten the nuts in a crisscross pattern as in **Figure 74-9**.

Replacing Lug Studs

Lug studs can become stripped or damaged. To replace them, force out the old stud with a special pressing tool or a hydraulic press. Do not use a hammer to drive the studs out because the hammer blows could damage the wheel bearing.

To install the new stud, use flat washers and a lug nut. You can usually draw the new stud into place by tightening the nut on the washers. Double-check that the stud is fully seated before installing the wheel.



Chrysler

Figure 74-9. Use a torque wrench to tighten lug nuts to specifications in crisscross pattern. Modern lightweight wheels and hubs require exact lug nut torque to avoid wheel warpage and damage.

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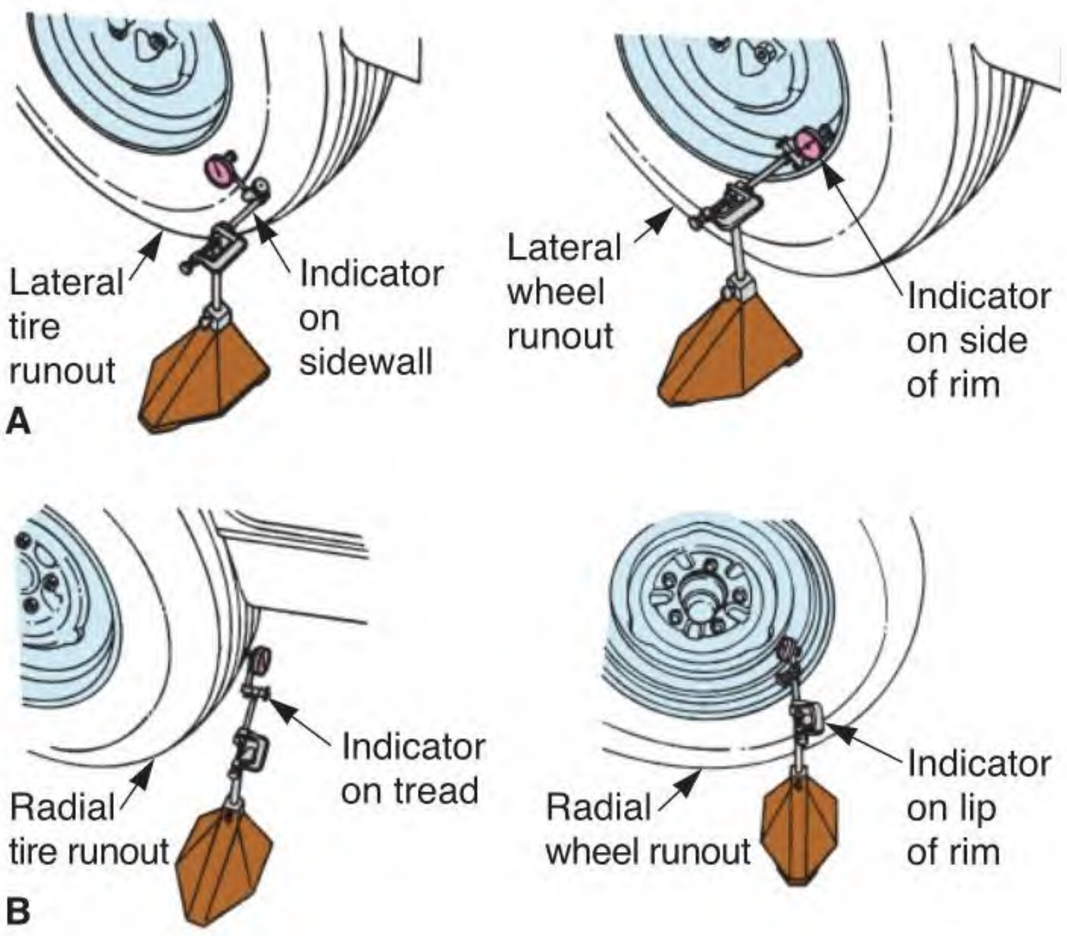
Measuring Tire and Wheel Runout

Tire runout or wobble is caused by a faulty tire (ply separation or manufacturing defect). ***Wheel runout***, or wobble, is caused by impact damage or incorrect welding of the spider and rim. When you suspect a minor runout problem, use a dial indicator to measure tire and wheel runout.

Lateral runout is side-to-side movement. It is measured by placing a dial indicator against the side of the rim or on the tire sidewall. A special indicator with a small wheel or roller is commonly used to measure lateral runout. The technician turns the tire by hand while noting the indicator reading. See **Figure 74-10A**.

Radial runout is caused by a difference in radius from the center axis of rotation. It is measured by placing the dial indicator on the tire tread and on the inner part of the rim. Again, the tire is turned by hand and the indicator reading is noted. This is illustrated in **Figure 74-10B**.

Compare your dial indicator readings to specifications. If either lateral or radial runout is beyond specifications, replace the wheel or tire.



Chrysler

Figure 74-10. Using a dial indicator and a large base to measure tire and wheel runout (wobble). A—To measure lateral runout, mount the indicator on the tire sidewall and the side of rim. Rotate the tire and read the indicator. B—To measure radial runout, or out-of-round, mount the indicator on the tread and on the wheel inner lip as shown. Turn the tire by hand and read the indicator.

Sometimes, it is possible to reduce tire runout by rotating the tire 180° on the wheel. Typically, tire radial runout should *not* exceed 0.060″ (1.5 mm). Tire lateral runout should be under 0.090″ (2.0 mm). Wheel radial runout should *not* be over 0.035″ (0.9 mm). Wheel lateral runout should *not* exceed 0.045″ (1.0 mm). However, always refer to exact specifications before condemning a wheel or tire.

Wheel Balance

Improper wheel balance is one of the most common causes of tire and steering wheel vibration. When one side of the tire is heavier than the other, centrifugal force tries to throw the heavy side outward when the tire is spinning. There are two types of tire imbalance: static imbalance and dynamic imbalance.

Static imbalance, called *wheel tramp* or *hop*, causes the tire to vibrate up and down. For a wheel and tire assembly to be in static balance, its weight must be evenly distributed around the axis of rotation. See **Figure 74-11A**.

Dynamic imbalance causes both ***wheel hop*** (up-and-down movement) and ***wheel shimmy*** (side-to-side movement). To be in dynamic balance, the top-to-bottom weight and side-to-side weight must all be equal, **Figure 74-11B**.

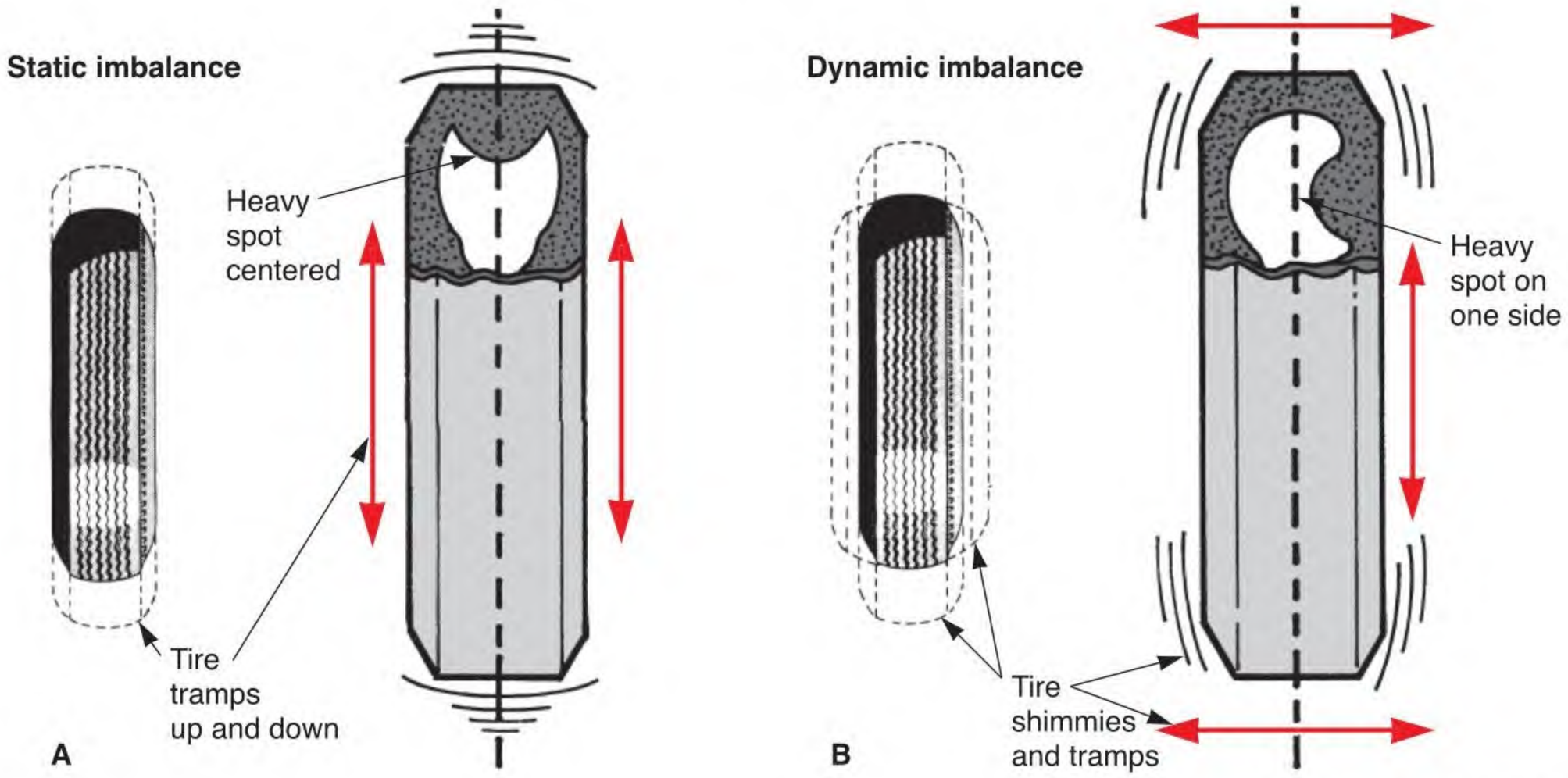
When *not* in dynamic balance (one side heavier than the other), centrifugal force tries to throw the heavy area outward. As a result, the tire and wheel assembly is pushed one way (thrown downward and toward center) and then the other way (thrown upward and away from center).

Wheel Balancing

Wheel balancing involves adding ***wheel weights*** (special lead weights that clip or stick on the rim) to the side opposite the heavy area found on the wheel/tire assembly. Lead wheel weights for steel wheels often clip over the edge of the rim. Special aluminum wheel weights have a wider opening and can be hammered in place on thicker aluminum wheels. Lead weights for soft aluminum wheels have an adhesive backing to adhere the weight onto the inner wheel drop center area.

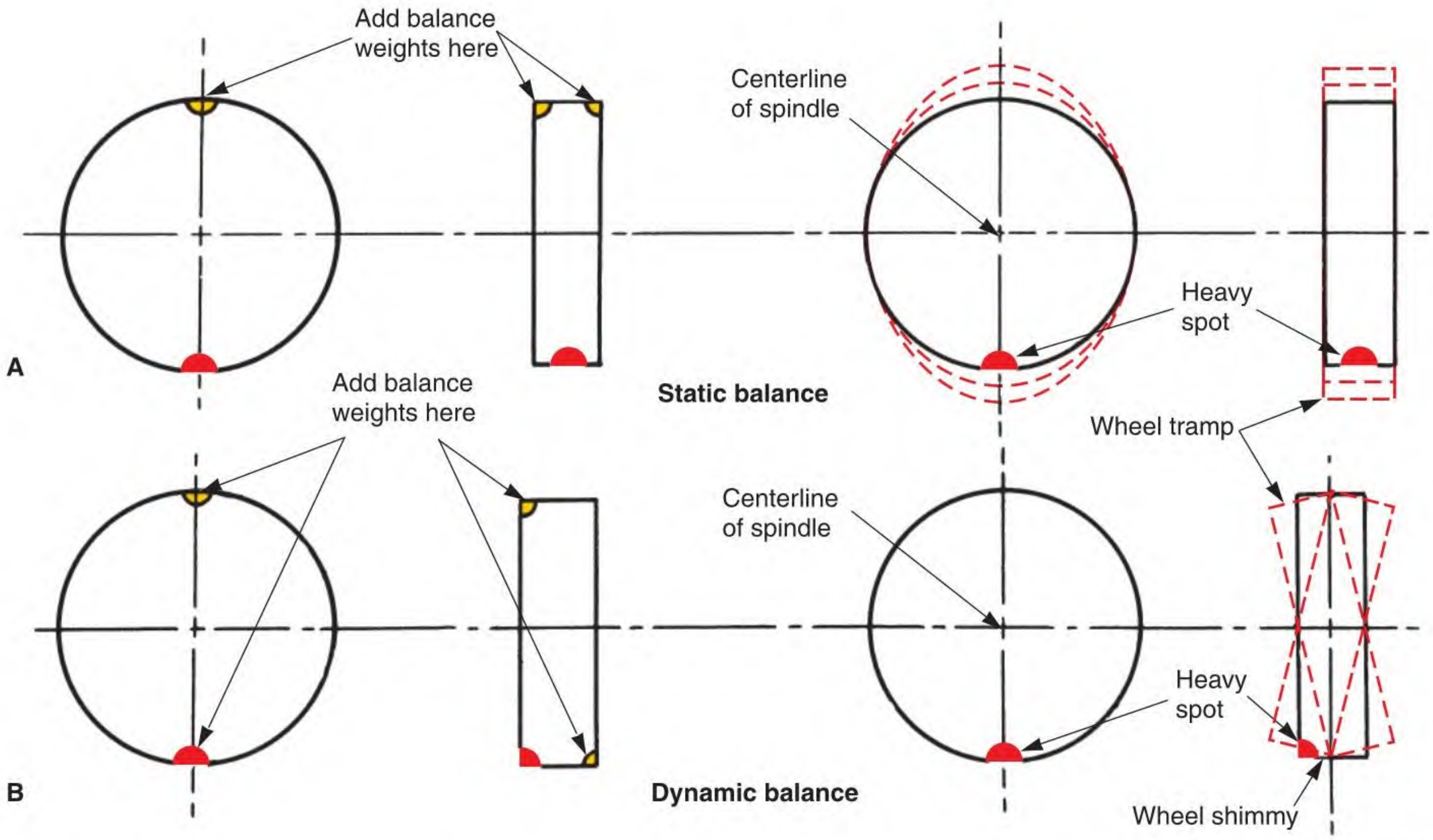
To static balance a wheel and tire assembly, add wheel weights opposite the heavy area of the wheel. If a large amount of weight is needed, add half to the inside of the wheel and the other half to the outside of the wheel. This helps keep dynamic balance correct. Look at **Figure 74-12A**.

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Figure 74-11. Static and dynamic imbalance are common causes of vibration. A—Static imbalance will cause tire to vibrate up and down. It is caused by a heavy spot located in the center of the tire tread. B—Dynamic imbalance will make tire vibrate from side to side and up and down. The heavy spot on tire is to one side of the tread or on sidewall.



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Figure 74-12. Note the basic procedure for correcting static and dynamic imbalance. A—Static imbalance will cause wheel tramp. Add weight opposite the heavy area on both sides of the wheel. Each weight should be half as heavy as the heavy spot on the tire. B—Dynamic imbalance will cause wheel shimmy. Add weight in two locations to counteract the heavy area.

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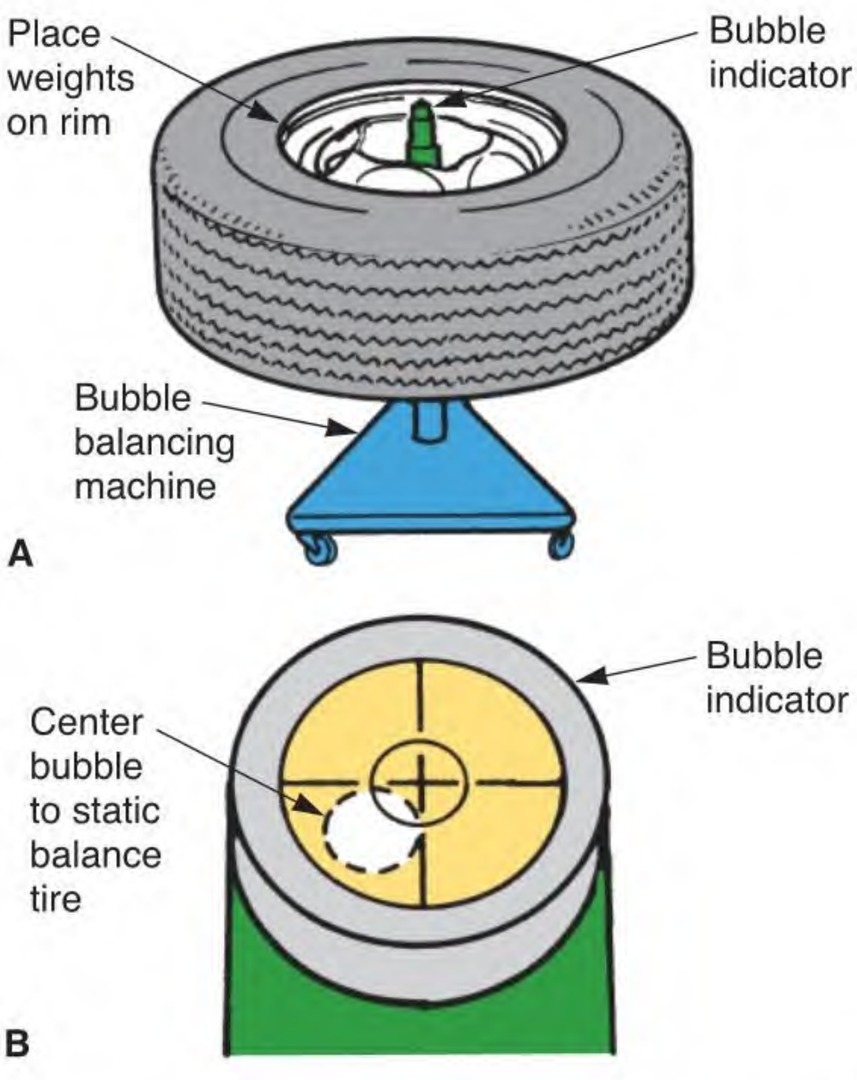
To dynamically balance a wheel and tire, you must add weights exactly where needed, **Figure 74-12B**. The dynamic balancing machine will indicate where and how much weight to add to bring the assembly into dynamic balance.

When balancing a wheel assembly, follow these safety rules:

- Wear eye protection when spinning the wheel and tire assembly.
- Remove rocks and other debris from tire tread before balancing the wheel assembly.
- Follow the operating instructions provided with the wheel balancing equipment. Machine designs vary and so do operating procedures.

Wheel Balancing Machines

A ***wheel balancing machine*** is used to determine which area of a wheel/tire assembly is heavy. A ***bubble balancer*** will static balance a wheel and tire assembly. The wheel and tire assembly must be removed from the car and placed on the balancer. An indicating bubble on the machine is then used to locate the heavy area of the assembly. Wheel weights are added to the wheel until the bubble is *centered* on the crosshairs of the machine. See **Figure 74-13**.



Ammco

Figure 74-13. A bubble balancer will correct static imbalance only. A—The tire is mounted on a bubble balancer as shown. B—Use balancer instructions to place weights on the wheel until the bubble centers in the circle on the balancer head.

An ***off-car balancer*** can either be a static- or dynamic-type machine. The wheel and tire assembly is mounted on the balancer and spun. The machine will detect vibration of the assembly and indicate where wheel weights should be added on a monitor screen. See **Figure 74-14**. After adding weights, spin the tire again to check for vibration. When perfectly balanced, the balancing machine will indicate zero weight is needed.

Mounting and Dismounting Tires

When mounting or dismounting a tire on its wheel, ***tire changing machine***, often called a ***tire changer***, is used to force the rubber tire on and off the metal wheel. One type of tire changer is illustrated in **Figure 74-15**.

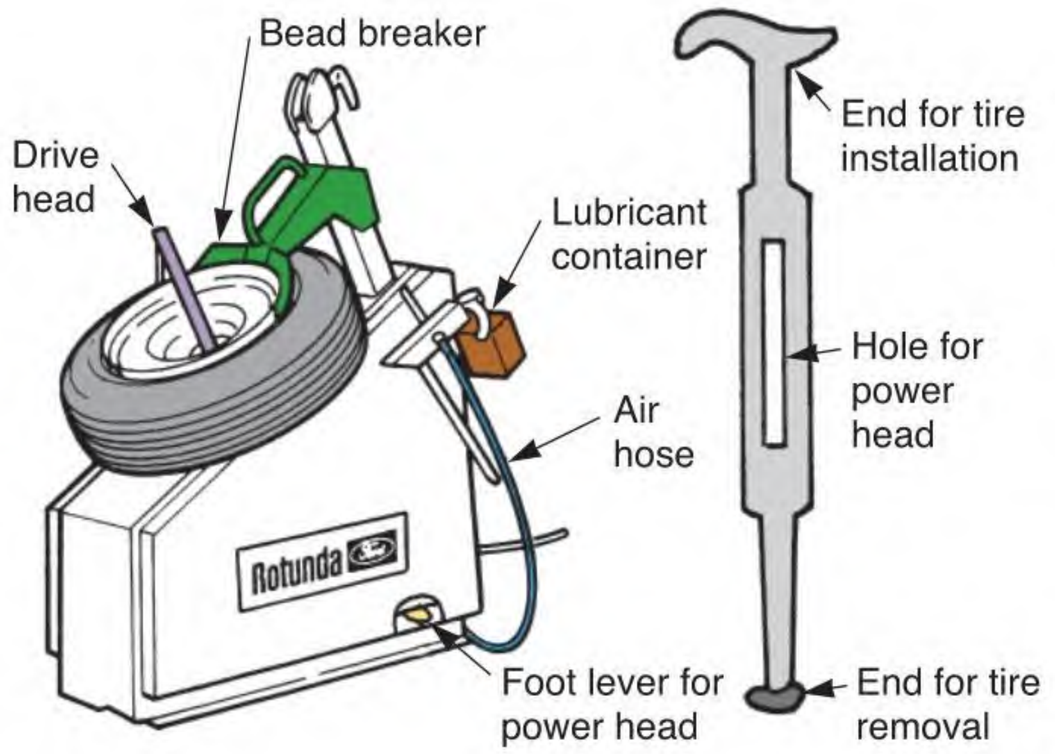
The pneumatic ***bead breaker*** is used first to force the tire bead away from the wheel rim, **Figure 74-16**. The bead beaker arms should be positioned to contact the tire



Hunter Engineering Co.

Figure 74-14. This wheel balancer applies the pressure of a steel roller to the tire tread when spinning and balancing the wheel/tire assembly. A roller spins with the tire to measure run-out and to more closely emulate driving conditions. The computer screen indicates where to add stick-on wheel weights.

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Ford

Figure 74-15. Modern tire changers use air pressure to force the tire on and off the wheel. Follow all safety rules provided with the equipment. The bar is mounted on the power head. The head turns the bar to force the beads over the rim.

bead and not the wheel. Then, a special bar is attached to the machine's drive head. The head turns the bar, which pries the bead over and off the rim. The other end of the bar is used when installing the tire on the wheel.

A few rules to follow when mounting or dismounting tires include:

- Wear eye protection and remove the valve core before breaking the bead away from the wheel.
- Keep your fingers out of the way when removing a tire from a wheel.
- Never mount a tire on a rim that is *not* smooth and clean.
- Always lubricate the tire bead and wheel flange with proper lubricant (vegetable oil-soap solution) before mounting a tire. *Never* use antifreeze, motor oil, or any other nondrying petroleum-based substance as a lubricant. Tire deterioration or movement on the wheel may result.
- Use care when mounting or dismounting tires on wheels equipped with air pressure sensors. Improper procedures may damage these sensors.



A B

Hunter Engineering Co.

Figure 74-16. Always follow operating instructions for the specific make and model of the tire changer. A—Tire changers exert tremendous force to stretch tire beads on and off the wheel. Use care. B—Automated tire changers greatly simplify equipment operation. Make sure you read operating instructions for the particular unit before use.

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- Do *not* inflate a tire when it is lying on the floor. When the beads seat, the tire could fly dangerously into the air.
- Stand away from the tire when adding air after mounting. Usually, a loud "pop" sound will be made when the beads seat.
- Do *not* exceed 40–50 psi (276–345 kPa) when initially inflating a tire to seat its bead on the wheel.
- After initial inflation, install the core and inflate the tire to the recommended pressure.

Some modern, automated tire changers use a rubber wheel or plastic covered arm to force the bead back over the wheel. This protects wheels from paint damage or scuffing of the finish.

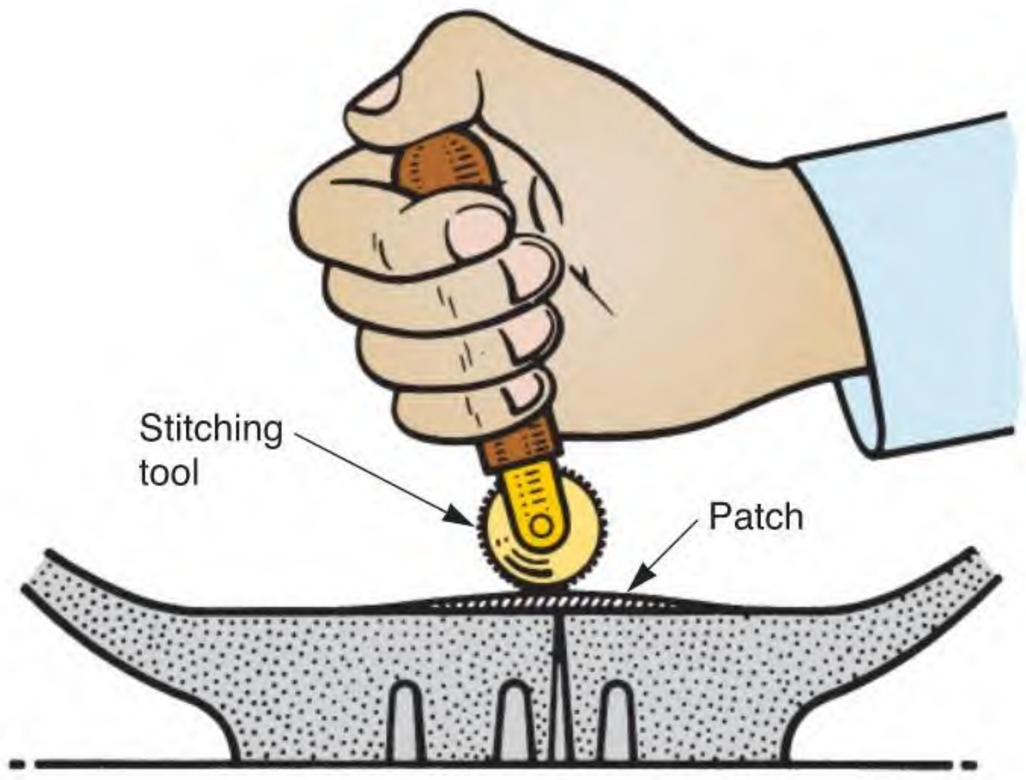
Tire Puncture Repair

To find a leak, fill the tire with air. Then, place the tire in a drum full of water or wet the tire with soapy water in a spray bottle. Look for air bubbles forming on the tire. Bubbles indicate a leak. Mark the leak with a crayon or chalk.

Service Procedure

To properly repair a small tire puncture:

1. Remove the tire from the rim.
2. After dismounting the tire, *inspect* the inside surface carefully to locate the puncture and to determine the nature and extent of the damage.
3. Fill the injury to the tire using a recommended plug or liquid sealant.
4. Select a patch that extends well beyond the damaged area, so that it will adhere properly to the inner liner and withstand the heat and mechanical stresses of tire use.
5. Scuff (roughen) the area that the patch will cover, so that it will adhere tightly.
6. Apply the proper cement (adhesive) to the inner liner, following the repair kit directions.
7. Remove the covering from the adhesive side of the patch and carefully place the patch on the inner liner.
8. Use a stitcher tool to tightly bond the patch to the inner liner. See **Figure 74-17**.



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Figure 74-17. Patch on inside of tire is needed for all repairs. Basically, scuff the area around the injury. Apply a coat of approved cement. Remove the cover from the patch and apply the patch over the damage. Use a stitcher to adhere the patch to the tire liner.

The following are a few basic rules for tubeless tire repair:

- Do *not* attempt to repair a puncture by plugging it from the outside of the tire. *Always* dismount the tire and patch the inner liner.
- Never attempt to repair sidewalls or tires with punctures larger than 1/2″ (13 mm) in diameter.
- When removing an object from the tire, reduce air pressure to 15 psi (103 kPa) or less.
- Broken strands in steel belted tires may indicate serious damage. Also, the broken strands could puncture the patch or plug, causing a serious tire failure.
- Follow the exact procedures given with the tire repair kit.

Tech Tip

Do not perform a quick tire repair by simply inserting a rubber or rope plug into the hole in the tire. According to the Rubber Manufacturer's Association (RMA), using a plug to attempt a tire repair without dismounting is effective only 80% of the time. The remaining 20% will result in tire failure, which may take the form of a dangerous sudden deflation. RMA lists two requirements for correct puncture repair: the damage to the tire must be filled and the inner liner must be soundly patched.

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Tire Pressure Monitoring System Service

There are two types of tire pressure monitoring systems: direct systems and indirect systems.

A direct tire pressure monitoring system uses pressure sensor mounted inside each tire to monitor tire pressure and report low-pressure conditions to a receiver in the passenger compartment. Each pressure sensor is capable of generating a weak electromagnetic radio wave, and the output frequency represents tire air pressure. The ECM has its own antenna tuned to this frequency for interpreting the radio signals coming from the four tire pressure sensors. Direct tire pressure monitoring sensors may or may not contain a small battery.

An ***indirect tire pressure monitoring*** system relies on the anti-lock brake system wheel speed sensors to monitor wheel rotational speeds and tire pressure. A tire with very low air pressure has a smaller effective diameter or circumference. The vehicle's wheel spindle is also closer to the ground. The smaller-diameter, deflated tire rotates a little faster than the fully-inflated, larger-diameter tires.

If a tire in a direct system has low air pressure but the system does not activate, suspect the tire pressure sensors. These sensors are battery operated and the batteries can become drained after a long period of service. In most cases, a sensor must be replaced when its battery becomes discharged. If the sensors are working properly, the problem may be in the receiver, the warning light, or the wiring between the receiver and the warning light.

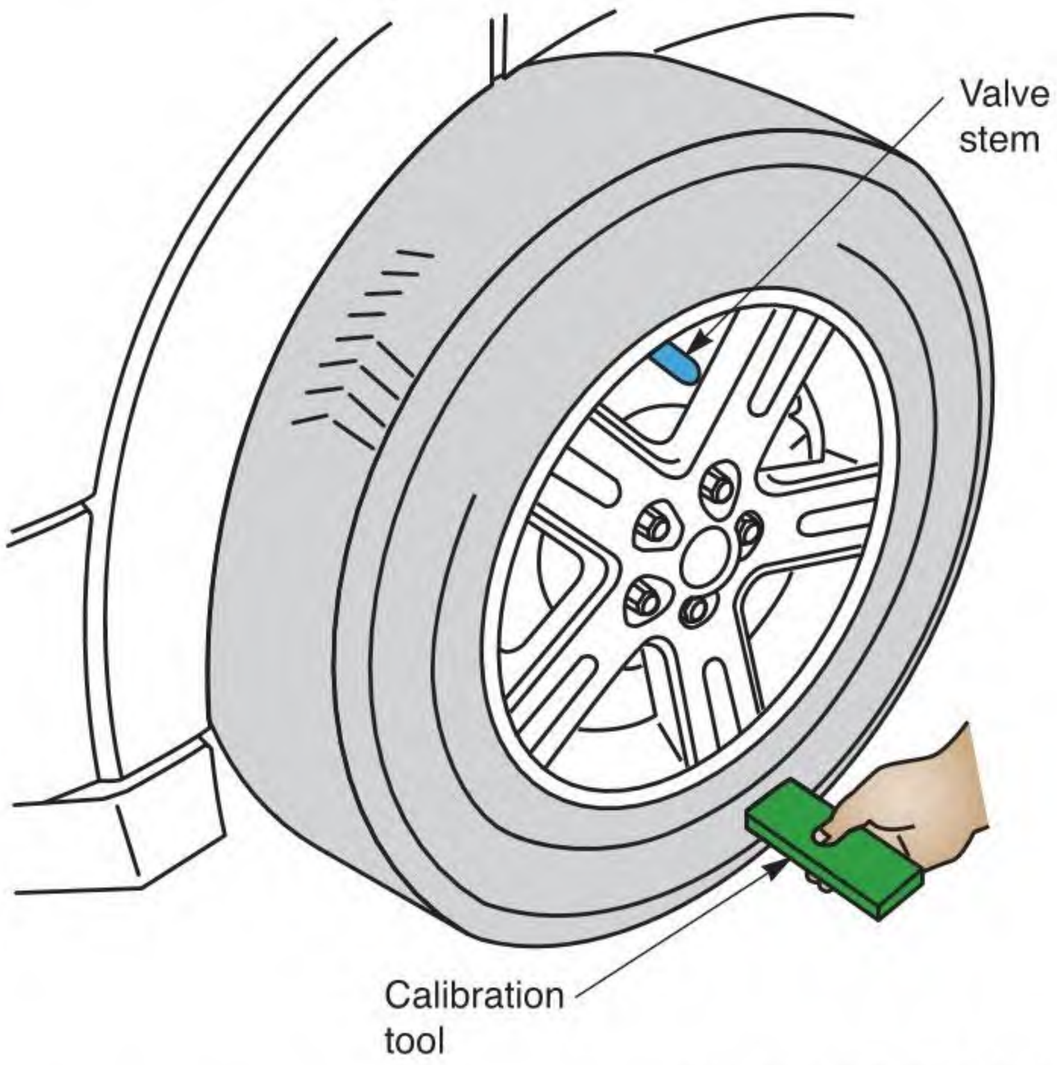
Tech Tip

Many manufacturers recommend that the battery-powered tire pressure sensors be replaced whenever the tires are replaced. Battery life for these sensors is typically 5–6 years.

Care must be taken when removing the tire from a wheel equipped with a pressure sensor. Since the pressure sensor and ring are inside the wheel, do not hit the sensor with the bead breaker bar tool. Position the breaker bar near the valve stem to avoid contact with the sensor. When removing the tire from a wheel equipped with a stem-mounted sensor, position the valve stem 180° from the bead breaker on the tire machine to prevent sensor damage.

When installing a new drop center-mounted sensor, position new sensor 180° from the valve stem. When installing a valve-mounted sensor, use new stem seals and torque the stem retaining nut to specifications to prevent leaks and damage to the sensor. After pressure sensor replacement, be careful not to damage the sensor when reinstalling the tire on the wheel. Most sensors will begin transmitting a signal within two minutes after you inject normal air pressure into the tire.

After a sensor is replaced or a vehicle's tires are rotated, the sensors must be calibrated using a dedicated calibration tool so the receiver recognizes which sensor is at which wheel. To calibrate a sensor, inflate the tires to the correct air pressure. Then, aim the calibration tool at the sensor inside the tire and press the calibration button on the tool, **Figure 74-18**. This will force the sensor to transmit a signal. There is generally a specific sequence that you must follow when calibrating the pressure sensors. For example, you might have to begin at the left front tire, then move to the right front, the right rear, and finally the left rear. Follow the instrument instructions to program the vehicle ECM to read accurately. The frequency produced by the sensor should be programmed to read the exact air pressure you installed in the tire earlier.



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Figure 74-18. A calibration tool is needed to calibrate a tire pressure sensor. After inflating the tire to the recommended pressure, hold the tool near the sensor and then press the button on the tool to calibrate the sensor. This particular tire has a sensor located in the drop center of the wheel, 180° from the valve stem.

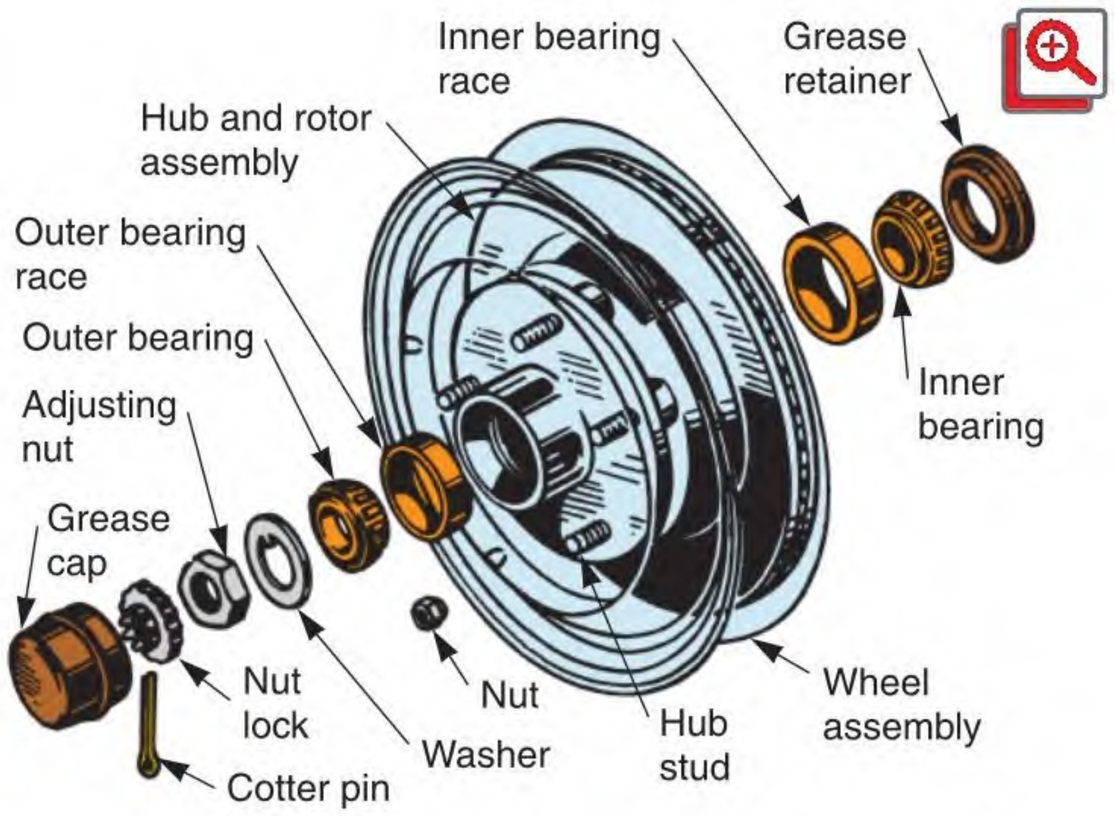
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Problems in indirect tire pressure monitoring systems are often caused by faulty wheel speed sensors. Malfunctions in indirect systems generally also cause anti-lock brake system malfunctions. In most cases, these systems can be diagnosed using a scan tool and standard anti-lock brake system troubleshooting procedures.

Wheel Bearing Service

Wheel bearings are normally filled with grease. If this grease dries out, the bearing will fail. It is wise to check wheel bearings for wear when performing wheel- or tire-related service. Some wheel bearings can be disassembled and packed (filled) with grease. Others are sealed units that require replacement when worn.

As you will learn, service methods for vehicles with rear-wheel drive are quite different than those for vehicles with front-wheel drive.



Ford

Figure 74-19. Servicing a nondriving hub and tapered roller wheel bearing assembly involves cleaning, inspection, lubrication, and adjustment. Study how parts fit together.

Tech Tip

If, during your test-drive, you hear the hum of a bad wheel bearing, there is an easy way to verify your diagnosis. Raise the car on a lift and rotate the tire and bearing while touching the suspension spring with your other hand. Spring oscillations will amplify the rough, dry bearing so that you can feel the vibration more easily. A stethoscope held on the knuckle will also allow you to hear the rough, dry bearing noise.

Servicing Wheel Bearings (Tapered Roller Bearings)

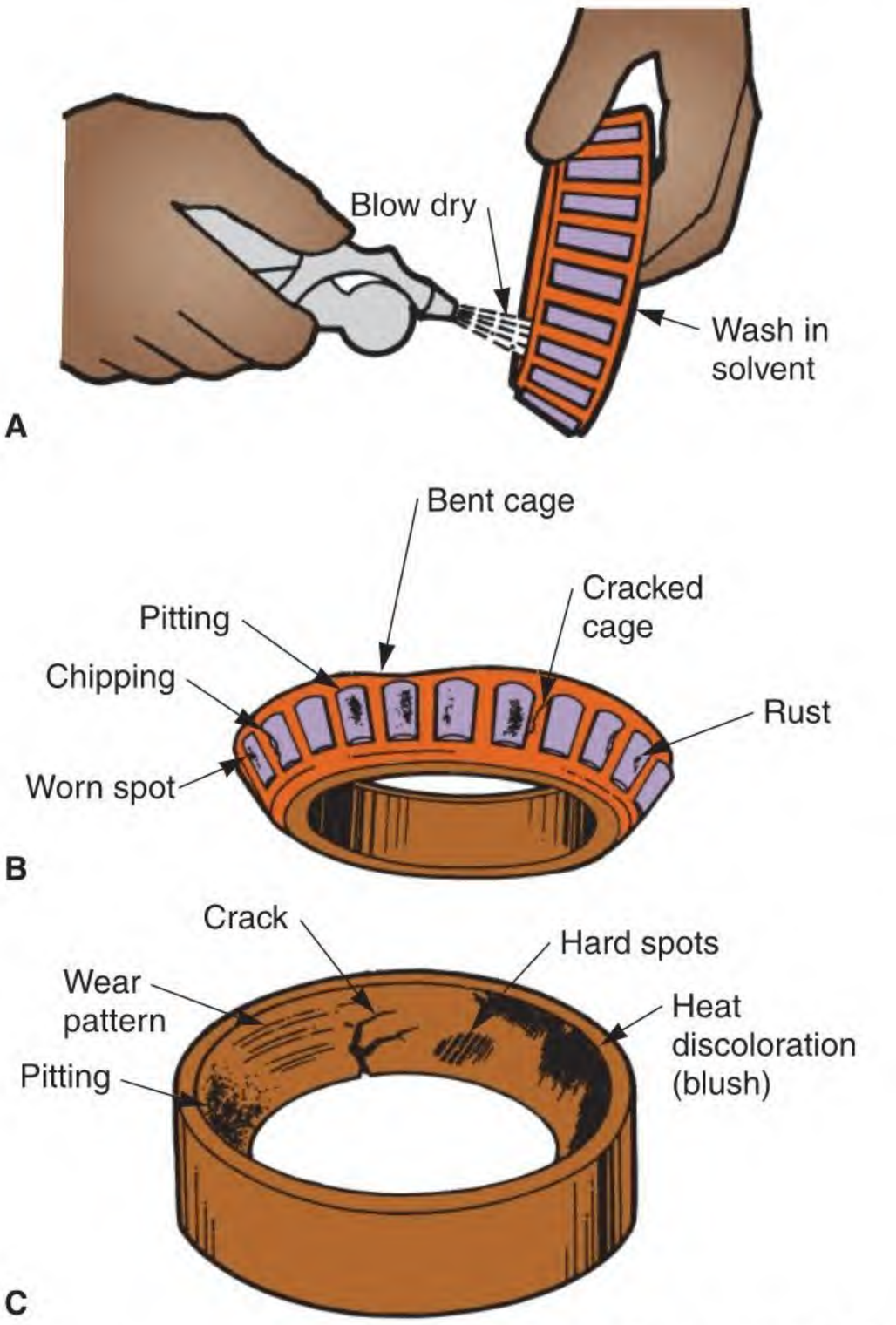
An exploded view of a typical nondriving tapered roller wheel bearing assembly is shown in **Figure 74-19**.

Service Procedure

To disassemble tapered roller bearings:

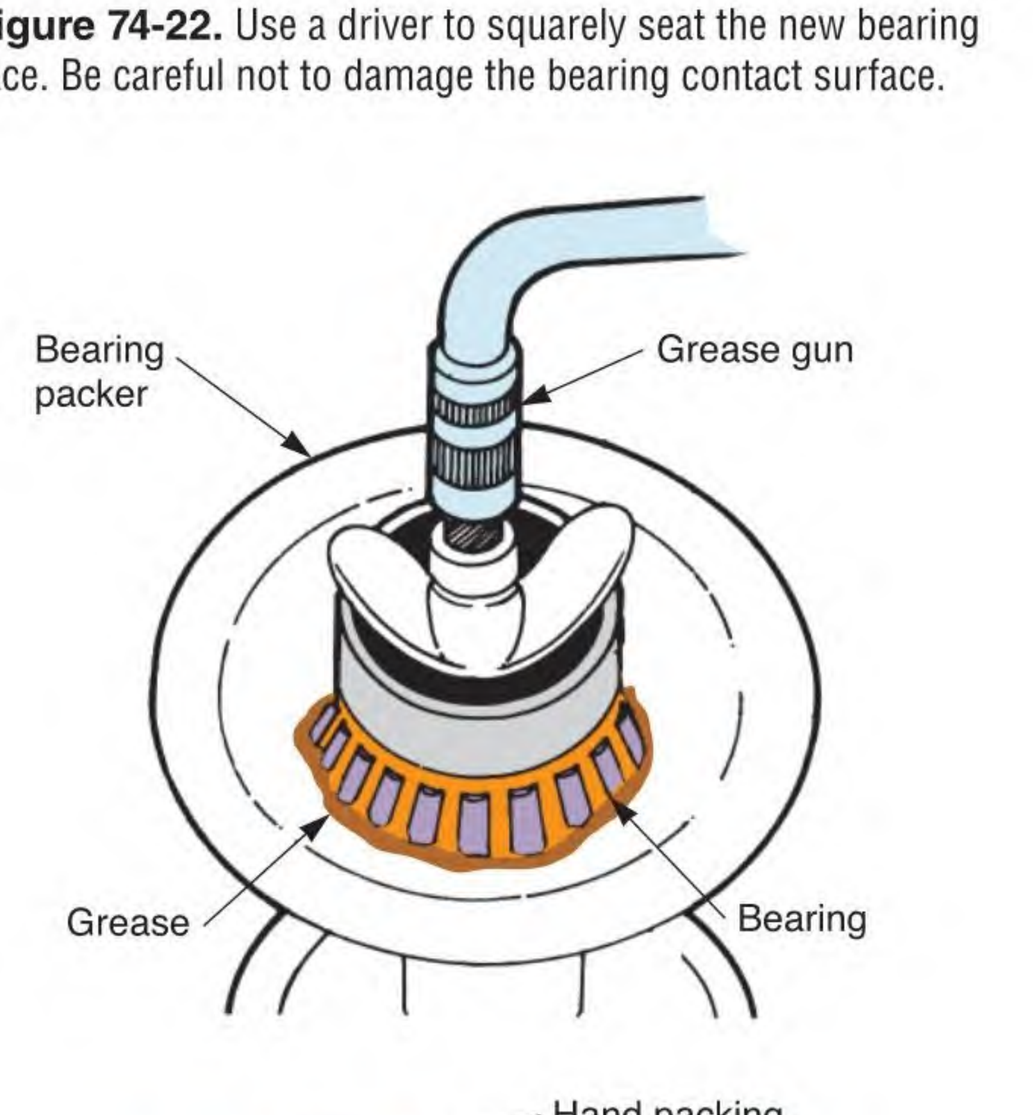
1. Partially loosen the lug nuts.
2. Raise the vehicle and secure it on jack stands.
3. Remove the wheel, grease cap, cotter pin, nut lock, adjusting nut, and safety washer.
4. Wiggle the hub and pull out the outer wheel bearing.
5. Screw the adjusting nut back onto the spindle.
6. Unbolt the brake caliper and secure it to one side, if needed.
7. Slide the hub outward on the spindle. When the inner bearing catches on the adjusting nut, the grease seal and the inner wheel bearing will pop out.
8. Wipe the bearings and races clean.
9. Keep the bearings in *order*, because they must be reinstalled in the same races.
10. Closely inspect the bearings and races for damage. If problems are found, you must replace both the bearing and race as a *set*. See **Figure 74-20**.
11. To replace a bearing race, drive out the old race with a large drift punch and hammer, **Figure 74-21**. Be careful not to damage the hub.
12. To install the new race, use a driving tool, as shown in **Figure 74-22**.
13. Wipe out all the old grease from the inside of the hub.
14. Partially fill the cavity with new wheel-bearing grease. Use the recommended type of grease. High-temperature wheel-bearing grease is recommended in most cases.
15. To pack the bearings, use your hands or a ***bearing packer*** (device for filling bearing cage with grease) to properly lubricate the bearing assemblies. Make sure grease is worked completely through each bearing cage and around every ball or roller, **Figure 74-23**.

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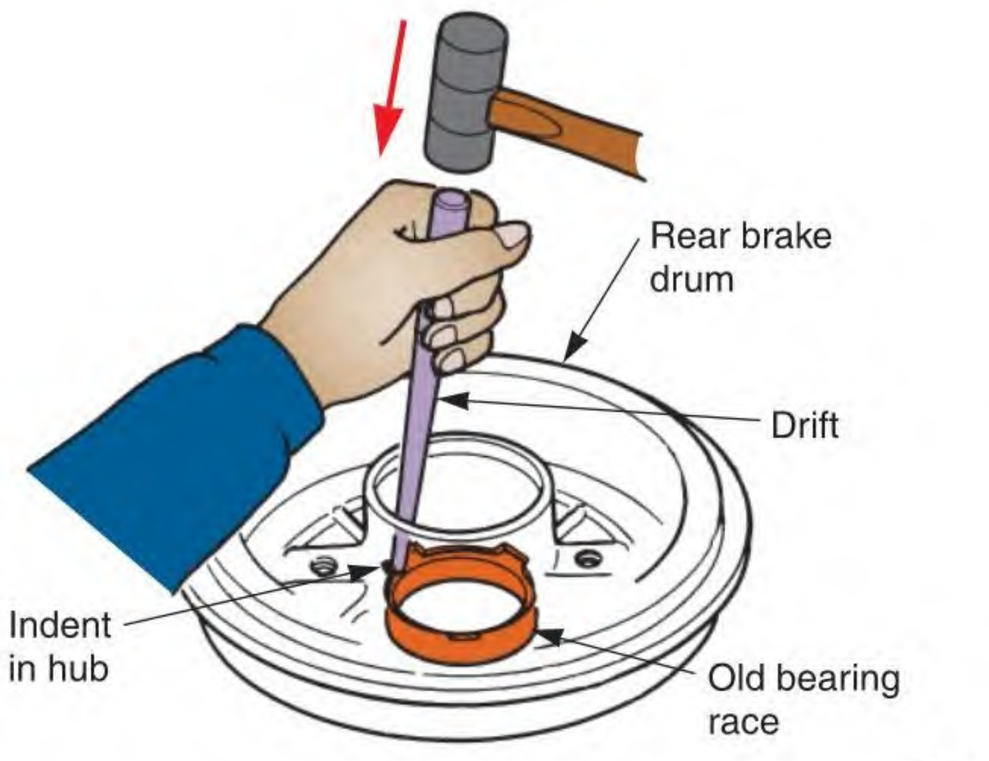
Florida Dept. of Voc. Ed.

Figure 74-20. Clean bearings and races before inspecting for wear and damage. A—Wash and dry bearings. Do not let bearings spin while blowing them dry. B and C—Inspect the bearing and race for these kinds of troubles.



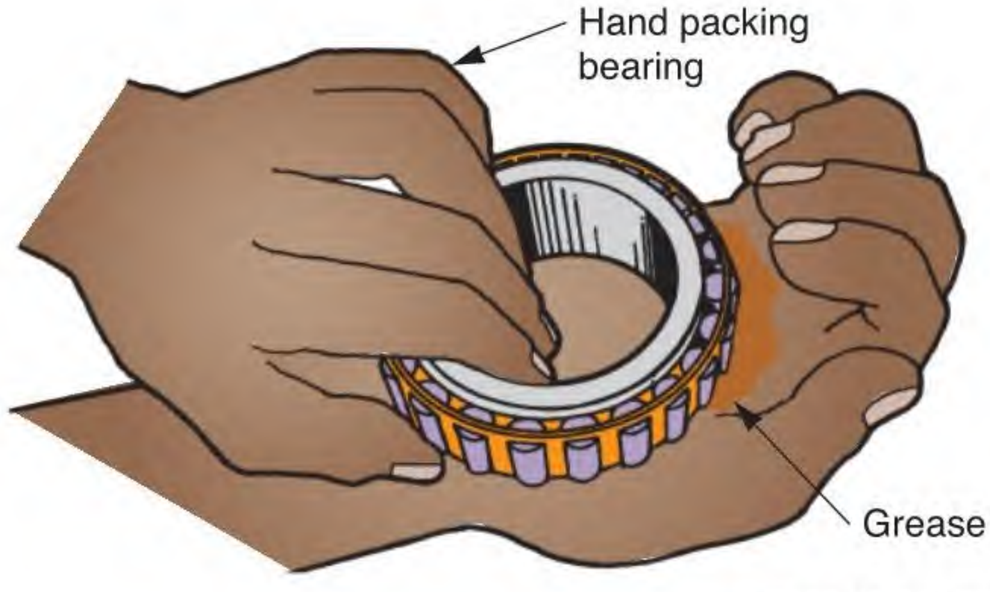
Honda

Figure 74-22. Use a driver to squarely seat the new bearing race. Be careful not to damage the bearing contact surface.



Honda

Figure 74-21. If a bearing is bad, the race will also be damaged and must also be replaced. Use a flat-nose drift to force the old race out of the hub.



Florida Dept. of Voc. Ed.

Figure 74-23. Pack bearings with quality, high-temperature wheel-bearing grease. Use either a bearing packer or the palm of your hand to work grease into cage and around rollers.

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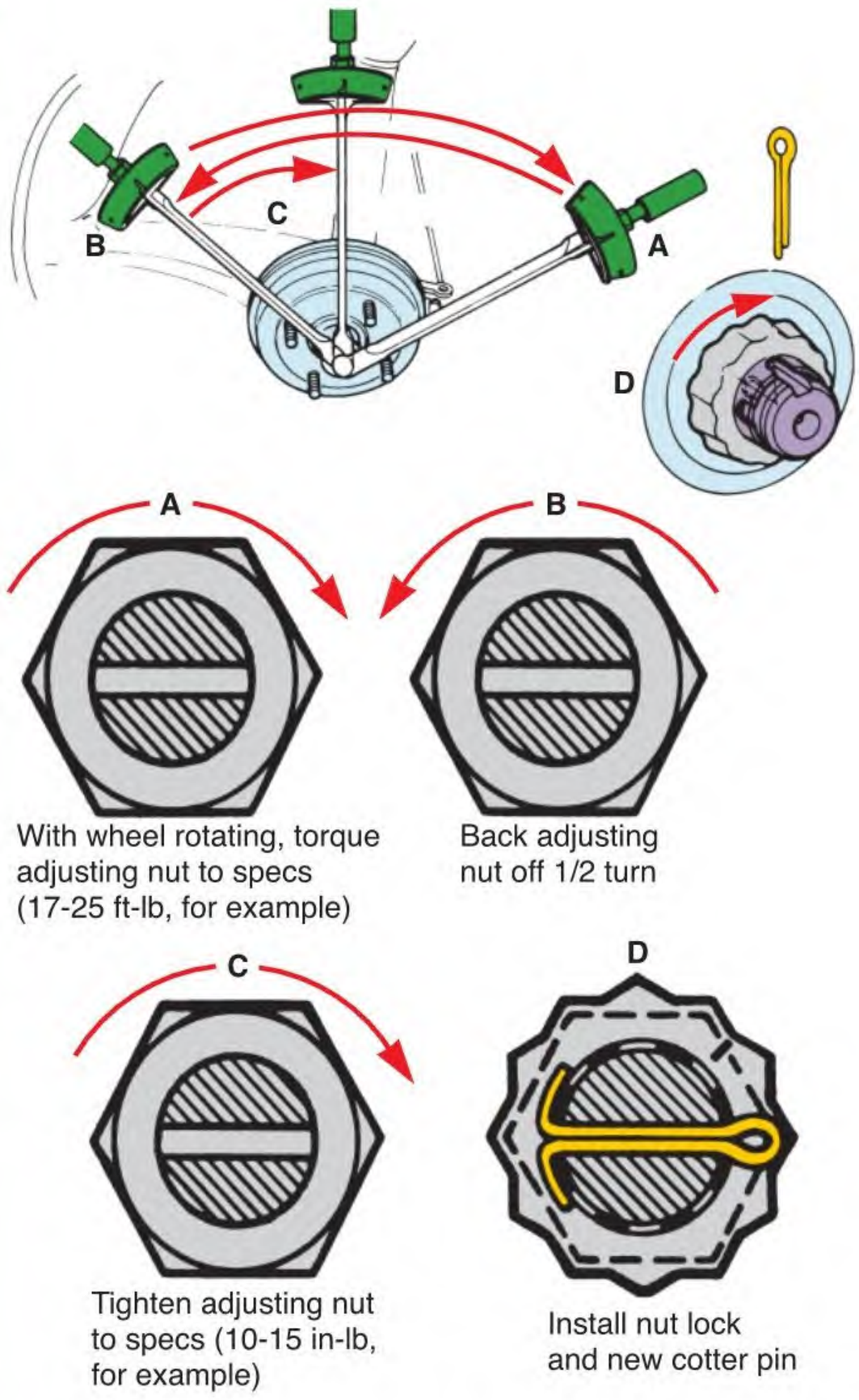
Caution

Do not use all-purpose wheel-bearing grease in wheel bearings on cars with disc brakes. The heat generated by the brakes can liquefy the grease and cause leakage out of the grease seals.

16. Place the inner bearing into its race.
17. Using a seal driver, install the new grease seal in the hub. If a seal driver is not available, drive the seal into the hub with light taps from a hammer. Tap in a circular pattern around the seal. Make sure you do not dent the seal.
18. Wipe the spindle clean.
19. Slide the hub into position and install the outer bearing.
20. Fit the safety washer against the bearing and screw on the adjusting nut.
21. Tighten the adjusting nut as described in a service manual. One manual gives the procedures presented in **Figure 74-24**.
22. Install the nut lock.
23. Install and bend the new cotter pin. This is very important because it keeps the adjusting nut, bearings, hub, and front wheel from falling off.
24. Force the dust cap back into the hub to protect the bearings from road dirt or water.

Caution

Keep grease off the brake disc or drum when servicing the wheel bearings. The slightest amount of grease could ruin the brake pads or shoes or cause squeaking.



Honda; Ford

Figure 74-24. Typical procedure for tightening the adjusting nut on a nondriving wheel bearing assembly. A—Torque the nut to specifications to seat the bearings. Rotate the hub. B—Back off the adjusting nut one-half turn. C—Tighten the adjusting nut to specs (about one foot-pound or less). D—Install a new cotter pin.

Servicing Wheel Bearings (Ball or Straight Roller Bearings)

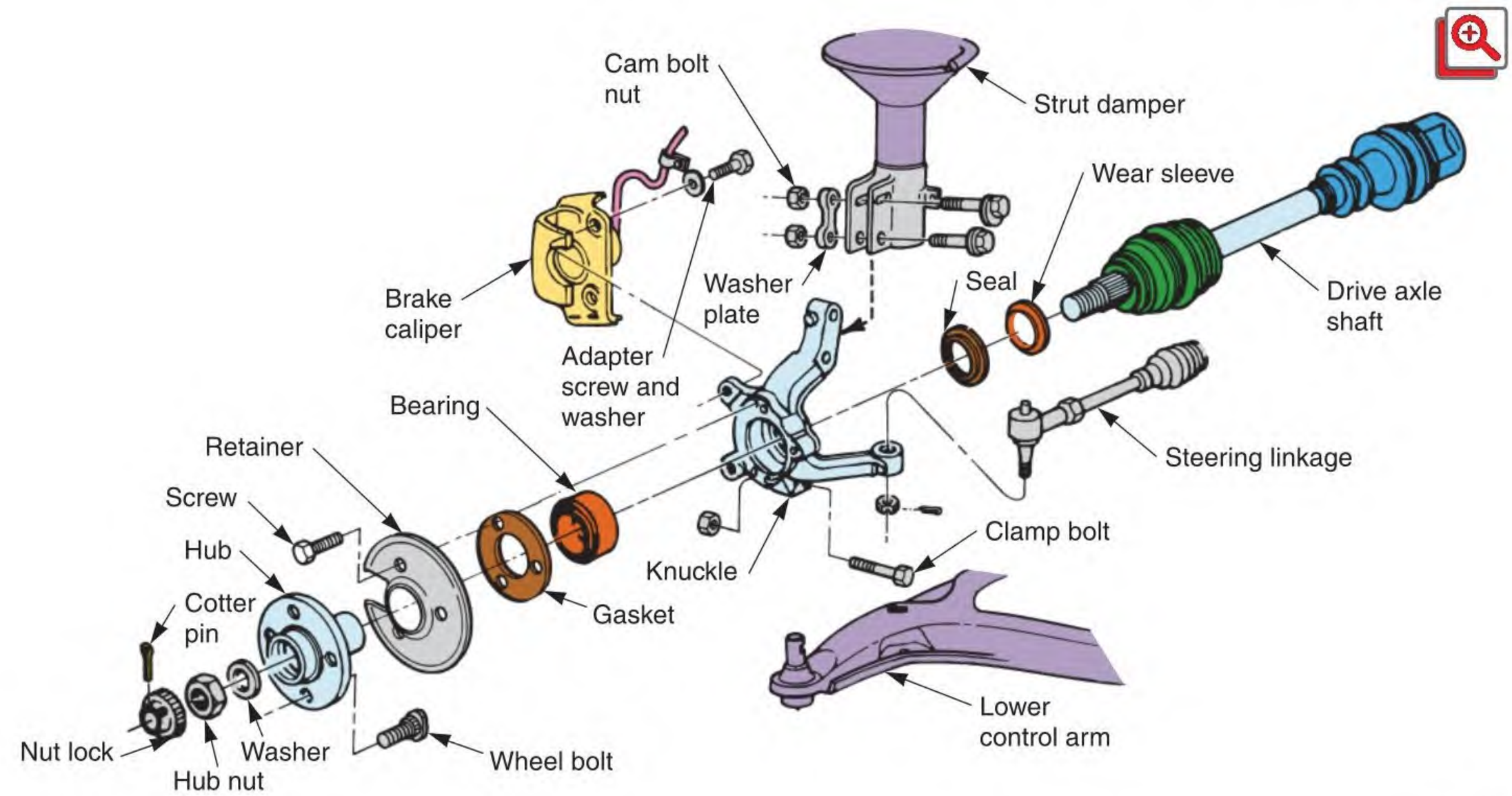
Ball or straight roller wheel bearing assemblies are normally not serviced unless specified or when major repairs are needed. **Figure 74-25** shows an exploded view of a typical driving hub and wheel bearing assembly.

Service Procedure

To service a front-drive ball-type wheel bearing:

1. Loosen the wheel lug nuts and spindle nut.
2. Raise the vehicle and secure it on jack stands.
3. Remove the lug nut or bolts, the wheel, and the axle nut.
4. Remove the caliper and hang it to one side.
5. Unbolt the brake disc from the hub, if needed.

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Chrysler

Figure 74-25. A driving hub assembly requires different service procedures than nondriving unit. The steering knuckle or bearing support must frequently be removed from car to service the bearings.

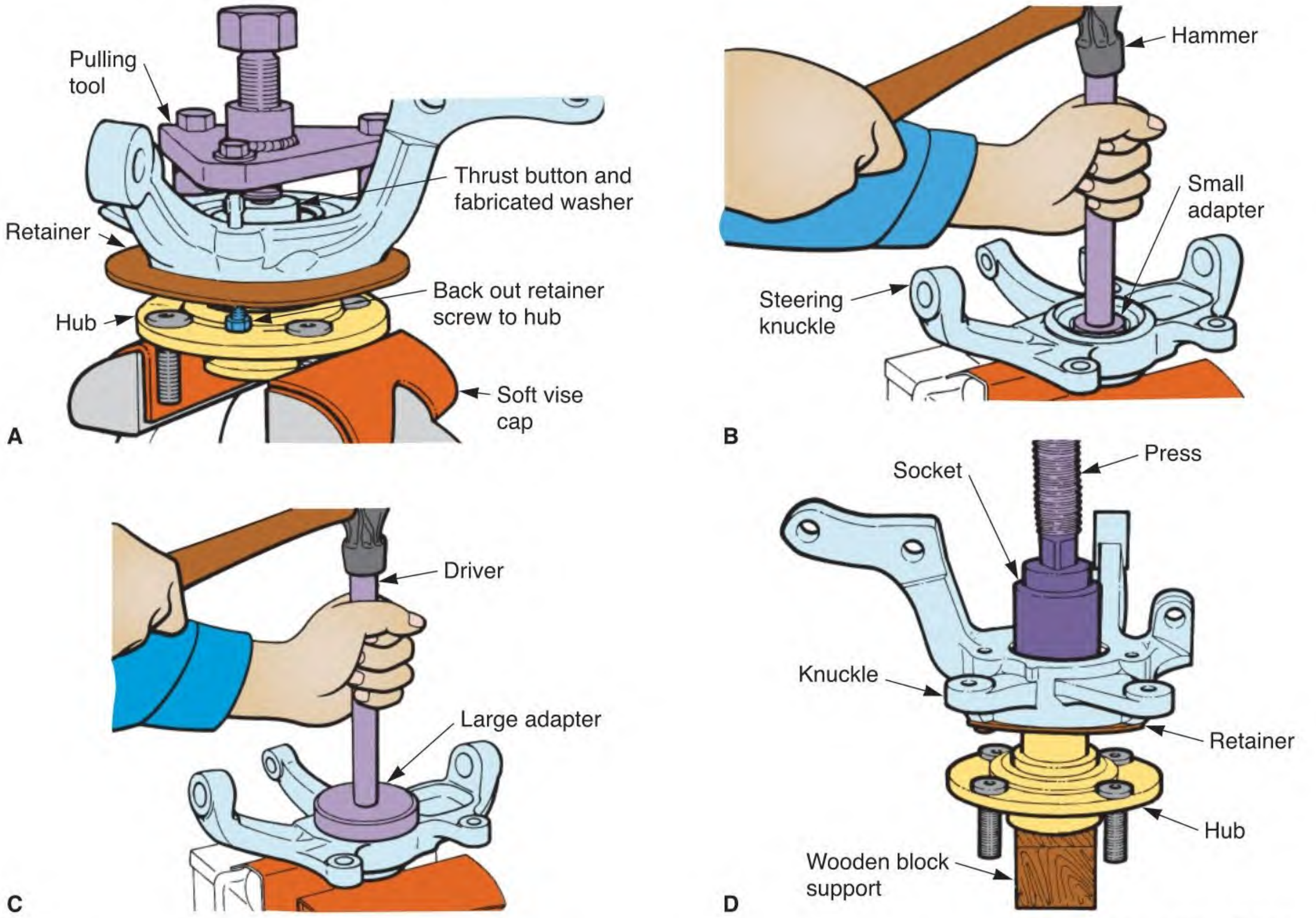
6. Remove the steering knuckle and hub assembly from the vehicle.
7. Depending on the design of the hub, you may need to remove the hub either before or after removing the steering knuckle. See **Figure 74-26A**.
8. After hub removal, remove the bearing using a hydraulic press or a driver.
9. Before installing new bearings, pack them with grease if they are not sealed units.
10. Using a press or driving tool, force the new bearings into place. Follow service manual procedures. See **Figure 74-26B**.

Warning

When pressing new front-wheel drive bearings into position, do *not* exceed manufacturer's press load limits. If excessive pressure is used, parts can shatter and throw metal shards into your work area. Wear eye protection and work gloves when using a hydraulic press on case hardened parts.

11. After pressing or driving the bearings into the steering knuckle or the bearing support, install a new grease seal.
12. Coat the inner lip of the grease seal with grease and the outer diameter with sealer.
13. Use a seal driving tool and light hammer taps to force the seal into the hub. Avoid excessive driving pressure that could bend or distort the seal body and cause leakage. Look at **Figure 74-26C**.
14. Press the hub into the steering knuckle and wheel bearing assembly, if needed. See **Figure 74-26D**.
15. When pressing the wheel bearing in or out, apply force to the correct bearing race (one press fit into part). Bearing damage will result if the incorrect race is pressed and jammed into the bearings. See **Figure 74-27**.
16. After assembling the wheel bearings, install the steering knuckle assembly on the vehicle.
17. Install the brake disc, caliper, and other components.
18. Make sure the spindle nut is tightened to specifications.
19. You may need to ***stake*** (dent or bend) the spindle nut or install a new lock nut and a new cotter pin, **Figure 74-28**.

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Figure 74-26. Basic steps for replacing wheel bearings in driving hub assembly. A—After knuckle or support removal, use a special puller to remove the hub, if needed. B—Remove old bearings using a driver or hydraulic press. Wear safety glasses! C—Install the new bearings and grease seals. D—Use a press to reinstall the hub. Install new grease seals.

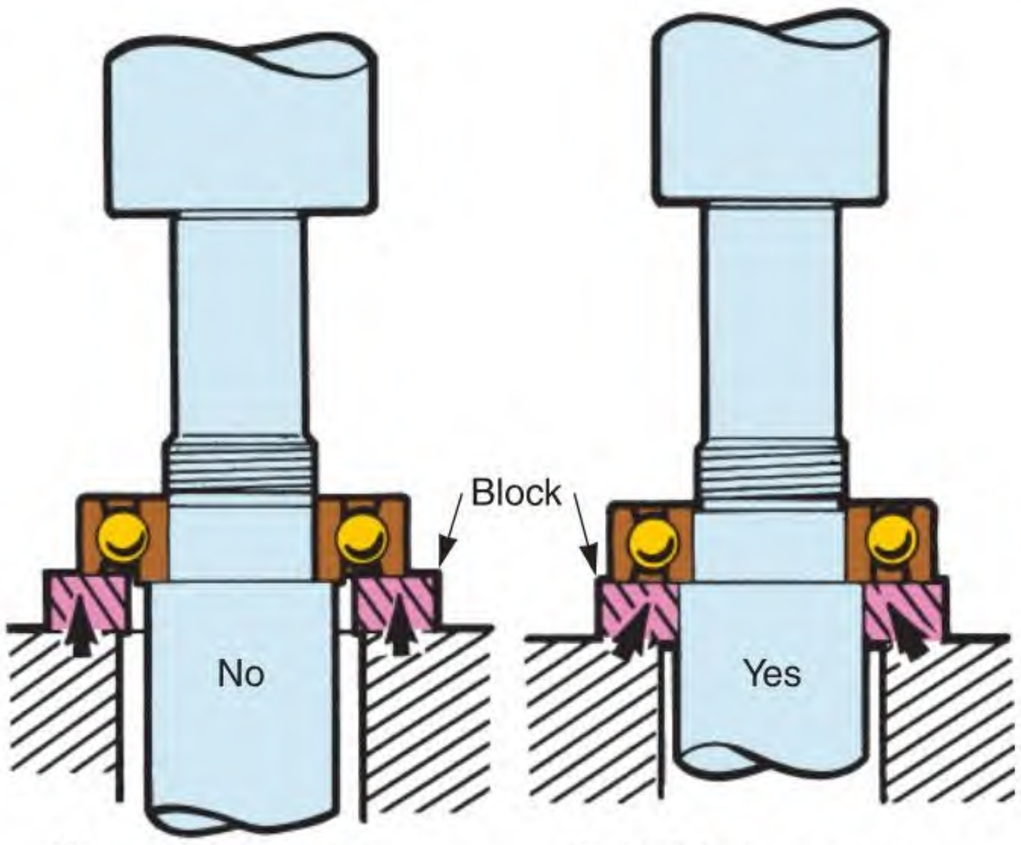
Replacing Nonserviceable Hub and Bearing Assembly

To replace a nonserviceable hub and bearing assembly, remove the bolts holding the bearing and hub assembly to the vehicle. When installing the new hub and bearing assembly, torque the bolts to specifications. Some manufacturers require new fasteners be used when bearings and hubs are replaced.

Tech Tip

A common and time-consuming mistake is to install a front-wheel drive wheel bearing backward. With some front-wheel drive bearings, only one edge has magnets for operating the wheel speed sensor and they are very difficult to see. Since both ends of the bearing have black plastic on them, you must look carefully to locate the tiny ribbing on the side that contains the magnets and trigger wheel. This side must face inward to be in close proximity to wheel speed sensor. If you install this type of front-wheel drive wheel bearing backward, it will trigger a bad wheel speed sensor code during the test-drive. You will have to do the whole repair over again for free to fix your mistake.

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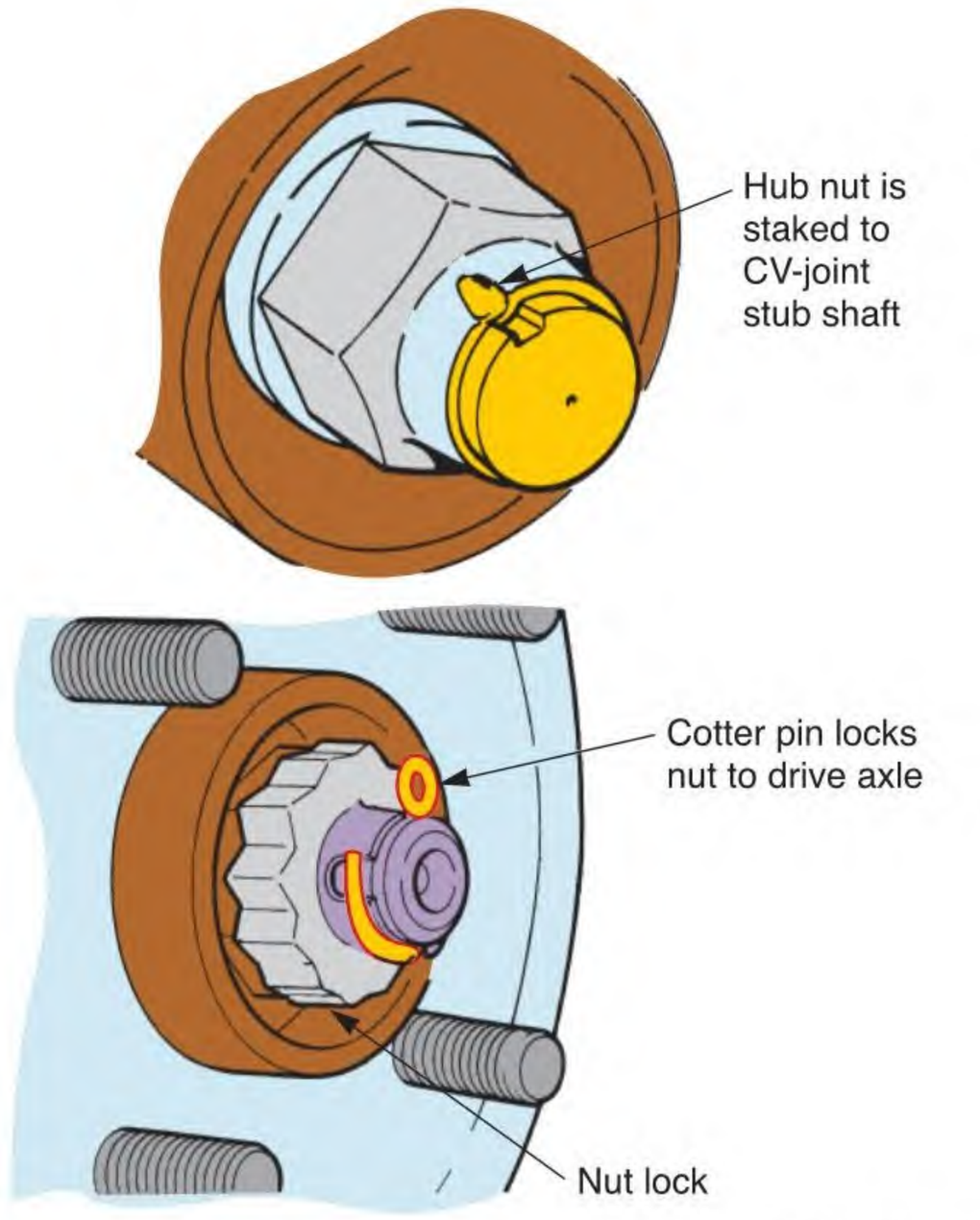


Wrong–Blocks contact bearing outer ring only, could ruin balls.

Right–Blocks contact inner ring–or both rings if bearing is flush faced.

Federal Mogul

Figure 74-27. When pressing bearings in or out, apply driving force so that pressure is not applied to the balls or rollers. This will prevent bearing damage.



Ford; Chrysler

Figure 74-28. After reassembling the driving hub and bearings, make sure you torque the spindle nut to specifications. Stake the spindle nut or install a cotter pin as recommended. This keeps front wheel and hub from coming off, possibly causing a serious accident.

Diagnostic Case Study

Concern: Mr. Watson brings his 2001 Toyota to the shop. He complains of a slight vibration in the steering wheel when driving.

Cause: Duff drives the car to verify the complaint, then raises the car on a lift. He spins each tire and inspects it closely. The tires look good, but he notices a small amount of runout on the lip of one of the lightweight aluminum rims. He turns the repair over to one of the shop's technicians.

The technician uses a dial indicator to check the runout of the rims. The radial and axial runouts are measured for each of the wheels. The two front wheels are bent beyond specifications from impact damage. The runout on the rear wheels is within specifications, less than 0.035" (0.89 mm).

Correction: The technician removes the front wheel-and-tire assemblies from the vehicle. She then uses a tire changer to dismount the front tires and install them on two new rims. Next, she reinstalls the wheels on the vehicle and tightens the lug nuts to factory specifications with a torque wrench. Finally, she test-drives the car and releases it to the customer.

Summary

- Tires are a common source of trouble. Normal wear, damage from road debris, and improper inflation pressure commonly cause tire failures.
- Tire problems usually show up as vibration, abnormal tread wear patterns, steering wheel pull, abnormal noises, and other similar symptoms.
- A tire wear pattern (area of tread worn *off*) can usually be studied to determine the cause of abnormal wear.
- Tire underinflation (low air pressure) is a very common and destructive problem that wears the outer corners of the tread.
- Tire overinflation (too much air pressure) causes the center area of the tread to wear.
- Tire vibration is commonly caused by an out-of-balance condition, ply separation, excessive tire runout, a bent wheel, tire stiffness variation, or tire cupping.

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- Tire noise usually shows up as a thumping sound caused by ply separation or as a whine caused by abnormal tread wear (cupping, for example).
- Wheel bearing noise is normally produced by a dry, worn wheel bearing.
- Tire rotation involves changing the location of the tires on the vehicle to ensure maximum tire life.
- Lug nut torque is very important, especially on vehicles using mag wheels and lightweight hubs.
- Lateral runout is side-to-side movement. It is measured by placing a dial indicator against the side of the rim or on the tire sidewall.
- Radial runout is caused by a difference in diameter from the center axis of rotation.
- Static imbalance causes the tire to vibrate up and down.
- Dynamic imbalance makes the tire vibrate up and down and from side to side.
- A wheel assembly is balanced by adding wheel weights to the side opposite the heavy area found on the wheel/tire assembly.
- When mounting or dismounting a tire, a tire changing machine is used to force the tire on and off the wheel.
- Wheel bearings are normally filled with grease. If the grease dries out, the bearing will fail.
- Never use all-purpose wheel-bearing grease in wheel bearings on cars with disc brakes. The heat generated by the brakes can liquefy the grease and cause leakage out of the grease seals.
- When pressing a wheel bearing in or out, apply force to the correct bearing race (one press fit into part).

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

bead breaker
bearing packer
bubble balancer
dynamic imbalance
improper wheel balance
indirect tire pressure monitoring
lateral runout
lug nut torque
lug studs
off-car balancer
overinflation
ply separation
radial runout
road damage
stake
static imbalance
steering wheel pull
tire changer
tire changing machine
tire impact damage
tire load index number
tire maintenance
tire pressure gauge
tire rotation
tire runout
tire vibration
tire wear pattern
underinflation
wheel balancing machine
wheel bearing noise
wheel cap
wheel cover
wheel hop
wheel runout
wheel shimmy
wheel weights

Activities

1. On a vehicle assigned by your instructor, test a wheel bearing complaint and diagnose the problem.
2. Perform a tire rotation on a vehicle assigned by your instructor.
3. Demonstrate the procedure for balancing a wheel and tire. Describe each step of the procedure and explain why it is done.
4. Use a dial indicator to measure the lateral and radial runout of each wheel on a vehicle of your choice. Record your readings and compare them to specifications.

Review Questions

Answer the following questions using the information provided in this chapter.

1. What are four common symptoms of tire problems?
2. Why is a tire wear pattern useful?
3. A customer complains of excessive right-front tire wear. The tread is worn along the outer edges. The center of the tread shows little wear. Technician A says that incorrect alignment is causing the wear and that the car needs a wheel alignment. Technician B says that underinflation could be the problem and that tire pressure should be checked. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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4. What is ply separation?
5. A metal ball peen hammer should be used to install wheel covers. True or False?
6. Why is periodic tire rotation important?
7. Excessive lug nut _____ can cause wheel or hub distortion.
8. Explain the difference between lateral runout and radial runout.
9. Describe the major differences between static and dynamic tire imbalance.
10. Which of the following is *not* a type of wheel balancer?
    (A) Dynamic wheel balancer.
    (B) Bubble balancer.
    (C) Neutral balancer.
    (D) Off-car balancer.
11. Often, a hole in a tire can be repaired by inserting a plug from the outside of the tire. True or False?
12. Define the phrase "pack the bearings."
13. All-purpose grease can be used to pack wheel bearings on a car with disc brakes. True or False?
14. Why should a new cotter pin be used when assembling a wheel bearing?
15. When pressing a ball bearing assembly in or out of the hub, what part of the bearing should contact the driving tool?

ASE-Type Questions

1. A car's left-front tire has a puncture hole. Technician A tells the owner of the car that this problem is called "tire impact damage." Technician B tells the owner of the car that this problem is called "tire road damage." Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
2. A car's front tires are worn excessively. Technician A checks the car's front-wheel alignment. Technician B checks the tire's inflation pressure. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
3. Bulges are discovered on an automobile's front tires. Technician A immediately replaces the tires. Technician B is not going to replace the tires until after determining the cause of the tire damage. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
4. The outer corners of a tire's tread are worn. Technician A checks to see if the tire is underinflated. Technician B says an underinflated tire will not produce this type of wear problem. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
5. An automobile has a steering wheel pull problem. Technician A checks to see if the tires are inflated evenly. Technician B checks for loose shock absorbers. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
6. A car is brought into the shop with a tire vibration problem. Technician A looks for ply separation. Technician B checks to see if the wheel is damaged. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
7. Vibration is coming from a car's center and rear. Technician A checks the condition of the rear tires. Technician B checks the front ball joints. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
8. A car is brought in with a noise coming from the right front tire. Technician A checks the tire's tread. Technician B looks for a worn wheel bearing. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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9. Vibration is coming from an automobile's front end. Technician A checks the condition of the car's front tires. Technician B says automotive tire problems will not produce front-end vibration. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. A customer wants her car's tires checked. Technician A checks for cracks. Technician B inspects the inner sidewall condition. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
11. An automobile is brought into the shop with damaged lug studs on the left wheel hub assembly. Technician A removes the damaged studs with a hammer and punch. Technician B uses a hydraulic press to remove the damaged studs. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
12. A customer wants his car's front wheel bearings greased. Technician A tells the customer that some automotive wheel bearings can be cleaned, packed with grease, and reinstalled. Technician B tells the customer that certain types of wheel bearings are sealed and must simply be removed and replaced. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
13. A car equipped with disc brakes is brought into the shop with worn front wheel bearings. Technician A replaces the bearings and packs the new bearings with all-purpose bearing grease. Technician B replaces the bearings and packs the new bearings with high-temperature wheel-bearing grease. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
14. Technician A says front wheel bearings on a driving hub and ball-type wheel bearing assembly are serviced during a brake job. Technician B says this type of wheel bearing assembly is not normally serviced. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
15. Technician A says if rear wheel bearings are dry and noisy when turned by hand, they should be replaced. Technician B says the fasteners on the rear wheel bearing and assembly should exceed the vehicle's recommended torque to prevent bolts from coming loose. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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Tire, Wheel, and Bearing Diagnosis

Condition	Possible Causes	Correction
Wheel tramp.	1. Brake drum, rotor, wheel, or tire out of static balance. 2. Wheel or tire out-of-round (excessive radial runout). 3. Bulge on tire. 4. Loose or worn wheel bearings.	1. Balance assembly statically and dynamically. 2. Change tire position on wheel or discard tire or wheel as needed. 3. Replace tire. 4. Adjust or replace bearings.
Wheel shimmy.	1. Wheel and tire assembly out of dynamic balance. 2. Uneven tire pressure. 3. Worn or loose front wheel bearings. 4. Excessive tire or wheel runout. 5. Worn tires. 6. Low tire pressure. 7. Loose wheel lugs. 8. Bent wheel. 9. Incorrect wheel alignment.	1. Balance assembly statically and dynamically. 2. Inflate both front tires to same pressure. 3. Adjust or replace bearings. 4. Correct by moving tire on rim or replace defective parts. 5. Move to rear if still serviceable. 6. Inflate tires to correct pressure. 7. Tighten lugs. 8. Replace wheel. 9. Correct alignment. See Chapter 79.
Poor recovery following turns and/or hard steering.	1. Low tire pressure. 2. Lack of lubrication. 3. Incorrect wheel alignment.	1. Inflate to proper pressure. 2. Lubricate steering system. 3. Correct alignment. See Chapter 79.
Vehicle pulls to one side.	1. Uneven tire pressure. 2. Tires not same size. 3. Worn or improperly adjusted wheel bearings. 4. Dragging brakes. 5. Incorrect wheel alignment.	1. Inflate both front tires to same pressure. 2. Install same size tires on both sides. 3. Adjust or replace bearings. 4. Adjust brakes. 5. Correct alignment. See Chapter 79.
Vehicle wanders from side to side.	1. Low or uneven tire pressure. 2. Worn or improperly adjusted front wheel bearings. 3. Vehicle overloaded or loaded too much on one side. 4. Incorrect wheel alignment.	1. Inflate tires to recommended pressure. 2. Replace or adjust wheel bearings. 3. Advise owner regarding vehicle load limits. 4. Correct alignment. See Chapter 79.
Tire squeal on corners.	1. Low tire pressure. 2. Excessive cornering speed. 3. Incorrect wheel alignment.	1. Inflate to recommended pressure. 2. Advise driver. 3. Correct alignment. See Chapter 79.
Loose, erratic steering.	1. Loose front wheel bearings. 2. Loose wheel lugs. 3. Wheel out of balance.	1. Replace or adjust. 2. Tighten lugs. 3. Balance wheel assembly.
Hard riding.	1. Excessive tire pressure. 2. Improper tire size. 3. Heavy-duty shock absorbers installed.	1. Reduce pressure to specifications. 2. Install correct size. 3. Advise driver and/or change shocks.

Continued

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Tire, Wheel, and Bearing Diagnosis

Condition	Possible Causes	Correction
Noise from front or rear wheels.	1. Loose wheel lugs. 2. Defective wheel bearings. 3. Loose wheel bearings. 4. Lack of lubrication. 5. Lump or bulge on tire tread. 6. Rock or debris stuck in tire tread. 7. Damaged wheel. 8. Wheel hub loose on axle taper (where used). 9. Worn or defective wheel bearing.	1. Tighten lugs. 2. Replace wheel bearings. 3. Adjust wheel bearings. 4. Lubricate bearings. 5. Replace tire. 6. Remove rock or debris. 7. Replace wheel. 8. Inspect and tighten. 9. Replace wheel bearing.
Tires lose air.	1. Puncture. 2. Bent, dirty, or rusty rim flanges. 3. Leaking valve core or stem. 4. Striking curbs with excessive force. 5. Flaw in tire casing. 6. Excessive cornering speed, especially with low tire pressure. 7. Porous wheel rim.	1. Repair puncture. 2. Clean or replace wheel. 3. Replace as needed. 4. Advise driver. 5. Repair or replace tire. 6. Advise driver. 7. Repair porous wheel rim.
Tire wears in center.	1. Excessive pressure.	1. Reduce tire pressure to specifications.
Tire wears on one edge.	1. Incorrect wheel alignment. 2. High speed cornering.	1. Correct alignment. See Chapter 79. 2. Advise driver.
Tire wears on both sides.	1. Low tire pressure. 2. Overloading vehicle.	1. Inflate tires to specifications. 2. Advise driver.
Tire scuffing or feather edging.	1. Excessive cornering speed. 2. Improper tire pressure. 3. Wheel shimmy. 4. Excessive runout. 5. Incorrect wheel alignment.	1. Advise driver. 2. Inflate tires to specifications. 3. Balance wheels statically and dynamically. 4. Correct or replace tire or wheel. 5. Correct alignment. See Chapter 79.
Tire cupping.	1. Incorrect wheel alignment. 2. Improper tire pressure. 3. Excessive runout. 4. Wheel and tire assembly out of balance. 5. Worn or improperly adjusted wheel bearings. 6. Grabby brakes.	1. Correct alignment. See Chapter 79. 2. Inflate tires to specifications. 3. Correct or replace wheel or tire. 4. Balance both statically and dynamically. 5. Replace or adjust wheel bearings. 6. Repair brakes.
Heel and toe wear.	1. Grabby brakes. 2. Heavy acceleration.	1. Repair brakes. 2. Advise driver.

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Chapter 75
Suspension System Technology

After studying this chapter, you will be able to:

- Identify the major parts of a suspension system.
- Describe the basic function of each suspension system component.
- Compare the various types of suspension systems.
- Explain the operation of the four common types of springs.
- Explain automatic suspension leveling systems.
- Correctly answer ASE certification test questions requiring a knowledge of suspension system construction and design.

The ***suspension system*** allows a vehicle's tires and wheels to move up and down over bumps and holes in the road. It makes the vehicle ride more smoothly over rough roads. The suspension system consists of a series of arms, rods, ball joints (swivel joints), bushings, and other parts.

The suspension system works in unison with the tires, unibody or frame, wheels, wheel bearings, brake system, and steering system to provide a safe and comfortable means of transportation.

This chapter will summarize the most important parts of a basic suspension system and introduce the most common suspension system designs. It will also prepare you to better understand information on the diagnosis and repair of suspension systems.

Functions of a Suspension System

A suspension system has several important functions:

- Supports the weight of the frame, body, engine, transmission, drive train, and passengers.
- Provides a smooth, comfortable ride by allowing the wheels and tires to move up and down with minimum movement of the vehicle body.
- Allows rapid cornering without extreme ***body roll*** (vehicle leans to one side).
- Keeps the tires in firm contact with the road, even after striking bumps or holes in the road.
- Prevents excessive ***body squat*** (body tilts down in rear) when accelerating or heavily loaded.
- Prevents excessive ***body dive*** (body tilts down in front) when braking.
- Allows the front wheels to turn from side to side for steering.

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- Works with the steering system to help keep the wheels in correct alignment.

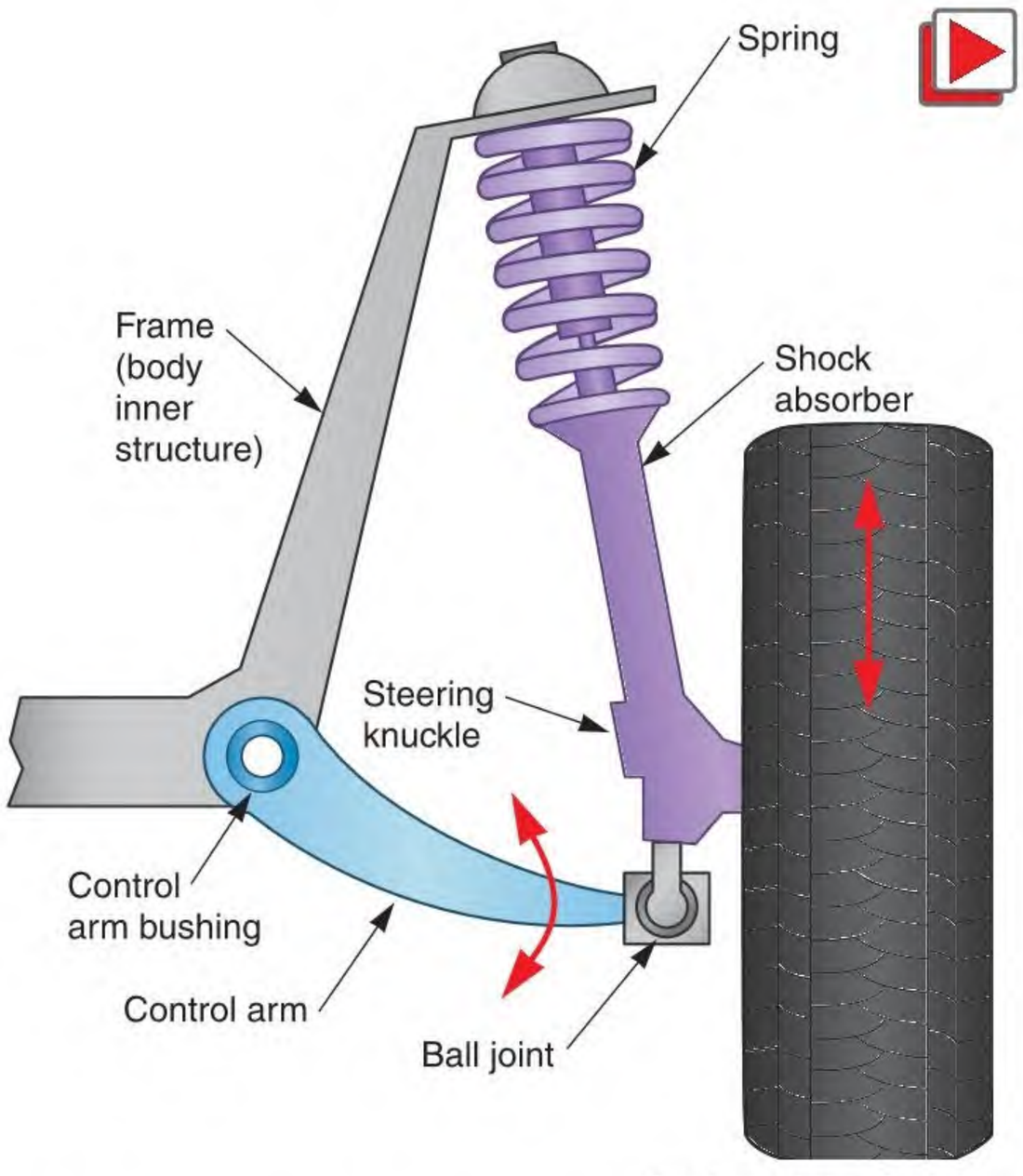
As you will learn, a suspension system uses springs, swivel joints, dampening devices, movable arms, and other components to accomplish these functions.

Tech Tip

Chassis stiffness is a primary factor affecting the quietness and smoothness of a vehicle's ride—the stiffer the chassis, the better. ***Chassis hertz*** is a measurement of the stiffness of a vehicle's structure. A high-hertz chassis (25 hertz, for example) is stiffer and stronger than a low-hertz chassis.

Basic Suspension System

Before discussing suspension system components in detail, you should be able to visualize each major part and understand how it functions in relation to the other parts. See **Figure 75-1**.



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Figure 75-1. Review the elementary parts and motion of a simplified car suspension system.

The following are basic parts of a suspension system:

- Control arm—The control arm is a movable lever that fastens the steering knuckle to the vehicle's body or frame.
- Steering knuckle—The steering knuckle provides a spindle or bearing support for the wheel hub, bearings, and wheel assembly.
- Ball joint—The ball joint is a movable connection that allows the control arm to move up and down while allowing the steering knuckle to swivel from side to side.
- Suspension spring—Suspension springs support the weight of the vehicle and permit the control arm and wheel to move up and down.
- Shock absorber or damper—A shock absorber or damper helps keep the suspension from continuing to bounce after spring compression and extension.
- Control arm bushing—The control arm bushing is a sleeve that allows the control arm to swing up and down on the frame.

Types of Suspension Systems

Suspension systems may be grouped into two broad categories: independent and nonindependent. See **Figure 75-2**. Both can be found on today's cars and trucks. Passenger cars normally use independent suspension at all four wheels. Pickup trucks often have a solid rear axle with a nonindependent suspension at the rear.

Independent Suspension

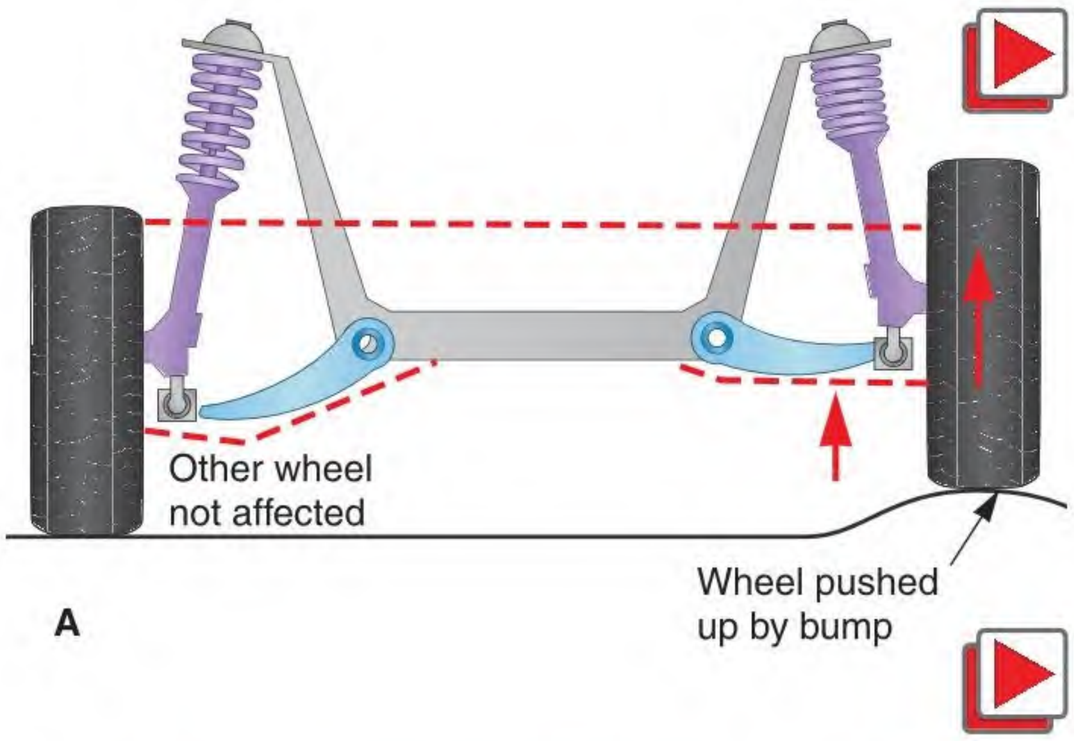
Independent suspension allows one wheel to move up and down with minimal effect on the other wheels. Look at **Figure 75-2A**. Since each wheel in an independent suspension system is attached to its own suspension unit, movement of one wheel does *not* cause direct movement of the wheel on the other side of the vehicle.

There are many types of independent suspension systems, many of which will be discussed later in this chapter. Independent suspension is widely used on modern vehicles, especially passenger cars.

Nonindependent Suspension

Nonindependent suspension has both the right and left wheels attached to the same solid axle. A truck's solid axle carries and pulls a heavier load than a lighter

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Figure 75-2. Comparison of independent and nonindependent suspension systems. A—Independent suspension allows one wheel to roll over a bump with minimal effect on the other wheel. B—Nonindependent suspension causes the action of one wheel to tilt and affect the other wheel.

independent car suspension system. When one tire hits a bump in the road, its upward movement causes a slight upward *tilt* of the other wheel. Hence, neither wheel is independent of the other, **Figure 75-2B**.

Understeer and Oversteer

Understeer means that the vehicle is slow to respond to steering changes in a turn. The rear tires retain traction, but the front tires may slip on the road surface due to lack of downforce or other factors.

Oversteer basically means that the rear tires try to skid around sideways in a sharp or hard turn. The front tires retain traction, but the rear tires skid.

Suspension systems are designed to balance oversteer and understeer. The perfect suspension system provides ***neutral steering***—all four wheels have equal traction in turns.

Lateral Acceleration

Lateral acceleration is the amount of side force a vehicle can handle before its tires lose traction and skid in a sharp turn. It is measured in units of gravity, or "g-force," usually on a ***skidpad*** (round or circular driving course). The higher the "Gs," the better. Passenger cars can attain a lateral acceleration of about 1.0 G, while race cars can produce more than 3.0 Gs in turns.

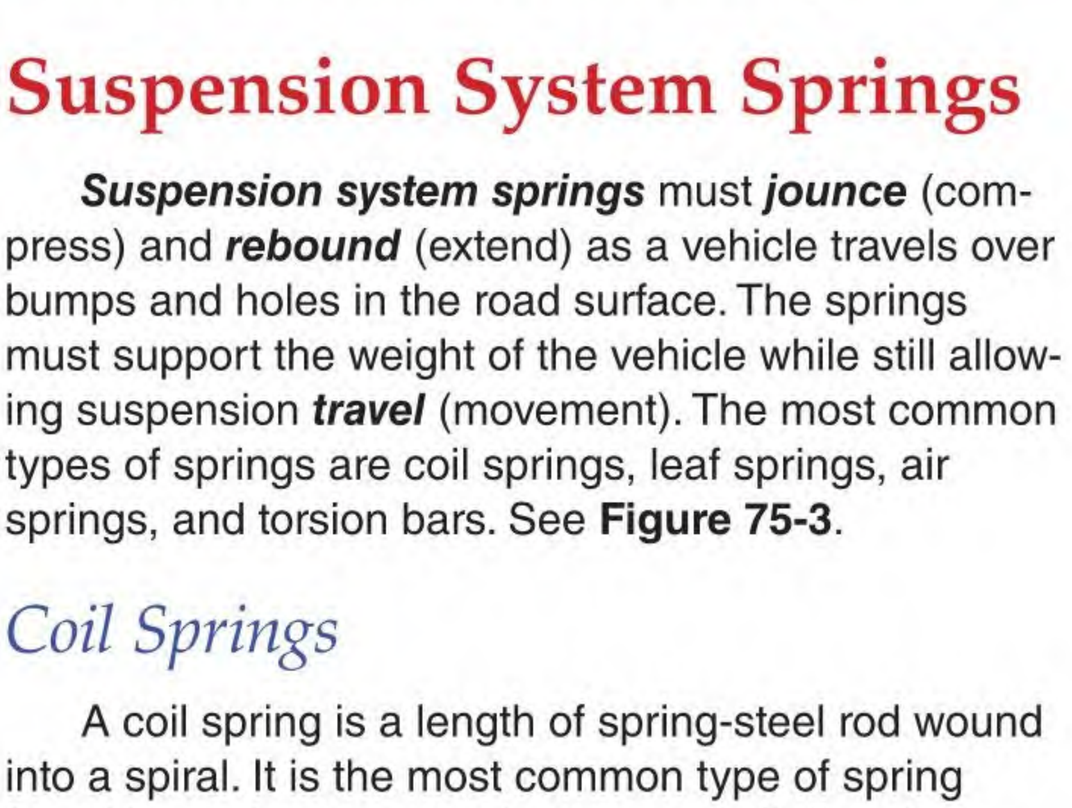
Independent suspension systems generally obtain higher lateral acceleration than nonindependent designs. Independent suspension systems are able to keep all four tires in full contact with the road surface better than older, heavier, solid-axle designs.

Suspension System Springs

Suspension system springs must ***jounce*** (compress) and ***rebound*** (extend) as a vehicle travels over bumps and holes in the road surface. The springs must support the weight of the vehicle while still allowing suspension ***travel*** (movement). The most common types of springs are coil springs, leaf springs, air springs, and torsion bars. See **Figure 75-3**.

Coil Springs

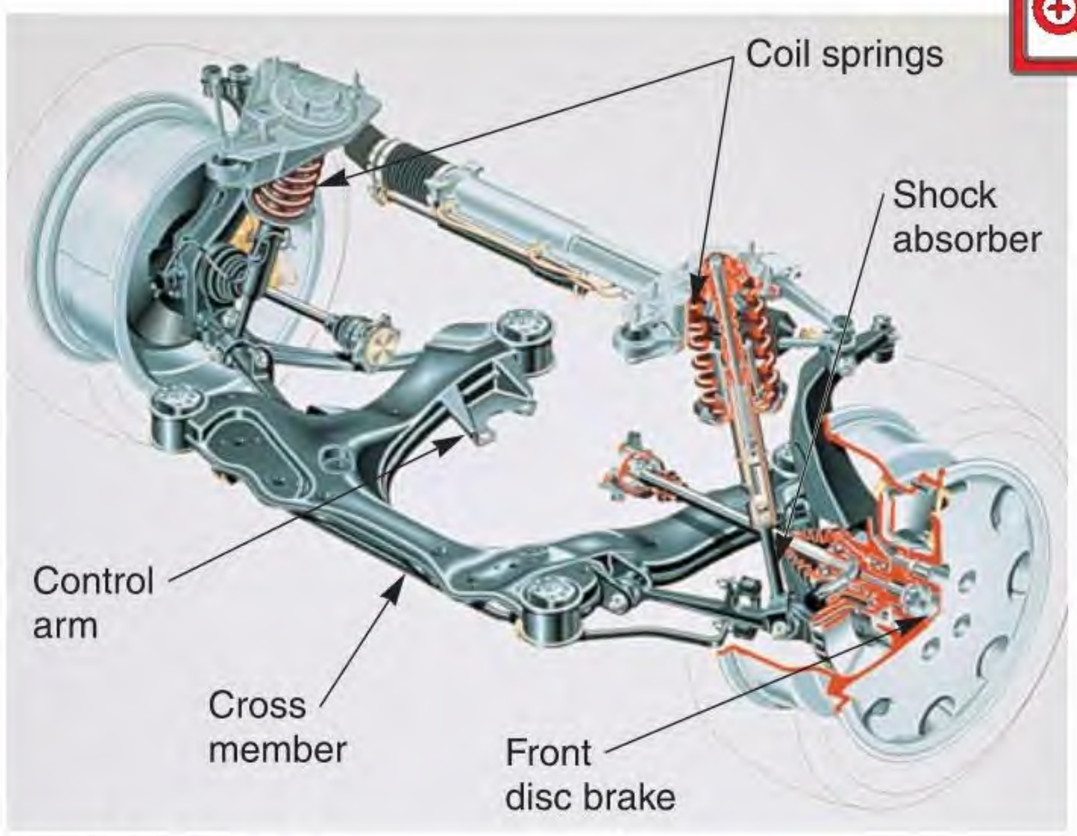
A coil spring is a length of spring-steel rod wound into a spiral. It is the most common type of spring found in modern suspension systems. Coil springs may be used on both the front and rear of a vehicle. See **Figure 75-4**.



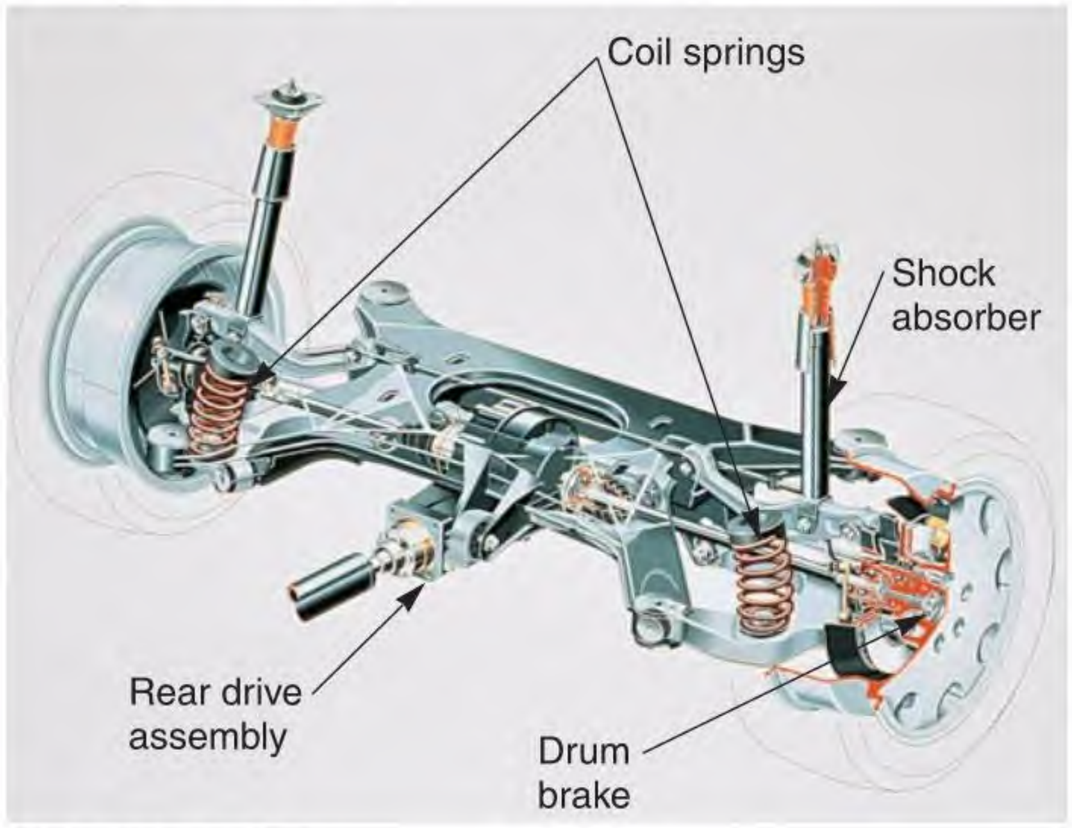
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Figure 75-3. Suspension system springs. A—Coil spring. B—Leaf spring. C—Air spring. D—Torsion bar.

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Front suspension



Rear suspension

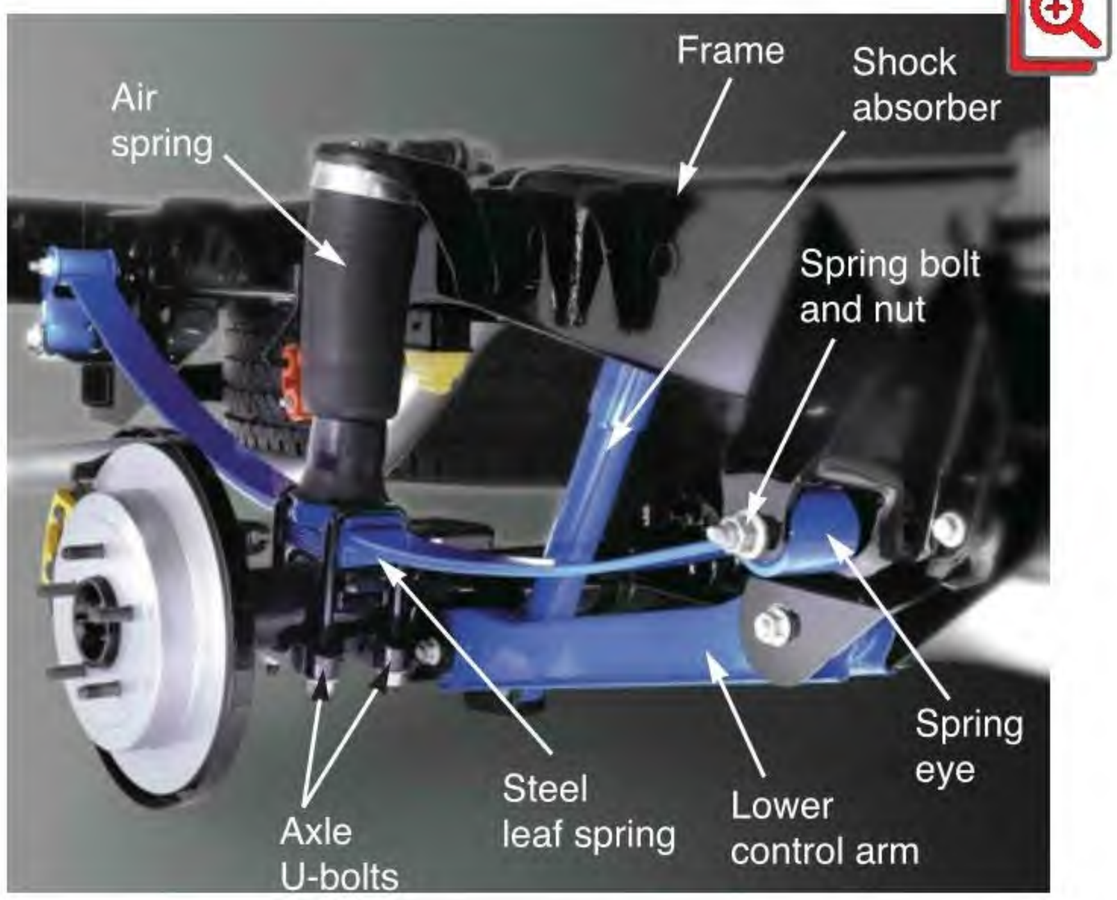
Audi

Figure 75-4. Both the front and rear of the vehicle may use coil springs. They are the most common springs used on passenger cars and light trucks.

Leaf Springs

A ***leaf spring*** is commonly made of flat plates or strips of spring steel that are bolted together. A few are made of fiberglass. Although leaf springs were once used on front suspension systems, they are now limited to the rear of some cars. An exploded view of a leaf spring assembly is given in **Figure 75-5**.

A monoleaf spring is made of a single, thick leaf, which is usually made of reinforced fiberglass. Multiple-leaf springs have several thin steel leaves sandwiched together.



Ford

Figure 75-5. This single leaf spring is aided by an air spring that supports the weight of the truck and can adjust the ride height with different cargo loads.

Each end of the leaf spring has an eye (cylinder shaped hole), which holds a bushing. The front spring eye normally bolts directly to the frame structure. Two large U-bolts secure the axle or axle housing to the leaf springs. A ***shackle*** fastens the rear leaf spring eye to the vehicle's frame and allows the spring to change length when bent. Shackles are short brackets that allow one end of the leaf spring to move from front to rear as its effect length changes with suspension movement. ***Insulators*** are synthetic rubber bushing and metal inserts that press-fit into the leaf spring eyes. They are placed between the springs to prevent squeaks and rattles.

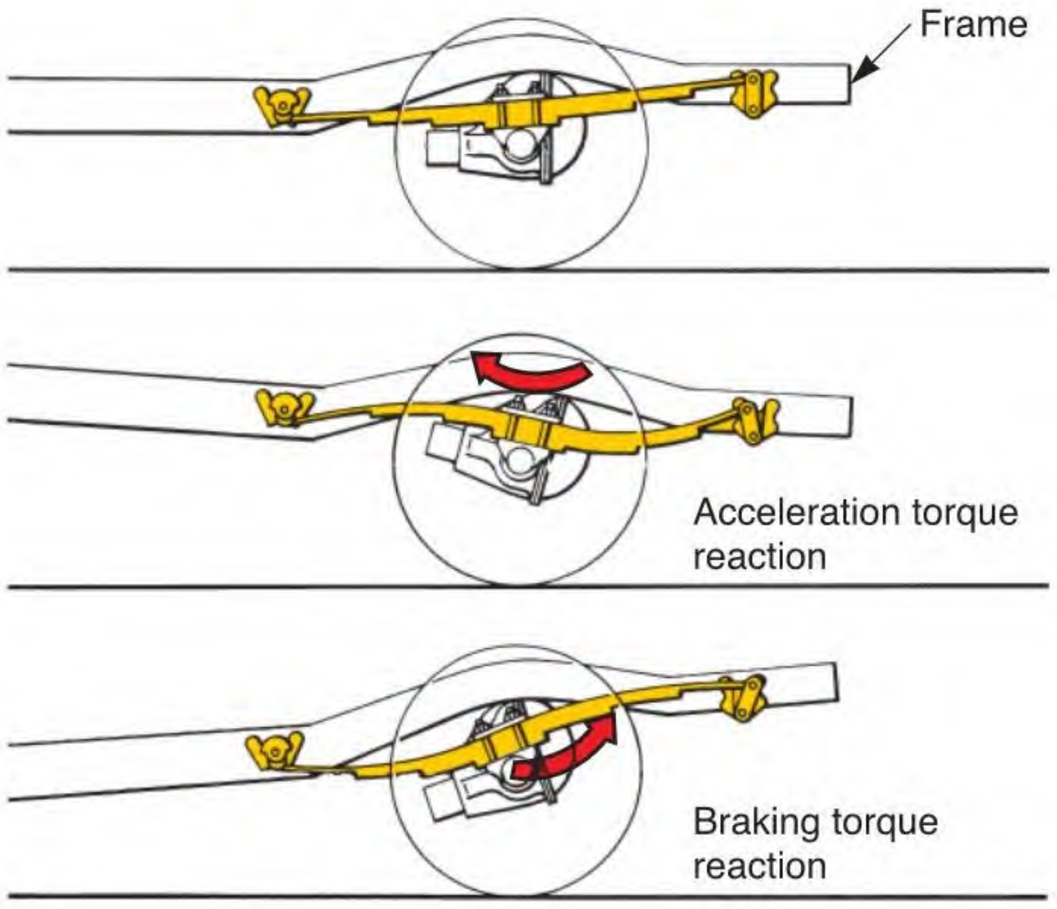
Leaf spring windup is a condition that causes the rear leaf springs to flex when driving or braking forces are applied to the suspension system. The twisting and distortion of the spring can cause body squat and dive, **Figure 75-6**.

Air Springs

An ***air spring*** is typically a two-ply rubber cylinder that is filled with air. End caps are formed on the air spring for mounting. Air pressure in the rubber cylinder gives the unit a spring action, similar to that of a coil spring. Refer to **Figure 75-7**.

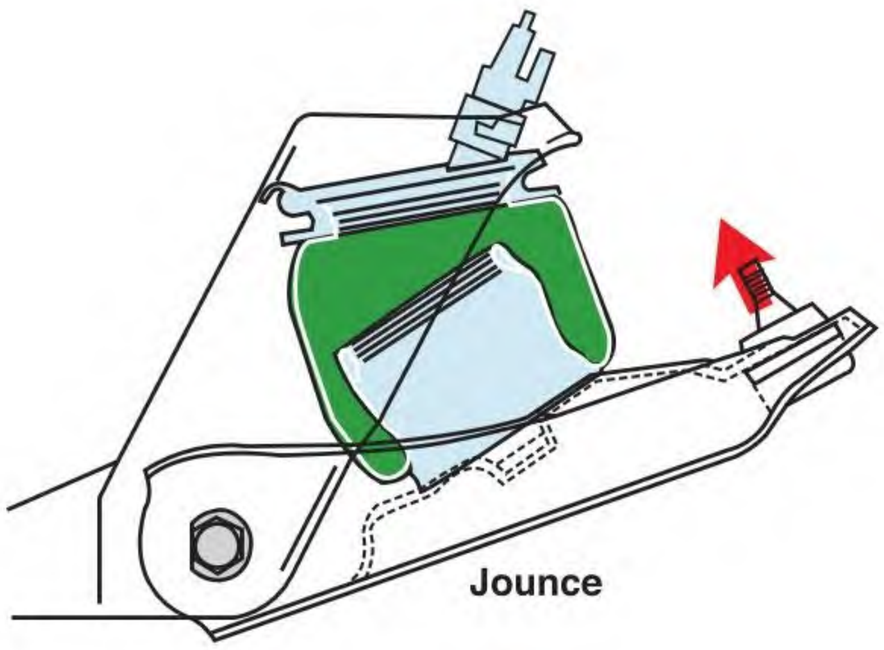
An air spring is lighter than a coil spring. This gives an air spring the potential to produce a smoother ride than a coil spring. Special synthetic rubber compounds must be used so the air spring can

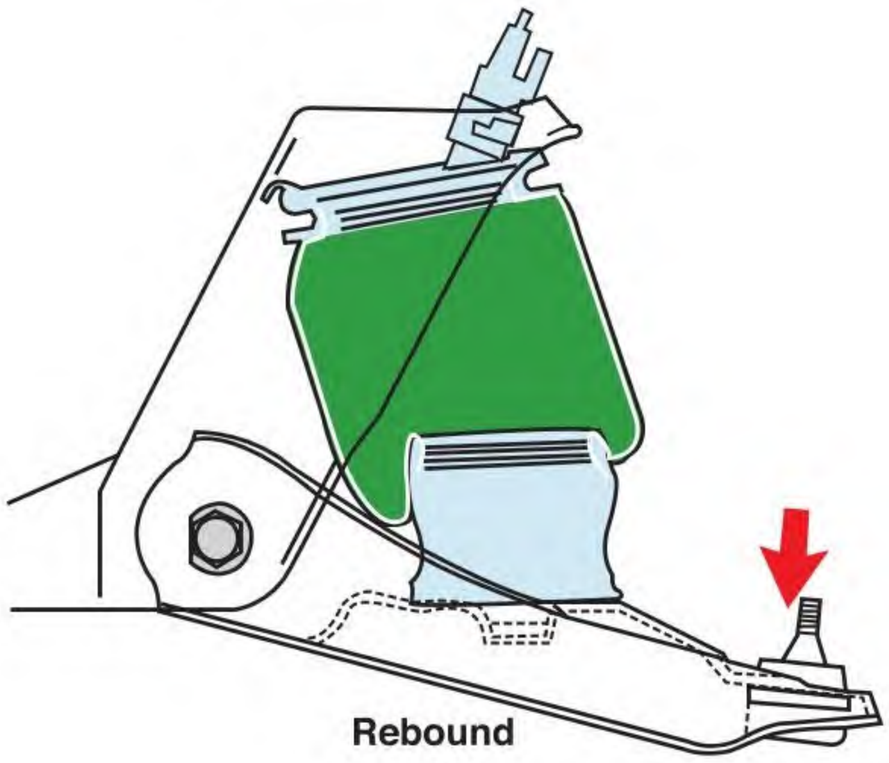
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Ford

Figure 75-6. Leaf spring windup is a problem when leaves support driving axle. Torque tends to twist the springs.





Ford

Figure 75-7. Air springs are used on some late-model cars. They are especially adaptable to automatic leveling systems.

operate properly in cold weather—low temperatures tend to stiffen rubber.

Torsion Bars (Springs)

A ***torsion bar*** is made of a large spring-steel rod. One end of the torsion bar is attached to the frame. The other end is fastened to the suspension system control arm. See **Figure 75-8**.

Up-and-down movement of the suspension system twists the torsion bar. The bar then tries to return to its original shape, moving the control arm back into place.

Suspension Spring Specifications

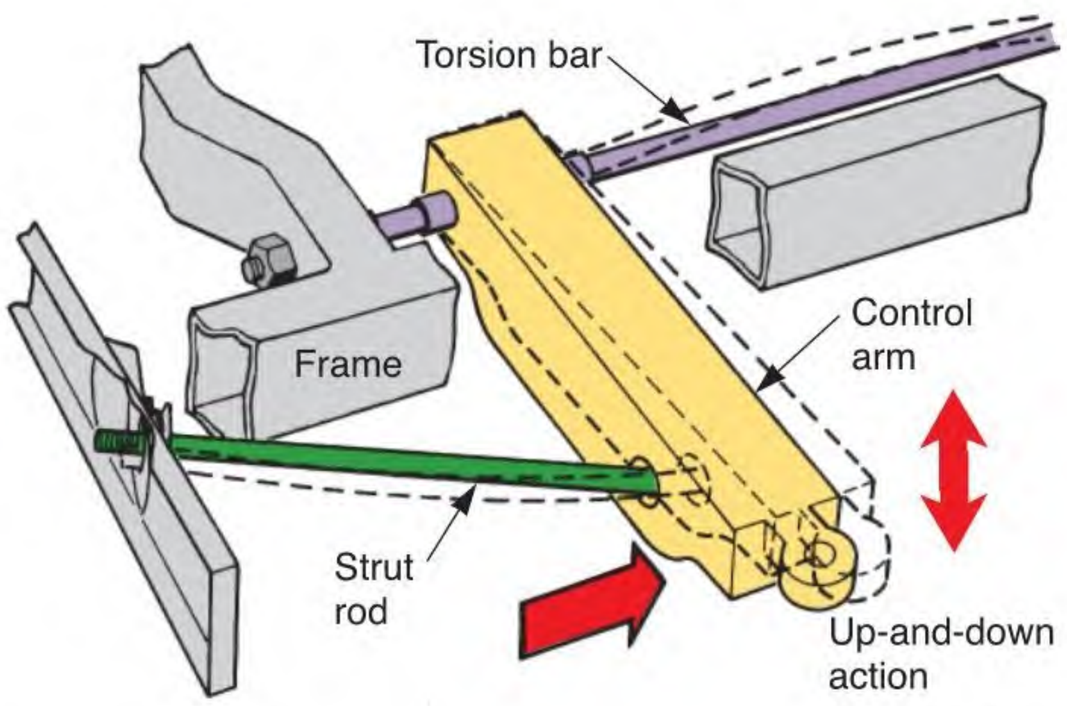
There are several specifications relating to springs that you should understand. A few of the most important ones are discussed in the following section.

Spring rate refers to the stiffness, or tension, of a spring. The rate of a spring is determined by the weight needed to bend and compress it.

Sprung weight is the weight of the parts that are supported by the springs and suspension system. Sprung weight should be kept high in proportion to unsprung weight.

The ***unsprung weight*** is the weight of the parts that are *not* supported by the springs. The tires, wheels, wheel bearings, steering knuckles, and axle housing would be considered unsprung weight.

Unsprung weight should be kept *low* to improve ride smoothness. Movement of a high unsprung weight (heavy wheel and suspension components) would tend to transfer vibration to the passenger compartment.



Moog

Figure 75-8. The torsion bar is twisted with control arm movement. The bar resists twisting action and acts like a conventional spring.

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Suspension System Construction

Now that you have been introduced to suspension system basics, we will cover the construction of each part in detail.

Control Arms

A ***control arm*** holds the steering knuckle, bearing support, or axle housing in position as the wheel moves up and down. Look at **Figure 75-9**.

The outer end of a control arm contains a ball joint; the inner end contains bushings. A rear suspension control arm may have bushings on both ends. Many modern suspension systems use four control arms: two on the top and two on the bottom. This helps reduce unsprung weight and adds more ball joints to carry the weight of the vehicle.

Control arm bushings act as bearings, allowing the arm to swing up and down on a shaft bolted to the frame or suspension unit. Bushings may either be pressed or screwed into holes in the control arm.

Strut Rod

A ***strut rod*** fastens to the outer end of the lower control arm and to the unibody or frame. It keeps the control arm from swinging toward the front or rear of the vehicle. See **Figure 75-8**.

The front of the strut rod contains rubber bushings that soften the action of the rod. They permit a controlled amount of lower control arm front-to-rear flex, while allowing full suspension travel.

Ball Joints

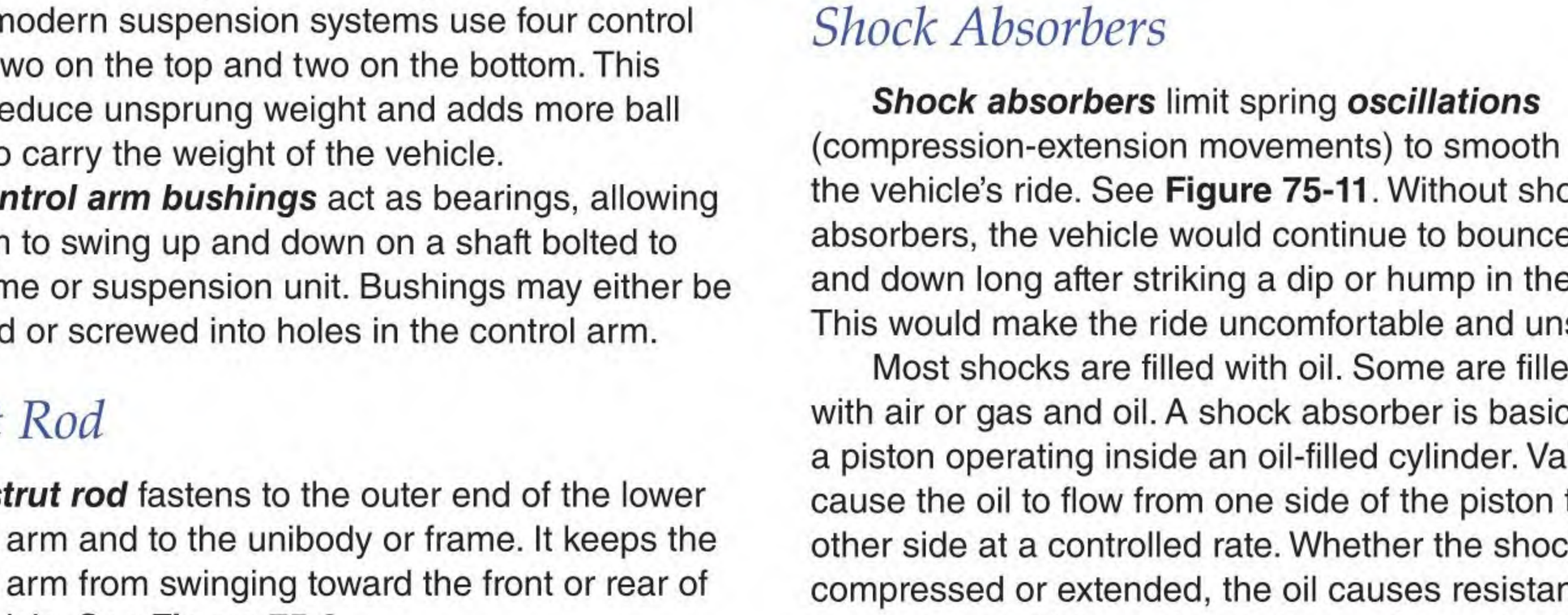
Ball joints (short for ball-and-socket joints) are connections that allow limited rotation in every direction. They connect the outer ends of control arms to the steering knuckle. See **Figure 75-10**.

Since the ball joint must be filled with grease, a grease fitting and a grease seal are normally placed on the joint. The end of the stud on the ball joint is threaded for a large nut. When the nut is tightened, it draws the tapered stud into the steering knuckle or bearing support, creating a force fit.

Shock Absorbers

Shock absorbers limit spring ***oscillations*** (compression-extension movements) to smooth the vehicle's ride. See **Figure 75-11**. Without shock absorbers, the vehicle would continue to bounce up and down long after striking a dip or hump in the road. This would make the ride uncomfortable and unsafe.

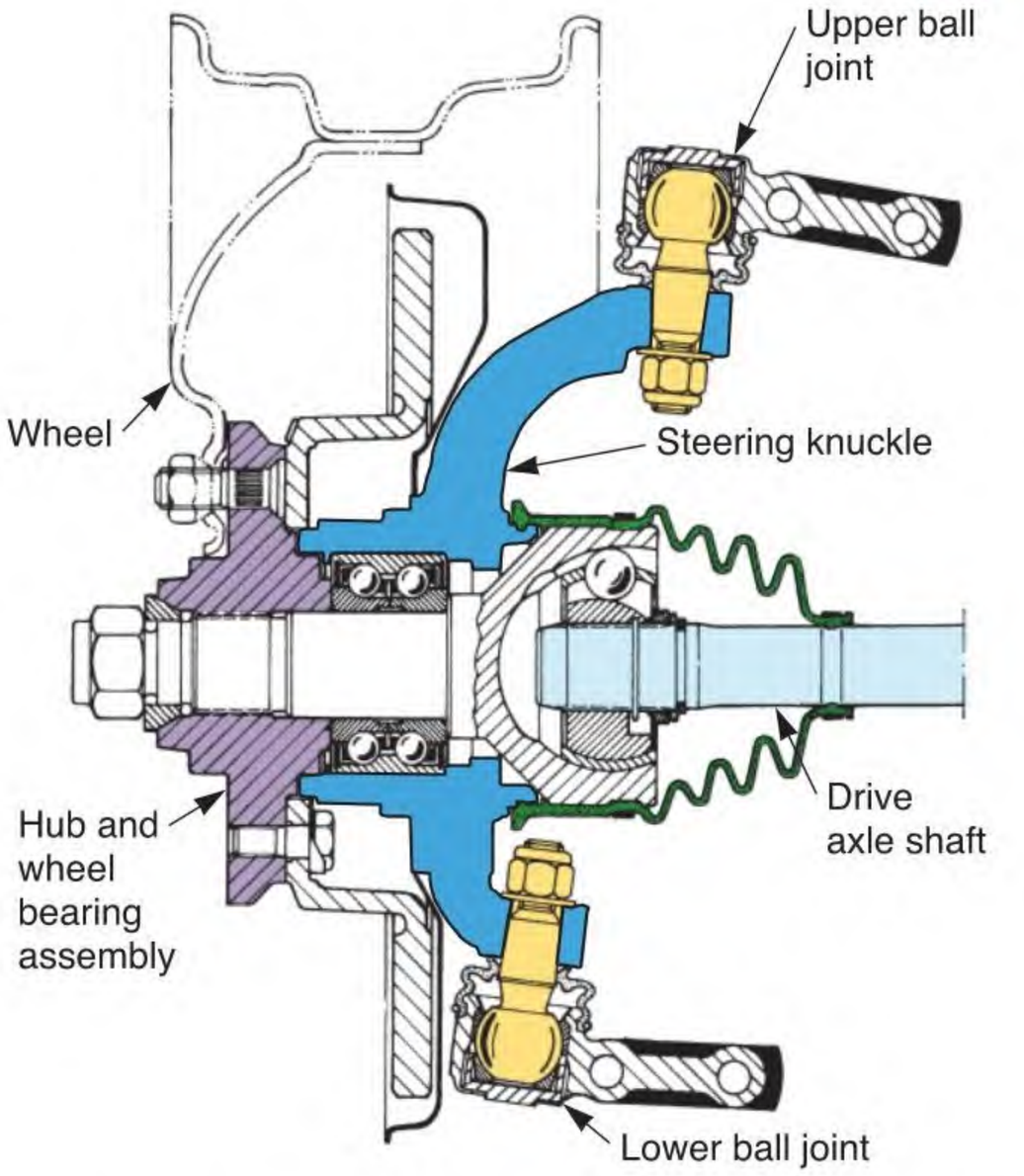
Most shocks are filled with oil. Some are filled with air or gas and oil. A shock absorber is basically a piston operating inside an oil-filled cylinder. Valves cause the oil to flow from one side of the piston to the other side at a controlled rate. Whether the shock is compressed or extended, the oil causes resistance to movement. This produces dampening action that restricts spring oscillations. Gas-pressure dampened shocks operate like conventional oil-filled shocks.



Fiat

Figure 75-9. Study the basic parts of a control arm. Bushings fit into the inner ends of the arm. A ball joint fits into the outer end of the control arm. The ball joint is connected to the steering knuckle.

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Chrysler

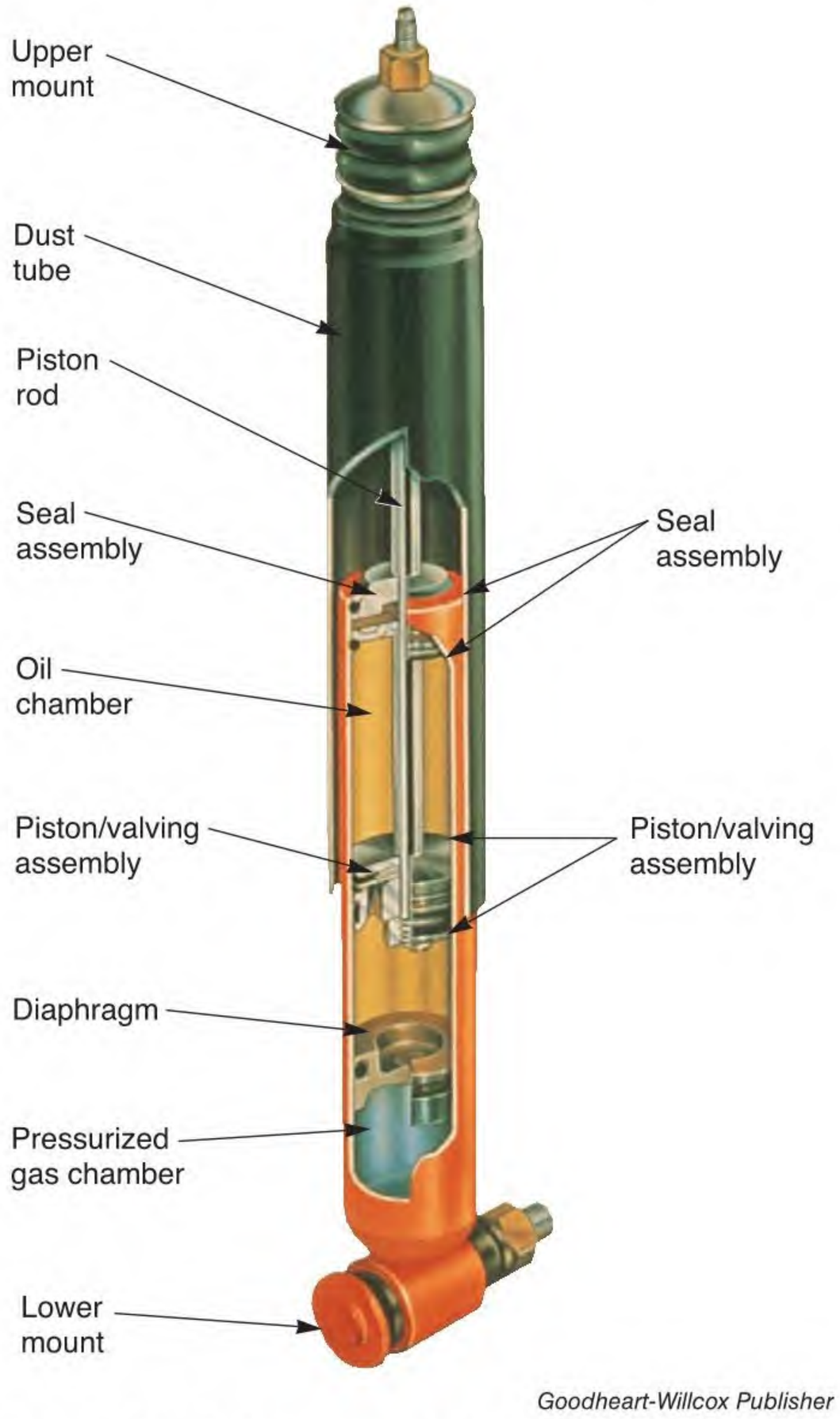
Figure 75-10. Cutaway view shows the ball joints, steering knuckle, and driving hub for a front-wheel-drive vehicle. Study the construction of the parts.

One end of the shock absorber connects to a suspension component, such as a control arm. The other end of the shock fastens to the vehicle's body or frame. In this way, the shock rod is pulled in and out and resists suspension system movements.

Shock absorber operation is illustrated in **Figure 75-12**. ***Shock absorber compression*** occurs when the vehicle's tire is forced upward upon hitting a bump. This compresses the coil spring and hydraulic shock absorber. ***Shock absorber extension*** is the outward movement of the piston and rod as the control arm moves down. This occurs right after a compression stroke or when the tire encounters a hole in the road.

Gas-Charged Shock Absorbers

Gas-charged shock absorbers use a low-pressure gas to help keep the oil in the shock from foaming. Usually, nitrogen gas is enclosed in a chamber separate from the main oil cylinder. The shock piston operates in the oil. The gas maintains constant pressure on the oil to stop air bubbles from forming.



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Figure 75-11. Basic components of a shock absorber.

Self-Leveling Shock Absorbers

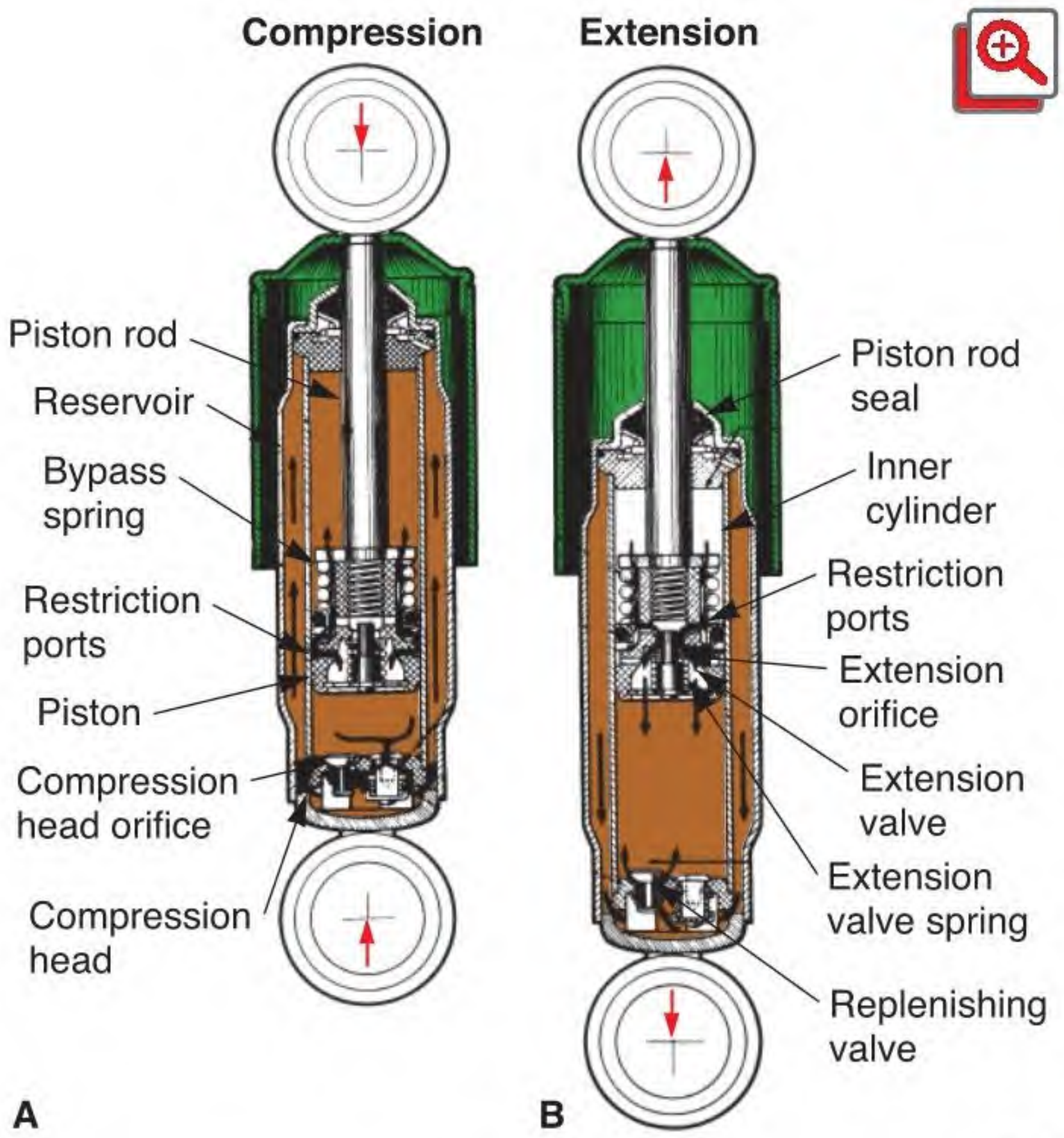
A ***self-leveling shock absorber*** uses a special design that causes a hydraulic lock action to help maintain normal vehicle curb height.

A valve system in each shock retains hydraulic pressure when the shock is compressed near its minimum length setting. This hydraulic lock action helps keep the shock rod at the same length with changes in force or curb weight. This tends to help keep the vehicle level under varying conditions.

Adjustable Shocks

Adjustable shock absorbers provide a means of changing shock stiffness. Usually, by turning the shock outer body or an adjustment knob, you can set the shock soft for a smooth ride or stiff for better handling.

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Gabriel

Figure 75-12. Cutaway view of a shock absorber in action. A—Compression stroke forces the piston down in the cylinder. Oil is forced into the upper area of the shock. B—Extension stroke causes oil to be pulled back into the lower area. Note the valve action.

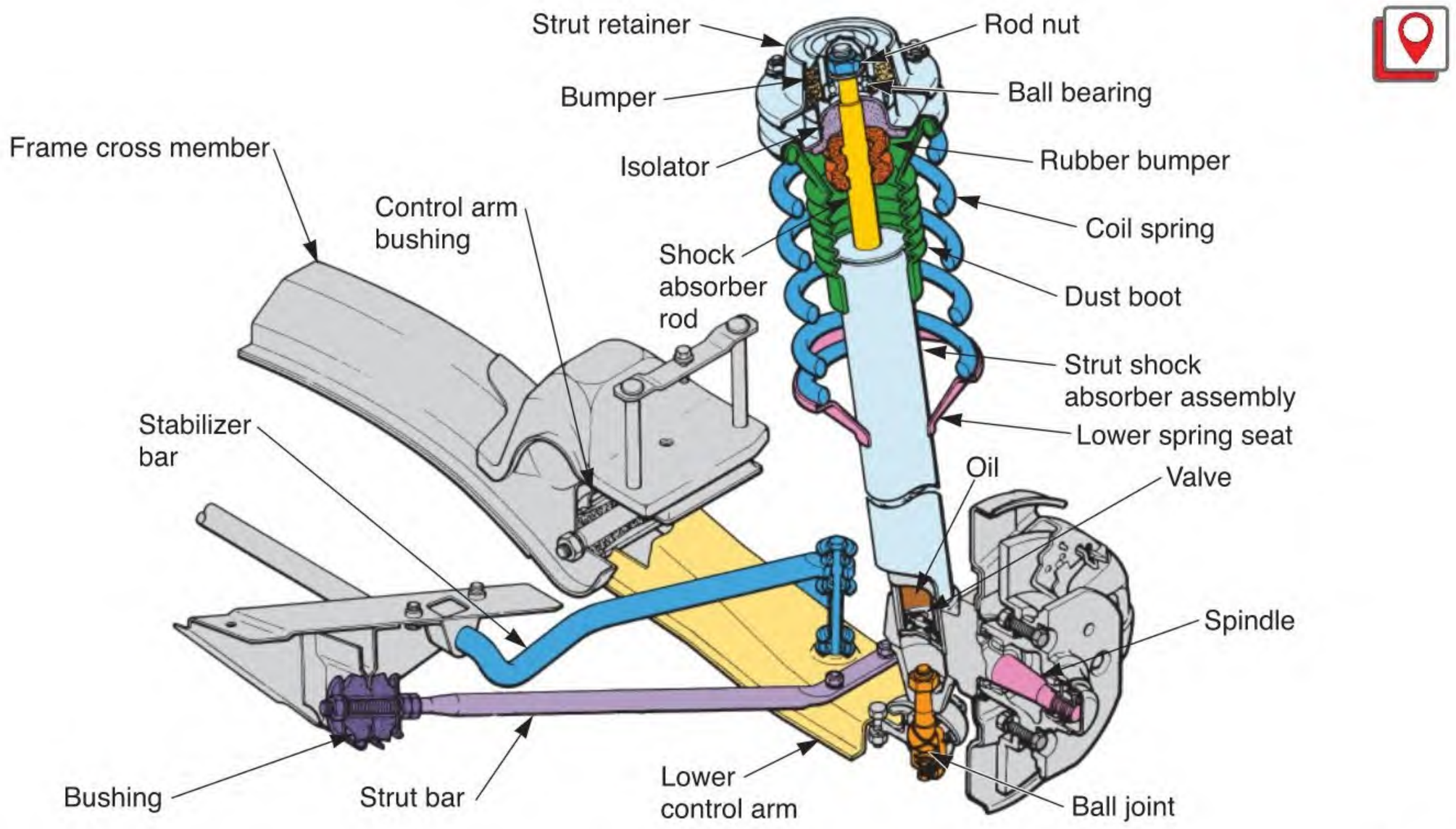
Some electronic (computer-controlled) suspension systems automatically change shock dampening stiffness with road and driving conditions.

Strut Assembly

A ***strut assembly*** consists of a shock absorber, a coil spring (most types), and an upper damper unit. The strut often replaces the upper control arm. Only the lower control arm and the strut are needed to support the front wheel assembly.

The basic parts of a typical strut assembly are shown in **Figure 75-13**. They include:

- ***Strut shock absorber***—The strut shock absorber is a piston operating in an oil-filled (or oil and gas) cylinder to prevent coil spring oscillations.
- ***Dust shield***—A dust shield is a metal shroud or rubber boot that keeps road dirt off the shock absorber rod.
- ***Lower spring seat***—The lower spring seat is a lower mount formed around the shock body for the coil spring.
- ***Coil spring***—The coil spring supports the weight of the vehicle and allows suspension action.



Chrysler

Figure 75-13. Study the parts of this strut assembly closely. This is one of the most modern suspension systems and is commonly used on today's vehicles.

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- ***Upper spring seat***—The upper spring seat holds the upper end of the coil spring and contacts the strut bearing.
- ***Strut bearing***—The strut bearing is a ball bearing that allows the shock-and-spring assembly to rotate for steering action. It is only used on the front of the vehicle.
- ***Rubber bumpers***—Rubber bumpers are jounce and rebound bumpers that prevent metal-to-metal contact during extreme suspension compression and extension.
- ***Rubber isolators***—Rubber isolators prevent noise from transmitting into the body structure of the vehicle.
- ***Upper strut retainer***—The upper strut retainer secures the upper end of the strut assembly to the frame or unibody.
- ***Strut rod nut***—A strut rod nut is a hex nut that holds the shock absorber rod in the upper strut retainer.
- ***Damper unit***—The damper unit is a shock that fits inside a coil spring to prevent excessive jounce and rebound.

A strut shock absorber is similar to a conventional shock absorber. However, it is longer and has provisions (brackets or connections) for mounting and holding the steering knuckle (front of vehicle) or bearing support (rear of vehicle) and spring.

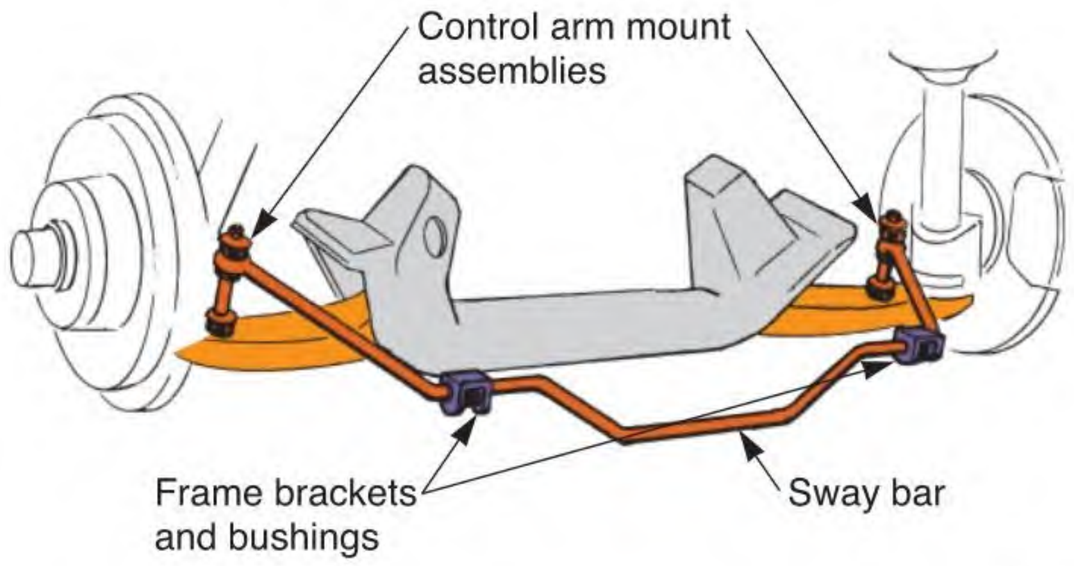
Sway Bar (Stabilizer Bar)

A ***sway bar***, or ***stabilizer bar***, is used to keep the body from leaning excessively in sharp turns. The sway bar is made of spring steel. It fastens to both lower control arms and to the frame. Rubber bushings fit between the bar and the control arms. Brackets and bushings are used to secure the bar to the frame. ***Sway bar links*** connect the sway bar to the control arms. See **Figure 75-14**.

When a vehicle rounds a corner, centrifugal force makes the outside of the body drop and the inside of the body rise. This twists the sway bar. The bar's resistance to this twisting motion limits body lean in corners.

Track Rod (Lateral Control Rod)

A ***track rod***, also known as a ***lateral control rod***, is sometimes used on rear suspension systems to prevent side-to-side axle movement during cornering. The track rod is almost parallel to the rear axle. One end of the rod is fastened to the axle, and the other end of the rod is fastened to the frame or body structure on the opposite side of the vehicle, **Figure 75-15**.



Moog

Figure 75-14. The sway bar attaches to both control arms. When the car rounds a corner, its body leans to one side. The sway bar bends, which lessens sway, or body lean, in turns.

Jounce Bumpers

Jounce bumpers are blocks of hard rubber that keep the suspension system parts from hitting the frame or body when the car hits large bumps or holes.

If you drive over a large hump in the road too quickly, you will hear the suspension arms hit the jounce bumpers with a loud bang or thud. This warns you that the tires are leaving the road surface.

Long-Short Arm Suspension

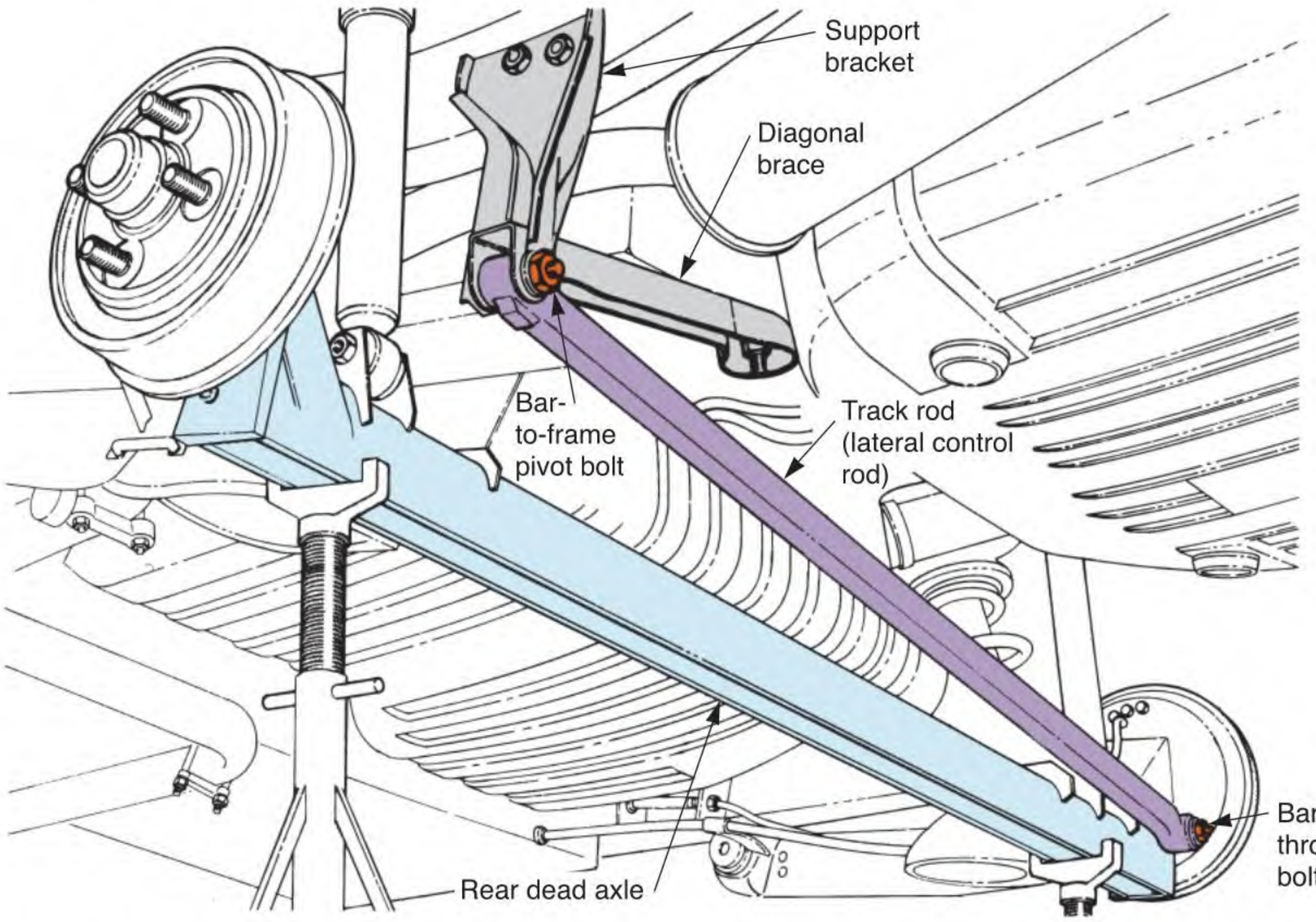
A ***long-short arm suspension*** uses control arms of different lengths to keep the tires from tilting with suspension action. The upper control arms are shorter than the lower control arms. See **Figure 75-16**.

If the control arms were the same length, the front tires would pivot outward at the top when the vehicle hits a bump. This would cause undue tire scuffing and wear.

Torsion Bar Suspension

A ***torsion bar suspension*** is a suspension system that contains torsion bar springs instead of coil springs. Most torsion bar suspensions allow easy adjustment of ***curb height*** (distance from the road up to a specific point on the car). By turning an adjustment bolt, you can increase or decrease the tension on the torsion bar. This either raises or lowers the frame and/or body of the vehicle.

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Chrysler

Figure 75-15. A track rod is commonly used on the rear axle to prevent side-to-side movement. Note how the rod connects to the frame and axle.

MacPherson Strut Suspension

A ***MacPherson strut suspension*** uses only *one* control arm and a *strut assembly* (spring, damper, and shock absorber unit) to support each wheel assembly, **Figure 75-17**. Note that the ***modified strut suspension*** has the coil spring mounted on top of the lower control arm, not around the strut.

A conventional lower control arm attaches to the frame and to the lower ball joint. The ball joint holds the control arm to the steering knuckle or bearing support. The top of the steering knuckle or bearing support is bolted to the strut assembly. The top of the strut is fastened to the reinforced body structure, **Figure 75-18**.

MacPherson strut suspension is the most common type of suspension found on late-model cars, and may be used on both the front and rear wheels. It reduces the number of parts in the suspension system, lowering the unsprung weight and smoothing the ride, **Figure 75-19**.

Pickup Truck Suspension Systems

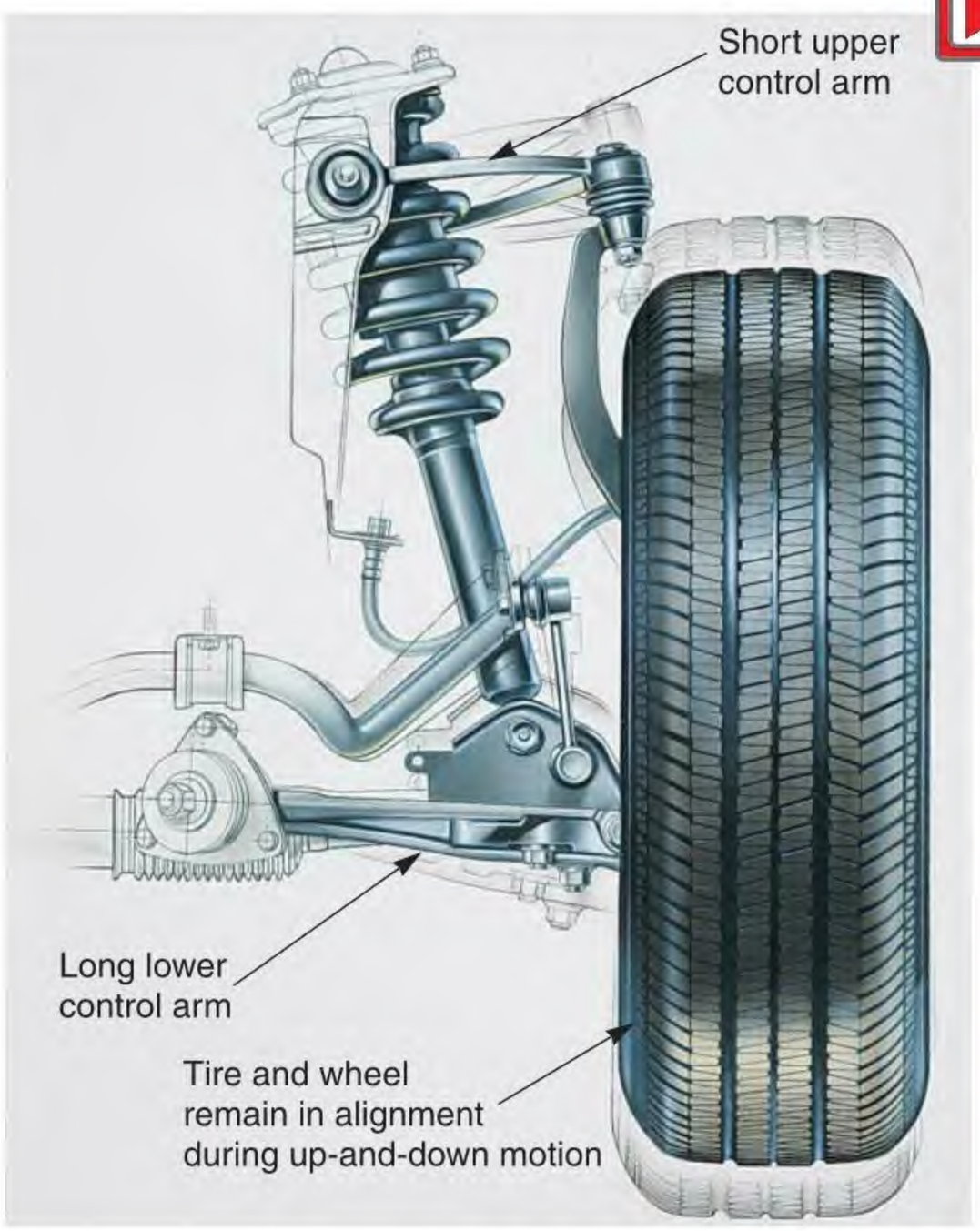
Pickup trucks use numerous suspension system designs: long-short control arm, MacPherson strut, solid axle, and twin axle (or twin I-beam) suspension. The control arm and strut types are basically the same as those used on passenger cars, but are heavier and stronger. **Figure 75-20** shows a twin-axle, or twin I-beam, suspension.

A four-wheel-drive truck can have a solid axle housing and differential in the front. The steering knuckles are mounted on the axle housing so that they will swivel left or right for cornering.

Rear Suspension Systems

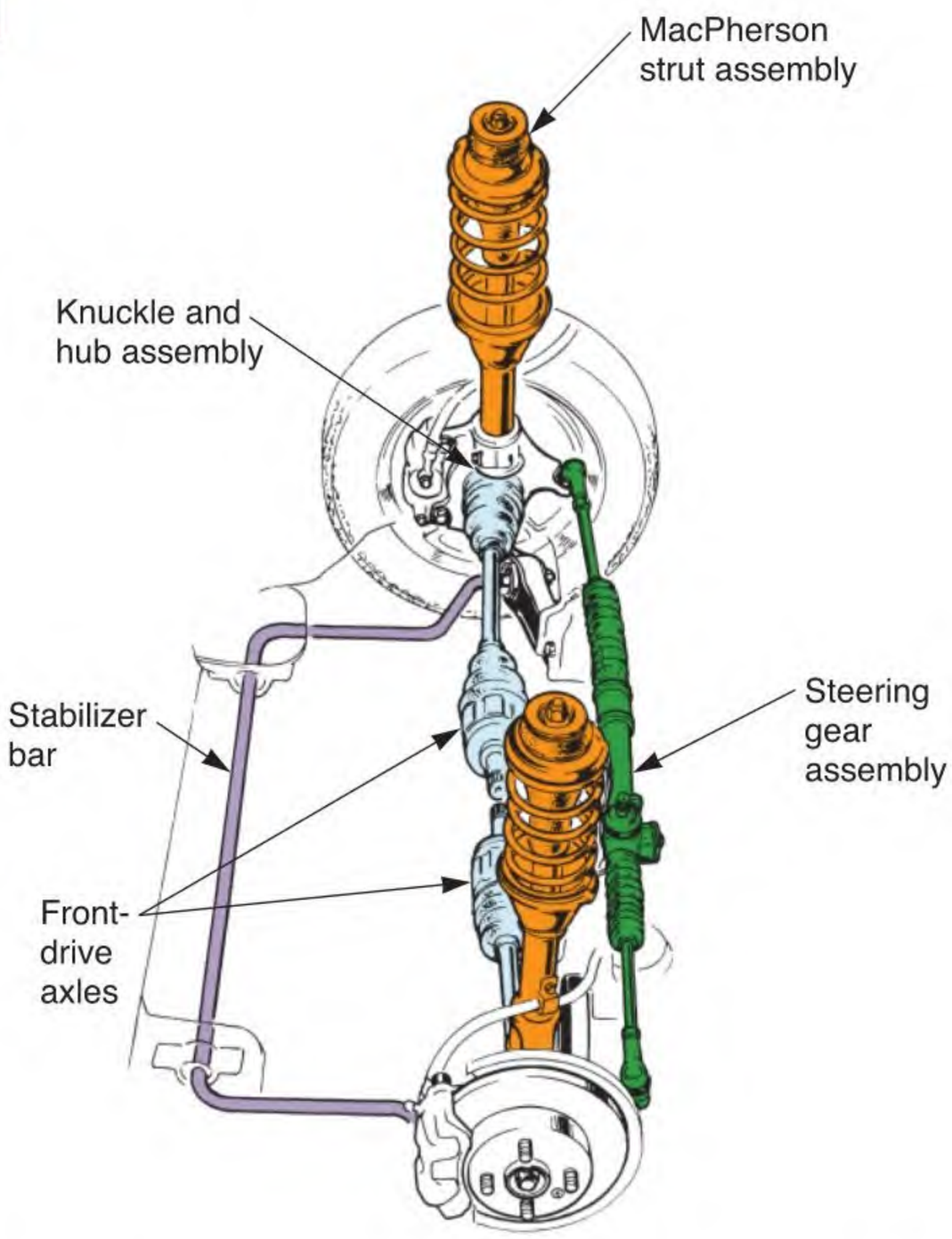
Rear suspension systems are similar to front suspension systems, but they normally do *not* provide for steering. Look at **Figure 75-21**. With a rear-wheel-drive vehicle, the rear axle housing may be solid, resulting in nonindependent suspension. However,

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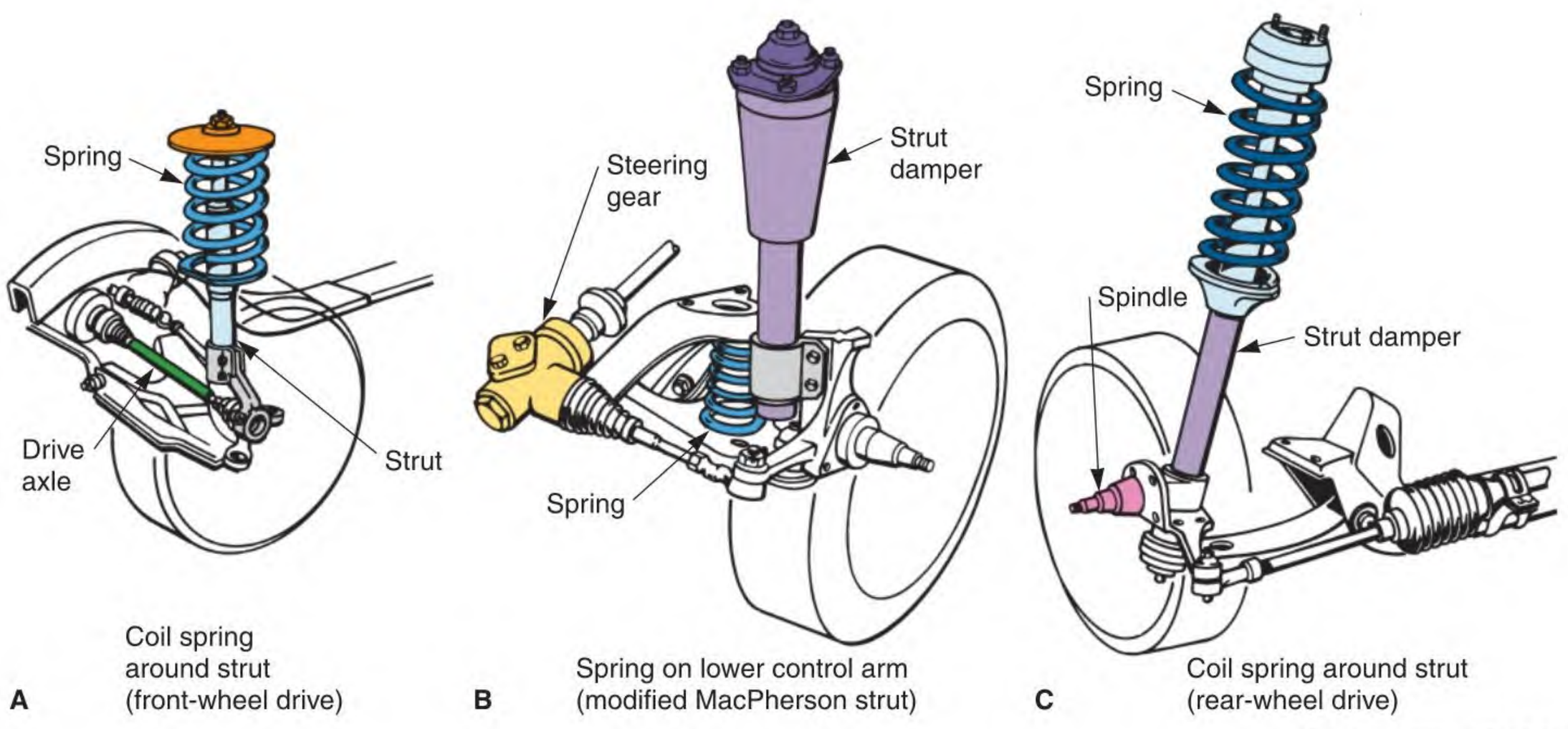
Lexus

Figure 75-16. Long-short arm suspension has different length control arms. This helps keep the steering knuckle in alignment with suspension travel.



Honda

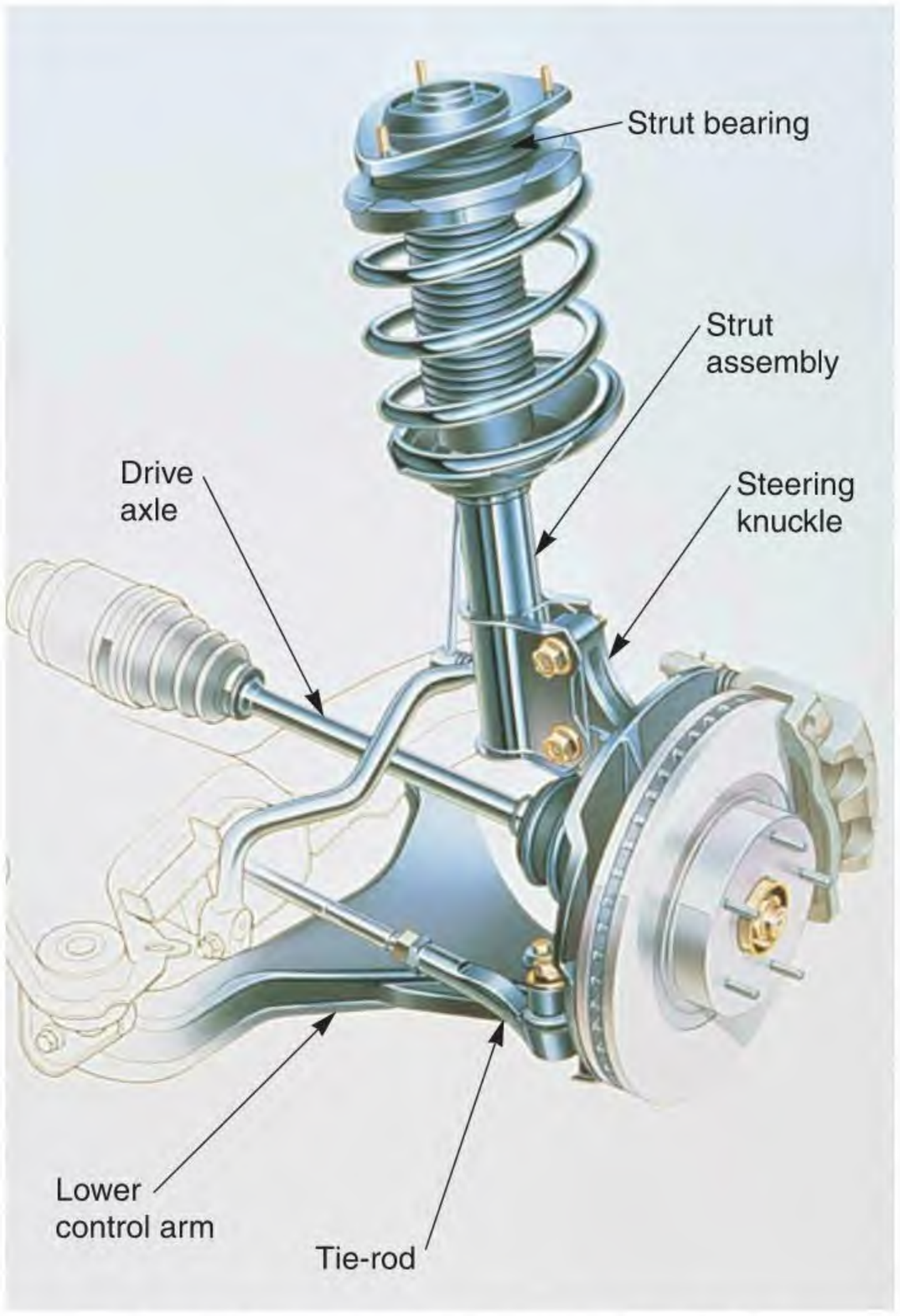
Figure 75-18. MacPherson strut suspension.



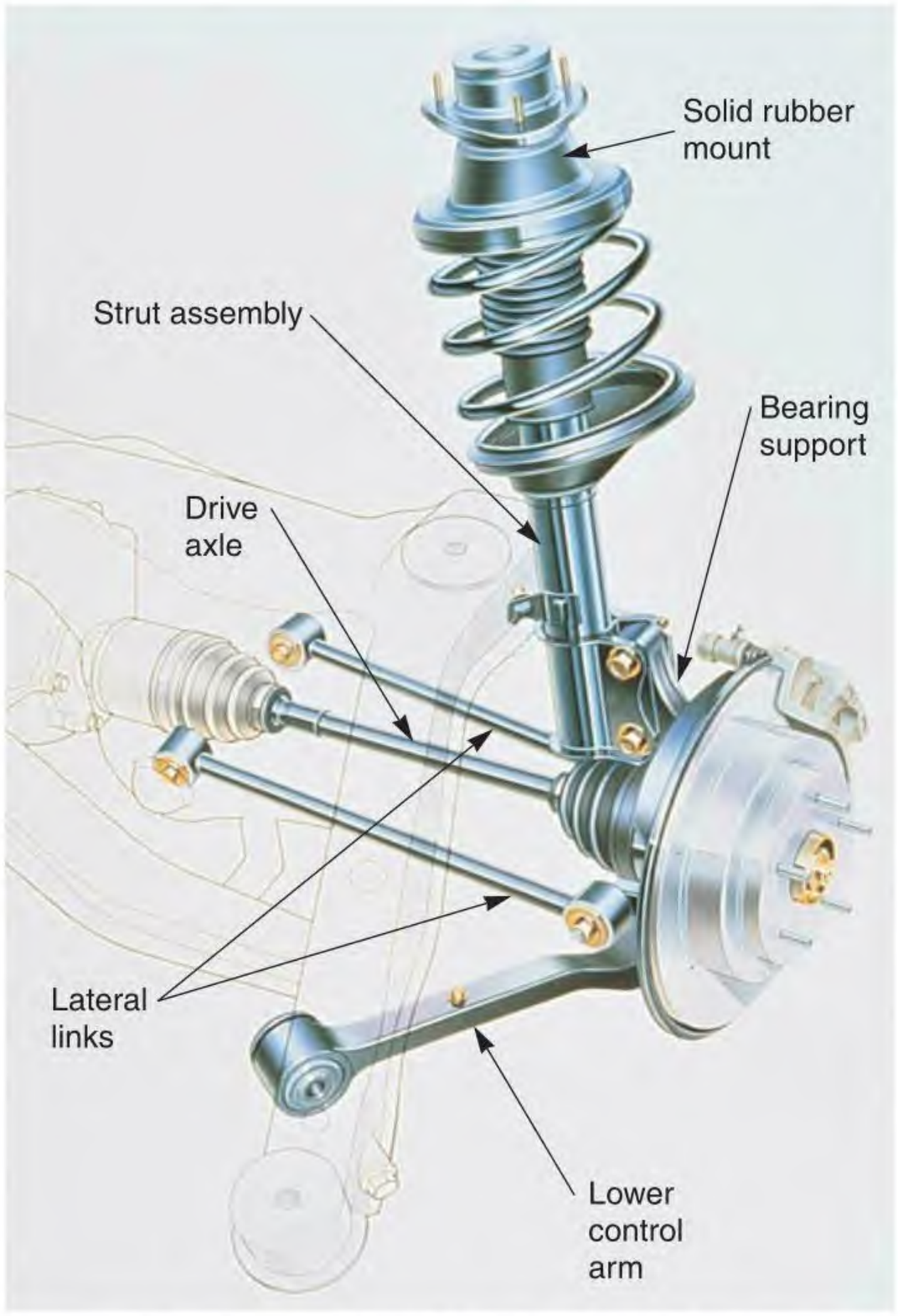
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Figure 75-17. MacPherson strut suspensions. A—Front-wheel drive; coil spring is mounted around the strut. B—Modified strut has the coil spring mounted on the control arms. C—Rear-wheel drive; coil spring is mounted around the strut.

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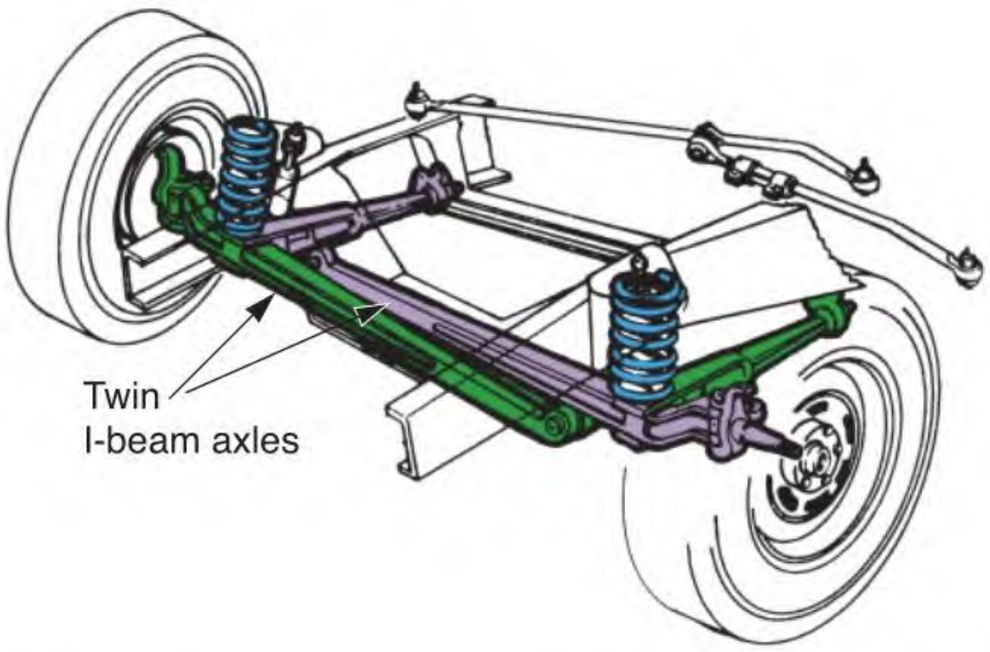
Front Suspension, with Front-Wheel Drive



Rear Suspension, with Rear-Wheel Drive

Subaru

Figure 75-19. Compare struts for the front and rear of a vehicle.



Ford

Figure 75-20. Twin I-beam suspension is used on a few pickup trucks.

rear swing axles and independent suspension can also be used.

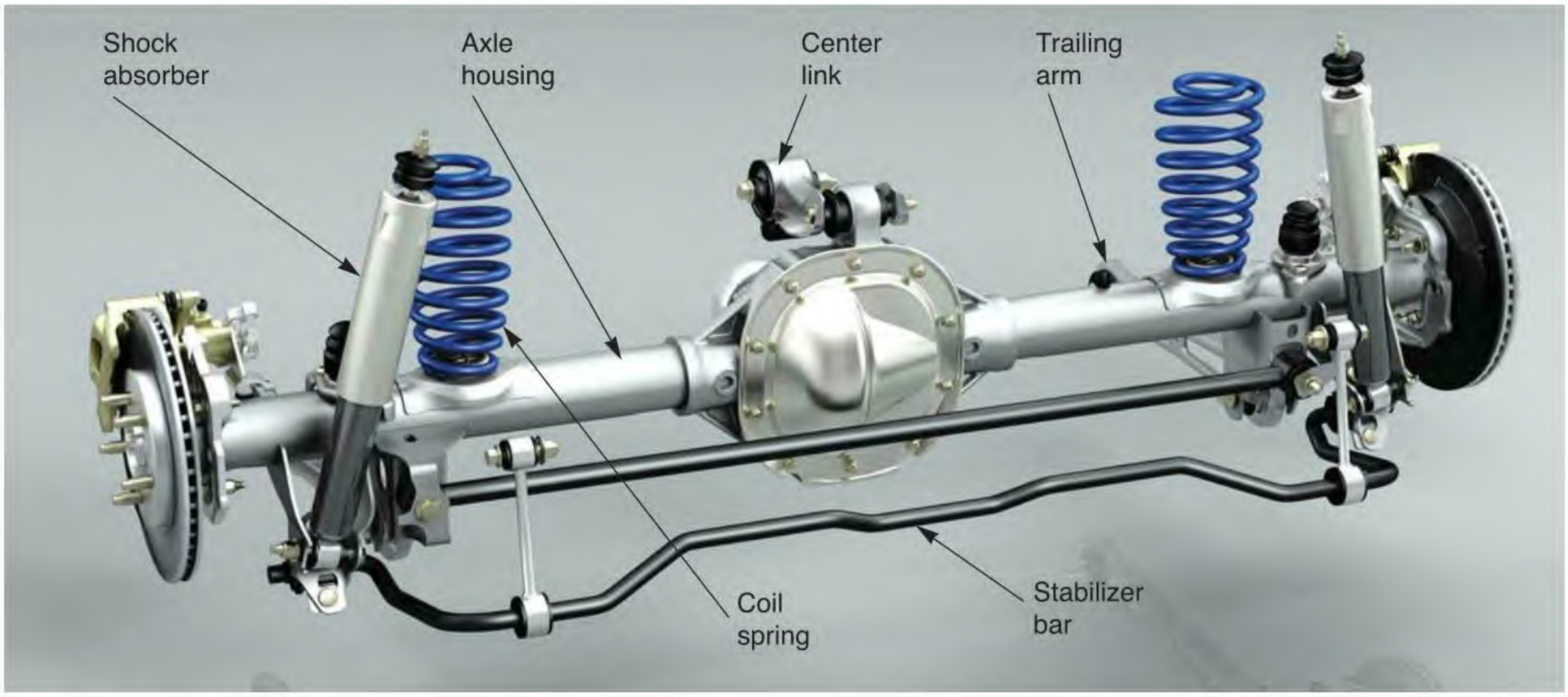
Dead Axle

A ***dead axle*** is a term used to describe a solid rear axle on a front-wheel-drive vehicle. Since the front wheels transfer driving power to the road, the rear axle is simply a straight, or solid, axle, **Figure 75-22**.

Semi-Independent Suspension

Semi-independent suspension means that the right and left wheels are partially independent of each other. This type of suspension uses a flexible axle. When one tire hits a bump, its control arm moves up. Since the axle can flex or twist, the effect on the other tire is minimized.

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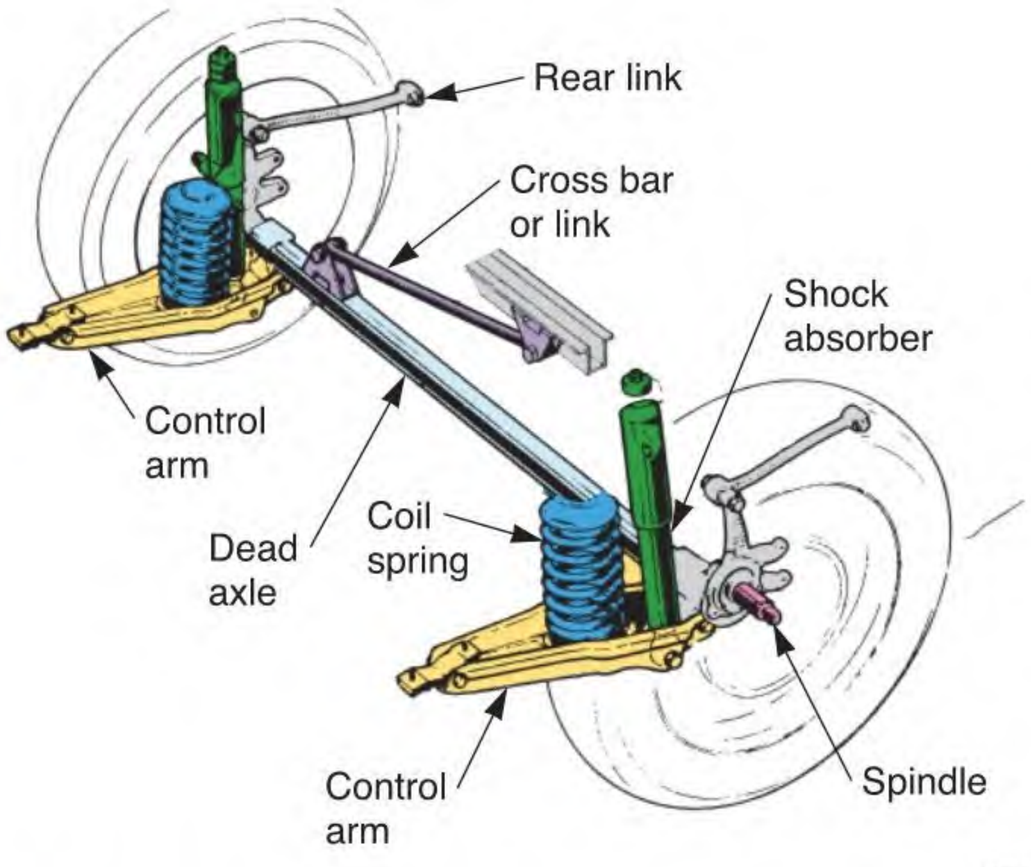


Ford

Figure 75-21. Solid axle housing rear suspension for rear-wheel-drive vehicle. Solid rear axles are commonly used on pickup trucks and full-size cargo vans. Study the parts.

Independent Rear Suspension

Most new cars use independent rear suspension to improve handling and ride quality. As with front suspension, independent suspension increases ride smoothness and cornering capabilities. Variations of this modern suspension design can be used with either a front- or rear-wheel-drive vehicle. Refer to **Figures 75-23** through **75-25**.



Saab

Figure 75-22. The term *dead axle* generally refers to a solid axle that does not drive wheels.

Suspension Leveling Systems

A ***suspension leveling system*** is used to maintain the ride height and vehicle ***attitude*** (height ratio between front and rear of body) with changes in the amount or distribution of weight in the car. For example, if weight is added in the trunk, the suspension leveling system keeps the springs from compressing and lowering the body height.

There are two classifications of suspension leveling systems: manual and automatic.

Manual Suspension Leveling System

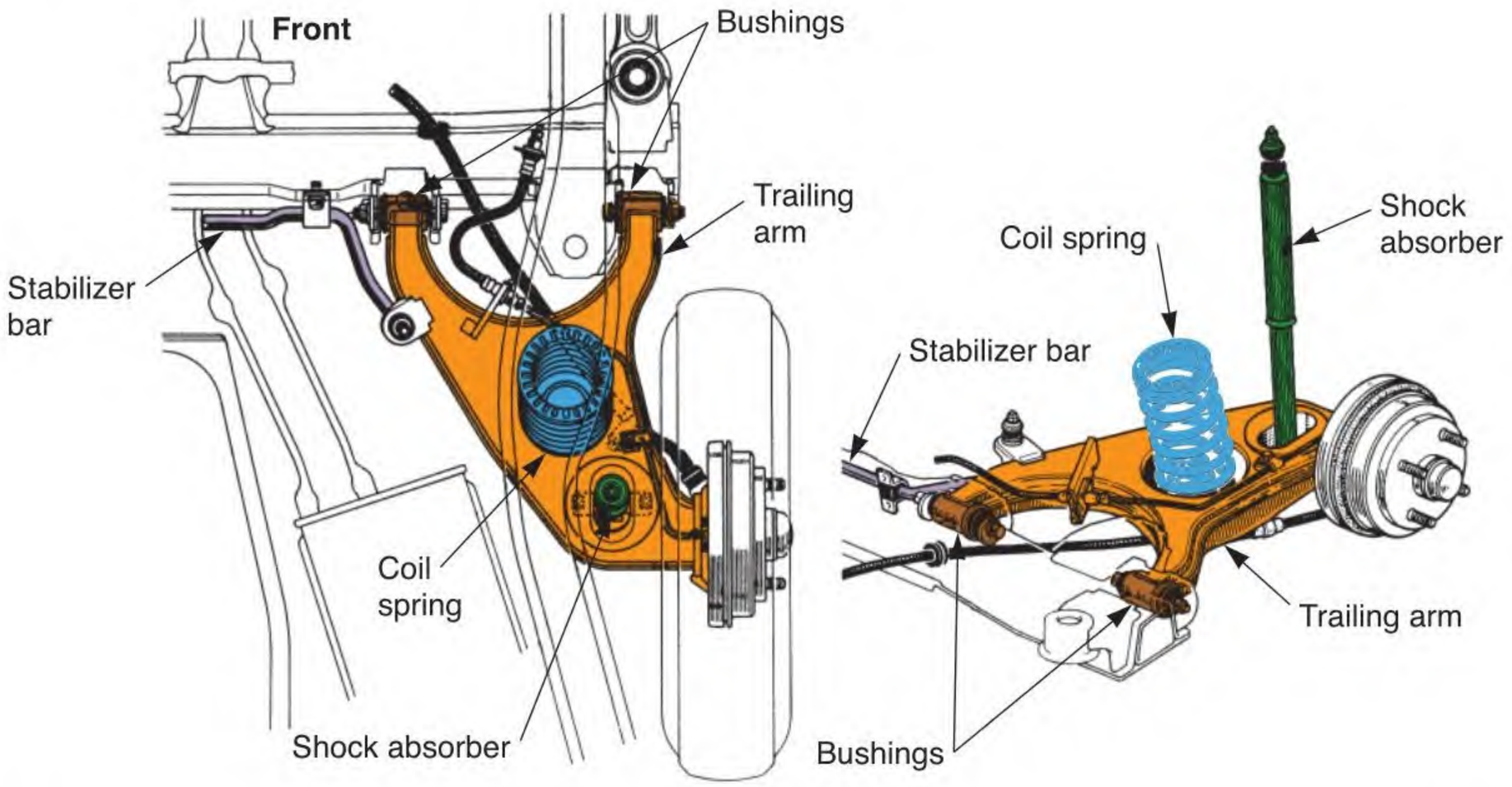
A ***manual suspension leveling system*** uses air shocks and an electric compressor to counteract changes in passenger and luggage weight. A manual switch is used to activate the compressor to alter air shock pressure and body height.

Automatic Suspension Leveling System

Automatic suspension leveling systems use air shocks or air springs, height sensors, and a compressor to maintain curb height. System designs vary. Refer to **Figure 75-26**.

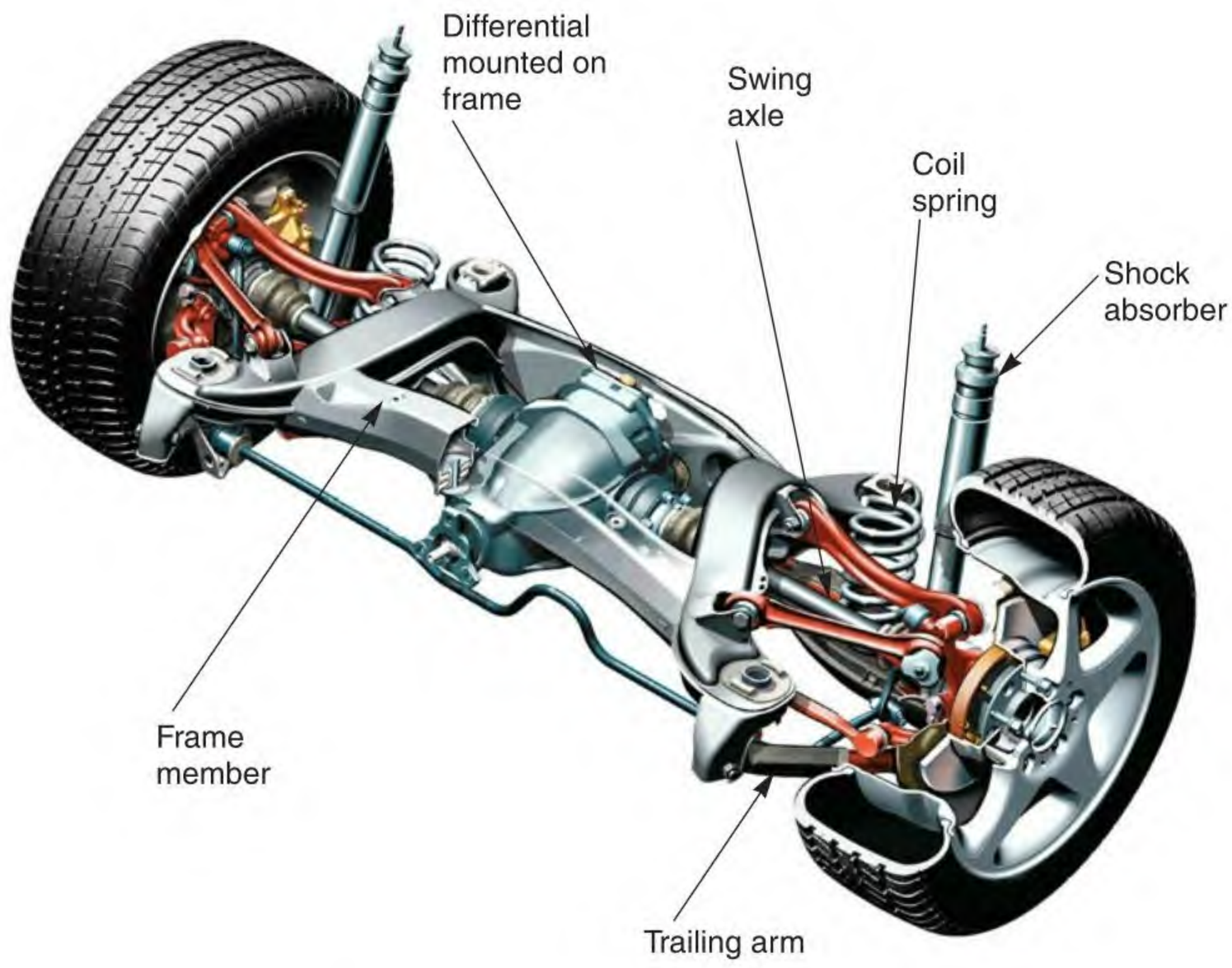
Most automatic suspension leveling systems use air shock absorbers. See **Figure 75-27**. A height sensor is connected to the frame and to the axle housing.

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Toyota

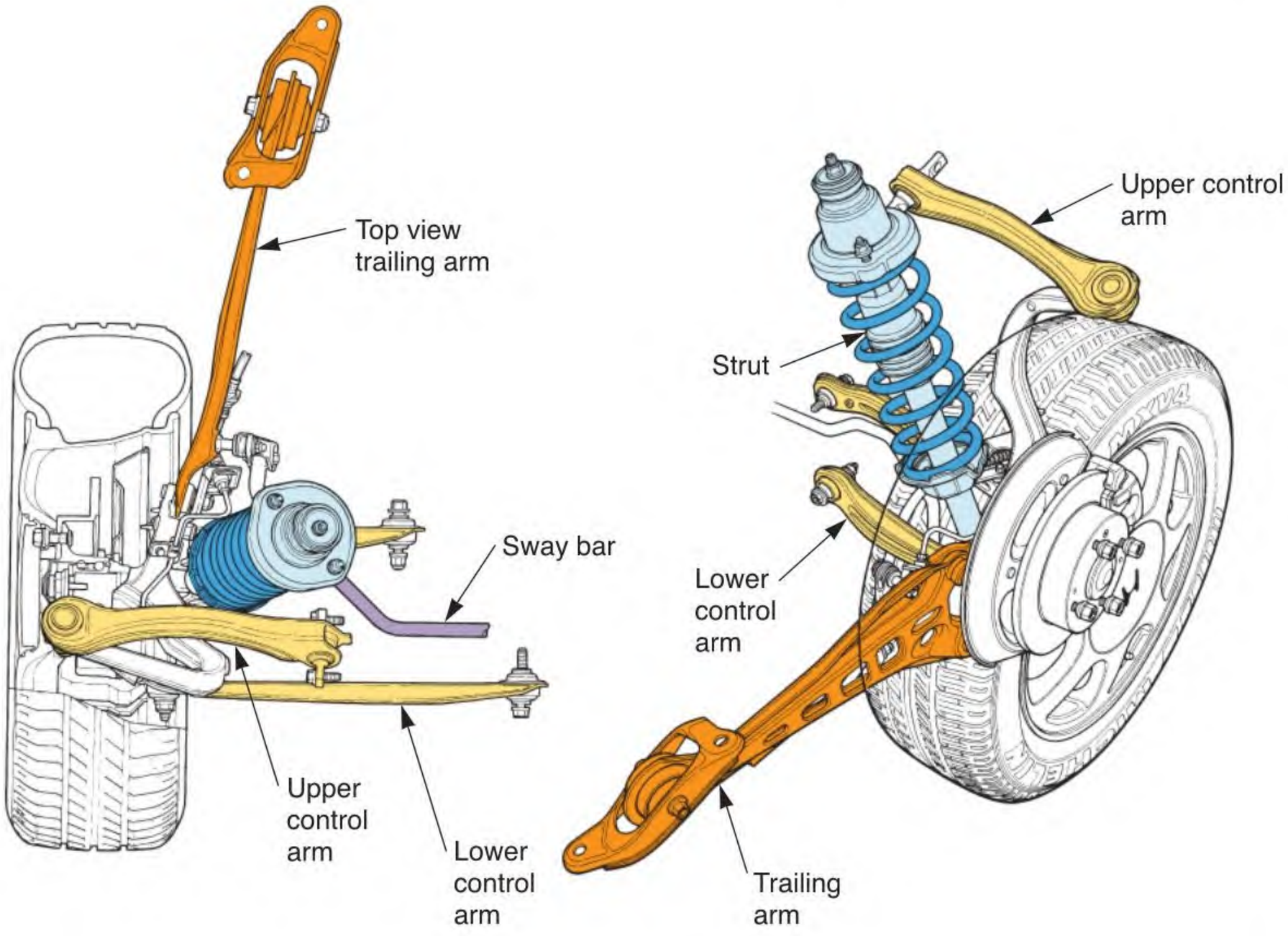
Figure 75-23. Top and side views of a trailing-arm independent rear suspension. Note the location of the bushings, the spring, and the shock absorber.



Mercedes-Benz

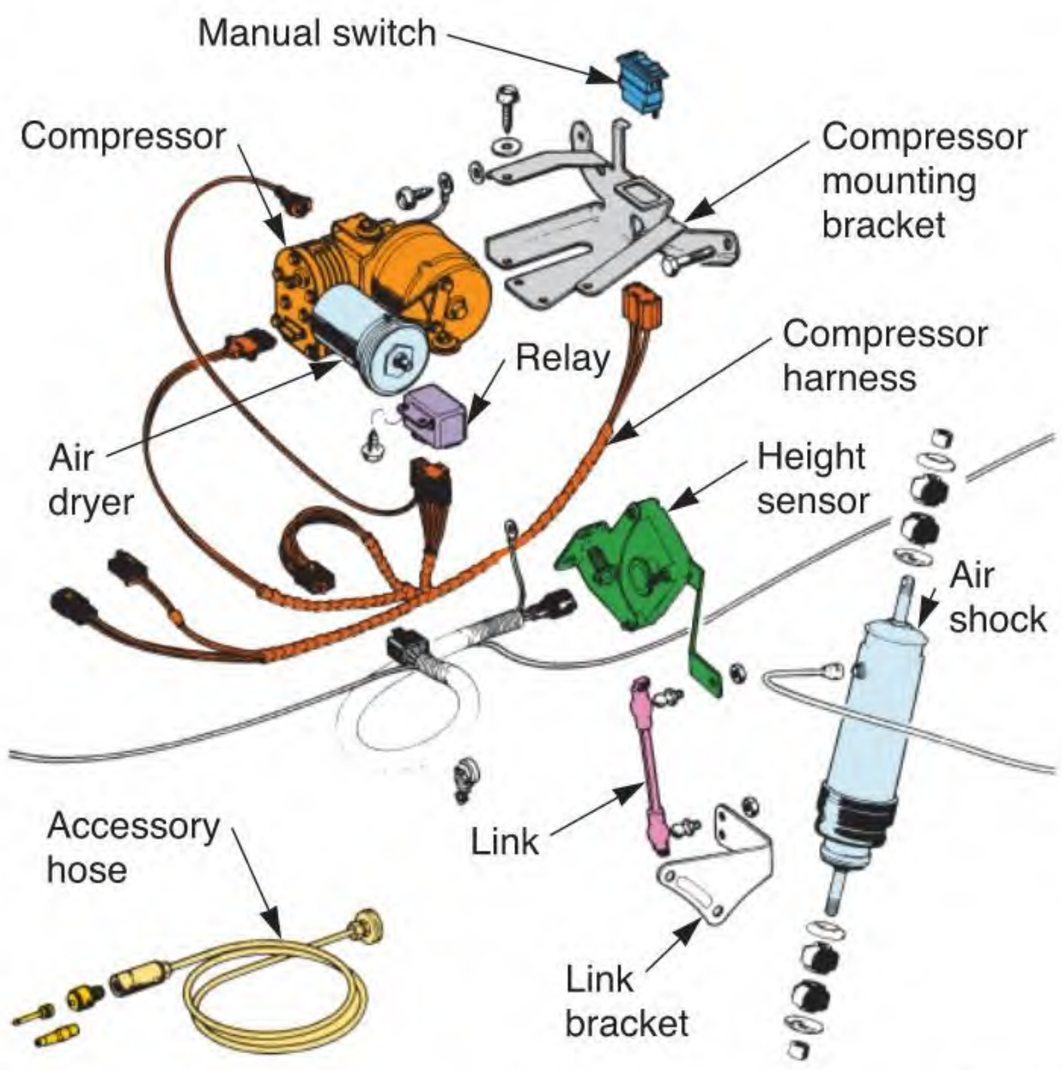
Figure 75-24. This rear drive axle uses a differential that is mounted on the frame. Swing axles extend out to the drive wheels. Note the trailing arms and the other components.

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Honda

Figure 75-25. This double wishbone suspension system is a long-short arm design. The lower trailing arms have been lightened by forming holes in them. This improves ride smoothness.



Chrysler

Figure 75-26. Major parts of suspension leveling system. Basically, the height sensor triggers the air pump. The air pump operates the air shocks to maintain the correct vehicle height.

If load changes, the sensor can turn the compressor on, increasing pressure in the air shocks to counteract the increased load. It can also bleed air out of the shocks to counteract decreased load.

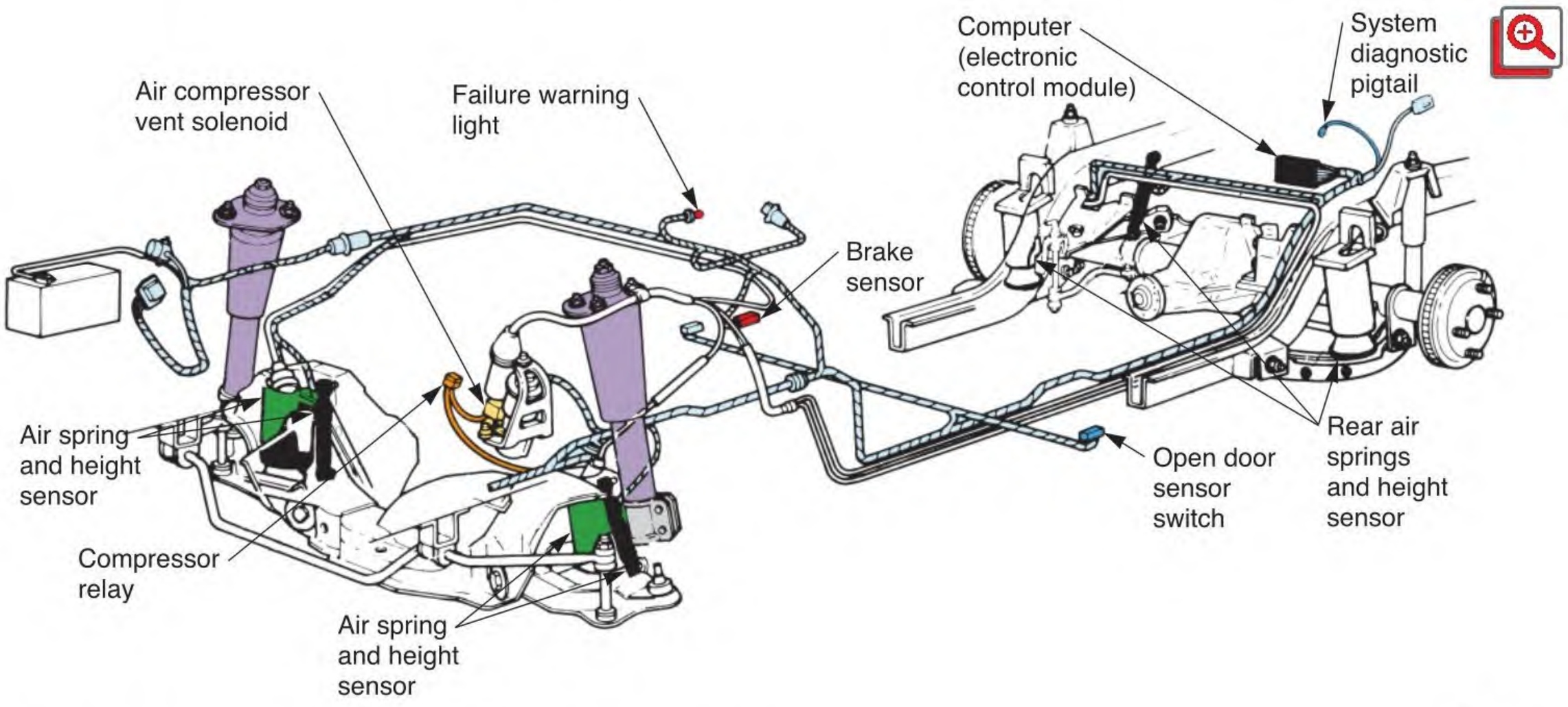
Electronic Height Control System

An ***electronic height control system*** uses height sensors and an electronic control module to control the operation of a small electric air compressor, which maintains the correct ride height. This system is used on the rear of the car to compensate for loads placed in the trunk or for the weight of passengers in the back-seat.

The main parts of an electronic height control system include:

- ***Height sensor***—The height sensor is a lever-operated switch that reacts to changes in body height and suspension movement.
- ***Compressor assembly***—The compressor assembly is a motor-powered air pump that produces pressure for the system.

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Ford

Figure 75-27. Suspension leveling system using air springs. Study the parts.

- ***Pressure lines***—Pressure lines are air hoses that connect the compressor to the air shock absorbers.
- ***Air shocks***—These air-filled shock absorbers act on the suspension system to alter ride height.
- ***Sensor link***—A sensor link is a linkage rod that connects the height sensor to the suspension.
- ***Solenoid valve***—A solenoid valve is a solenoid-operated air valve that can release air pressure from the system.
- ***Suspension control module***—The suspension control module is an ECM, or small computer, that operates the solenoid valve by responding to signals from the height sensor.

When the car body is at a normal riding height, the electronic height control system is off. Air pressure in the shocks is adequate to keep the car body at the correct distance from the road surface. The height sensor does not feed current to the control module.

If the trunk is loaded with heavy luggage, the weight of the luggage compresses the rear air shocks. This lowers the ride height. When the car is started, the height sensor is activated by the action of the sensor link and the sensor switch closes. The signal from the height sensor prompts the suspension control module to energize the compressor. The compressor pumps more air pressure into the rear shock absorbers, extending the shocks and raising the car body.

When the specific ride height is reached, the height sensor switch opens to turn off the compressor. This restores the vehicle to the correct ride height, even with extra weight in the trunk.

When the weight is removed from the trunk, the car body will rise. The height sensor switch is then moved in the other direction by the link. This closes another set of contacts in the switch, energizing the pressure release solenoid valve. Air pressure is then expelled from the rear shocks until the body drops down to the correct ride height.

Electronic Suspension System

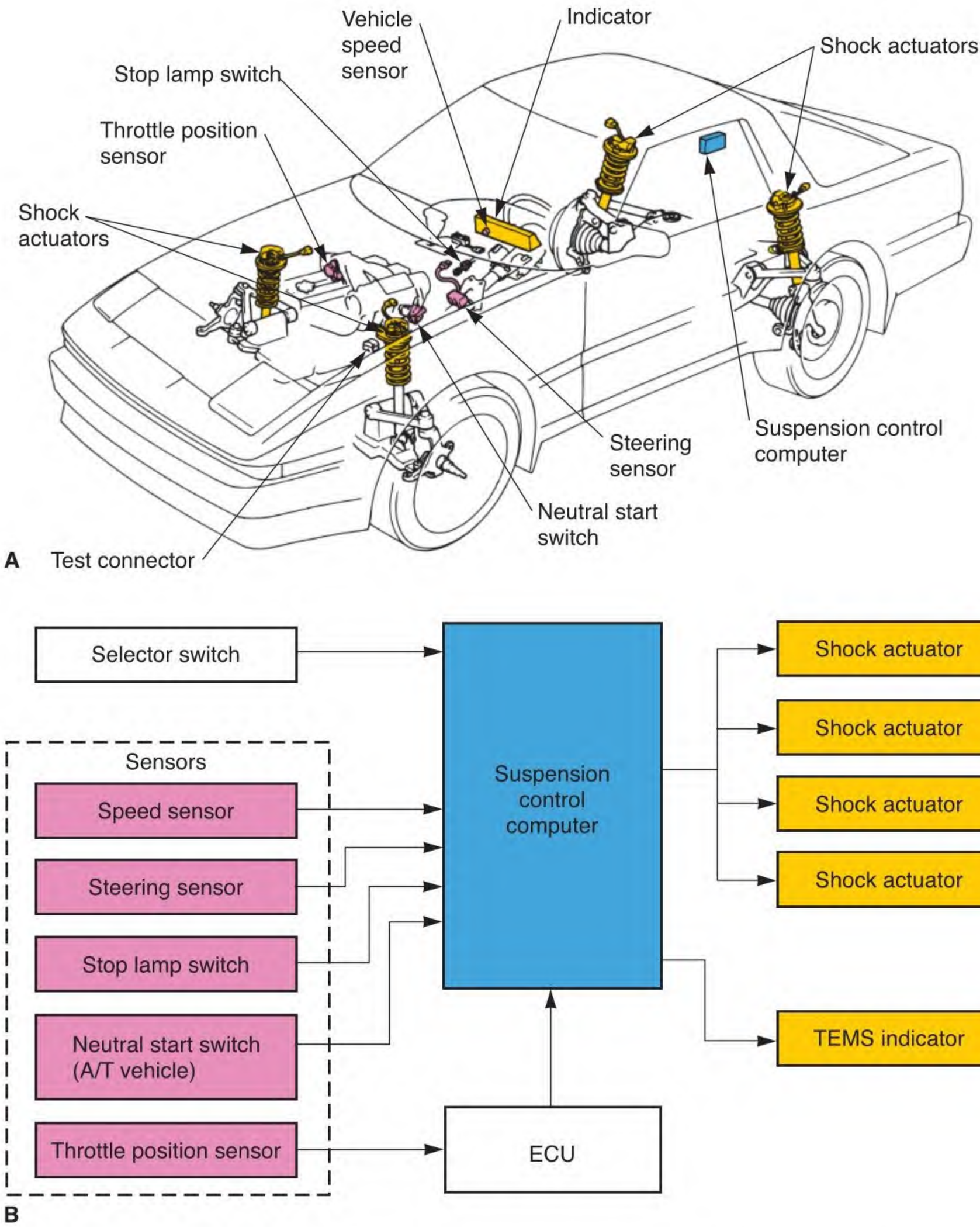
An ***electronic suspension system*** uses various sensors, a computer, and shock absorber actuators to control ride stiffness. It is designed to increase comfort and safety by matching suspension system action to driving conditions, **Figure 75-28**.

The major components of a typical electronic shock absorber system include:

- ***Steering sensor***—The steering sensor detects steering wheel rotational direction and speed, and feeds data about vehicle direction to the computer.
- ***Brake sensor***—Usually, the brake light switch is used to report when the brakes are applied.

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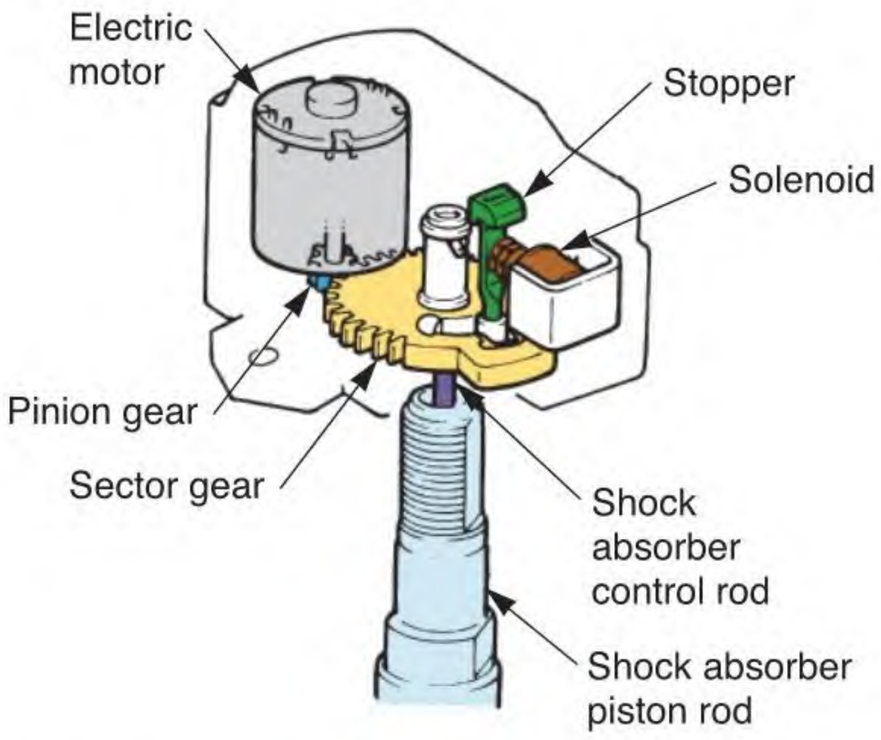
- ***Acceleration sensor***—Usually, the throttle position sensor and accelerator pedal sensor are used to detect when the car is accelerating rapidly.
- ***Mode switch***—This dash-mounted switch allows the driver to choose the desired shock action or stiffness, and sometimes ride height.
- ***Electronic control module***—This small computer uses sensor inputs to control the shock actuators.
- ***Shock actuators***—Shock actuators are solenoid-operated valves that control fluid flow inside the shock absorbers. See **Figure 75-29**.



Toyota

Figure 75-28. This electronic suspension system automatically adjusts shock stiffness to match driving and road conditions. A—Note the major components of an electronic suspension system. B—This block diagram shows how the sensors feed data to the suspension control computer. The computer then energizes the shock actuators to modify ride stiffness and shock action.

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Figure 75-29. This shock actuator uses a small electric motor and a solenoid to move the shock piston rod in and out. Piston rod movement alters shock dampening action.

If a car is being driven on curving country roads, the driver might switch to a stiff setting with the mode switch. The electronic control module would then energize the shock actuators to close or restrict the shock absorber valves to increase dampening action. This stiffens the ride and makes the car corner better.

If driving on a rough highway, the mode switch might be moved to a soft setting. The electronic control module would then energize the shock actuators to open the valves more. This softens the ride by allowing easier shock movement.

Under hard braking, the brake sensor could send a signal to the electronic control module. The control module could then stiffen the shocks to prevent the front of the car from diving.

With rapid turning or cornering, the steering sensor could also signal the electronic control module. The module could then stiffen the shocks to prevent excess body roll, or lean, in turns.

Some cars use air shocks or air bags instead of hydraulic shock absorbers. The operation of these systems is similar.

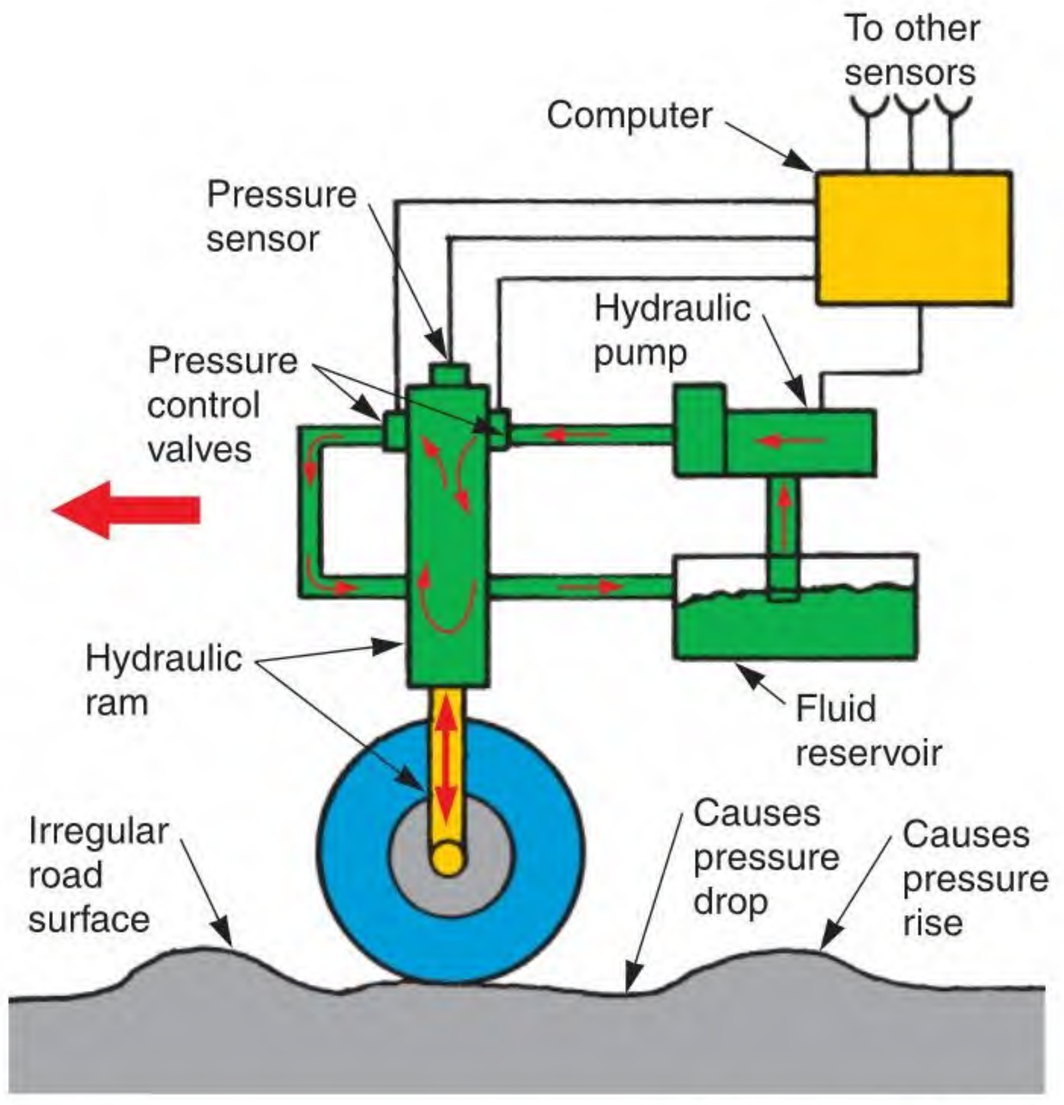
One type of electronic shock absorber system uses a sonar sensor to detect changes in road conditions. The sensor is mounted at the front of the vehicle and produces sound waves. These waves bounce off the road and back into the sensor. The sensor's output signal is determined by the amount of time needed for the waves to strike the road surface and bounce back. The computer uses the output signals from the sonar sensor to determine proper ride stiffness. If, for example, there is a dip in the road, the sound waves take longer to return to the sensor. This causes the sensor to modify its output signal. The computer analyzes the sensor's output signals and adjusts shock action as necessary.

Active Suspension System

An ***active suspension system*** uses computer-controlled hydraulic rams instead of conventional springs and shock absorber actuators to control ride characteristics. A fully active suspension is called an "intelligent suspension" because a computer controls the hydraulic system.

The hydraulic rams support the weight of the car and react to the road surface and driving conditions. An active suspension system is similar to an electronic shock absorber system, but it is more complex. Refer to **Figure 75-30**.

Basically, pressure sensors on each hydraulic ram provide the main control for the system. The sensors react to suspension system movement and send signals to the computer. The computer can then extend or retract each ram to match the road surface. A hydraulic pump provides pressure to operate the rams. Pressure control valves are located on each ram. By opening and closing these valves, the computer can



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Figure 75-30. This simplified illustration shows the major components of an active suspension system.

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adjust the pressure of the rams and the resulting height of each corner of the vehicle.

For example, if one side of the vehicle travels over a bump in the road, the pressure sensors can instantly detect a rise in pressure inside the ram as the tire and wheel push up on the suspension and the hydraulic ram. Instead of the vehicle's body rising with spring action, the computer can release enough ram pressure to allow the suspension to move up over the bump without causing body movement. Then, as the tire travels back down over the bump, the sensor detects a pressure drop in the ram and the computer increases ram pressure so the tire follows the road surface.

The active suspension system can make a car feel as if it is floating on a cushion of air. It can, theoretically, eliminate most body movement as the car travels over small dips and bumps in the road. It can also help keep the body level under various driving conditions. During hard braking, the active suspension system can keep the front of the body from diving and the rear from rising, thus improving action.

In turns, the active suspension system's ability to prevent body roll (lean) can make the car stay level to increase cornering ability. It can tilt the vehicle's body against a turn to improve handling. It can also be used to lower the body for highway driving aerodynamics and to raise the body for added ground clearance during city driving.

Many auto manufacturers are experimenting with active suspension systems of this type. We may see them in the future, at first on more exotic sports cars, but someday on everyday passenger cars.

In the Rearview Mirror

The Ford Model-T was the first mass-produced passenger car. Affectionately called the "Tin Lizzie," this vehicle was first introduced in 1908. It was deemed "the car for the multitude" and was an instant success. Henry Ford developed this car and succeeded in building one of the largest automobile-manufacturing companies in the world. Not much more than a horse buggy with an engine, the Model-T drove like a log wagon and belched smoked like a steam engine.

Summary

- The suspension system allows the tires and wheels to move up and down over bumps and holes in the road surface.
- Chassis stiffness is a primary factor affecting how quiet and smooth a vehicle drives—the stiffer the chassis, the better.
- Independent suspension allows one wheel to move up and down with little effect on the other wheels.
- Nonindependent suspension has both the right and left wheels attached to the same solid axle.
- Lateral acceleration is the amount of side force a vehicle can handle in a sharp turn or curve before its tires lose traction and skid.
- Suspension system springs must jounce (compress) and rebound (extend) with bumps and holes in the road surface.
- A control arm holds the steering knuckle, bearing support, or axle housing in position as the wheel moves up and down.
- A strut rod fastens to the outer end of the lower control arm and to the frame. It keeps the control arm from swinging toward the rear or front of the vehicle.
- Ball joints (short for ball-and-socket joints) are connections that allow limited rotation in every direction.
- Shock absorbers limit spring oscillations (compression-extension movements) to smooth the vehicle's ride.
- A strut assembly consists of a shock absorber, a coil spring (most types), and an upper damper unit.
- A sway bar, also called stabilizer bar, is used to keep the body from leaning excessively in sharp turns.
- Jounce bumpers are blocks of hard rubber that keep the suspension system parts from hitting the frame or body when the vehicle hits large bumps or holes.
- A long-short arm suspension uses control arms of different lengths to keep the tires from tilting with suspension action.
- A MacPherson strut suspension uses only one control arm and a strut assembly (spring, damper,

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and shock absorber unit) to support each wheel assembly.

- A dead axle is a term used to describe a solid rear axle on a front-wheel-drive vehicle.
- A suspension leveling system is used to maintain a constant vehicle attitude (height ratio between front and rear of body) as the amount or distribution of weight in the vehicle changes.
- To maintain correct ride height, an electronic height control system uses height sensors and an ECM to control the operation of a small electric air compressor.
- An electronic shock absorber system uses various vehicle sensors, an electronic control module, and shock absorber actuators to control ride stiffness.
- An active suspension system uses computer-controlled hydraulic rams instead of conventional suspension system springs and shock absorbers.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

acceleration sensor
active suspension system
adjustable shock absorbers
air shocks
air spring
attitude
automatic suspension leveling systems
ball joints
body dive
body roll
body squat
brake sensor
chassis hertz
chassis stiffness
coil spring
compressor assembly
control arm
control arm bushings
curb height
damper unit
dead axle
dust shield
electronic control module
electronic height control system
electronic suspension system
gas-charged shock absorbers
height sensor
independent suspension
insulators
jounce
jounce bumpers
lateral acceleration
lateral control rod
leaf spring
leaf spring windup
long-short arm suspension
lower spring seat
MacPherson strut suspension
manual suspension leveling system
mode switch
modified strut suspension
neutral steering
nonindependent suspension
oscillations
oversteer
pressure lines
rebound
rubber bumpers
rubber isolators
self-leveling shock absorber
semi-independent suspension
sensor link
shackle
shock absorber compression
shock absorber extension
shock absorbers
shock actuators
skidpad
solenoid valve
spring rate
sprung weight
stabilizer bar
steering sensor
strut assembly
strut bearing
strut rod
strut rod nut
strut shock absorber
suspension control module
suspension leveling system
suspension system
suspension system springs
sway bar
sway bar links
torsion bar
torsion bar suspension
track rod
travel
understeer
unsprung weight
upper spring seat
upper strut retainer

Activities

1. Create a visual presentation (a poster-size drawing, a model, or a multimedia presentation) of a suspension system. Explain to the class the function of each part in the system.
2. Examine actual shop vehicles to determine the type of suspension used at each wheel.
3. In a group, discuss the merits of different suspension systems. Which suspension systems would be better for a sports car versus a pickup truck?

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Review Questions

Answer the following questions using the information provided in this chapter.

1. List eight functions of a suspension system.
2. List and explain the six major parts of a suspension system.
3. _____ suspension allows one wheel to move up and down with a minimum effect on the other wheels.
4. The most common type of suspension system spring is the _____ spring.
   (A) leaf
   (B) coil
   (C) air
   (D) torsion
5. A(n) _____ fastens the rear of a leaf spring to the car frame.
6. Define the phrase "leaf spring windup."
7. How does a torsion bar work?
8. The _____ weight of a car is the weight of the parts *not* supported by the springs.
9. A strut rod is used to keep the steering knuckle from swiveling. True or False?
10. Why are ball joints needed?
11. Summarize the basic operation of a conventional shock absorber.
12. What is the advantage of gas-charged shocks?
13. List and explain the eleven major parts of a strut assembly.
14. The _____ is used to keep the car body from rolling or leaning excessively in turns or corners.
    (A) strut rod
    (B) jounce bumper
    (C) track rod
    (D) sway bar
15. Describe a MacPherson strut suspension.

ASE-Type Questions

1. Technician A says an automotive suspension system supports the weight of the engine. Technician B says an automotive suspension system supports the weight of the transmission. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. All of the following are functions of an automotive suspension system, *except:*
   (A) helps provide a smooth ride for passengers.
   (B) keeps tires in firm contact with the road.
   (C) allows the front wheels to turn from side to side for steering.
   (D) allows the body to tilt when heavily loaded.
3. Technician A says an automotive suspension system works with the steering system to help keep the wheels in correct alignment. Technician B says an automotive suspension system works independently of the steering system and has no effect on wheel alignment. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. All of the following are basic components of an automotive suspension system, *except:*
   (A) control arm.
   (B) steering knuckle.
   (C) internal control shaft.
   (D) shock absorber.
5. Technician A says a suspension system's control arm fastens the steering knuckle to the shock absorber. Technician B says the control arm fastens the steering knuckle to the frame. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Technician A says a ball joint allows control arm movement. Technician B says a ball joint allows steering knuckle movement. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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7. Technician A says the control arm bushing allows the suspension system control arm to swing up and down on the vehicle frame. Technician B says the control arm bushing allows the control arm to move from side to side on the suspension system damper. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. Technician A says that in an independent suspension system, movement of one wheel does not cause direct movement of the wheel on the opposite side of the vehicle. Technician B says that in a nonindependent suspension system, movement of one wheel does not cause direct movement of the other wheel on the opposite side of the vehicle. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Technician A says an independent suspension system has both the right and left wheels attached to the same solid axle. Technician B says a nonindependent suspension system has both the right and left wheels attached to the same solid axle. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. Technician A says a coil spring is the most common spring used on modern automotive suspension systems. Technician B says a leaf spring is the most common spring used on modern automotive suspension systems. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
11. Technician A says coil springs are used on either the front or the rear of an automobile. Technician B says coil springs are only used on the front of an automobile. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
12. Technician A says a torsion bar fastens to the vehicle's frame. Technician B says a torsion bar fastens to the suspension system control arm. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
13. Technician A says most automotive shock absorbers are filled with oil. Technician B says most automotive shock absorbers are filled with air. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
14. Technician A says an automotive strut assembly normally consists of a shock absorber, a coil spring, and an upper damper unit. Technician B says an automotive strut assembly normally consists of a shock absorber, a coil spring, and a control arm. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
15. Technician A says the term "dead axle" is used to describe a solid rear axle on a front-wheel-drive vehicle. Technician B says the term "dead axle" refers to a solid rear axle on an independent suspension system. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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Chapter 76
Suspension System Diagnosis and Repair

After studying this chapter, you will be able to:

- Diagnose problems relating to a suspension system.
- Replace shock absorbers and ball joints.
- Describe the removal and replacement of springs.
- Replace control arm bushings.
- Service a strut assembly.
- Use safe work procedures while repairing suspension systems.
- Diagnose and repair electronically-controlled suspension systems.
- Correctly answer ASE certification test questions about the diagnosis and repair of suspension systems.

A suspension system takes a tremendous pounding during normal vehicle operation as it supports the weight of a vehicle going over millions of road surface irregularities. Bumps and potholes in the road cause constant movement, fatigue, and wear of shock absorbers, ball joints, bushings, springs, and other parts. After prolonged use, major repairs may be needed to restore the suspension system to its original condition.

This chapter covers the most common procedures for diagnosing and repairing suspension system problems. You will learn how to properly inspect, remove, and replace suspension parts using specialized suspension system tools. You will also learn a few tricks of the trade for finding worn suspension parts.

Suspension System Diagnosis

Suspension system problems usually show up as:

- Abnormal noises—These noises include pops, squeaks, and clunks from suspension parts.
- Tire wear—Worn suspension system parts allow the wheels to go out of alignment.
- Steering wheel pull—Part wear and incorrect wheel alignment make the vehicle wander or veer to one side of the road.
- Front end shimmy—Side-to-side vibration of the front wheels is caused by part wear in suspension system.

Make sure that the trouble is in the suspension system, not in the steering system, wheel bearings, tires, or other related parts. Suspension system wear can upset steering system operation and change wheel alignment angles. Worn ball joints may let the steering

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knuckles tilt sideways on their control arms. This, in turn, allows the wheels and tires to cock, or lean.

To begin diagnosis of a suspension system, talk to the customer or the service writer. Then, inspect the parts that could cause the problem or test-drive the vehicle.

Figure 76-1 shows typical problem areas. **Figure 76-2** is an exploded view of the parts of a common front-wheel suspension assembly. Study the relationship between parts.

Shock Absorber Service

Worn shock absorbers will cause a vehicle to ride poorly on rough roads. When the tire strikes a bump, a bad shock will not dampen spring oscillations. The suspension system will continue to jounce and rebound up and down. This movement is transferred to the frame, body, and passenger compartment.

A loose or damaged shock absorber may produce a loud clanking or banging sound. The rapid up-and-down suspension movement can hammer the loose shock absorber shaft against the body, shock tower, or control arm.

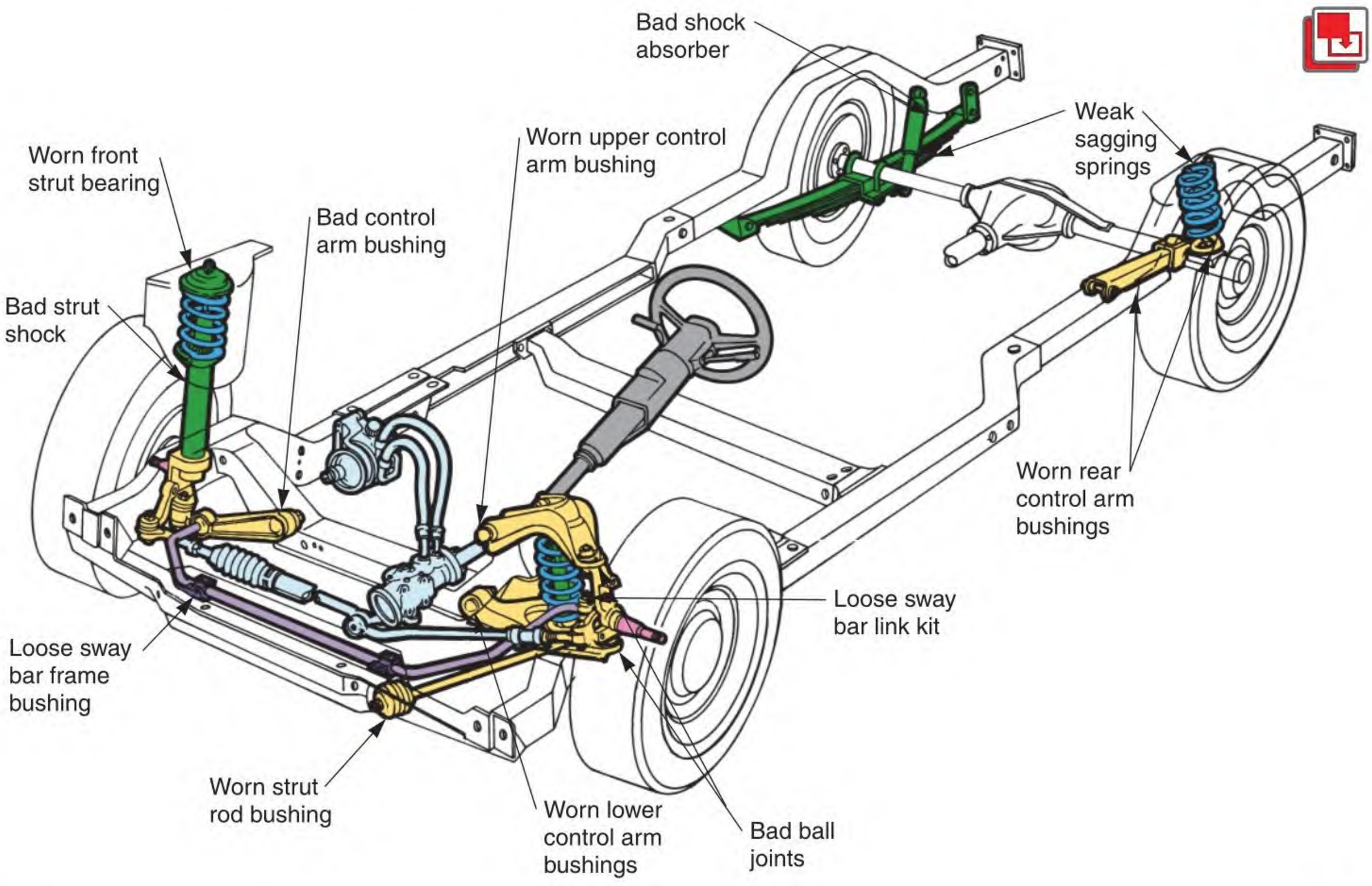
Checking Shock Absorber Condition

A ***shock absorber bounce test*** and visual inspection will normally locate shock absorber problems. To perform a shock absorber bounce test, simply push down on one corner of the vehicle's body. Then, release the body and count the number of times the vehicle rebounds (moves up and down).

Generally, good shock absorbers should stop body movement in one or two rebounds. Bad shock absorbers will let the body bounce three or more times. The bounce test should be performed on each corner of the vehicle.

Also, inspect the shock absorbers for signs of leakage (oily wetness) and damage. If the shock is leaking oil, new shocks are needed.

Check the rubber bushings on each end of the shock. They should not be smashed or split. Make sure the shock absorber fasteners are tight.



Moog

Figure 76-1. Study the types of problems that can develop in a suspension system.

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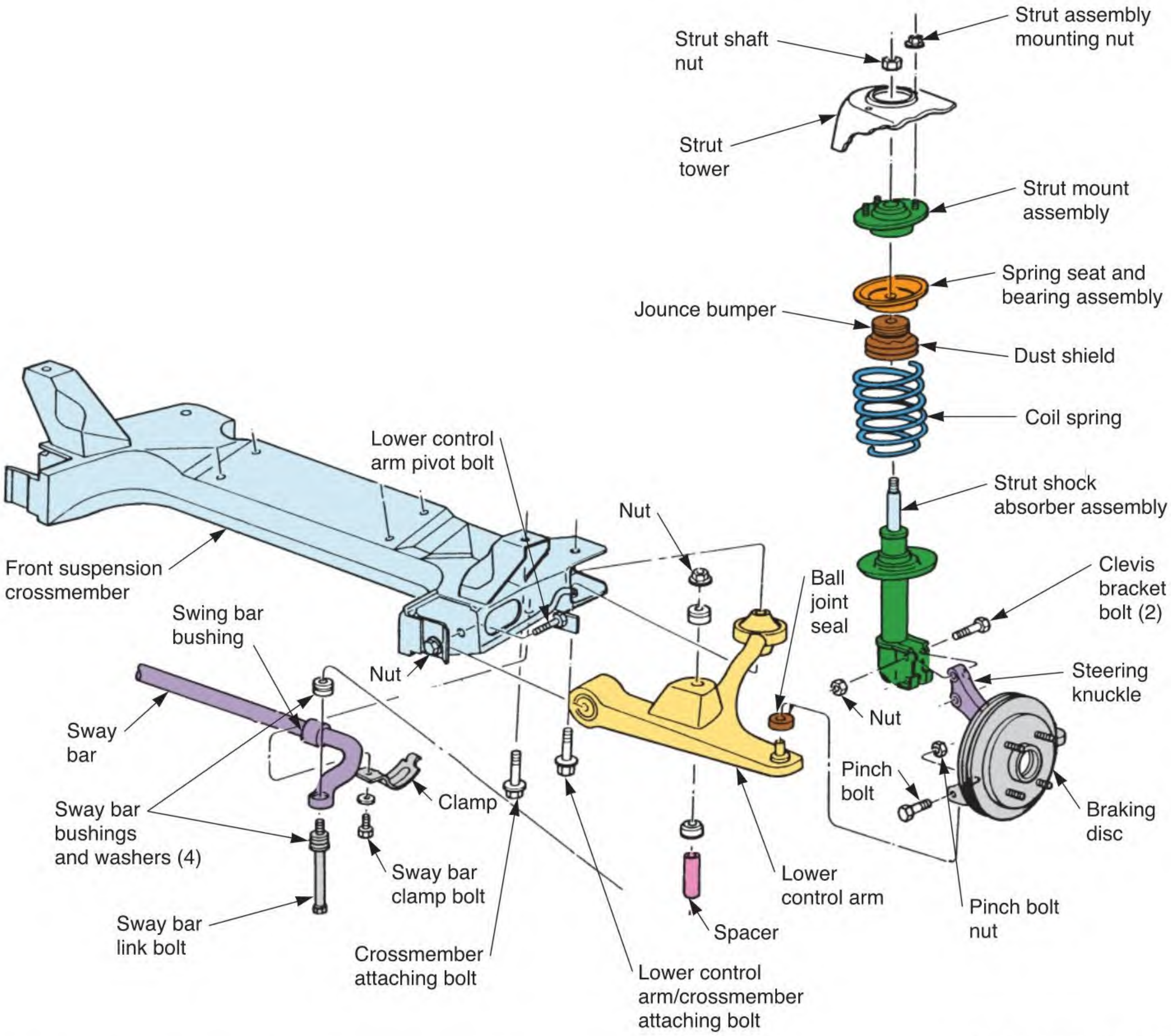


Figure 76-2. Note the parts of this front suspension system.

Replacing Shock Absorbers

When shock absorbers are faulty, they must be replaced.

Warning

With many suspension systems, you must place jack stands or lifting devices under the control arms or the axle before removing the shock absorbers. This will keep the control arms or axle from flying downward when the shocks are unbolted.

Service Procedure

The typical procedure for replacing shock absorbers is as follows:

1. Place the vehicle on jack stands or on a lift.
2. Remove the wheel-and-tire assemblies.
3. Place jack stands or other lifting devices under the control arms or the axle housing, if necessary. See **Figure 76-3A**. Raise the control arm or axle just enough so the shock rod is not

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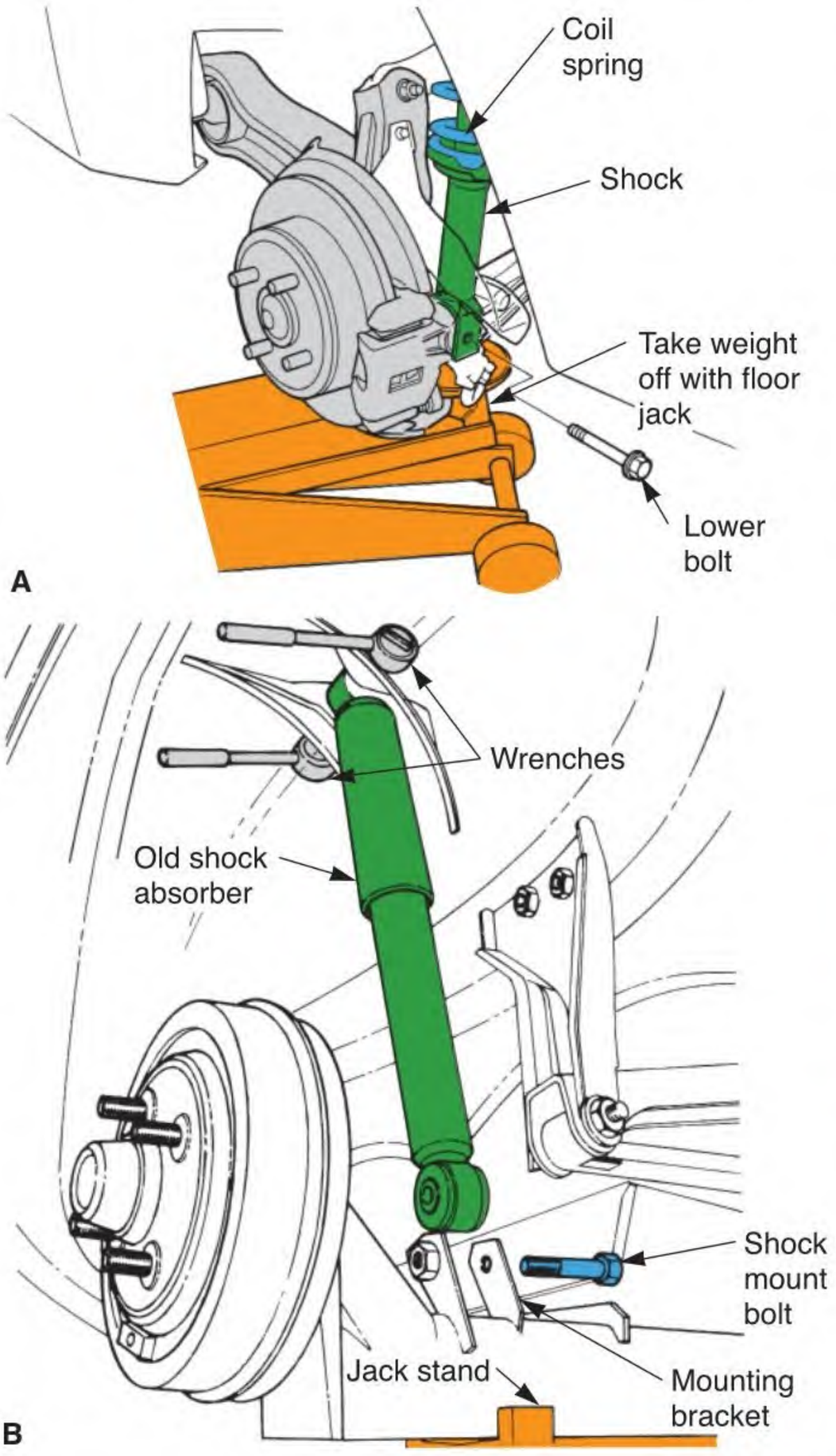


Figure 76-3. A—Before removing the bolts that secure the shock absorber, support the weight of the suspension system to keep the spring from forcing parts down violently. B—Conventional shock absorber removal simply involves unbolting the top and bottom of the shock.

fully extended. You do not want the weight of the axle or fully extended control arm to pull down on the shock rod during removal.

4. Using an air impact gun, remove the fasteners securing the old shock absorbers, **Figure 76-3B**. When a threaded stud and a nut are used, you may need to hold the stud while turning the nut.
5. If the fasteners are rusted, spray rust penetrant on the threads to ease removal of the nuts and bolts.
6. Install the new shock in reverse order of removal.

Air- and Gas-Charged Shock Service

Air- and gas-charged shocks are replaced using the same general procedures described for conventional shocks. Gas-filled shocks must be replaced when faulty. Air shocks may be repairable.

The most common problem with air shocks is air leakage. The air lines, air valve, or shocks can develop pinhole leaks that allow air pressure to bleed off.

To find air leaks, wipe on a soap-and-water solution at possible leakage points, such as air line fittings, shock boots, and air valves. Bubbles are signs of leakage. If a line, fitting, or shock leaks, it should be tightened or replaced.

Caution

Never exceed the recommended maximum air pressure given for air shocks. If excess pressure is forced into the system, the shocks can be ruptured (blown apart) and ruined.

Suspension Spring Service

Spring fatigue (weakening) allows a vehicle's body to settle toward the axles, lowering vehicle ride height. This settling or sagging changes the position of the control arms, resulting in misaligned wheels. This condition also affects the ride and appearance of the vehicle. Fatigue can occur after prolonged service.

Curb Height and Curb Weight

To check spring condition, measure the vehicle's curb height when the vehicle is at a specified curb weight. ***Curb height*** is the distance from a specific point on the vehicle to the ground. ***Curb weight*** is generally the weight of the vehicle with a full tank of fuel and no passengers or luggage. It is given in pounds or kilograms.

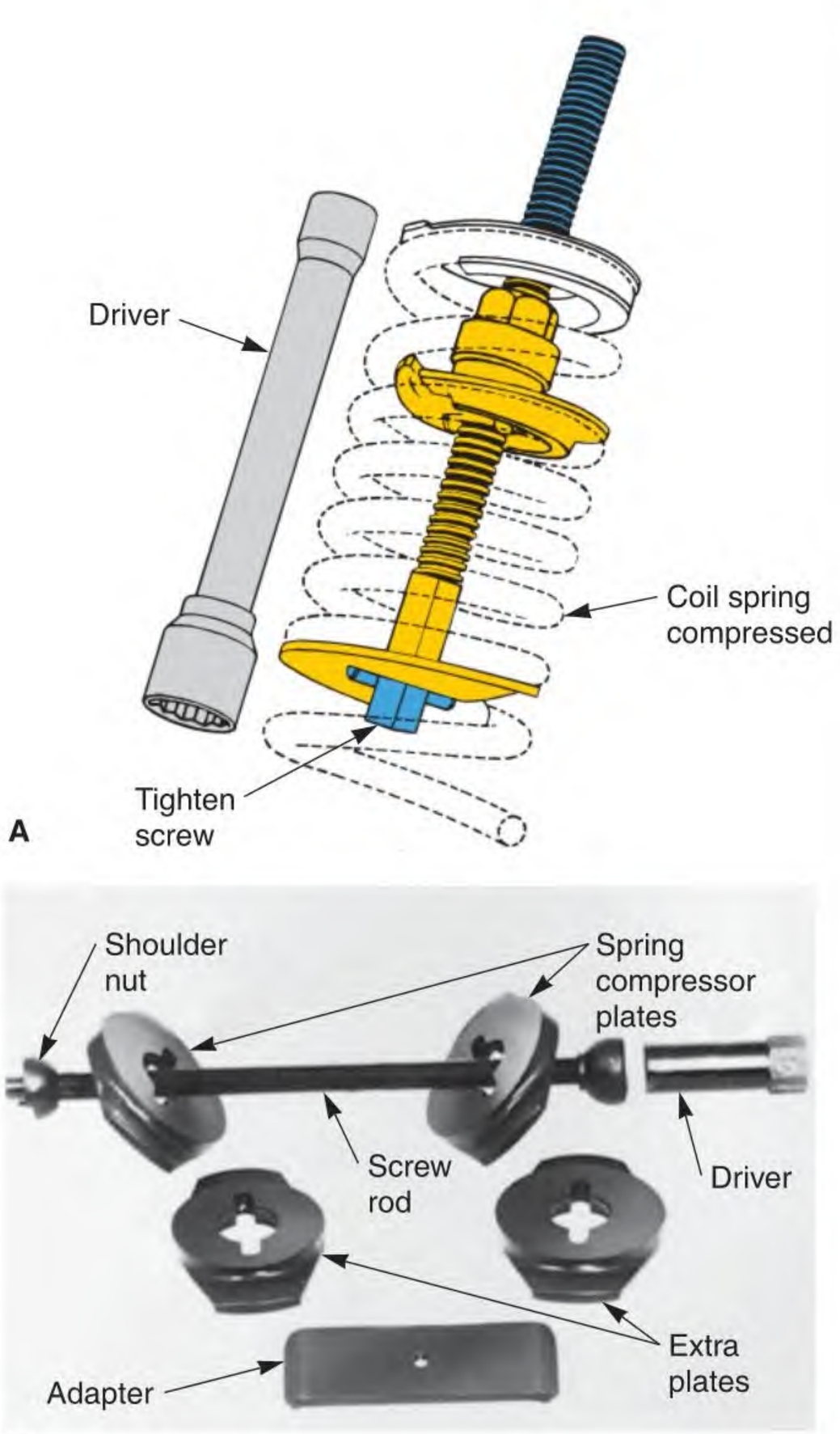
The vehicle should be at curb weight when measuring curb height to determine spring condition. Remove everything from the trunk except the spare tire and jack. Also make sure nothing is in the back or front seats that could increase curb weight.

To measure curb height, place the vehicle on a level surface. Then, measure from a specified point on the frame, body, or suspension down to the shop floor. Compare your measurements to specifications. If the curb height is too low (measurement is too small), replace the fatigued springs.

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Coil Spring Replacement

Fatigued coil springs lower the ride height of the vehicle and throw off the suspension geometry. A ***coil spring compressor*** is needed to remove and install a coil spring. The screw-type compressor squeezes the spring coils closer together, reducing the overall height of the coil spring. This gives you enough room to slide the spring out of the control arm. See **Figure 76-4**.



OTC Div. of SPX Corp.

Figure 76-4. A coil spring compressor must be used to squeeze the coils together before unbolting the ball joints. This will keep the spring from flying out with deadly force.

Tech Tip

Many full-size pickup trucks still use a large coil spring mounted against the control arm. They do not use a McPherson strut suspension because it cannot support such a heavy load.

Service Procedure

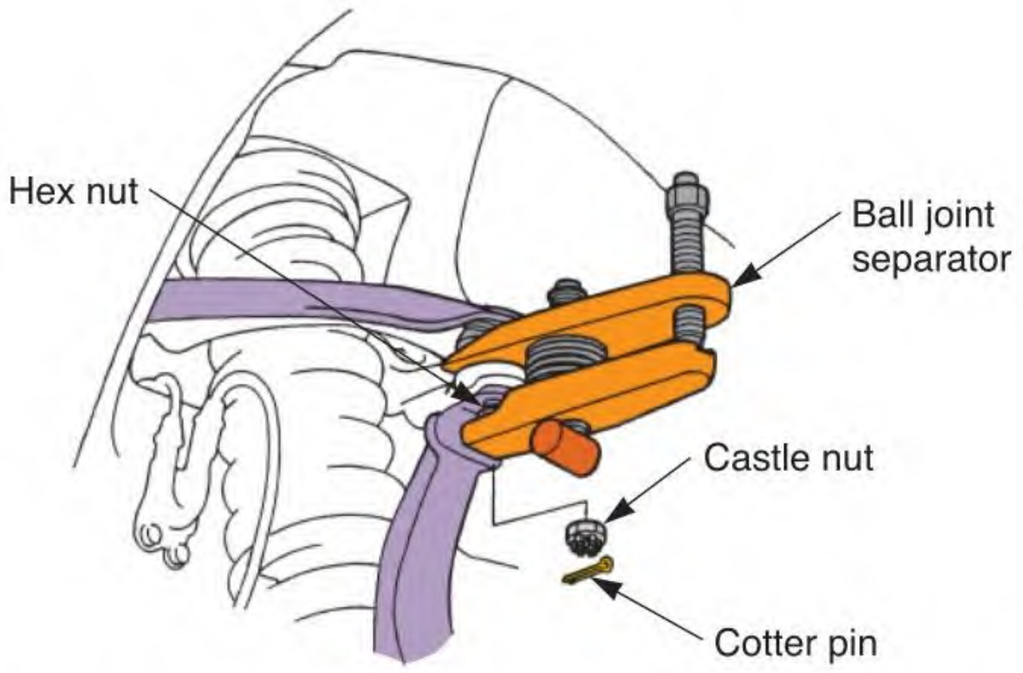
To remove a coil spring:

1. Place the vehicle on jack stands and remove the shock absorber.
2. Install the spring compressor over the coil spring. Follow tool directions.
3. Oil the tool threads to ease spring removal. Then tighten the tool down to compress and shorten the spring.
4. Depending on the suspension system design, you may have to separate the lower or upper ball joint. Refer to the service manual for details.
5. Use a ***fork tool***, or ***ball joint separator***, and hammer blows to remove the ball joint from the steering knuckle. Special pullers and drivers are also available for ball joint separation, **Figure 76-5**.
6. Remove any other components (brake line, strut rod, steering linkage) that could be damaged when the control arm is lowered.
7. Pull the spring and the compressor out as a unit.

Warning

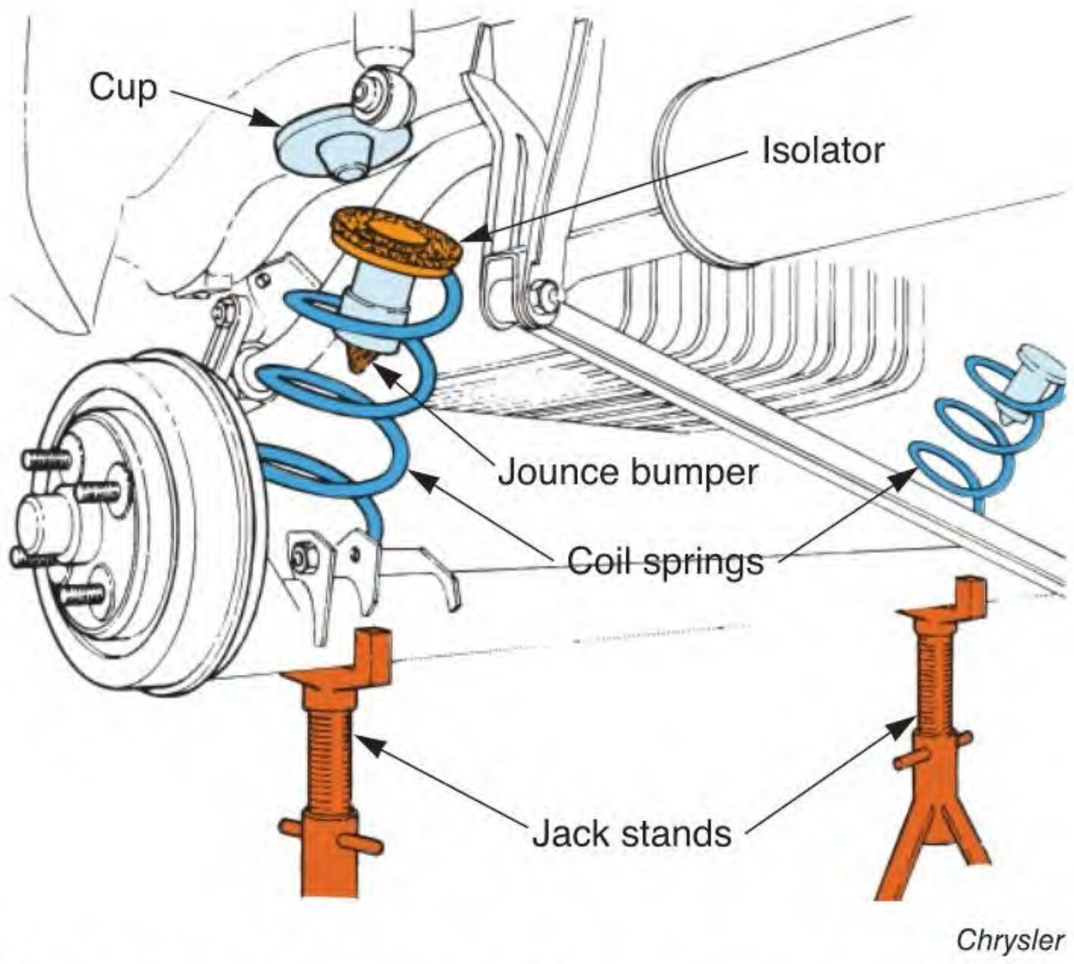
A compressed coil spring has a tremendous amount of stored energy. *Never* unbolt the ball joint without *first* compressing the coil spring. If the spring is *not* compressed, the lower control arm and the spring could shoot downward with *deadly force* as soon as the ball joint is unbolted. The suspension arm can fly down with enough force to break your legs!

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Honda

Figure 76-5. A fork or ball joint separator is used to force the ball joint stud out of the steering knuckle.



Chrysler

Figure 76-6. A rear coil spring can usually be removed by simply dropping the axle slowly after unbolting the shock.

Service Procedure

To install a new coil spring:

1. Compress the new spring with the spring compressor.
2. Slip the spring into place and position the coil ends in the same location as the ends of the old spring.
3. Reassemble the ball joint and other components.
4. Unscrew the spring compressor while guiding the coil into its seats.

Warning

Keep your fingers out from under or near a compressed suspension system spring. They could be badly crushed or severed if the tool slips off and releases the spring's stored kinetic energy.

When replacing a rear coil spring, a spring compressor may *not* be needed. After shock removal, the axle should drop far enough to free the coil spring. Support the weight of the axle or hub on jack stands or a floor jack, **Figure 76-6**. Always reinstall isolators or the new spring could squeak or rattle. Check a service manual for exact procedures.

Leaf Spring Service

Leaf spring service usually involves spring or bushing replacement. Leaf springs can break, especially in the middle. Always inspect leaf springs closely for cracks. Look at both edges of each spring near the axle mount.

Tech Tip

Leaf springs are still used on the new Chevrolet Corvette. A transverse leaf spring supports the rear suspension control arms. Some large trucks also use leaf springs at the rear. Modern leaf springs can be made of spring steel or carbon fiber.

Service Procedure

To replace a leaf spring:

1. Place jack stands under the frame and use a floor jack to raise the weight of the rear axle off the leaf spring.
2. Use a box wrench and an impact wrench to remove the nuts on each end of the leaf spring. Leave the through-bolts installed.

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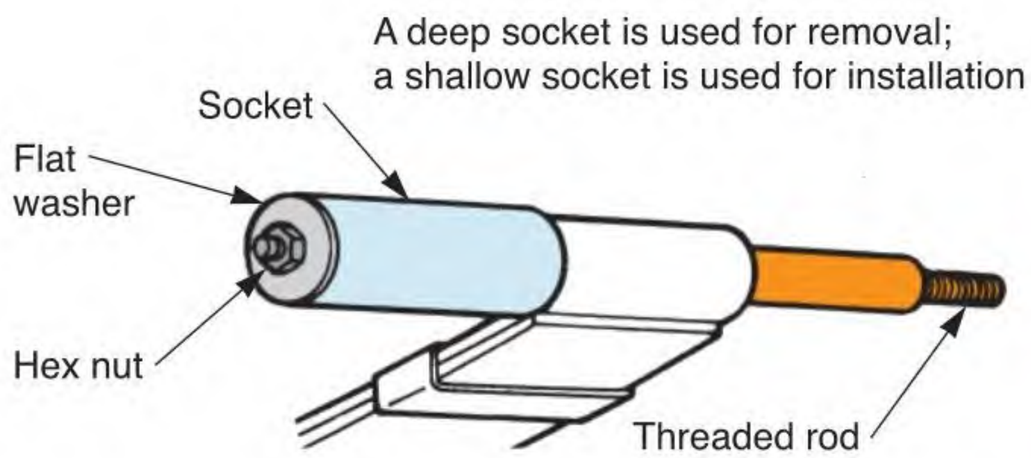
3. Remove the U-bolts that clamp around the middle of the spring and the axle. If the jack is adjusted properly, the through-bolts should now slide out with little resistance.
4. Lift the old leaf spring off the vehicle.

Warning

Never drive out the leaf spring eye bolts or shackle bolts unless all force is released from the spring. The eye or shackle bolts should pull out or drive out easily. If the bolts are removed with weight on the spring, the spring could fly upward or downward with *lethal force*.

5. Install the new leaf spring in the opposite order.
6. Make sure you position the axle assembly on the leaf spring correctly. A small guide pin may be provided to ensure proper rear axle alignment. The pin must fit through a hole in the leaf spring.

When just the leaf spring bushings are worn, they can be replaced without spring removal. With the through-bolt removed, select the correct diameter pulling-driving tool, **Figure 76-7**. One end of the tool should fit inside the spring eye, and the other end should contact the face of the eye. Tighten the tool nut to force out the old bushing. To install the new spring bushing, use the tool to pull the bushing into the spring eye. Install the spring eye bolts and torque them to specifications.



Chrysler

Figure 76-7. A driving tool makes worn bushing removal easy. When the hex nut is tightened, the tool pushes the bushing out of the spring.

Torsion Bar Service

Most torsion bars are adjustable. Therefore, torsion bar replacement is *not* frequently needed. A torsion bar and its related components are illustrated in **Figure 76-8**.

To adjust a torsion bar, you must usually turn a bolt to increase or decrease the tension, or twist, on the bar. When curb height is too low, tension must be increased to raise the vehicle.

Ball Joint Service

Worn ball joints cause the steering knuckle and wheel assembly to be loose on the control arms. A worn ball joint might make a clunking or popping sound when turning or when driving over a bump.

Ball Joint Lubrication

Ball joint wear is usually a result of improper lubrication or prolonged use. The load-carrying ball joints support the weight of the vehicle while swiveling into various angles. If not greased, the joints will become dry and can wear out quickly. Look at **Figure 76-9**.

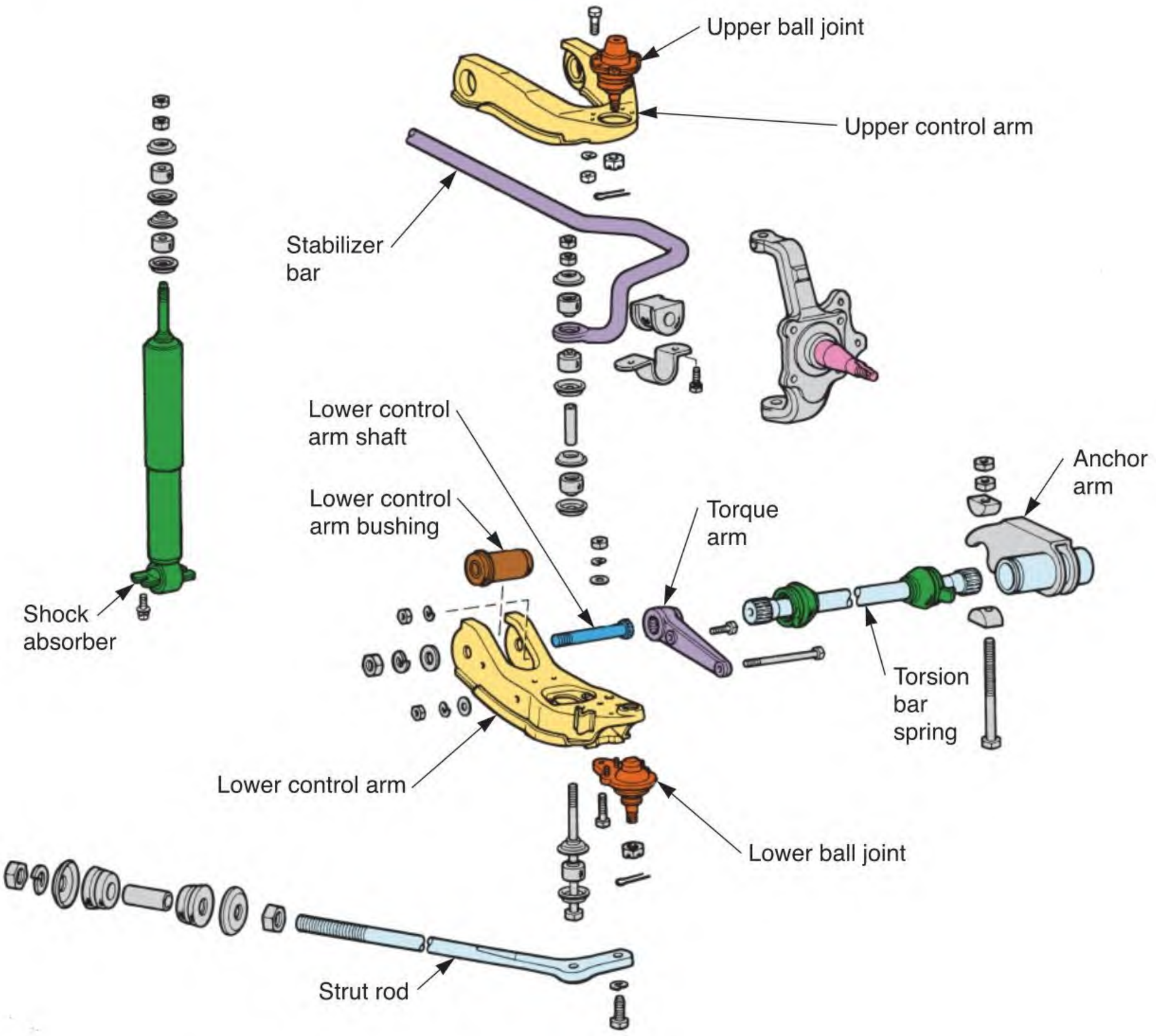
A dry ball joint is easily identified because its rubber boot is collapsed inward—it is not swollen with grease. When you squeeze a properly greased boot with your fingers, you will feel a slight pressure, similar to an air-filled balloon. If dry, the boot will feel hard because the boot is collapsed and is touching the joint ball.

Grease fittings or lube plugs are usually provided for ball joint lubrication. If plugs are provided, they must be replaced with grease fittings before the joint can be lubricated. A ***grease gun*** is used to inject chassis grease into the ball joint grease fittings. This is illustrated in **Figure 76-10A**.

Caution

When greasing a ball joint equipped with a balloon seal (airtight seal), be careful not to inject too much grease. Inject only enough grease to cause the seal to bulge slightly. Too much grease can rupture the rubber boot. See **Figure 76-10B**.

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Toyota

Figure 76-8. Exploded view of a torsion bar suspension. Study the part relationships.

Checking Ball Joint Wear

To check for ball joint wear, inspect the ***ball joint wear indicator*** or measure the play in the joint. With a ball joint wear indicator, simply inspect the shoulder on the joint to determine ball joint's condition. If the shoulder on the joint is recessed, the joint should be replaced. This is shown in **Figure 76-11**.

Another way to check ball joint wear involves jacking up the vehicle and physically moving the control arm and joint. Depending on the type of suspension, you may need to raise the vehicle by the frame or by the lower control arm, **Figure 76-12**. With the suspension properly raised, use a long steel pry bar to wiggle the tire up and down and sideways. While wiggling, note the amount of movement in the ball joints. Refer to service manual specifications and replace any ball joint that is worn too much and shows movement and play. See **Figure 76-13**.

Ball Joint Replacement

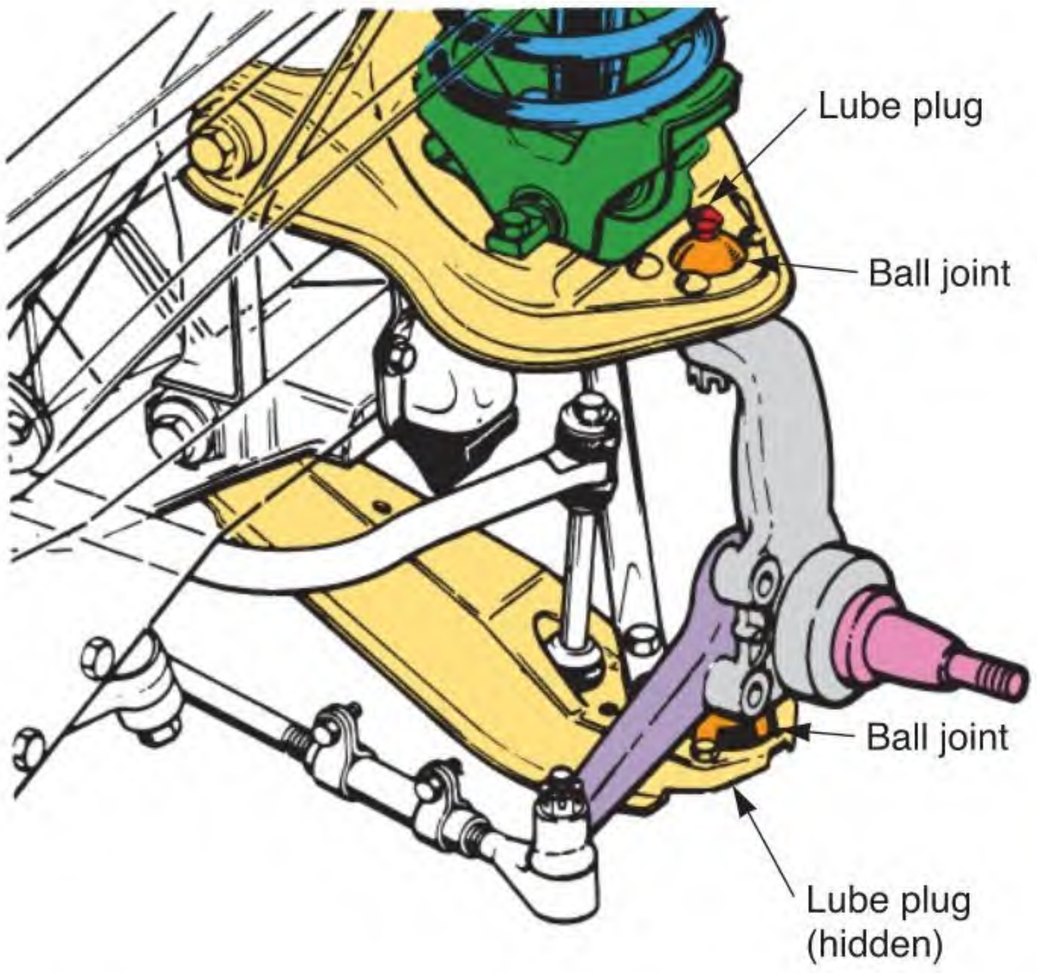
A ball joint can usually be replaced without removing the control arm from the vehicle. However, it is sometimes necessary to replace the entire control arm to replace a worn ball joint.

Service Procedure

To replace a ball joint:

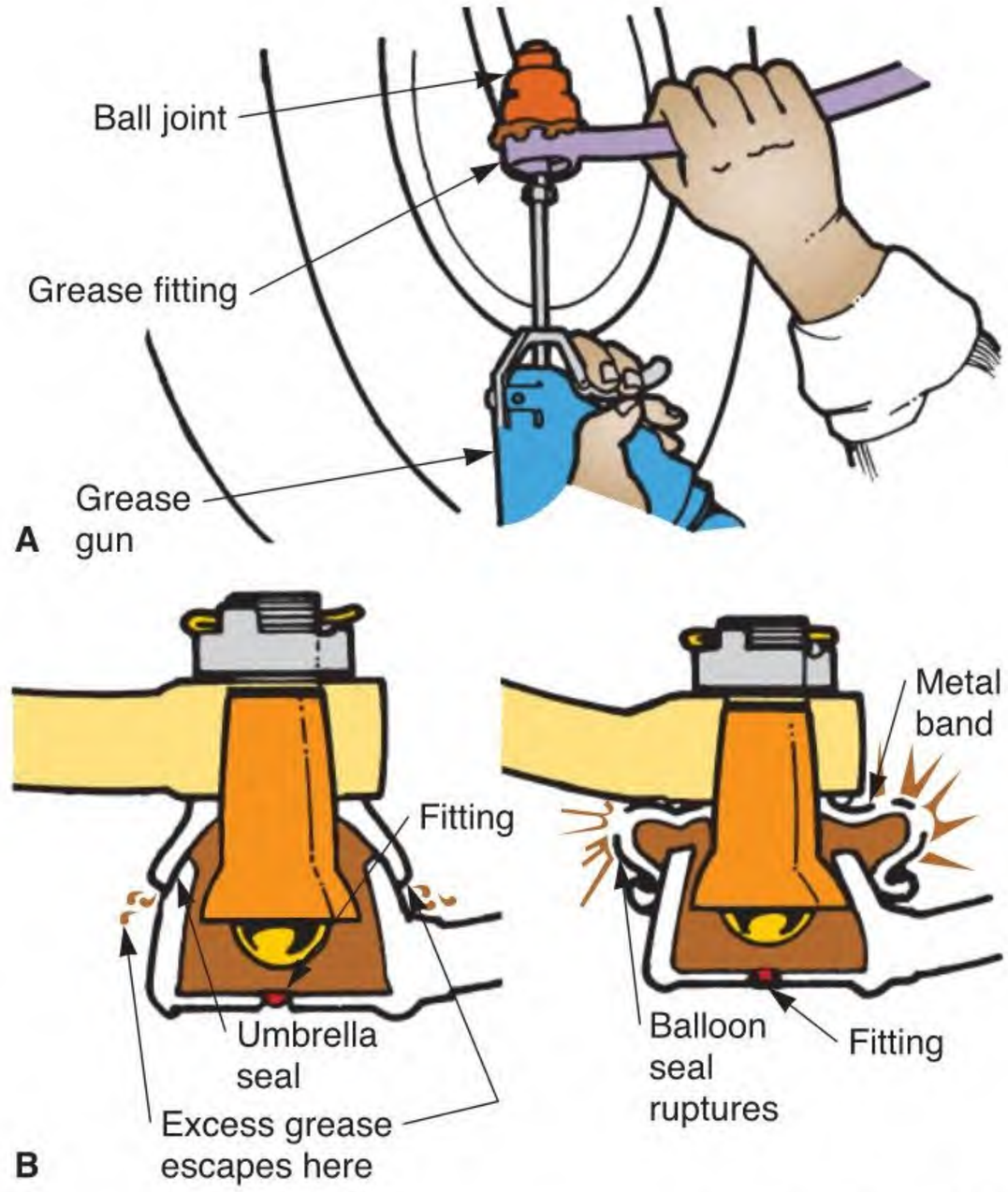
1. Place the vehicle on jack stands.
2. Remove the shock absorber and install a spring compressor on the coil spring.
3. Remove the nut securing the ball joint to the steering knuckle and separate the knuckle and

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Chrysler

Figure 76-9. Grease fittings or lube plugs are normally provided at the upper and lower ball joints. Grease fittings can also be located on the upper shaft of the inner control arm and on the steering components.

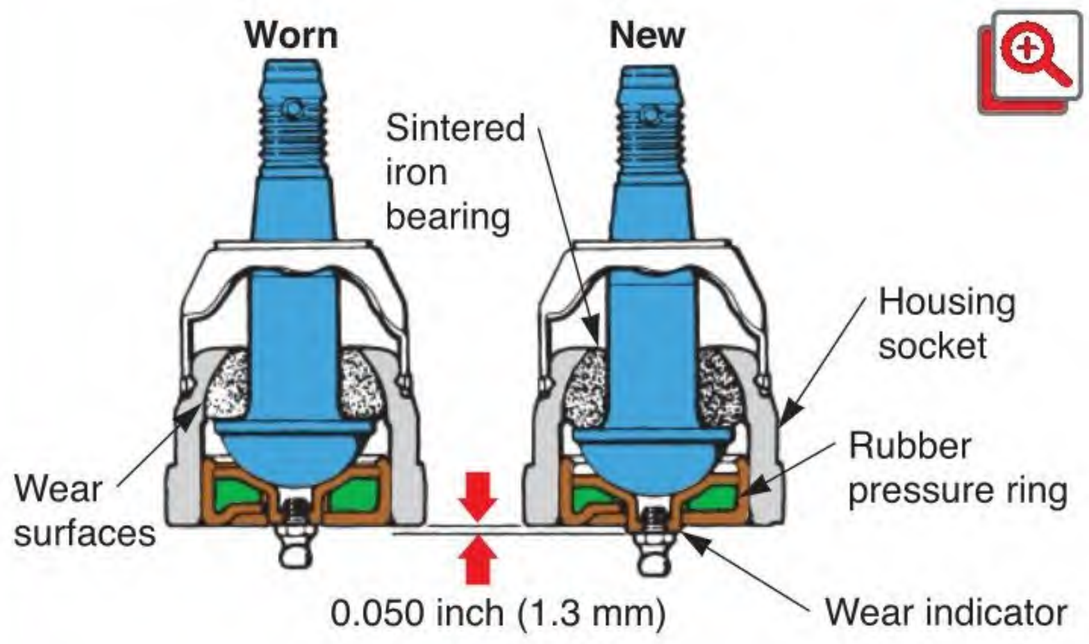


Florida Dept. of Voc. Ed.

Figure 76-10. Dry, unserviced ball joints wear and fail quickly. A—After cleaning the outside of the fitting, use a grease gun to force chassis grease into the ball joints or other fittings. B—Only install enough grease to fill the boot. Too much grease can rupture some types of boots.

the joint. The ball joint may be pressed, riveted, bolted, or screwed into the control arm. A service manual will give the details for the specific make and model vehicle.

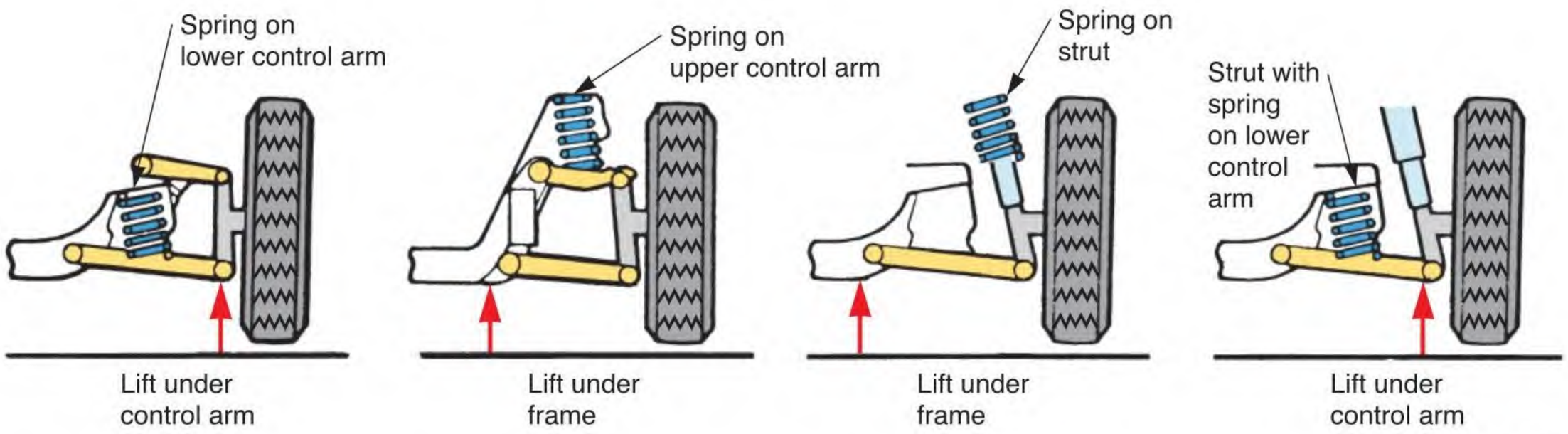
4. If the ball joint is pressed in, it can be hammered or driven out with a special tool. Be careful not to damage the control arm.
5. If the ball joint is riveted in place, drill out the old rivets with the correct diameter drill bit.
6. Use hardened bolts (that come with the kit) to secure the new unit. **Figure 76-14** illustrates service of a riveted ball joint.
7. If the ball joint is screwed into place, use a large wrench to unscrew it.
8. If it is rusted, free the threads with rust penetrant or heat from a torch first.
9. Clean the threads in the control arm before threading in the new ball joint.
10. Torque the ball joint properly.



Moog

Figure 76-11. This ball joint has a wear indicator. When the shoulder recedes into the socket, a new joint is needed.

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Ford

Figure 76-12. Study the lift points for different suspension systems. A specific lift point is needed when checking for ball joint and bushing wear.



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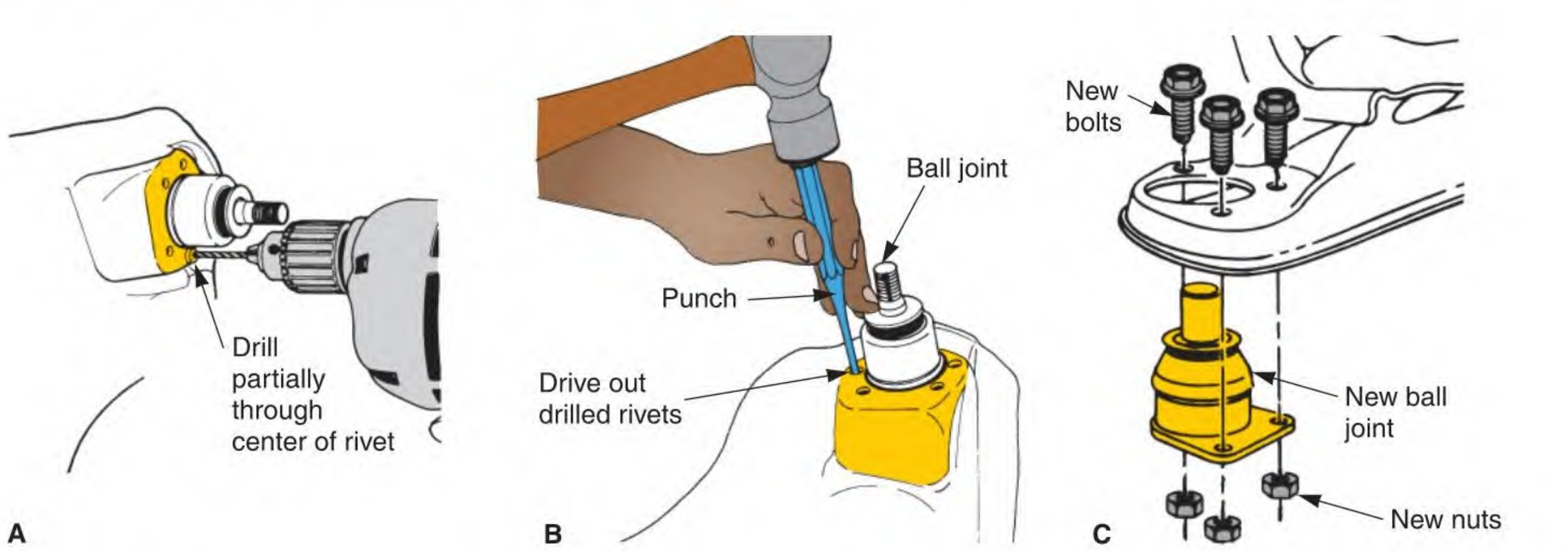
Figure 76-13. With the vehicle jacked up properly, use a long pry bar to wiggle the tire up and down. This will help detect part wear.

Warning

Always install a *new cotter pin* when a ball joint nut is removed. An old cotter pin could break, causing a serious auto accident. The wheel and tire can come off the car, causing the driver to lose control of the vehicle.

Suspension Bushing Service

Rubber bushings are commonly used in the inner ends of front control arms, rear control arms, and other parts. These bushings are wear prone and should be inspected periodically.



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Figure 76-14. Replacement of a riveted ball joint. A—Drill out the rivet heads. B—Use a punch to drive out the rivets. C—Bolt on the new ball joint.

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Worn control arm bushings can let the control arms move sideways, causing tire wear and steering problems. **Figure 76-15** shows the various bushings used on a front suspension. **Figure 76-16** pictures the bushings used on a rear suspension system.

Checking Bushing Wear

To check for bushing wear, try to move the control arm against normal movement while watching the bushings. If the arm moves in relation to its shaft, the bushings are worn and must be replaced.

Sticktion

Sticktion is a term used to describe the initial resistance to movement between rubber seals or bushings and metal parts. Engineers try to keep sticktion to a minimum. For example, sticktion afflicts suspension system bushings and shock absorber seals. Sticktion resists initial motion and affects ride smoothness.

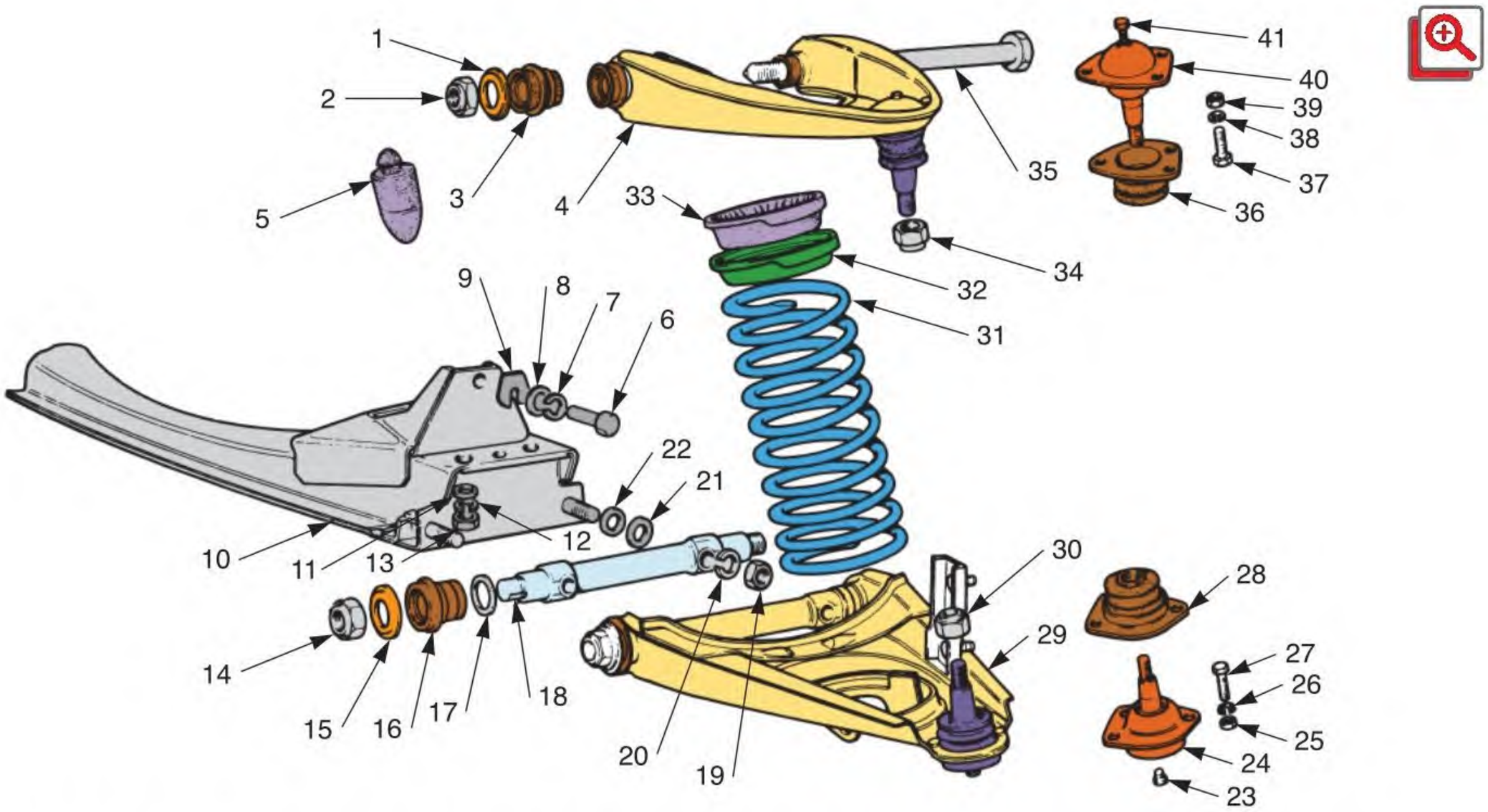
Sticktion often causes old, dry, hardened bushings to make a loud squeaking noise when moved. This noise is caused by the high-frequency vibration set up in the bad bushing.

Tech Tip

With worn bushings, you might have heard sticktion. It makes a loud squealing sound when you bounce the body of the vehicle and slowly move the worn, sticking bushings.

Bushing Replacement

Exact procedures for installing new suspension system bushings vary. Refer to a service manual for exact directions to ensure a safe, quality repair.

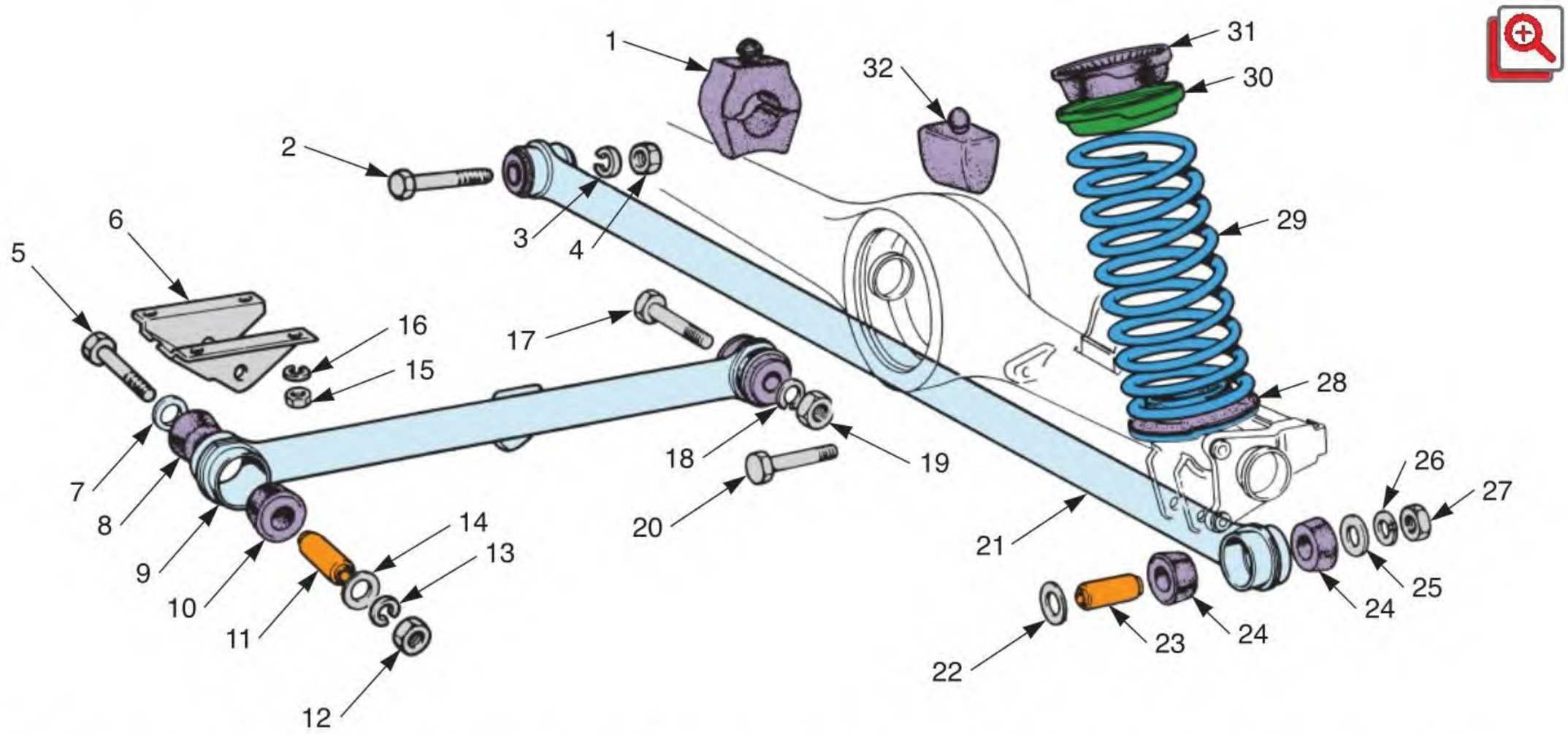


1. Cup. 2. Nut fixing upper control arm to body. 3. Resilient bushing. 4. Upper control arm. 5. Buffer. 6. Bolt. 7. Spring washer. 8. Flat washer. 9. Tab strip. 10. Crossmember. 11. Flat washer. 12. Spring washer. 13. Nut. 14. Nut fixing pivot bar 18 to lower control arm. 15. Cup. 16. Resilient bushing. 17. Flat washer. 18. Pivot bar. 19. Nut fixing lower control arm to crossmember 10. 20. Spring washer. 21. Flat washer. 22. Tab strip. 23. Plug. 24. Lower ball joint. 25. Nut. 26. Spring washer. 27. Bolt. 28. Seal. 29. Lower control arm. 30. Self-locking nut fixing steering knuckle to lower control arm. 31. Spring. 32. Spring seat. 33. Rubber pad. 34. Self-locking nut fixing steering knuckle to upper control arm. 35. Bolt. 36. Seal. 37. Bolt. 38. Spring washer. 39. Nut. 40. Upper ball joint. 41. Plug.

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Figure 76-15. Study how ball joints fit into the upper and lower control arms. Bolts secure the joints. Note the location of the control arm bushings.

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1. Rubber pad. 2. Bolt anchoring cross rod to body. 3. Lock washer. 4. Nut. 5. Bolt anchoring lower side rod to bracket. 6. Bracket. 7. Flat washer. 8. Rubber bushing. 9. Lower side rod. 10. Rubber bushing. 11. Spacer. 12. Nut. 13. Lock washer. 14. Flat washer. 15. Nut. 16. Lock washer. 17. Bolt anchoring lower side rod to axle housing. 18. Lock washer. 19. Nut. 20. Bolt anchoring cross rod to axle housing. 21. Cross rod. 22. Flat washer. 23. Spacer. 24. Rubber bushings. 25. Flat washer. 26. Lock washer. 27. Nut. 28. Lower ring-pad. 29. Coil spring. 30. Upper seating ring. 31. Upper rubber ring-pad. 32. Rubber buffer.

Fiat

Figure 76-16. Exploded view shows bushings on one type of rear suspension.

Service Procedure

To replace bushings:

1. Remove the control arm when replacing the bushings in a front suspension. This usually requires ball joint separation and compression of the coil spring.
2. Unbolt the stabilizer bar and strut rod from the control arm.
3. Remove the bolts that pass through the bushings, **Figure 76-17**.
4. Mount the control arm in a vise.
5. Either press or screw out the old bushings. **Figure 76-18** shows a bushing driver, which can be used to press a bushing into and out of a control arm.
6. Install the control arm in the reverse order of removal.
7. Torque all bolts properly.
8. Install the ball joint cotter pin and other components.

The procedure for preloading the control arm bushings depends on their design. Check the service manual for detailed instructions. Generally, you must install the bushing and lightly torque the nuts on the control arm shaft (if used). Then the weight of the vehicle is lowered onto the suspension system. This places the control arms in their most common location or angle. Then, tighten and preload the control arm bushings fully.

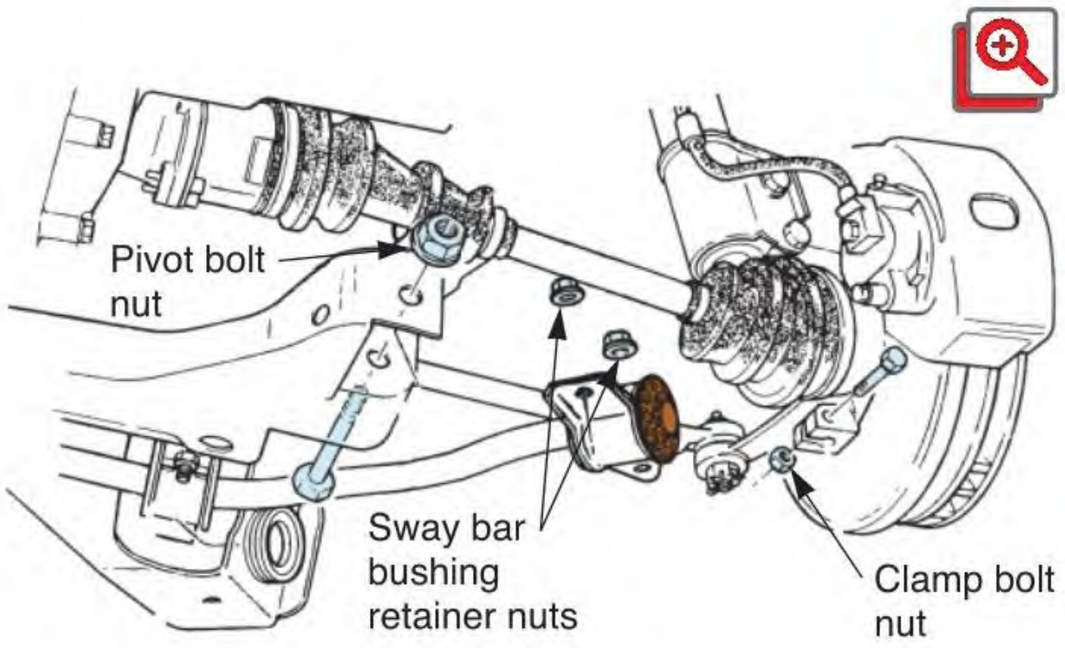
Strut rod bushings and stabilizer (sway) bar bushings also require replacement when worn. Refer back to **Figure 76-17**.

MacPherson Strut Service

The MacPherson strut suspension can wear and cause problems similar to those covered for other types of suspension systems. The major difference in service procedures relates to how the strut assembly is disassembled and reassembled.

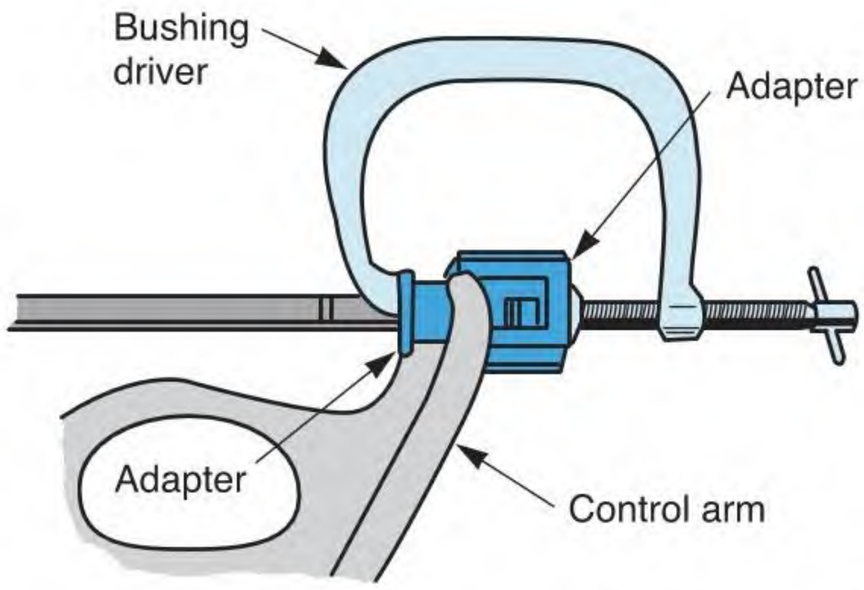
The most common trouble with a MacPherson strut suspension is worn strut shock absorbers. Like conventional shocks, the pistons and cylinders inside

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Chrysler

Figure 76-17. Control arm bushing replacement requires control arm removal. Note the parts that must be disconnected on a front-wheel-drive vehicle.



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Figure 76-18. A bushing driver is helpful when removing or installing control arm bushings.

the strut shocks can begin to leak. This reduces the dampening action and causes the vehicle to ride poorly.

Strut Removal

Service Procedure

To remove a strut:

1. Raise and secure the car on stands or a lift to remove the vehicle weight from the suspension system.
2. Unbolt the steering knuckle (front) or bearing support (rear) from the strut.
3. If used, mark the cam bolt or knuckle with a scratch awl or marker to help during reassembly. You can realign this mark to roughly adjust camber. See **Figure 76-19**.
4. Disconnect the brake line if needed to avoid hose damage.
5. Separate the bottom end of the strut from its knuckle. Swing it to one side of the knuckle so it can drop down.
6. Unscrew the upper strut-to-body fasteners on the side of the engine compartment.
7. Remove the strut assembly (coil spring and shock) as a single unit, **Figure 76-20**.
8. Do not remove the nut on the end of the shock rod, or the unit could fly apart.

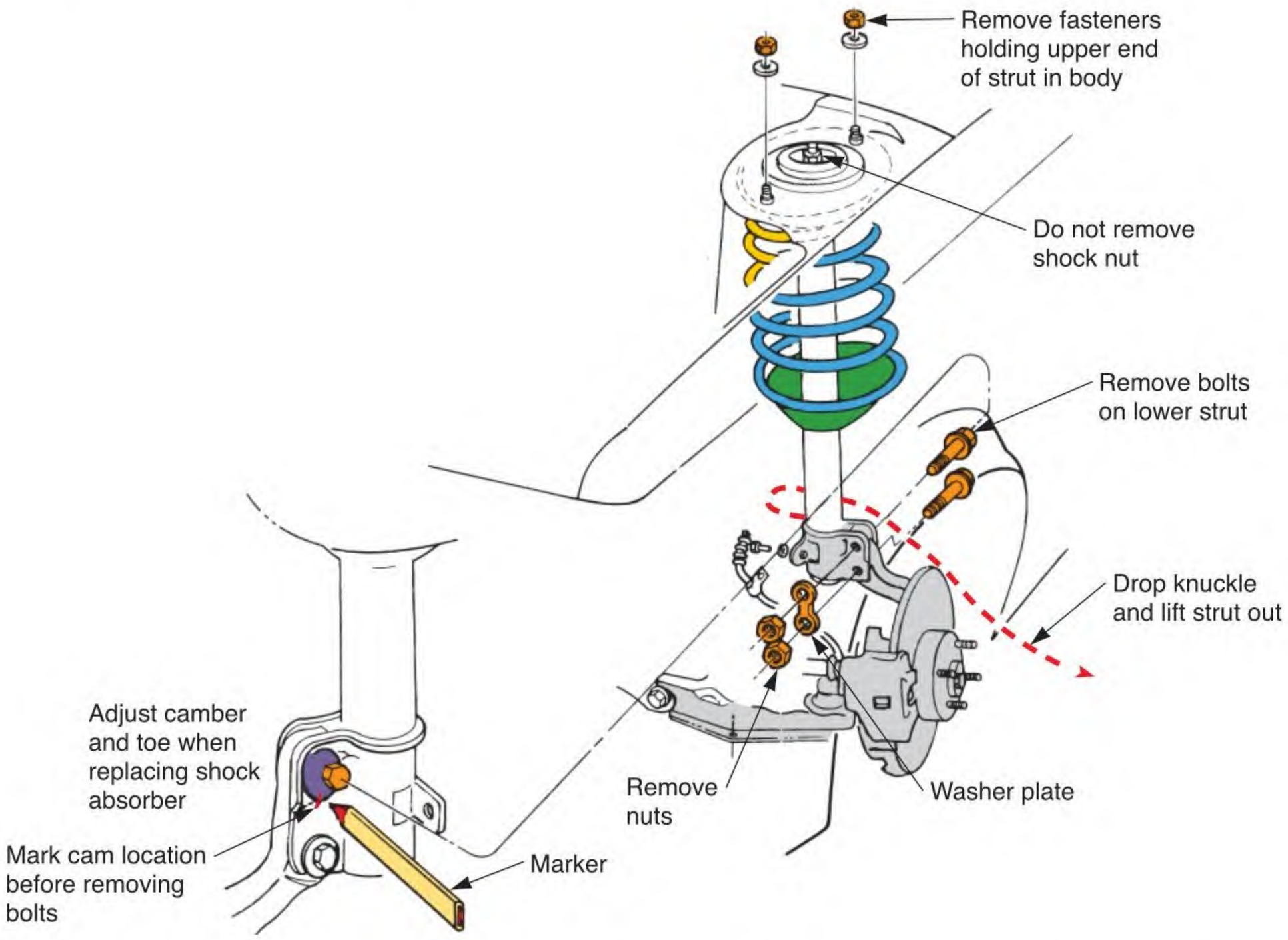
Strut Assembly Service

Strut assembly service generally involves replacing or rebuilding the strut shock absorber. Before removing the strut shock absorber, use a ***strut spring compressor*** to collapse the spring. Then, remove the coil spring from the strut. Look at **Figure 76-21**. After the coil spring has been squeezed together, remove the upper damper assembly. Then, release spring tension and lift the spring off the strut. Inspect all parts closely, **Figure 76-22**.

Warning

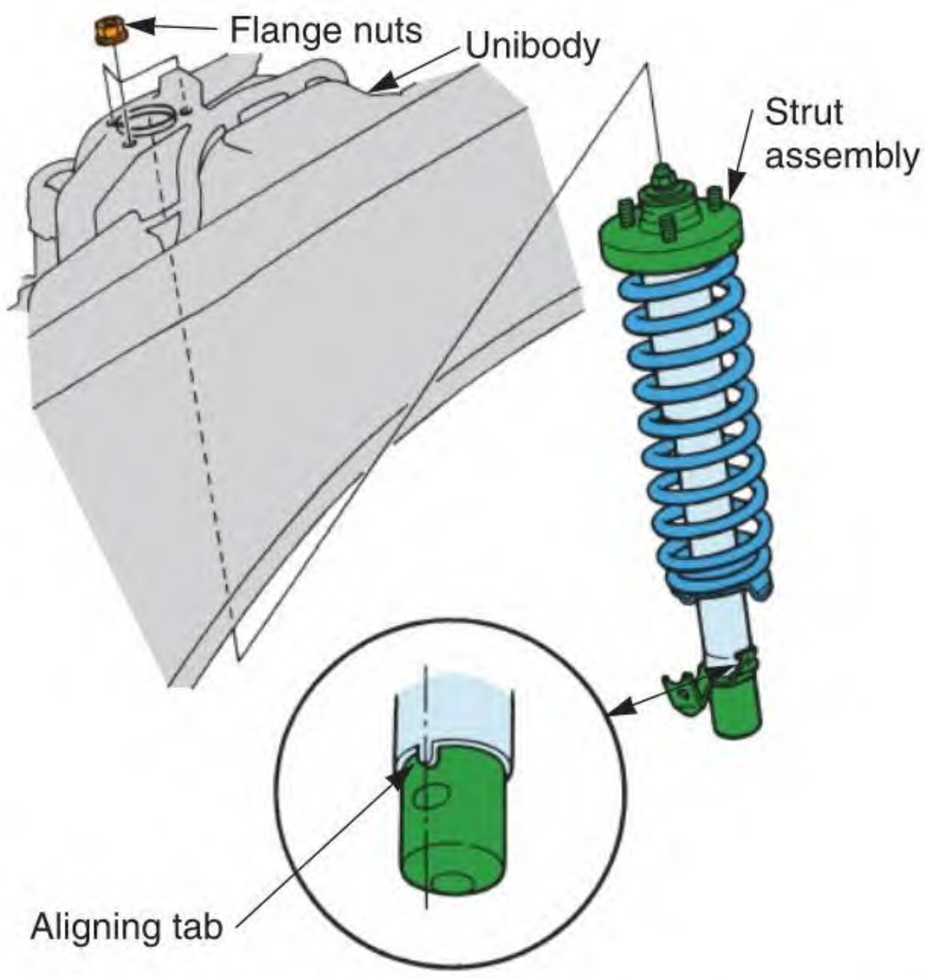
When compressing any suspension system spring, be extremely careful to position the compressor properly. If the spring were to pop out of the compressor, serious injury or death could result.

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Chrysler

Figure 76-19. Before removing a strut assembly, mark the cam-type bolt, if used. Remove the steering knuckle bolts and the upper fasteners from strut.



Honda

Figure 76-20. Carefully lift the strut out of the vehicle. Be ready to support its weight. Note how the unit aligns in the vehicle for easier reassembly.

Most automakers recommend replacing a faulty strut shock absorber (removable shock cartridge). The new shock simply screws into the strut's outer housing. A spanner wrench may be needed to turn the nut on the top of the cartridge. **Figure 76-23** shows a replacement shock absorber cartridge.

After replacing or rebuilding the strut shock absorber, fit the strut into the compressor and compress the coil spring. Then, install the upper spring seat and related components. After releasing the spring compressor, the strut can be installed on the vehicle.

Tech Tip

To safely dispose of gas-filled shocks, drill a small hole through the gas chamber. This will keep the shocks from possibly blowing up if burned or crushed. Wear eye protection when drilling to keep metal bits from flying in your face as the gas pressure is released from the chamber. Refer to **Figure 76-24**.

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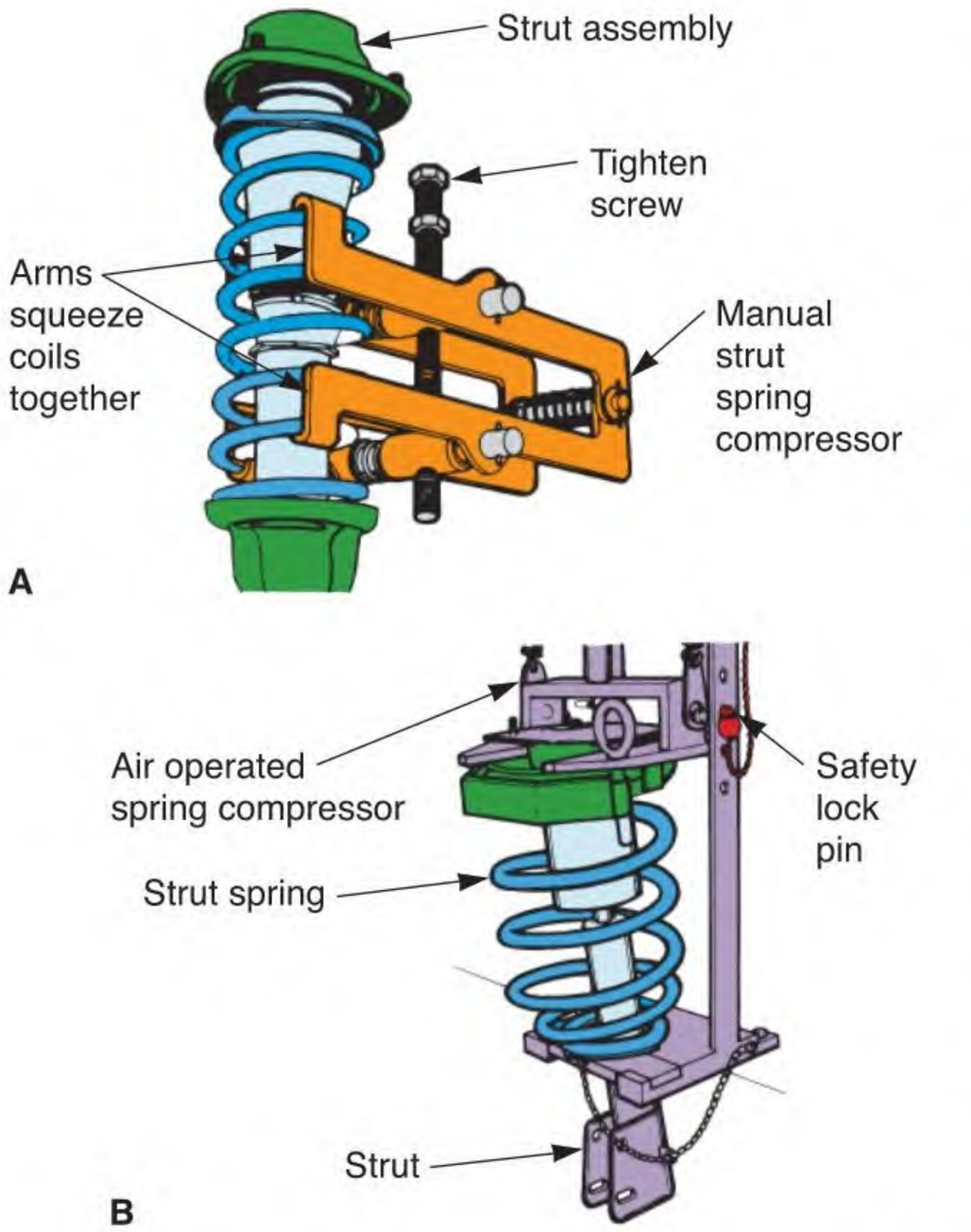


Figure 76-21. A spring compressor is needed to remove the spring from the strut assembly. A—Portable strut spring compressor. B—Bench-mounted strut spring compressor.

Strut Installation

Install the strut assembly in the reverse order of removal. See **Figure 76-25**. Lift the strut into position in the upper body mount. Attach the lower end of the strut to the steering knuckle or bearing support. Align your reference marks. Install the fasteners and torque them to specifications. Install any other parts and double-check your work.

Warning

Always torque all suspension systems bolts and nuts to factory specifications. This is essential for a competent, safe, dependable repair. If you fail to torque a suspension system fastener properly and the part disengages, a deadly auto accident could result. See **Figure 76-26**.

Wheel Alignment Is Needed

After servicing ball joints, control arm bushings, strut rods, springs, strut assemblies, or other suspension parts, wheel alignment must be checked and adjusted. *Never* let a vehicle leave the shop without checking alignment. Rapid tire wear or handling problems could occur.

Computerized Suspension Diagnosis

Discussed in the previous chapter, many modern suspension systems use some means of computer control to maintain ride height, adjust suspension system stiffness, and improve handling. A wiring diagram for an electronic suspension system is given in **Figure 76-27**.

To start troubleshooting a computer-controlled suspension, connect a scan tool or diagnostic table to the vehicle's diagnostic connector. Read any stored diagnostic trouble codes and check operating values for all suspension-related components. Look at **Figure 76-28**.

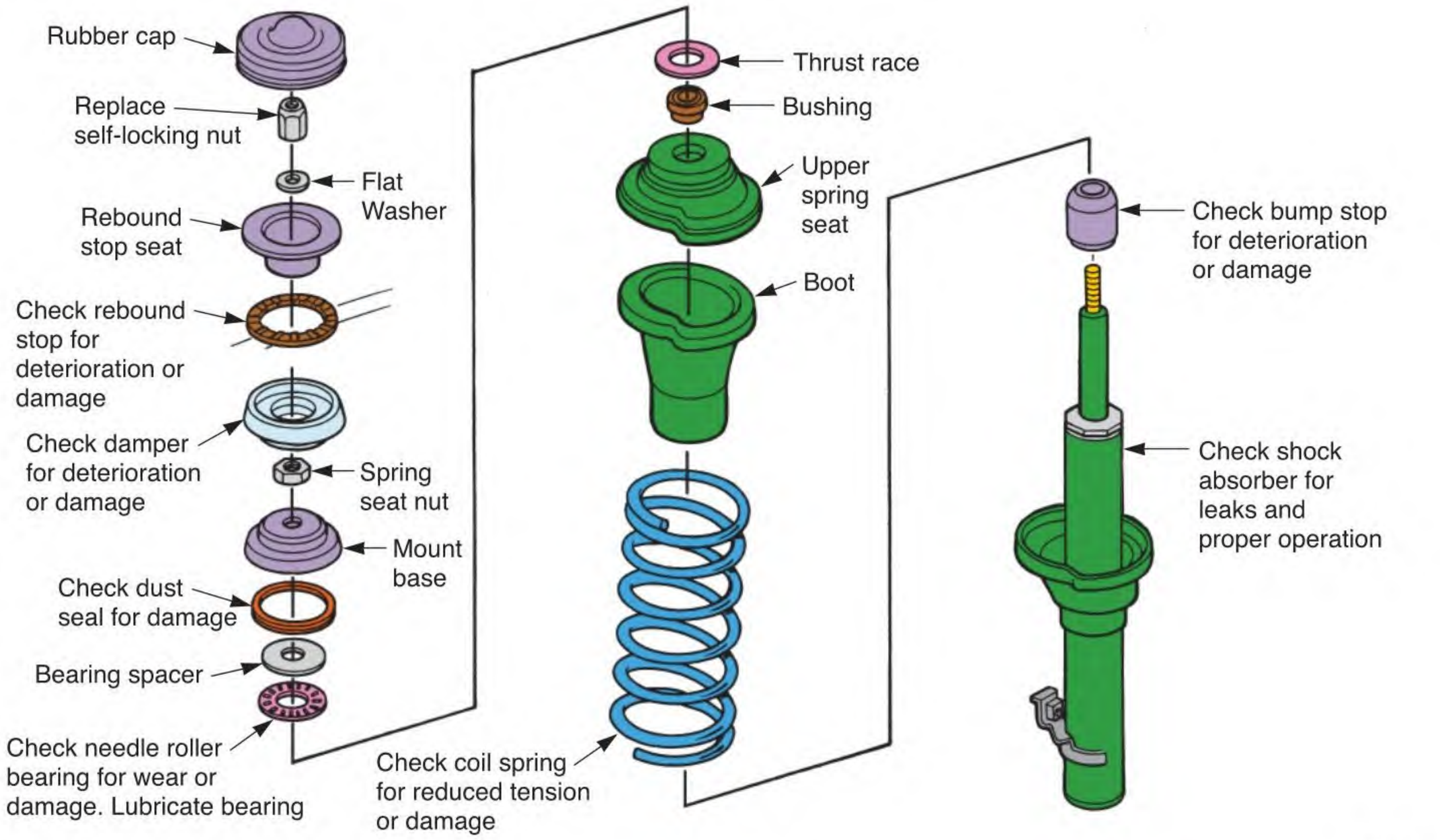
Your scan tool might find problems with the following parts: solenoids and sensors, shock actuator motor, electrical relays, height sensors, compressor motor, and other electrical or electronic suspension components.

If the scan tool indicates a possible problem with a certain part or circuit, use pinpoint multimeter tests to verify the exact source of the trouble. For example, if the scan tool indicates a problem with the height sensor, use a VOM to test the unit's output in different positions, **Figure 76-29**.

Height Sensor Service

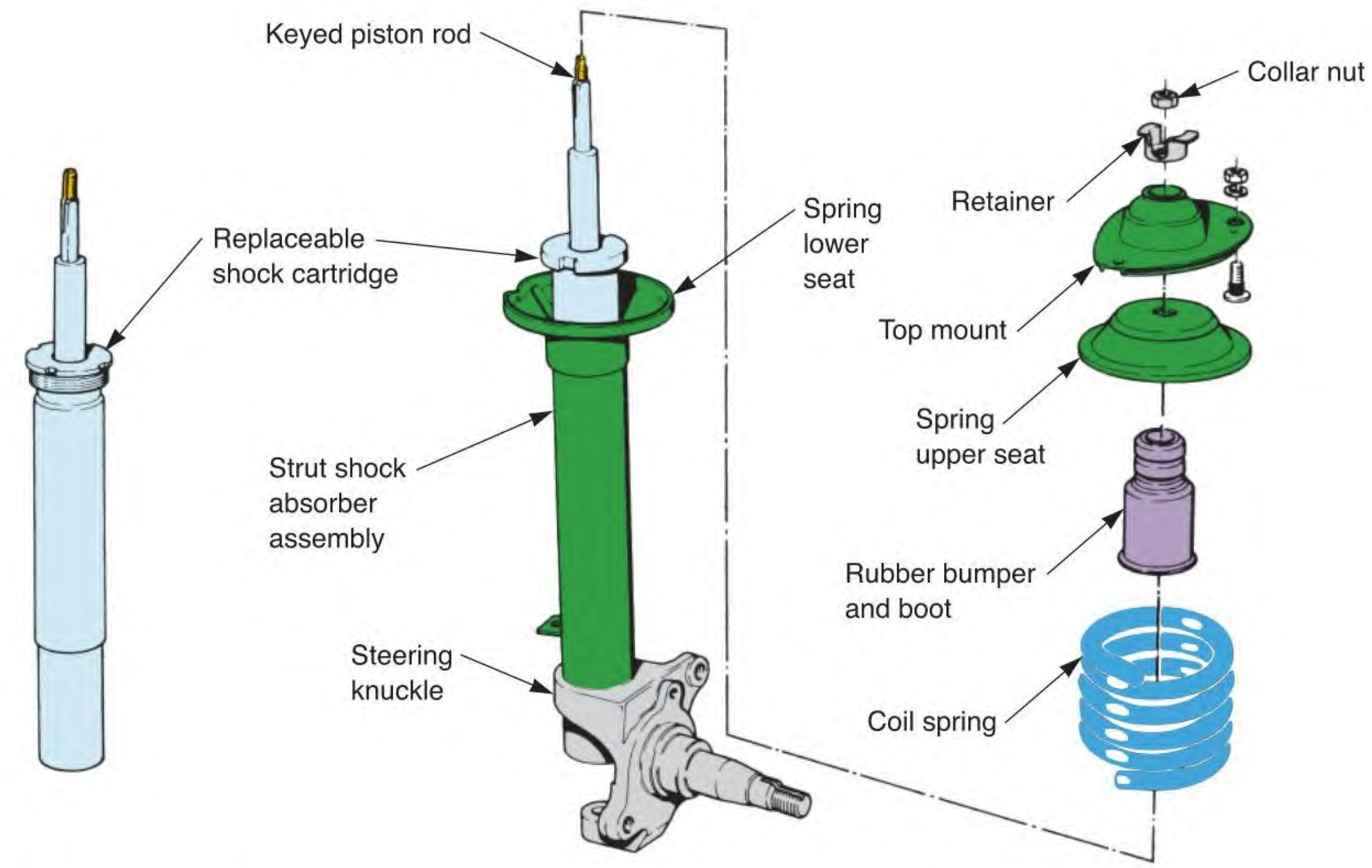
A faulty height sensor will fail to produce a normal output signal for each lever or height position. The sensor can fail mechanically due to worn parts, a bent arm, or broken parts. It can also fail electrically, ceasing to produce a normal signal. Replace the sensor if it does not work properly and cannot be adjusted.

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Honda

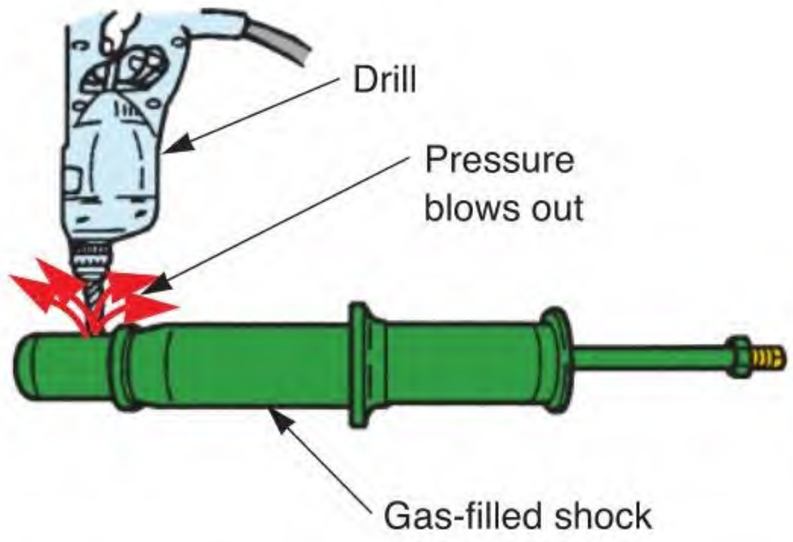
Figure 76-22. Exploded view shows the parts of a strut assembly. Note the strut bearing, which should be in good condition. Inspect all parts carefully.



Mercury

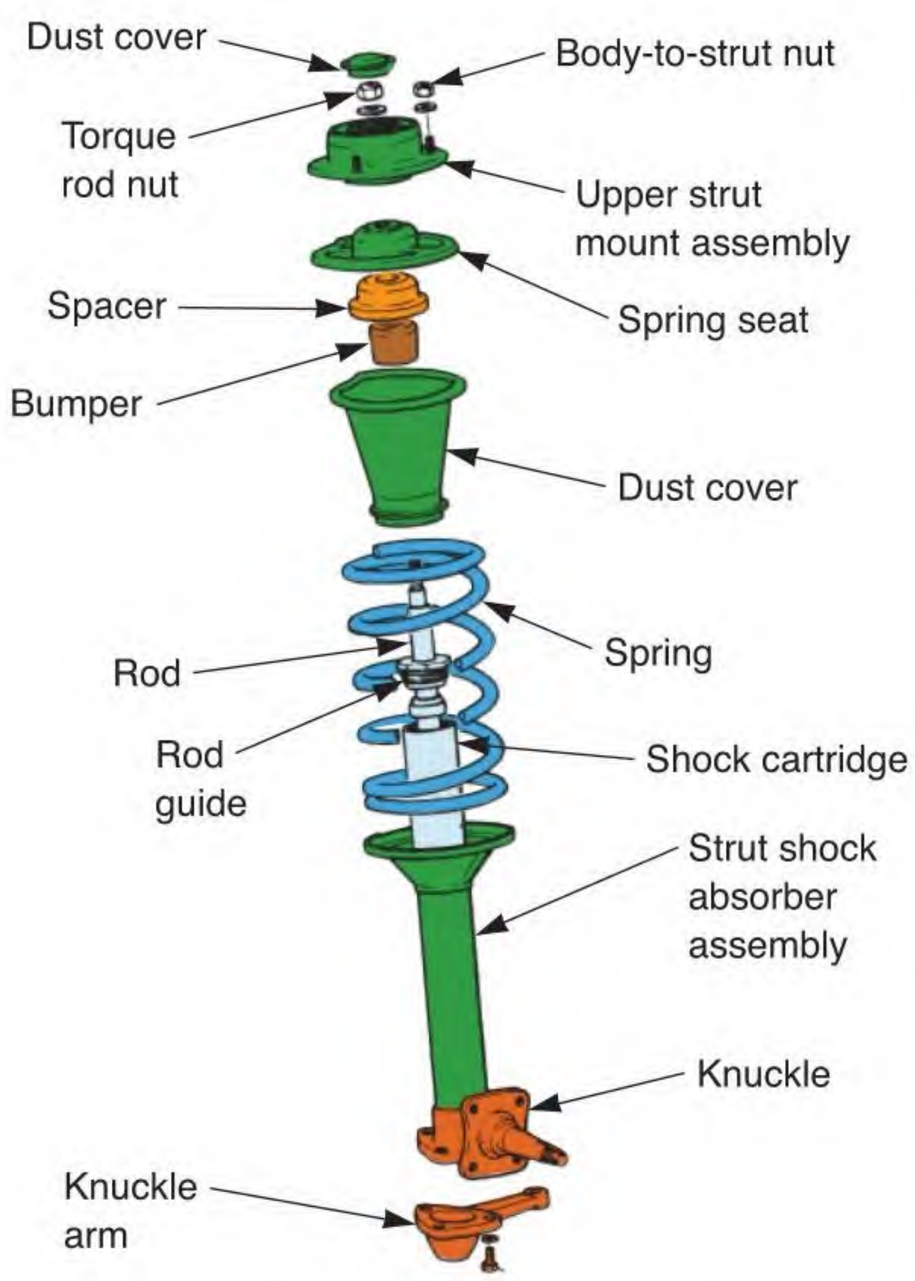
Figure 76-23. In this design, the new strut cartridge simply screws into strut housing.

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Mazda

Figure 76-24. Before discarding gas-filled shocks, you should drill a small hole in the gas chamber to release the gas pressure. Wear face protection and follow service manual details.



Toyota

Figure 76-25. This exploded view shows how strut parts fit together.

Compressor Service

A faulty compressor will not produce the air pressure needed to maintain the correct ride height. First check the compressor's electrical connections and its source of voltage. Then, connect a pressure gauge to the output hose fitting to measure the compressor's pressure output. If the pressure reading is not within specs, replace the compressor.

Electronically-Controlled Shock Service

When replacing the shocks on electronic suspension systems, you may be able to transfer some of the electronic parts from the old units onto the new ones. If you try to install conventional shocks to save the customer money, it could confuse the computer and cause constant trouble codes and other problems. Do not try to modify electronic suspension systems without the manufacturer's guidance.

Diagnostic Case Study

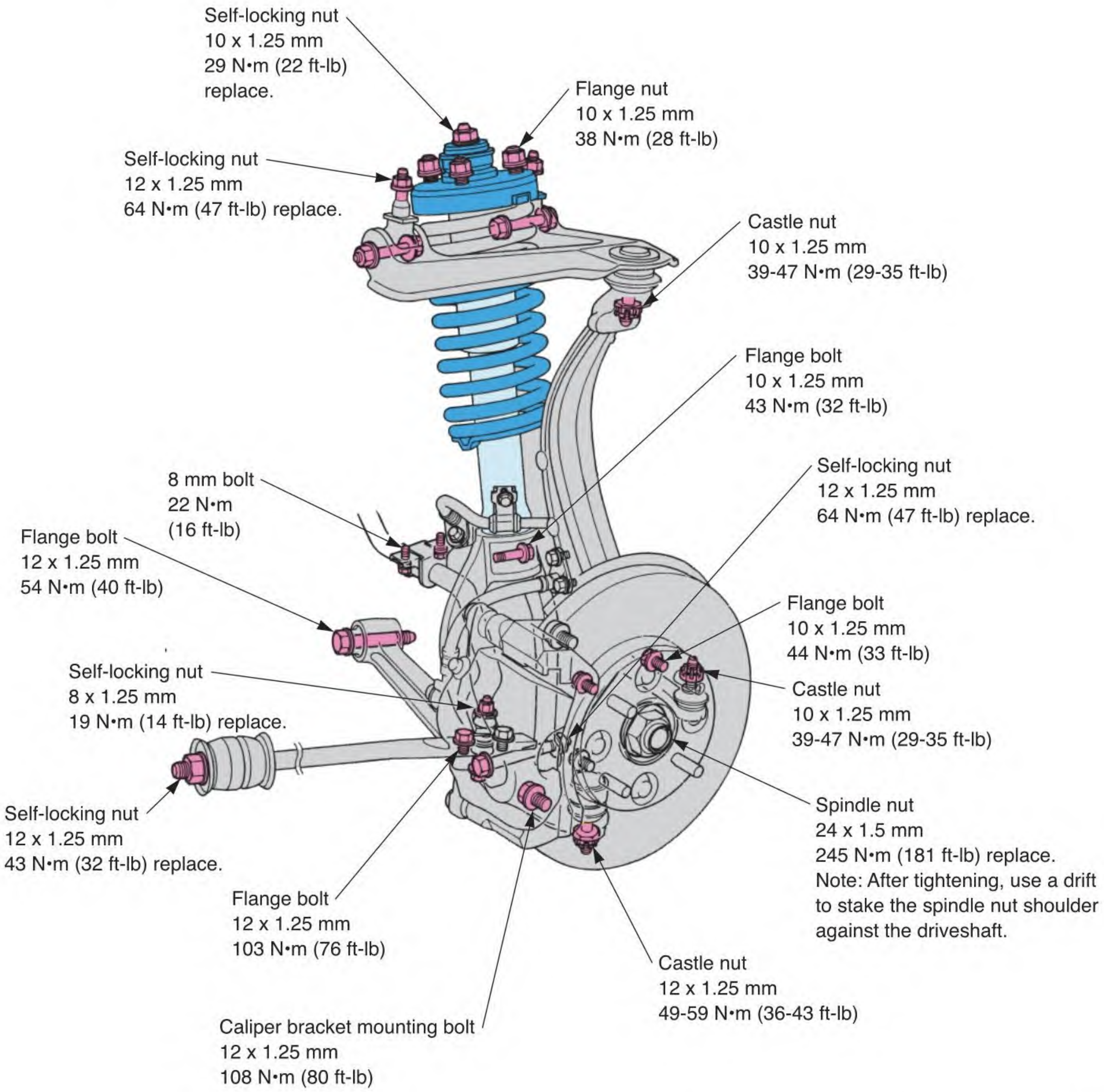
Concern: Mr. Brown brings his 2010 Kia Sedona to the shop. He complains that his minivan is making a loud popping or knocking sound when turning corners.

Cause: Duff takes the van for a test-drive and hears a deep-pitched knocking or clunking sound coming from the right front of the vehicle during turns. He speculates that the loud deep knock must be coming from a large suspension or steering part, like a ball joint. Smaller suspension and steering parts would make higher-pitched or lighter knocking sound.

Duff turns the car over to the shop's suspension and steering technician. The technician raises the car and unloads the ball joints. He positions a pry bar under one front tire and wiggles the suspension. He notes that there is excessive play in the lower ball joint. He then repeats the procedure on the other wheel.

Correction: The technician removes the front shock absorbers and removes the coil springs with a spring compressor. He then removes the steering knuckles. He bolts new ball joints to the control arms and reassembles the suspension parts. After reassembly, the technician corrects vehicle wheel alignment and then takes the car for a brief test drive. The noises are eliminated, and the vehicle is released to the owner.

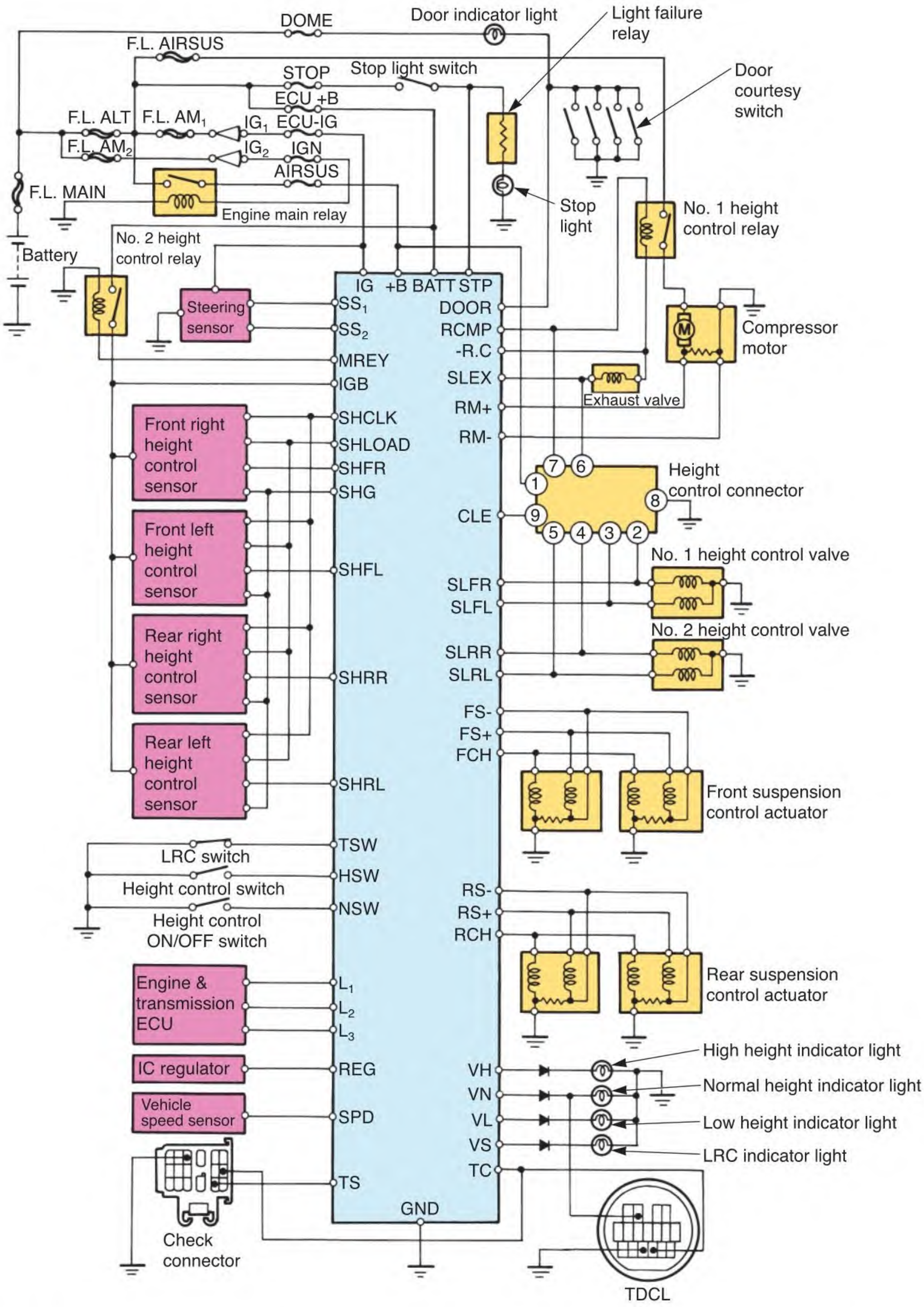
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Honda

Figure 76-26. Always torque suspension system fasteners to specifications. The torque values shown are for this suspension only. Refer to a service manual to find the correct torque values for the vehicle at hand.

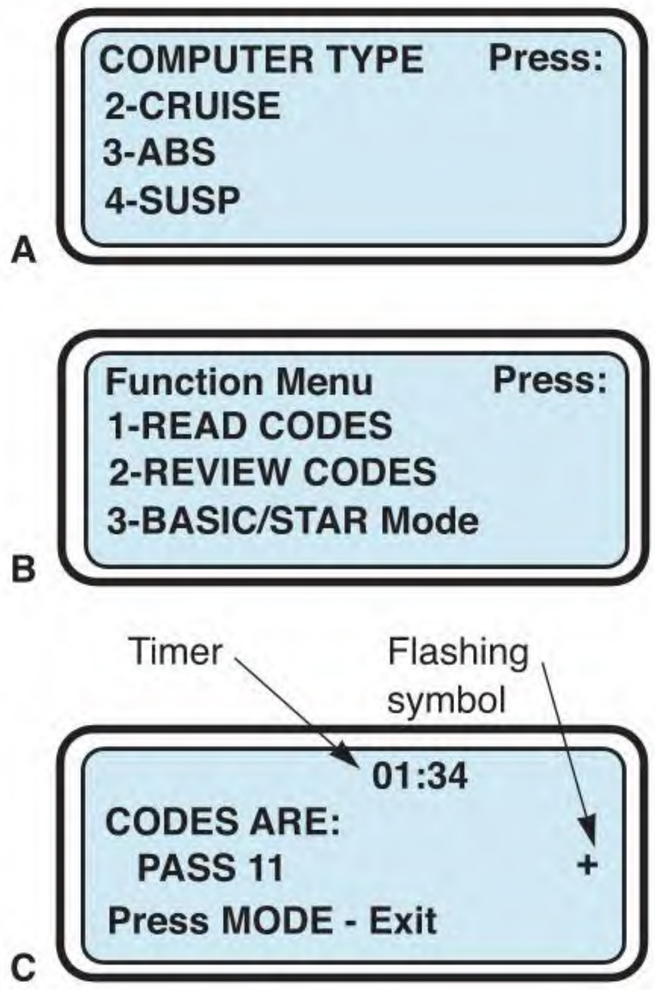
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Lexus

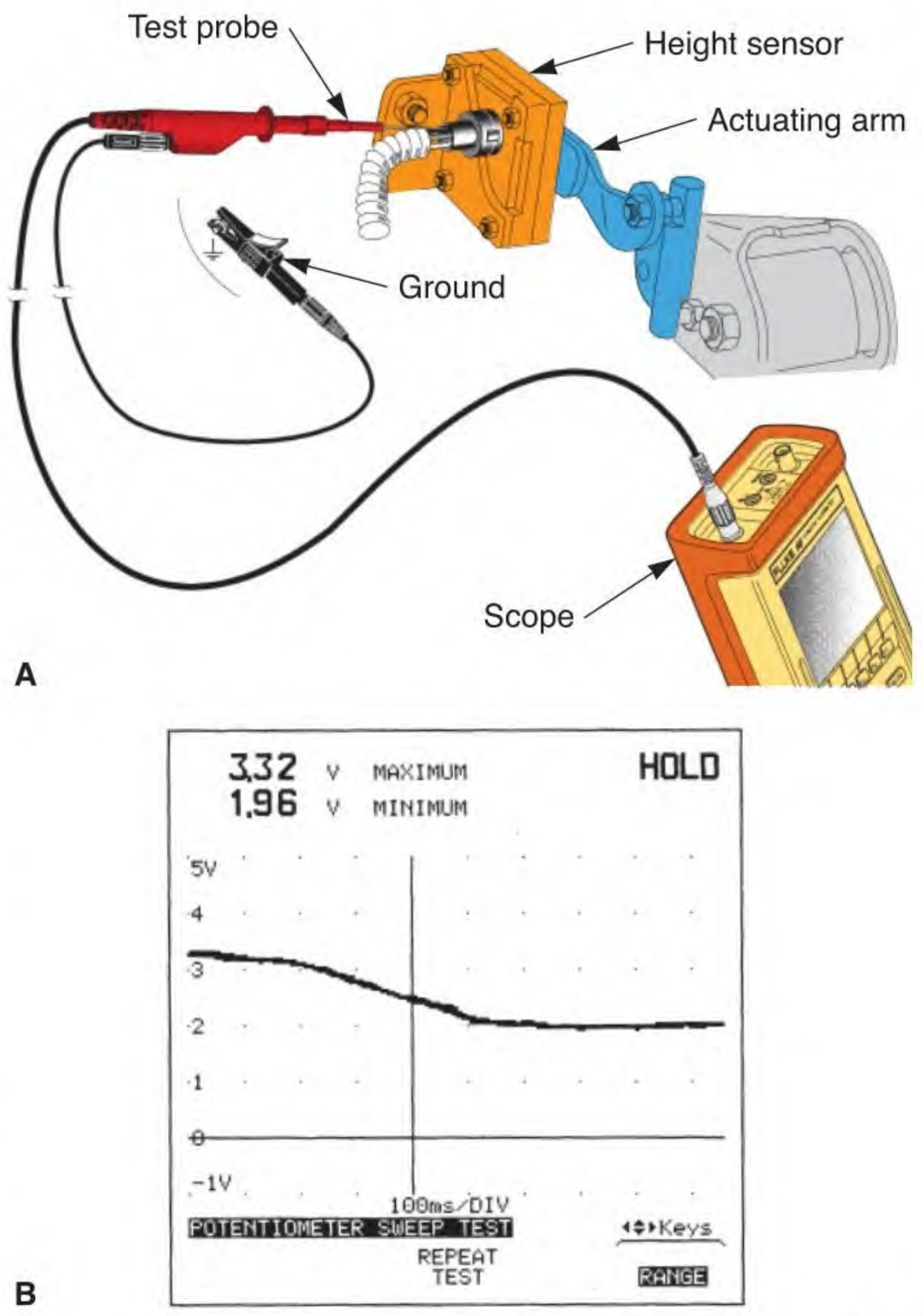
Figure 76-27. This wiring diagram shows the major connections in a computer-controlled suspension system. It is helpful when problems are hard to diagnose.

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OTC

Figure 76-28. A scan tool displays trouble codes and operating values. A—The scanner will ask you to select the computer or control module to be analyzed. B—From the function menu, choose to read present codes, review old codes, or switch to a special factory test mode. C—Trouble codes for the suspension system are displayed.



Fluke

Figure 76-29. Pinpoint tests are needed to locate the exact source of trouble. A—A handheld scope checks the output signal from a height sensor. Voltage should steadily increase and decrease as the sensor arm is moved up and down. B—This voltage waveform is for a typical height sensor. If there are spikes or abnormal voltages, check the reference voltage before replacing the sensor.

Summary

- A suspension system takes a tremendous pounding during normal vehicle operation. Bumps and potholes in the road cause constant movement, fatigue, and wear of shock absorbers, ball joints, bushings, springs, and other parts.
- Make sure that the suspected troubles are actually in the suspension system, *not* in the steering, wheel bearings, tires, or other related parts.
- Worn shock absorbers cause a vehicle to ride poorly on rough roads.
- Generally, good shock absorbers should stop body movement in one or two rebounds.
- Spring fatigue (weakening) lowers the height of the vehicle, allowing the body to settle toward the axles.
- To check spring condition, measure the vehicle's curb height.
- A coil spring compressor may be needed when removing and installing a coil spring.
- Worn ball joints cause the steering knuckle to be loose on the control arms.
- A grease gun is used to inject chassis grease into the ball joint grease fittings.
- Worn control arm bushings can allow the control arms to move sideways, causing tire wear and steering problems.
- Sticktion is a term used to describe the initial resistance to movement between rubber seals or bushings and metal parts.
- Most automakers recommend that faulty strut or shock cartridges be replaced.

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- To safely dispose of gas-filled shocks, drill a small hole through the gas chamber.
- Always torque all suspension system bolts and nuts to factory specifications.
- The first step in troubleshooting a computer-controlled suspension is to connect a scan tool or diagnostic tablet to the vehicle's diagnostic connector.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

ball joint separator
ball joint wear indicator
coil spring compressor
curb height
curb weight
fork tool
grease gun
shock absorber bounce test
spring fatigue
sticktion
strut spring compressor

Activities

1. Measure a vehicle for proper curb height after checking curb weight.
2. Inspect ball joints for wear and report their condition to your instructor.
3. Inspect and test-drive a vehicle with suspension problems. Diagnose the problem and suggest what service is needed.
4. Prepare a bill for a customer for replacement of front struts. Base your bill on an hourly charge rate established by your instructor. Find the cost of parts from a manufacturer's online parts catalog or by searching an automotive parts store's website. Use a flat rate manual on the shop's computer to find repair time.

Review Questions

Answer the following questions using the information provided in this chapter.

1. List several symptoms of common suspension system problems.
2. A customer complains that her vehicle's ride is very rough and the vehicle continues to rebound long after going over humps in the road. Technician A says that a bounce test is needed to check the shocks. Technician B says that a general inspection for worn suspension parts is also needed. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. What happens with spring fatigue?
4. Define the terms *curb height* and *curb weight*.
5. A(n) _____ is needed to remove and install a suspension system coil spring.
6. Why is suspension spring removal dangerous?
7. A(n) _____ tool or _____ is needed to force the ball joint stud from the steering knuckle.
8. How do you check for ball joint wear?
9. Generally, how do you remove a strut assembly?
10. Which of the following is *not* normally needed during strut service?
    (A) Shock or strut cartridge.
    (B) Jack stands or a car lift.
    (C) Spring compressor.
    (D) Air chisel.

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ASE-Type Questions

1. A car with an electronic air suspension is brought into the shop with an air compressor problem. Technician A checks the compressor's electrical connections and its source of voltage. Technician B tests the compressor's output pressure with a pressure gauge. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. A car's wheel alignment angles are not within specifications. Technician A checks the condition of the ball joints. Technician B looks for worn control arms bushings. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. All the following are typical automotive suspension system problems *except:*
   (A) bad control arm bushings.
   (B) damaged flex plate.
   (C) worn strut rod bushings.
   (D) bad ball joints.
4. A customer brings an automobile into the shop with a rough ride complaint. Technician A looks for worn strut shock absorbers. Technician B checks the condition of the strut mounting nuts. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. A vehicle's body bounces five times after a "shock bounce test" is performed. Technician A says this indicates that the shocks are in good condition. Technician B says the results of this test indicate bad shock absorbers. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. A small pickup truck is brought into the shop with a leaking shock absorber. Technician A says the leaking shock will produce a high-pitch screeching noise when the vehicle is driven. Technician B says that the leaking shock must be replaced. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. A car's strut shock absorbers are being replaced. During the procedure, Technician A says jack stands must be placed under the vehicle's strut assemblies. Technician B says jack stands should be placed under the axles. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. One of an automobile's air shocks is leaking. Technician A says that exceeding the recommended maximum air pressure given for air shocks is safe and smoothes operation. Technician B says the shock's air line can be repaired if it is leaking. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. A customer wants to know why his car's wheels are out of alignment. Technician A says weak suspension system springs can affect an automobile's wheel alignment. Technician B says vehicle suspension problems cannot cause wheel misalignment. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. A car's curb weight is being measured. Technician A checks curb weight with the automobile's gas tank empty. Technician B checks curb weight with the automobile's gas tank full. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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11. A truck's coil springs are being replaced (spring over control arm). During this procedure, Technician A unbolts the ball joint before compressing the coil spring. Technician B compresses the coil spring before unbolting the ball joint. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
12. Technician A says leaf springs are used in many late-model vehicles because they cannot break. Technician B says a spring compressor is not always required when replacing a rear coil spring. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
13. A car is brought into the shop with a possible ball joint problem. Technician A uses a ball joint wear indicator to check the condition of the automobile's ball joints. Technician B jacks up the vehicle and moves the control arm and joint. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
14. A car's front tires are worn. Technician A tells the car's owner that worn control arm bushings may have caused this problem. Technician B tells the owner that worn control arm bushings do not affect tire wear. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
15. An automobile's ball joints have been replaced. After performing this procedure, Technician A says the vehicle should be road tested before further adjustments are made. Technician B says the vehicle's wheel alignment should be checked before the vehicle is road tested. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Suspension System Diagnosis

Condition	Possible Causes	Correction
Front end whines on turns.	1. Defective wheel bearing. 2. Incorrect wheel alignment. 3. Worn tires.	1. Replace wheel bearing. 2. Check and reset wheel alignment. 3. Replace tires.
Front end growl or grinding on turns.	1. Defective wheel bearing. 2. Engine mount grounding. 3. Worn or broken CV-joint. 4. Loose lug nuts. 5. Incorrect wheel alignment. 6. Worn tires.	1. Replace wheel bearing. 2. Check for motor mount hitting frame rail and reposition engine as required. 3. Replace CV-joint. 4. Verify wheel lug nut torque. 5. Check and reset wheel alignment. 6. Replace tires.
Front end clunk or snap on turns.	1. Loose lug nuts. 2. Worn or broken CV-joint. 3. Worn or loose tie-rod, ball joint, control arm bushing, sway bar, or upper strut attachment. 4. Loose crossmember bolts.	1. Verify wheel lug nut torque. Tighten as necessary. 2. Replace CV-joint. 3. Tighten or replace tie-rod end or ball joint; replace control arm bushing; tighten sway bar or upper strut attachment to specified torque. 4. Tighten crossmember bolts to specified torque.
Front end whine with vehicle going straight at a constant speed.	1. Defective wheel bearing. 2. Incorrect wheel alignment. 3. Worn tires. 4. Worn or defective transaxle gears or bearings.	1. Replace wheel bearing. 2. Check and reset wheel alignment. 3. Replace tires. 4. Replace transaxle gears or bearings.
Front end growl or grinding with vehicle going straight at a constant speed.	1. Engine mount grounding. 2. Worn or broken CV-joint.	1. Reposition engine as required. 2. Replace CV-joint.
Road wander.	1. Incorrect tire pressure. 2. Incorrect wheel toe. 3. Worn wheel bearings. 4. Worn control arm bushings. 5. Excessive friction in steering gear. 6. Excessive friction in steering shaft coupling. 7. Excessive friction in strut upper bearing.	1. Inflate tires to recommended pressure. 2. Check and reset front wheel toe. 3. Replace wheel bearing. 4. Replace control arm bushing. 5. Replace steering gear. 6. Replace steering coupling. 7. Replace strut bearing.
Lateral pull.	1. Unequal tire pressure. 2. Radial tire lead. 3. Incorrect front wheel camber. 4. Power steering gear imbalance. 5. Wheel braking.	1. Inflate tire to recommended pressure. 2. Perform lead correction procedure. 3. Check and reset front wheel camber. 4. Replace power steering gear. 5. Correct braking condition causing lateral pull.
Excessive steering effort.	1. Low tire pressure. 2. Lack of lubricant in steering gear. 3. Low power steering fluid level. 4. Loose power steering pump belt. 5. Lack of lubricant in steering ball joints. 6. Steering gear malfunction. 7. Lack of lubricant in steering coupler.	1. Inflate all tires to recommended pressure. 2. Replace steering gear. 3. Fill power steering fluid reservoir to correct level. 4. Correctly adjust power steering pump belt. 5. Lubricate or replace steering ball joints. 6. Replace steering gear. 7. Replace steering coupler.

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Chapter 77
Steering System Technology

After studying this chapter, you will be able to:

- Explain the operating principles of steering systems.
- Identify the major parts of a steering system.
- Compare the differences between a linkage steering and a rack-and-pinion steering system.
- Describe the operation of hydraulic and electric-assist power steering systems.
- Explain the operation of four-wheel steering systems.
- Correctly answer ASE certification test questions requiring a knowledge of modern steering system designs.

The steering system is vital to the safety of an automobile and its occupants. The steering wheel and its power transfer mechanisms allow the driver to safely maneuver the vehicle. To be a good diagnostic and repair technician, you must first understand the construction and operation of modern steering systems.

Early steering systems were simple mechanical mechanisms. A series of shafts, rods, and gears transferred steering wheel motion to the wheels and tires. Today's steering systems are much more sophisticated. They still use mechanical mechanisms for safety, but they also use hydraulics or electric motors and electronic circuits to improve steering ease and precision.

This chapter will build upon your knowledge of automotive technology by introducing late-model steering system variations. It will explain basic manual steering systems before progressing to more complex hydraulic-mechanical and electronic-mechanical designs.

Functions of a Steering System

A steering system must perform the following important functions:

- It provides precise control of the front-wheel direction and, sometimes, the rear-wheel direction.
- It maintains the correct amount of effort needed to turn the wheels.
- It transmits ***road feel*** (slight steering wheel pull caused by road surface irregularities) to the driver's hands.
- It absorbs most of the shock going to the steering wheel as the tires hit bumps and potholes in the road.

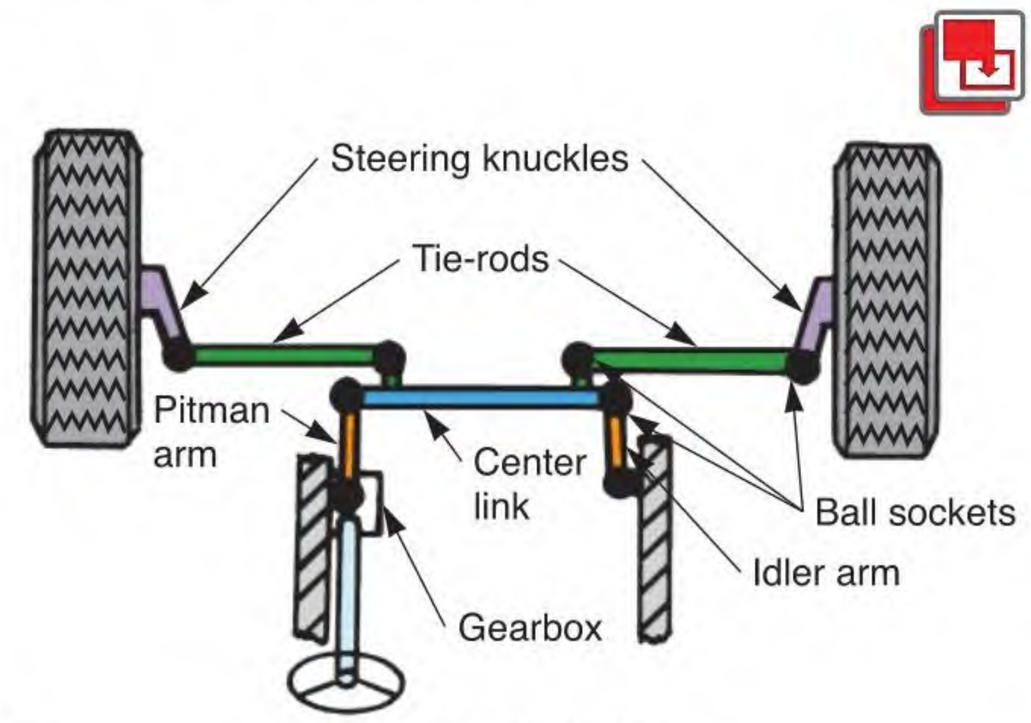
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- It allows for suspension action with minimal effect on the direction and alignment of the front wheels of the vehicle.

Basic Steering Systems

There are two basic kinds of steering systems in wide use today: linkage (worm gear) and rack-and-pinion. ***Linkage steering systems*** are found on large, full-size pickup trucks and full-size vans, both two- and four-wheel drive. ***Rack-and-pinion steering systems*** are lighter and are better for passenger cars and small trucks. Each type may be operated manually or with power assist.

To effectively diagnose and repair steering systems, you must first understand the major parts of a steering system and their functions. This will allow you to develop a better "picture" of how each component operates. See **Figure 77-1**.



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Figure 77-1. There are two types of steering systems. Rack-and-pinion steering is found on passenger cars. Linkage steering is still used on full-size trucks, vans, and SUVs.

Basic Linkage Steering

The following are the parts that make up a linkage steering system:

- ***Steering wheel***—The steering wheel is used by the driver to rotate a steering shaft that passes through the steering column and firewall.
- ***Steering shaft***—The steering shaft consists of a long steel shaft that transfers turning motion from the steering wheel to the steering gearbox.
- ***Steering column***—The steering column is a hollow tube that supports the steering wheel and the steering shaft.
- ***Steering gearbox***—The steering gearbox changes turning motion into a straight-line motion (from left or right) for moving the steering knuckles.
- ***Steering linkage***—Steering linkage connects the steering gearbox to the steering knuckles and the wheels. Tie-rod assemblies are a part of the linkage.
- ***Ball sockets***—Ball sockets on the tie-rod ends are grease-filled swivel joints that allow linkage arms to swivel up and down (for suspension action) and from left to right (for turning).

Basic Rack-and-Pinion Steering

A rack-and-pinion steering system also uses a steering wheel, steering column, and steering shaft. These components transfer the driver's turning effort to gears in the steering gear assembly or steering rack.

Other than the parts just covered, the following are the major components of a rack-and-pinion steering system:

- ***Steering pinion gear***—This small gear is rotated by the steering wheel and steering shaft; its teeth mesh with the teeth on the rack.
- ***Rack***—The rack is a long steel bar with teeth along one section; it slides sideways in its housing as the pinion gear turns.
- ***Gear housing***—This housing holds the pinion gear and the rack.
- ***Tie-rods***—Tie-rods are steel rods with swivel sockets on each end that connect the rack with the two front steering knuckles.

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Steering Column Assembly

The ***steering column assembly*** consists of the steering wheel, steering shaft, column (outer housing), and, sometimes, ignition key mechanism, a flexible coupling, and a universal joint. Look at **Figure 77-2**.

The steering column normally bolts to the underside of the dash. The column sticks through the firewall and fastens to the steering gear assembly.

Bearings fit between the steering shaft and the column. They let the shaft rotate freely. The steering wheel is splined to the shaft. A large nut holds the steering wheel on the shaft splines. The driver's-side air bag fastens to the steering wheel.

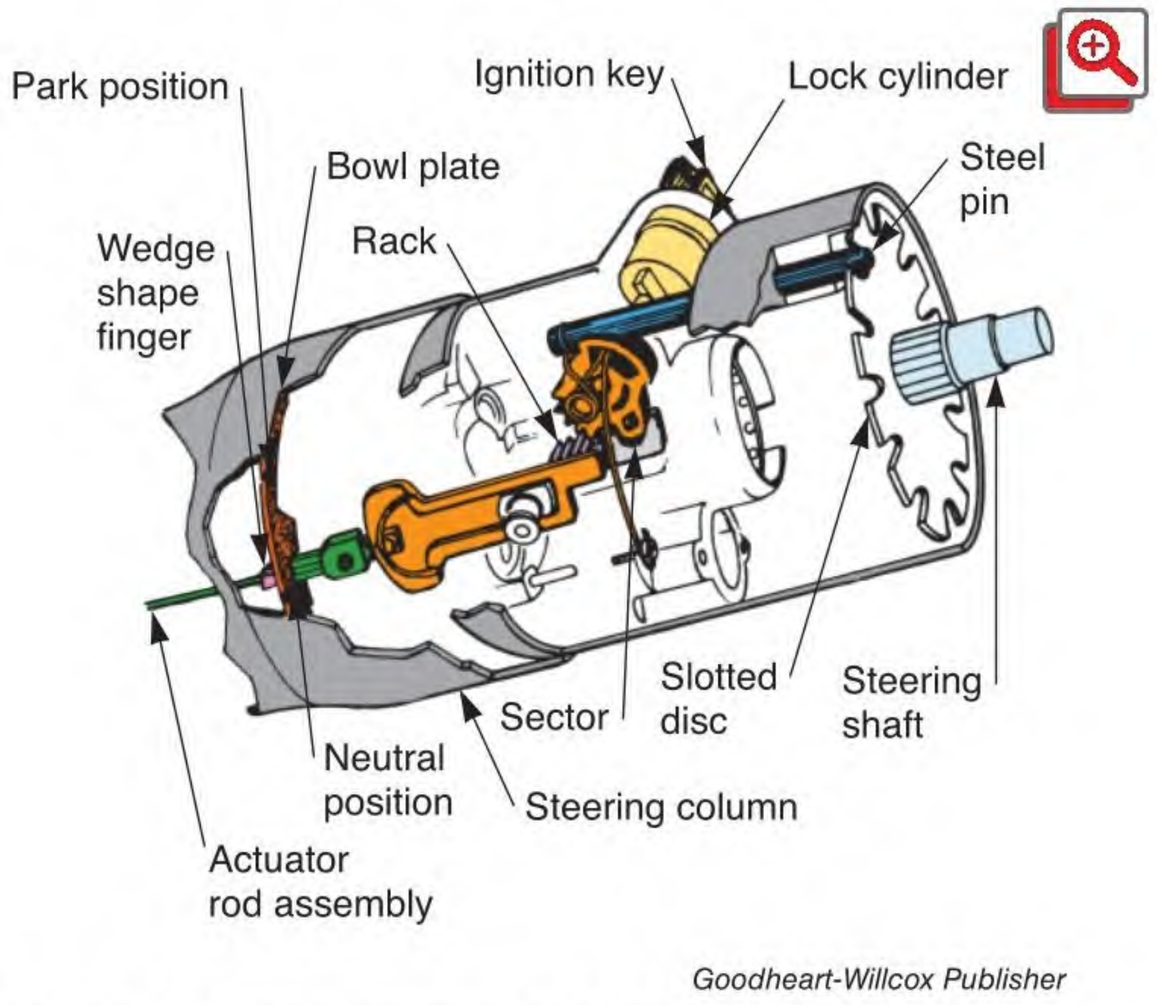
Ignition Lock and Switch

The ignition lock and switch mechanism are mounted on the steering column in most vehicles. The ***ignition lock mechanism*** is normally on the top, right-hand side of the column. The ***ignition switch*** is usually bolted inside the steering column.

Locking Steering Wheel

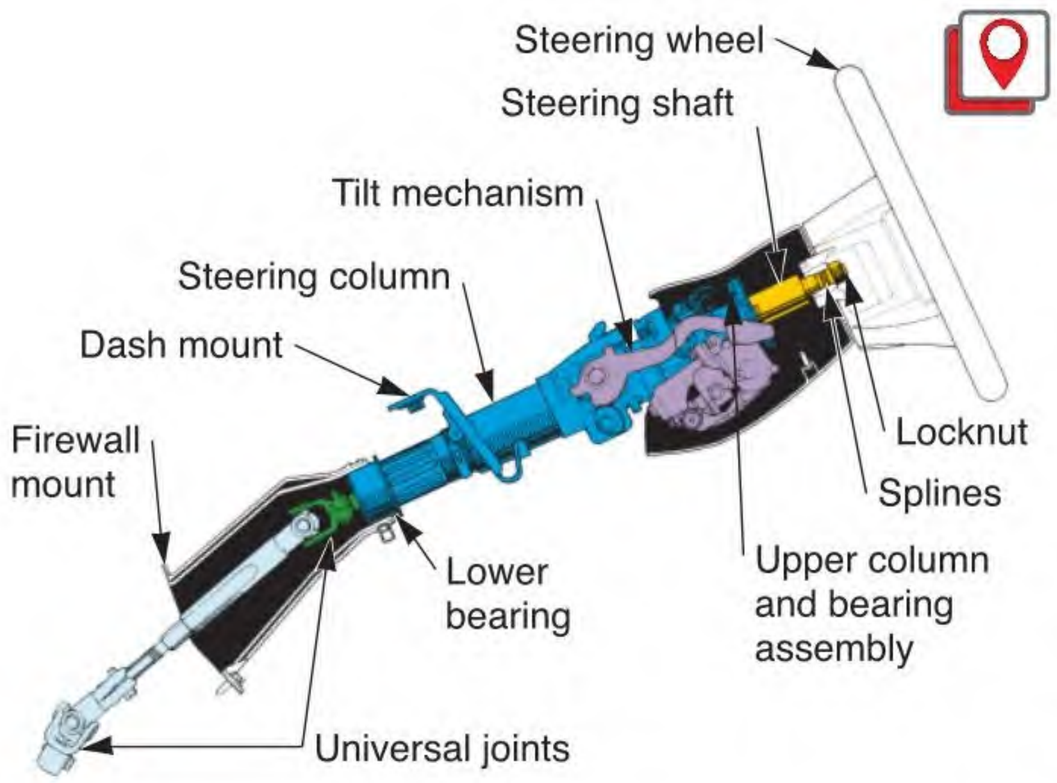
To help prevent theft, late-model vehicles have a ***locking steering wheel***. When the ignition key is off, the steering wheel cannot be turned.

Figure 77-3 shows a common method of locking the steering wheel. A rack and a sector are used to slide a steel pin into mesh with a slotted disc that is splined to the steering shaft. This locks the steering shaft to the column, preventing the steering wheel from being turned.



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Figure 77-3. Cutaway view shows how a locking steering column functions. The steel pin slides into a slot in the disc to keep the wheel from turning after the key is removed. Also note the small rod that extends down to the ignition switch.



Lexus

Figure 77-2. Note the steering column components. The steering wheel is splined to a shaft that extends through the column and down into the steering gearbox. This is a tilt column, which allows the steering wheel to be moved into different driving positions.

Collapsible Steering Column

Most vehicles use a ***collapsible steering column*** to help prevent driver chest and face injury during an auto accident. The column is designed to crumple or slide together when forced forward during a collision. Look at **Figure 77-4**.

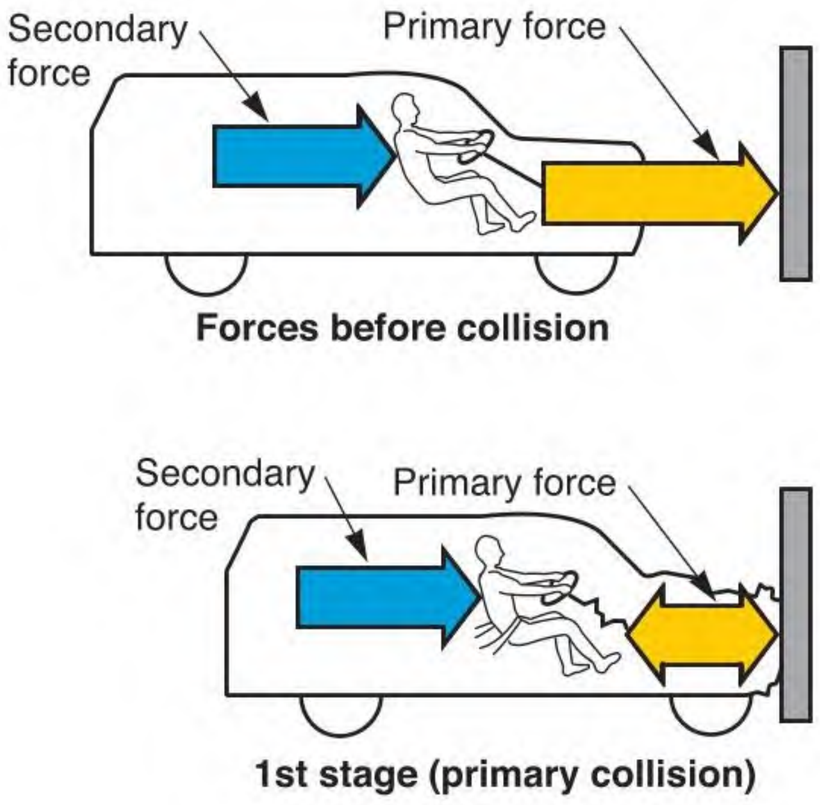
When a vehicle hits a stationary object, the engine and the front body structure can be pushed rearward into the steering column. At the same time, the driver can be thrown forward into the steering wheel. With a rigid steering column, the driver's chest could be injured.

There are several types of collapsible steering columns: steel mesh (crushing) columns, tube-and-ball (sliding) columns, and the shear capsule (break and slide) columns. In all types, the column is made up of two pieces.

Tilt Steering Columns

A ***tilt steering column***, or ***tilt steering wheel***, has a flex joint, or U-joint, that allows the top half of the column and the steering wheel to be positioned at different angles.

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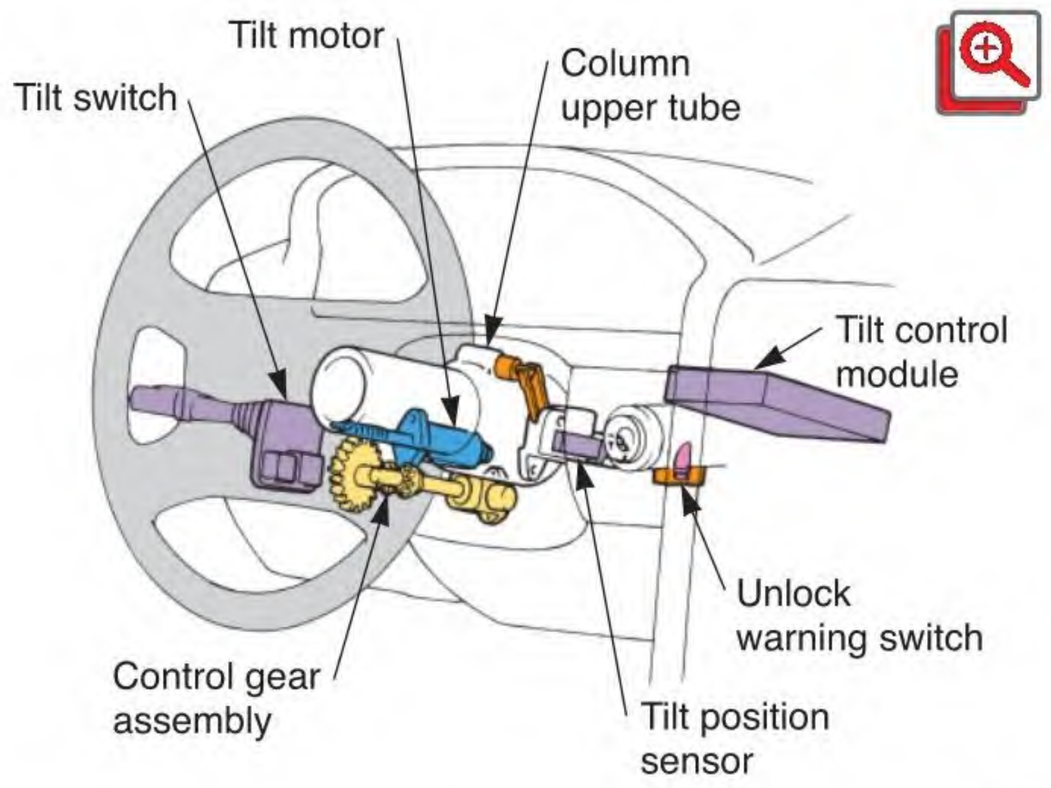
Figure 77-4. A collapsible steering column crushes, protecting the driver.

A ***manual tilt column*** uses a lever on the steering column to unlock the flex joint so the wheel can be moved up or down.

A ***power tilt column*** uses a small electric motor, a control switch, and a gear mechanism to change steering wheel angle or height. When the tilt switch is activated, current to the motor spins the small gears to move the steering column's upper tube. Moving the switch the other way reverses current flow through the motor and moves the wheel in the opposite direction.

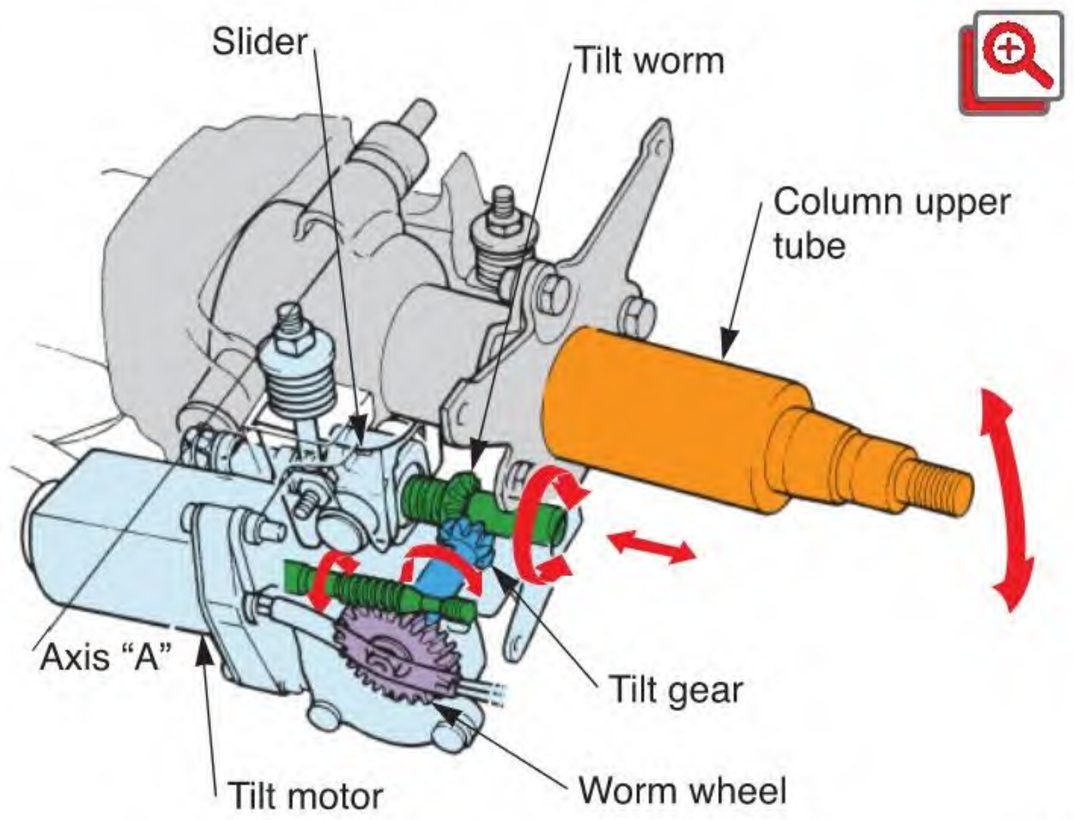
Memory tilt wheels use a tilt control module (computer) to "remember" more than one steering wheel position. A sensor in the steering column provides feedback so the tilt control module knows where the wheel is located. When the driver presses the proper steering wheel position switch, the control module energizes the power tilt motor until the wheel has moved to the driver's preprogrammed position. Refer to **Figure 77-5**.

Many memory tilt wheels will move the steering wheel upward whenever the ignition switch is turned off or on. This gives the driver more room to enter and exit the vehicle. One mechanism for a power tilt steering wheel is detailed in **Figure 77-6**.



Lexus

Figure 77-5. Note the parts of a power tilt steering wheel. This system can be programmed to remember the steering wheel position for more than one driver. The module receives data on steering wheel position from the tilt position sensor. When the driver presses the appropriate tilt switch, the module operates the motor to move the steering wheel to the correct position. In a memory-type system, the module will remember the tilt settings programmed by the driver.



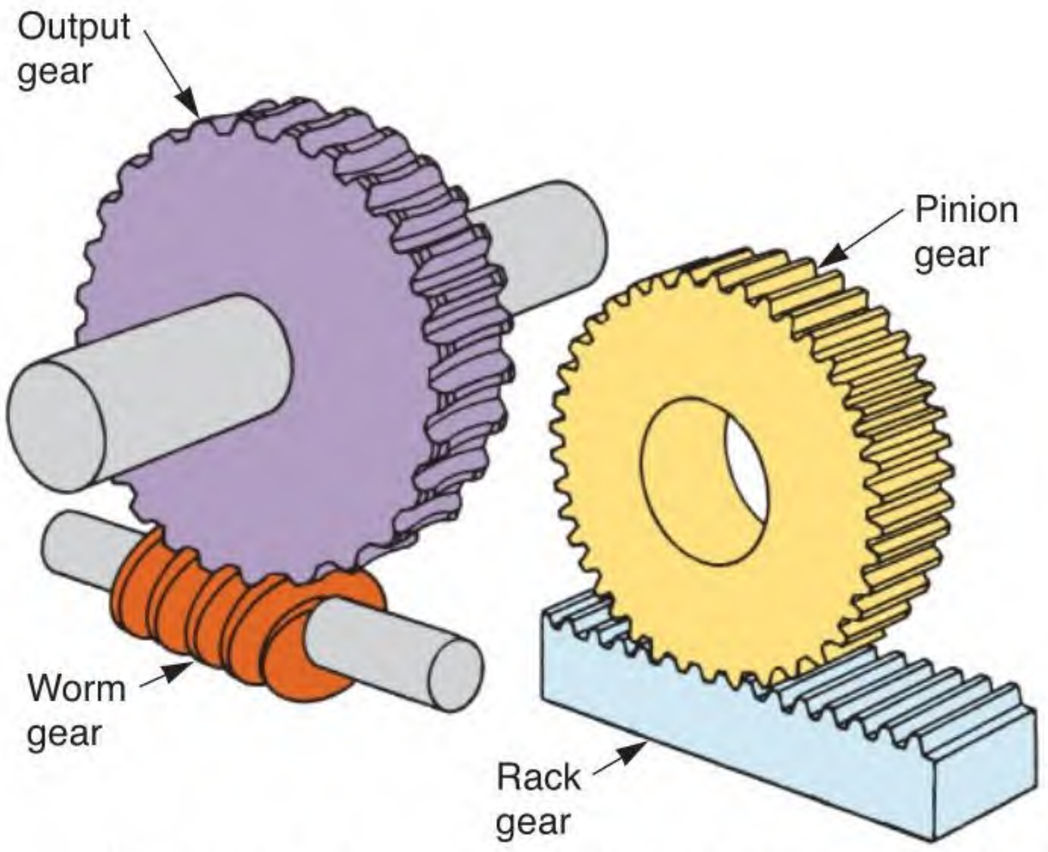
Lexus

Figure 77-6. Note the gear mechanism in this power tilt steering wheel system.

Steering Gear Principles

Mentioned briefly, large pickup trucks sometimes use a worm-type steering gear assembly. Modern passenger cars normally use lighter, less complex rack-and-pinion systems. These two gear principles are illustrated in **Figure 77-7**.

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Figure 77-7. Two basic types of gear mechanisms are found in steering gearboxes: worm gears and rack-and-pinion gearset.

Cutaway views of both rack-and-pinion and worm-type (recirculating-ball) steering mechanisms are given in **Figure 77-8**.

Recirculating-Ball Gearbox

The ***recirculating-ball gearbox*** is normally used with a linkage steering system on large trucks. It has small steel balls that circulate between the gear members. See **Figure 77-9**.

A ***worm shaft*** is the input gear connected to the steering column shaft. The balls fit and ride in the grooves in the worm gear.

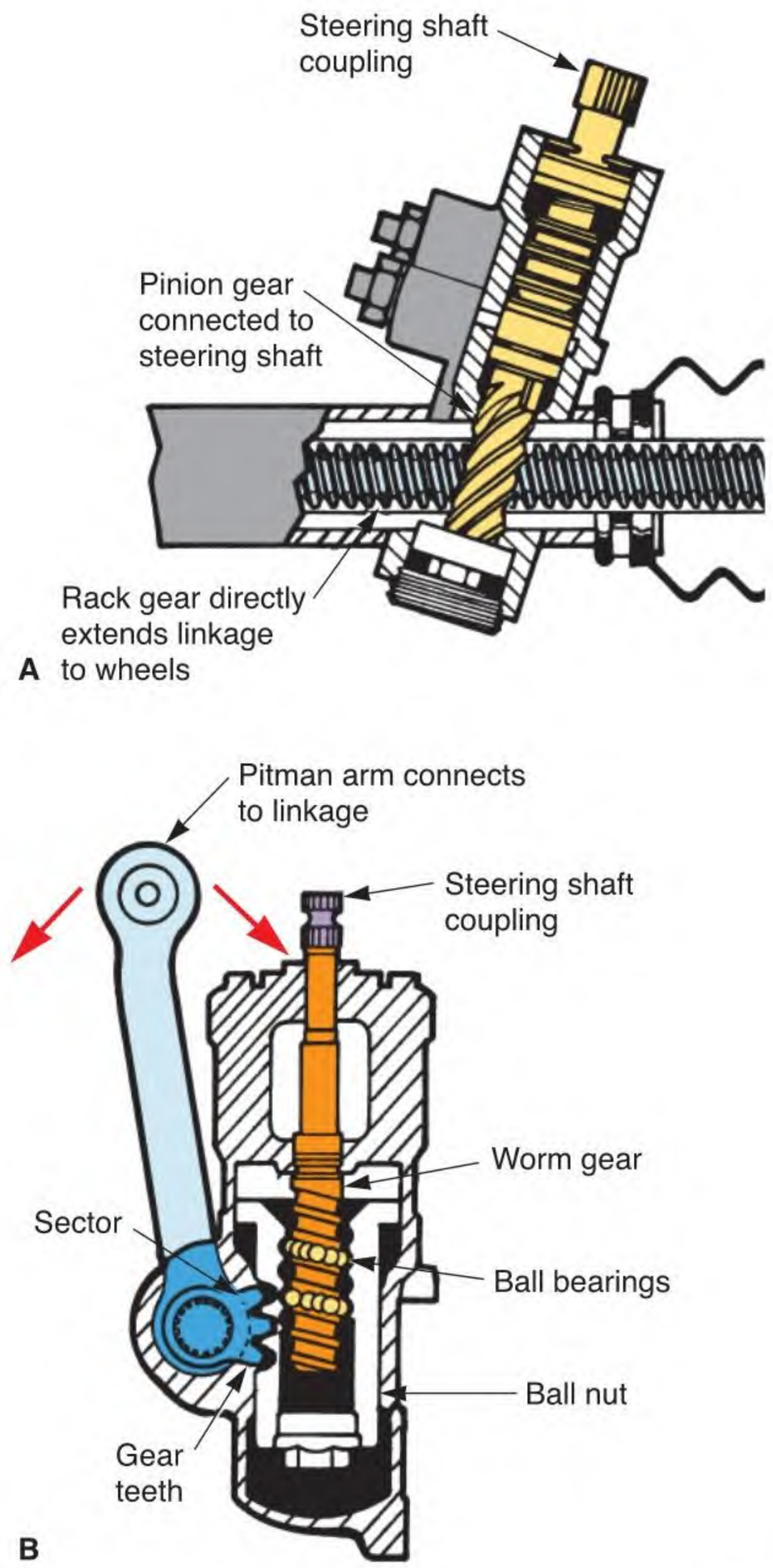
The ***sector shaft*** is the output gear from the steering gearbox. It transfers motion to the steering linkage. A sector gear is machined on the inner end of the sector shaft.

A ***ball nut*** rides on the ball bearings and the worm gear. Grooves are cut in the ball nut to match the shape of the worm gear. Since the ball nut cannot rotate, it slides up and down as the worm gear rotates.

Ball guides route extra ball bearings in and out from between the worm and ball nut.

The worm shaft is mounted in either ball bearings or roller bearings. The sector shaft is also mounted on antifriction bearings.

A bearing ***adjusting nut*** is usually provided to set worm shaft bearing preload. An ***adjusting screw*** is used to set the sector shaft clearance.



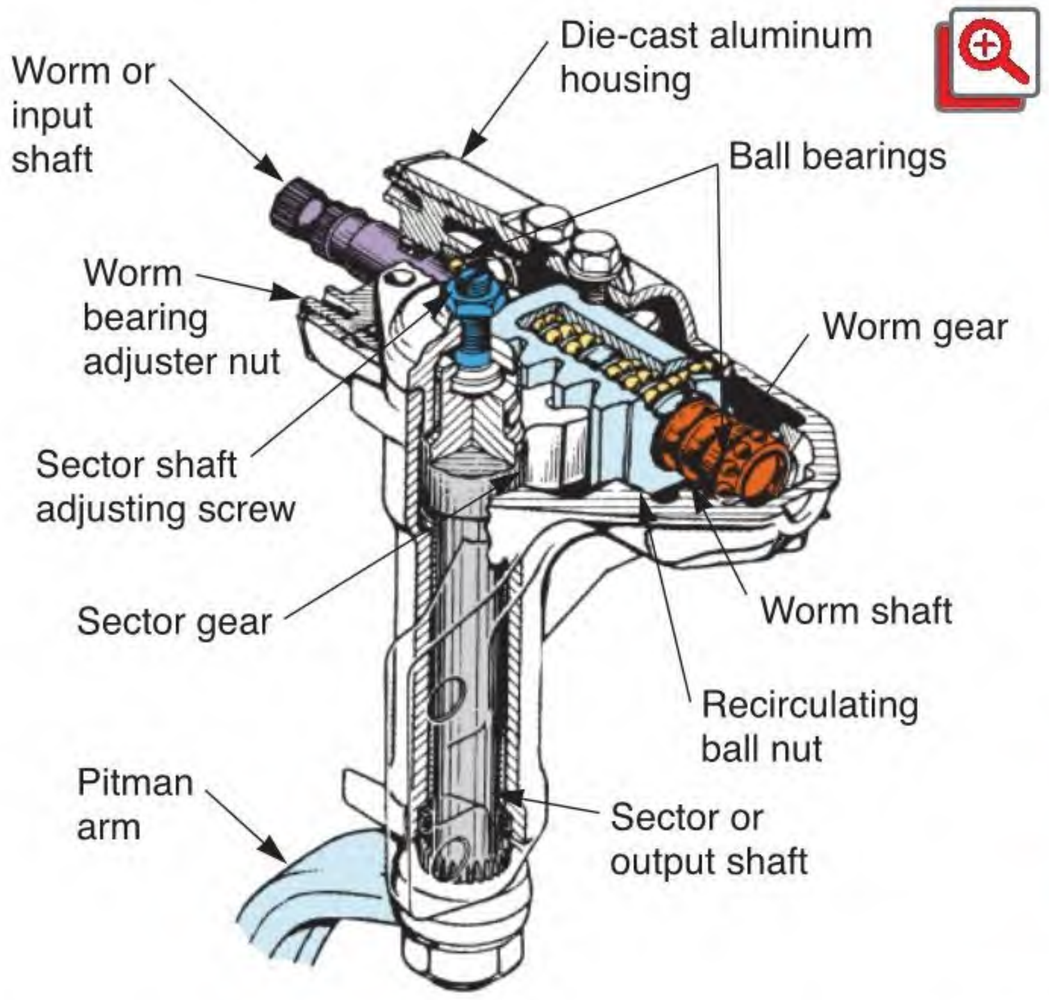
Chrysler

Figure 77-8. Another view of two types of steering gears. A—Rack-and-pinion gear. B—Worm steering gear.

The ***gearbox housing*** provides an enclosure for the other components. Seals press into the housing to prevent lubricant leakage at the worm and sector shafts. The shaft bearings also press into the gearbox housing. The housing bolts to the vehicle frame or to a reinforced area on the unitized body.

An ***end cover*** normally bolts on the housing to cover the end of the sector gear. It can be removed for gearbox service.

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Figure 77-9. Cutaway view of a recirculating-ball steering gearbox. Study the part relationships. When the steering wheel is turned, the shaft and the worm gear rotate. This causes the balls and the ball nut to walk on the worm. As a result, the ball nut turns the sector gear and shaft.

Gearbox Ratio (Steering Gear Reduction)

Gearbox ratio, also termed ***steering ratio*** or ***steering gear reduction***, is basically a comparison between steering wheel rotation and sector shaft rotation. Steering gearbox ratios range from 15:1 to 24:1. With a 15:1 ratio, the worm shaft turns 15 times to turn the sector shaft once.

A manual gearbox will have a high gearbox ratio to reduce the amount of effort needed to turn the steering wheel. Power steering gearboxes have a lower gearbox ratio so that turning the front wheels requires less steering wheel rotation for faster steering response.

Variable- and Constant-Ratio Gearboxes

A ***variable-ratio gearbox*** changes the internal gear ratio as the front wheels are turned from the center position. Most modern recirculating-ball gearboxes are variable-ratio designs.

Variable-ratio steering is faster when cornering, requiring fewer turns to move the steering wheel from full right to full left. It also provides better control and response when maneuvering.

A ***constant-ratio gearbox*** has the same gear reduction from full left to full right. The sector gear teeth are the same length.

Worm-and-Roller Steering Gearbox

A ***worm-and-roller steering gearbox*** contains a roller that is mounted on the pinion shaft and meshes with the worm gear. The roller replaces the ball bearings and the ball nut used in the recirculating-ball gearbox. The roller imparts a rotary force on the pitman shaft as the worm gear rotates. The worm-and-roller design helps reduce internal friction.

Steering Linkage (Worm-type Gearbox)

The ***steering linkage*** is a series of arms, rods, and ball sockets that connect the worm-type steering gearbox to the steering knuckles. The linkage used with a worm-type gear box is commonly called a ***parallelogram steering linkage***. This type of steering linkage typically includes a pitman arm, a center link, an idler arm, and two tie-rod assemblies. It may also include a steering damper. See **Figure 77-10**.

Pitman Arm

The ***pitman arm*** transfers gearbox motion to the steering linkage. The pitman arm is splined to the gearbox sector (output) shaft. A large nut and lock washer secure the arm to its shaft. The outer end of the pitman arm is normally connected to the linkage through a ball socket, **Figure 77-10**.

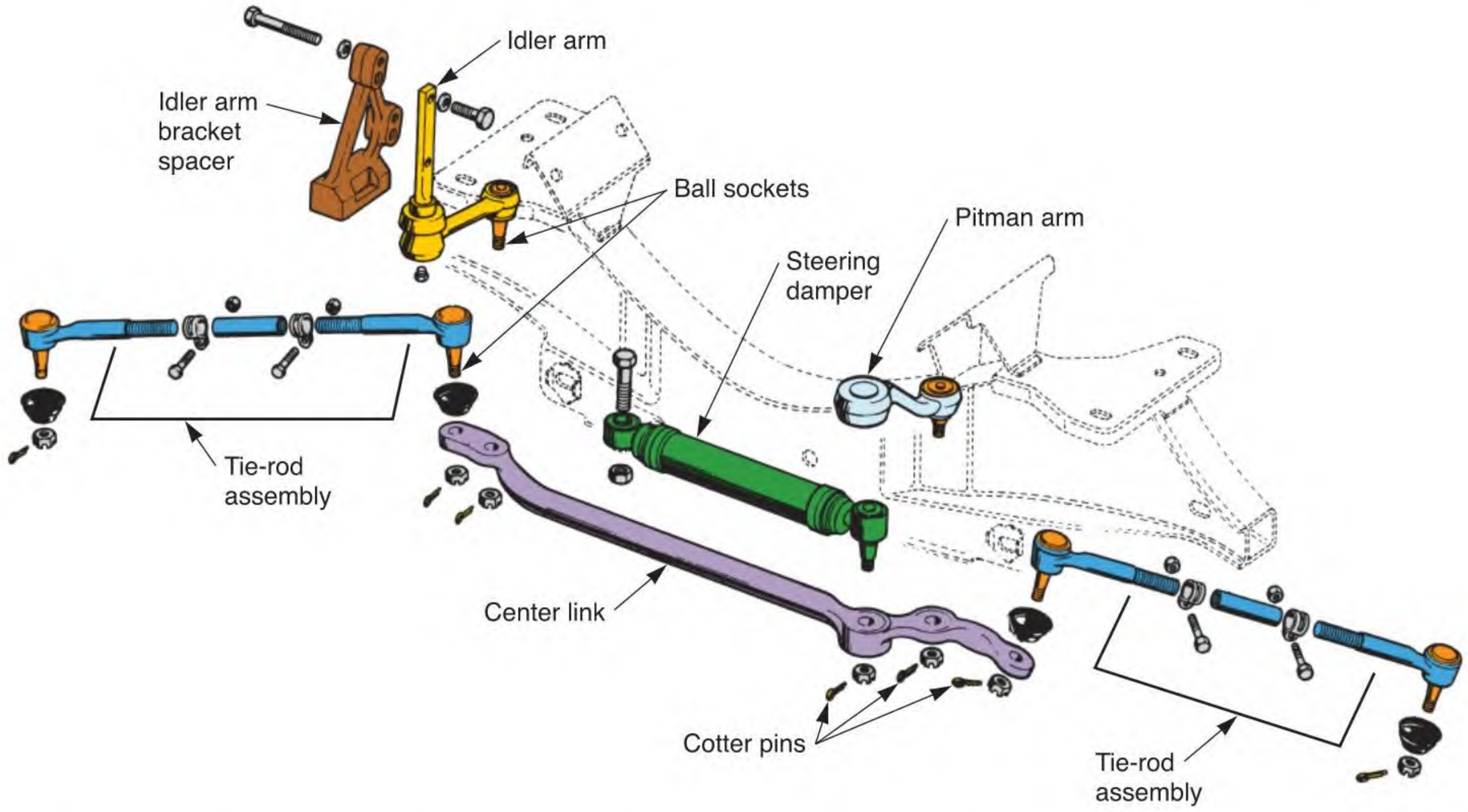
Ball sockets provide for motion in all directions between two connected parts. They are needed so the steering linkage is *not* bent and damaged when the wheels turn or move up and down over rough road surfaces. Cutaway views of various ball sockets are given in **Figure 77-11**. Note how a ball stud fits into a socket.

Ball sockets are filled with grease to reduce friction and wear. Some ball sockets are sealed. Others have a grease fitting that allows chassis grease to be injected with a grease gun.

Center Link (Relay Rod)

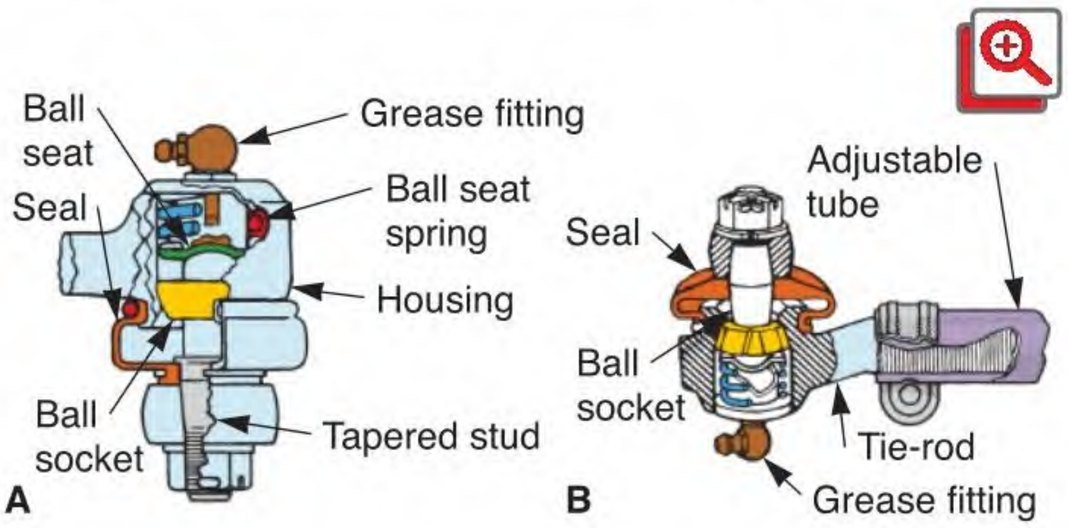
The ***center link***, also called a ***relay rod***, is simply a steel bar that connects the right and left sides of the steering linkage. It has holes that accept the pitman arm, tie-rods, and idler arm, as shown in **Figure 77-10**.

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Figure 77-10. Study the arrangement of this linkage-type steering system. A pitman arm connects to the steering gearbox. The arm swings right or left and moves the other linkage components. This type of steering system is commonly used on large, full-size trucks.



Ford

Figure 77-11. Ball sockets allow linkage components to swivel freely. They are commonly used on the end of the pitman arm, idler arm, and tie-rods. A—Ball socket for an idler arm. B—Ball socket for a tie-rod.

Idler Arm

The ***idler arm*** supports the end of the center link on the passenger side of the vehicle. The idler arm bolts to the vehicle's frame or subframe, **Figure 77-10**.

Steering Damper

The ***steering damper*** is an oil-filled shock absorber found in some parallelogram linkage arrangements. It is attached between the vehicle's frame and the center link to help absorb road shocks before they reach the steering gear. See **Figure 77-10**.

Tie-Rod Assemblies

Two ***tie-rod assemblies*** fasten the center link to the steering knuckles. A tie-rod assembly typically consists of two tie-rods and a toe adjustment sleeve. Ball sockets are normally used on both ends of each tie-rod assembly with linkage steering systems. Look at **Figure 77-10**.

The tie-rod that connects to the center link is called the inner tie-rod. The tie-rod that fastens to the steering knuckle is called the outer tie-rod.

The ***toe adjustment sleeve*** is provided for changing the length of the tie-rod assembly during wheel alignment. The tie-rods and sleeves are threaded so the assembly can be lengthened or shortened to adjust toe-in or toe-out of the front wheels. This is explained fully in a later chapter.

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Manual Rack-and-Pinion Steering

Rack-and-pinion steering is the most popular type of steering system on today's vehicles. For this reason, it is important that you understand its parts and operating principles. **Figure 77-12** shows the external parts of a manual rack-and-pinion steering mechanism. Note that the steering gear is bolted to the frame crossmember.

Steering Shaft, Flexible Coupling, and Universal Joint

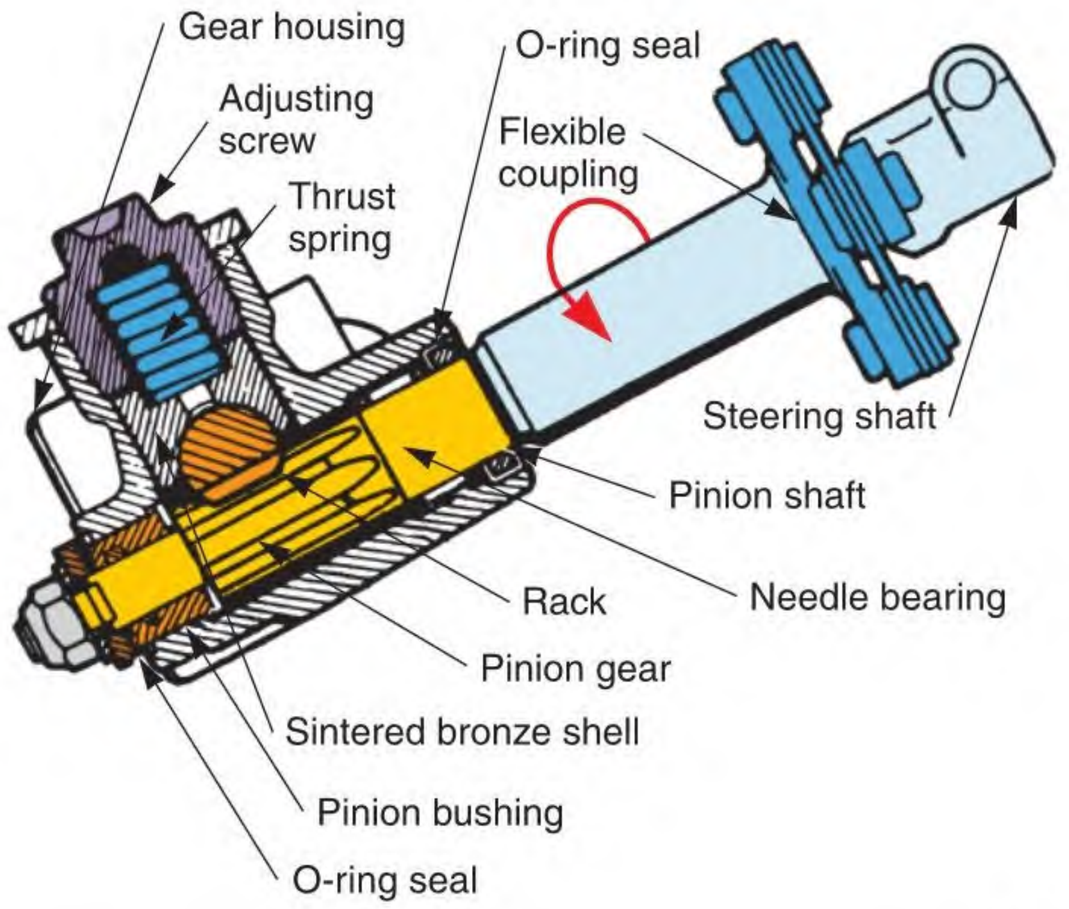
Many steering systems have a flexible coupling and/or a universal joint in the steering shaft. Look at **Figures 77-12** and **77-13**.

The ***flexible coupling*** helps keep road shock from being transmitted to the steering wheel. It also allows for slight misalignment of the steering shaft and steering gear input shaft (pinion shaft).

A ***universal joint*** allows for a change in the angle between the steering column and steering shaft. One is shown in **Figure 77-12**.

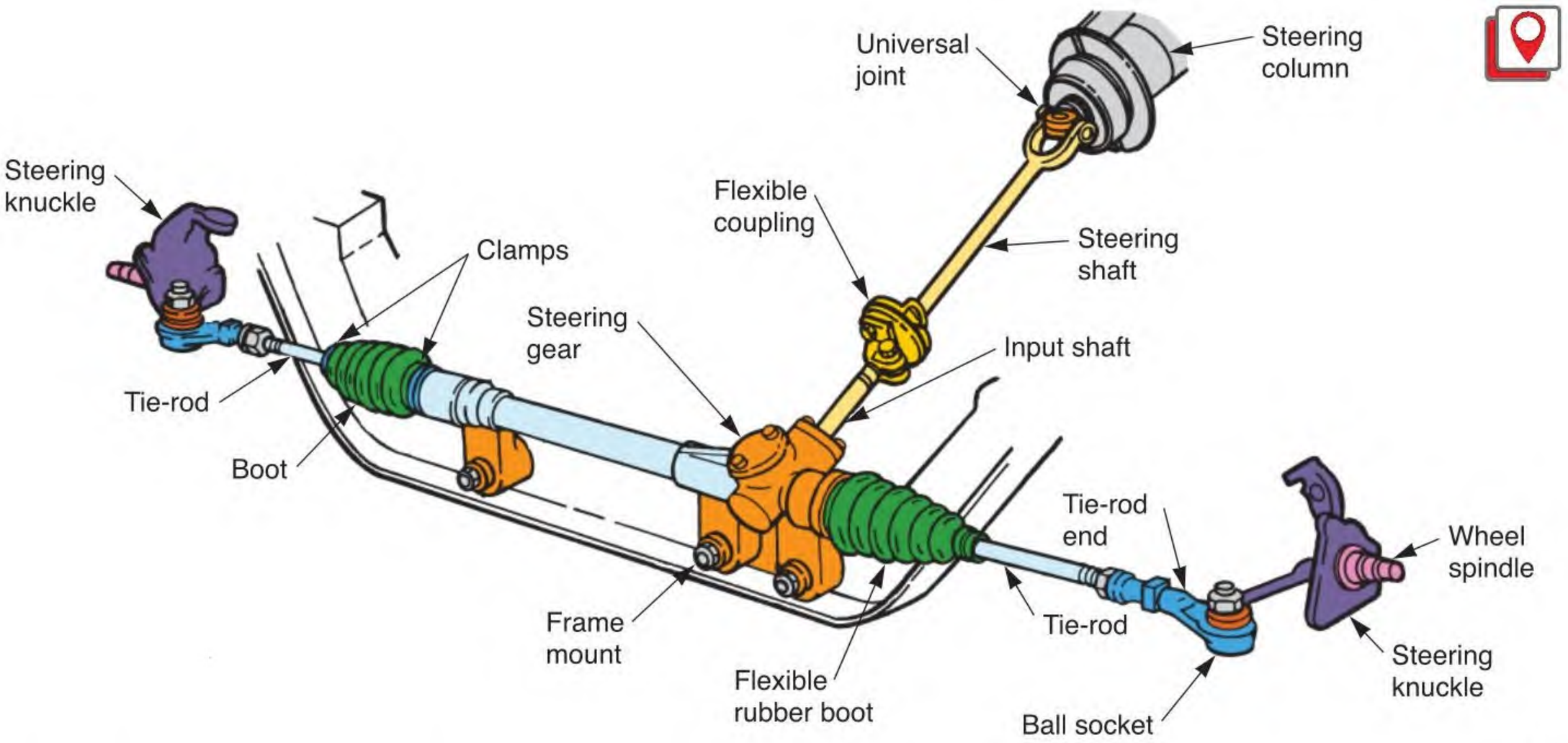
Rack-and-Pinion Steering Gear

A manual ***rack-and-pinion steering gear*** basically consists of a pinion shaft, a rack, a thrust spring, bearings, seals, and a gear housing. The assembly bolts to the vehicle's frame or unibody structure. Large bolts with rubber bushings secure the unit and help absorb road shock. A cutaway view of a rack-and-pinion steering gear is shown in **Figure 77-13**.



Ford

Figure 77-13. Cutaway shows how a pinion shaft gear rotates in its housing. The pinion gear teeth mesh with the rack gear teeth to slide the rack left or right for steering action. The thrust spring holds the rack-and-pinion gears in contact.



Ford

Figure 77-12. Study the components of this manual rack-and-pinion steering system. It uses fewer parts than a linkage system.

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When the steering shaft turns the pinion shaft, the pinion gear acts on the rack gear. The rack then slides sideways inside the gear housing, **Figure 77-14**.

The ***thrust spring*** preloads the rack-and-pinion gear teeth to prevent excessive gear backlash (play). Adjustment screws or shims may be used to set thrust spring tension.

Either bushings or roller bearings may be used on the pinion shaft and the rack. Frequently, the pinion shaft uses roller bearings and the rack uses plain bushings.

Rack-and-Pinion Tie-Rod Assemblies

Tie-rod assemblies for rack-and-pinion steering systems connect the ends of the rack with the steering knuckles. Look at **Figure 77-15**.

Note the unique construction of the tie-rods used in rack-and-pinion steering. A very large ball formed on one end of each inner tie-rod fits into a socket that screws onto the end of the rack. A conventional ball socket is used on one end of each outer tie-rod.

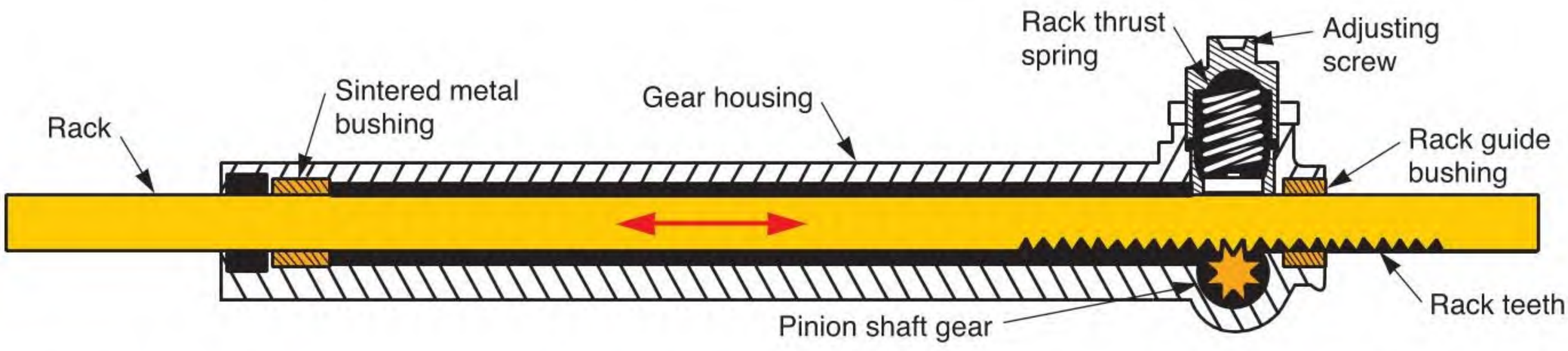
Rubber dust boots fit over the inner ball sockets to keep out road dirt and water, as well as to hold in lubricating grease. Clamps secure each end of the dust boots.

Power Steering Systems

Power steering systems normally use an engine-driven pump and a hydraulic system to assist steering action. They can also use an electric motor in the rack to provide power assist.

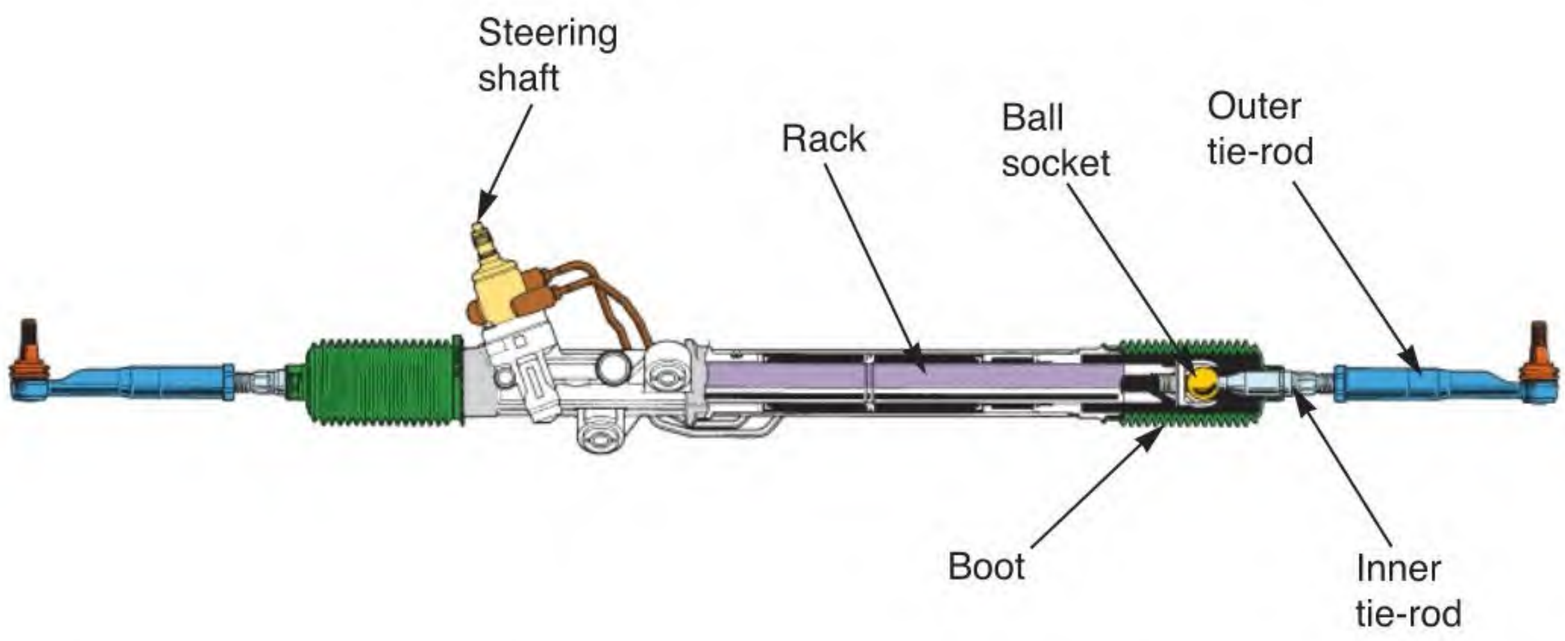
Figure 77-16 illustrates a simplified hydraulic power steering system. Pressure from an oil pump is used to operate a piston-and-cylinder assembly. When the control valve routes oil pressure into one end of the piston, the piston slides in its cylinder. Piston movement can then be used to help move the steering system components and the front wheels of the vehicle.

There are three major types of power steering systems used on modern automobiles: integral-piston linkage systems, external cylinder power steering systems, and power (hydraulic or electric) rack-and-pinion systems. See **Figure 77-17**. The rack-and-pinion system is further divided into the integral and the external power piston systems. The integral rack-and-pinion power steering system is the most common.



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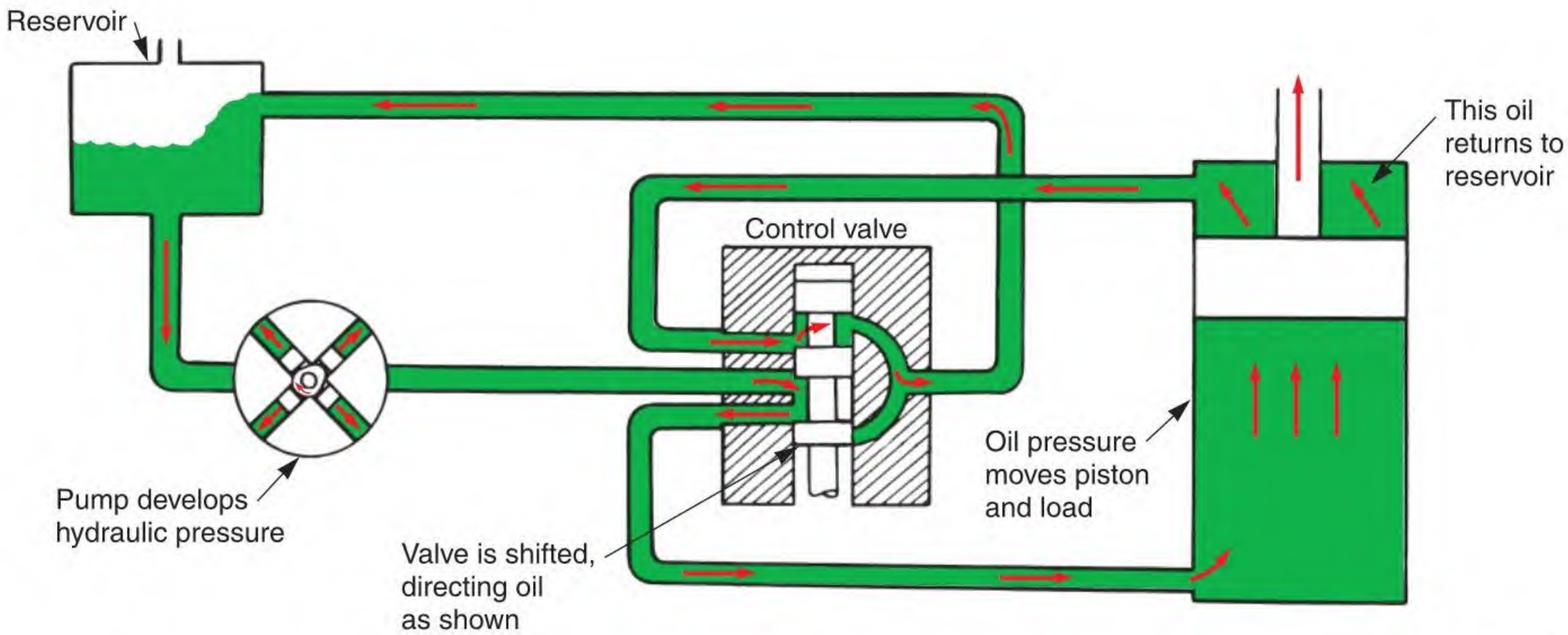
Figure 77-14. The rack slides sideways and pushes or pulls on the tie-rods. This rotates the steering knuckles and the front wheels.



Toyota

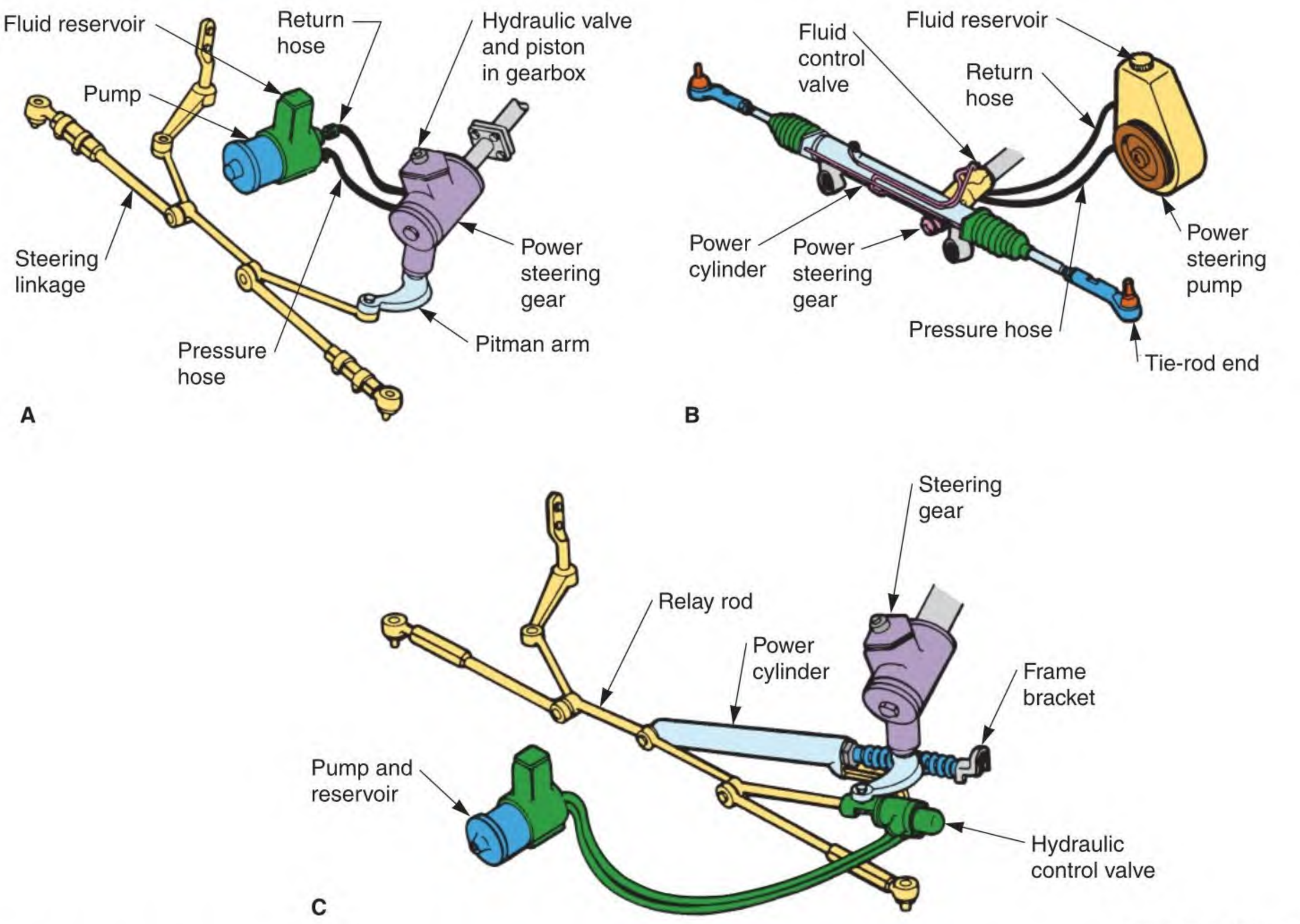
Figure 77-15. Tie-rod assemblies for a rack-and-pinion steering system. Note how the inner tie-rod attaches to the rack.

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Deere & Co.

Figure 77-16. Study basic components of a power steering system. A hydraulic (oil) pump pressurizes the system. The control valve routes oil to either side of the piston. Piston action can then be used to aid in moving the front wheels.



Florida Dept. of Voc. Ed.

Figure 77-17. Study the three major power steering systems. A—Integral-piston linkage system. B—Rack-and-pinion system. C—External cylinder power steering.

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A cutaway view of a modern power rack-and-pinion mechanism is shown in **Figure 77-18**.

Power Steering Pumps

The ***power steering pump*** is engine driven and produces the hydraulic pressure for steering system operation. In most cases, a belt running from the engine crankshaft pulley powers the pump.

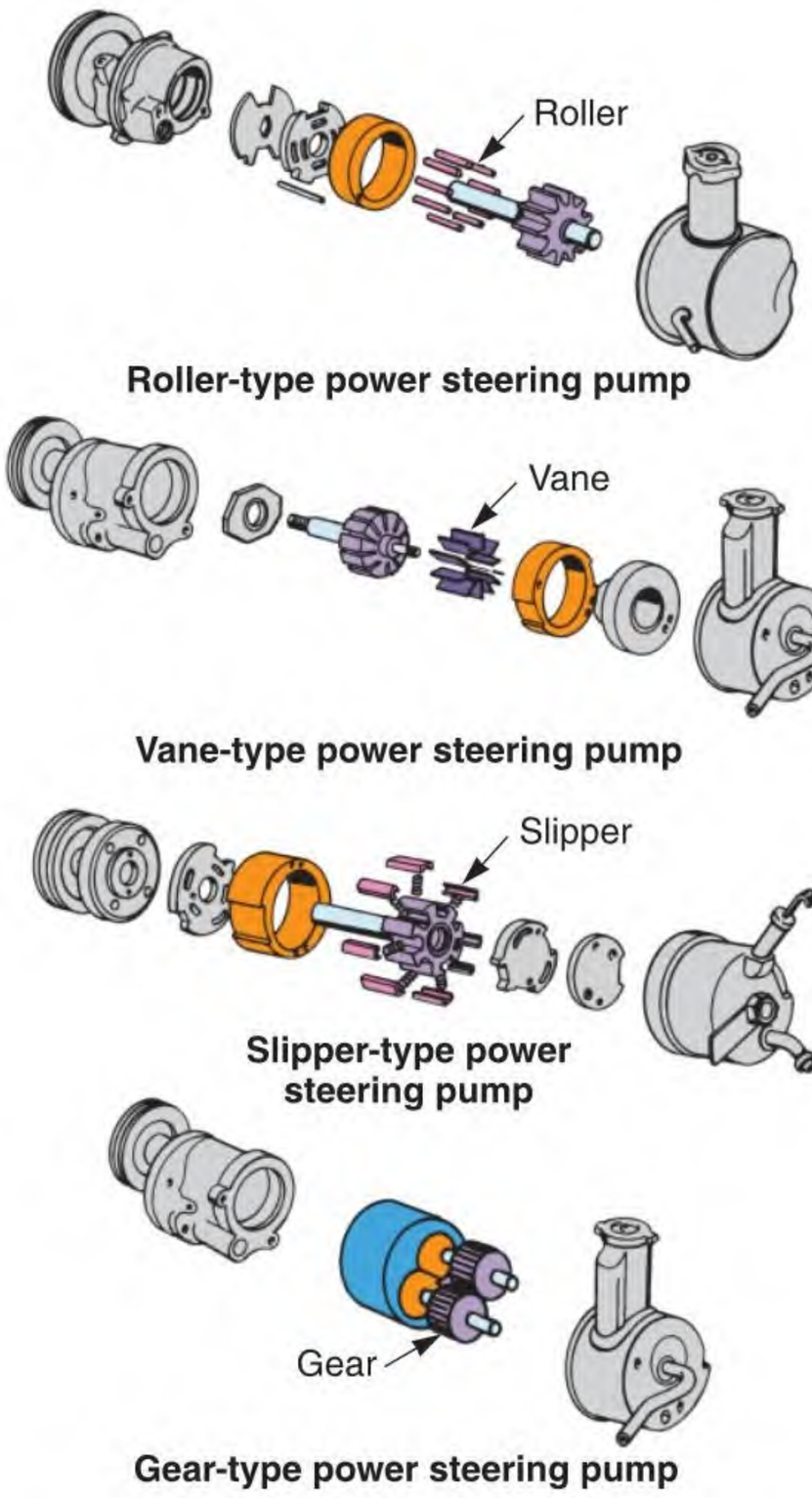
Figure 77-19 shows the four basic types of power steering pumps: roller, vane, slipper, and gear. A cutaway view of a modern power steering pump is shown in **Figure 77-20**.

The ***power steering fluid reservoir*** holds an extra supply of power steering oil or fluid. It can be formed as part of the pump body or it can be a separate container. See **Figure 77-21**.

During pump operation, the drive belt turns the pump shaft and pumping elements. Oil is pulled into one side of the pump by vacuum. The oil is then trapped and squeezed into a smaller area inside the pump. This pressurizes the oil at the output, causing it to flow to the rest of the power steering system, **Figure 77-22**.

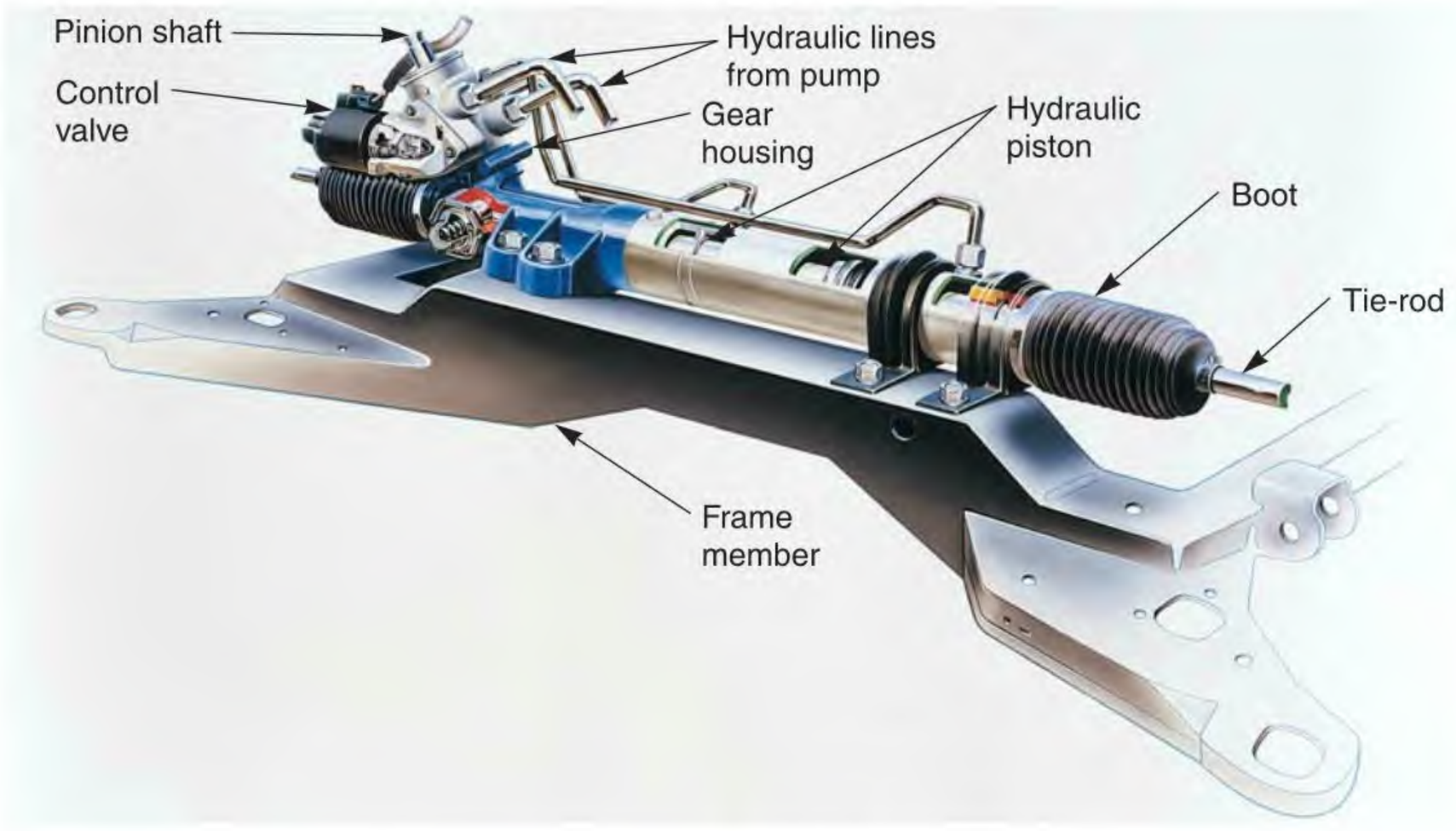
Pressure-Relief Valve

A ***pressure-relief valve*** is used in a power steering system to control maximum oil pressure. It prevents system damage by limiting pressure when needed. Look at **Figure 77-23**.



Moog

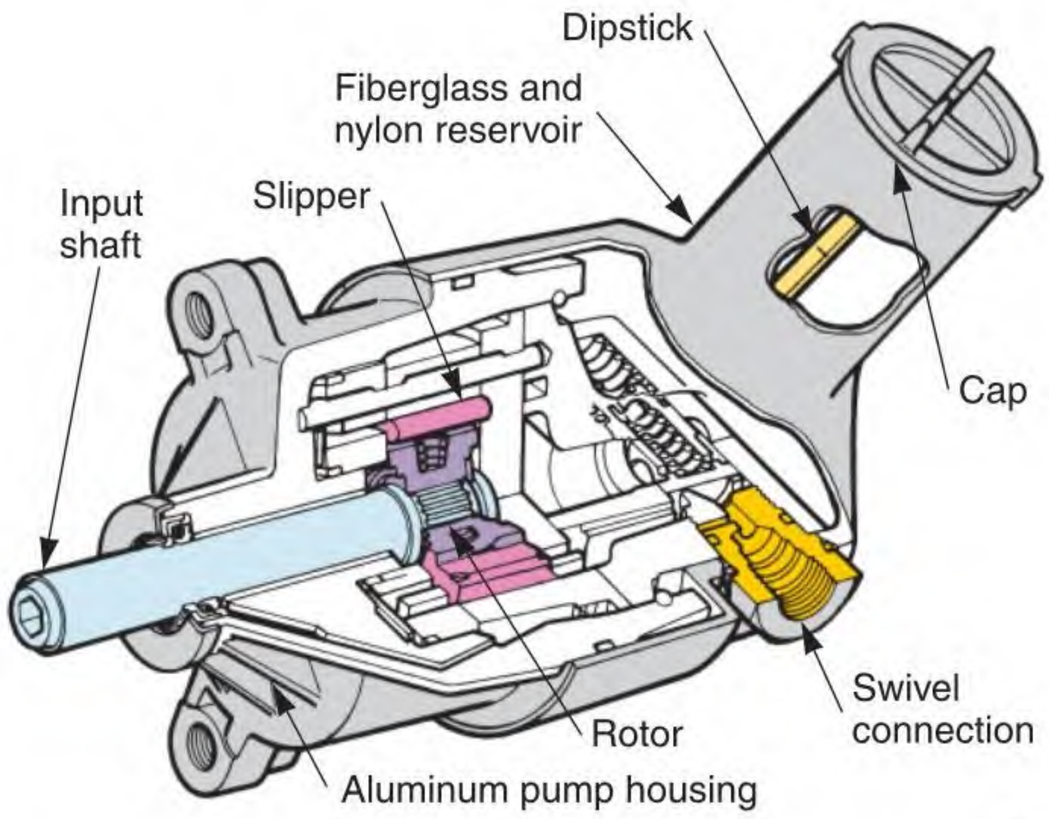
Figure 77-19. Study the four basic types of power steering pumps.



Ford

Figure 77-18. Cutaway of a power rack-and-pinion assembly. Study its parts carefully.

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Ford

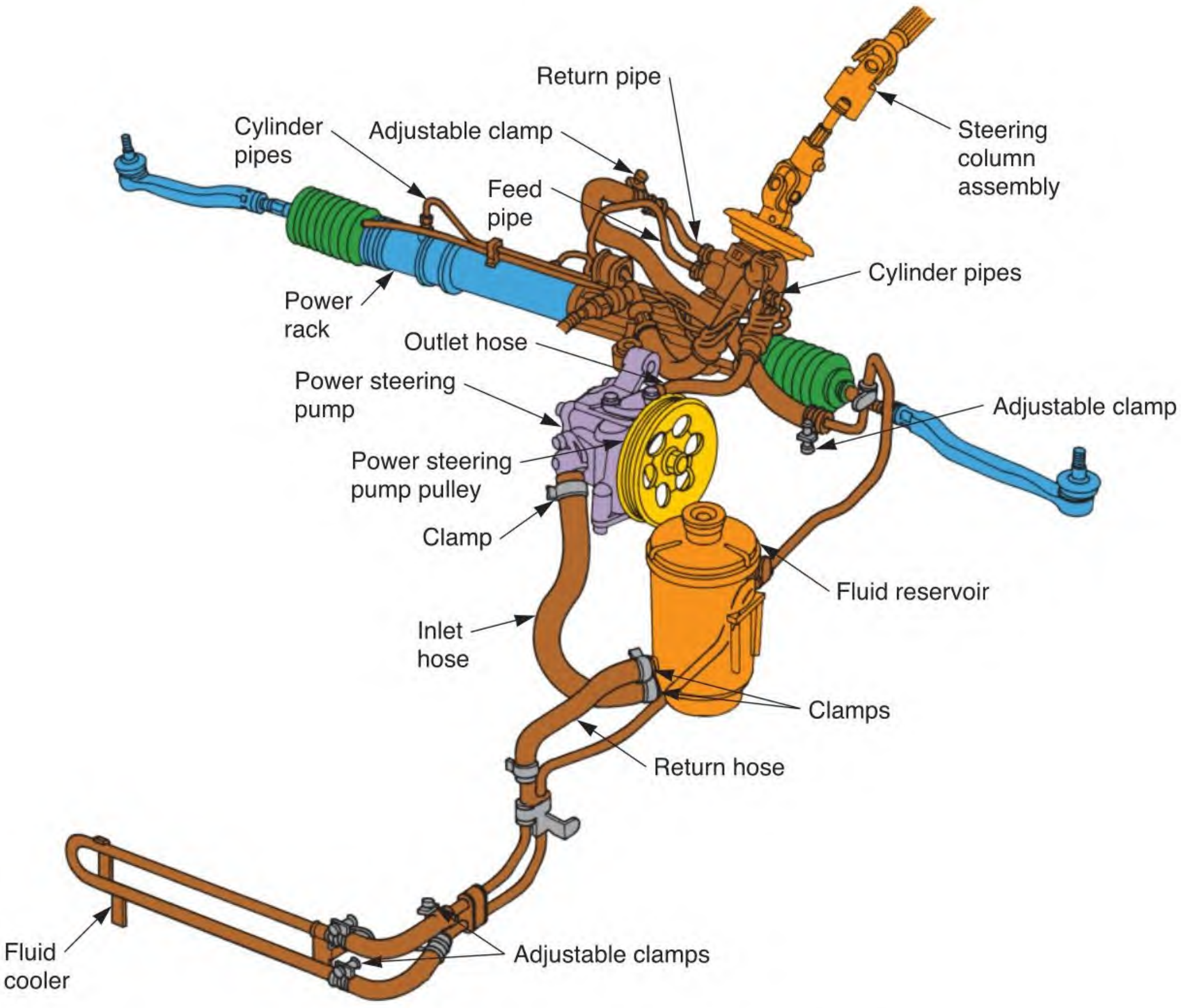
Figure 77-20. Rotation of the input shaft turns the rotor and slippers. Power steering fluid is forced out under pressure.

Power Steering Hoses

Power steering hoses are high-pressure, hydraulic, synthetic rubber hoses that connect the power steering pump and the integral gearbox or the power cylinder. One line serves as the pressure feed line. The other acts as a return line to the reservoir. Metal lines are also used to carry fluid between parts where vibration or part movement is not a problem.

Linkage-Type Power Steering Systems

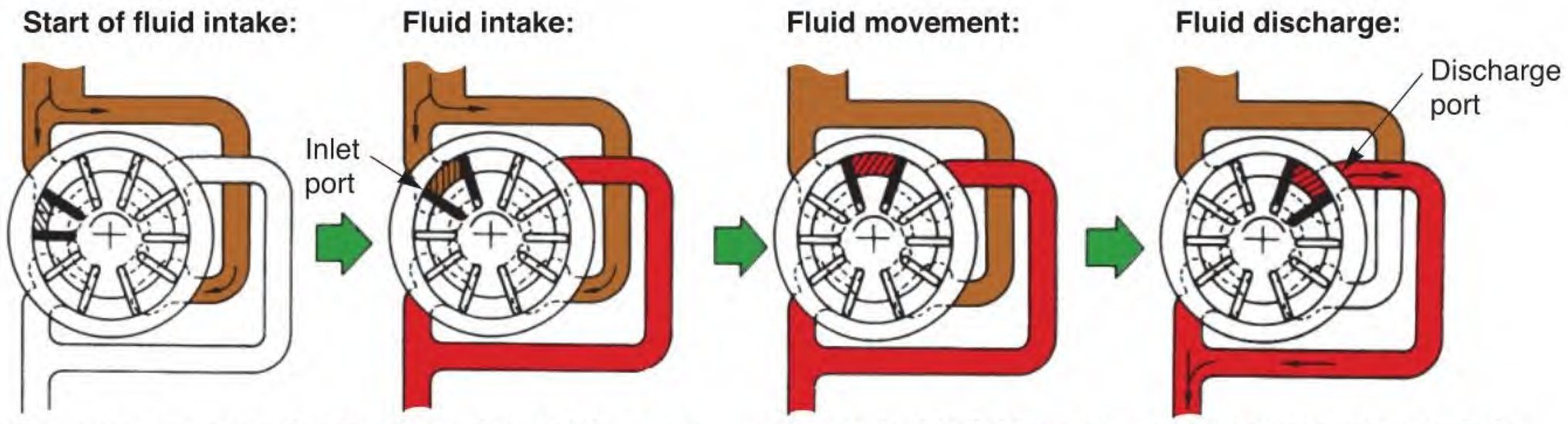
As mentioned, a heavy-duty, linkage-type power steering system is still used on full-size trucks. This makes it important for you to have a basic understanding of these systems.



Honda

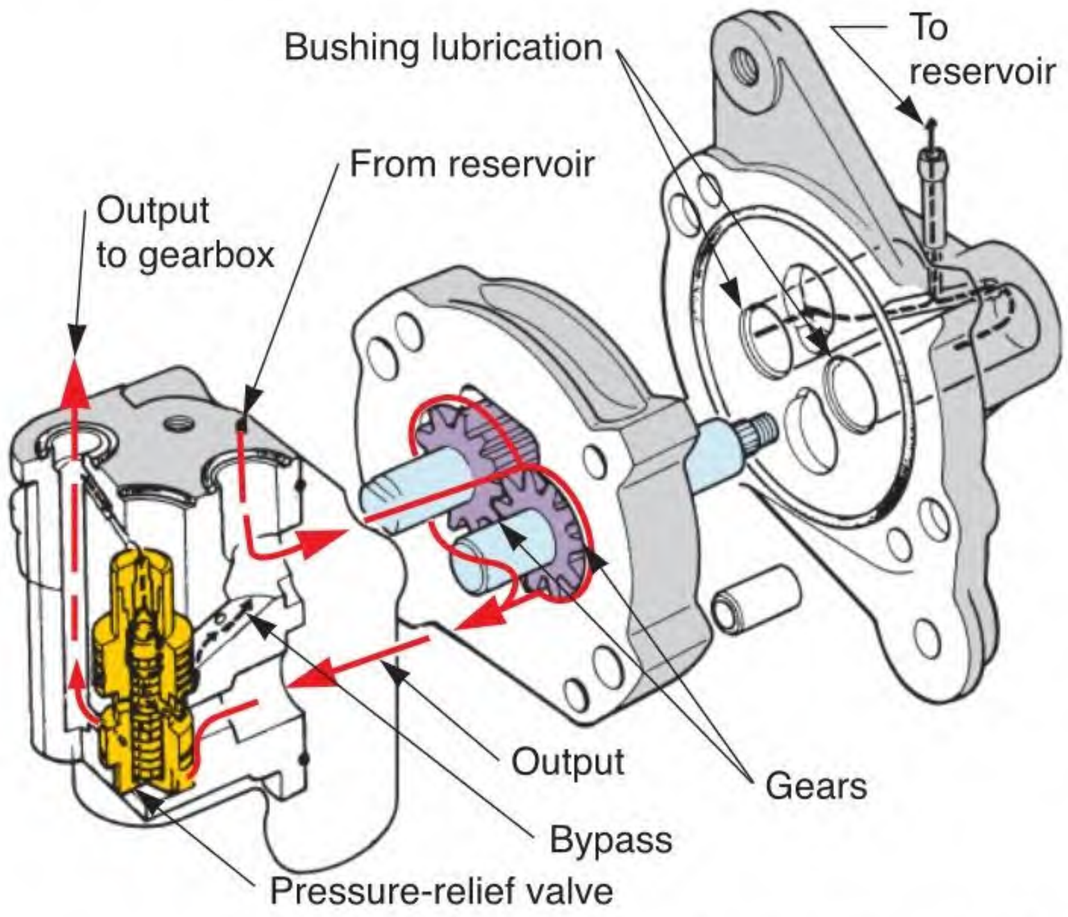
Figure 77-21. The power steering pump generally bolts to the front of the engine. The belt spins the pump. Power steering lines connect the parts of the system. Note the remote reservoir and the oil cooler.

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Honda

Figure 77-22. Note the pumping action inside this vane-type power steering pump.



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Figure 77-23. Note the construction of this gear-type power steering pump. A pressure-relief valve is built into the body of the pump. The relief valve is designed to open when pressure becomes too high, such as when the steering wheel is turned to the full-right or full-left position.

An ***integral-piston power steering system*** has the hydraulic piston mounted inside the steering gearbox housing. Basically, it consists of a power steering pump, hydraulic lines, and an integral power-assist gearbox.

The ***integral power steering gearbox*** contains a conventional worm-and-sector gear, a hydraulic piston, and a flow-direction valve. One type of integral power steering gearbox uses a ***spool valve***. Another popular type is equipped with a rotary valve.

A spool valve–type power steering gearbox uses a small spool valve to control the pressure entering the power assist chambers.

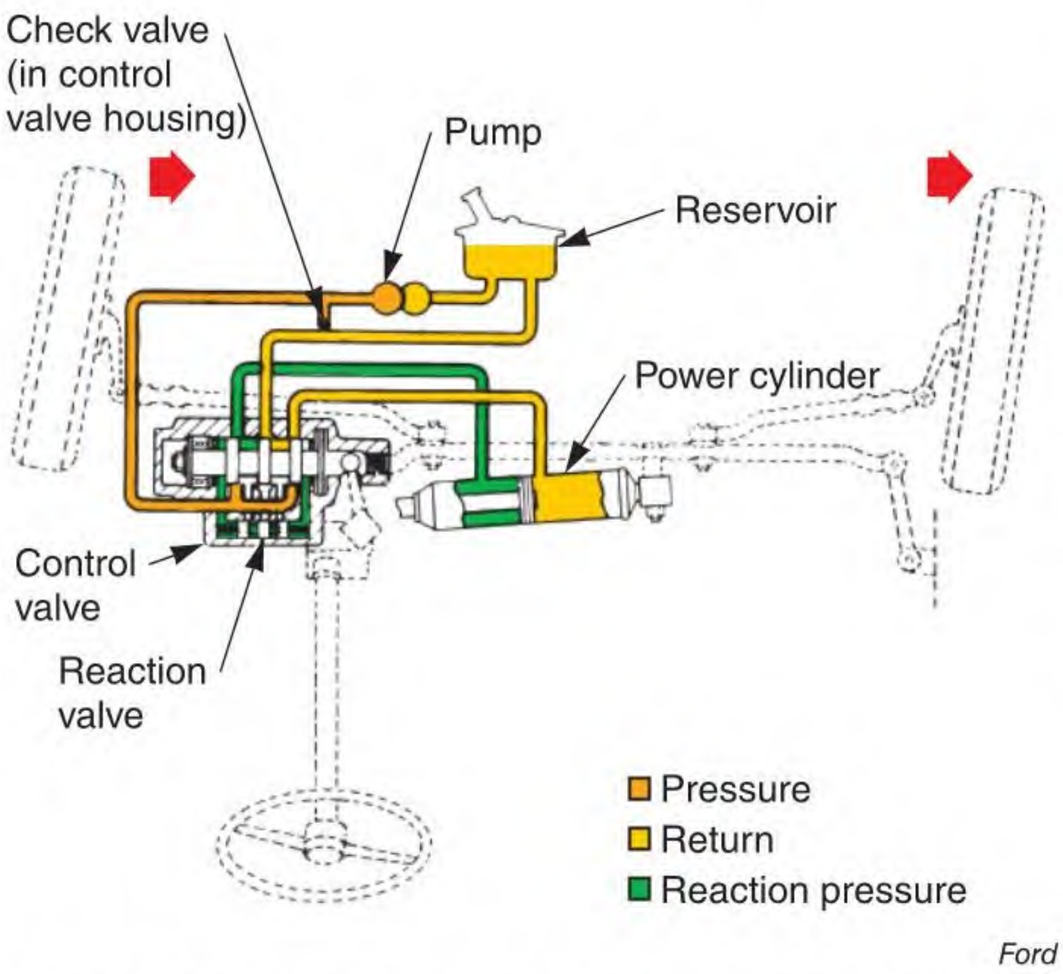
When the steering wheel is turned to the right, the pivot lever moves the spool valve so that pressure enters the right-turn chamber. This forces the power piston to the left and helps turn the sector shaft for a right turn. Pressure enters the opposite chamber when the steering wheel is turned to the left.

A rotary valve–type power steering gearbox has a small torsion bar to detect steering wheel turning direction and turning effort. When the steering wheel is turned, the torsion bar twists and turns the rotary valve. The ***rotary valve*** then directs hydraulic pressure to the correct side of the power piston. Rotary valve action will be covered later, when discussing power rack-and-pinion steering.

In an ***external cylinder power steering system***, the power cylinder is commonly bolted to the frame and center link. The control valve may be located in the gearbox or on the steering linkage. This is shown in **Figure 77-24**.

External power steering cylinders can be found on older passenger cars and large industrial equipment. This design has been phased out for more compact arrangements.

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Ford

Figure 77-24. Power steering system using a power cylinder mounted on the steering linkage. Note the system pressures.

Power Rack-and-Pinion Steering

Power rack-and-pinion steering uses hydraulic pump pressure to assist the driver in moving the rack and the front wheels. **Figure 77-25** shows this type of system.

The power steering pump is normally mounted on the front of the engine. A drive belt powers the pump. Power steering hoses and metal lines connect the pump with the rack-and-pinion gear assembly.

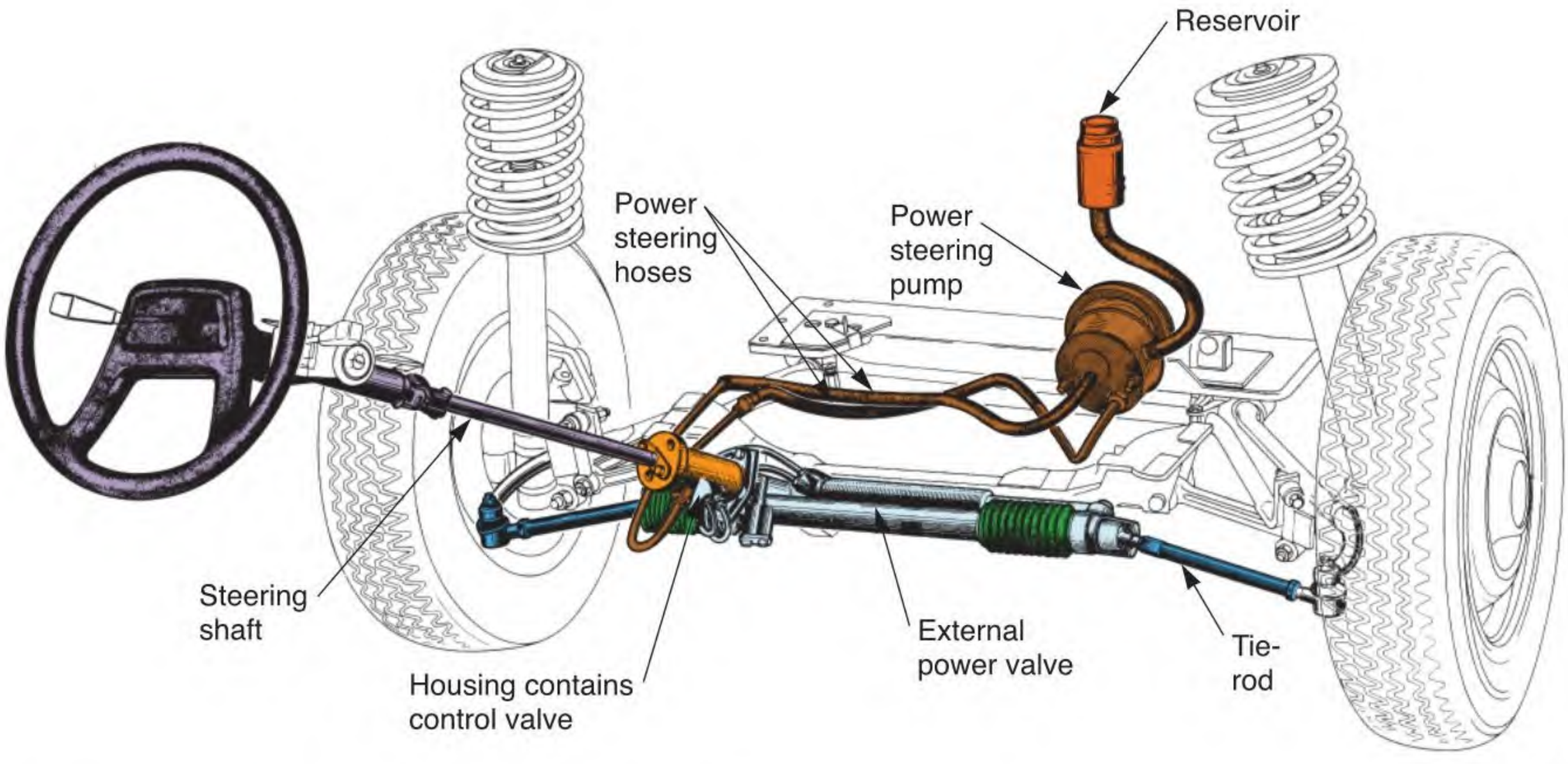
A power rack-and-pinion assembly basically consists of the following:

- ***Power cylinder***—The power cylinder is a hydraulic cylinder machined inside the rack or gear housing.
- ***Power piston***—The power piston is a hydraulic, double-acting piston formed on the rack shaft.
- ***Hydraulic lines***—The hydraulic lines are steel tubing connecting the control valve and the power cylinder.
- ***Control valve***—The control valve is either a rotary valve or a spool valve that regulates pressure entry into each end of the power cylinder.

The other parts of the assembly are similar to those that are found on a manual rack-and-pinion assembly. As shown in **Figure 77-26**, routing oil pressure into either end of the power cylinder causes piston operation and steering assist. The hydraulic assist reduces the amount of arm strength required to turn the steering wheel.

Power Cylinder and Piston

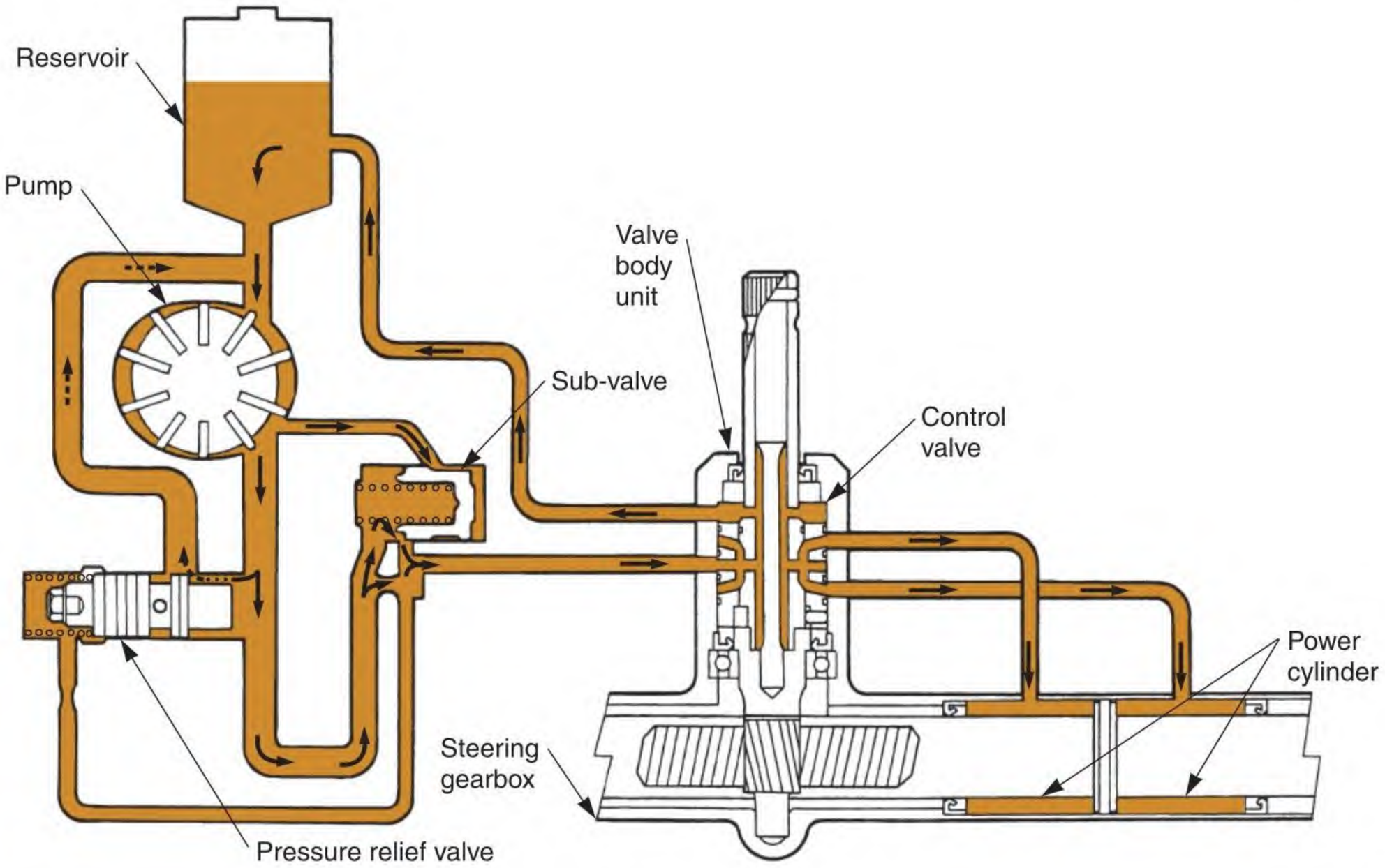
A power cylinder for a rack-and-pinion steering system is a precisely machined tube designed to



Peugeot

Figure 77-25. External view of a power rack-and-pinion setup.

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Honda

Figure 77-26. The power cylinder is formed around the rack. Pressure acts on the rack piston to help slide the rack in its housing. Although the valve shown here is in the neutral position, the control valve can direct pressure to either side of the power piston.

accept the power piston. Provisions are made for the hydraulic lines. The cylinder housing bolts to the vehicle frame member, just like a manual unit.

The power piston is formed by attaching a hydraulic piston to the center of the rack. A rubber seal fits around a groove in the piston to prevent oil pressure leakage. Seals are also used on each end of the piston to keep fluid from leaking into the boots. This is shown in **Figure 77-27**.

Power Rack-and-Pinion Control Valves

There are two types of control valve mechanisms used on power rack-and-pinion gears: rotary control valves and spool control valves. The rotary is more common.

The ***rotary control valve*** is operated by a torsion shaft connected to the pinion gear. Study **Figure 77-27** closely. It illustrates the operation of a power rack-and-pinion gear using a rotary control valve.

The thrust action of the pinion shaft shifts the ***spool control valve***. The control valve can then route oil to the power cylinder. Refer to **Figure 77-28**.

Power Rack-and-Pinion Operation

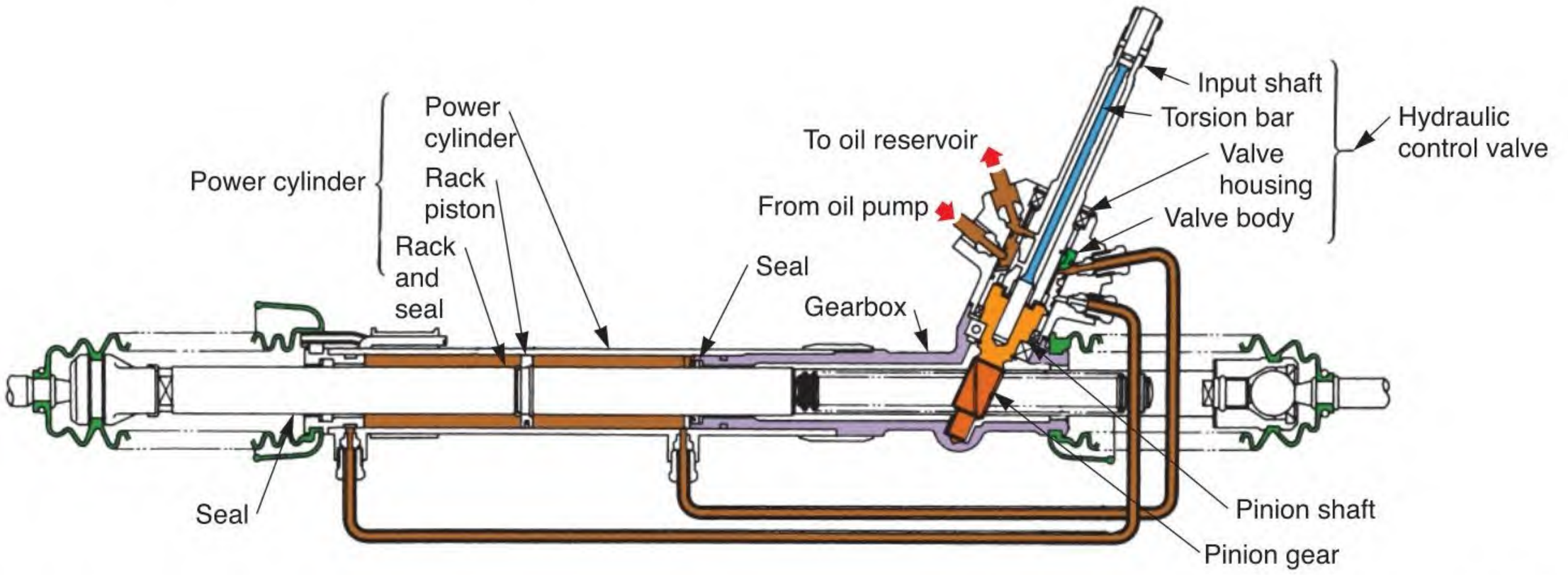
When the steering wheel is turned, the weight of the vehicle causes the front tires to resist turning. This twists a torsion bar (rotary valve mechanism) or thrusts the pinion shaft (spool valve mechanism) slightly. This makes the control valve move and align specific oil passages.

Pump pressure flows through the control valve, through the hydraulic line, and into the power cylinder. Pressure then acts on the power piston. The piston helps push the rack and the front wheels for turning. Refer to **Figure 77-29**.

Since the steering gear is filled with oil, the internal parts of the system are always lubricated. They slide or turn easily, with little friction and wear.

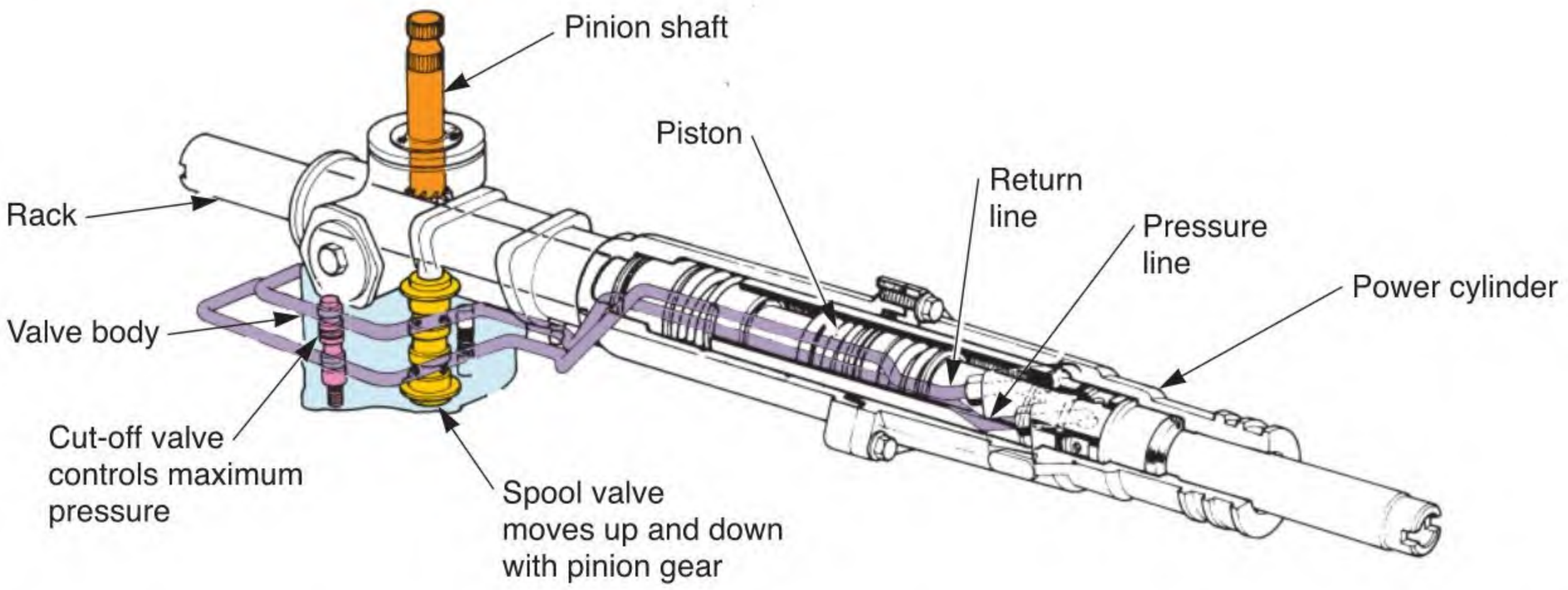
A ***power steering oil cooler*** is used to remove excess heat from the oil. It is usually a small metal line or radiator located in one of the power steering lines. Refer back to **Figure 77-21**.

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Subaru

Figure 77-27. Study the parts of this modern power steering system.



Honda

Figure 77-28. This power rack-and-pinion steering assembly uses a spool valve that detects thrust action of the helical pinion gear. It can then control oil pressure to the rack piston.

Electronic Steering Assist

Electronic steering assist uses a small electric motor to help move the rack-and-pinion gearbox. The motor is mounted inside the rack housing or on the steering column. The motor acts directly on the steering rack or steering column shaft. See **Figure 77-30**.

A steering control module electronically reacts to steering pressure to energize the rack motor to help move the rack left or right for steering. The steering control module can reverse motor rotation and alter motor speed as needed to help the driver steer the car.

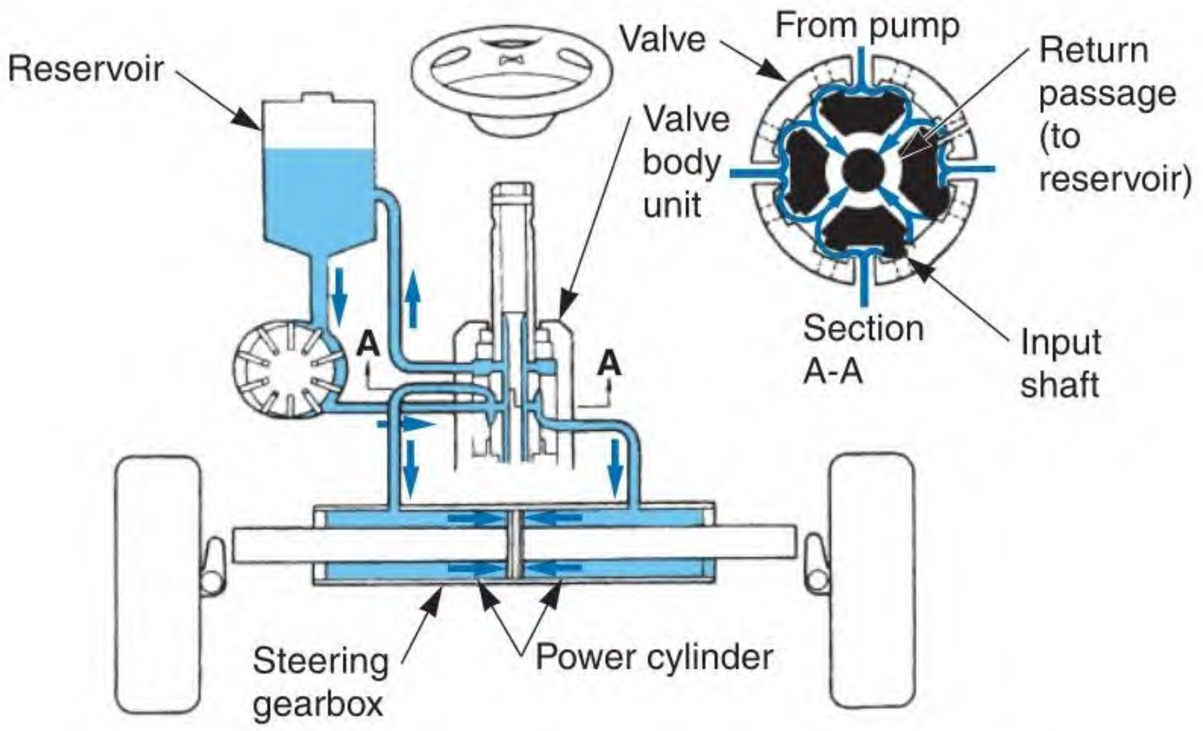
An electronic steering mechanism eliminates the need for hydraulic steering assist and the bulky power steering pump, hoses, and hydraulic cylinder.

Tech Tip

Idle speed can be affected by the signal from the power steering pressure sensor. Some systems signal the hydraulic control module when the wheels are turned to full lock and higher-than-normal power steering system pressures are present. The control module can then operate the idle speed motor to prevent engine stalling.

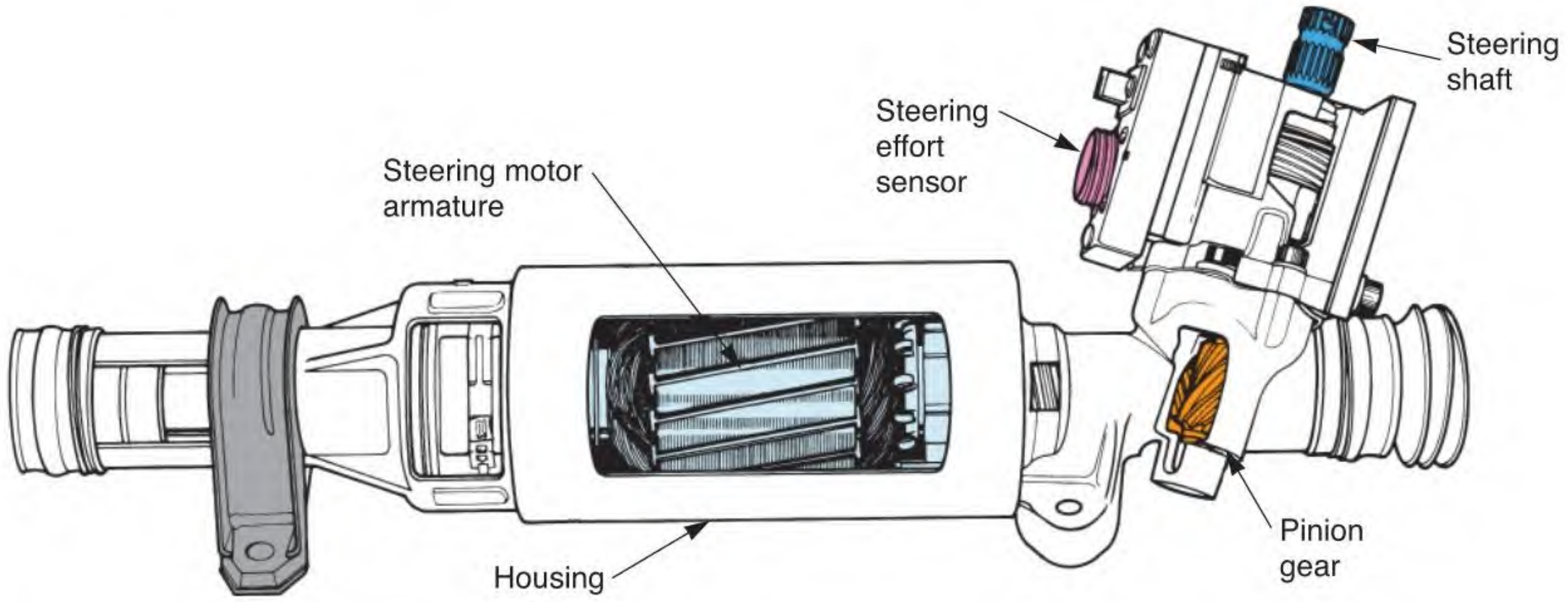
A different design of electronic steering assist has a small electric drive motor, gearbox, clutch, and control circuit mounted inside the steering wheel. The assembly is mounted inside the center section of the steering

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Honda

Figure 77-29. Study the operation of this speed-sensitive steering system. A—When driving at high road speeds, low power assist is desirable. Less force is needed to steer the wheels. B—When stopped or driving at low road speeds, more power assist is needed. Wheels resist turning more because of the high friction between the stationary tires and the road surface.



Moog

Figure 77-30. An electronic assist rack-and-pinion steering gear has a small electric motor inside the housing and a steering effort sensor on the steering shaft. The electric motor is used to supplement manual effort of the driver to turn the steering wheel and provide power assist. This system is much lighter and more compact than a conventional hydraulic power steering system.

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wheel, underneath the driver's-side air bag. The power steering motor applies power assist directly to the top of the steering shaft. When the driver turns the wheel to the left or right, sensors detect torque in that direction and energize the small motor to help rotate the steering shaft in the same direction. This mounting location keeps the power assist motor away from road debris, moisture, dirt, snow, and ice. Refer to **Figure 77-31**.

Proportional Rack-and-Pinion Power Steering

Proportional rack-and-pinion power steering senses vehicle speed and steering load to ensure adequate road feel (small road imperfections felt in steering wheel for more feedback). This type of system can also be called ***speed-sensitive power steering***.

Proportional steering systems alter steering wheel effort as road speed changes. They increase effort at higher speeds for more road feel. They also lower steering effort at low speeds to help the driver turn the steering wheel when parking.

In some systems, a computer-controlled electromagnet is mounted around the steering gear stub shaft. The stub shaft acts on a small torsion bar. The stub shaft and torsion bar operate the power steering valve, which controls fluid flow to the rack for power assist.

If the vehicle is not moving or is moving slowly, an electronic control module (computer) sends current through the electromagnet in one direction to help attract and pull on the stub shaft and torsion bar, increasing valve output pressure to make the vehicle easier to steer. Then, when the vehicle reaches road speed, the module reverses electrical flow through the electromagnet. This increases steering effort to improve road feel.

Other systems use a stepper motor or a solenoid to act upon the steering mechanism. The computer-operated stepper motor or solenoid helps shift the fluid valve to affect steering effort. The stepper motor is not as smooth or as variable as the electromagnetic-assist system.

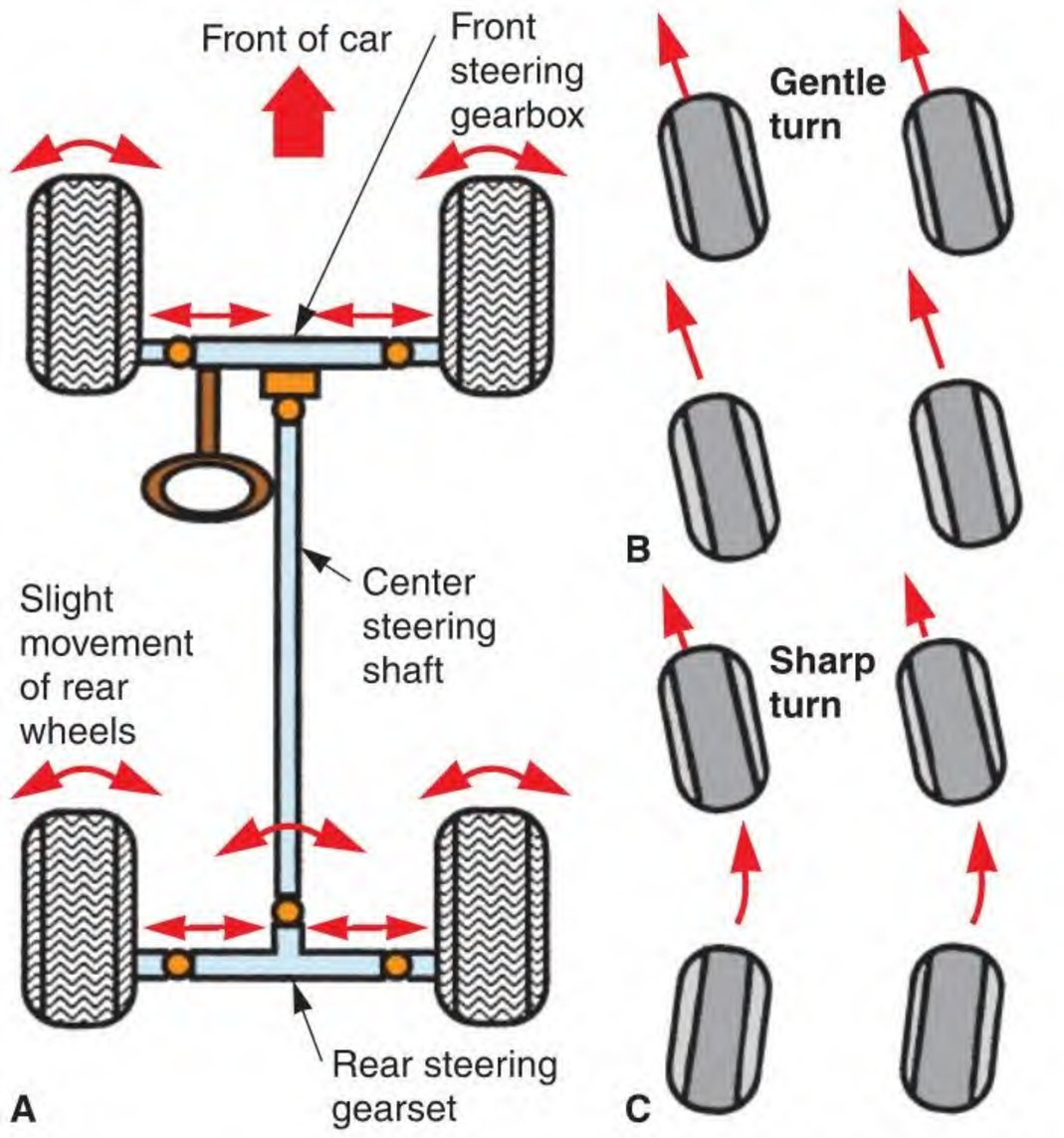


Ford Motor Co.

Figure 77-31. The basic parts of a modern electronic steering assist system. The small reversible motor and control board mount around the steering shaft to apply motor torque to the shaft. If any part of the system fails, the motor is disengaged from the steering shaft so that the vehicle can still be steered but with slightly more turning effort by the driver.

Four-Wheel Steering Systems

Several automakers now provide four-wheel steering systems on their high-performance vehicles. Instead of just the front two wheels, all four wheels change direction to improve handling, stability, feel, and maneuverability. See **Figure 77-32**.



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Figure 77-32. A—Note the basic parts of this four-wheel steering system. B—When the steering wheel is turned gently, the wheels pivot in the same direction. C—When the steering wheel is turned more sharply, the wheels pivot back and then turn in opposite directions.

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There are three types of four-wheel steering systems: mechanical, hydraulic, and electronic.

The ***mechanical four-wheel steering system*** uses a special front rack-and-pinion gearbox with a transfer box. The transfer box operates a long shaft that extends back to the rear rack. When the front wheels are turned, the shaft rotates to turn the rear wheels. This was the first four-wheel steering system on the market.

A ***hydraulic four-wheel steering system*** uses a conventional power rack-and-pinion steering system up front. A vane pump forces fluid to the rack to provide power assist. Hydraulic lines extend back to a rear power steering pump, which is driven by the differential. Depending on vehicle speed, the rear pump forces fluid under pressure into a control valve.

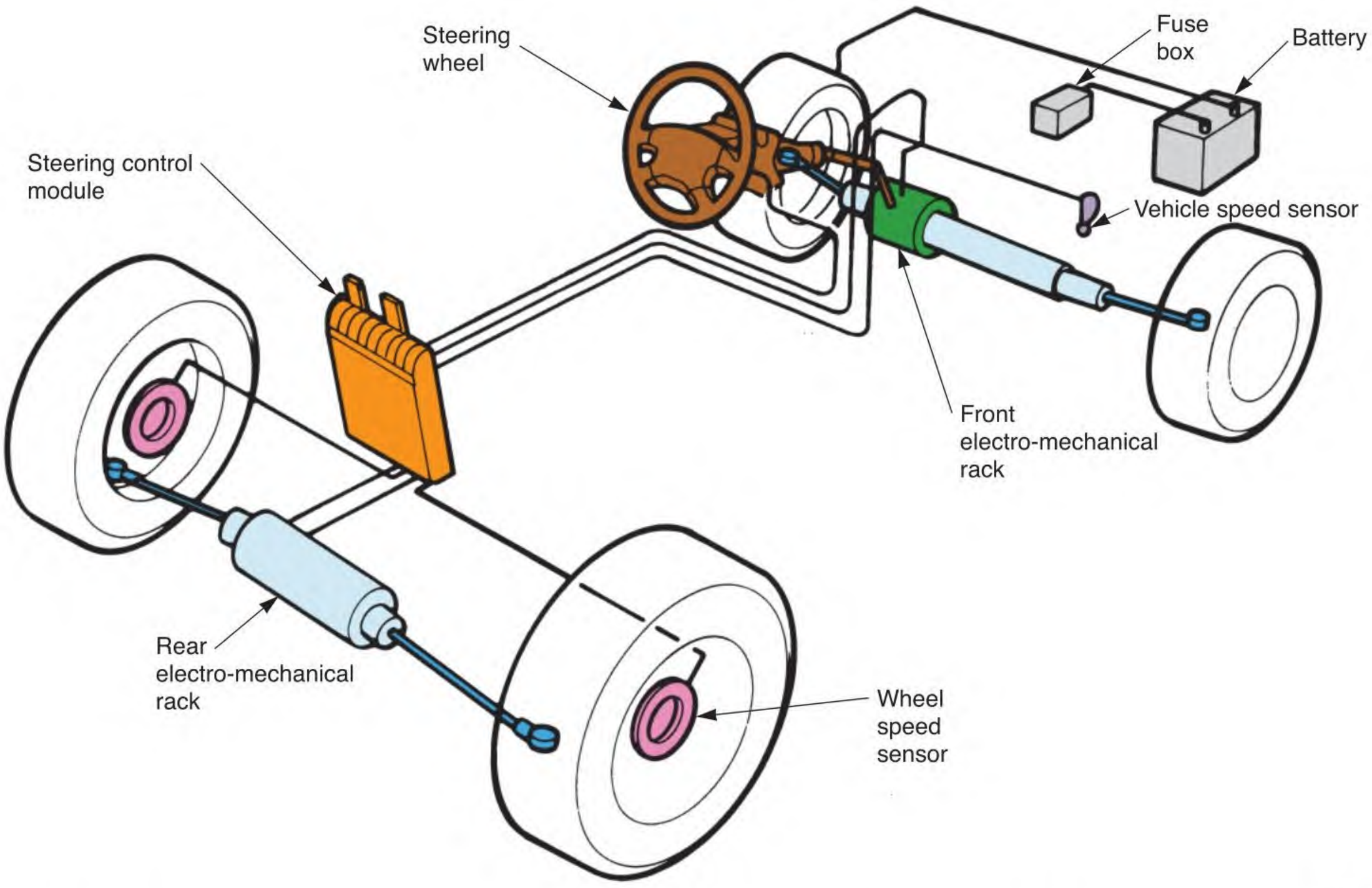
When a specific road speed is reached, the control valve can then operate the rear steering system. With this design, the rear rack tie-rod ends are attached to the suspension system's trailing arm. When activated, the rack shifts the trailing arm to steer the rear wheels.

Modern ***electronic four-wheel steering systems*** have an electric-motor-driven power rack that acts upon the rear wheels via its own recirculating-ball drive and mechanical links. See **Figure 77-33**.

An electronic control module controls rear-wheel steering angles. The module analyzes signals from angle sensors in the front steering, from wheel speed sensors in the anti-lock brake system, and from a yaw sensor.

The motor-driven power rack is then energized by the module to move the rear wheels as needed. The module energizes a dc motor inside the power rack. The motor powers a recirculating-ball drive to slide the rack right or left to respond to control module signals. Refer to **Figure 77-34**.

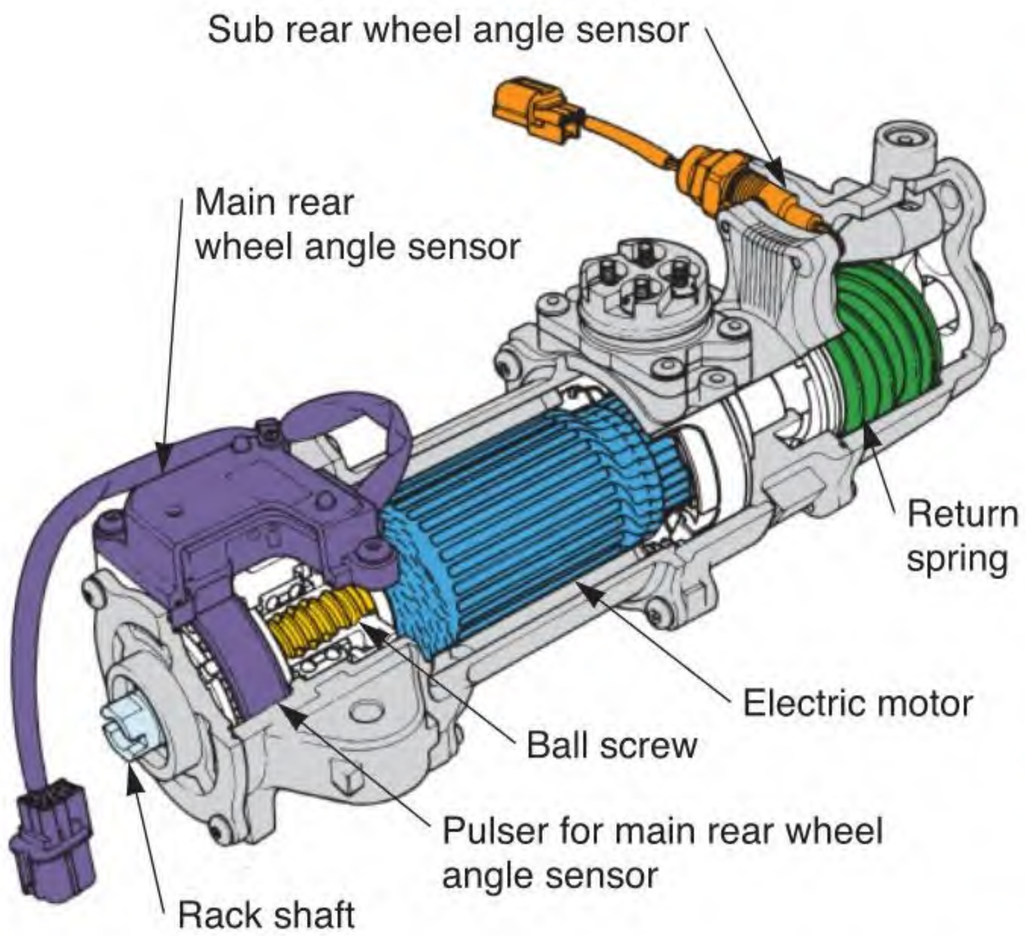
With a slight turn of the steering wheel, the four-wheel steering system turns the rear wheels in the same direction as the front wheels. However, during a sharp turn, the special gear box straightens out the rear wheels and then turns them in the opposite direction of the front wheels.



Honda

Figure 77-33. This is an electronically-controlled four-wheel steering system. A dedicated computer, or steering control module, is used to monitor and control this system.

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Honda

Figure 77-34. This is the rear actuator, or electric power steering assist unit, for a four-wheel steering system. Note how it has rear wheel angle sensor built into the assembly. The electric motor operates a ball screw, which transfers turning force to the rack shaft.

Electronic systems also react to changes in vehicle speed. Generally, when at high speeds, the wheels steer in the same direction to improve maneuverability. At low vehicle speeds, the wheels steer in opposite directions to reduce turning radius.

Industry Trend

Automobile manufacturers are working to develop steer-by-wire systems. These systems eliminate the mechanical connection between the steering wheel and the vehicle's wheels. In a typical steer-by-wire system, the steering wheel sends electrical signals to a control module. Based on these signals, the control module operates actuators (electric motors) located at the wheels. The actuators move the wheels to steer the vehicle. Steer-by-wire systems will increase reliability, reduce system weight, and improve fuel economy.

Summary

- The steering system is vital to the safety of an automobile. It allows the driver to safely maneuver the vehicle.
- There are two basic kinds of steering systems in use today: linkage (worm gear) steering systems and rack-and-pinion steering systems.
- The steering column assembly consists of the steering wheel, steering shaft, steering column (outer housing), and, sometimes, ignition key mechanism, a flexible coupling, and a universal joint.
- To help prevent theft, late-model vehicles also have a locking steering wheel.
- Most vehicles use a collapsible steering column to help prevent driver chest and face injury during an auto accident.
- A tilt steering column has a flex joint, or U-joint, that allows the top half of the column and the steering wheel to be positioned at different angles or heights.
- The recirculating-ball gearbox is normally used with a linkage steering system on large trucks.
- Gearbox ratio, or steering gear reduction, is basically a comparison between steering wheel rotation and sector shaft rotation.
- The steering linkage is a series of arms, rods, and ball sockets that connects the steering gearbox to the steering knuckles.
- Ball sockets provide for motion in all directions between two connected parts.
- A manual rack-and-pinion steering gear basically consists of a pinion shaft, a rack, thrust spring, bearings, seals, dust boots, tie-rods, and a gear housing.
- Tie-rod assemblies for rack-and-pinion steering connect the ends of the rack with the steering knuckles.
- Power steering systems normally use an engine-driven pump and a hydraulic system to assist steering action. They can also use an electric motor in the rack or inside the steering wheel to provide power assist.
- A power cylinder for rack-and-pinion steering is a precisely machined tube that accepts the power piston.

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- Proportional rack-and-pinion power steering senses vehicle speed and steering load to ensure adequate road feel at the steering wheel.
- In a four-wheel steering system, all four wheels change direction to improve handling, stability, feel, and maneuverability.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

adjusting nut
adjusting screw
ball guides
ball nut
ball sockets
center link
collapsible steering column
constant-ratio gearbox
control valve
electronic four-wheel steering systems
electronic steering assist
end cover
external cylinder power steering system
flexible coupling
gear housing
gearbox housing
gearbox ratio
hydraulic four-wheel steering system
hydraulic lines
idler arm
ignition lock mechanism
ignition switch
integral power steering gearbox
integral-piston power steering system
linkage steering systems
locking steering wheel
manual tilt column
mechanical four-wheel steering system
memory tilt wheels
parallelogram steering linkage
pitman arm
power cylinder
power piston
power rack-and-pinion steering
power steering fluid reservoir
power steering hoses
power steering oil cooler
power steering pump
power steering systems
power tilt column
pressure-relief valve
proportional rack-and-pinion power steering
rack
rack-and-pinion steering gear
rack-and-pinion steering systems
recirculating-ball gearbox
relay rod
road feel
rotary control valve
rotary valve
rubber dust boots
sector shaft
speed-sensitive power steering
spool control valve
spool valve
steering column
steering column assembly
steering damper
steering gear reduction
steering gearbox
steering linkage
steering pinion gear
steering ratio
steering shaft
steering wheel
thrust spring
tie-rod assemblies
tie-rods
tilt steering column
tilt steering wheel
toe adjustment sleeve
universal joint
variable-ratio gearbox
worm shaft
worm-and-roller steering gearbox

Activities

1. Examine a vehicle in the shop and determine what type of power steering system it has.
2. Identify the major parts of a vehicle's power steering system.
3. Use an Internet-connected computer or tablet to look up various types of modern steering systems and research automated vehicle steering advancements.

Review Questions

Answer the following questions using the information provided in this chapter.

1. Name five functions of the steering system.
2. List and explain the six major parts of a linkage-type steering system.
3. Define the term *road feel*.
4. In addition to the steering column, shaft, and wheel, list and explain the four major parts of a manual rack-and-pinion steering system.
5. Today's vehicles commonly use a(n) _____ steering column to help prevent driver injury during an accident.

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6. Which of the following is *not* a part in a recirculating-ball steering gearbox?
   (A) Universal joint.
   (B) Worm shaft.
   (C) Sector shaft.
   (D) Ball nut.
7. Define the term *gearbox ratio*.
8. The idler arm supports the pitman arm on the passenger side of the vehicle. True or False?
9. What is the purpose of tie-rods on a rack-and-pinion steering system?
10. _____-and-_____ is the most popular type steering system used on modern vehicles.
11. Power steering systems normally use an engine-driven _____ and a(n) _____ system to assist steering action.
12. A pressure-relief valve is used in a power steering system to control maximum oil pressure. True or False?
13. Describe an integral-piston power steering system.
14. List and explain the four major parts found on a power rack-and-pinion steering system but not on a manual rack-and-pinion system.
15. How does electronic steering assist work?

ASE-Type Questions

1. Technician A says one of the functions of an automotive steering system is to transmit "road feel" to the driver's hands. Technician B says one of the functions of a steering system is to prevent excessive "body squat." Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Technician A says a steering shaft transfers turning motion from the steering wheel to the steering column. Technician B says a steering shaft transfers turning motion from the steering wheel to the steering gearbox. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. Technician A says an automotive steering linkage connects the steering gearbox to the steering wheel. Technician B says a steering linkage connects the steering gearbox to the steering knuckles and wheels. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. All of the following are basic components of a linkage steering system *except:*
   (A) steering gearbox.
   (B) steering rack.
   (C) steering shaft.
   (D) ball sockets.
5. Technician A says power steering gearbox ratios will be higher than manual steering gearbox ratios. Technician B says tie-rod assemblies are used in rack-and-pinion steering systems. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Technician A says tie-rod assemblies for rack-and-pinion steering connect the ends of the pitman arms with the steering knuckles. Technician B says tie-rod assemblies for rack-and-pinion steering connect the ends of the rack with the steering knuckles. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. Technician A says a Woodruff key is used to lock the steering wheel to the steering shaft. Technician B says splines are used to lock the steering wheel to the steering shaft. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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8. Technician A says an automotive ignition switch is usually bolted to the steering column. Technician B says special clamps are normally used to secure an automotive ignition switch to the steering column. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Technician A says a steel mesh collapsible steering column is a one-piece unit. Technician B says a steel mesh collapsible steering column is a two-piece unit. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. Technician A says a pitman arm is a component of a parallelogram linkage. Technician B says an idler arm is a component of a parallelogram linkage. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
11. Technician A says "worm gear" steering systems are used on most modern automobiles. Technician B says rack-and-pinion steering systems are used on most late-model automobiles. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
12. Technician A says screws are used to secure a rack-and-pinion steering system's rubber dust boots. Technician B says clamps are used to secure a rack-and-pinion steering system's rubber dust boots. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
13. Technician A says that power steering hoses connect the power steering pump to the tie-rod assemblies in a rack-and-pinion system. Technician B says a belt running from the engine's crankshaft normally powers an automobile's power steering pump. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
14. Technician A says a speed-sensitive steering system uses a control module (computer) in its design. Technician B says that when making a sharp turn with an electronic four-wheel steering system, the rear wheels will turn in the opposite direction of the front wheels. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
15. A new electric rack-and-pinion steering system is needed to repair a badly worn and leaking system. The new rack assembly costs $345 with 7% tax to be included. The labor time is 3.5 hours at $75 per hour. What is the total cost of the repair?
   (A) $510.55
   (B) $369.15
   (C) $607.50
   (D) $631.65

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Winai Tepsuttinun/Shutterstock.com

When diagnosing a power steering system, ensure the power steering fluid is at the proper level.

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Chapter 78
Steering System Diagnosis and Repair

After studying this chapter, you will be able to:

- Describe common steering system problems.
- Properly inspect and determine the condition of a steering system.
- Service power steering belts, hoses, and fluid.
- Explain basic steering column repair operations.
- Adjust rack-and-pinion gears.
- Describe service and repair procedures for a rack-and-pinion steering gear.
- Explain how to complete basic power steering tests.
- Describe power steering gear and pump service practices.
- Diagnose electronic assist power steering systems.
- Correctly answer ASE certification test questions about the diagnosis and repair of today's steering systems.

After prolonged use, the steering system gearbox, ball sockets, belts, hoses, and other system parts can wear. This can cause play in the steering system. The vehicle can wander from side to side when the driver is holding the steering wheel straight. This can render the vehicle unsafe to drive. It is important that the steering system be kept in perfect working condition to prevent an accident.

As a technician, it is your job to find and correct steering system troubles. This chapter will help you develop the most important skills for troubleshooting and repairing all types of automotive steering systems.

Steering System Problem Diagnosis

The most common steering system problems are play in the steering wheel, hard steering, and abnormal noises when turning the steering wheel. These problems normally point to part wear, lack of lubrication, or an incorrect adjustment. You must inspect and test the steering system to find the source of the trouble. Refer to **Figure 78-1**.

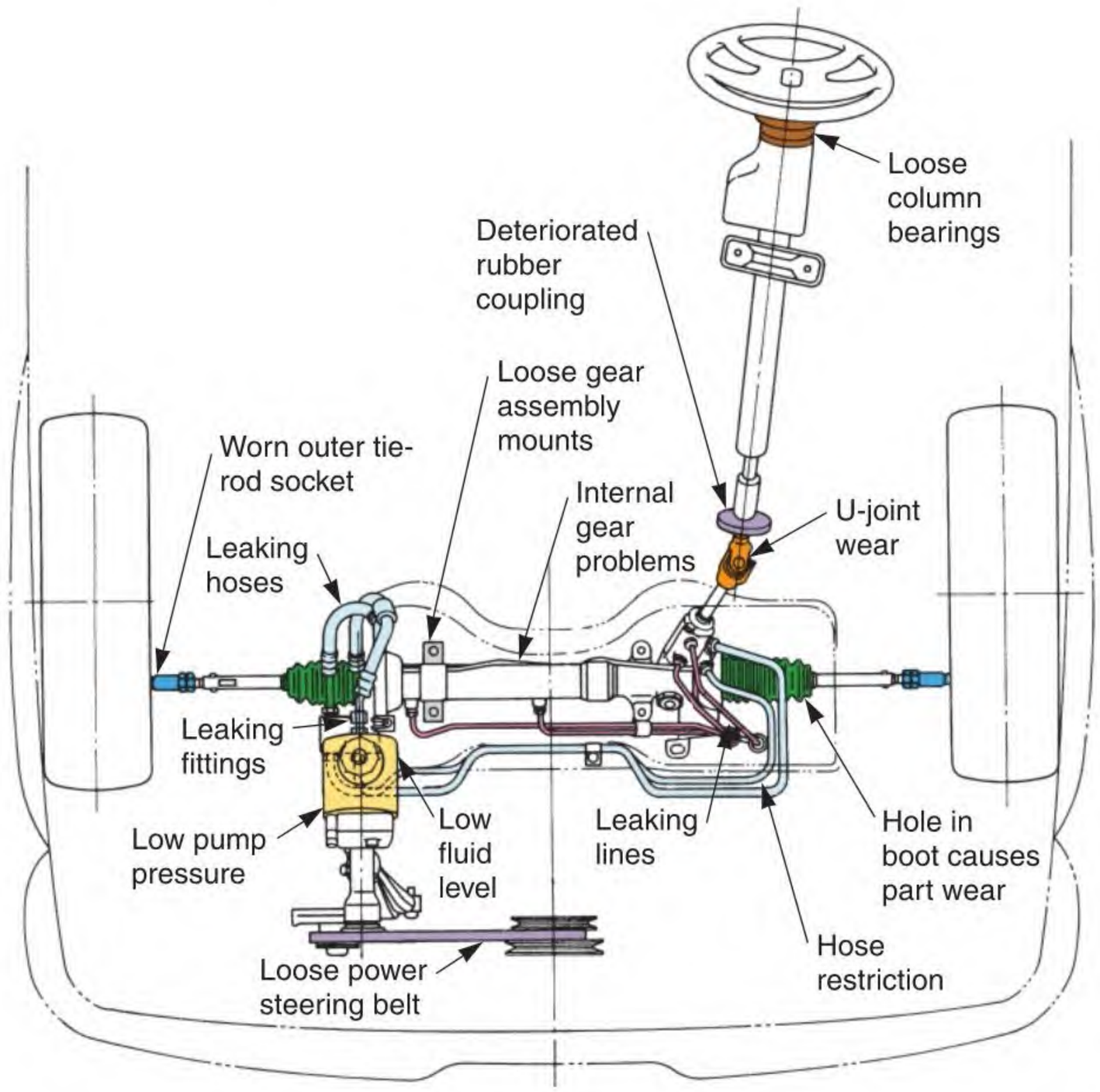
Steering Wheel Play

The most frequent of all steering system problems is excessive play in the steering wheel. ***Steering wheel play*** is normally caused by worn ball sockets, a worn idler arm, or too much clearance in the steering gearbox (worm or rack-and-pinion types).

Typically, you should *not* be able to turn the steering wheel more than about 1 1/2″ (38 mm) without causing movement of the front wheels. If the steering wheel rotates excessively without moving the wheels, a serious steering problem exists.

The ***dry park test*** is an effective way to check play in the steering linkage or the rack-and-pinion

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Figure 78-1. Study the types of problems that can develop in a modern steering system.

mechanism. With the full weight of the vehicle on the wheels, ask someone to rock the steering wheel back and forth while you look for looseness in the steering system.

You can also place the vehicle on a lift to inspect the steering parts for wear. Have someone wiggle one of the tires right and left as you look for play between parts. See **Figure 78-2**.

Start your inspection at the steering column shaft and work your way out to the tie-rod ends. Make sure that movement of one steering part causes an equal amount of movement of the adjoining steering part.

In particular, watch for ball studs that wiggle in their sockets. With rack-and-pinion steering, you must squeeze the rubber boots and feel the inner tie-rods to detect wear and play. If the tie-rod moves sideways (parallel with rack), the socket is worn and should be replaced.

Hard Steering

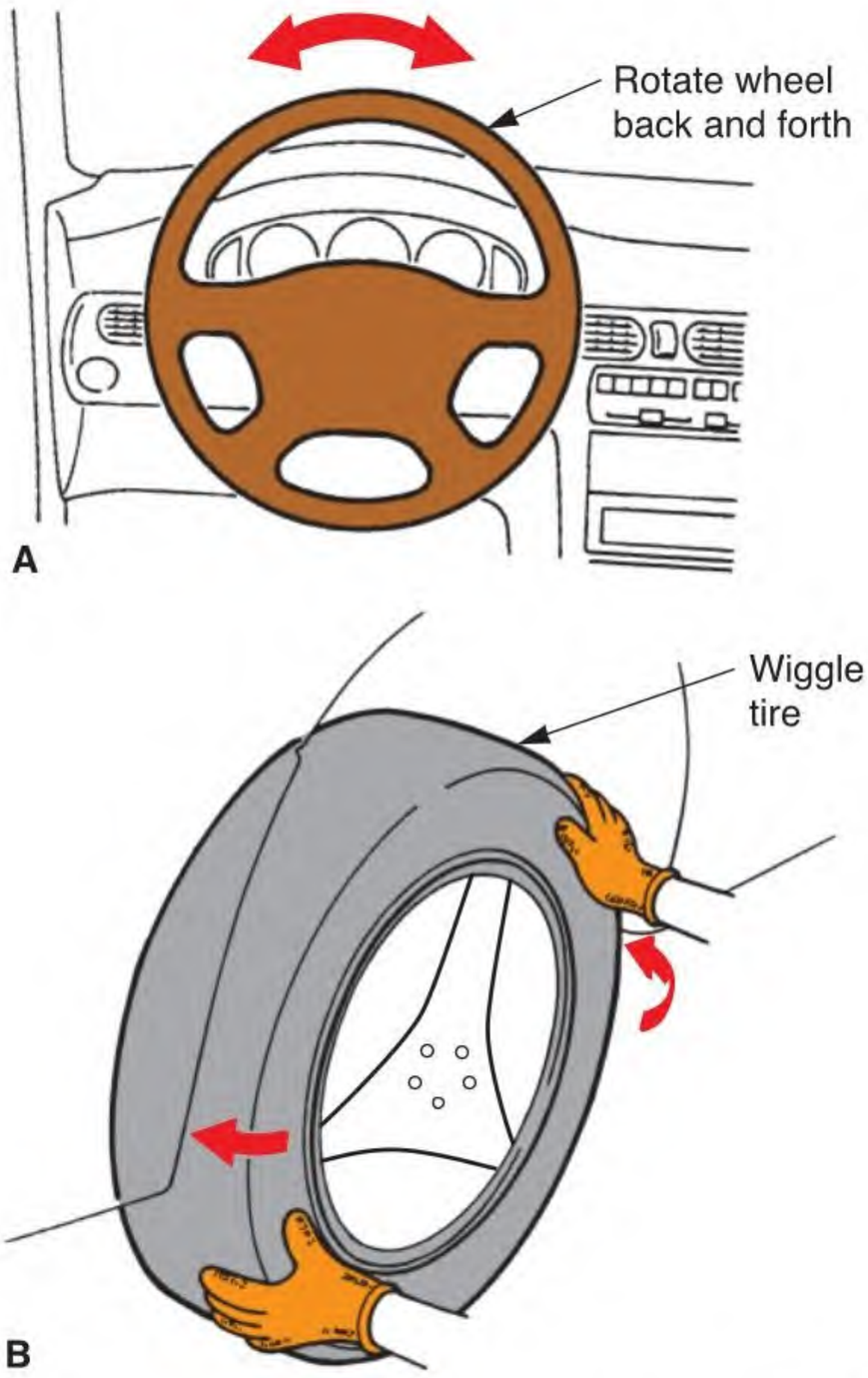
Hard steering (steering that requires excessive effort) can be caused by problems with the steering gearbox, the rack-and-pinion steering gear, the power steering components, the ball sockets, and the suspension system.

Power steering systems commonly suffer from hard steering. When this occurs, check the fluid level in the power steering pump. If the fluid level is low, inspect the system for leaks. Also, check the power steering pump belt. If the belt is slipping, hard steering could result. Look at **Figure 78-3**.

Steering System Noise

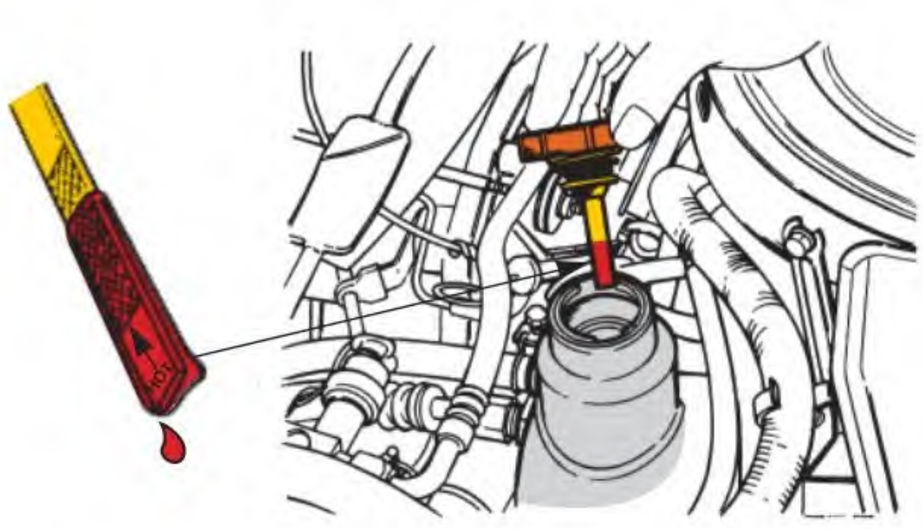
Steering system problems can produce abnormal noises. Steering system noise can be a sign of worn parts, unlubricated bearings or ball sockets, loose parts, slipping belts, a low power steering fluid level, or other system troubles.

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Honda and Mazda

Figure 78-2. Check all steering parts for wear carefully. A—With the vehicle on the ground, rotate the steering wheel back and forth while someone watches for part wear. B—You could also raise the vehicle on a lift and wiggle the tires back and forth while watching for steering play.



Subaru

Figure 78-3. A visual inspection will identify many power steering problems. If a dipstick is used, check the power steering fluid level as shown in the illustration. If low, check for leaks and add the correct type and amount of fluid. Also always check power steering belt condition and tension.

Belt squeal is a loud screeching sound produced by a slipping belt. A slipping power steering belt usually shows up when turning the steering wheel. Turning the steering wheel to the full right or full left position increases system pressure and can cause belt squeal.

Power steering pump noise is usually a loud whine that only occurs when you turn the steering wheel. It is often due to a low fluid level and air in the system. When fluid is added, the noise should go away after turning the wheels from full right to full left several times.

Steering System Maintenance

Steering system maintenance typically involves checking for low fluid level, belt problems, system leaks, and other troubles. It may also include lubricating (greasing) ball sockets.

Tech Tip

The safety of the vehicle and its passengers depends on the condition of the steering system. Always take steering system repairs seriously.

Checking Power Steering Fluid

To check the level of fluid in the power steering system, the engine should *not* be running. Set the parking brake and place the transmission in park or in neutral.

If the vehicle is equipped with a see-through reservoir, simply compare the fluid level to the markings on the side of the reservoir.

In some vehicles, the level must be checked using a dipstick that is part of the power steering reservoir cap. Unscrew and remove the cap from the power steering reservoir. Wipe off the dipstick and reinstall the cap. Remove the cap and inspect the level of fluid on the stick, as shown in **Figure 78-3**.

Most power steering dipsticks have markings for checking the fluid when *hot* and *cold*. Make sure you read the correct marking on the dipstick. The fluid level rises on the stick as the system warms.

If needed, add only enough fluid to reach the correct mark on the dipstick or the side of the reservoir. Do *not* overfill the system. Overfilling could cause fluid to spray out the top of the reservoir onto the engine and other components.

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Servicing Power Steering Belts

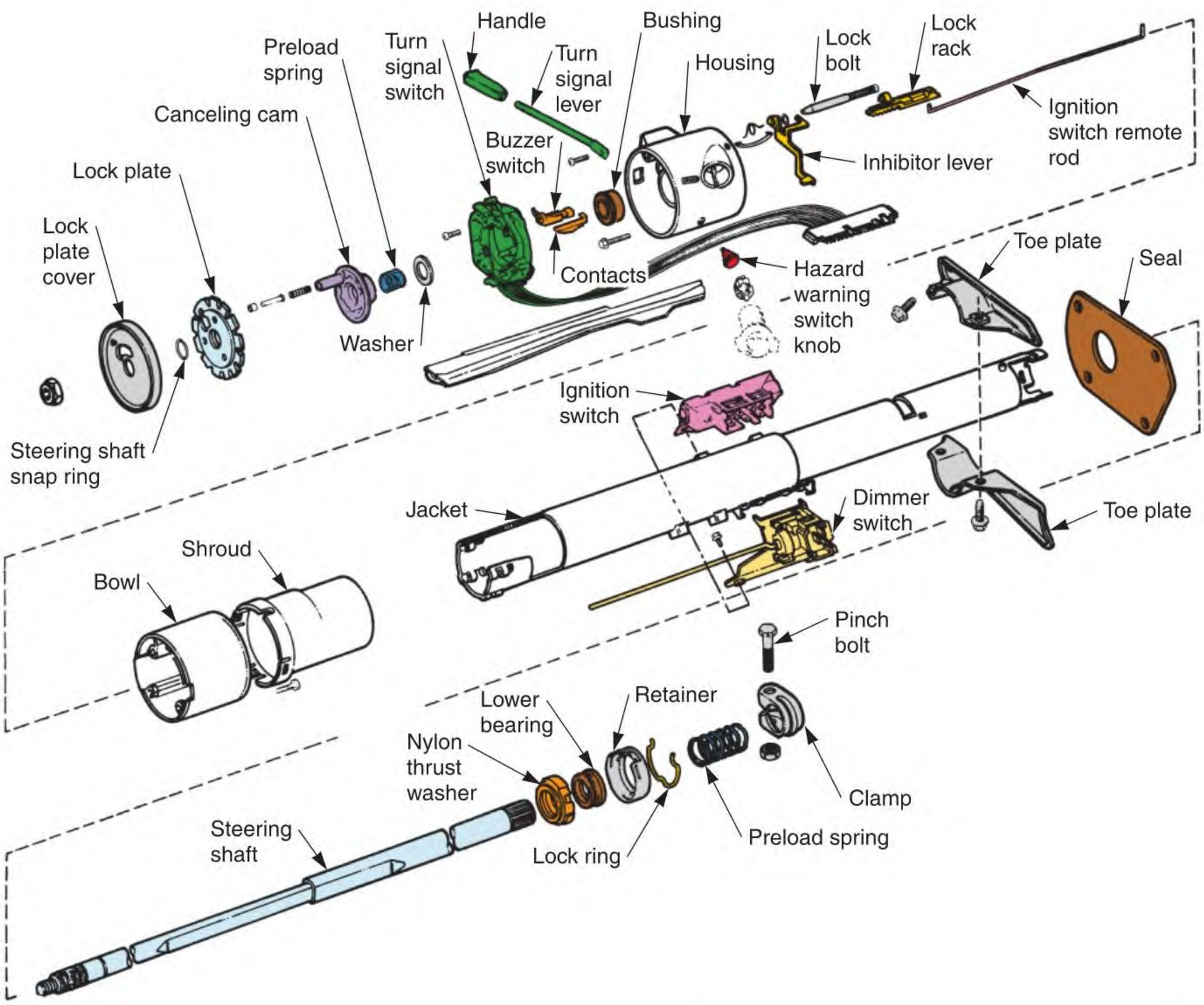
A loose power steering belt can slip, squeal, and cause erratic or high steering effort. A worn or cracked belt may snap, causing a loss of power assist. Always inspect the belt very closely.

To remove a serpentine belt, use a breaker bar to swing the belt tensioner sideways and release tension. Pull the belt off its pulleys. Check the condition of all idler pulleys by spinning them with your fingers. If any feel dry and rough, replace the pulley. Damaged, worn, or loose idler pulleys can cause the new belt to fail prematurely.

Before installation, compare the lengths and widths of the old and new belts. See vehicle service information or a belt diagram sticker on the engine bay frame for the correct belt path and work the new belt over its pulleys. After you position the belt, use the breaker bar again to swing the belt tensioner sideways so the new belt will fit over the tensioner pulley. Double-check that the new belt is tight and properly installed against all pulleys. Then start the engine and check belt operation.

Steering Column Service

Steering column service is needed after a collision (crushing of collapsible steering column) or when internal parts of the column fail. Most steering column repairs can be done with the column mounted in the vehicle. However, some repairs require that the steering column be removed. Refer to **Figure 78-4**.



Chrysler

Figure 78-4. This exploded view shows the relationship between the parts of a steering column.

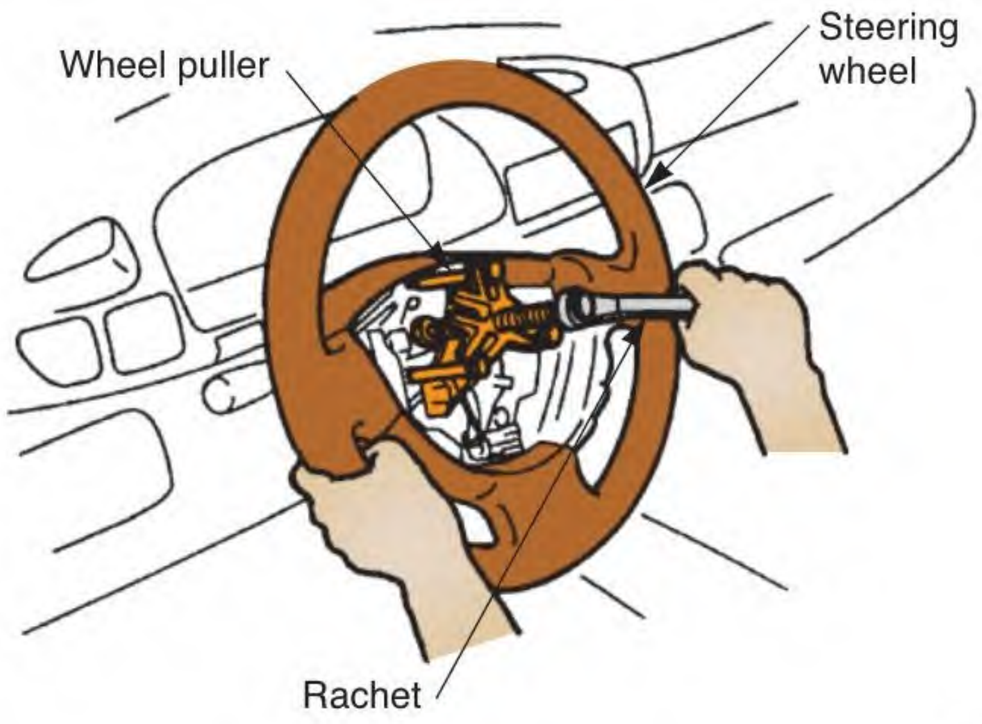
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Warning
When disassembling a steering column, follow the manufacturer's precautions concerning air bag deployment.

Steering Wheel Removal and Replacement

Before servicing the steering wheel, disconnect the battery to prevent accidental air bag deployment. Follow the manufacturer's instructions to remove the air bag unit. Remove the horn button and the steering shaft nut. Scribe alignment marks on the steering wheel and the steering shaft to help you correctly position the steering wheel during reassembly. Many steering shafts and wheels have a distinctly shaped spline and matching indentation to prevent the steering wheel from being reinstalled incorrectly.

A ***wheel puller*** is used to remove a steering wheel from its shaft. Mount the wheel puller as shown in **Figure 78-5**. Screw the bolts into the threaded holes in the steering wheel. Make sure the bolts have the correct thread type. Use a wrench or ratchet to tighten the puller down against the steering shaft to remove the wheel.



Mazda

Figure 78-5. A wheel puller is normally needed to force the steering wheel off its shaft. Wear safety glasses while tightening the center puller bolt.

Warning
Wear eye protection when tightening a wheel puller. If one of the bolts were to break, bits of metal could fly into your face.

Follow service manual directions to replace the worn or damaged parts in the steering column (upper steering shaft bearing, turn signal assembly, etc.). Assemble the column in the reverse order of disassembly.

Steering Column Joint Replacement

Many steering column assemblies use a flexible coupling or a universal joint on the lower part of the steering shaft. The flexible coupling is normally made of reinforced rubber. The rubber coupling can deteriorate after prolonged service or long-term exposure to engine heat or oil. The metal universal joint can wear and develop play after prolonged service.

Steering Linkage Service

Carefully inspect steering linkage components for signs of wear. Common signs of wear in steering linkage components include:

- Excessive play in the idler arm.
- Looseness in ball sockets.
- Worn tie-rods.
- Damaged adjuster tube.
- Bent center link.
- Worn pitman arm splines.
- Misadjusted nut.
- Worn joint in tie-rods.
- Loose mounting bolts.

Idler Arm Service

A ***worn idler arm*** is the most common cause of play in the steering wheel. The front wheels, mainly the right wheel, can turn without causing movement of the steering wheel. An idler arm is a very common wear point in a linkage steering system. Check it carefully.

To check an idler arm for wear, grasp the outer end of the arm (the end opposite the frame). Force the idler arm up and down by hand. Note the amount of

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movement at the end of the arm. Compare this movement to specifications. Typically, an idler arm should *not* wiggle up and down more than about 1/4″ (6.5 mm).

A worn idler arm must be replaced. Remove the cotter pin and the castle nut from the outer end of the idler arm. Then, use a fork tool or a puller to force the arm's ball stud out of the hole in the center link. Finally, unbolt the idler arm from the frame.

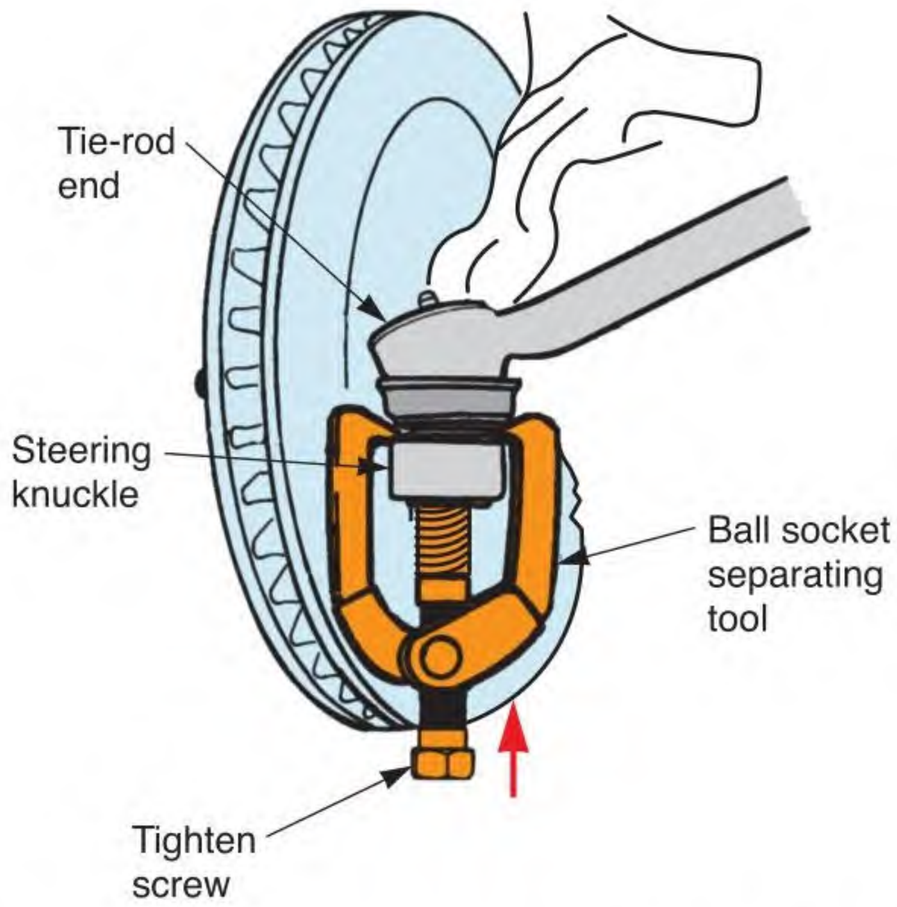
Install the new idler arm in the reverse order of removal. Make sure you properly torque the idler arm fasteners. Install a new cotter pin and bend it properly.

Tie-Rod Service

A worn tie-rod will also cause steering play. When you detect movement between the ball stud and its socket, install a new tie-rod.

To remove a tie-rod, separate the tie-rod from the steering knuckle or center link. Use a fork or a puller as shown in **Figure 78-6**. Be careful *not* to damage any components.

Before loosening the adjustment sleeve, measure or mark the tie-rod length. This will allow you to set the new tie-rod at about approximately the same length as the old one. The alignment of the front wheels is altered when the length of a tie-rod is changed.



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Figure 78-6. A special puller, such as the one shown above, or a fork tool can be used to separate the tie-rod end from the steering knuckle. This tool can also be used on other ball sockets.

Tech Tip

Instead of measuring tie-rod length, you can count the number of turns required to remove the tie-rod from the adjustment sleeve. The new tie-rod end should be installed the same number of turns.

Loosen the tie-rod adjustment sleeve and unscrew the tie-rod end. Turn the new tie-rod end into the sleeve until it is the exact length of the old tie-rod. Install the tie-rod ball stud in the center link or the steering knuckle. Tighten the fasteners to specifications. Install new cotter pins and bend them correctly. Tighten the adjustment sleeve and check steering action. After tie-rod service, always check toe for proper adjustment.

Inner Tie-Rod End Service—Rack-and-Pinion Steering

The service of an inner tie-rod end on a rack-and-pinion assembly is similar to that for a conventional tie-rod end. However, the inner tie-rod end on a rack-and-pinion assembly is enclosed in a rubber boot. Various methods are used to secure the inner tie-rod end.

To remove an inner tie-rod end, remove the boot straps. You usually have to cut them off with side cut pliers. Then, unscrew the inner end of the tie-rod from the rack. See **Figure 78-7**.

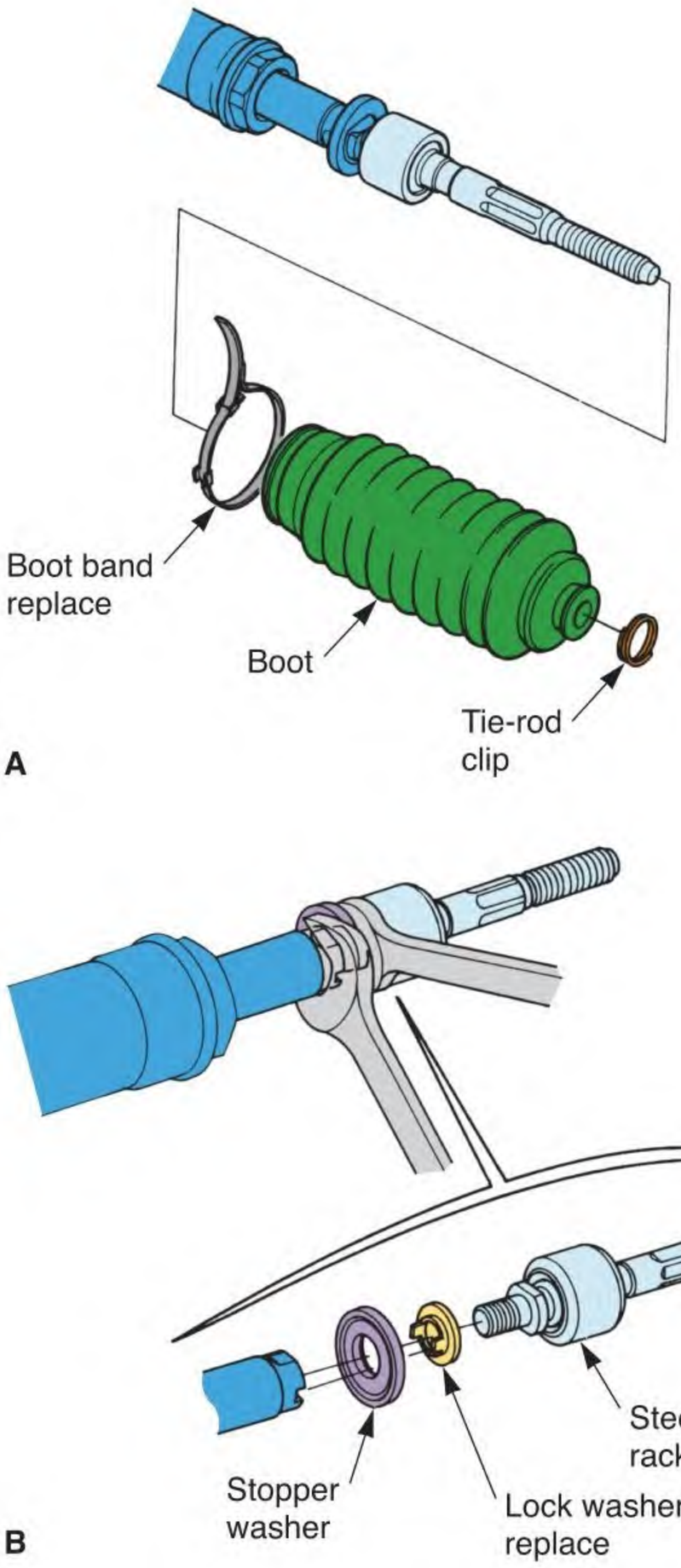
When installing the new inner tie-rod end, install all flat and lock washers in their original locations. Torque the tie-rod nut to factory specs. Replace the boot and boot straps, making sure they are secured into any grooves formed in the tie-rod end and rack.

Manual Rack-and-Pinion Service

A manual rack-and-pinion steering system can develop problems similar to those described for a linkage-type system. However, a rack-and-pinion system has fewer parts to fail. When problems do develop, they are frequently in the tie-rod ends. The rack-and-pinion gear may also wear and cause problems when *not* properly lubricated.

Since so many cars use rack-and-pinion steering, it is important that you learn common service and repair procedures for this type of system.

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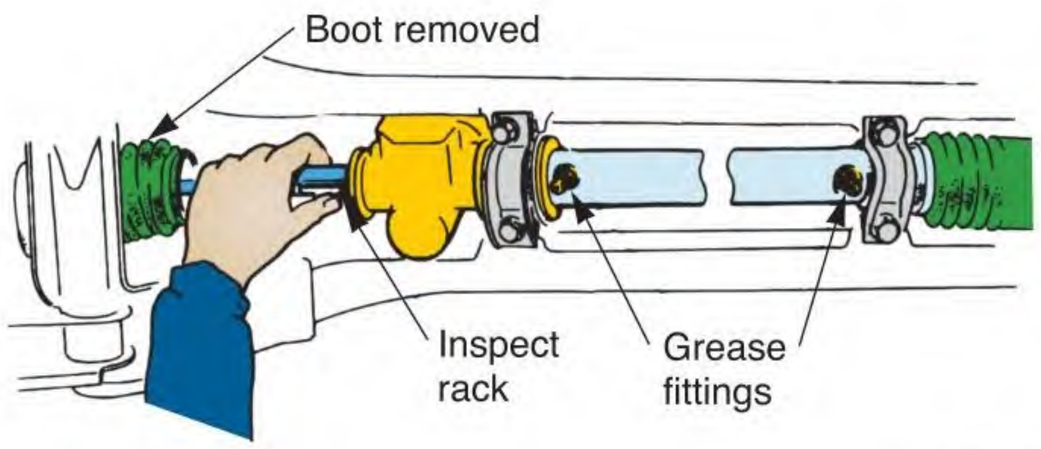
Honda

Figure 78-7. The inner end of the tie-rod on a rack-and-pinion is a common wear point. If wear is not excessive, you may have to remove boot to find play in the inner joint. A—Cut off the old boot straps and slide the boot out of the way. A new boot and straps are normally installed since the boot can rupture after prolonged service. B—Two wrenches are commonly needed to unscrew inner tie-rod end from rack shaft.

Manual Rack-and-Pinion Lubrication

Some manual rack-and-pinion steering gears require periodic lubrication. See **Figure 78-8**. Others only need lubrication when the unit is torn down for repairs.

A grease gun is used to place chassis grease into the fittings. Use only a small amount of grease, as described by the auto manufacturer.



Honda

Figure 78-8. Many steering system components have grease fittings that require lubrication. In this illustration, the boot has been removed to inspect the inner tie-rod socket.

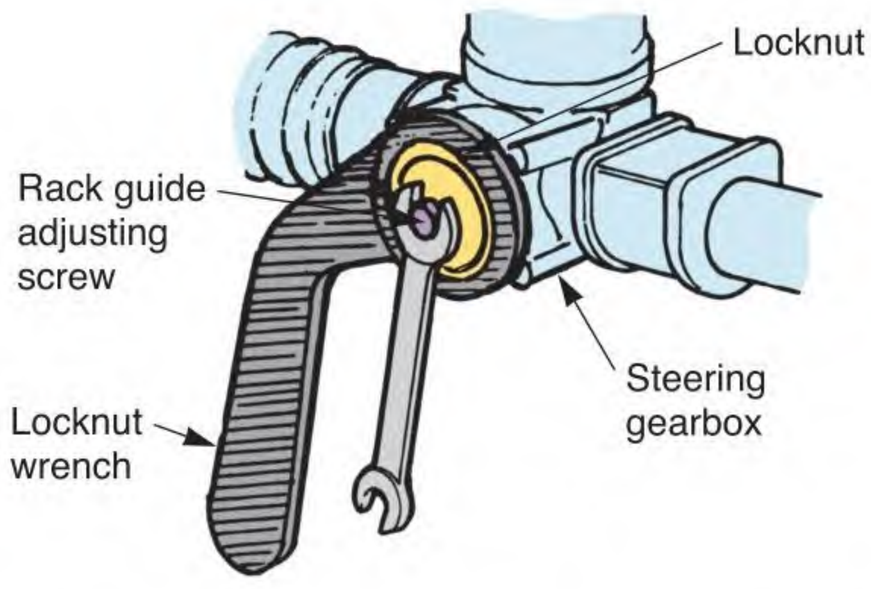
Manual Rack-and-Pinion Gear Adjustment

Most manual rack-and-pinion steering gears have a rack guide adjustment screw. When there is play in the steering, try adjusting the steering gear, **Figure 78-9**. Follow the manufacturer's directions.

To adjust the rack guide screw, loosen the locknut on the screw. Then, turn the rack guide screw in until it bottoms lightly. Back off the screw the recommended amount (approximately 45%) or until a prescribed turning effort is obtained. Tighten the locknut. Recheck for tight or loose steering and measure steering effort. If not within specs, the steering gear may require major repairs.

Manual Rack-and-Pinion Gear Removal

To remove a manual rack-and-pinion steering gear, separate the outer tie-rods from the steering knuckles. Then, unbolt the steering gear mounting



Honda

Figure 78-9. To adjust the rack guide adjustment screw, hold the locknut while turning the screw. Bottom the adjustment screw and then back it off the prescribed amount.

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brackets from the frame or the crossmember. Disconnect the steering column coupler or universal joint. Rotate the steering gear and slide it out of the chassis, **Figure 78-10**.

Refer to a service manual for additional information. You may have to remove the front wheels or slide the gear out on one particular side of the car.

Manual Rack-and-Pinion Gear Overhaul

Exact procedures for overhauling a manual rack-and-pinion steering gear will vary with vehicle make and model. Generally, however, you must disassemble the unit and check each part closely. See **Figure 78-11**. Replace any part that shows signs of wear. All seals and other rubber or plastic parts must also be replaced. Use a service manual to obtain the exact procedures for rebuilding a particular unit.

Power Steering System Service

Many of the parts of a power steering system are the same as those used on a manual steering system. However, a pump, power piston, control valve, and hoses are added. These parts can also fail, requiring repair or replacement.

Power Steering Leaks

Power steering fluid leakage is a common problem. With the extremely high pressures produced in power steering systems (over 1000 psi or 6895 kPa), leaks can easily develop around fittings, in hoses, at the gearbox seals, or at the rack-and-pinion assembly. See **Figure 78-12**.

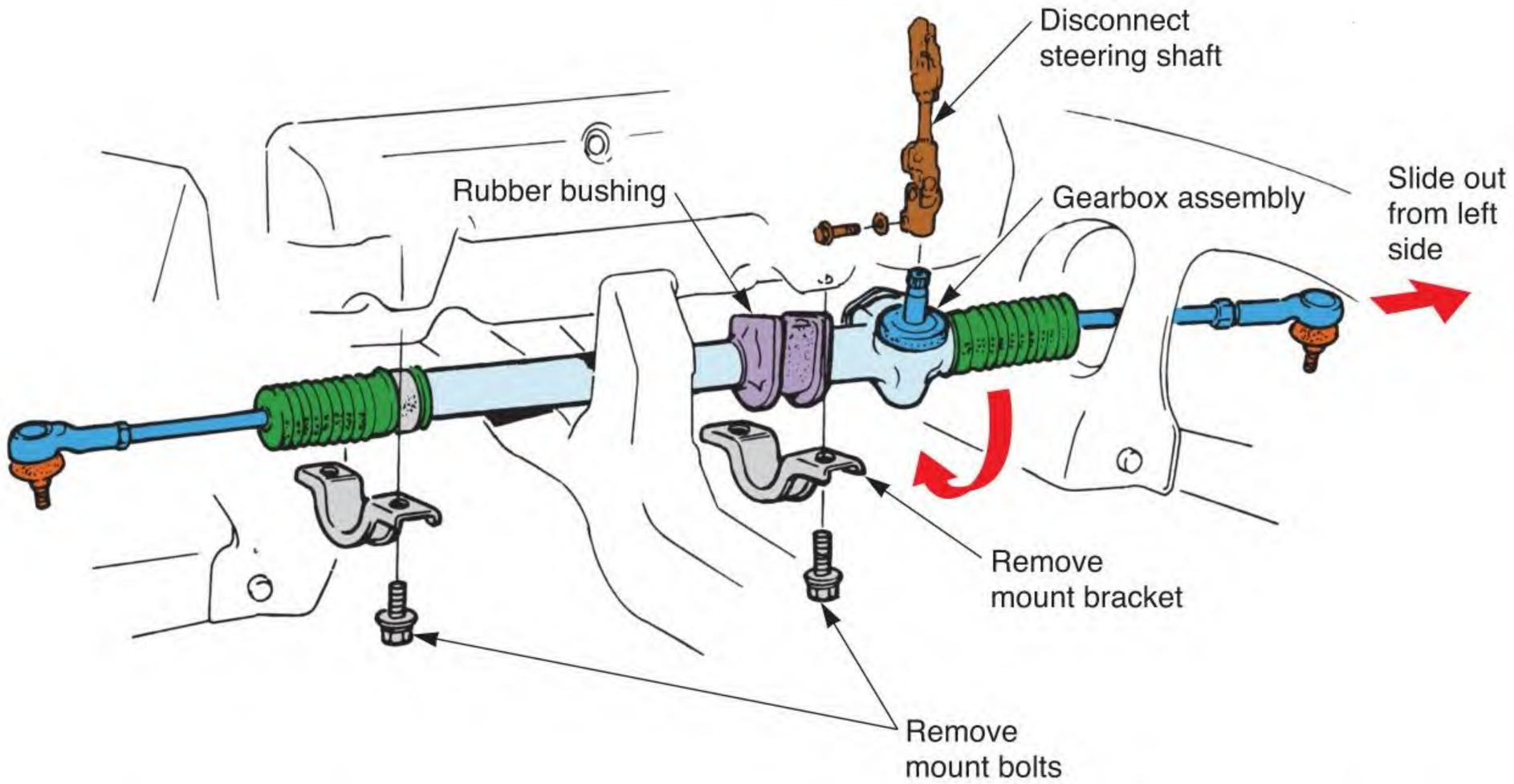
To check for leaks, wipe fluid-soaked areas clean. Then, have a helper start and idle the engine. Watch for leaks as your helper turns the steering wheel to the right and left. Turning the steering wheel pressurizes all parts of the system that might be leaking.

Servicing Power Steering Hoses

Always check the condition of power steering hoses when checking a power steering system. The high-pressure hose can be exposed to tremendous pressures. If this hose ruptures, a sudden and dangerous loss of power assist can occur.

Warning

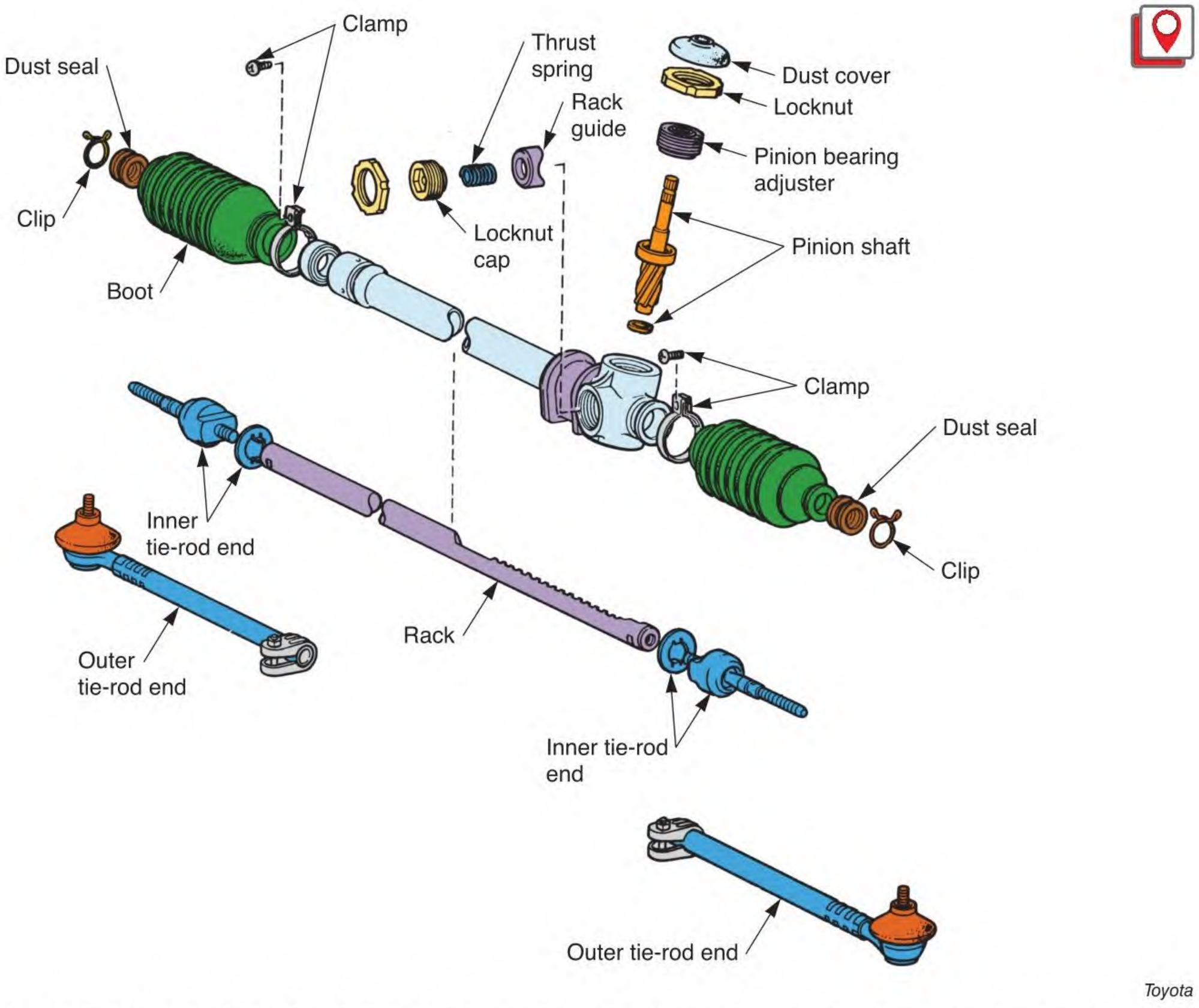
Power steering pump pressure can exceed 1000 psi (6895 kPa). This is enough pressure to cause a serious eye injury. Wear eye protection when working on a power steering system.



Honda

Figure 78-10. Removal of a rack-and-pinion gear mechanism usually involves disconnecting the parts shown. Slide the unit out one side of the vehicle.

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Toyota

Figure 78-11. Exploded view of typical rack-and-pinion steering mechanism. During service, inspect each component and measure wear.

When installing a new hose, start the new hose fittings by hand to avoid cross threading. Use a tubing wrench to tighten the hose fittings properly. Make sure the hose does *not* contact moving or hot parts. This could cause hose failure.

Power Steering Pressure Test

A ***power steering pressure test*** checks the operation of the power steering pump, pressure relief valve, control valve, hoses, and power piston. Connect a pressure gauge and shutoff valve into the high-pressure hose, as shown in **Figure 78-13**.

When checking power steering system pressure, follow the manufacturer's recommended procedures. Torque the hose fittings properly. Make sure the system is full of fluid. Start the engine and allow it to idle (test valve open) while turning the steering wheel back and forth to bring the fluid up to operating temperature.

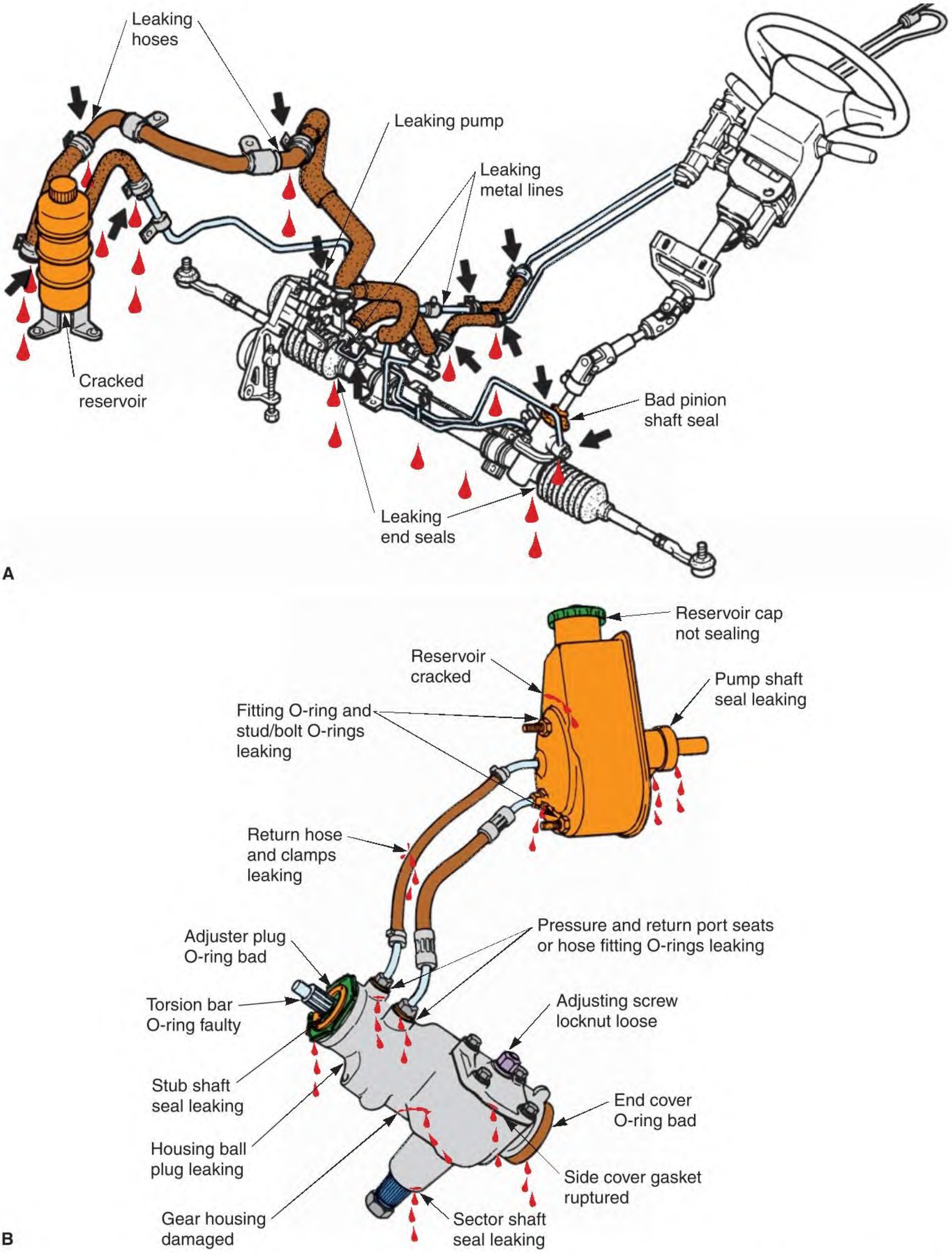
To check system pressure, close the test valve. Compare your pressure reading with specifications. When the pressure is *not* within specs, check the condition of the pressure relief valve and the pump.

Caution

Do *not* close the test valve for more than about *five seconds*. If the valve is closed longer, the power steering pump could overheat and be damaged.

To check the action of the power piston, control valve, and hoses, measure system pressure as you turn the steering wheel to full lock (right and left) with

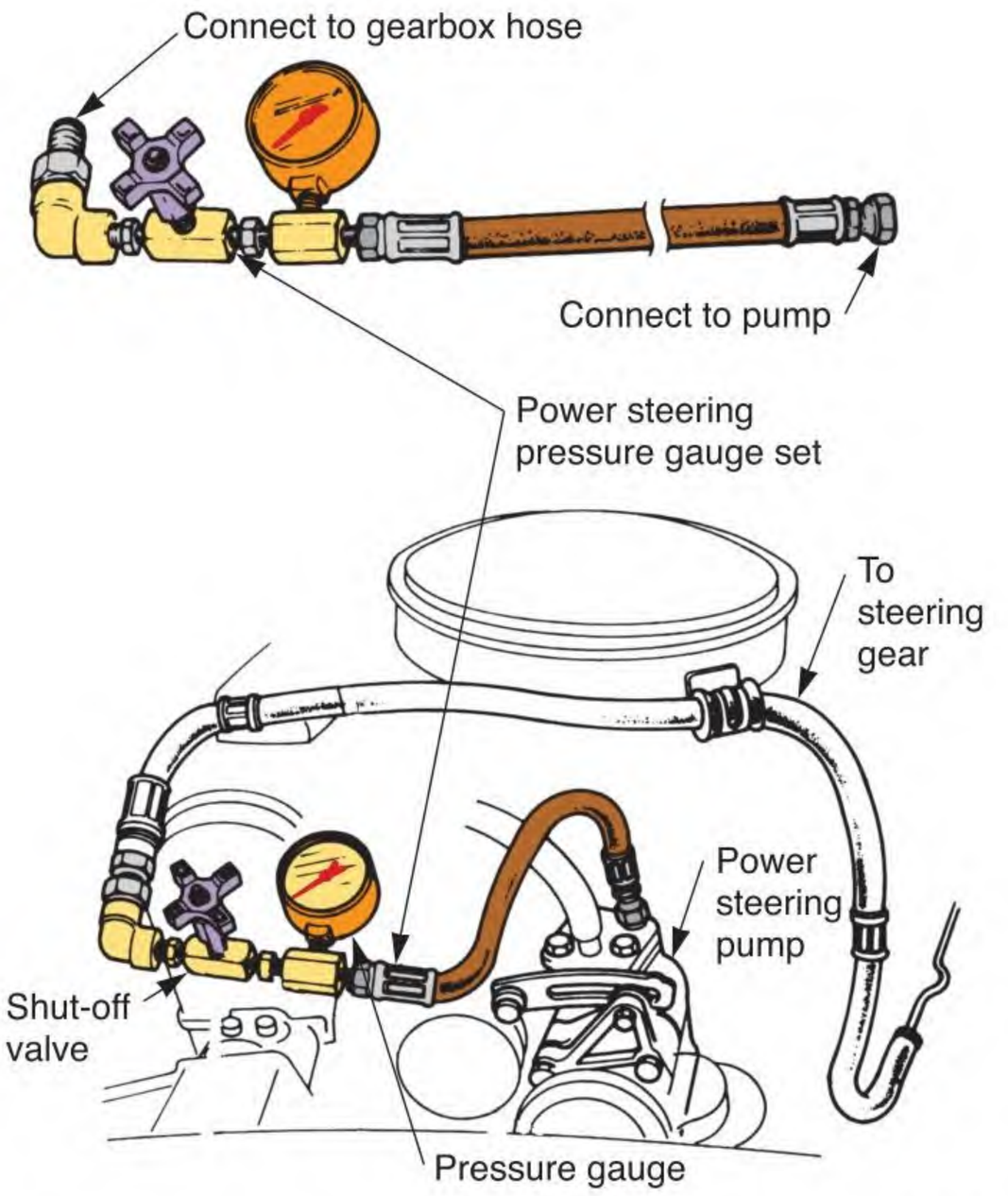
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Honda and Ford

Figure 78-12. Note possible leakage points on power steering systems. A—Rack-and-pinion system. B—Linkage system.

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Honda

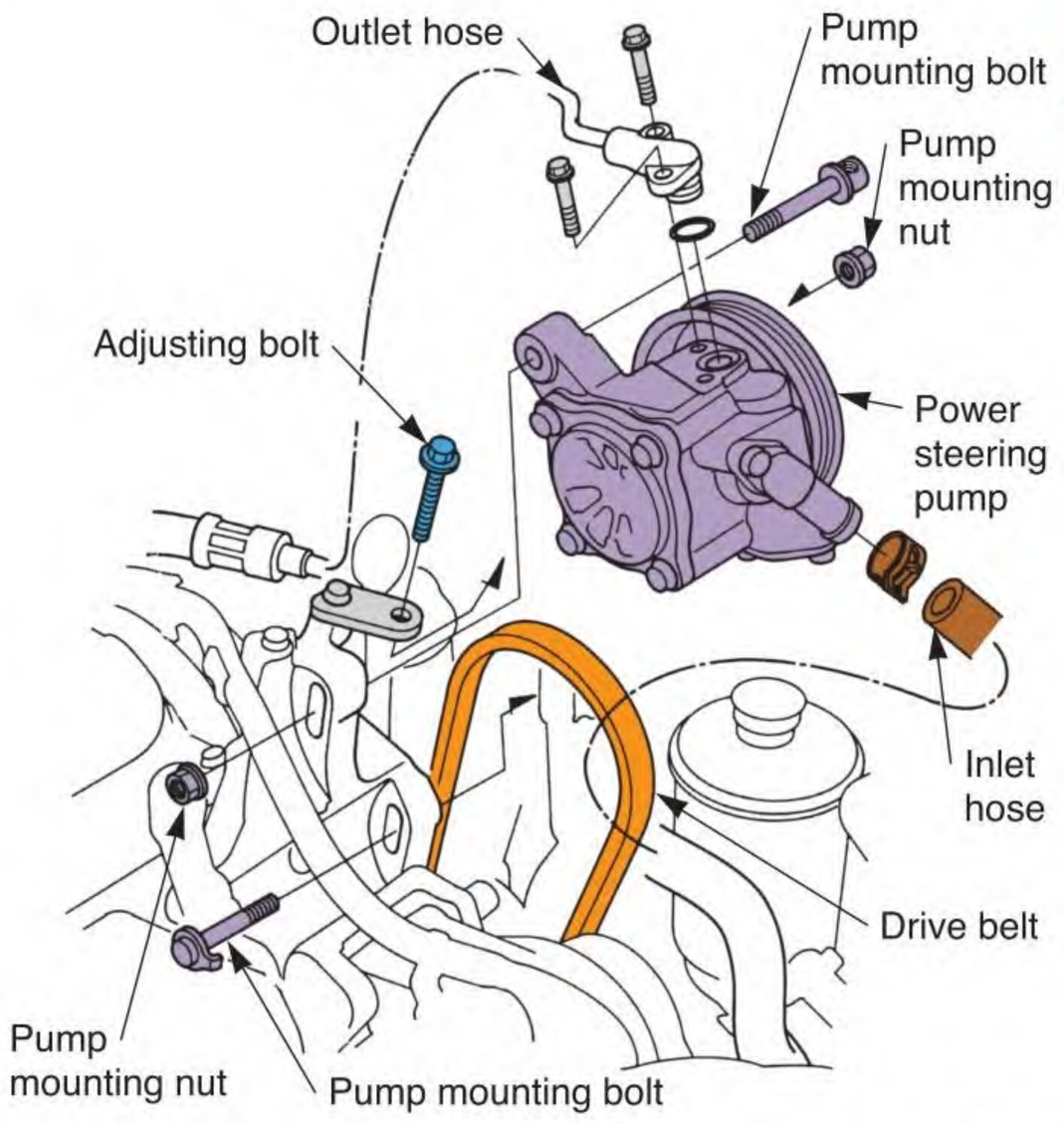
Figure 78-13. The pressure test gauge is connected to the high-pressure hose or line from the pump. Follow service manual instructions when testing a power steering system.

the test valve open. Note the gauge readings and compare them to specs. Use the information in a service manual to determine the source of any trouble.

Power Steering Pump Service

When your tests indicate a bad power steering pump, the pump must be removed for repair or replacement. See **Figure 78-14**. Most shops simply replace a bad power steering pump with a new or factory rebuilt unit. A few shops may disassemble and rebuild the defective pump. Before attempting to rebuild a power steering pump, make sure a rebuild kit is available for the particular unit.

During a pump rebuild, clean and inspect all the parts. In particular, check the pump vanes, thrust plate, and pump ring. Replace all O-rings, gaskets, and seals, as well as any other parts showing signs of wear or damage. Lubricate the parts with the proper fluid before assembly.



Honda

Figure 78-14. Note the bolts, hoses, and brackets that must be removed when replacing a power steering pump.

Power Steering Gear Service

The procedures for servicing power steering gears also vary with the make and model of the vehicle and the type of gear assembly. Follow service manual directions. Note the measurements used to check part wear. Replace all worn parts and every seal, **Figure 78-15**.

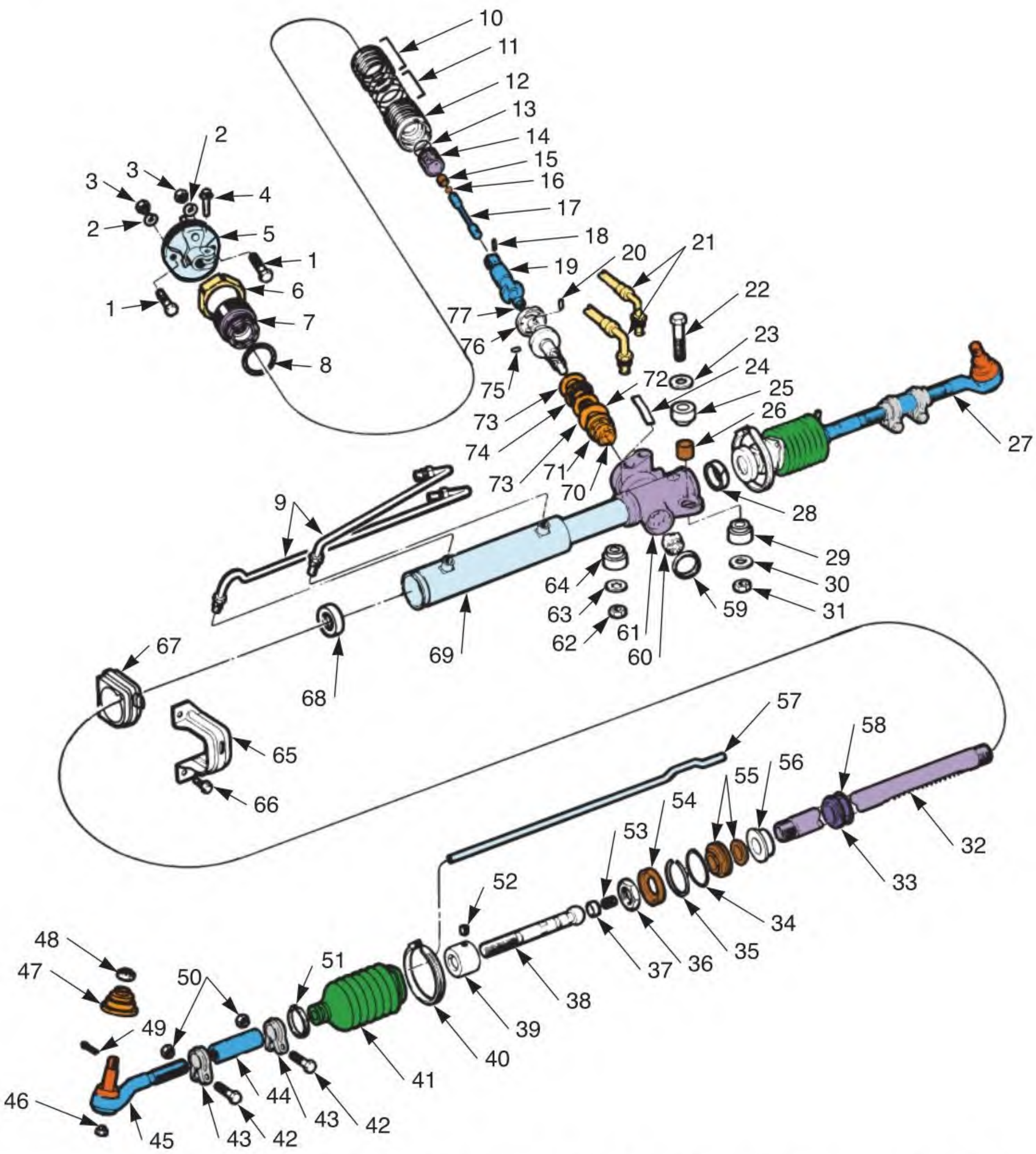
Clean and lubricate the parts before reassembly. Use special drivers or pullers to replace worn bushings, if needed. Reassemble the gear assembly according to service manual instructions, **Figure 78-16**.

Bleeding a Power Steering System

When any of the hydraulic components (pump, power piston, hoses) are serviced, you should bleed the power steering system. Bleeding ensures that all air is out of the lines, pump, and gearbox. Air can cause the power steering system to make a buzzing sound. The sound will occur as the steering wheel is turned to the right or left.

To bleed a power steering system, start the engine and turn the steering wheel fully from side to side. Check the fluid level often and add fluid as needed. This forces air into the reservoir and out of the system.

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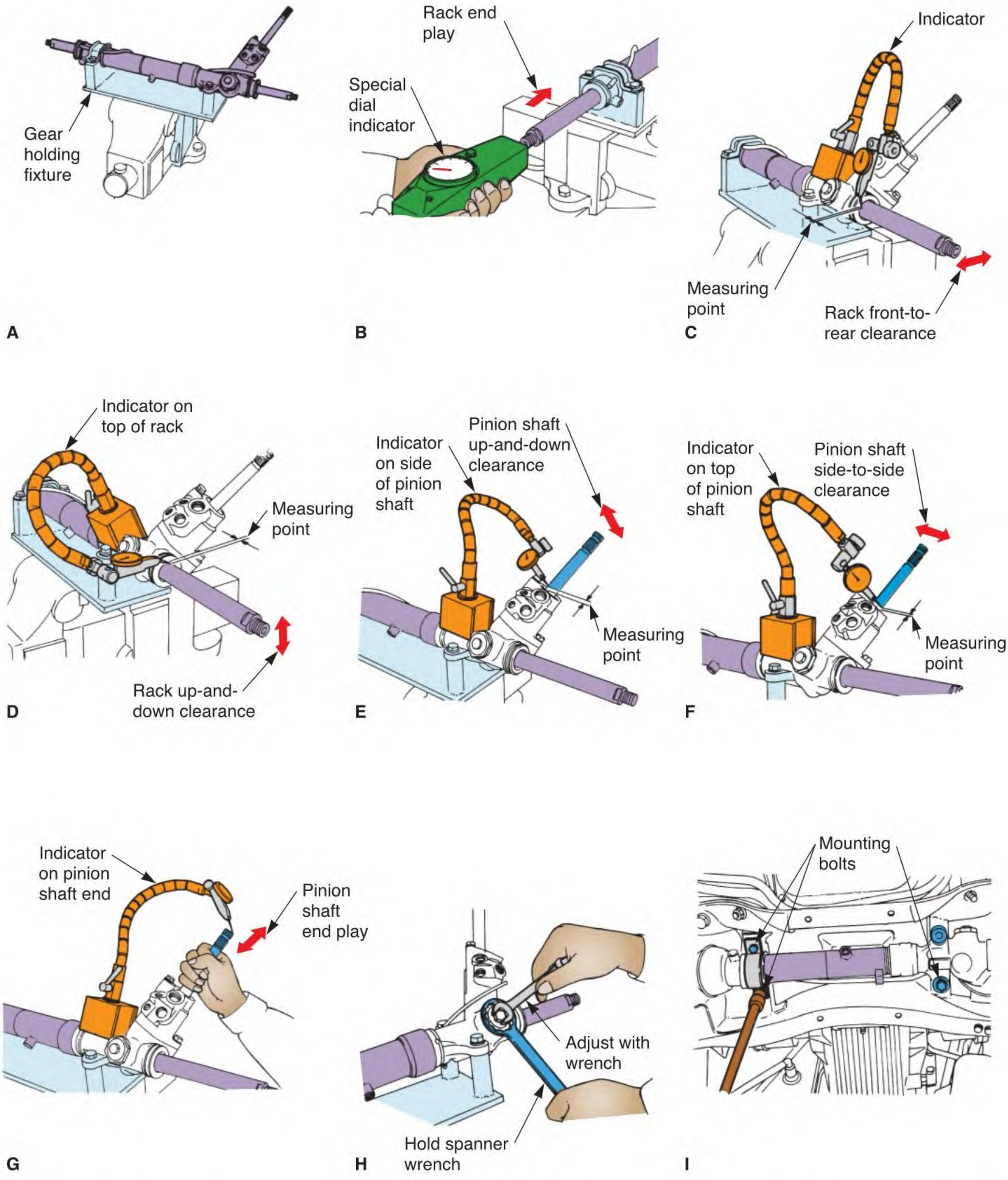


1. Flexible coupling-to-intermediate shaft attaching bolt
2. Lockwasher
3. Nut
4. Pinch bolt
5. Flexible coupling
6. Adjuster plug locknut
7. Adjuster plug assembly
8. Adjuster plug O-ring
9. Oil lines
10. Valve body seal rings
11. Valve body O-rings
12. Valve body
13. Spool valve damper O-ring
14. Spool valve
15. Torsion bar bushing (included in stub shaft)
16. Torsion bar seal ring (included in stub shaft)
17. Torsion bar (included in stub shaft)
18. Drive pin (included in stub shaft)
19. Stub shaft
20. Drive pin (included in stub shaft)
21. Power steering hoses
22. Mounting bolt
23. Washer
24. Preload spring
25. Grommet
26. Bushing
27. Steering linkage (assembled)
28. Rack bushing
29. Grommet
30. Washer
31. Nut
32. Steering rack
33. Rack piston
34. Outer bulkhead O-ring
35. Bulkhead retaining ring
36. Jam nut
37. Ball seat
38. Inner tie-rod
39. Inner tie-rod housing
40. Boot clamp
41. Boot
42. Adjuster tube clamp bolt
43. Adjuster tube clamp
44. Adjuster tube
45. Tie-rod end
46. Lube plug
47. Tie-rod end seal
48. Tie-rod end-nut
49. Cotter pin
50. Adjuster tube clamp nut
51. Boot clamp
52. Tie-rod housing set screw
53. Ball seat spring
54. Shock dampener ring
55. Outer bulkhead and seal assembly
56. Inner bulkhead
57. Breather tube
58. Rack piston seal ring
59. Contraction plug
60. Lower pinion bushing
61. Housing (included in tube and housing assembly
62. Nut
63. Washer
64. Grommet
65. Mounting clamp
66. Bolt
67. Mounting grommet
68. Inner rack seal
69. Tube and power cylinder (included in tube and housing assembly)
70. Upper pinion bushing
71. Pinion shaft seal (lip type)
72. Support washer
73. Conical thrust bearing race
74. Thrust bearing
75. Drive pin (included in stub shaft)
76. Shaft cap (included in stub shaft)
77. Torsion bar bushing (included in stub shaft)

Ford

Figure 78-15. Exploded view of a complete power rack-and-pinion steering gear. Study the location of all the components.

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Fiat

Figure 78-16. Fundamental measurements and service steps for a power rack-and-pinion steering gear. A—Mount the unit in a holding fixture. B—Use a special indicator to measure rack end play. C—Use a dial indicator to check front-to-rear clearance at the rack. D—Measure rack up-and-down movement. E—Measure pinion shaft up-and-down clearance. F—Measure pinion shaft side-to-side clearance. G—Measure pinion shaft end play. H—Adjust the rack guide screw. I—Install the rack-and-pinion assembly in the vehicle.

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Electronic Assist Steering Service

The service procedures for electronic assist power steering systems are about the same as the procedures described earlier in the text. Since circuit designs vary, you should refer to the shop manual for wiring diagrams, part locations, and electrical values.

Problems with the steering system's electronic circuits will trip diagnostic trouble codes. Your scan tool will let you read operating values in the steering system and quickly isolate the problem area.

A scan tool might show codes for the steering sensor circuit, power steering pump pressure, fluid pressure control solenoid, lateral acceleration sensor, rack motor circuit, and other components or circuits. Use pinpoint tests with a multimeter to verify the source of the problem.

Diagnostic Case Study

Concern: Ms. Love brings in her 2010 Beetle, saying there is too much play in the steering.

Cause: Duff drives the car to verify the problem. Finding excessive play in the steering wheel, he turns the car over to the shop's suspension and steering technician. The technician has a helper wiggle the steering wheel back and forth while she lies on a creeper and checks for play in steering parts. The steering wheel moves almost 2″ (50.8 mm) without movement of wheel and tires.

The technician traces the play to the tie-rod ends. She raises the car on the lift and pushes back and forth on the front tire, revealing play in outer tie-rod ends. The inner tie-rod ends show no signs of wear or play.

Correction: The technician counts the number of threads showing on the tie-rod ends. After removing the cotter pins and nuts, she uses a puller to separate the tie-rod ends from the steering knuckles. She installs new tie-rod ends, making sure the same number of threads are showing so that wheel alignment is not thrown off too much. Finally, she performs a four-wheel alignment, test-drives the vehicle, and releases car to its owner.

Summary

- After prolonged use, the steering system idler arm, gearbox, ball sockets, belts, hoses, and other system parts can wear, causing play in the steering system.
- The dry park test is an effective way to check play in the steering linkage or rack-and-pinion mechanism.
- Hard steering can be caused by problems with the steering gearbox, the rack-and-pinion steering gear, the power steering components, the ball sockets, and the suspension system.
- Steering system noise can be signs of worn parts, unlubricated bearings or ball sockets, loose parts, slipping belts, low power steering fluid, or other system troubles.
- Belt squeal is a loud screeching sound produced by a slipping belt.
- Power steering pump noise is usually a loud whine that occurs when you turn the steering wheel.
- A wheel puller is used to remove a steering wheel from its shaft.
- A worn idler arm from a linkage steering system will cause play in the steering wheel. The front wheels, mainly the right wheel, can turn without causing movement of the steering wheel.
- A worn tie-rod end will cause steering play. When you detect movement between the ball stud and its socket, install a new tie-rod end.
- Most manual rack-and-pinion steering gears have a rack guide adjustment screw. When there is play in the steering, try adjusting the steering gear.
- Exact procedures for overhauling a manual rack-and-pinion steering gear will vary with vehicle make and model.
- Power steering fluid leakage is a common problem.
- Power steering pump pressure can exceed 1000 psi (6895 kPa)—enough pressure to cause serious eye injury.
- A power steering pressure test checks the operation of the power steering pump, pressure relief valve, control valve, hoses, and power piston.
- When tests indicate a bad power steering pump, the pump must be removed for repair or replacement. Most shops simply replace a bad power steering pump with a *new* or factory *rebuilt unit*.
- Bleeding a power steering system ensures that all the air is out of the lines, pump, and gearbox.
- Steering system electrical problems will trip trouble codes that can be read and diagnosed by a scan tool or diagnostic tablet.

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Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

belt squeal
dry park test
hard steering
power steering pressure test
steering wheel play
wheel puller
worn idler arm

Activities

1. Check the level of power steering lubricant on a vehicle that is in the shop for service.
2. Check a shop manual for lube points, and then lubricate a steering system.
3. Test a steering system and diagnose any problems detected.
4. Prepare a repair bill for a repair to the steering system. Use a flat rate manual to determine time on the job or use an hourly rate set by your instructor. Check a parts catalog for cost of parts.

Review Questions

Answer the following questions using the information provided in this chapter.

1. Excessive steering wheel play is usually shown by turning the steering wheel more than _____ without causing front wheel movement.
   (A) 1 1/2″ (38 mm)
   (B) 3/4″ (19 mm)
   (C) 1/32″ (0.8 mm)
   (D) 1/4″ (6.5 mm)
2. How do you do a "dry park test" of a steering system?
3. A(n) _____ is commonly needed to force a steering wheel off its shaft.
4. Steering system noise can be caused by all of the following problems *except:*
   (A) unlubricated ball sockets.
   (B) broken condenser.
   (C) loose or slipping belt.
   (D) low power steering fluid level.
5. Which of the following components can wear and cause play in the steering system?
   (A) Tie-rod end.
   (B) Idler arm.
   (C) Ball socket.
   (D) All of the above.
6. A(n) _____ system has fewer steering parts to fail compared to a(n) _____ system.
7. Power steering pump pressure can exceed:
   (A) 10,000 psi (68,900 kPa).
   (B) 5000 psi (34,450 kPa).
   (C) 2500 psi (17,236 kPa).
   (D) 1000 psi (6895 kPa).
8. A power steering pressure test checks the operation of the pump, relief valve, control valve, hoses, and power piston. True or False?
9. Most technicians install rebuilt or new power steering pumps rather than overhauling the defective unit in the shop. True or False?
10. After hydraulic steering components have been serviced, the system should be _____.

ASE-Type Questions

1. A car is brought into the shop with excessive steering wheel play. Technician A checks for worn ball sockets. Technician B checks the condition of the system's idler arm. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. A car's steering wheel turns three inches before causing movement of the front wheels. Technician A tells the owner of the vehicle that this indicates normal play in the steering system. Technician B tells the owner of the vehicle that this indicates excessive steering wheel play. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. Lubricant is leaking from a car's power steering system. Technician A says that, if equipped, a dipstick attached to the reservoir cap can be used to measure power steering fluid level. Technician B says that a cracked reservoir could be the source of the leakage. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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4. An automobile has a "hard steering" problem. Technician A checks the steering gearbox for problems. Technician B inspects the suspension system for problems. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. Noise is coming from a steering pump. Technician A checks the inner tie-rod ends. Technician B checks the pump's fluid level. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. An automotive power steering system's fluid level needs to be checked. Technician A checks the steering system's fluid level with the engine off. Technician B checks the fluid level while the engine is running. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. Technician A says the alignment of the front wheels is changed when a tie-rod is changed. Technician B says that during steering wheel and air bag removal, it is recommended to keep the vehicle battery connected. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. A car's power steering belt is loose. Technician A says the belt may be worn and stretched and might require replacement. Technician B says the belt tensioner may be broken and unable to apply enough tension to the belt. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. An automobile's steering column needs servicing. Technician A tells the owner of the car that most steering columns can be repaired with the column mounted in the car. Technician B tells the owner of the car that most steering columns must be removed from the vehicle when service is required. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. A car's steering wheel needs to be removed from its shaft. Technician A uses a hammer and brass punch to perform this service procedure. Technician B uses a wheel puller to perform this service procedure. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
11. Technician A says that power steering systems are not susceptible to "hard steering" problems. Technician B says that accurately diagnosing an electronic assist steering system requires a scan tool or diagnostic tablet. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
12. A car equipped with manual rack-and-pinion steering is brought into the shop with excessive steering wheel play. Technician A adjusts the steering gear. Technician B adjusts the idler arm. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
13. An automobile's power steering pump is not operating properly. Technician A performs a power steering pressure test to check the operation of the power steering pump. Technician B says a power steering pressure test will not detect power steering pump malfunctions. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
14. A "buzzing" sound is coming from an automobile's power steering system when the wheel is turned. Technician A tells the owner of the vehicle that this problem may be the result of a damaged pitman arm. Technician B tells the owner of the vehicle that this problem may be caused by air in the power steering system. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Manual and Power Steering Systems Diagnosis

Condition	Possible Causes	Correction
Hard steering and poor recovery following turns.	1. Low tire pressure. 2. Defective power steering pump. 3. Power steering pump fluid level low. 4. Manual steering gear lubricant level low. 5. Incorrect front wheel alignment. 6. Dry ball joints. 7. Dry steering linkage sockets. 8. Binding linkage. 9. Damaged suspension arms. 10. Steering gear adjusted too tight. 11. Dry steering shaft bushing. 12. Binding steering shaft bushing or coupling. 13. Excessive caster. 14. Sagged front springs. 15. Bent spindle body. 16. Steering wheel rubbing steering column jacket. 17. Misaligned steering gear. 18. Sticky valve spool. 19. Loose steering pump belt. 20. Kinked or clogged power steering hose. 21. Different size front tires. 22. Malfunctioning steering gear pressure port poppet valve. 23. Maladjusted rack-and-pinion. 24. High internal leakage of rack-and-pinion assembly. 25. Rack-and-pinion mountings loose, causing binding. 26. Defective steering stabilizer.	1. Inflate to correct pressure. 2. Repair or replace pump. 3. Add fluid to reservoir. 4. Add lubricant. 5. Align front wheels. 6. Lubricate ball joints. 7. Lubricate linkage. 8. Relieve binding. 9. Replace arms. 10. Adjust gear correctly. 11. Lubricate bushings. 12. Align shaft or coupling. 13. Adjust caster. 14. Replace springs. 15. Replace spindle. 16. Adjust jacket; check for steering shaft damage. 17. Align gear. 18. Clean or replace spool valve. 19. Adjust belt tension. 20. Replace hose. 21. Install correct size tires on both sides. 22. Repair or replace. 23. Adjust to specifications. 24. Repair leaks or replace gear. 25. Tighten mountings to specifications. 26. Replace stabilizer.
Vehicle pulls to one side.	1. Uneven tire pressure. 2. Brakes dragging. 3. Improper front end alignment. 4. Improperly adjusted wheel bearings. 5. Damaged or worn steering valve assembly. 6. Tire sizes not uniform. 7. Broken or sagging spring. 8. Misaligned rear axle housing. 9. Bent spindle. 10. Frame sprung. 11. Radial tire problem.	1. Equalize pressure. 2. Adjust brakes. 3. Align front end. 4. Adjust bearings. 5. Replace steering valve assembly. 6. Install tires of the same size. 7. Replace spring. 8. Align rear housing. 9. Replace spindle. 10. Straighten frame. 11. Switch front tires. If vehicle now pulls in the other direction, tires are defective.

Continued

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Manual and Power Steering Systems Diagnosis

Condition	Possible Causes	Correction
Vehicle wanders from side to side.	1. Weak shock absorber or strut. 2. Loose steering gear. 3. Loose rack-and-pinion mountings. 4. Ball joints and steering linkage need lubrication. 5. Steering gear not on high point. 6. Broken or missing stabilizer bar or link. 7. Improperly adjusted rack-and-pinion. 8. Loose tie-rod end.	1. Replace shocks or struts. 2. Torque mounting fasteners. 3. Tighten to specifications. 4. Lubricate suspension. 5. Adjust steering gear properly. 6. Replace stabilizer or link. 7. Adjust to specifications. 8. Tighten. Replace if worn.
Sudden increase in steering wheel resistance.	1. Slipping pump belt. 2. Internal leakage in gear. 3. Fluid level low in pump. 4. Low engine idle. 5. Air in system. 6. Low tire air pressure. 7. Insufficient pump pressure. 8. High internal leakage in rack-and-pinion. 9. Defective steering stabilizer.	1. Adjust belt tension. 2. Overhaul or replace gear. 3. Add fluid. 4. Adjust idle. 5. Bleed system. 6. Inflate to recommended level. 7. Test and repair or replace as required. 8. Repair leaks or replace gear. 9. Replace stabilizer.
Steering wheel action jerky during parking.	1. Loose pump belt. 2. Oily pump belt. 3. Defective flow control valve. 4. Insufficient pump pressure.	1. Adjust belt tension. 2. Replace belt. Clean pulleys. Repair source of leak. 3. Replace flow control valve. 4. Test and repair.
No effort required to turn steering wheel.	1. Broken steering gear torsion bar. 2. Broken tilt column U-joint. 3. Missing steering wheel hub-to-shaft key. Stripped splines. Loose nut.	1. Replace spool valve and shaft assembly. 2. Replace U-joint. 3. Replace key, shaft, or wheel. Tighten nut to specifications.
Excessive wheel kickback and play.	1. Worn steering linkage. 2. Air in system. 3. Improperly adjusted front wheel bearings. 4. Loose gear over-center adjustment. 5. Worm gear not preloaded. 6. No worm to rack-piston preload. 7. Loose pitman arm. 8. Loose steering gear. 9. Steering arms loose on spindle body. 10. Excessive play in ball joints. 11. Defective rotary valve. 12. Worn steering shaft universal joint. 13. Extra large tires. 14. Defective steering stabilizer.	1. Replace worn linkage components. 2. Bleed and add fluid if needed. 3. Adjust front wheel bearings. 4. Make correct over-center adjustment. 5. Preload worm gear. 6. Install larger set of rack-piston balls. 7. Torque pitman arm nut. 8. Tighten mounting fasteners. 9. Tighten arm fasteners. 10. Replace ball joints. 11. Replace rotary valve. 12. Replace joint and/or shaft. 13. Advise owner. Install a steering stabilizer or replace with a larger stabilizer. 14. Replace stabilizer.
No power assist in one direction.	1. Defective steering gear.	1. Overhaul or replace gear as needed.

Continued

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Manual and Power Steering Systems Diagnosis

Condition	Possible Causes	Correction
Steering pump pressure low.	1. Loose pump belt. 2. Oily belt. 3. Worn pump parts. 4. Relief valve springs defective or stuck open. 5. Low fluid level in reservoir. 6. Air in system. 7. Defective hose. 8. Flow control valve stuck open. 9. Pressure plate not seated against cam ring. 10. Scored pressure plate, thrust plate, or rotor. 11. Vanes incorrectly installed. 12. Vanes sticking in rotor. 13. Worn or damaged O-rings.	1. Adjust belt. 2. Clean pulleys. Replace belt. Correct source of leak. 3. Overhaul pump. 4. Repair or replace as needed. 5. Add fluid. 6. Correct source of leak. Bleed system. 7. Replace hose. 8. Clean or replace valve. 9. Repair or replace cam ring and pressure plate. 10. Replace damaged parts and flush system. 11. Install vanes correctly. 12. Free vanes. Clean thoroughly. 13. Replace O-rings.
Steering pump noise.	1. Air in system. 2. Loose pump pulley. 3. Loose belt. 4. Glazed belt. 5. Hoses touching splash shield. 6. Low fluid level. 7. Clogged or kinked hose. 8. Scored pressure plate. 9. Scored rotor. 10. Vanes installed wrong. 11. Vanes sticking in rotor. 12. Defective flow control valve. 13. Loose pump. 14. Plugged reservoir vent. 15. Dirty fluid. 16. Worn pump bearing. 17. Loose belt (chirping). 18. Low fluid (whining or growling).	1. Correct leak and bleed system. 2. Tighten pulley. 3. Tension belt correctly. 4. Replace belt. 5. Reroute hose to prevent contact. 6. Add fluid, check for leaks. 7. Replace hose. 8. Polish. Replace if badly scored. 9. Polish. Replace if badly scored. 10. Install vanes correctly. 11. Free vanes and clean thoroughly. 12. Replace flow control valve. 13. Tighten pump mounting fasteners. 14. Clean vent. 15. Drain, flush, and refill. 16. Overhaul as needed. 17. Tighten belt. 18. Fill to proper level.
Steering gear dull rattle or chuckle.	1. Gear loose on frame. 2. Loose over-center adjustment. 3. No worm shaft preload. 4. Insufficient or improper lubricant (manual gear).	1. Tighten gear mounting fasteners. 2. Make correct over-center adjustment. 3. Adjust preload. 4. Fill with specified lubricant.
Hissing sound in gear.	1. Normal sound when turning wheel when vehicle is standing still or when holding wheel against stops. 2. Loose gear. 3. Noisy pressure control valve. 4. Intermediate shaft rubber plug missing.	1. Normal condition, advise driver. 2. Tighten mounting fasteners. 3. Replace valve. 4. Replace plug.

Continued

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Manual and Power Steering Systems Diagnosis		
Condition	**Possible Causes**	**Correction**
Tire squeal on turns.	1. Excessive speed. 2. Low air pressure. 3. Faulty wheel alignment. 4. Excessive load. 5. Loose rack-and-pinion mountings.	1. Advise driver. 2. Inflate to correct pressure. 3. Align wheels. 4. Advise driver. 5. Tighten mountings to specifications.
External fluid leaks.	1. Defective hose. 2. Loose hose connections. 3. Cracked hose connections. 4. Defective pitman shaft seal in gear. 5. Gear housing end cover O-ring seal leaking. 6. Leaking gear torsion bar seal. 7. Leaking adjuster plug seals. 8. Leaking side cover gasket. 9. Pump too full. 10. Pump shaft seal defective. 11. Scored shaft in pump. 12. Oil leaking out of reservoir from air contamination. 13. Pump assembly fasteners loose. 14. Leaking power cylinder (linkage type). 15. Cracked rack-and-pinion housing. 16. Extreme cam ring wear. 17. Scored pressure plate, rotor, or thrust plate. 18. Incorrectly installed vanes. 19. Cracked reservoir. 20. Leaking pump reservoir cap. 21. Defective rack-and-pinion stub shaft seal.	1. Replace hose. 2. Tighten to proper torque. 3. Replace hose. 4. Replace seal. Check bearing for excessive wear. 5. Replace seal. 6. Replace valve and shaft assembly. 7. Replace seals. 8. Replace gasket. 9. Reduce fluid level. 10. Replace shaft seal. 11. Replace shaft. 12. Correct source of air leak. 13. Torque fasteners. 14. Overhaul as needed. 15. Replace steering gear. 16. Replace parts. Flush system. 17. Replace parts. Flush system. 18. Install pump vanes properly. 19. Replace reservoir. 20. Repair or replace cap. 21. Replace stub shaft seal.

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Chapter 79
Wheel Alignment

After studying this chapter, you will be able to:

- Explain the principles of wheel alignment.
- List the purpose of each wheel alignment setting.
- Explain toe-out on turns, steering axis inclination, and tracking.
- Perform a prealignment inspection of tires, steering, and suspension systems.
- Describe caster, camber, and toe adjustment.
- Describe the use of different types of wheel alignment equipment.
- Correctly answer ASE certification test questions about wheel alignment angles and procedures.

The term ***alignment*** means "to position in a straight line." Relating to passenger vehicles, wheel alignment means to adjust the suspension geometry so that all four tires roll in a straight line with full tread contact on the road surface.

Correct wheel alignment is essential to automobile safety, sure handling, maximum fuel economy, and long tire life. This chapter introduces both the principles and the basic procedures for wheel alignment.

Tech Tip

For a complete understanding of the information in this chapter, you should have studied the previous chapters on wheel bearings, suspension systems, and steering systems. These systems must be in good condition before attempting wheel alignment.

Wheel Alignment Principles

The main purpose of ***wheel alignment*** is to make the tires roll without scuffing, slipping, or dragging under all operating conditions. Six fundamental angles or specifications are needed for proper wheel alignment:

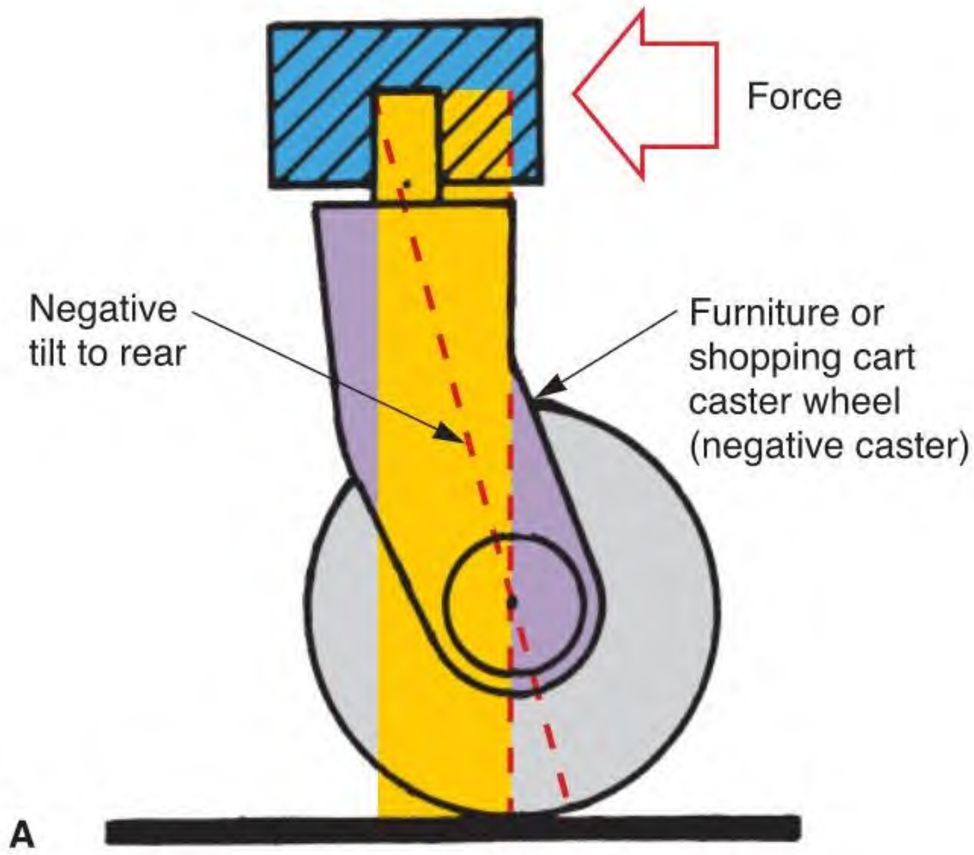
- Caster.
- Camber.
- Toe.
- Steering axis inclination.
- Toe-out on turns (turning radius).
- Tracking (thrust line).

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Caster

Caster is basically the forward or rearward tilt of the steering knuckle (spindle support) when viewed from the side of the vehicle. You are probably familiar with the term *caster* from furniture casters. See **Figure 79-1**.

Caster controls the tire's load distribution in relation to an imaginary centerline drawn through the spindle support. It is *not* a tire wearing angle, but a directional stability angle.



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Figure 79-1. Caster is determined by the contact point of the tire and an imaginary centerline through the spindle support. A—Negative caster of ball joints is illustrated by a shopping cart wheel. The wheel follows the irregular surfaces in the floor. B—Positive caster, like that on a front bike tire, makes the front wheel travel straight ahead.

The basic purposes of caster are:

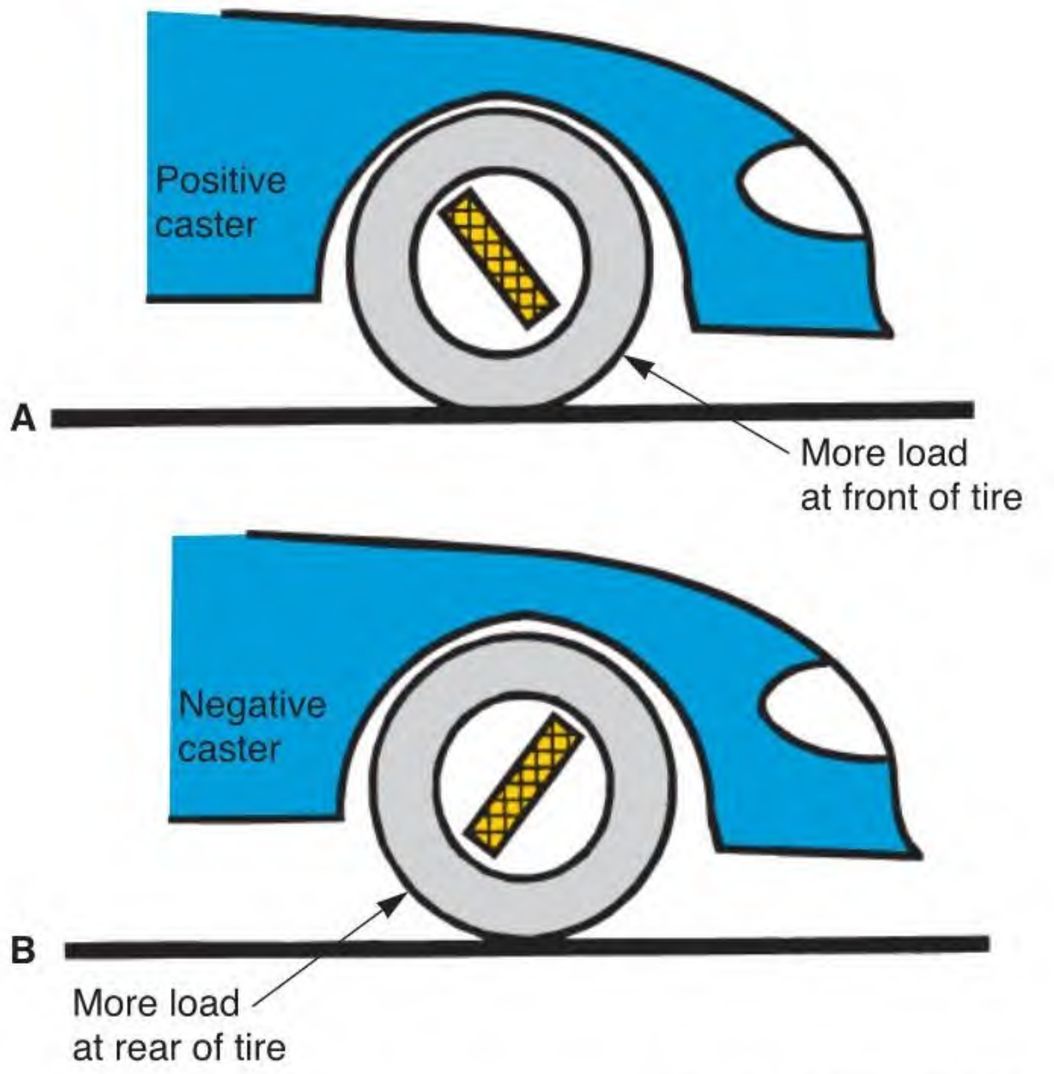
- To aid directional control of the vehicle.
- To cause the wheels to return to the straight-ahead position.
- To offset ***road crown pull*** (steering wheel pull caused by hump in center of road).

Positive caster tilts the top of the steering knuckle toward the rear of the vehicle. Positive caster helps keep the vehicle's wheels traveling in a straight line. When you turn the wheels, it lifts the vehicle. Since this takes extra turning force, the wheels resist turning and try to return to the straight-ahead position. See **Figure 79-2A**.

Negative caster tilts the top of the steering knuckle toward the front of the vehicle. It is the opposite of positive caster. With negative caster, the wheels will be easier to turn. However, the wheels will tend to swivel and follow imperfections in the road. Look at **Figure 79-2B**.

Caster is measured in *degrees*, starting at the true vertical (plumb line). Auto manufacturer's give specs for caster as a specific number of degrees positive or negative. This is illustrated in **Figure 79-3**.

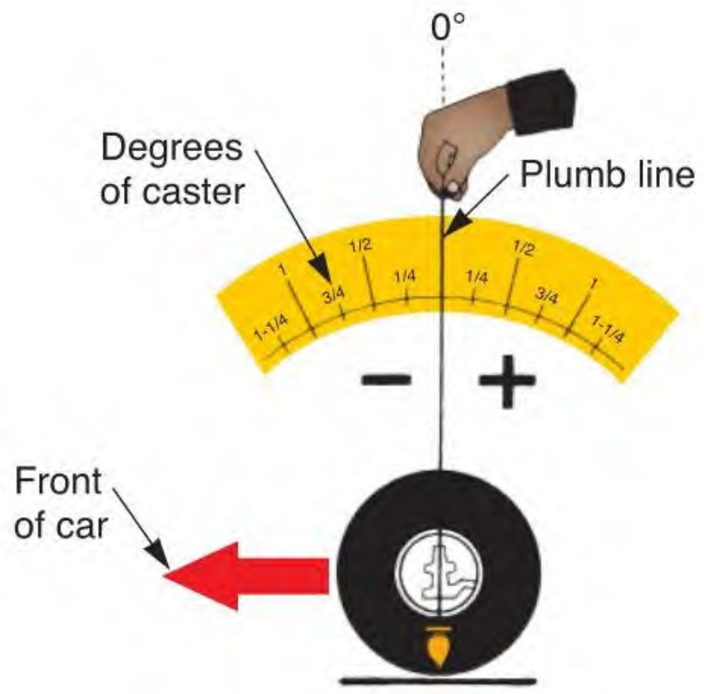
Typically, positive caster is recommended for vehicles with power steering. To ease steering effort,



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Figure 79-2. A—Positive caster tilts the steering knuckle toward the rear of the vehicle. B—Negative caster tilts the steering knuckle toward the front of the vehicle.

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Bear

Figure 79-3. Caster is measured in degrees, as shown.

negative caster is recommended for vehicles with manual steering.

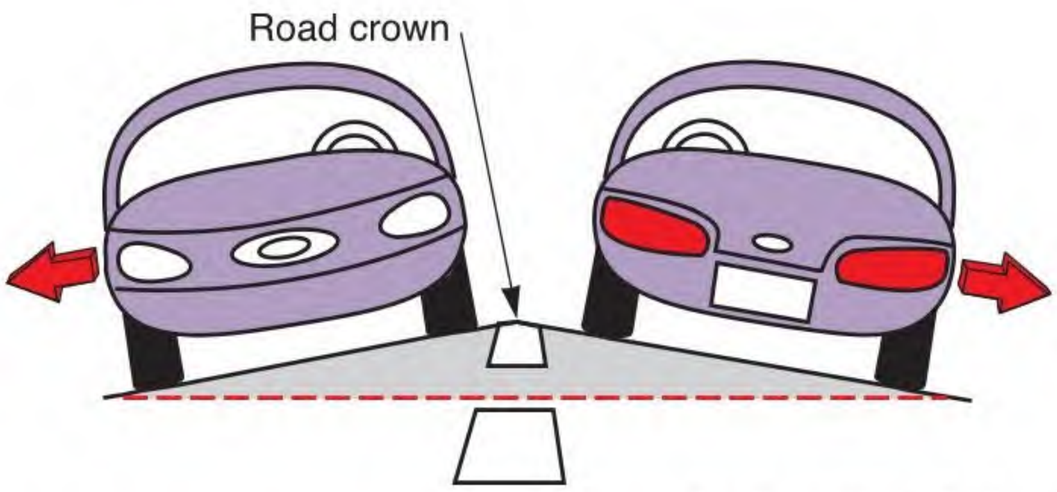
Caster and Road Crown Effect

Caster is a *directional control* angle. It determines whether the vehicle travels straight or pulls (steering wheel tries to turn) to the right or left.

Road crown is the normal slope toward the outer edge of the road surface. Most road surfaces angle downward from the center. This helps keep rainwater from collecting on the pavement.

If the caster of both front wheels were the same, the road crown could make the vehicle pull or steer toward the outside (lower) edge of the road, **Figure 79-4**.

Since caster is a directional control angle, it is commonly used to offset the effect of road crown. The right front wheel may be set with slightly more positive caster than the left. This counteracts the forces caused by the road crown, and the vehicle will travel straight ahead.



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Figure 79-4. Most roads are crowned in the center to help water flow off the surface. Unequal caster can be used to offset road crown and keep the vehicle from trying to steer off the road.

Camber

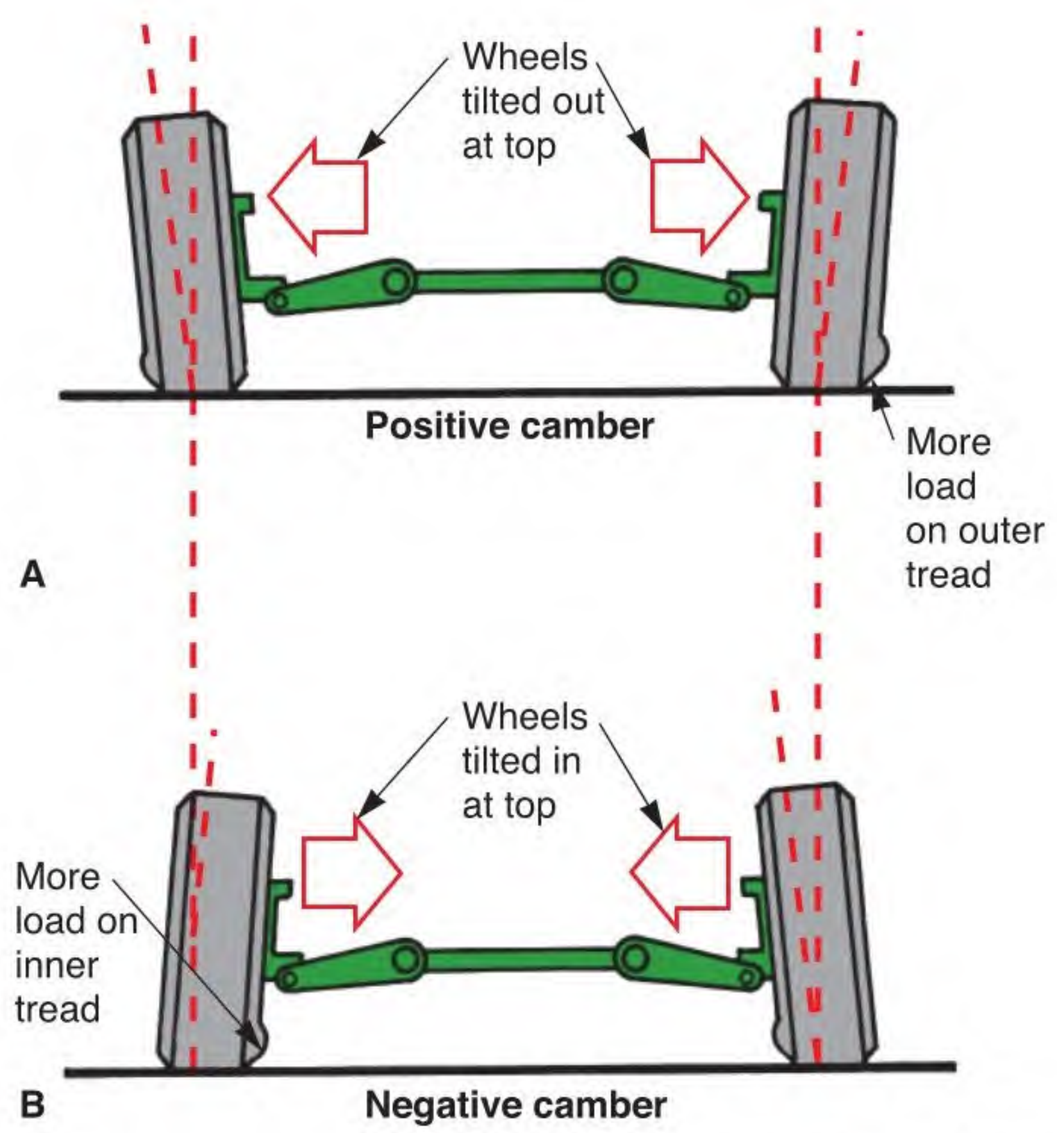
Camber is the inward or outward tilt of the wheel and tire assembly when viewed from the front of the vehicle. It controls whether the tire tread touches the road surface evenly. Camber is a tire-wearing angle and is measured in degrees. Refer to **Figure 79-5**.

There are three reasons for camber:

- To prevent tire wear on the outer or inner tread.
- To load the larger inner wheel bearing.
- To aid steering by placing vehicle weight on the inner end of the spindle.

With ***positive camber***, the tops of the wheels tilt outward when viewed from the front of the vehicle, **Figure 79-5A**. With ***negative camber***, the tops of the wheels tilt inward when viewed from the front. Refer to **Figure 79-5B**.

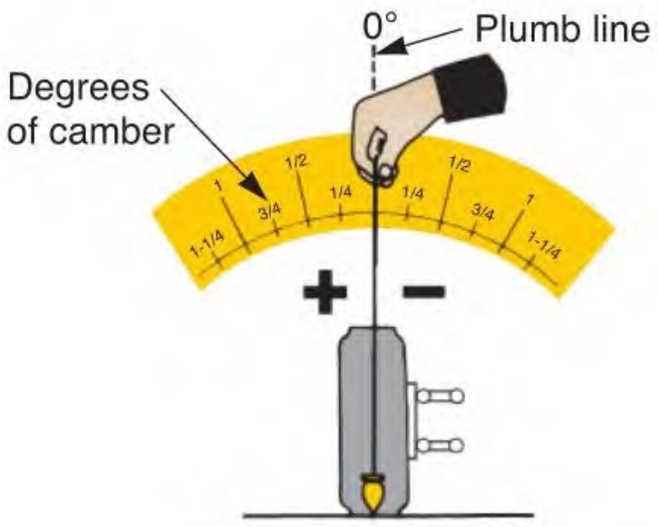
Negative and positive camber are measured from the true vertical (plumb line). If the wheel is aligned with the plumb line, camber is zero, **Figure 79-6**.



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Figure 79-5. Camber is determined by the inward or outward tilt of the wheels when viewed from the front of a vehicle. Positive camber has the wheels tilted out at the top. Negative camber has the wheels tilted out at the bottom.

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Bear

Figure 79-6. Camber is measured in degrees, as shown.

Camber Settings

Most vehicle manufacturers suggest a slight positive camber setting (about 1/4° to 1/2°). Suspension wear and above-normal weight, caused by several passengers or extra luggage, tend to increase negative camber. Positive camber counteracts this tendency.

Toe

Toe is determined by the difference in distance between the front and rear of the left- and right-hand wheels. Look at **Figure 79-7**.

Measured in inches or millimeters, toe controls whether the wheels roll in the direction of travel. Toe is very critical to *tire wear*. If the wheels do *not* have the correct toe setting, the tires will scuff, or skid sideways.

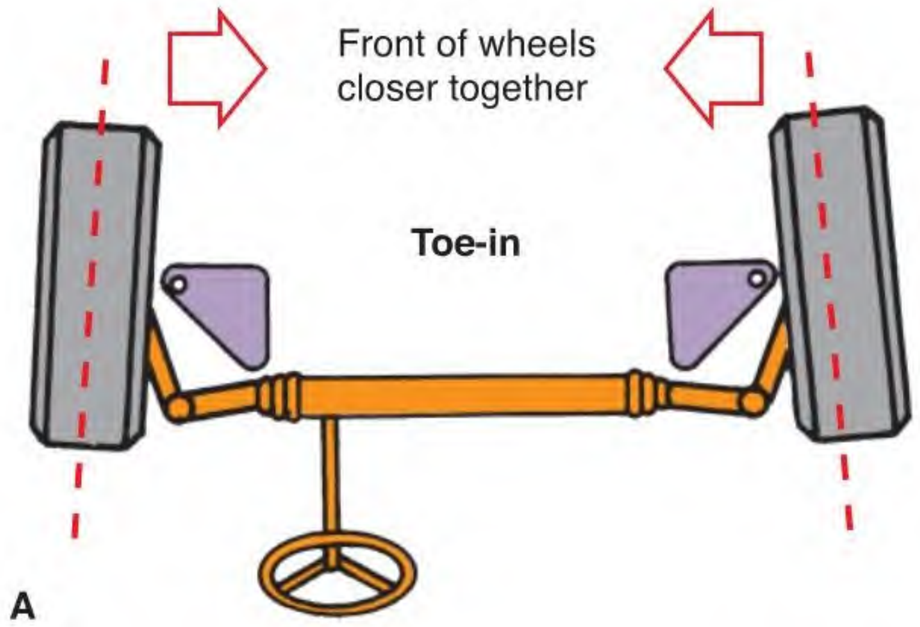
Toe-in is produced when the wheels are closer at the front than at the rear. Toe-in causes the wheels to point inward at the front, **Figure 79-7A**.

Toe-out results when the wheels are farther apart at the front than at the rear. Toe-out causes the front of the wheels to point away from each other. See **Figure 79-7B**.

Front-wheel-drive and rear-wheel-drive vehicles normally require much different toe settings. This is because the front-wheel drive tends to pull the front tires forward. With rear-wheel-drive vehicles, rolling resistance tends to push the front tires backward.

Rear-Wheel-Drive Toe Settings

Rear-wheel-drive vehicles are usually set to have *toe-in* at the front wheels. This is because the front wheels tend to toe-out while driving. Toe-in is needed to compensate for the action of tire rolling resistance, play in the steering system, and suspension system action.



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Figure 79-7. Toe is an inward or outward angle of the wheels. Toe-in is produced when the wheels are closer together at the front than at the rear. Toe-out results when the wheels are farther apart at the front than at the rear.

As the tires roll over the road, they are pushed rearward. This turns the tires outward at the front, causing toe-out. By adjusting the wheels for a slight toe-in (approximately 1/16″–1/4″ or 1.6 mm–6 mm), the wheels and tires roll straight ahead when driving.

Front-Wheel-Drive Toe Settings

Front-wheel-drive vehicles require different adjustment for toe. Since the front wheels propel the vehicle, they are pushed forward by engine torque. This makes the wheels toe in, or point inward when the vehicle is driven.

To compensate for this action, front-wheel-drive vehicles normally have front wheels adjusted for a slight toe-out (approximately 1/16″ or 1.6 mm). Theoretically, this will give the front end a zero toe setting when the vehicle moves down the road.

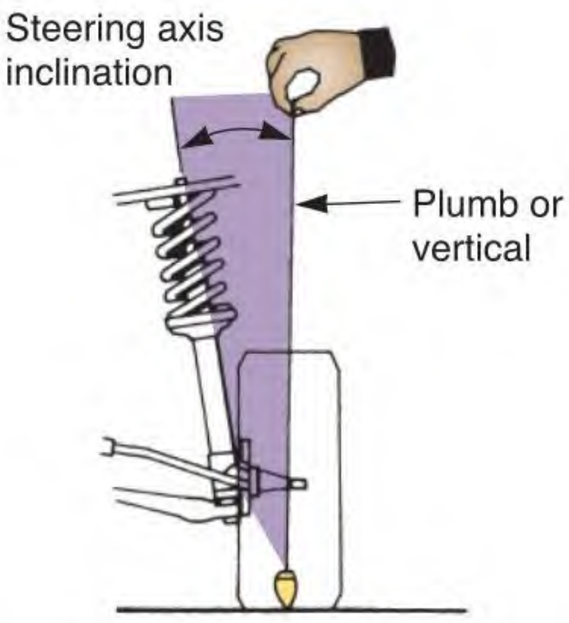
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Steering Axis Inclination

Steering axis inclination is the angle, away from the vertical, formed by the inward tilt of the ball joints, king pin, or MacPherson strut tube. Steering axis inclination is always an inward tilt, regardless of whether the wheel tilts inward or outward. See **Figure 79-8**.

Steering axis inclination is *not* a tire wearing angle. Like caster, it aids directional stability by helping the steering wheel return to the straight-ahead position.

Steering axis inclination is *not* adjustable. It is designed into the suspension system by the vehicle manufacturer. If the angle is *not* correct, you must replace parts to correct the problem.



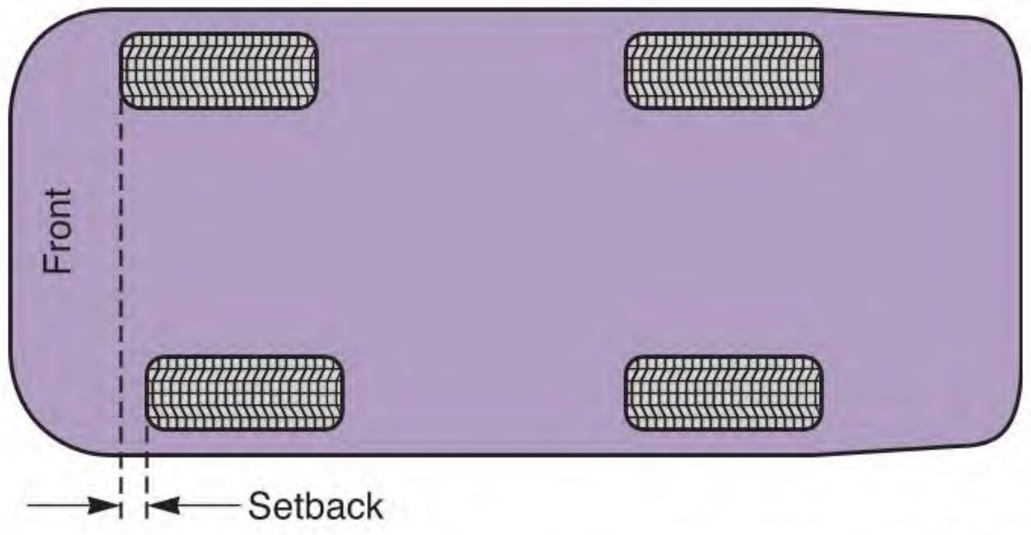
Bear

Figure 79-8. Steering axis inclination is determined by a vertical line and a projected line through upper ball joint, king pin, or MacPherson strut tube.

Setback

Setback is a condition in which one front wheel is set farther back from the front of the vehicle than the other front wheel. See **Figure 79-9**. When setback is positive, the right wheel is farther back than the left wheel. Negative setback is present when the left wheel is farther back than the right wheel.

Manufacturing tolerances generally allow a small amount of setback. However, excessive setback will cause the vehicle to pull toward the side with the wheel that is the farthest back. Excessive setback is generally the result of collision damage.



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Figure 79-9. Setback is present when one front wheel is set farther back than the other front wheel. Excessive setback is an indication of suspension system damage.

Toe-Out on Turns (Turning Radius)

Toe-out on turns, also termed ***turning radius***, is the amount the front wheels toe-out when turning corners. As the vehicle goes around a turn, the inside tire must travel in a smaller radius circle than the outside tire. The steering system is designed to turn the inside wheel sharper than the outside wheel.

Figure 79-10 illustrates toe-out on turns. Note how each front wheel turns at a different angle. This eliminates tire scrubbing and squealing by keeping the tires rolling in the right direction during turns.

Toe-out on turns is *not* an adjustable angle. It is controlled by the built-in angle of the steering arms. If this angle is incorrect, it indicates bent or damaged steering parts.

Tracking

Tracking refers to the position or direction of the two front wheels in relation to the two rear wheels. With proper tracking, the rear tires follow in the tracks of the front tires, with the vehicle moving straight ahead. Look at **Figure 79-11**.

With improper tracking, or "***dog tracking***," the rear tires do *not* follow the tracks of the front tires. This causes the back of the vehicle to actually shift sideways compared to the front when the vehicle is traveling down the road. Poor tracking will increase tire wear, lower fuel economy, and degrade handling tremendously.

Prealignment Inspection

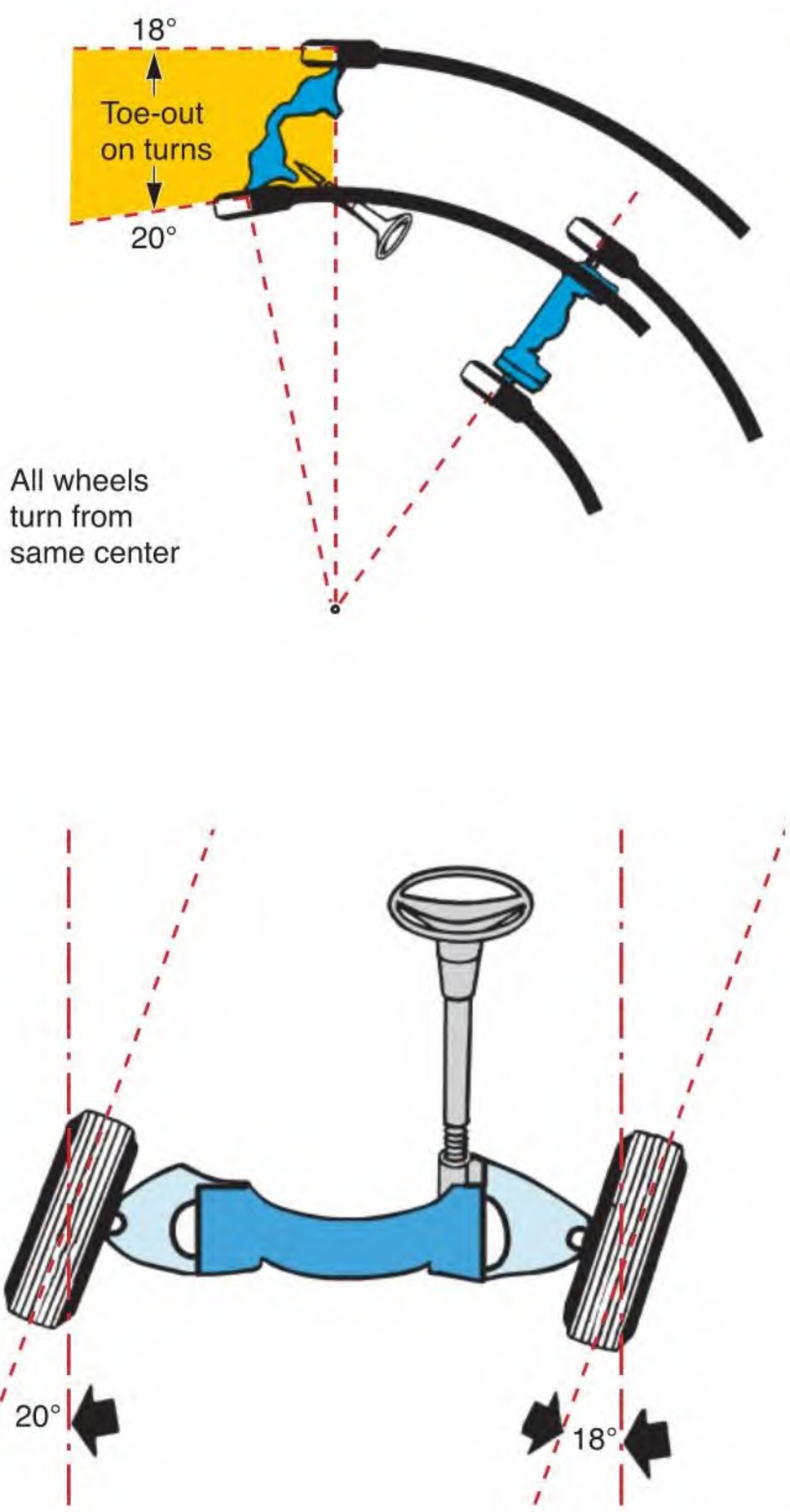


Before attempting wheel alignment, make sure all steering- and suspension-related parts are in good condition. It is impossible to properly align the wheels on a vehicle with worn or damaged parts.

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You should check for:

- Loose wheel bearings.
- Wheel or tire runout.
- Worn tires.
- Tires of different sizes and types.
- Incorrect tire inflation.
- Worn steering components.
- Worn suspension components.
- Incorrect curb height and weight.
- Incorrect cradle alignment.



Hunter

Figure 79-10. When rounding corners, the inside tire must turn more sharply than the outside tire. Angles built into the steering system produce proper toe-out on turns.

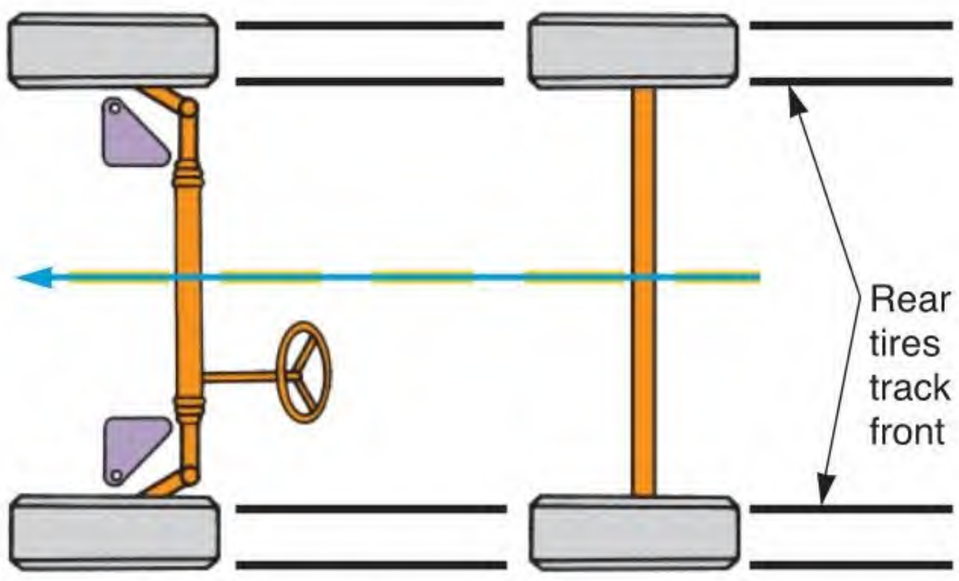
Figure 79-12 shows several components that frequently cause problems during alignment. Adjust or replace worn or damaged parts before doing a wheel alignment. Refer to the text index for details on checking the specific components.

Tech Tip

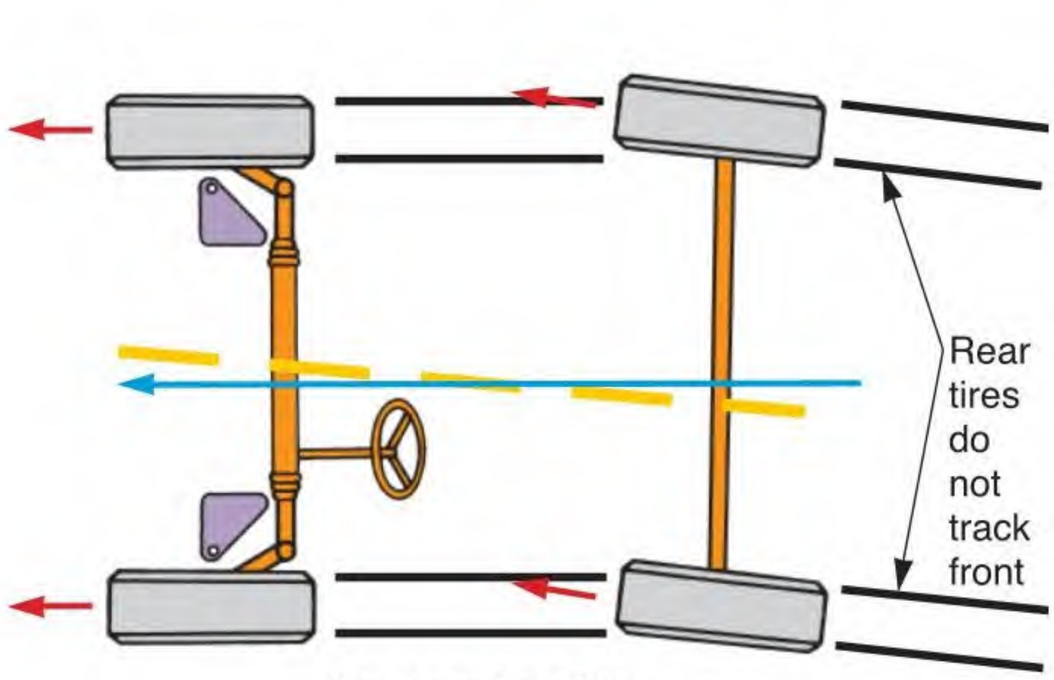
Many technicians like to road test the vehicle before doing a wheel alignment. This allows them to check for the kinds of problems just listed. The road test helps them detect steering wheel pull or play, abnormal noises from worn parts, and similar troubles that could affect wheel alignment.

Reading Tire Wear

Reading tires is done by inspecting tire tread wear and diagnosing the cause for any abnormal



4-wheel alignment

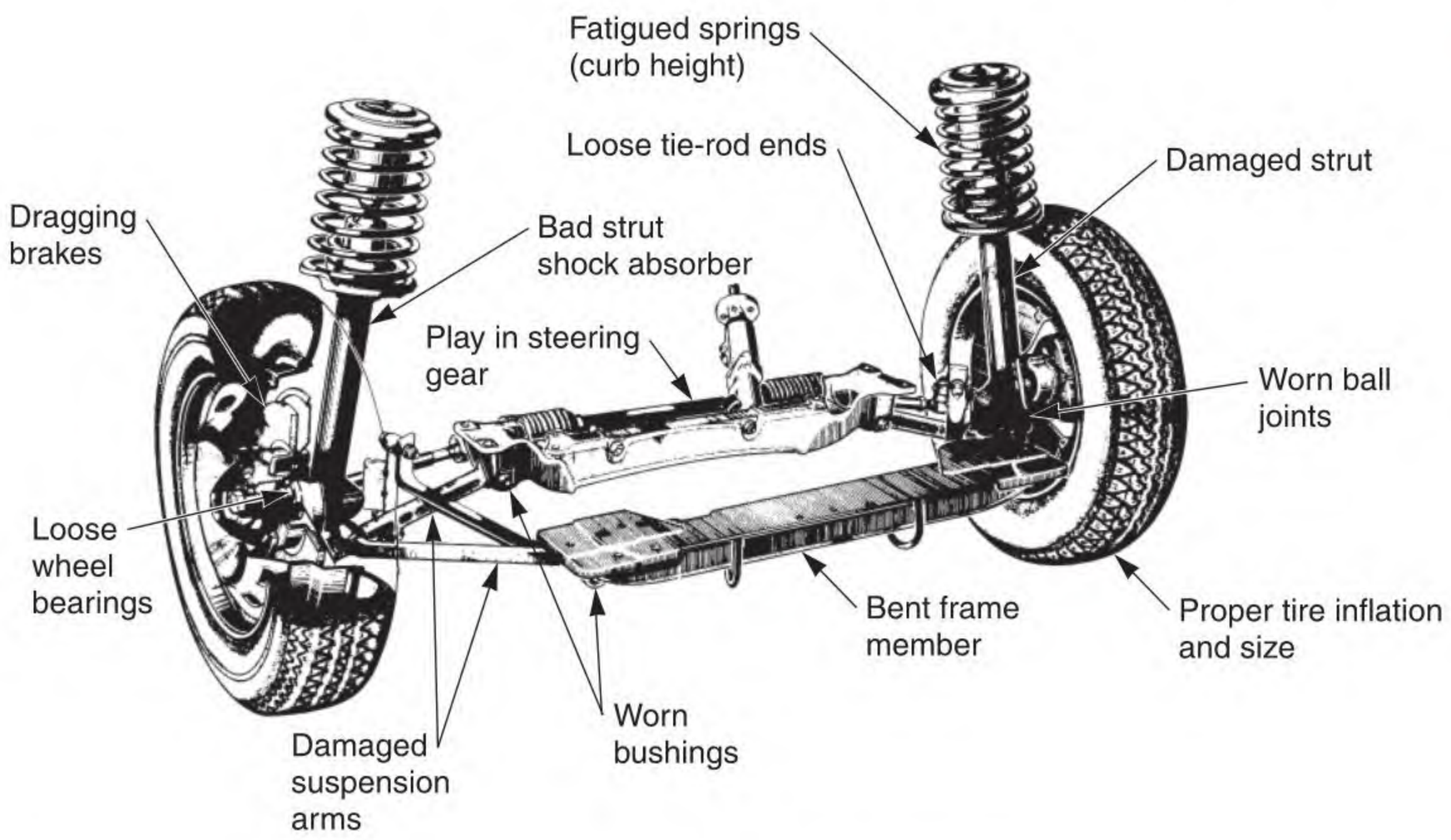


Improper tracking

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Figure 79-11. Proper tracking causes the rear wheels to follow directly behind the front wheels.

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Alignment Inspection Report Form

Name_____ Date_____, 20____

Address_____ Phone: Bus._____ Home_____

Make_____ Yr. and Model_____ License_____ Odometer _____

Tire and wheel checks

Tire condition-	Inspection	OK: LF__ RF__ LR __ RR__	**Comments:**
Tire pressure		OK: LF__ RF__ LR __ RR__	
Wheel bearings-	Adjustment	OK: LF__ RF__ LR __ RR__	
	Roughness	OK: LF__ RF__ LR __ RR__	
Runout-Lateral		OK: LF__ RF__ LR __ RR__	
Radial		OK: LF__ RF__ LR __ RR__	
Wheel balance		OK: LF__ RF__ LR __ RR__	
Shock absorbers-	Operational	OK: LF__ RF__ LR __ RR__	
	Leakage and	OK: LF__ RF__ LR __ RR__	
	Bushings	OK: LF__ RF__ LR __ RR__	
Riding height		OK: LF__ RF__ LR __ RR__	

Suspension checks

Tracking	OK:__	**Comments:**
MacPherson-type struts	OK: LF__ RF__	
Ball joints	OK: LU__ LL__ RU __ RL__	
Front control arm assembly	OK: LU__ LL__ RU__ RL__	
Strut rod and bushing assembly	OK: L__ R__	
Stabilizer (or sway) bar, mounting brackets, and links	Front: OK__ Rear: OK__	
Leaf spring assembly	OK: L__ R__	
Rear coil spring assembly	OK: L__ R__	
Rear control arm assembly	OK: LU__ RU__ LL __ RL__	
Track bar and bushings	OK:__	

Steering linkage checks

Tie-rod end	OK: ____ L__ R__	**Comments:**
Tie-rods and inner ball/stud sockets	OK: ____ L__ R__	
Steering arms	OK: ____ L__ R__	
Tie-rod adjusting sleeves	OK: ____ L__ R__	**Comments:**
Relay rod	OK: ____	
Pitman arm	OK: ____	
Idler arm and bracket	OK: ____	
Steering shock absorber and bushings	OK: ____	
Steering gear mountings	OK: ____	

Manual steering gear – inspection

Lubricant leakage	OK: ____	**Comments:**
Operation	OK: ____	
Sector shaft and bearings	OK: ____	
Adjustment of gear	OK: ____	
Lubricant level	OK: ____	

Power steering gear – inspection

Fluid leakage	OK: ____	**Comments:**
Power steering hoses	OK: ____	
Power steering pump	OK: ____	
Fluid level	OK: ____	
Pump belt	OK: ____	
Power steering operation	OK: ____	
Steering gear adjustment	OK: ____	
Sector shaft and bushings	OK: ____	
Pinion shaft and bearings	OK: ____	
Control valve	OK: ____	

Front alignment check	Reading	Manufacturer's standard	OK
Caster	L__ ° R__ °	L__ ° R__ °	
Camber	L__ ° R__ °	L__ ° R__ °	
Steering axis inclination	L__ ° R__ °	L__ ° R__ °	
Turning radius	L__ ° R__ °	L__ ° R__ °	
Toe	In__ Out__	In__ Out__	

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Figure 79-12. Study the problems that can affect front wheel alignment. All these must be corrected before wheels can be aligned.

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wear. Note that incorrect camber and toe show up as specific tread wear patterns. **Figure 79-13** shows various tire wear patterns.

Incorrect camber produces wear on one side of the tire tread. Too much negative camber would wear the *inside* of the tire tread. Too much positive camber would wear the *outer* tread only. With correct camber, the *full* tread area will wear evenly.

Incorrect toe will cause a feathered edge to form on the tire tread. A ***feathered edge*** is a tire wear pattern in which one side of each tread rib is sharp and raised and the other side of each rib is rounded or recessed.

With too much toe-in, the sharp feathered edge points inward (toward the center of the vehicle). With too much toe-out, the sharp edge on the thread ribs points outward.

Covered in earlier chapters, tire wear patterns can also indicate incorrect wheel balance, incorrect tire inflation pressure, tire construction defects, and tire damage.

Checking Setback

To check for excessive setback, measure the distance from the rear of one front wheel or tire to the inside of the corresponding fender opening. Then, take the same measurement at the other front wheel or tire and compare the two dimensions. In most cases, setback should be 1/4″ (6 mm) or less.

Tech Tip

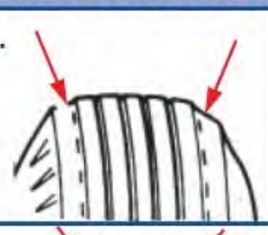
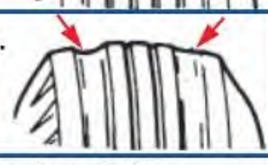
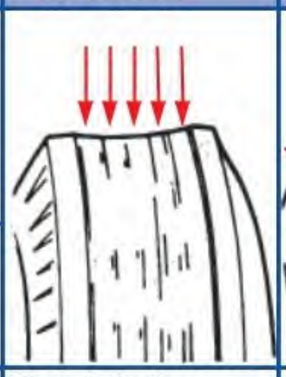
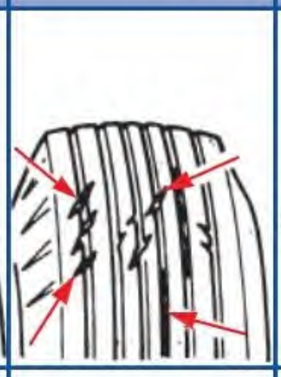
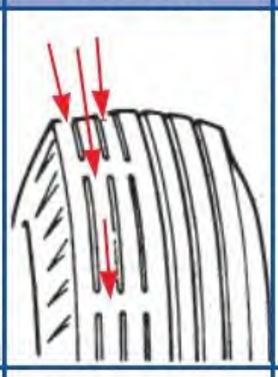
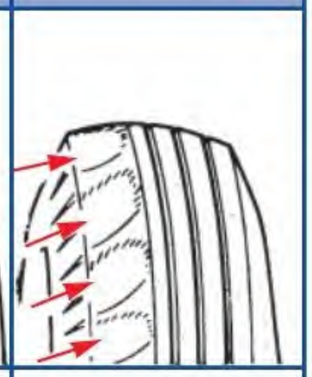
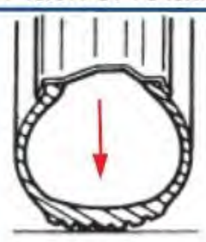
Some manufacturers purposely design a small amount of setback into their vehicles. Refer to appropriate service information for exact specifications.

Setback that is greater than specifications may indicate a bent or damaged suspension component. Cradle misalignment can also cause excessive setback. Identify the problem and make any needed repairs before performing an alignment.

Cradle Alignment

The ***vehicle cradle*** is a strong metal structure mounted at the lower front and sometimes the lower rear of the unibody structure. The thick metal cradle is bolted to the frame rails on the body. The cradle often holds the lower control arms, steering rack, and engine in alignment in the body.

Loosening and moving the cradle can alter wheel alignment (camber, caster, setback, and steering axis inclination). This misalignment might happen

	Rapid wear at shoulders	Rapid wear at center	Cracked treads	Wear on one side	Feathered edge	Bald spots	Scalloped wear
CONDITION	1.  2. 						
CAUSE	Underinflation or lack of rotation 	Overinflation or lack of rotation 	Underinflation or excessive speed	Excessive camber 	Incorrect toe 	Unbalanced wheel  or tire defect	Lack of rotation of tires or worn or out of alignment suspension
CORRECTION	Adjust pressure to specifications when tires are cool, rotate tires			Adjust camber to specifications	Adjust toe-in to specifications	Dynamic or static balance wheels	Rotate tires and check alignment

Chrysler

Figure 79-13. Tire wear patterns should be read to help determine which steering or suspension parts are worn and to help with alignment checks.

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after engine or transaxle and cradle removal. A major collision can also shift the cradle and upset wheel alignment.

Improper cradle location can reduce wheel alignment adjustment range. It can also cause premature tire wear, vehicle instability, and incorrect drive line angles.

If you ever remove a cradle, make sure it is reinstalled in the same location. This will help maintain proper wheel alignment. Alignment holes are often provided in the cradle and body. Make sure these holes align when reinstalling or adjusting a cradle. The service manual will give information on proper installation and location of the cradle.

Adjusting the position of the cradle is handy on front-wheel-drive vehicles that do not provide a method of adjusting caster and camber. By shifting the cradle forward, rearward, or to one side, you can alter these angles. Keep this in mind if you run into problems when trying to perform a wheel alignment.

Tech Tip

Before trying to align the wheels of a car, make sure all steering and suspension parts are in perfect working condition. Worn tie-rod ends or sloppy ball joints will have too much play to hold your alignment setting. Worn steering and suspension parts are very dangerous and must be replaced before proceeding with any wheel alignment job.

If the customer will not pay to replace the worn steering or suspension parts, have him or her sign a waiver on the work order. Write down the worn parts on the work order and have the customer sign or initial it before proceeding. This will protect you and your shop from liability if the worn steering or suspension parts fail and cause a serious auto accident later.

Adjusting Wheel Alignment

Caster, camber, and toe are the three commonly adjustable wheel alignment angles.

Before studying wheel alignment equipment, you should have a basic understanding of how alignment angles are changed. Then, you can relate this knowledge to the use of specific alignment equipment.

The basic sequence for wheel alignment is:

1. Inspect and correct tire, steering, and suspension problems.
2. Adjust caster.
3. Adjust camber and recheck caster.
4. Adjust toe.
5. Check toe-out in turns (needed if there is damage).
6. Check caster, camber, and toe on rear wheels (if needed).
7. Check tracking (if needed).

Caster Adjustment Methods

Caster is adjusted by moving the control arm so that the ball joint moves toward the front or rear of the vehicle. Depending on suspension system type, a control arm can be moved by adding or removing ***shims***, adjusting the ***strut rod***, turning an ***eccentric bolt***, or shifting the control arm shaft bolts in ***slotted holes***. See **Figure 79-14**.

If the upper control arm ball joint is moved forward, negative caster is increased, **Figure 79-15A**. If the upper control arm ball joint is moved rearward, positive caster is increased. The opposite is true for the lower control arm.

Camber Adjustment Methods

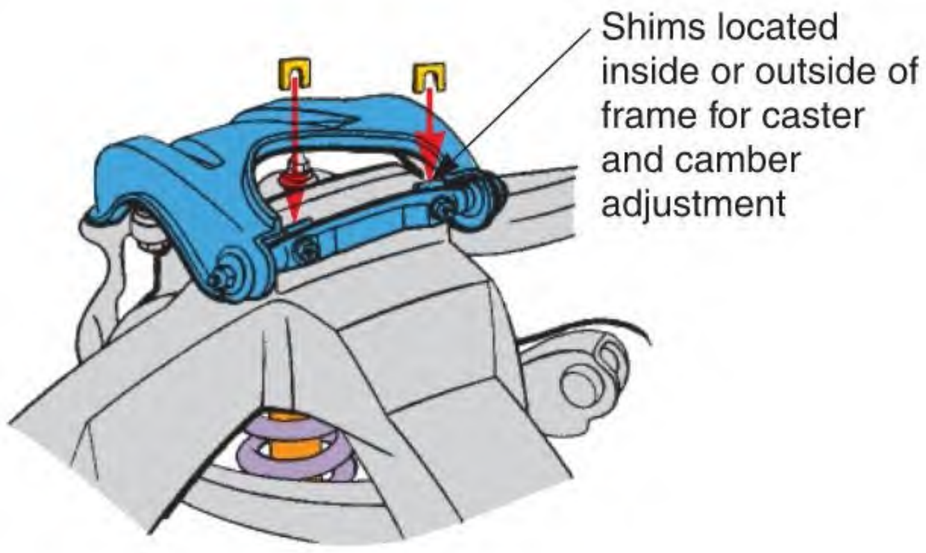
Camber is usually adjusted after setting caster. Camber is changed by moving the control arm in or out *without* moving the ball joint forward or rearward. *Shims* or *slots* in the control arm mount and *eccentric bolts* are the most common methods for adjustment. Refer to **Figure 79-15B**.

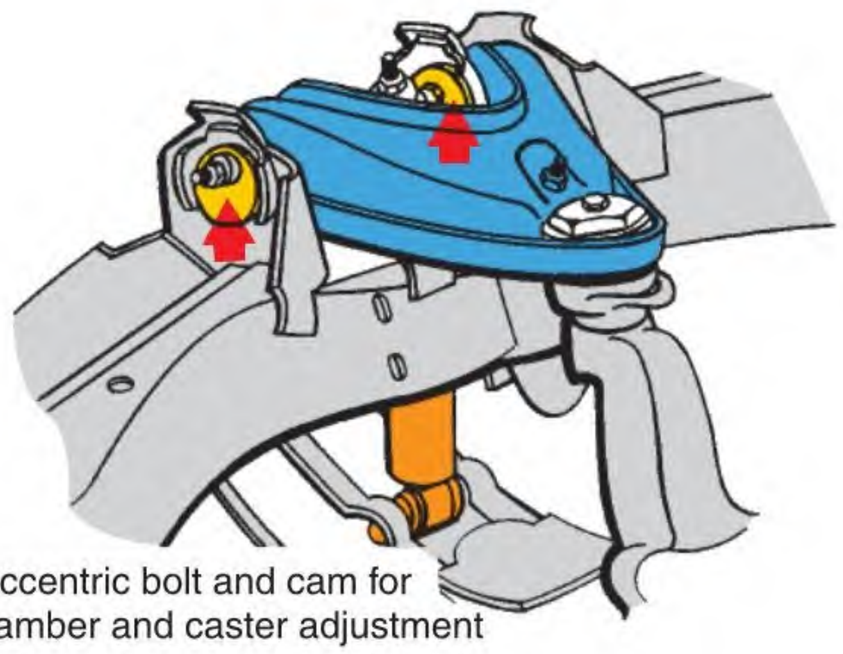
Some MacPherson strut suspensions do not have provisions for caster and camber adjustments. However, other strut-type suspension systems have a camber adjustment at the connection between the steering knuckle and strut. The top of the steering knuckle and the bottom of the strut can be pivoted in or out. The upper bolt on the steering knuckle may have an eccentric that moves the knuckle when turned.

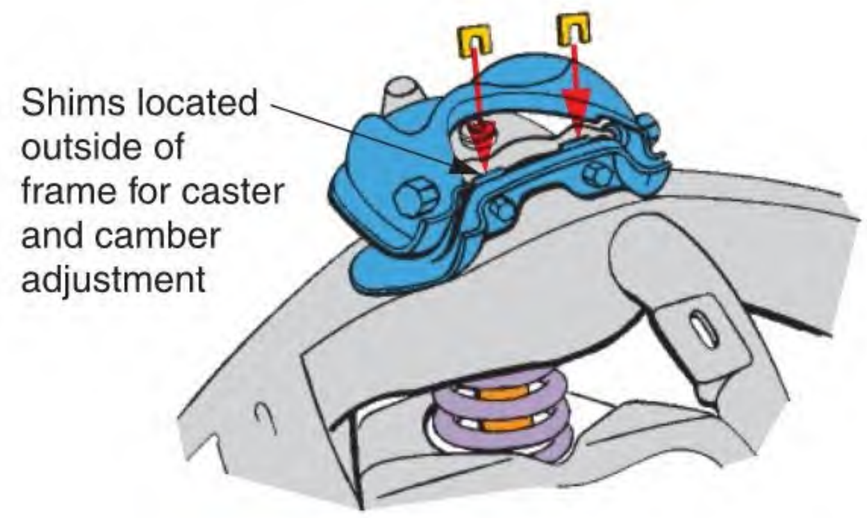
Toe Adjustment

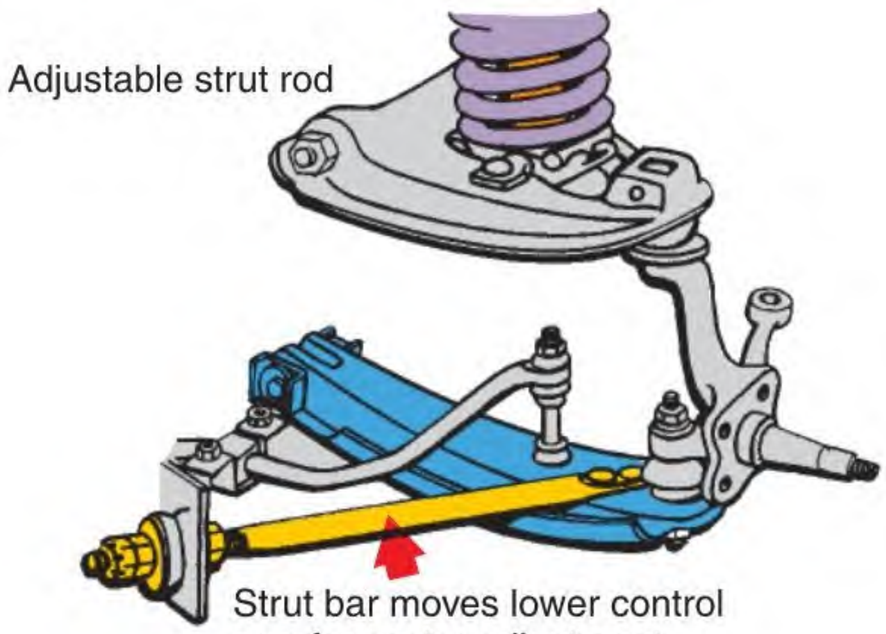
Toe is adjusted by lengthening or shortening the *tie-rods*. On most rack-and-pinion steering systems, the tie-rod is threaded into the outer ball socket, **Figure 79-16**. Linkage type steering systems normally have a sleeve that is threaded on a two-piece tie-rod, **Figure 79-17**.

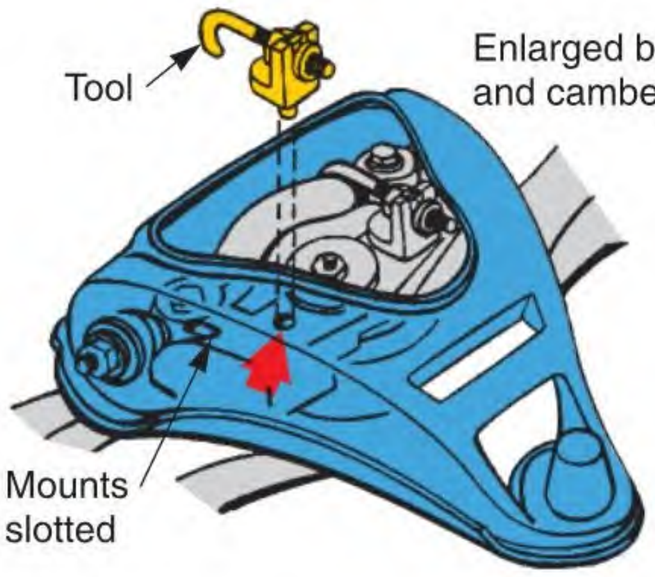
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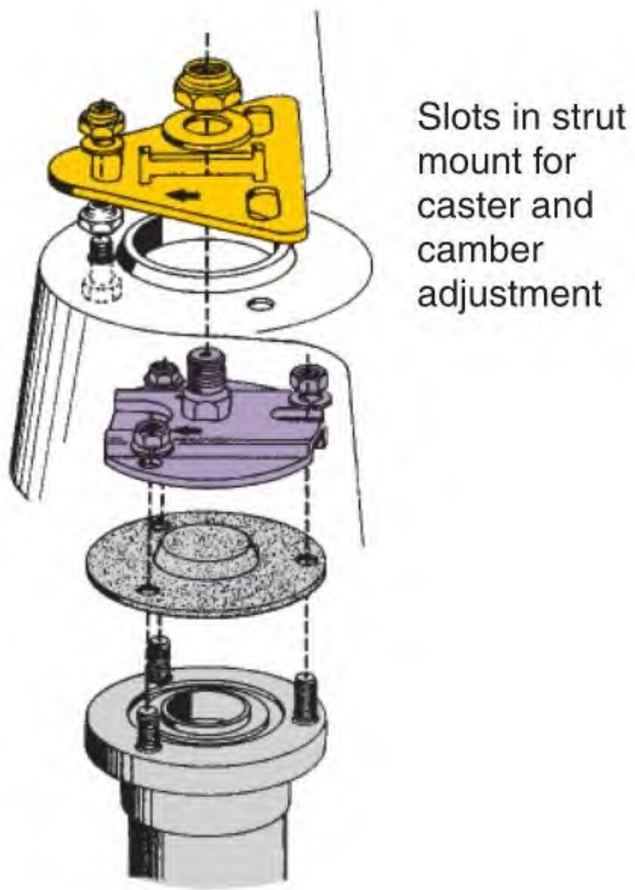


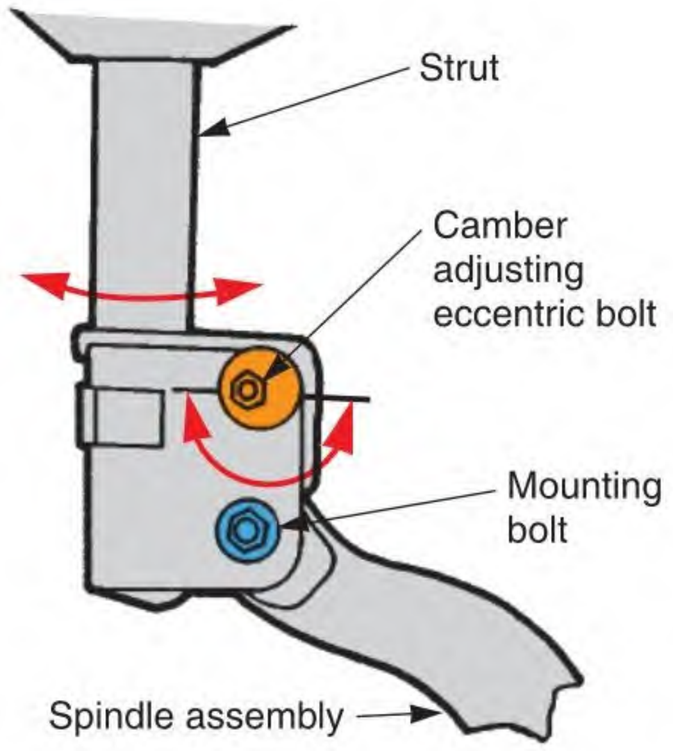








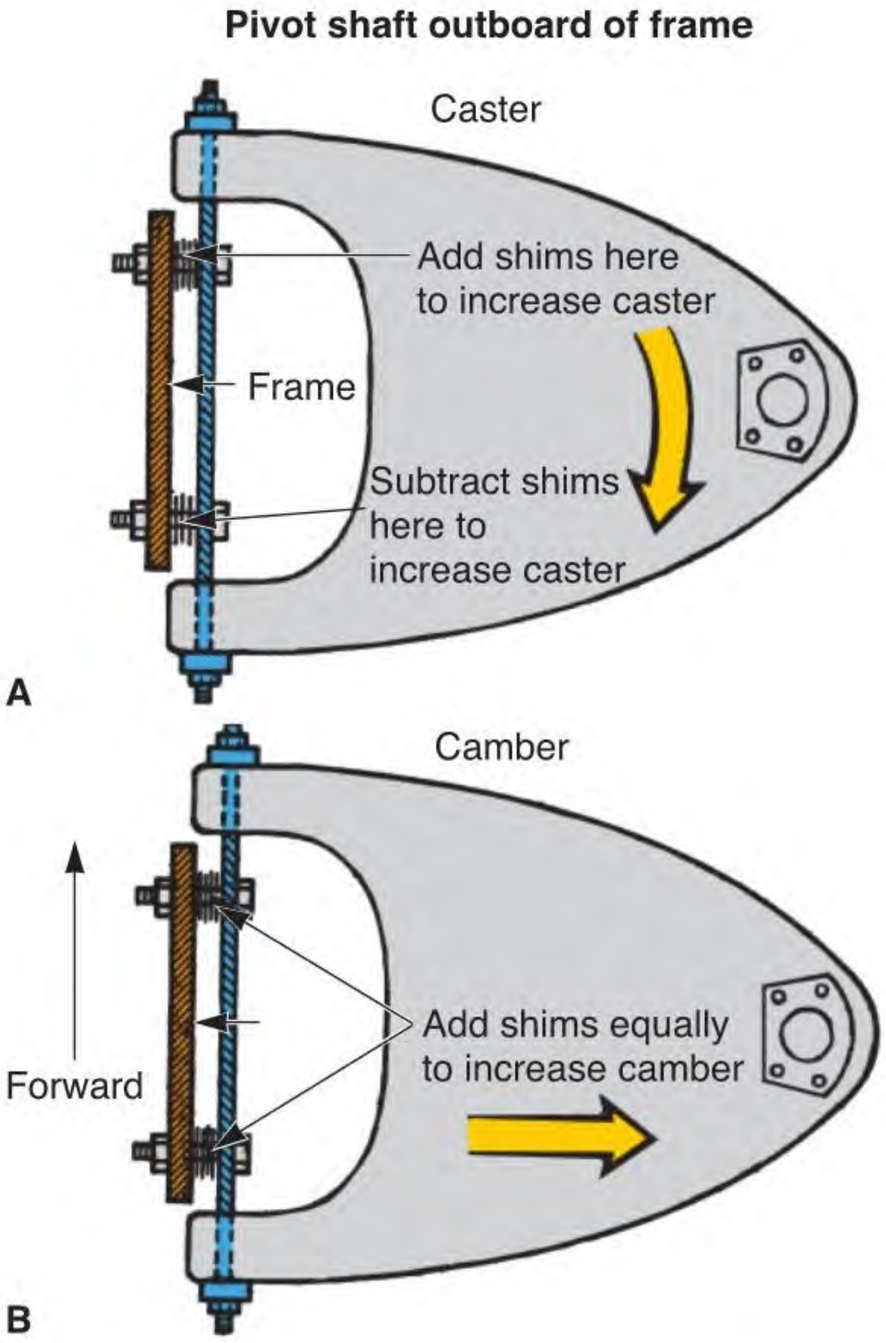




Hunter; Moog; Florida Dept. of Voc. Ed.

Figure 79-14. Study the various methods used to change caster and camber settings.

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Figure 79-15. A—Caster is adjusted by moving either the upper or lower control arm to the front or rear of the vehicle. B—Camber is adjusted by moving the control arm in or out without moving the ball joint forward or rearward.

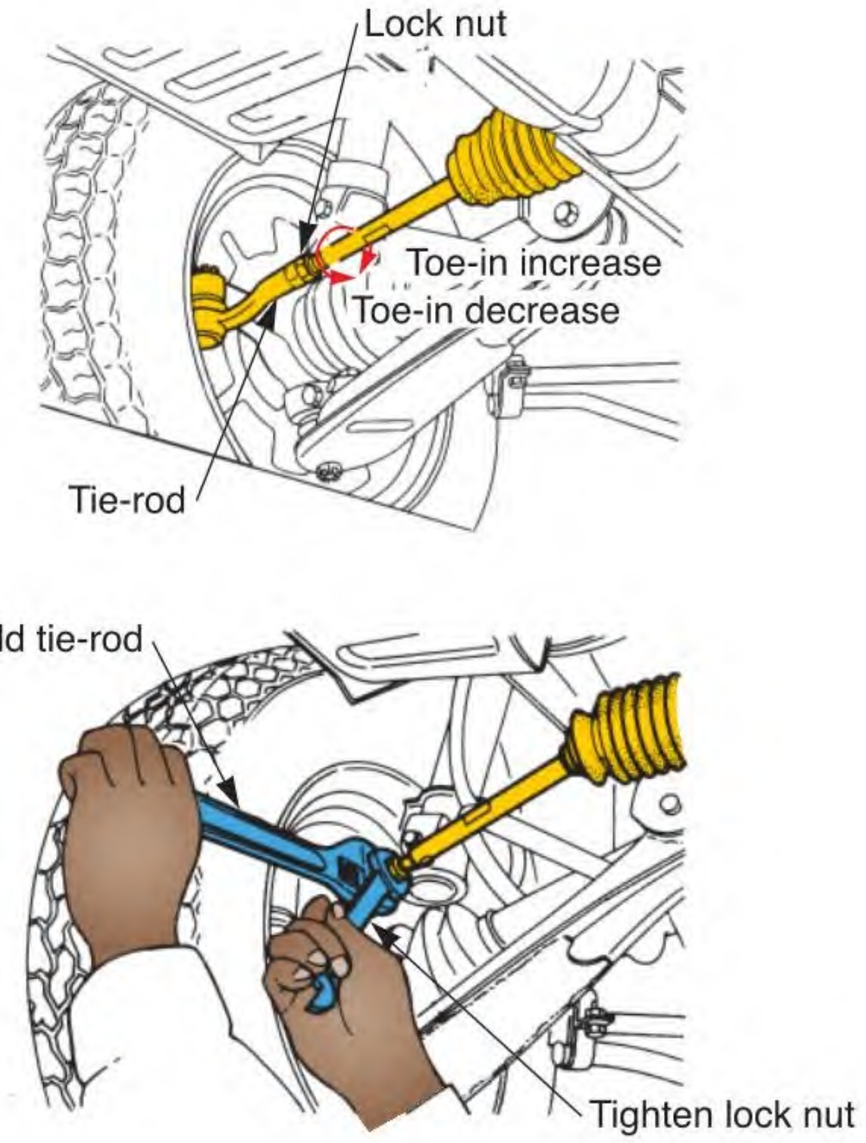
When the steering knuckle arms point to the rear of the vehicle, lengthen each tie-rod to increase toe-in and shorten each rod to increase toe-out. The opposite is true when the steering knuckle arms are pointed forward.

Centering Steering Wheel

To keep the steering wheel spokes centered, shorten or lengthen each tie-rod the same amount. Changing one tie-rod more than the other will rotate the steering wheel spokes. When the vehicle is traveling straight ahead, the wheel spokes should be positioned correctly. See **Figure 79-18**.

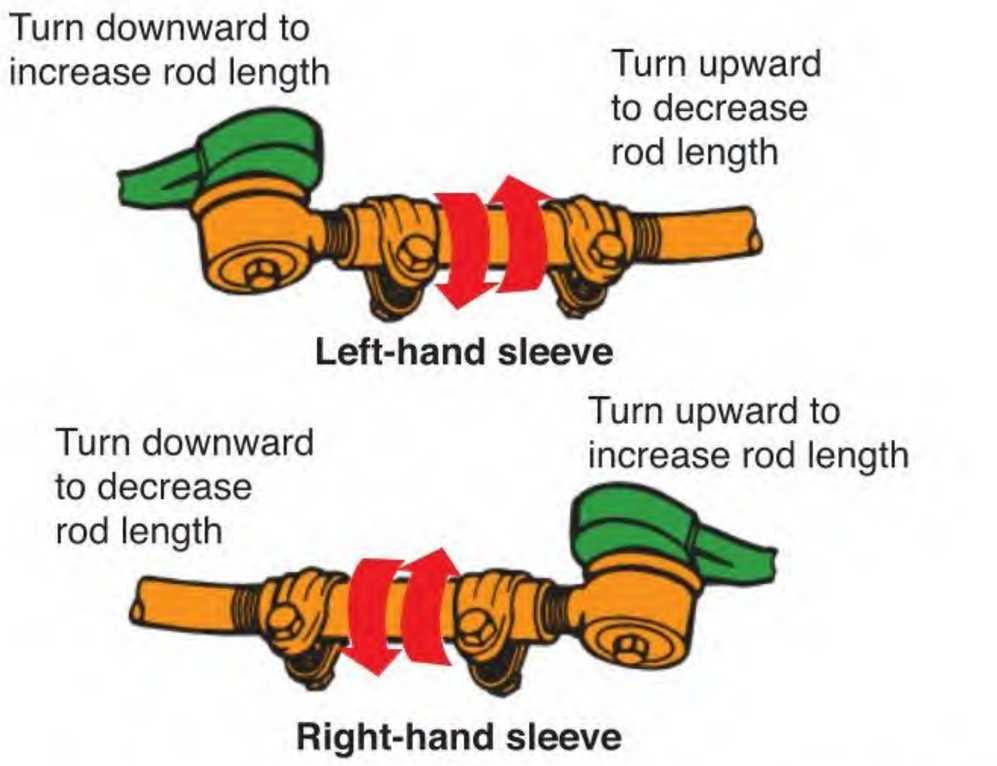
Adjusting Rear Wheel Alignment

Depending on vehicle make and model, a vehicle may or may *not* have provisions for adjusting rear wheel alignment. If the rear wheels fail to track properly, frame, unibody, or rear suspension damage may be the cause. The vehicle might have been in an accident that shifted the rear wheels out of place. Worn suspension system bushings can also upset tracking. To adjust rear wheel alignment, follow the same principles used for aligning front wheels. **Figure 79-19**



Subaru

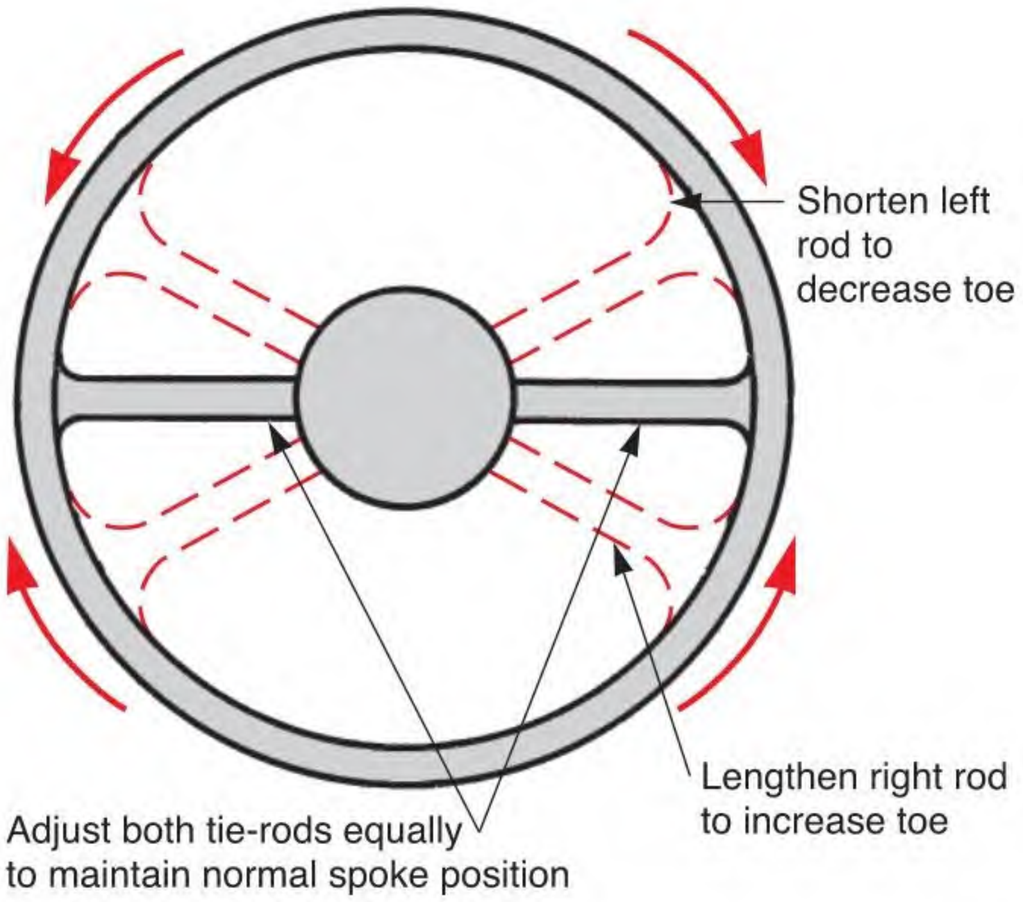
Figure 79-16. Toe is adjusted by lengthening or shortening the tie-rods.



Ford

Figure 79-17. A linkage-type steering system uses a sleeve to lengthen or shorten the tie-rod. Note the adjustment method.

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Ford

Figure 79-18. When adjusting toe, the steering wheel must be kept in the center position. Study how turning each tie-rod end affects the position of the steering wheel spokes.

shows how shims can be used to align the rear wheels of one type of front-wheel-drive vehicle. A shim of the correct thickness can be added to adjust camber and toe.

Wheel Alignment Tools and Equipment

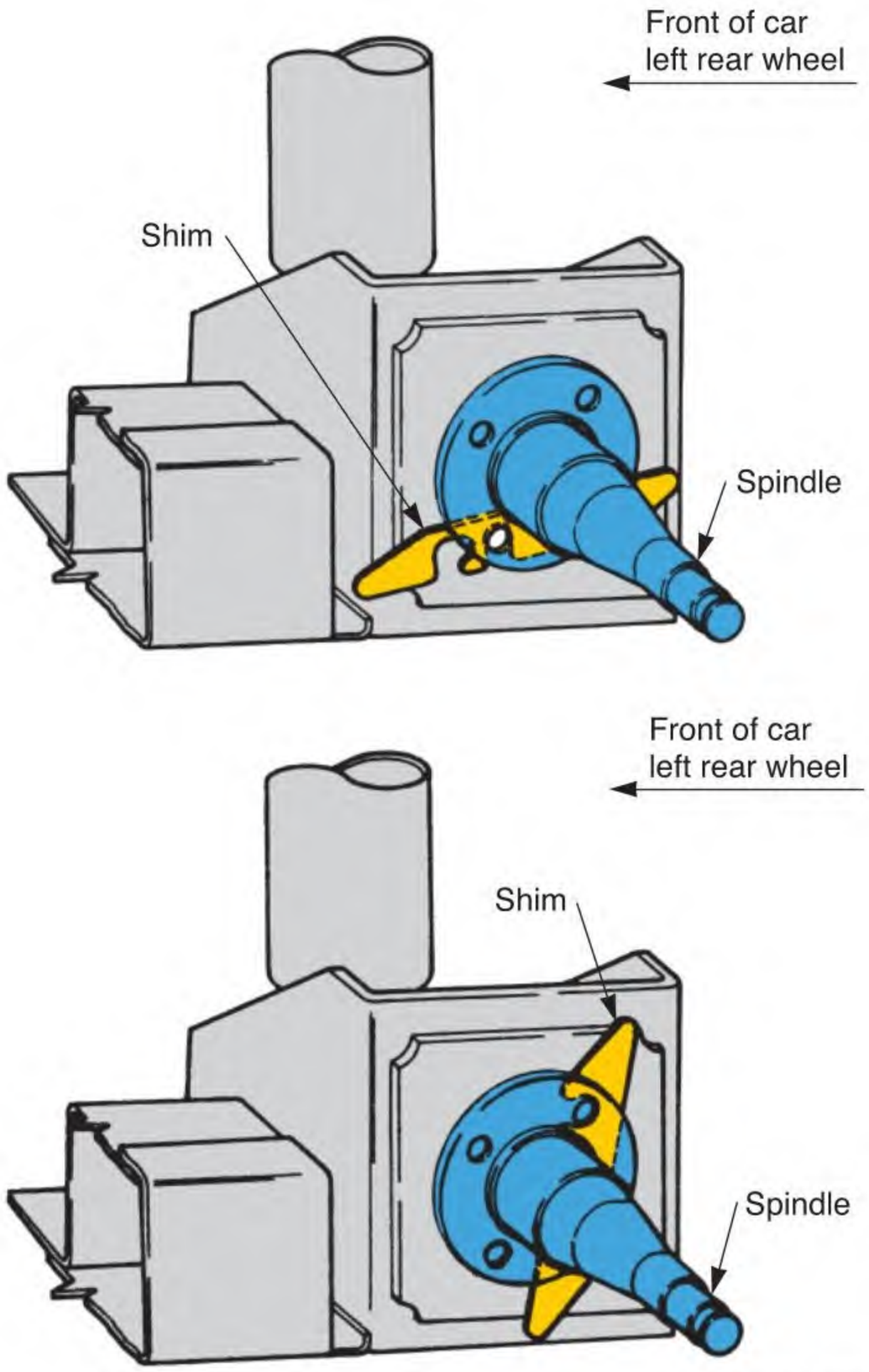
Various equipment and special tools are needed to adjust wheel alignment. Several special alignment tools are shown in **Figures 79-20** and **79-21**.

The most basic equipment for wheel alignment is the turning radius gauge, the caster-camber gauge, and the tram gauge. These are the least complicated of all alignment tools and easily illustrate the fundamentals of wheel alignment.

The combined measuring capabilities of these basic pieces of equipment are built into large alignment racks.

Turning Radius Gauges

Turning radius gauges measure how many degrees the front wheels are turned right or left. They are commonly used when measuring caster, camber, and toe-out on turns. Turning radius gauges may be portable units. However, they are commonly mounted and an integral part of an alignment rack.



Chrysler

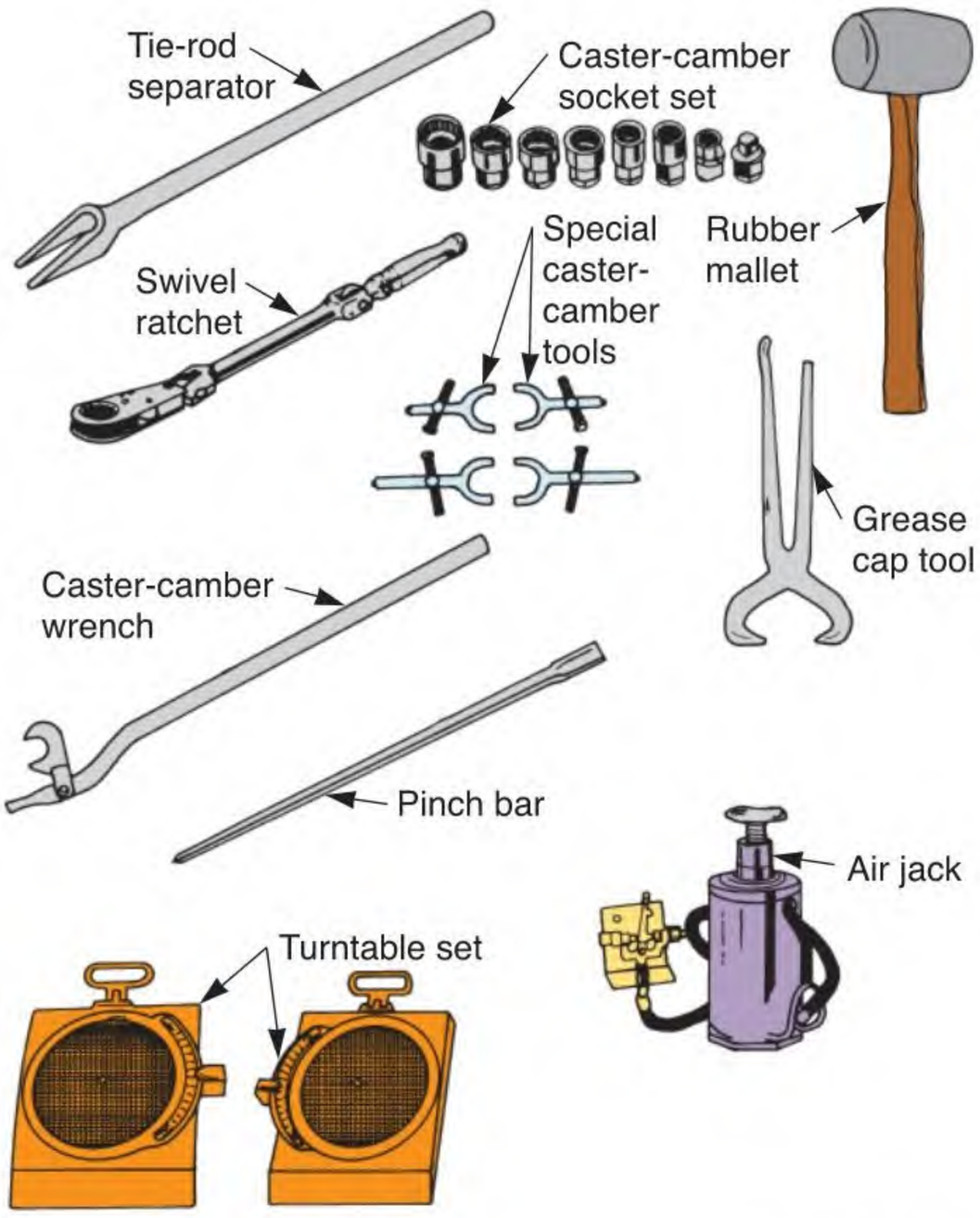
Figure 79-19. Note how a shim can be used to adjust alignment angles on the rear axle of this front-wheel-drive vehicle. Shims can be placed at the bottom, top, front, or rear to change any alignment angle.

The front wheels of the vehicle are centered on the turning radius gauges. Then, when the locking pins are pulled out, the gauge and tire turn together. The pointer on the gauge will indicate how many degrees the wheels have been turned.

Checking Toe-Out on Turns

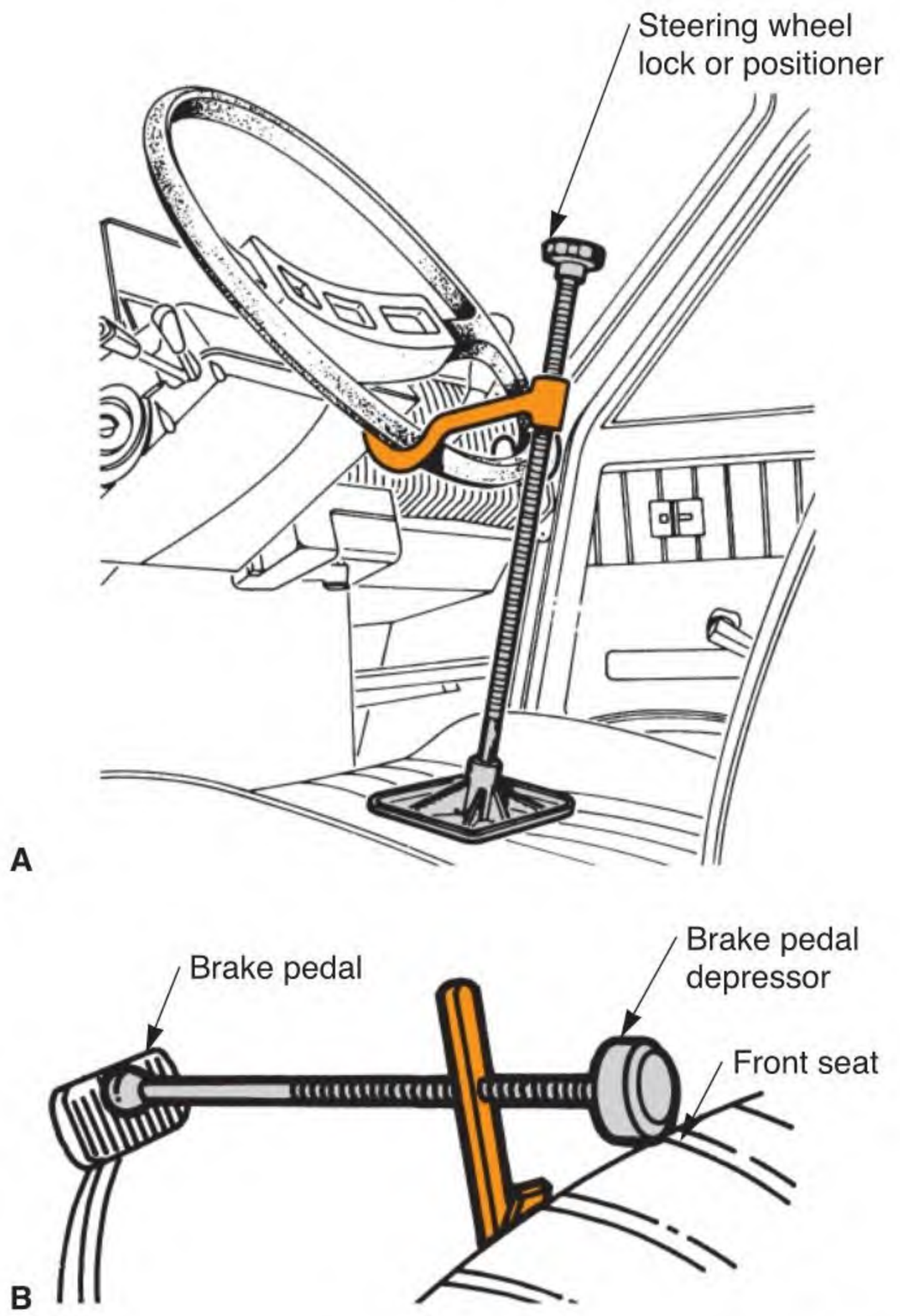
To check toe-out on turns, center the front tires of the vehicle on the turning radius gauges. Turn one of the front wheels until the gauge reads 20°. Then, read the number of degrees showing on the other gauge. Check toe-out on turns on both the right and left sides. If toe-out is not within specs, check for bent or damaged parts.

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Snap-on Tool Corp.

Figure 79-20. Common alignment tools.



Florida Dept. of Voc. Ed.; Renault

Figure 79-21. A—A steering wheel lock will hold the front wheels straight ahead. B—A brake pedal lock will keep the vehicle from rolling.

Alignment Machines

Most medium and large service facilities have alignment machines, or alignment racks. The ***alignment machine*** consists of the rack, console, and related parts.

The ***rack*** is comprised of the ramps, turning radius gauges, and one of several types of equipment for measuring alignment angles. The rack must be perfectly level so that all equipment readings are accurate. A modern ***console*** typically consists of a color monitor, keypad, and computer, all mounted in a roll-around cabinet. Refer to **Figure 79-22**.

Alignment Equipment Software

Alignment equipment software contains computer instructions, information for using the alignment equipment, alignment specifications for various makes and models of vehicles, and other helpful information. When loaded into the console computer, the software will help you adjust all alignment angles quickly and easily. Most software will even give you step-by-step instructions.

The alignment machine software is usually stored on a CD-ROM (compact disc). The information contained in a complete set of manuals can be stored on one CD-ROM.

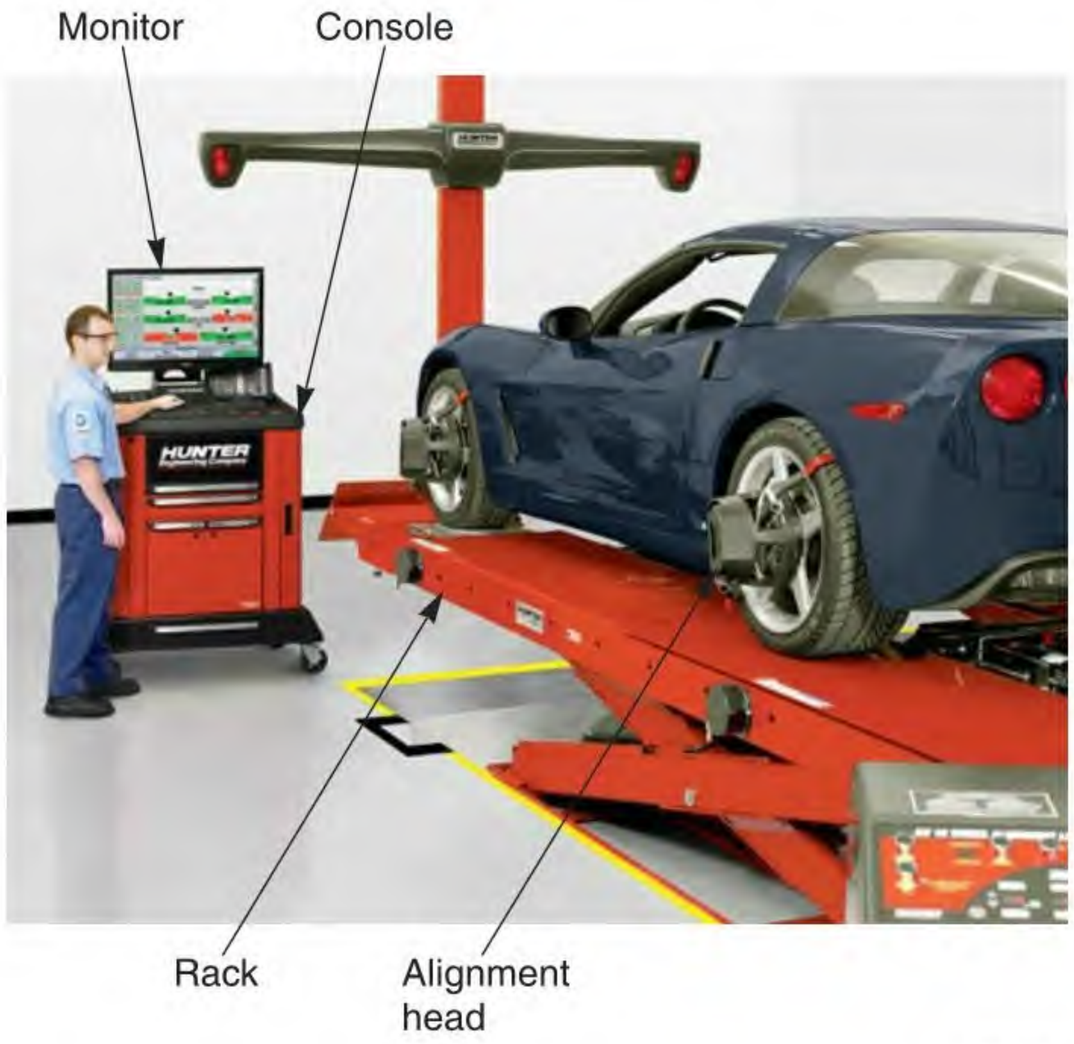
Depending on the type of the alignment machine, the monitor may prompt you to do a vehicle inspection before attempting wheel alignment.

Alignment Heads

Alignment heads mount on the vehicle wheels and are used to check caster, camber, and toe. They often use lasers or proximity sensors to compare the alignment of each wheel. Refer to **Figure 79-23**.

Special brackets are used for mounting the alignment heads on the wheels. Sometimes the brackets are an integral part of the heads.

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Hunter

Figure 79-22. A modern alignment machine contains a dedicated computer, console, large screen monitor, and wheel alignment heads for quickly reading and adjusting alignment angles.



Hunter

Figure 79-23. Make sure wheel alignment head is properly installed on wheel and strapped to tire or wheel so it cannot fall off and be damaged.

Using Alignment Equipment

Since there are so many types of alignment equipment, always follow the operating instructions provided by the manufacturer. Remember that alignment principles are the same regardless of the equipment used. Apply your knowledge of wheel alignment to the specific type of equipment.

To use an alignment rack, drive the vehicle up on the ramps. Carefully center the front tires on the turning radius gauges. Once the vehicle is positioned on the rack, block the rear wheels to keep the vehicle from accidentally rolling off the ramps.

Warning

Use extreme care when positioning a vehicle on an alignment rack. Ask a friend to guide you up the ramps and onto the turning radius gauges. Always block the rear wheels! If a vehicle falls off an alignment rack, it could kill you or a co-worker.

Today's computerized alignment equipment is easy to use. Mount the alignment heads on the vehicle wheels. For a two-wheel alignment, only mount the heads on the front wheels. For an all-wheel alignment, mount heads on all four wheels.

After turning on the alignment console, the computer might prompt you to enter the make, model, year, and other information about the car or truck. After you have keyed in the needed information, the computer will retrieve stored data about performing an alignment on the vehicle at hand, **Figure 79-24**.

The monitor will then let you select different equipment functions, including:

- Training on equipment.
- Inspection of vehicle.
- Vehicle specifications.
- Vehicle measurements.
- Vehicle adjustment locations and procedures.
- Printing out work order or measurements.
- Using help functions for additional information.

Most modern alignment equipment is "***icon***" based, which means it uses small pictures to help you operate the equipment. Both words and pictures give you the feedback needed to successfully use the equipment.

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Hunter

Figure 79-24. This technician is using a remote control to reset steering sensors while watching the monitor for instructions. The remote control interfaces with the vehicle's OBD-II system and communicates wirelessly with the alignment console.

As you make alignment adjustments, the equipment monitors the changes in the alignment angles. It shows you how much you have changed the wheel alignment and informs you when your adjustments are within specs. You can watch the monitor to check your progress. See **Figure 79-25**.

Caution

Always remember to use the operating manual provided with the specific alignment equipment. Procedures vary, and the slightest mistake could upset proper wheel alignment.



Hunter

Figure 79-25. This alignment machine provides a graphic display of the alignment readings for each wheel.

Road Test after Alignment

After completing the wheel alignment, you should road test the vehicle to check your work. As you test-drive the car or truck on level pavement, check for a misaligned steering wheel, steering wheel pull, and similar troubles. If you detect problems, alter your alignment adjustments to correct any troubles.

A chart outlining noise and vibration problems is shown in **Figure 79-26**. Make sure the vehicle is not suffering from any of these problems before releasing it to the customer.

Diagnostic Case Study

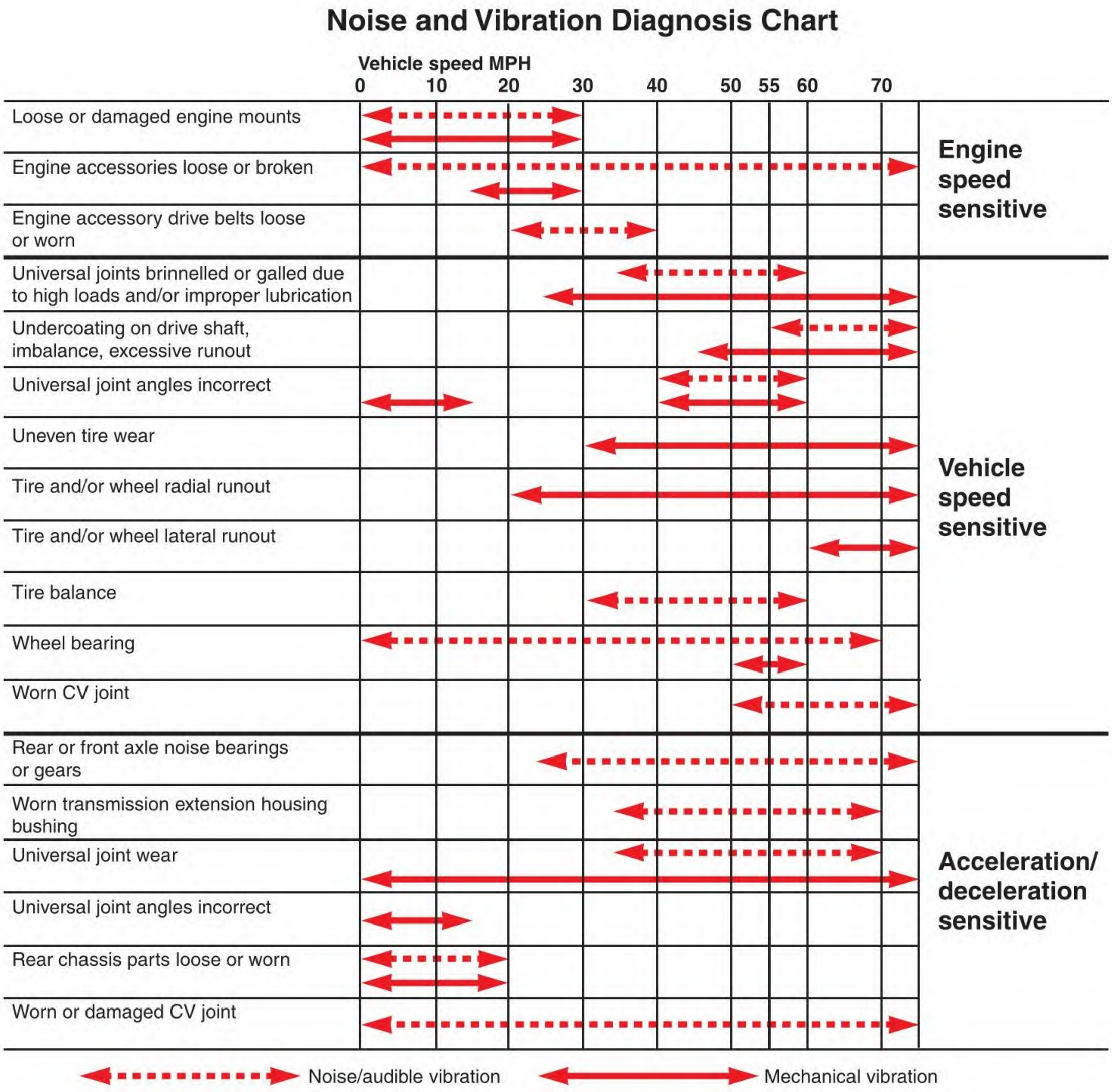
Concern: Mr. Smith enters the shop and says that the new tires he purchased from another shop have worn out even though he has put less than 1000 miles on them. He wants proof that the tires are defective. When asked, he says that he has not had a wheel alignment since he purchased the car several years ago.

Cause: Duff inspects the tires. He notices feathered edge wear on the front tires caused by improper toe adjustment. The inner edges of the tires are also worn more than the rest of the tire tread, indicating improper camber adjustment. Duff explains to the customer that the vehicle has an alignment problem and that the tires are not defective. He also informs the customer that the front tires should be replaced before the vehicle is aligned. The customer reluctantly agrees, and Duff turns the car over to the shop's suspension and steering technician.

Correction: The technician replaces the vehicle's front tires and then sets up the car on the wheel alignment machine. The readings show that the front wheels are toed out even though specifications call for a slight toe-in. The wheels also have excessive negative camber.

The technician loosens the nuts on the upper strut tower and shifts the strut to adjust the camber to specifications. Next, he rotates the tie-rod ends until toe is set to the manufacturer's specifications. The caster settings are within specifications and do not require adjustment. The car is test-driven to check for pull and then released to the customer.

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Dana-Perfect Circle

Figure 79-26. When doing a road test after alignment, you must make sure the vehicle drives and handles properly. There must not be any abnormal noises or vibration.

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Summary

- The main purpose of wheel alignment is to make the tires roll without scuffing, slipping, or dragging under all operating conditions.
- Caster is basically the forward or rearward tilt of the steering knuckle (spindle support) when viewed from the side of the vehicle.
- Road crown is the normal slope toward the outer edge of the road surface.
- Camber is the inward or outward tilt of the wheel and tire assembly when viewed from the front of the vehicle.
- Toe is determined by the difference in distance between the front and rear of the left- and right-hand wheels.
- Front-wheel-drive and rear-wheel-drive vehicles normally require much different toe settings.
- Steering axis inclination is the angle, away from the vertical, formed by the inward tilt of the ball joints, king pin, or MacPherson strut tube.
- Toe-out on turns, also termed turning radius, is the amount the front wheels toe-out when turning corners.
- Tracking, also called thrust line, refers to the position or direction of the two front wheels in relation to the two rear wheels.
- Reading tires is done by inspecting tire tread wear and diagnosing the cause for any abnormal wear.
- Camber is usually adjusted right after setting caster.
- Toe is adjusted by lengthening or shortening the tie-rods.
- Turning radius gauges measure how many degrees the front wheels are turned right or left.
- A caster-camber gauge is used with the turning radius gauge to measure caster and camber in degrees.
- The alignment rack consists of ramps, turning radius gauges, and one of several kinds of equipment for measuring alignment angles.
- A modern alignment console typically consists of a color monitor, keypad, and computer, all mounted in a roll-around cabinet.
- Alignment heads mount on the vehicle wheels to check caster, camber, and toe.
- After completing your wheel alignment, you should road test the vehicle to check your work.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

alignment
alignment equipment software
alignment heads
alignment machine
camber
caster
console
dog tracking
eccentric bolt
feathered edge
icon
incorrect camber
incorrect toe
negative camber
negative caster
positive camber
positive caster
rack
reading tires
road crown
road crown pull
setback
shims
slotted holes
steering axis inclination
strut rod
toe
toe-in
toe-out
toe-out on turns
tracking
turning radius
turning radius gauges
vehicle cradle
wheel alignment

Activities

1. Demonstrate for your instructor a prealignment inspection of tires, steering, and suspension of a vehicle in the shop for a front-end alignment.
2. Check and adjust the caster, camber, or toe-in of a front suspension.
3. Prepare a bill for an alignment. Use a flat labor rate established by your instructor and a $25/hour charge. Include the cost of any parts used. Add up all costs.

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Review Questions

Answer the following questions using the information provided in this chapter.

1. Define the term *alignment*.
2. What is the main purpose of wheel alignment?
3. _____ is the forward or rearward tilt of the steering knuckle or steering support when viewed from the side of the vehicle.
4. List the three basic functions of caster.
5. Explain the difference between positive and negative caster.
6. Which of the following pertains to caster?
   (A) Measured in degrees.
   (B) A directional control angle.
   (C) Can be used to offset road crown.
   (D) All of the above.
7. _____ is the inward or outward tilt of the wheel and tire assembly when viewed from the front of the vehicle.
8. List three functions of camber.
9. Explain the difference between positive and negative camber.
10. Most vehicle manufacturers suggest a slight negative camber setting. True or False?
11. _____ is determined by the distance between the front and rear of the left- and right-hand wheels.
12. Explain the difference between toe-in and toe-out.
13. Rear-wheel-drive cars commonly use toe-in and front-wheel-drive cars commonly use toe-out. True or False?
14. Define the term *tracking*.
15. Name seven possible problems you should check before attempting to align a vehicle's front end.
16. _____ _____ is done by inspecting tread wear and diagnosing the cause of abnormal wear.
17. List the seven basic steps for wheel alignment.
18. How do you change caster?
19. How do you change camber?
20. How do you adjust toe?
21. Turning radius gauges measure how many degrees the front wheels are turned right or left. True or False?
22. What is an alignment console?
23. What is an alignment rack?

ASE-Type Questions

1. Technician A says correct wheel alignment can improve an automobile's handling ability. Technician B says correct wheel alignment can improve an automobile's fuel economy. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Technician A says one of the main functions of wheel alignment is to make the tires roll without slipping under all operating conditions. Technician B says one of the main functions of wheel alignment is to adjust for badly worn steering parts. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. Technician A says the term "caster" refers to the forward or rearward tilt of the steering knuckle when viewed from the side of the car. Technician B says the term "caster" refers to the forward or rearward tilt of the tie-rod when viewed from the side of the car. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. Technician A says cars with manual steering have more "negative" caster than cars with power steering. Technician B says cars with power steering have more "negative" caster than cars with manual steering. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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5. Technician A says one of the purposes of caster is to aid directional control of the vehicle. Technician B says one of the purposes of caster is to load the larger inner wheel bearing. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. A car's steering wheel does not return to the straight-ahead position after turning. Technician A adjusts the automobile's caster angle. Technician B says the car's caster angle has nothing to do with this problem. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. Technician A tilts the top of a car's steering knuckle toward the rear of the car to adjust for "positive" camber. Technician B tilts the top of the tie-rod toward the front of the car to adjust for "positive" caster. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. Technician A says camber is the inward or outward tilt of the wheel and tire assembly when viewed from the front of the car. Technician B says camber is the inward or outward tilt of the steering knuckle when viewed from the front of the car. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Technician A says with "positive" camber, the tops of the wheels tilt outward when viewed from the front of the car. Technician B says with "positive" camber, the tops of the wheels tilt inward when viewed from the front of the car. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. Technician A normally adjusts a car's positive camber setting at about 1/4° to 1/2°. Technician B normally adjusts a car's positive camber setting at about 3° to 4°. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
11. Technician A says "toe-in" is produced when the front of the wheels are closer together than the rear of the wheels. Technician B says "toe-in" is produced when the front of the wheels are farther apart than the rear of the wheels. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
12. Technician A says a rear-wheel-drive car's toe-in setting should be 1/16″ to 1/4″. Technician B says a rear-wheel-drive car's toe-in setting should be 1.6 mm to 6 mm. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
13. An automobile needs a wheel alignment. Before performing this task, Technician A checks for loose wheel bearings. Before performing this task, Technician B checks for wheel or tire runout. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
14. Technician A adjusts an automobile's camber angle to help prevent tire wear on the inner or outer tread. Technician B adjusts an automobile's caster angle to help prevent tire wear on the inner or outer tread. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
15. Technician A adjusts a car's toe angle by lengthening or shortening the steering knuckle. Technician B adjusts a car's toe angle by lengthening or shortening the tie-rods. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Section 13

Brake System Technology

Chapter 80
Brake System Technology

Chapter 81
Brake System Diagnosis, Service, and Repair

Chapter 82
Anti-Lock Brakes, Traction, and Stability Control

An automotive brake system must be capable of bringing thousands of pounds of steel and plastic to a quick and controlled halt. To stop the vehicle, hydraulic brake systems convert mechanical energy (rotation of wheels) to heat energy. Hybrid vehicles use a regenerative braking system to assist the hydraulic brakes. These systems help slow the vehicle while converting the mechanical energy of the rotating wheels to electrical energy to help power the vehicle. A properly functioning brake system is imperative to safe vehicle operation.

Section 13 covers the construction, operation, service, and repair of all types of automotive braking systems. It includes detailed information on brake system hydraulics, disc brakes, drum brakes, anti-lock brakes, and regenerative braking systems, as well as traction control systems and stability control systems. This section will help you pass ASE Test A5, *Brakes*.



Chapter 80
Brake System Technology

After studying this chapter, you will be able to:

- Explain the hydraulic and mechanical principles of a brake system.
- Identify the major parts of an automotive brake system.
- Define the basic functions of the major parts of a brake system.
- Compare drum and disc brakes.
- Explain the operation of power brakes.
- Describe the operation of parking brakes.
- Correctly answer ASE certification test questions requiring a knowledge of automotive brake systems.

Automotive brakes provide a means of using friction to either slow, stop, or hold the wheels of a vehicle. When a car is moving down the highway, it has a tremendous amount of stored energy in the form of ***inertia*** (tendency to keep moving). To stop the vehicle, the brakes convert mechanical energy (rotation of wheels) into heat energy.

With ***hydraulic brakes***, confined brake fluid is used to transfer power and motion from the brake pedal to the wheel cylinders and brakes. The foot brake pedal acts on a hydraulic master cylinder, which sends fluid pressure to the hydraulic wheel cylinders. The wheel cylinder pistons then slide outward to push the brake pads into the spinning brake discs.

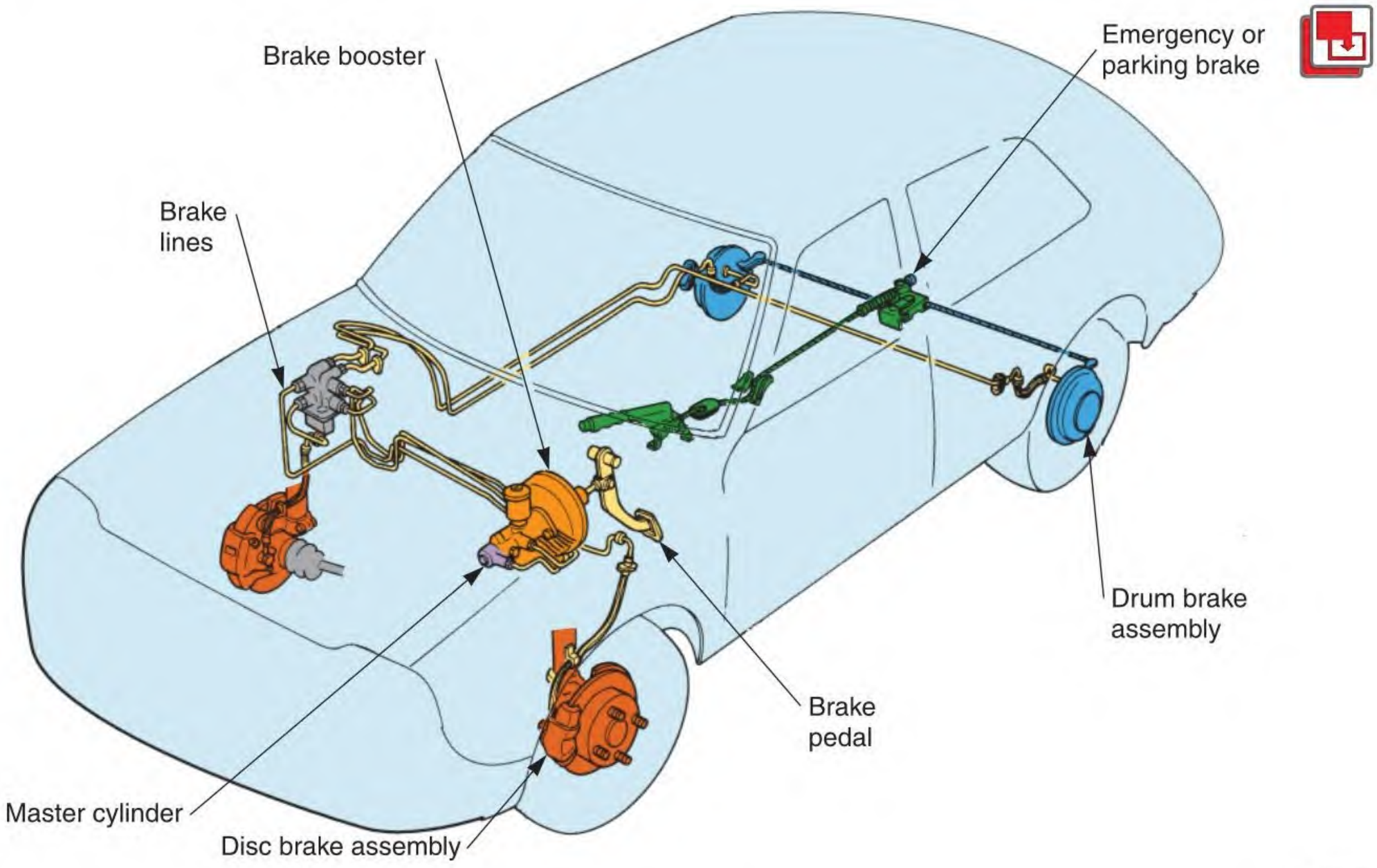
With ***hybrid brakes***, a conventional hydraulic brake system is combined with an electric regenerative braking system provided by the hybrid's driveline. The motor-generator serves as a high-power ac generator that requires considerable torque to rotate. The torque needed to spin the motor-generator places a drag on the driveline to help slow the vehicle while recharging the HV battery. All modern hybrids have regenerative braking to increase gas mileage ratings.

As you will learn, a modern automobile uses numerous devices to improve braking ability. For example, dual hydraulic brake systems that prevent total loss of braking, hydraulic valves that control pressure to each wheel brake, and electronic anti-lock braking systems that prevent tire spin on slippery pavement are all standard equipment.

Basic Brake System

Before studying the construction and operation of individual brake system parts, you should have a general understanding of overall system design and operation. The basic parts of an automotive brake system include:

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Honda

Figure 80-1. These are the basic parts of an automotive brake system. Study them.

- ***Brake pedal assembly***—The brake pedal assembly is a foot lever for operating the master cylinder and power booster. Look at **Figure 80-1**.
- ***Master cylinder***—The master cylinder is a hydraulic-piston pump that develops pressure for the hydraulic brake system.
- ***Brake booster***—The brake booster is a vacuum, electric, or power steering–operated device that assists brake pedal application.
- ***Brake lines and hoses***—Brake lines and hoses are metal tubing and rubber hose that transmit pressure to the wheel brake assemblies.
- ***Wheel brake assemblies***—Wheel brake assemblies are hydraulic-mechanical mechanisms that use hydraulic pressure to produce friction to slow or stop each wheel.
- ***Emergency brakes***, or ***parking brakes***—Emergency brakes are mechanical or electric systems for applying rear brake assemblies.

When the driver pushes on the brake pedal, lever action pushes a rod into the brake booster and master cylinder. This produces hydraulic pressure in the master cylinder. Fluid flows through the brake lines to the wheel brake assemblies. The brake assemblies use this pressure to cause friction for braking.

An emergency brake system uses cables or rods to mechanically apply the rear brakes. This provides a system for holding the wheels when the vehicle is parked on a hill or stopping the vehicle during complete hydraulic brake system failure.

Drum and Disc Brakes

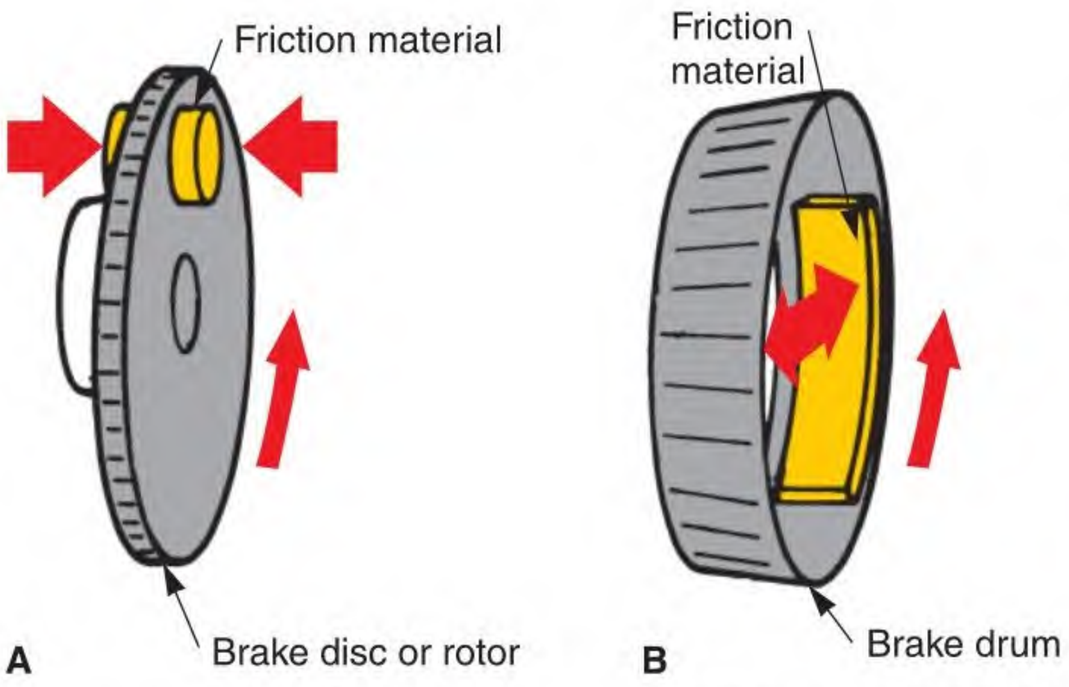
There are two common types of brake assemblies used on modern automobiles: disc brakes and drum brakes. Refer to **Figure 80-2**.

Disc brakes are frequently used on the two front wheels of a vehicle. Drum brakes are often used on the rear wheels. However, disc or drum brakes may be used on all four wheels.

The following are the components of a ***disc brake assembly***:

- ***Caliper***—The caliper is an assembly that holds a hydraulic cylinder, piston, seals, and brake pads.
- ***Caliper cylinder***—The caliper cylinder is a machined hole in the caliper; the piston fits into this cylinder.

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Figure 80-2. Compare basic disc brakes and drum brakes. A—Disc brakes are commonly used on the front of the vehicle and sometimes on the rear. B—Drum brakes are normally used on the rear of the vehicle.

- ***Brake pads***—The brake pads are friction members that are pushed against the disc by the action of the master cylinder, caliper cylinder, and piston.
- ***Brake disc***—The brake disc is a large metal ***rotor*** that holds the wheel and tire and uses friction from the brake pads to stop or slow wheel rotation.

The following are the components of a ***drum brake assembly***:

- ***Wheel cylinder assembly***—The wheel cylinder assembly houses a hydraulic piston that is forced outward by fluid pressure.
- ***Brake shoes***—The brake shoes are friction units that are pushed against the rotating brake drum by the action of the hydraulic wheel cylinder.
- ***Brake drum***—The brake drum rubs against the brake shoes to stop or slow wheel rotation.

Braking Ratio

Braking ratio refers to the comparison of front wheel braking effort to rear wheel braking effort. When a vehicle stops, its weight tends to transfer onto the front wheels. The front tires are pressed against the road with greater force. The rear tires lose some of their grip on the road. As a result, the front wheels do more of the braking than the rear.

For this reason, many vehicles have disc brakes on the front and drum brakes on the rear. Disc brakes are capable of producing more stopping effort than drum brakes. If drum brakes are used on both the front and rear wheels, the front shoe linings and drums normally have larger surface areas than the rear linings and drums.

Typically, front wheel brakes handle 60%–70% of the braking power. Rear wheel brakes handle 30%–40% of the braking. Front-wheel-drive cars, having even more weight on the front wheels, can have even a higher braking ratio at the front wheels.

Brake System Hydraulics

A ***hydraulic system*** is basically a system that uses a liquid to transmit motion or pressure from one point to another. Modern brake systems are hydraulic. They use a confined brake fluid to transfer brake pedal motion and pressure to each of the wheel brake assemblies.

Several principles apply to the operation of a hydraulic system. These include:

- Liquids in a confined area will not compress. However, air in a confined area will compress.
- When pressure is applied to a closed system, pressure is exerted equally in all directions.
- A hydraulic system can be used to increase or decrease force or motion.

Hydraulic System Action

Suppose two cylinders of equal diameter are placed side by side with a tube connecting them. The system is filled with liquid. Each cylinder contains a piston. If you push down on one of the pistons, the other piston will move an equal distance and with equal force.

Since the liquid will not compress and the cylinders are the same diameter, the same amount of liquid, pressure, and motion is transferred from one cylinder to the other.

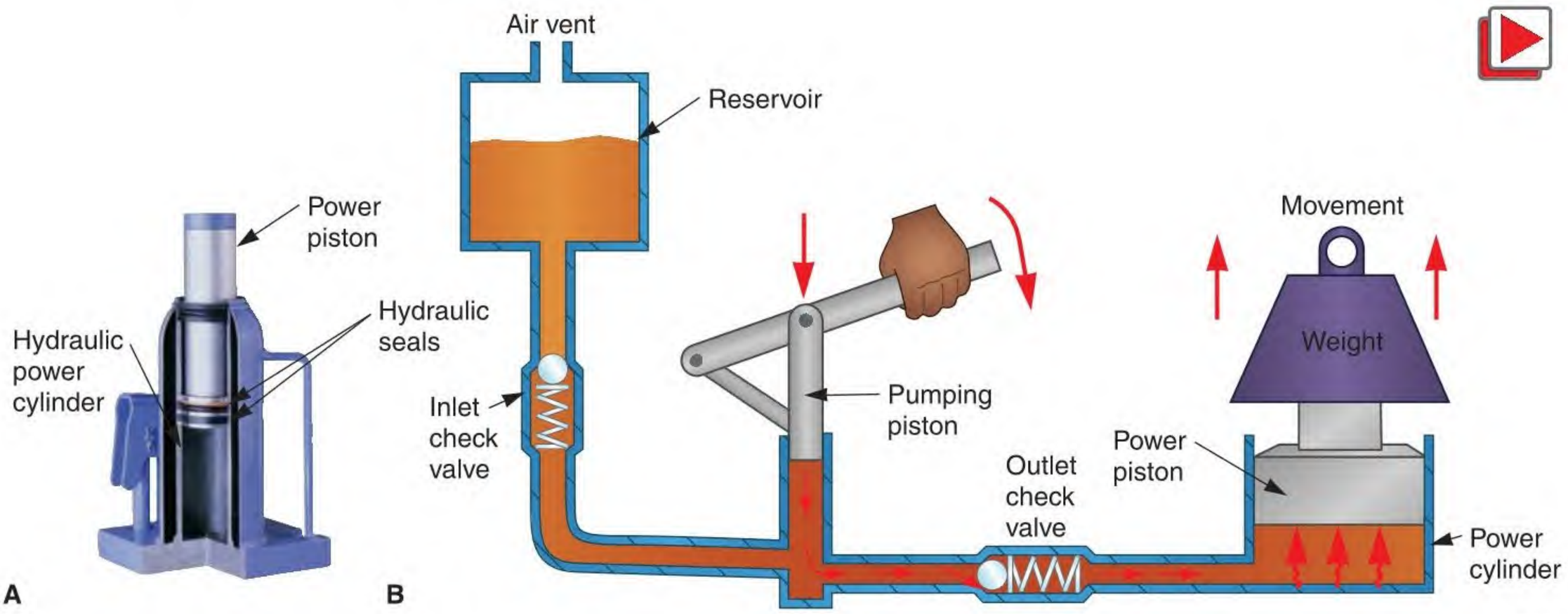
When pistons of different sizes are used, motion and force can be increased or decreased. Suppose a small piston acts on a larger piston. The larger piston will move with more force. However, it will move a shorter distance.

When a large diameter piston acts on a smaller piston, the opposite is true. The smaller piston slides farther in its cylinder than the large piston, but it moves with less force.

A simple hydraulic jack demonstrates the principles just discussed. Look at **Figure 80-3**.

Applying these hydraulic principles to a brake system, you can see how stopping force is transmitted from the master cylinder to each wheel brake assem-

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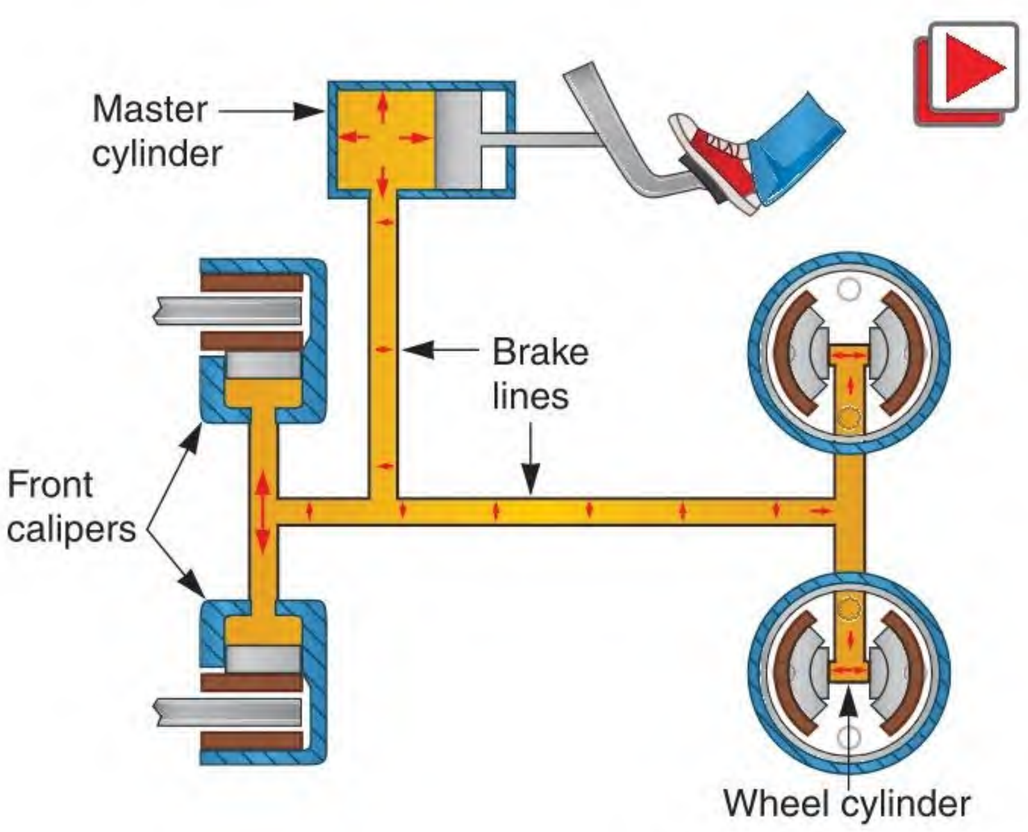
OTC

Figure 80-3. A hydraulic jack and a brake system use many of the same operating principles. A—Cutaway view shows how oil under pressure is used to raise the hydraulic jack when the handle is pumped. B—This drawing of a hydraulic jack demonstrates how a small piston acting on a large piston can increase force tremendously. Study how the check valves only allow oil flow in one direction.

bly. The master cylinder acts as the pumping piston that supplies system pressure. The wheel cylinder acts as the power piston, moving the friction linings into contact with the rotating drums or discs, **Figure 80-4**.

Brake System Components

It is important for you to know the location and construction of major brake system components. This will better prepare you to troubleshoot and repair these important parts.



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Figure 80-4. Like a basic hydraulic jack, the master cylinder acts as a pumping piston to move the pistons at the wheel brake assemblies.

Brake Pedal Assembly

The brake pedal assembly is a lever arm to increase the force applied to the master cylinder piston. A manual master cylinder bolts directly to the engine's firewall. The brake pedal assembly bolts under the dash, **Figure 80-5**.

The pedal swings on a hinge in the pedal support bracket. A push rod connects the brake pedal to the master cylinder piston.

Master Cylinder

A master cylinder is a foot-operated pump that forces fluid into the brake lines and wheel cylinders. Refer to **Figure 80-6**.

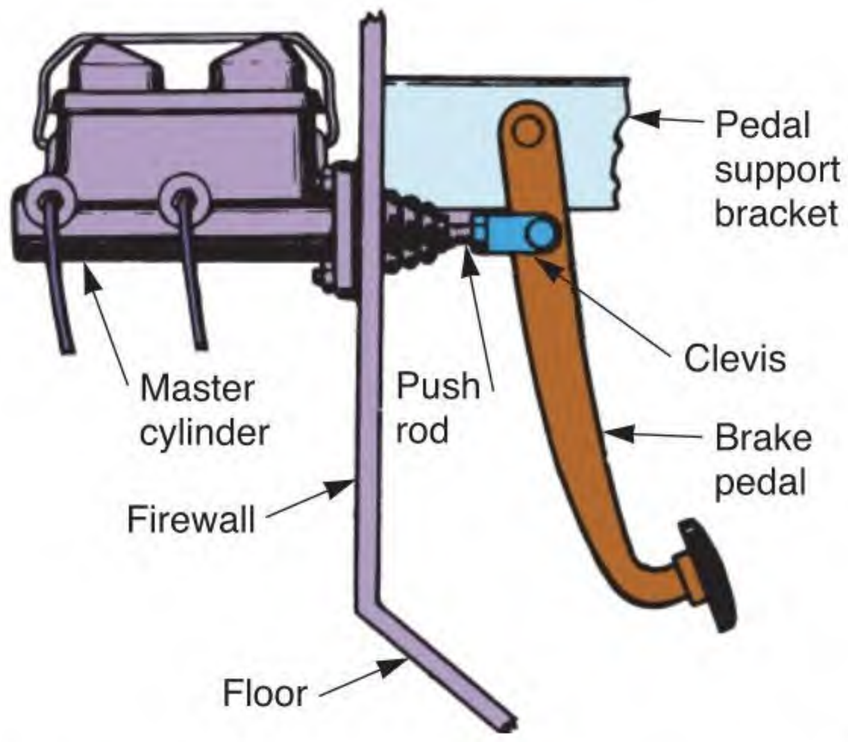
A master cylinder can have four basic functions:

- It develops pressure, causing the wheel cylinder pistons to move toward the discs or drums.
- After all the shoes or pads produce sufficient friction, it helps equalize the pressure required for braking.
- It keeps the system full of fluid as the brake linings wear.
- It can maintain a slight pressure to keep contaminants (air and water) from entering the system.

Master Cylinder Construction

In its simplest form, a master cylinder consists of a housing, reservoir, piston, rubber cup, return spring, and rubber boot. A cylinder is precision machined in

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Bendix

Figure 80-5. The brake pedal assembly bolts under the dash. A push rod transfers pedal movement into the master cylinder and operates the piston in the master cylinder.

the housing of the master cylinder. The spring, cup, and metal piston slide in this cylinder. Two ports are drilled between the reservoir and cylinder.

The ***cup*** and ***piston*** in the master cylinder are used to pressurize the brake system. When they are pushed forward, they trap the fluid, building pressure.

The master cylinder ***intake port***, or vent, allows fluid to enter the rear of the cylinder as the piston slides forward. Fluid flows out of the reservoir, through the intake port, and into the area behind the piston and cup.

Then, when the brake pedal is released, the return spring forces the piston and cup back in the cylinder. If needed, the rubber cup flexes forward, allowing fluid to enter the area in front of the piston and cup. Small holes are drilled in the edge of the piston so that fluid can flow past the cup. See **Figure 80-7**.

The ***compensating port*** releases extra pressure when the piston returns to the released position. Fluid can flow back into the reservoir through the compensating port. The action of the intake port and the compensating port keep the system full of fluid.

Residual pressure valves maintain residual fluid pressure of approximately 10 psi (69 kPa) to help keep contaminants out of the system. One valve is located in each outlet to the brake lines, **Figure 80-8**.

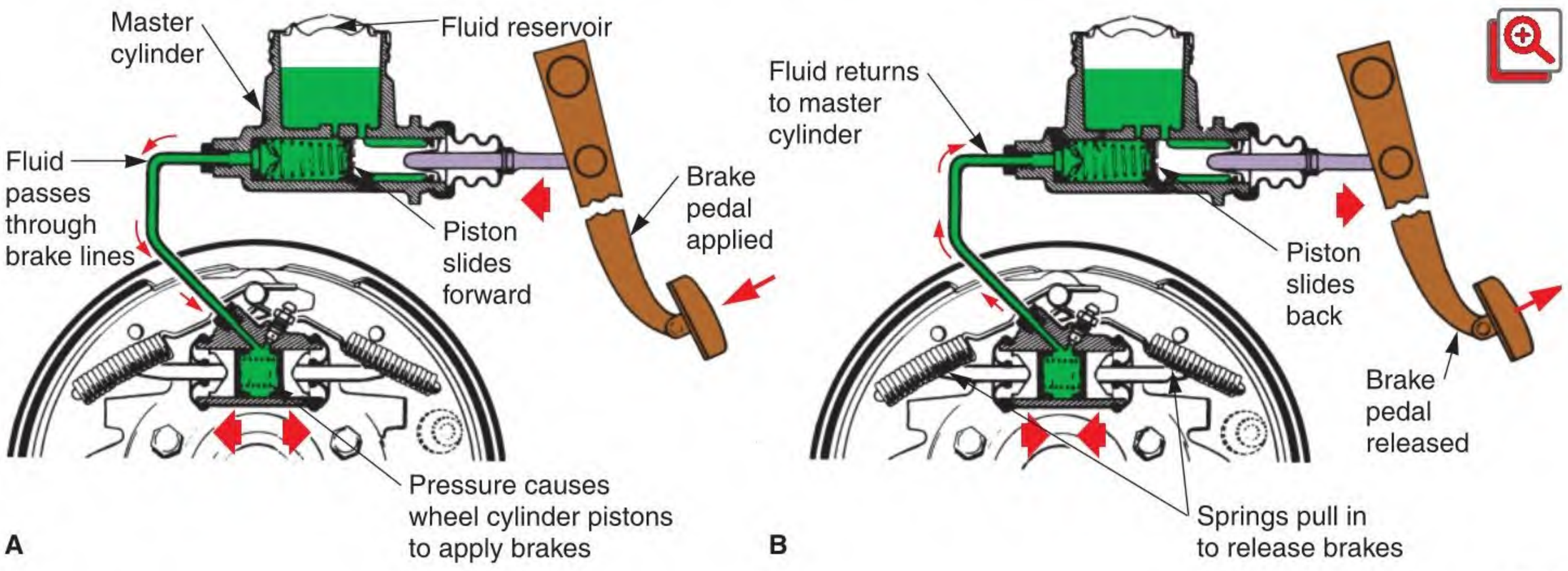
The ***rubber boot*** prevents dust, dirt, and moisture from entering the back of the master cylinder. The boot fits over the master cylinder housing and the brake pedal push rod.

The ***master cylinder reservoir*** stores an extra supply of brake fluid. The reservoir may be cast as part of the housing, or it may be a removable plastic part. Today's reservoirs normally have two sections, or compartments.

Dual Master Cylinder

Older vehicles used single-piston, single-reservoir master cylinders. However, they were dangerous. If a brake fluid leak developed (line rupture, seal damage, crack in brake hose), a sudden loss of braking ability could occur. Modern vehicles use a dual master cylinder for added safety, **Figure 80-9**.

The ***dual master cylinder***, also called the ***tandem master cylinder***, has two separate hydraulic



FMC

Figure 80-6. This single-piston master cylinder demonstrates the simplified action of a brake system. A—Application of pedal moves push rod into piston. Master cylinder piston pressurizes fluid in cylinder and line. Pressure pushes wheel cylinder pistons apart and brakes are applied. B—Release of brake pedal allows retracting springs to pull brake shoes away from brake drum. Fluid flows back through line and into master cylinder.

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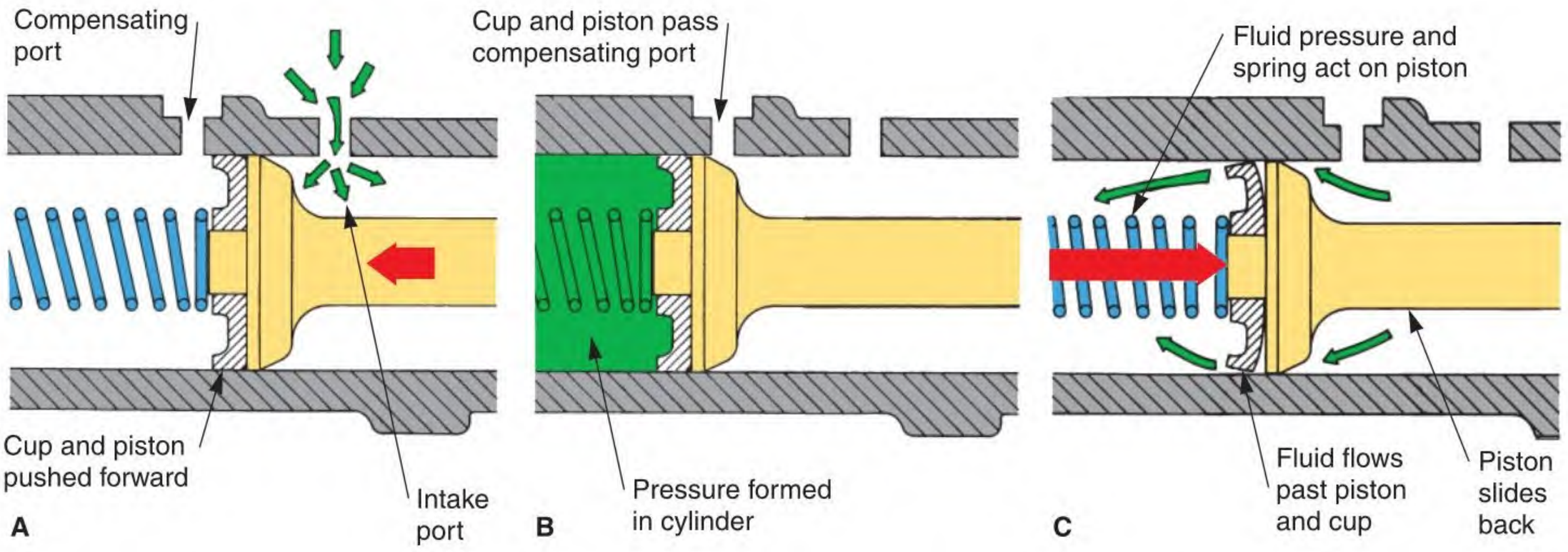


Figure 80-7. Note piston and cup action inside the master cylinder. A—Piston slides forward. Fluid flows into the area behind the piston. Excess fluid flows into the reservoir through the compensating port. B—Piston and cup move past the compensating port, and pressure forms in the front section of the cylinder to apply the brakes. C—When the brake pedal is released, the cup flexes forward so that fluid can flow to the front of the piston for release of the brakes.

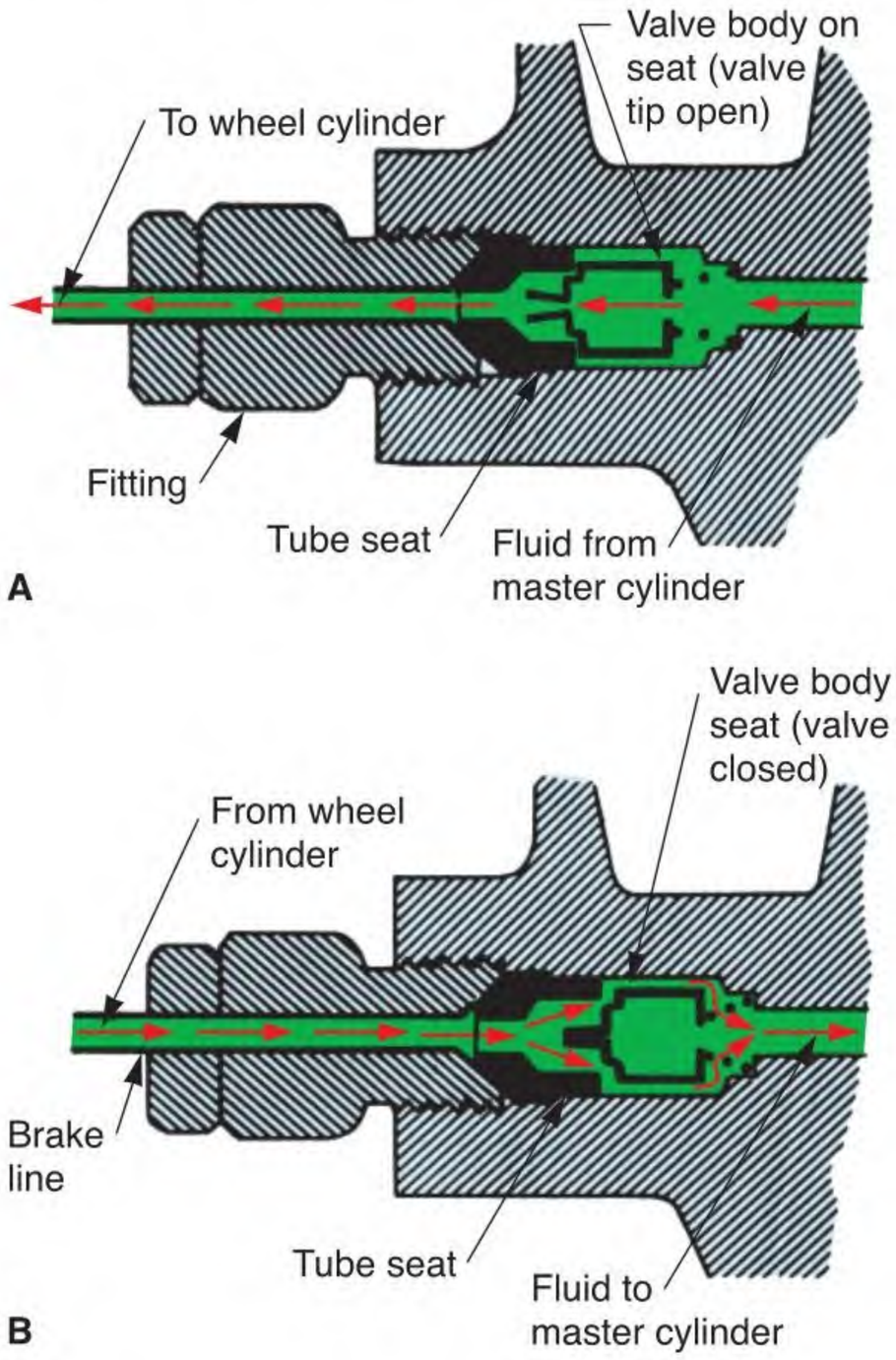


Figure 80-8. Residual pressure valves maintain some line pressure after the brakes are released. This helps keep air out of the system. A—When the brakes are applied, fluid flows freely through the valve. B—After the brakes are released, the valve closes to restrict the return of fluid to the master cylinder.

pistons and two fluid reservoirs. Each piston operates a hydraulic circuit that controls two wheel brake assemblies. Then, if there is a system leak in one of the hydraulic circuits, the other circuit can still provide braking action on two wheels. See **Figure 80-10**.

In the dual master cylinder, the rear piston assembly is called the ***primary piston***. The front piston is termed the ***secondary piston***.

Dual Master Cylinder Operation

The action of the pistons, cups, and ports in the dual master cylinder is similar to the action of those used in a single-piston unit. See **Figure 80-11A**.

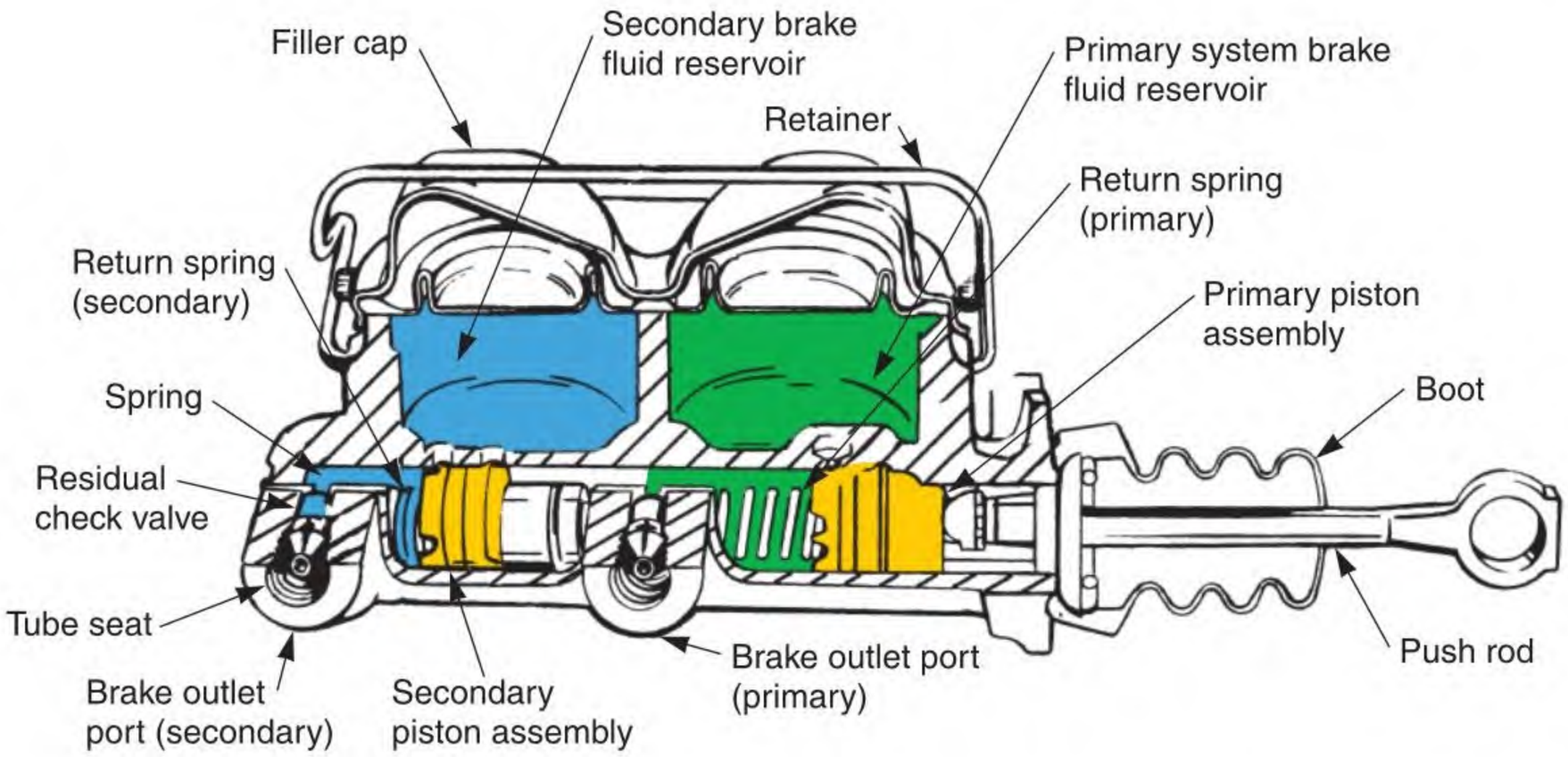
When both systems are intact (no fluid leaks), each piston produces and supplies pressure to two wheel cylinders (all four wheel brake assemblies are applied).

If there is a pressure loss in the primary section of the brake system (rear section of master cylinder), the primary piston slides forward and pushes on the secondary piston. This forces the secondary piston forward mechanically, building pressure in two of the wheel brake assemblies, as shown in **Figure 80-11B**.

When a brake line, wheel cylinder, or other component leaks in the secondary circuit (parts fed by secondary piston), the secondary piston slides completely forward in the cylinder. Then, the primary piston provides hydraulic pressure for the other two brake assemblies. See **Figure 80-11C**.

It is very unlikely that both systems would fail at the same time. If they did, the mechanical parking brake would be needed to slow and stop the vehicle.

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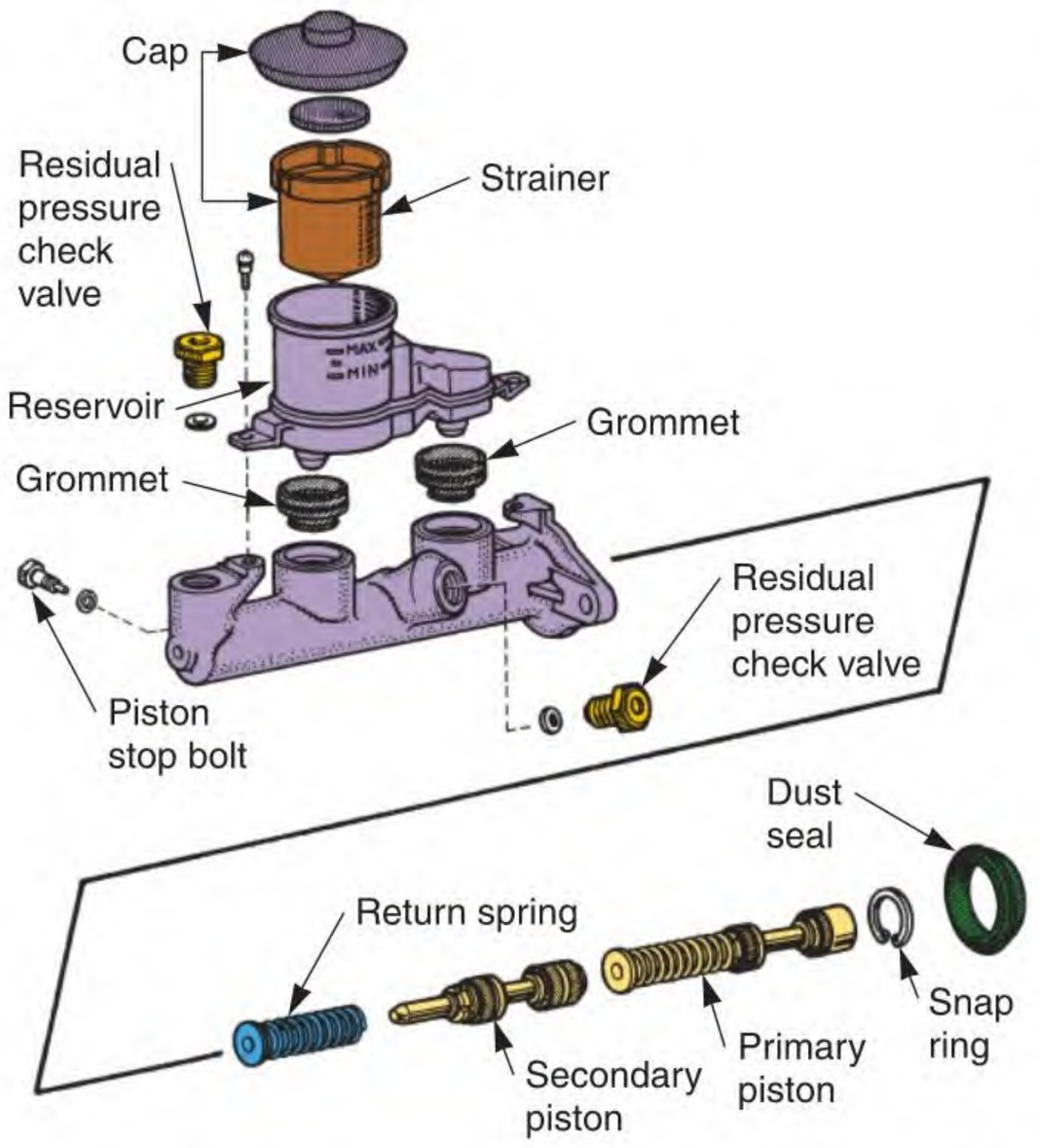


Delco

Figure 80-9. Dual master cylinders are now used because they will still provide braking action when a major hydraulic leak develops. With single-piston master cylinder, a leak could cause sudden and complete loss of brakes.

Power Brakes

Power brakes use a booster and either engine vacuum, electric pump, or hydraulic pressure to assist brake pedal application. The booster (assisting mechanism) is located between the brake pedal linkage and the master cylinder. When the driver presses the brake pedal, the brake booster helps push on the piston.



Toyota

Figure 80-10. Note the major parts of this modern dual master cylinder.

Power Brake Vacuum Boosters

A power brake ***vacuum booster*** uses engine vacuum (or vacuum created by a separate pump on diesel engines) to apply the hydraulic brake system. The principles of a vacuum booster are shown in **Figure 80-12**.

A vacuum booster basically consists of a cylindrical housing that encloses a diaphragm or a piston. When vacuum is applied to one side of the booster, the piston or diaphragm moves toward the low-pressure area. This movement is used to help force the piston into the master cylinder.

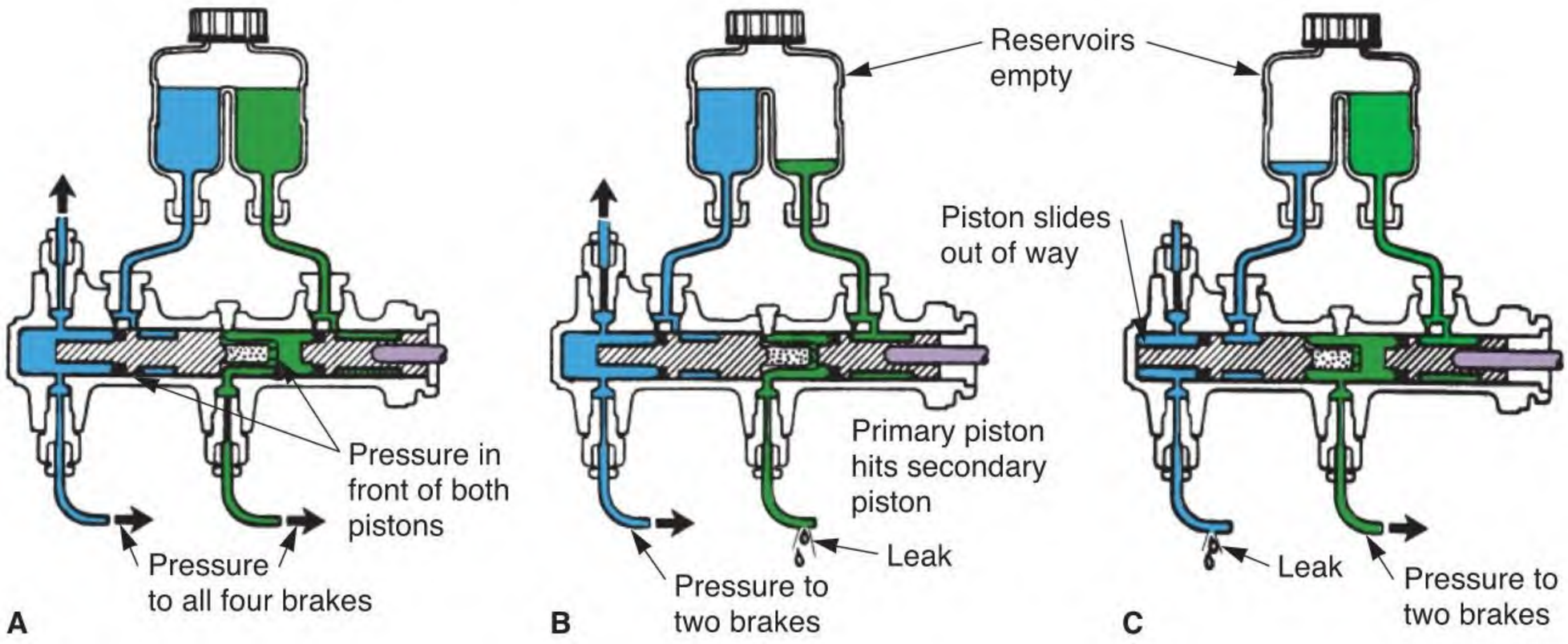
Vacuum Booster Types

There are two general types of vacuum brake boosters: atmospheric suspended boosters and vacuum suspended boosters.

An ***atmospheric suspended brake booster*** has atmospheric pressure (normal air pressure) on both sides of the diaphragm or piston when the brake pedal is released. As the brakes are applied, a vacuum is formed on one side of the booster. Atmospheric pressure then pushes on and moves the piston or diaphragm.

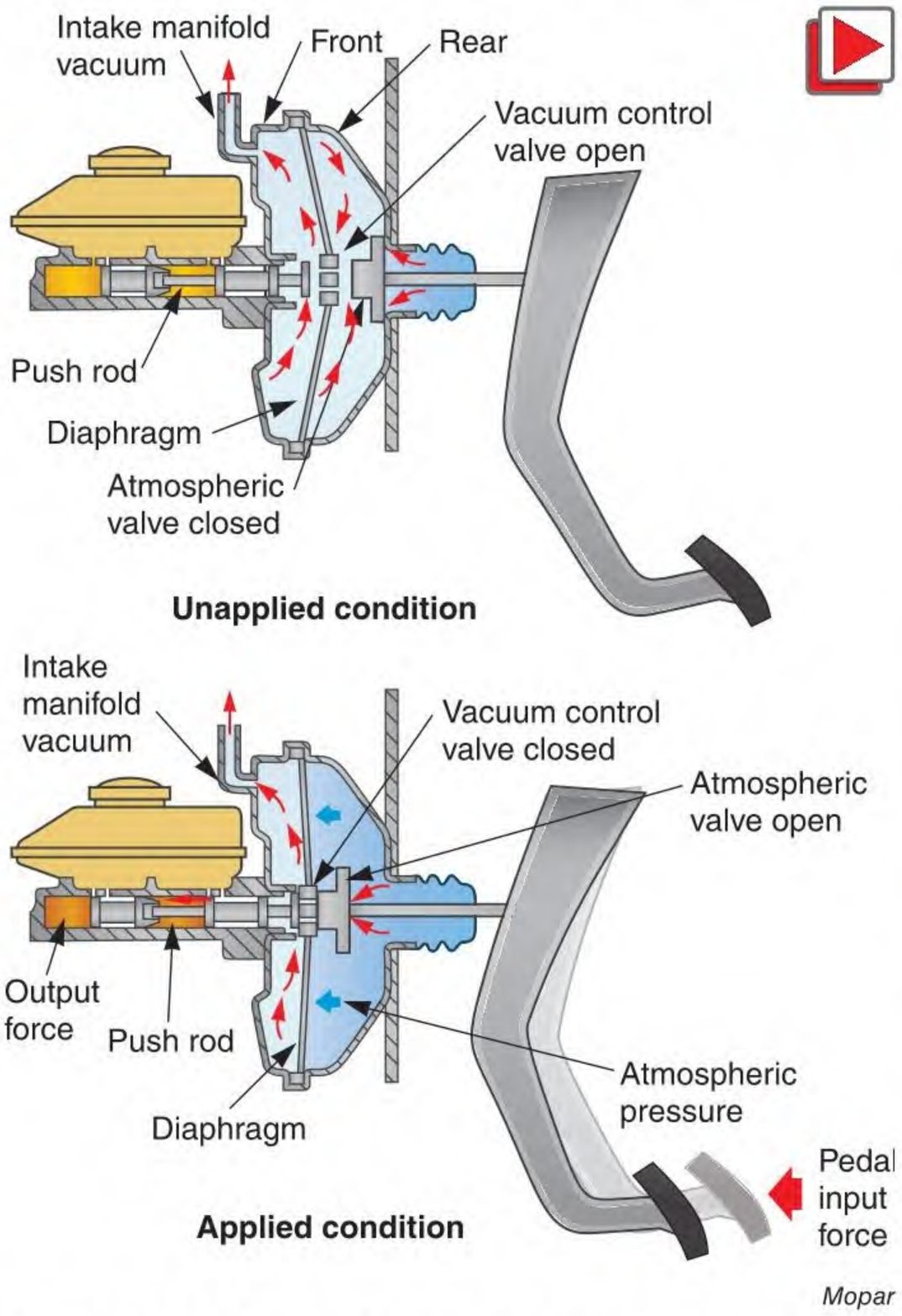
A ***vacuum suspended brake booster*** has vacuum on both sides of the piston or diaphragm when the brake pedal is released. Pushing down on the

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Figure 80-11. Study the operation of this dual master cylinder. A—No problem in the brake system. Both pistons produce pressure for all four wheel brake assemblies. B—The rear brake circuit is leaking. The primary piston pushes on the secondary piston, and two wheel brake assemblies still work to stop vehicle. C—With a front brake circuit leak, the secondary piston slides forward in the cylinder. The primary piston then operates normally to apply two wheel brake assemblies.



Mopar

Figure 80-12. A vacuum booster uses engine vacuum or vacuum created by an auxiliary pump to help apply the brake pedal. The vacuum acts on a diaphragm, which pushes on a push rod.

brake pedal releases the vacuum on one side of the booster. The difference in pressure pushes the piston or diaphragm for braking action. See **Figures 80-13**.

Power Brake Hydraulic Boosters

A power brake ***hydraulic booster*** uses power steering pump pressure to help the driver apply the brake pedal. Sometimes called ***hydro-boost*** or ***hydra-booster***, it uses fluid pressure, instead of vacuum, to help force the piston forward, **Figure 80-14**.

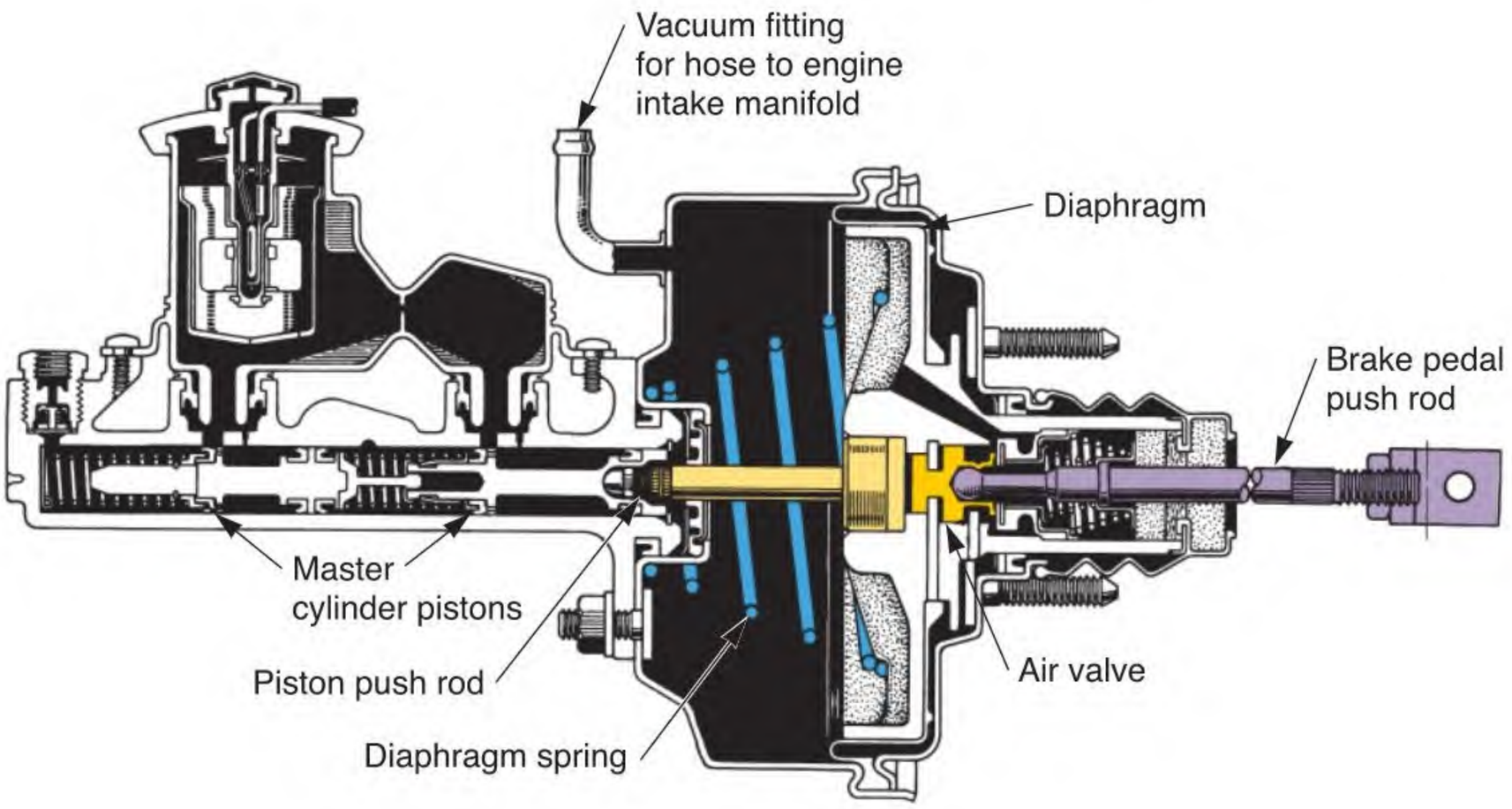
Hydro-boost power brakes are commonly used on vehicles equipped with diesel engines. A diesel engine does not produce enough intake manifold vacuum to operate a vacuum booster. The power steering pump becomes an excellent source of energy to assist brake application. Some gasoline engine-powered vehicles also use this setup. Refer to **Figure 80-15**.

Brake Fluid

Brake fluid is a specially blended hydraulic fluid that transfers pressure to the wheel brake assemblies. Brake fluid is one of the most important components of a brake system because it ties all the other components into a functioning unit.

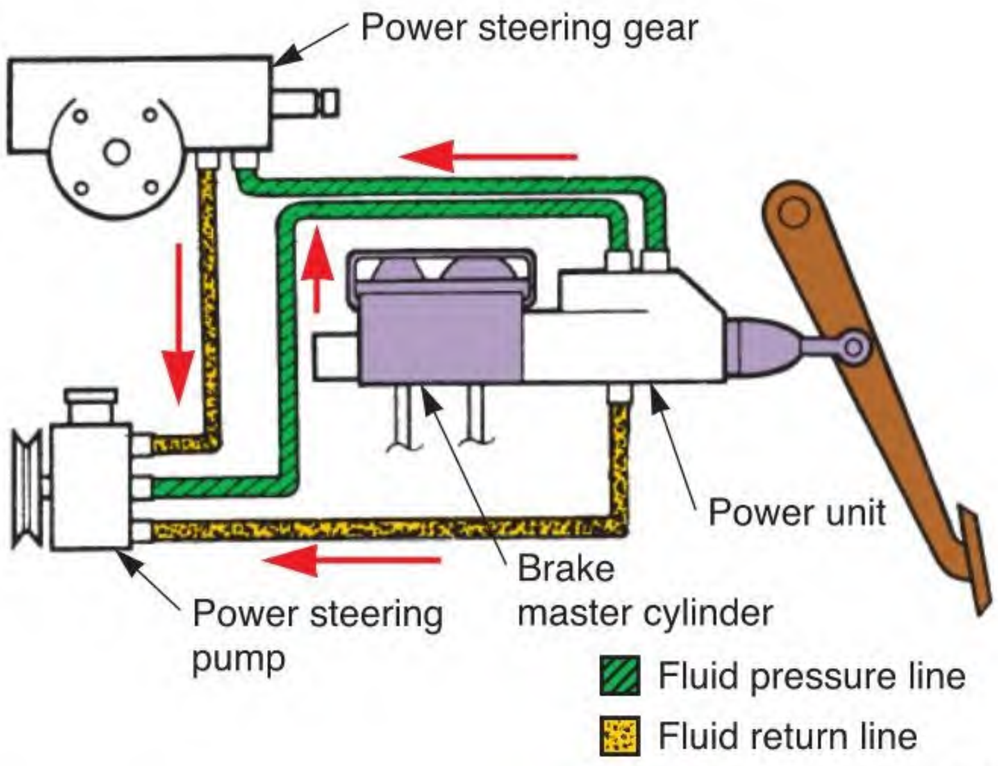
Automakers recommend brake fluid that meets or exceeds SAE (Society of Automotive Engineers) and DOT (Department of Transportation) specifications. Only brake fluid that satisfies their requirements should be used.

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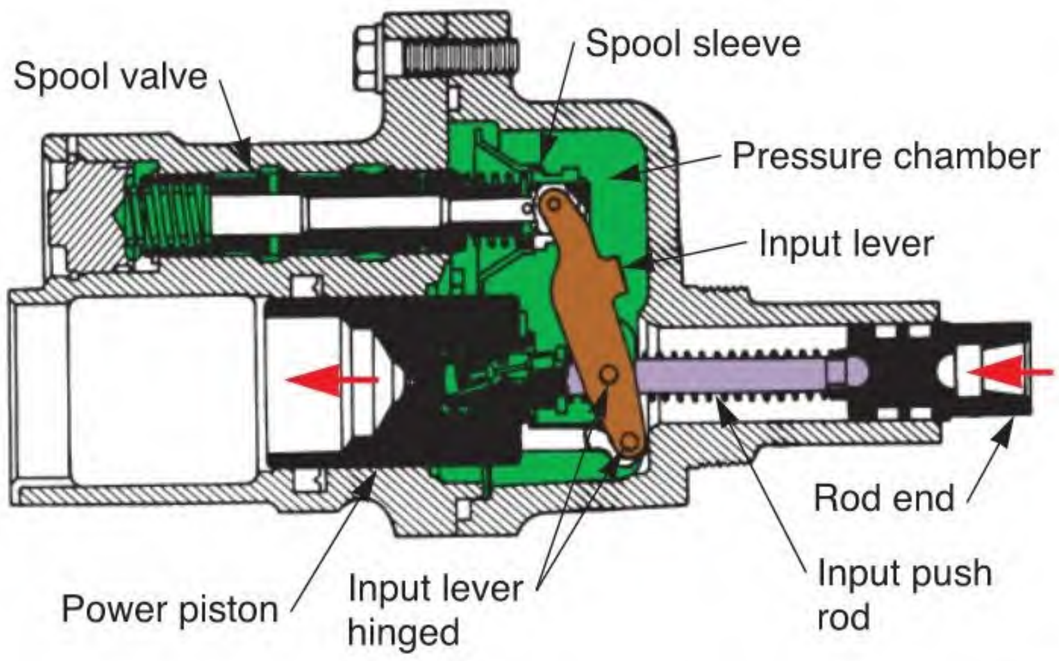
Toyota

Figure 80-13. Study the internal parts of this brake booster and master cylinder.



FMC

Figure 80-14. A hydraulic brake booster uses oil pressure from the power steering pump.



FMC

Figure 80-15. Cutaway view shows the inside of a hydraulic brake booster. When the pedal pushes on the unit, the spool valve allows more oil to enter the pressure chamber. This causes the power piston to act on the master cylinder to provide power assist.

Brake fluid must have the following characteristics:

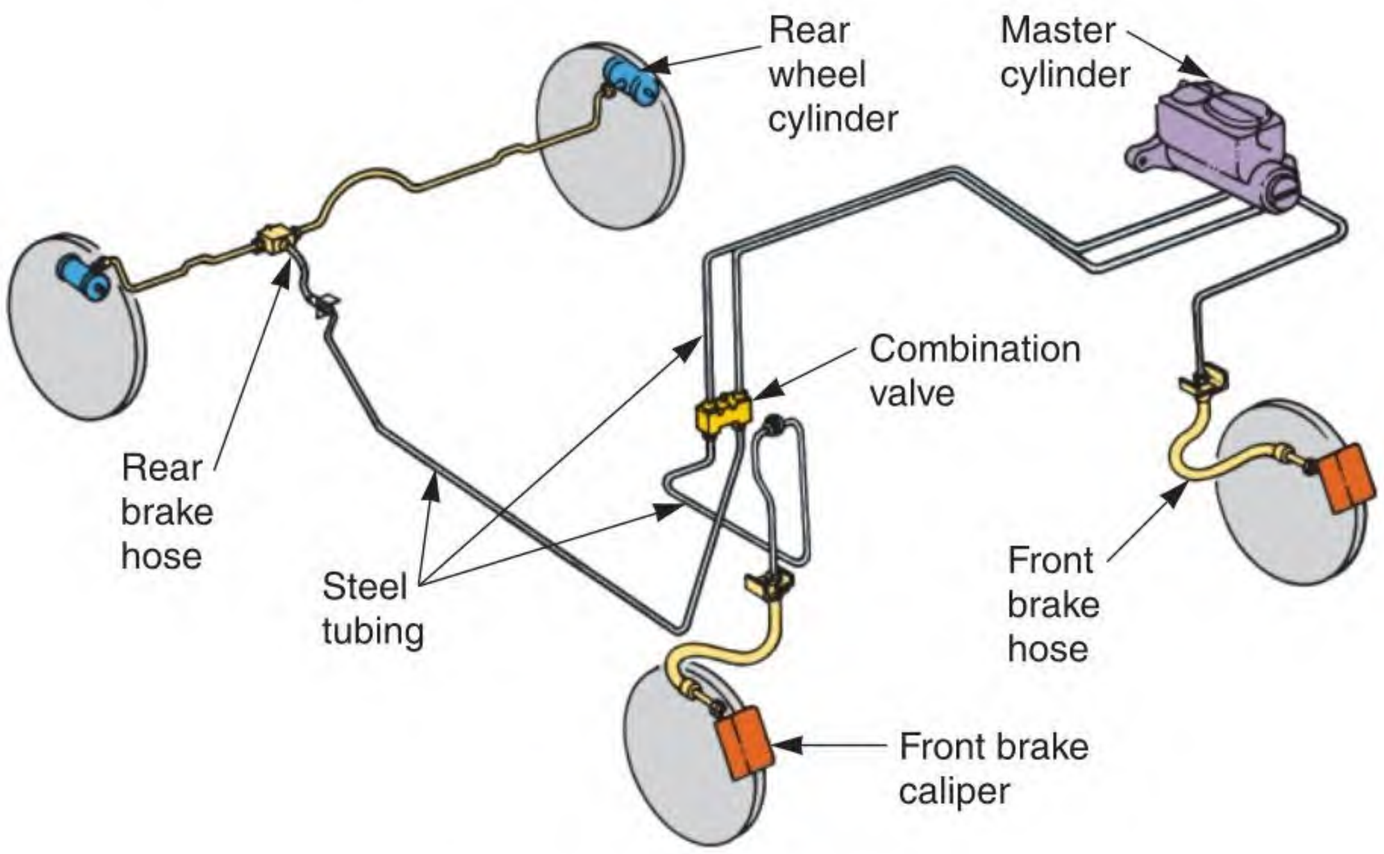
- Maintain correct viscosity—Brake fluid is free flowing at all temperatures.
- High boiling point—Brake fluid remains liquid at highest system operating temperature.
- Noncorrosive—Brake fluid does not attack metal or rubber brake system parts.
- Water tolerant—Brake fluid absorbs moisture that collects in the system.
- Lubricates—Brake fluid reduces wear of the pistons and cups.
- Low freezing point—Brake fluid does not freeze in cold weather.

Brake Lines and Hoses

Brake lines and ***brake hoses*** transfer fluid pressure from the master cylinder to the wheel brake assemblies. Look at **Figure 80-16**.

Brake lines are made of double-wall steel tubing and usually have double-lap flares on their ends to prevent high pressure leakage.

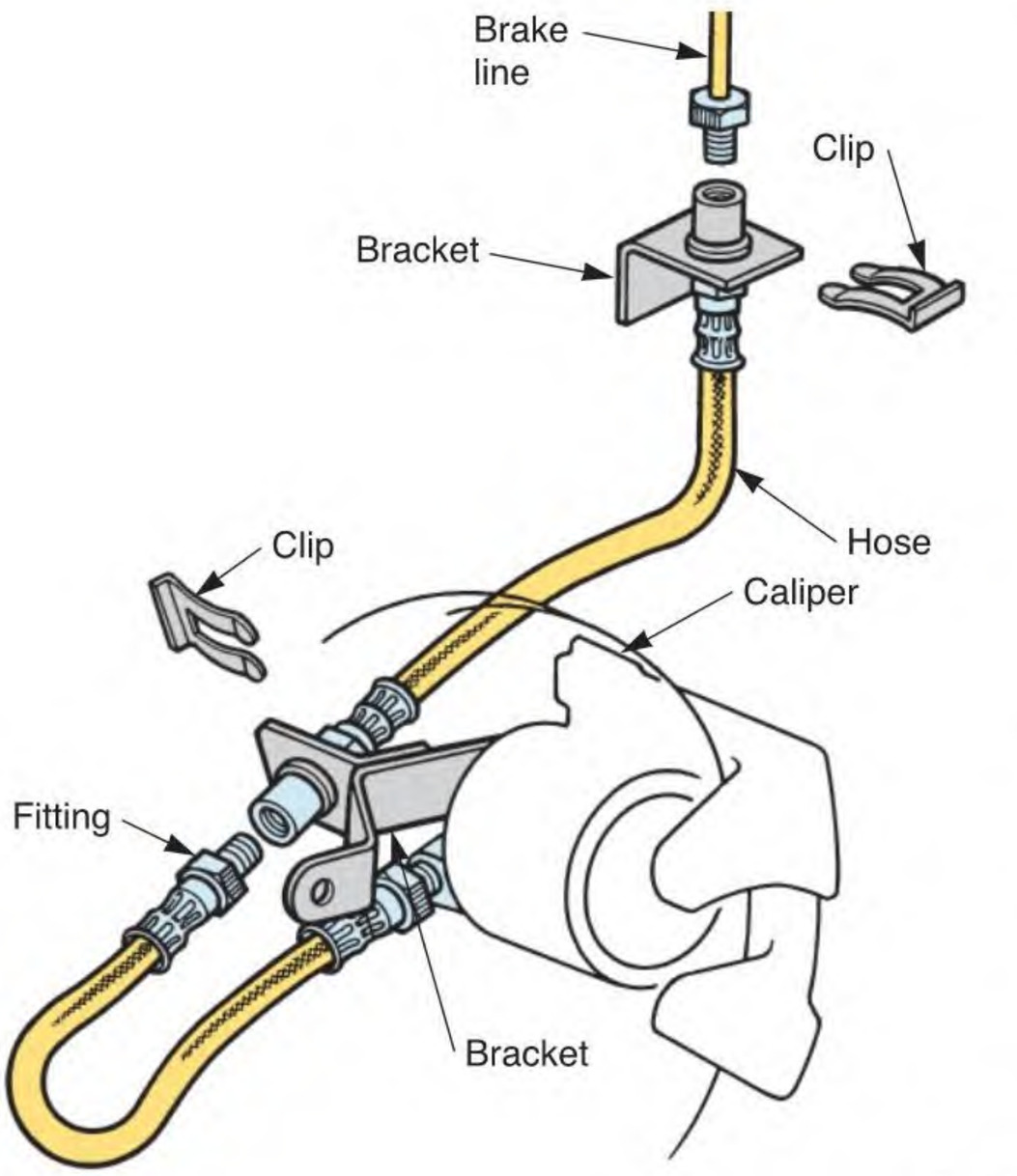
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Chrysler

Figure 80-16. Note the routing and location of metal brake lines and flexible hoses. Hoses are needed because suspension movement would break steel tubing.

Brake hoses are reinforced braided rubber hydraulic hoses with threaded metal end fittings. Hoses are used where a flexing action is needed. For instance, brake hose is used between the frame and the front caliper cylinders. This allows the wheels to move up and down or from side to side without brake line damage. Refer to **Figure 80-17**.



Toyota

Figure 80-17. Brackets and clips are used to secure the brake hoses and lines to the frame or body. Lines must not be allowed to vibrate or they can fatigue and break.

A junction block is used where a single brake line must feed two wheel cylinders. It is simply a hollow fitting with one inlet and two or more outlets.

In a ***longitudinally split*** (front to rear) brake system, one master cylinder piston operates the front wheel brake assemblies and the other operates the rear brake assemblies. See **Figure 80-18A**.

A ***diagonally split*** (corner to corner) brake system has each master cylinder piston operating the brake assemblies on opposite corners of the vehicle, **Figure 80-18B**.

Disc Brake Assemblies

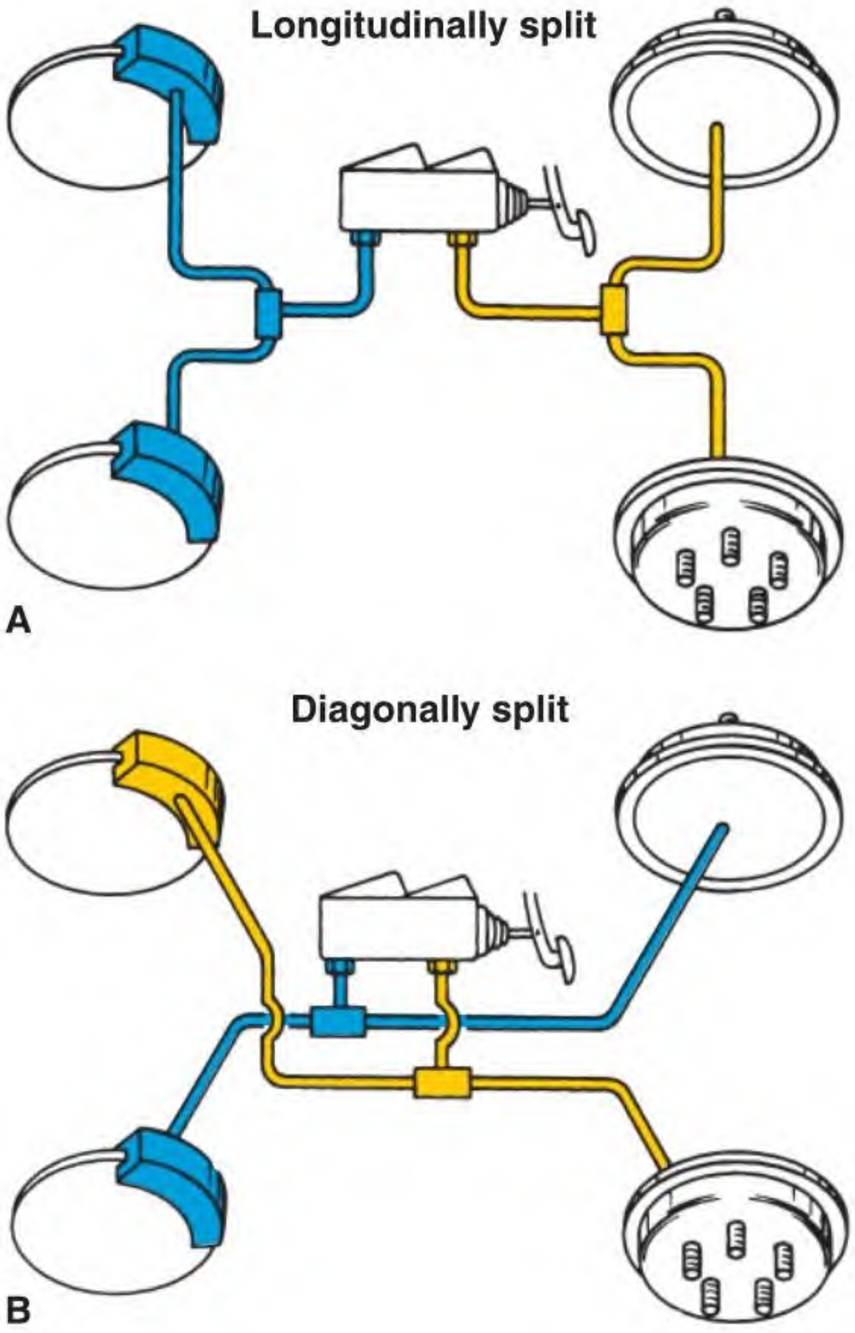
Disc brakes are basically like the brakes on a ten-speed bicycle. The friction elements are squeezed inward to clamp against a rotating disc, or wheel.

A disc brake assembly consists of a caliper, brake pads, a disc, and related hardware (bolts, clips, springs, etc.). See **Figure 80-19**. **Figure 80-20** shows section views of typical disc brake assemblies. Note how the caliper pistons move inward to clamp the brake pads against the rotor.

Brake Caliper

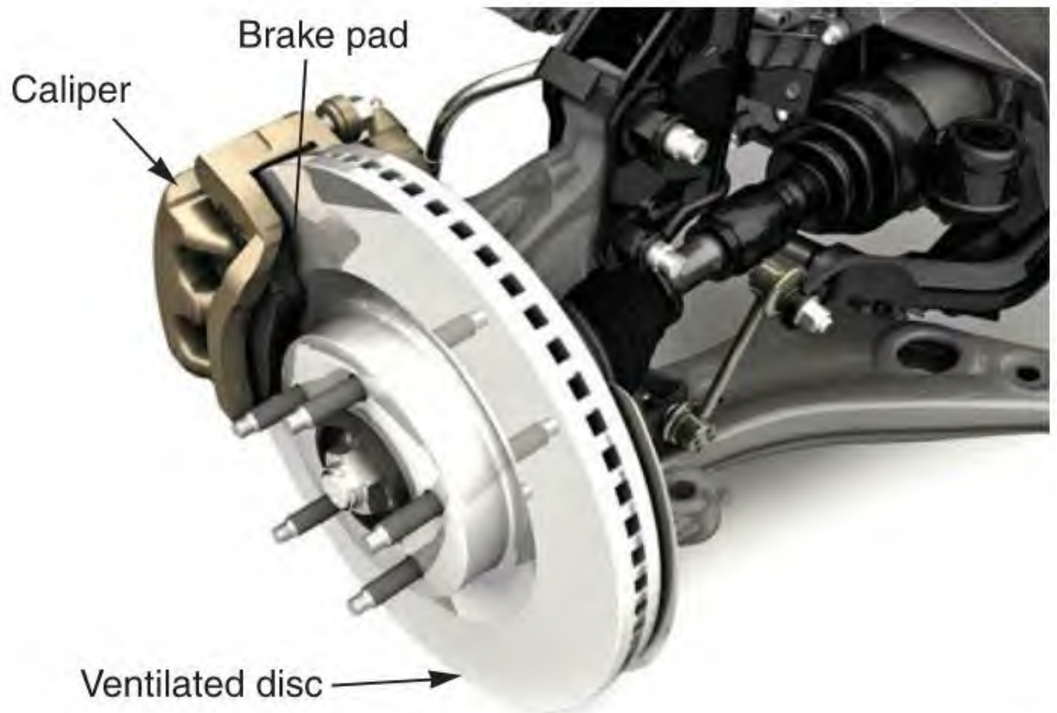
The ***brake caliper*** assembly includes the caliper housing, piston, piston seal, dust boot, brake pads, special hardware (clips, springs), and a bleeder screw. These parts are pictured in **Figure 80-21**.

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Figure 80-18. Study how each master cylinder piston operates different wheel brake assemblies.



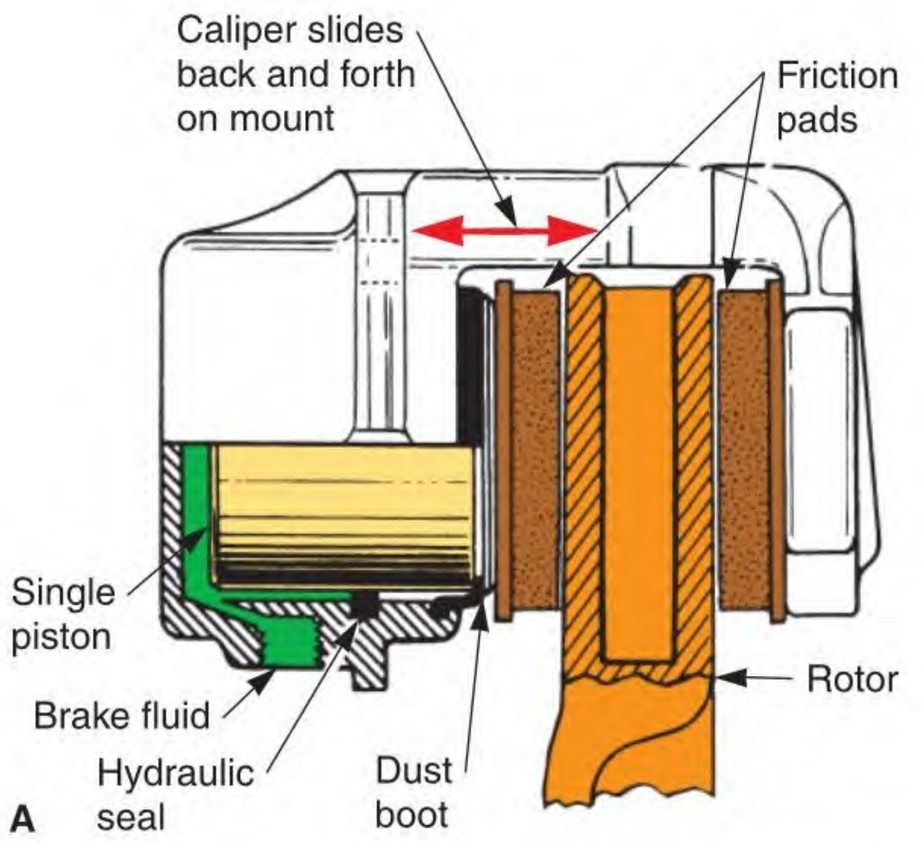
Ford

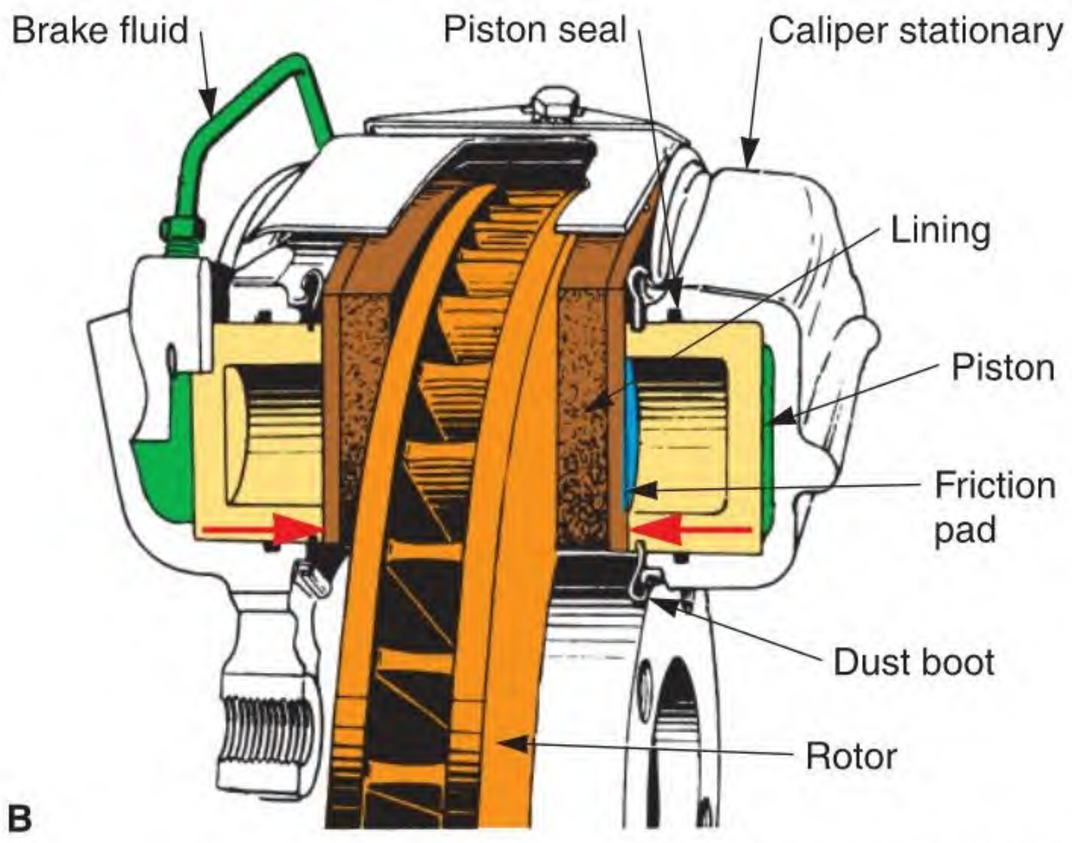
Figure 80-19. Note the parts of a disc brake unit.

When the brake pedal is applied, brake fluid flows into the caliper cylinder. The piston is then pushed outward by fluid pressure, forcing the brake pads into the disc. See **Figure 80-22**.

The ***piston seal*** in the caliper prevents pressure leakage between the piston and the cylinder. The piston seal also helps pull the piston back into the cylinder when the brakes are not applied. The elastic action of the seal acts as a spring to retract the piston.

The ***piston boot*** keeps road dirt and water off the caliper piston and the wall of the cylinder. The boot and seal usually fit into grooves cut in the caliper cylinder and piston, **Figure 80-22**.





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Figure 80-20. The caliper piston pushes the brake pad into a revolving disc to slow or stop the vehicle. A—The single-piston caliper is very common. The caliper floats, or slides, on its mount so both pads contact the disc. B—A fixed caliper uses pistons on both sides of disc. The caliper remains stationary on its mounting.

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A ***bleeder screw*** allows air to be removed from the hydraulic brake system. It is threaded into the side or top of the caliper housing. When the screw is loosened, hydraulic pressure can be used to force fluid and air out of the system, **Figure 80-21**.

Disc Brake Pads

Disc brake pads are steel plates to which linings are riveted or bonded. Each caliper has an inner and outer brake pad that fits inside the hydraulic brake caliper. Refer to **Figure 80-21**.

Brake pad linings are normally made of heat-resistant organic or semimetallic (metal-particle filled) friction material. Older pad linings were made of asbestos, which has been phased out because of its cancer-causing properties. Many new vehicles, especially those with front-wheel drive, use semimetallic linings on the front. Semimetallic linings can withstand higher operating temperatures without losing their frictional properties.

Anti-rattle clips are frequently used to keep the brake pads from vibrating and rattling. The clip snaps onto the brake pad to produce a force fit in the caliper. Sometimes, an anti-rattle spring is used instead of a clip.

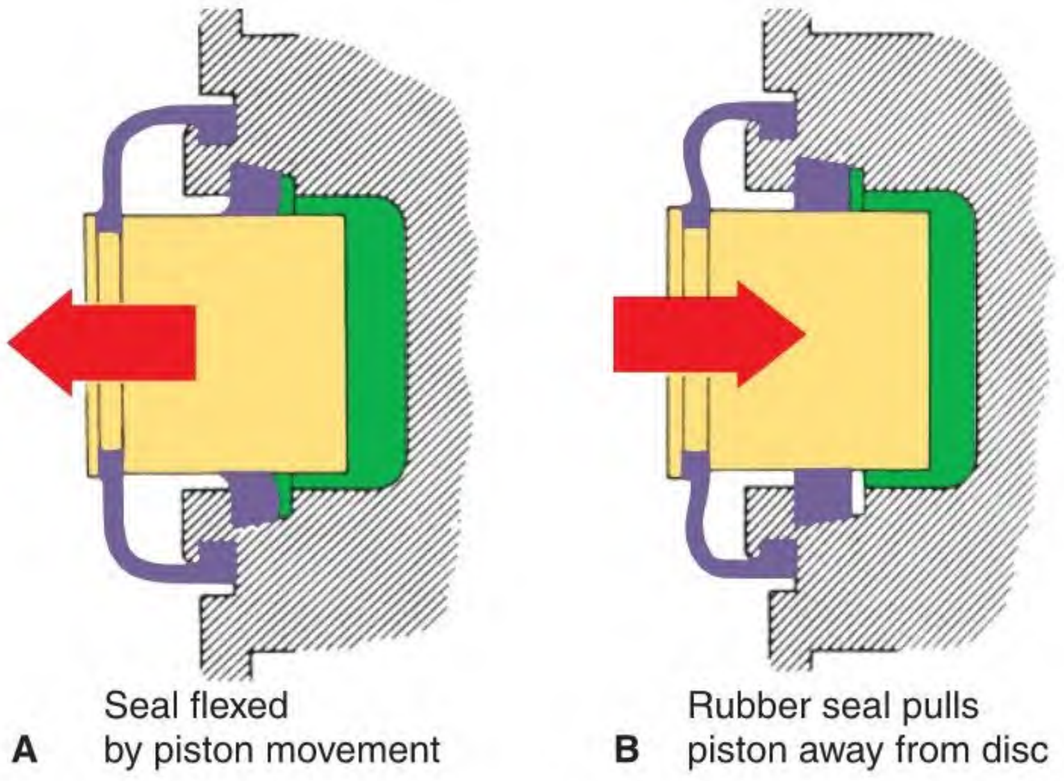
A ***pad-wear sensor*** is a metal tab on the brake pad that informs driver of worn brake pad linings. The wear sensor tab emits a loud squeal or squeak when it scrapes against the brake disc. The sensor only touches the disc when the brake lining has worn too thin.

Brake Disc

The brake disc, also called ***brake rotor***, uses friction from the brake pads to slow or stop wheel rotation. The brake disc is normally made of cast iron. It may be an integral part of the wheel hub. However, in many front-wheel-drive vehicles, the disc and the hub are separate units.

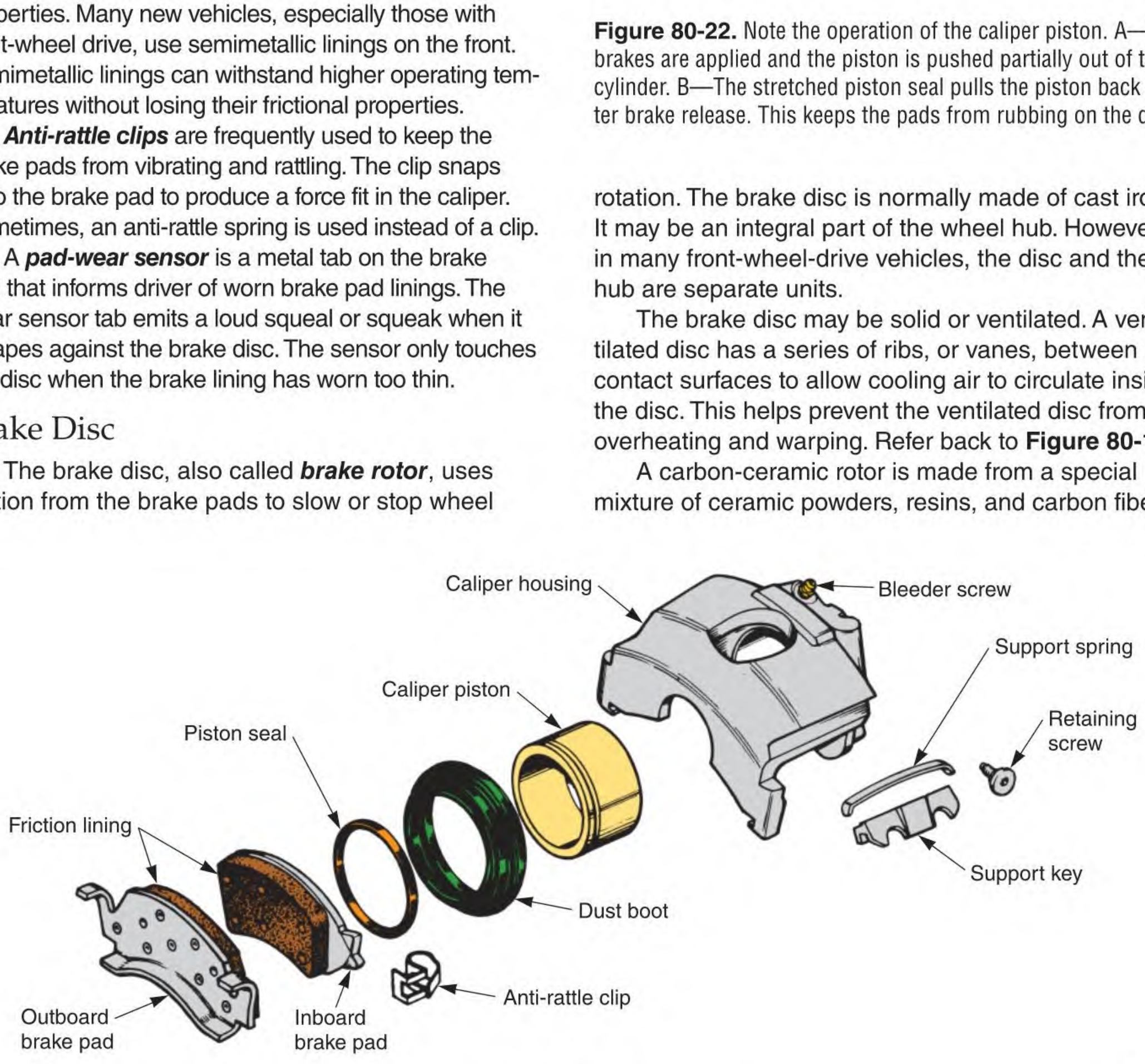
The brake disc may be solid or ventilated. A ventilated disc has a series of ribs, or vanes, between its contact surfaces to allow cooling air to circulate inside the disc. This helps prevent the ventilated disc from overheating and warping. Refer back to **Figure 80-19**.

A carbon-ceramic rotor is made from a special mixture of ceramic powders, resins, and carbon fibers.



EIS

Figure 80-22. Note the operation of the caliper piston. A—The brakes are applied and the piston is pushed partially out of the cylinder. B—The stretched piston seal pulls the piston back after brake release. This keeps the pads from rubbing on the disc.



Chrysler

Figure 80-21. Study disassembled view of a caliper. Note how the parts fit together.

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This type of rotor is much lighter than a cast iron rotor and is usually bolted to an aluminum hub. The carbon-ceramic rotor can resist and dissipate heat better than a cast iron rotor for decreased high-speed stopping distances. See **Figure 80-23**.

Disc Brake Types

Disc brakes can be classified as floating caliper brakes, sliding caliper brakes, and fixed caliper brakes. Floating and sliding calipers are common. Fixed calipers were used on a few older passenger cars.

The ***floating caliper*** disc brake is mounted on two bolts supported by rubber bushings. This one-piston caliper is free to shift, or float, in the rubber bushings.

The ***sliding caliper*** disc brake is a one-piston caliper that is mounted in slots machined in the caliper adapter. The caliper is free to slide sideways in the slots or grooves as the linings wear.

The ***fixed caliper*** disc brake normally uses more than one piston and caliper cylinder. The caliper is bolted directly to the steering knuckle. It is not free to move in relation to the disc. Pistons on both sides of the disc push against the brake pads.

Floating and sliding calipers are used to avoid vibration problems. With a fixed caliper, severe vibrations can occur with a slight ***runout*** (wobble) of the disc.



Brembo

Figure 80-23. Carbon-ceramic rotors are found on some high-performance sports cars.

Drum Brake Assemblies

Drum brakes use many of the principles covered in the section on disc brakes. However, drum brakes have a large drum that surrounds the brake shoes and the hydraulic wheel cylinder.

A drum brake assembly consists of a backing plate, a wheel cylinder, brake shoes and linings, retracting springs, hold-down springs, a brake drum, and an automatic adjusting mechanism, **Figure 80-24**. Drum brakes are becoming less common, but are still used for rear brakes on some vehicles.

Backing Plate

The ***brake backing plate*** holds the shoes, springs, wheel cylinder, and other parts inside the brake drum. It also helps keep road dirt and water off the brakes. The backing plate bolts to the axle housing or the spindle support.

Wheel Cylinder Assembly

The wheel cylinder assemblies use master cylinder pressure to force the brake shoes out against the brake drums. The cylinders bolt to the top of the backing plates.

A ***wheel cylinder*** consists of a cylinder or housing, an expander spring, rubber cups, pistons, dust boots, and a bleeder screw. See **Figure 80-25**.

The ***wheel cylinder housing*** forms the enclosure for the other parts of the assembly. It has a precision honed cylinder in it for the pistons, the cups, and the spring.

The ***wheel cylinder boots*** keep road dirt and water out of the cylinder. They snap into grooves on the outside of the housing.

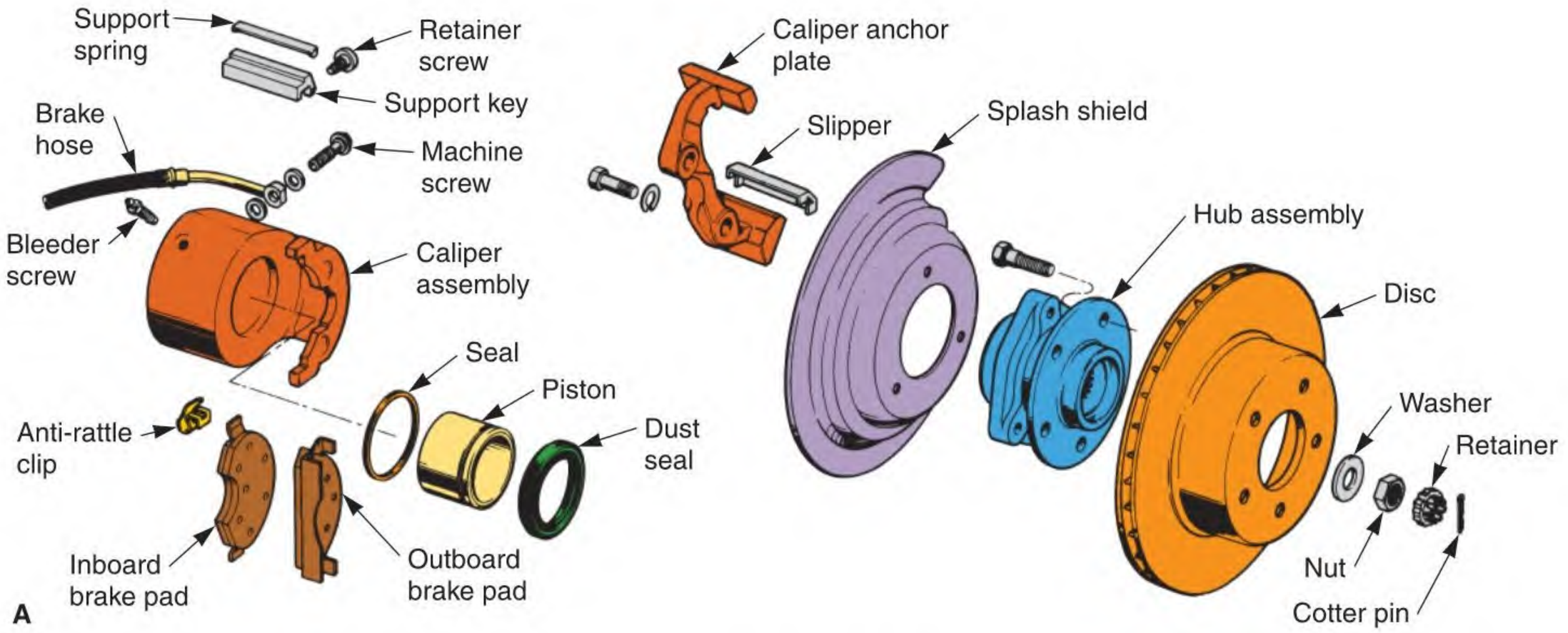
The ***wheel cylinder pistons*** are metal or plastic plungers that transfer force out of the wheel cylinder assembly. They act on push rods connected to the brake shoes or directly on the shoes.

The ***wheel cylinder cups*** are rubber seals that keep fluid from leaking past the pistons. They fit in the cylinder and against the pistons.

The ***wheel cylinder spring*** helps hold the rubber cups against the pistons when the wheel cylinder assembly is not pressurized. Sometimes, the ends of this spring have metal expanders. Called ***cup expanders***, they help press the outer edges of the cups against the wall of the wheel cylinder.

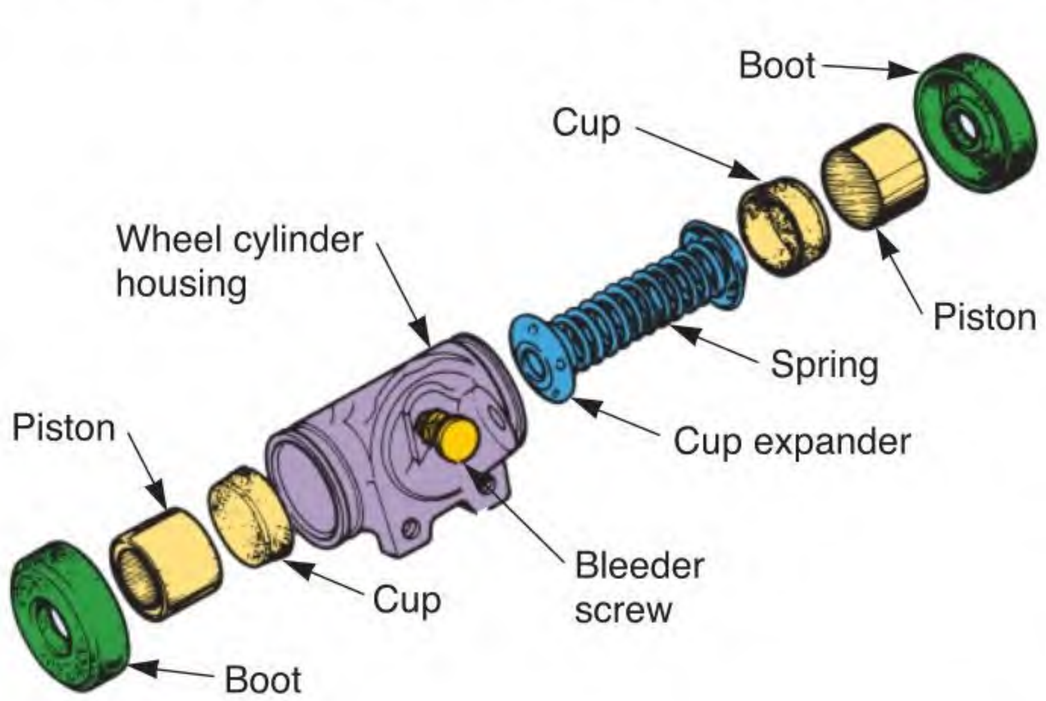
The bleeder screw provides a means of removing air from the brake system. It threads into a hole in the back of the wheel cylinder. When the screw is loosened, hydraulic pressure can be used to force air and fluid out of the system. Refer to **Figure 80-26**.

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Chrysler; Toyota

Figure 80-24. Compare complete disc and drum brake assemblies. A—Disc brake assembly. B—Drum brake assembly.



Renault

Figure 80-25. This exploded view shows a wheel cylinder for a drum brake. The cups prevent fluid leakage out of the cylinder. The boots keep debris out of the cylinder.

Drum Brake Shoes

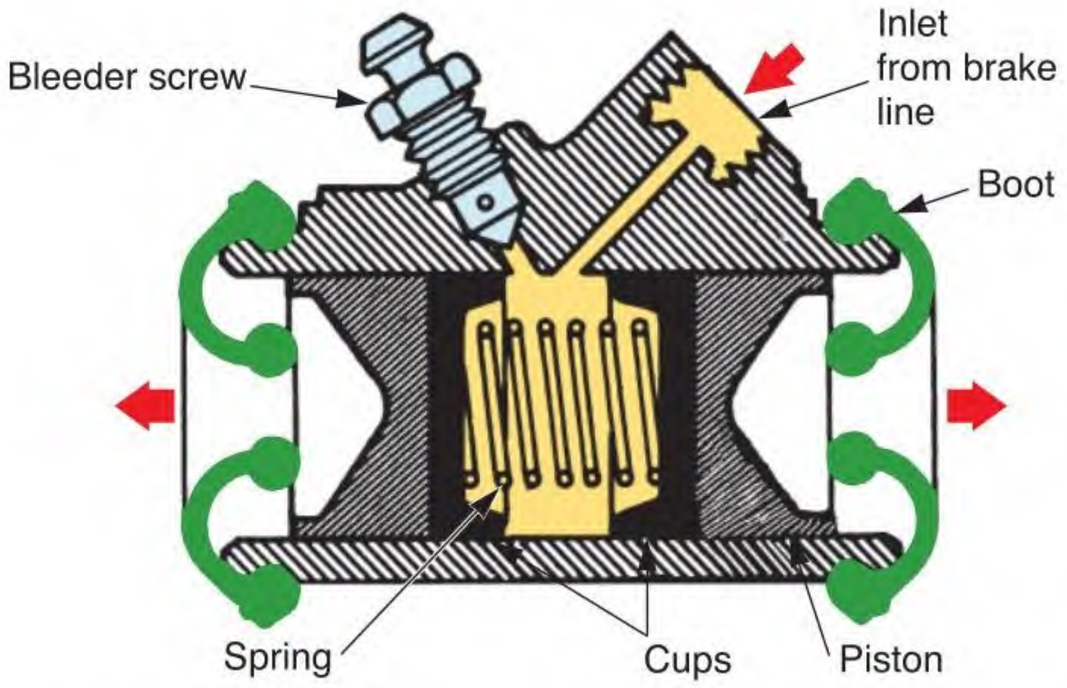
The ***drum brake shoe assemblies***, or brake shoes, rub against the revolving brake drum to produce braking action. Drum brake shoe assemblies are made by fastening friction material onto a metal shoe. The lining is a heat-resistant surface that contacts the brake drum.

The metal shoe supports and holds the soft lining material. The lining may be held on the shoe by either rivets or a bonding agent (glue).

The ***primary brake shoe*** is the front shoe. It normally has a slightly shorter lining than the secondary shoe.

The ***secondary brake shoe*** is the rear shoe. It has the largest lining surface area.

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Figure 80-26. This cutaway view of a drum brake wheel cylinder shows the fluid passages to the cylinder and the bleeder screw. Pressure inside the cylinder pushes the cups and pistons outward to force the linings into the drum.

Retracting Springs and Hold-Down Springs

Retracting springs pull the brake shoes away from the brake drums when the brake pedal is released. This, in turn, pushes the wheel cylinder pistons inward. Usually, the retracting springs fit in holes in the shoes and around an anchor pin at the top of the backing plate.

Hold-down springs hold the brake shoes against the backing plate when the brakes are in the released position. A hold-down pin fits through the back of the backing plate. Metal cups lock onto these pins to secure the hold-down springs to the shoes. Some manufacturers use spring clips instead of hold-down springs and locking cups. Others use a spring that is simply hooked to the shoe and the backing plate.

All brake springs are made from high-quality steel that is capable of withstanding the high temperatures encountered inside the brake drum.

Brake Shoe Adjusters

Brake shoe adjusters maintain the correct drum-to-lining clearance as the brake linings wear.

Many vehicles use a star wheel–type (screw-type) brake shoe adjusting mechanism. This type of adjusting mechanism includes a ***star wheel*** (adjusting screw assembly), an adjuster lever, an adjuster spring, and either an adjuster cable, lever arm, or link (rods). Other vehicles use latch-type adjusters. See **Figure 80-27**.

Automatic brake shoe adjusters normally function when the brakes are applied with the vehicle moving in reverse. If there is too much lining clearance, the brake shoes move outward and rotate with the drum enough to operate the adjusting lever. This lengthens the star wheel assembly. The linings are moved closer to the brake drum, maintaining the correct lining-to-drum clearance.

Brake Drums

Brake drums provide a rubbing surface for the brake shoe linings. The drum usually fits over the wheel lug studs. A large hole in the middle of the drum centers the drum on the front hub or the rear axle flange. The wheel and drum turn as a unit. See **Figure 80-28**.

Brake Shoe Energization

When the brake shoes are forced against the rotating drum, they are pulled away from their pivot point by friction. This movement, called ***self-energizing action***, draws the shoes tighter against the drum, **Figure 80-29A**.

With most drum brake designs, shoe energization is supplemented by servo action. ***Servo action*** results when the primary (front) shoe helps apply the secondary (rear) shoe. Study **Figure 80-29B**.

The backing plate anchor pin holds the secondary shoe during brake application. However, the primary shoe is free to float out and push against the end of the secondary shoe through the star wheel assembly. This action presses the secondary shoe into the drum with extra force.

Less wheel cylinder hydraulic pressure is needed to apply the brakes because of servo action.

Brake System Switches

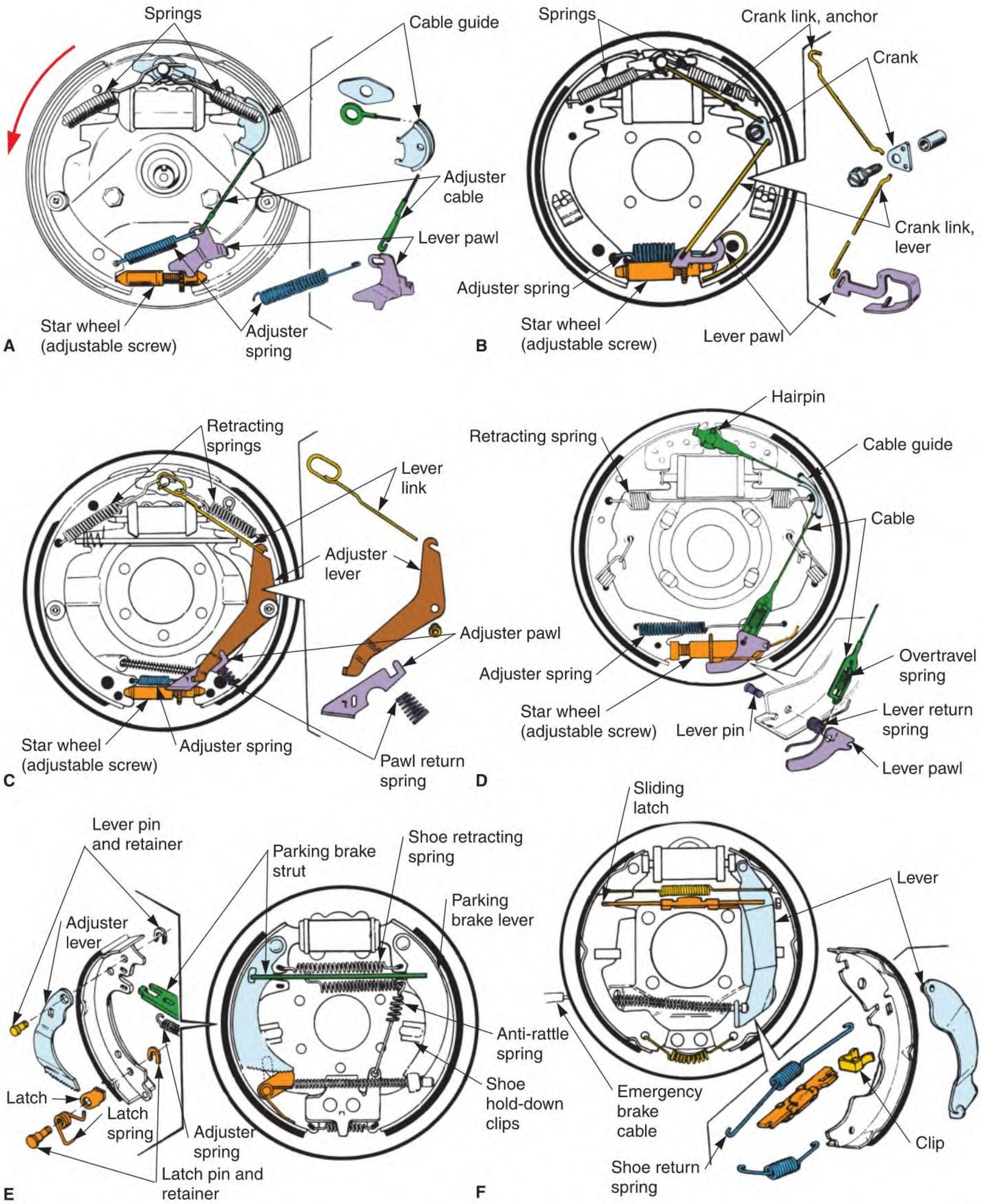
There are three types of switches commonly used in a brake system: the stoplight switch, brake warning light switch, and low-fluid warning light switch.

Stoplight Switch

The ***stoplight switch*** is a spring-loaded electrical switch that operates the rear brake lights of the vehicle. Most modern cars use a mechanical switch on the brake pedal mechanism. The switch is normally open. When the brake pedal is pressed, it closes the switch and turns on the brake lights.

Hydraulically operated stoplight switches are used on some older vehicles. Brake system pressure pushed on a switch diaphragm and closed the switch that operated the brake lights.

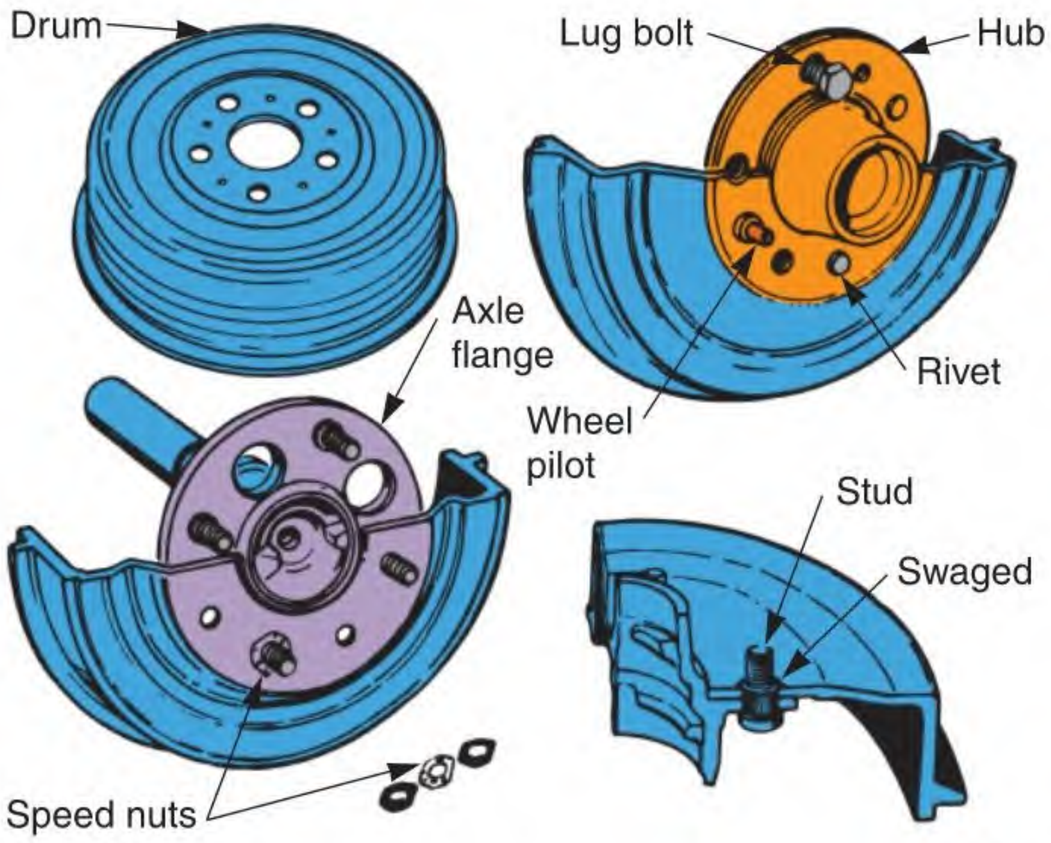
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FMC

Figure 80-27. These are the most common brake shoe adjuster mechanisms. A—Cable-type star wheel adjuster. B—Link-type star wheel adjuster. C—Lever-type star wheel adjuster. D—Cable-type star wheel adjuster with an overtravel spring. E—Lever-latch adjuster. F—Sliding-latch adjuster.

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Ford

Figure 80-28. The brake drum provides a friction surface for the brake shoe linings. Study the construction of the drum.

Brake Warning Light Switch (Pressure Differential Valve)

The ***brake warning light switch***, also called the ***pressure differential valve***, warns the driver of a pressure loss on one side of a dual brake system. Look at **Figure 80-30**.

If a leak develops in either the primary or secondary brake system, unequal pressure acts on the warning light switch piston. This pushes the piston to one side, grounding the indicator circuit, **Figure 80-31**.

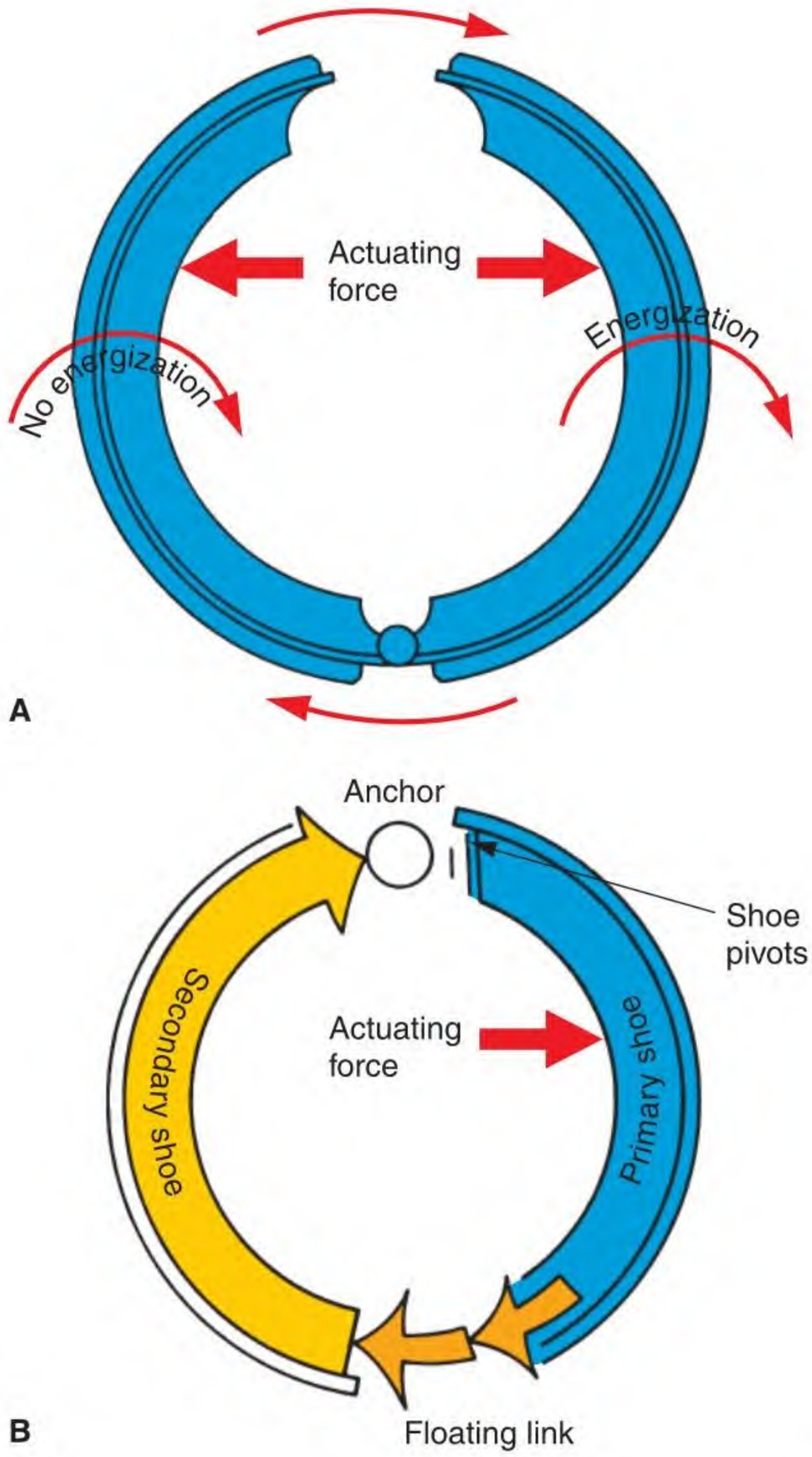
Low-Fluid Warning Light Switch

The ***low-fluid warning light switch*** turns on a dash light if the brake fluid in the master cylinder becomes low. It is a small switch that often mounts in the master cylinder lid or cover.

A float sometimes operates the switch. If the level of brake fluid in the reservoir drops below a critical point, the float moves down and turns the switch on. This illuminates a warning light, alerting the driver to a brake system problem. If the fluid level becomes too low, air will be pumped into the system, possibly causing a loss of braking action.

Brake System Control Valves

Many brake systems use control valves to regulate the pressure going to each wheel cylinder. The three types of valves are the metering valve, the proportioning valve, and the combination valve.



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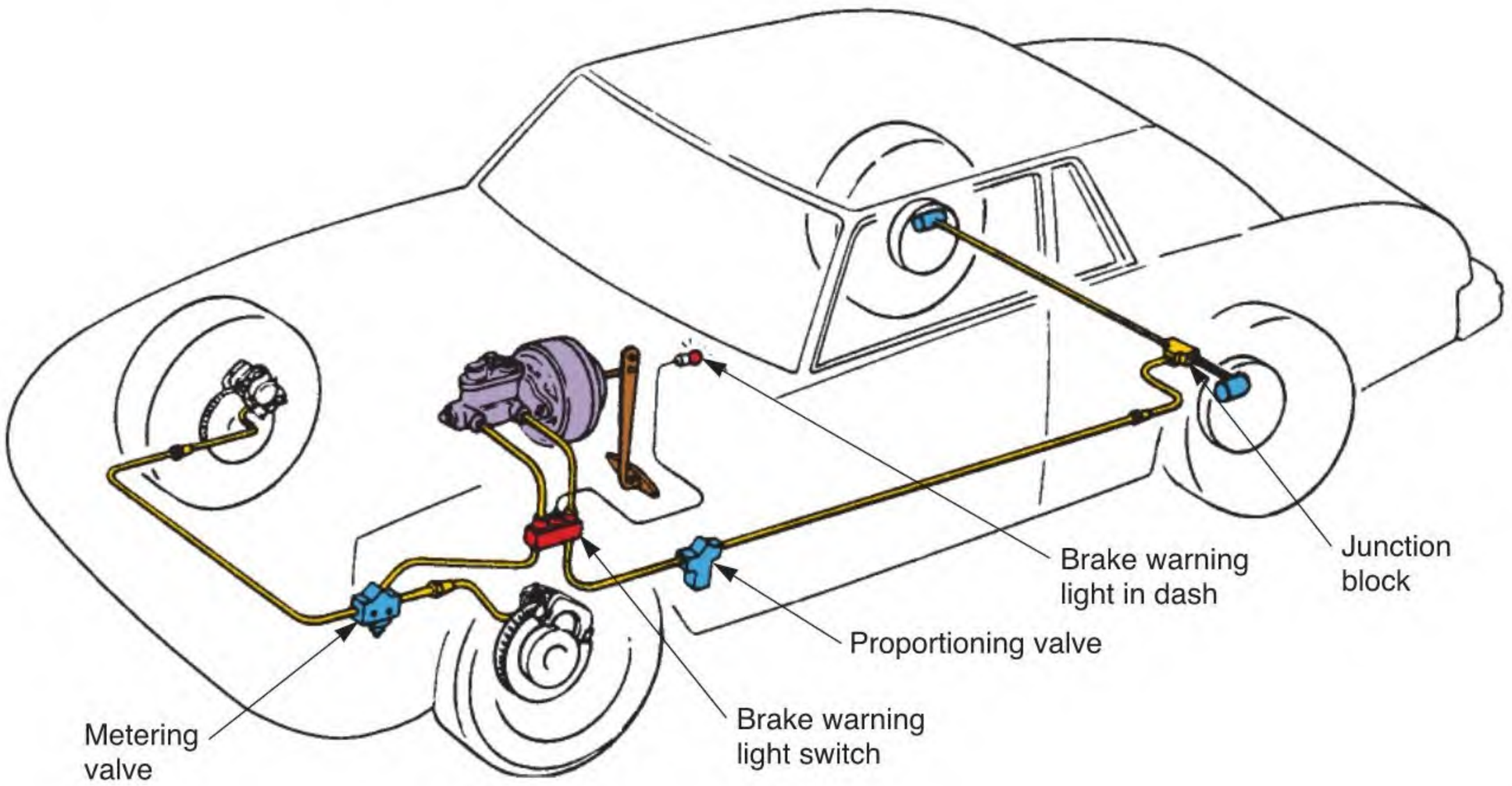
Figure 80-29. Note how brakes help apply linings to increase friction. A—Self-energizing brakes use friction to force one brake shoe tighter against drum. B—Servo action results when both shoes are free to swing into the drum and the primary shoe helps apply the secondary shoe.

Metering Valve

A ***metering valve*** is designed to equalize braking action at each wheel during light brake applications. A metering valve is used on vehicles with front-wheel disc brakes and rear-wheel drum brakes. The metering valve is located in the line to the disc brakes, **Figure 80-30**.

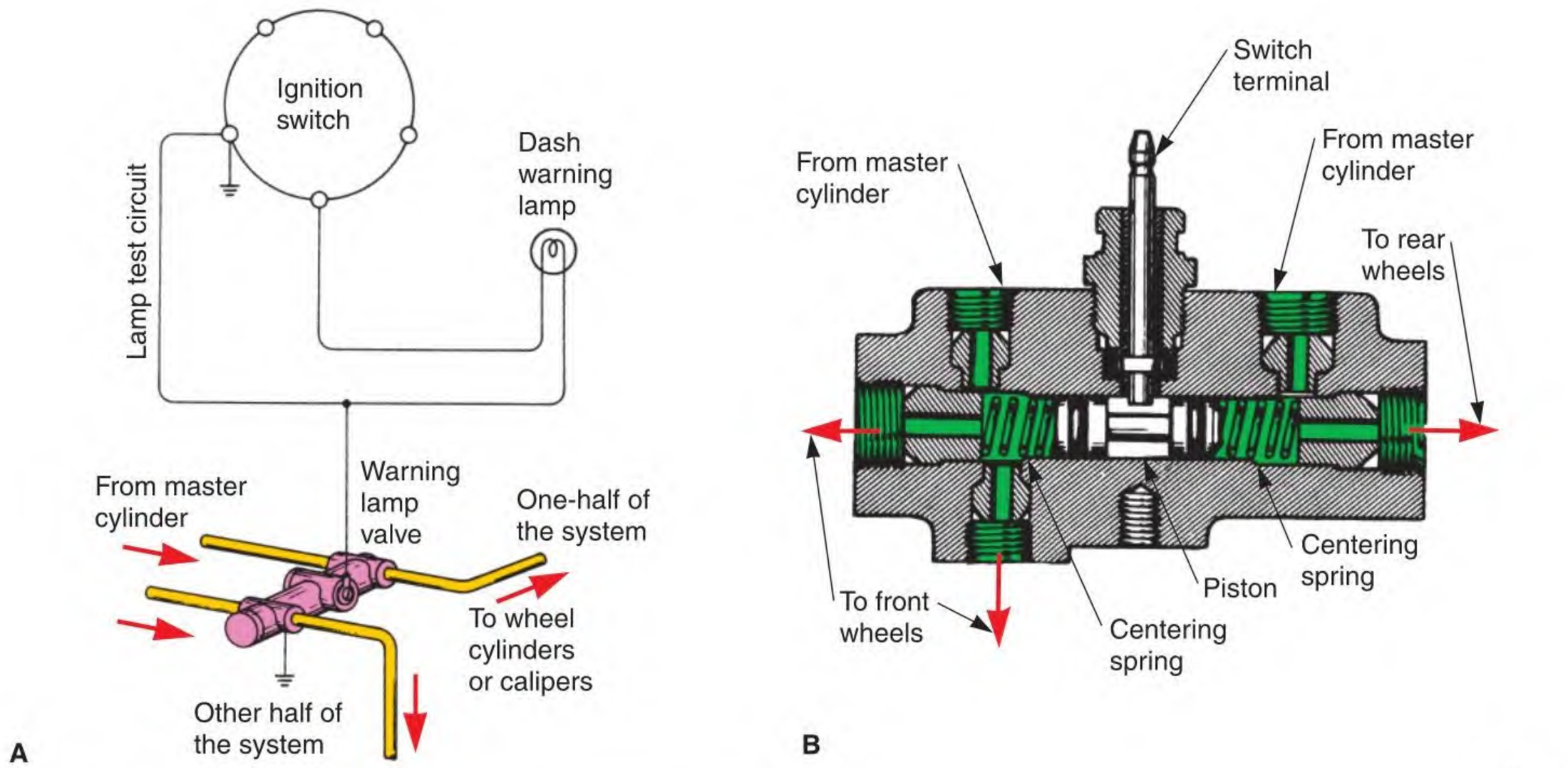
The metering valve functions by preventing the front disc brakes from applying until approximately 75–135 psi (517–930 kPa) has built up in the system. This pressure overcomes the rear drum brake return springs. Since the

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Figure 80-30. Note the location of the various valves used in a brake system.



Bendix

Figure 80-31. The brake warning light switch is activated by a difference in the pressures in the primary and secondary systems. A pressure difference pushes the small piston in the valve to close the warning lamp circuit. A—Brake warning lamp circuit. B—Cut-away view of a brake warning lamp switch.

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metering valve delays front brake application until this pressure is reached, the front disc brakes and the rear drum brakes will engage simultaneously.

Proportioning Valve

A ***proportioning valve*** is also used to equalize braking action in systems with front disc brakes and rear drum brakes. It is commonly located in the brake line to the rear drum brakes. Look at **Figure 80-30**.

The function of the proportioning valve is to limit pressure at the rear drum brakes when high pressure is needed to apply the front disc brakes. Thus, the proportioning valve prevents rear-wheel lockup during heavy brake applications.

Combination Valve

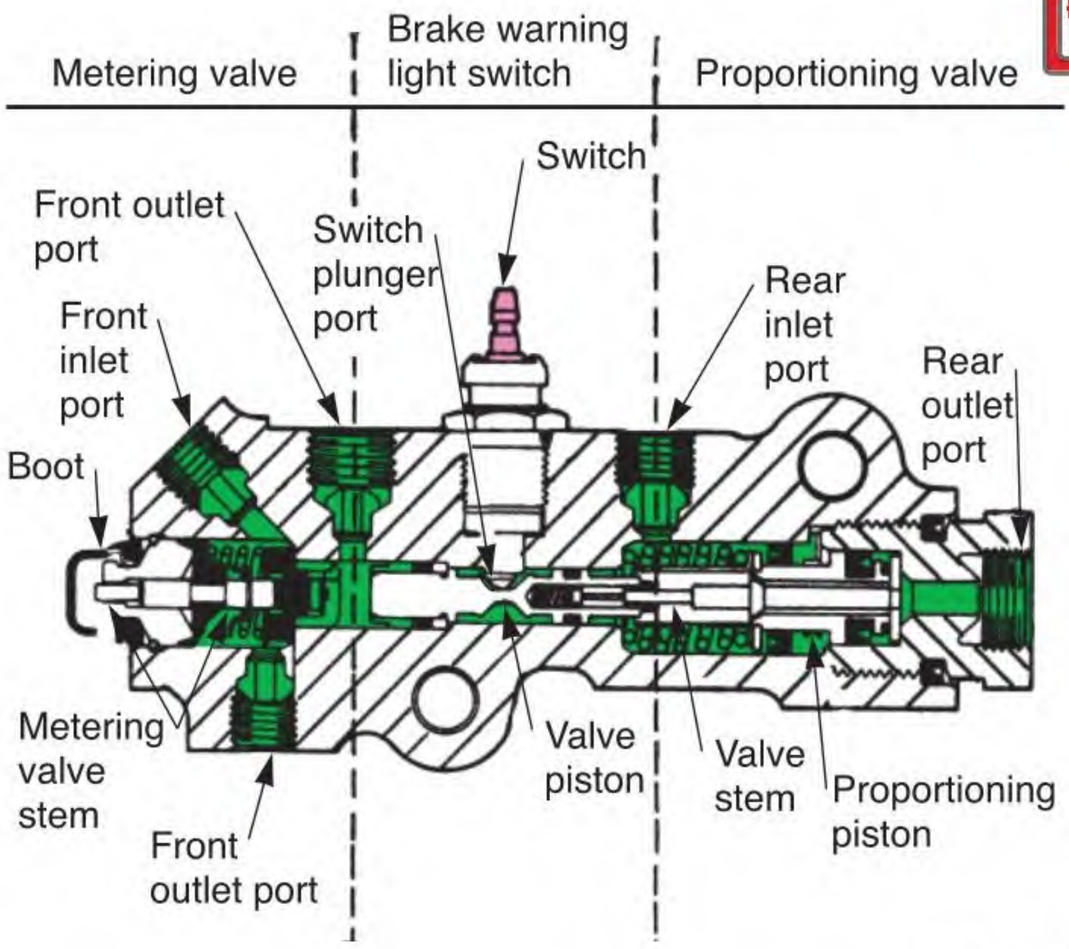
A ***combination valve*** is a single unit that functions as a brake warning light switch, a metering valve, and/or a proportioning valve. Many late-model vehicles use a combination valve. Refer to **Figure 80-32**.

With some master cylinders, the proportioning and warning lamp valves are mounted inside the master cylinder housing. This design uses the same operating principles, **Figure 80-33**.

Parking Brakes

Parking brakes, also called emergency brakes, provide a mechanical means (cable and levers) of applying the brakes. One is pictured in **Figure 80-34**.

When the parking brake hand or foot lever is activated, it pulls a steel cable that runs through a

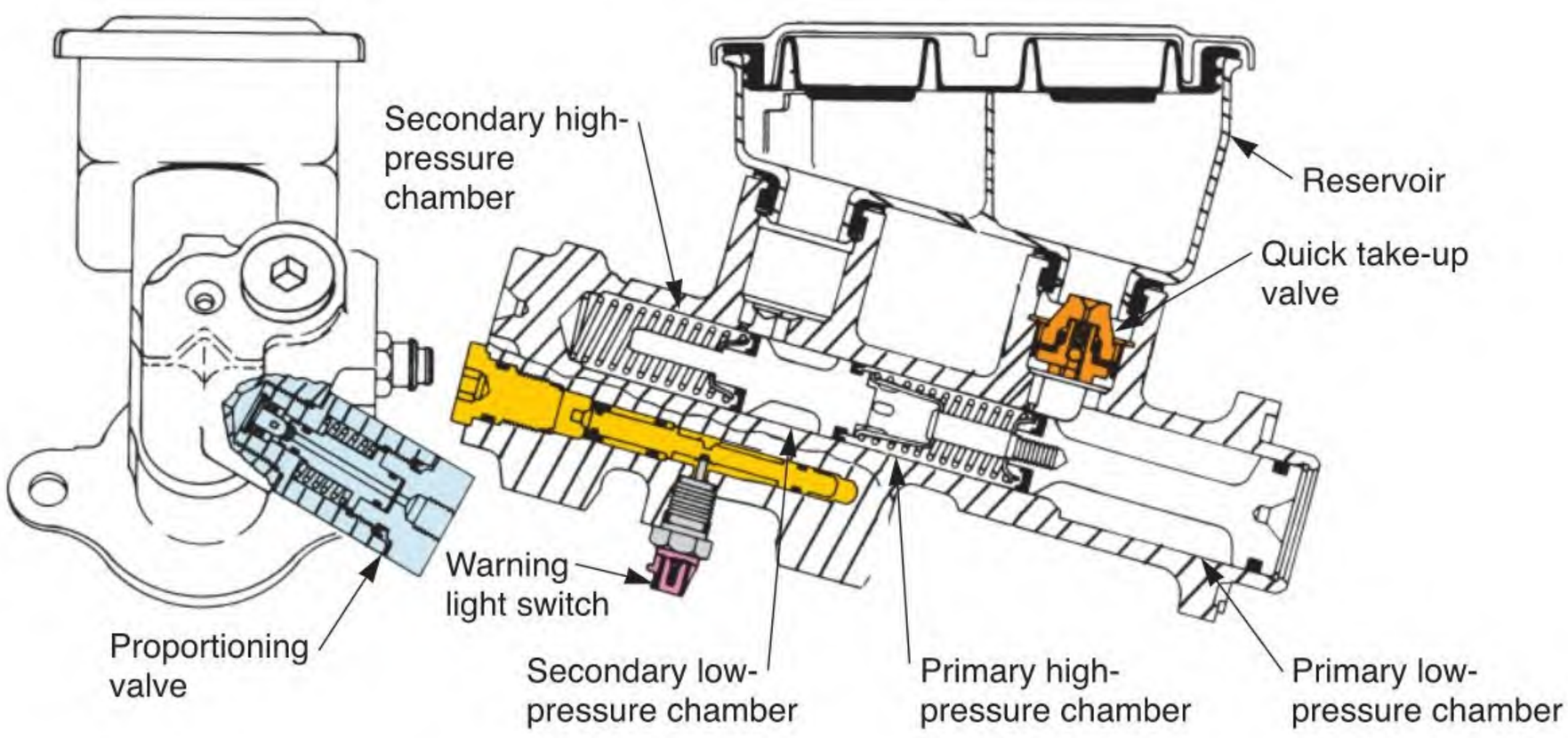


Chrysler

Figure 80-32. Study the sections of this combination valve.

housing. The movement of the cable pulls on a lever inside the drum or disc brake assembly. The lever action forces the brake linings against the rear drums or discs to resist vehicle movement. **Figure 80-35** shows a foot-operated parking brake unit.

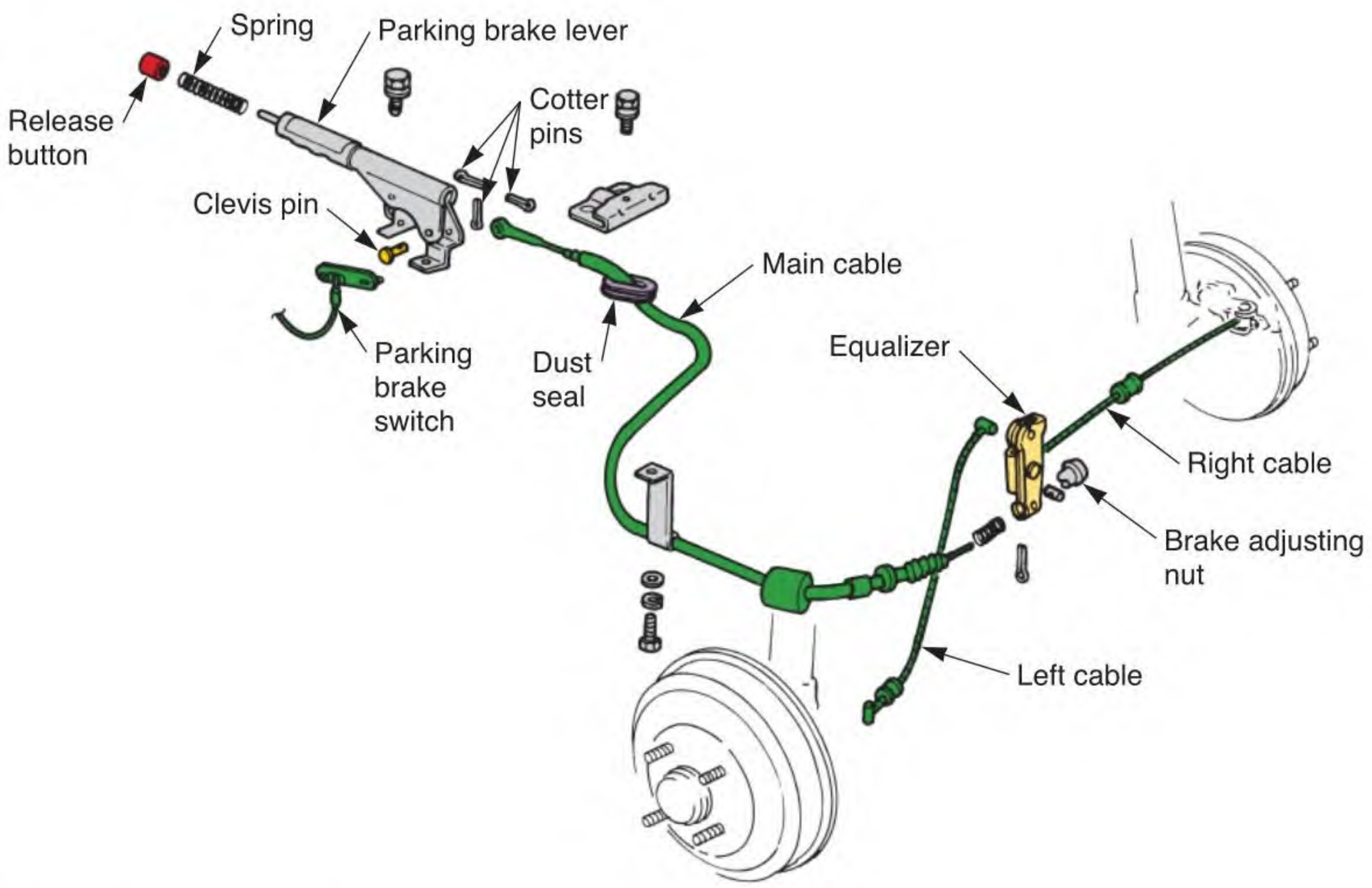
When disc brakes are used on the rear of a vehicle, a thrust screw and a lever can be added to the brake caliper. Then, when the parking brake is applied, the cable pulls on the caliper lever. The caliper lever turns the large thrust screw, which pushes on the caliper piston and applies the brake pads to the disc. See **Figure 80-36**.



Delco

Figure 80-33. This master cylinder has a proportioning valve and a warning light switch mounted internally.

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Toyota

Figure 80-34. Study the parts of this typical parking brake mechanism.

An ***electric parking brake*** uses the brake system control module to operate an electric servo motor that mechanically engages the rear brakes. A dashboard-mounted button signals the control module to apply the parking brake. A control module power transistor then operates the servo motor to apply the rear wheel brake assemblies. See **Figure 80-37**.

Tech Tip

Regenerative braking systems are explained in several other chapters of this textbook. Please refer to the Index for more information on hybrids and regenerative braking systems.

Hybrid Brakes

As discussed, today's hybrid vehicles are equipped with regenerative braking systems. These electric braking systems work with the conventional hydraulic brakes to slow the vehicle, while at the same time generating electricity to recharge the vehicle's HV battery.

When the brakes are applied, a brake pedal sensor sends a signal to the hybrid control module, prompting the motor-generator to operate as a generator. With moderate brake pedal pressure, the conventional hydraulic brakes do not apply the friction pads into the spinning brake discs. Instead, the motor-generator places a drag on the rotating tires, wheels, and drive train, slowing the vehicle. If the hybrid vehicle is slowed carefully, almost all the kinetic energy of the moving vehicle is recaptured as electrical energy and forced into the HV battery. This electrical energy is stored in the HV battery and is used to re-accelerate the vehicle from its next full stop.

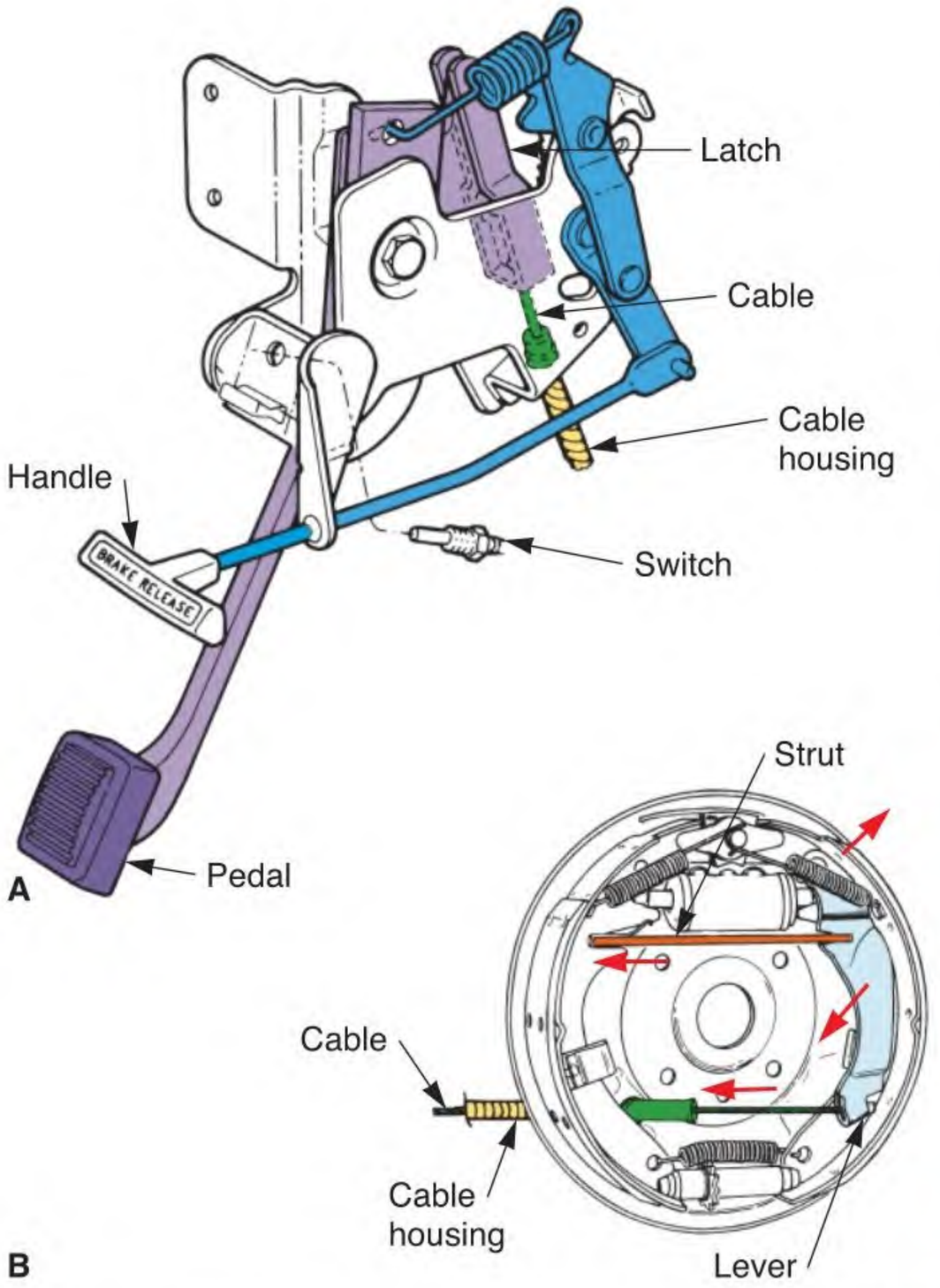


Green Tech

Volatile Organic Compounds (VOCs)

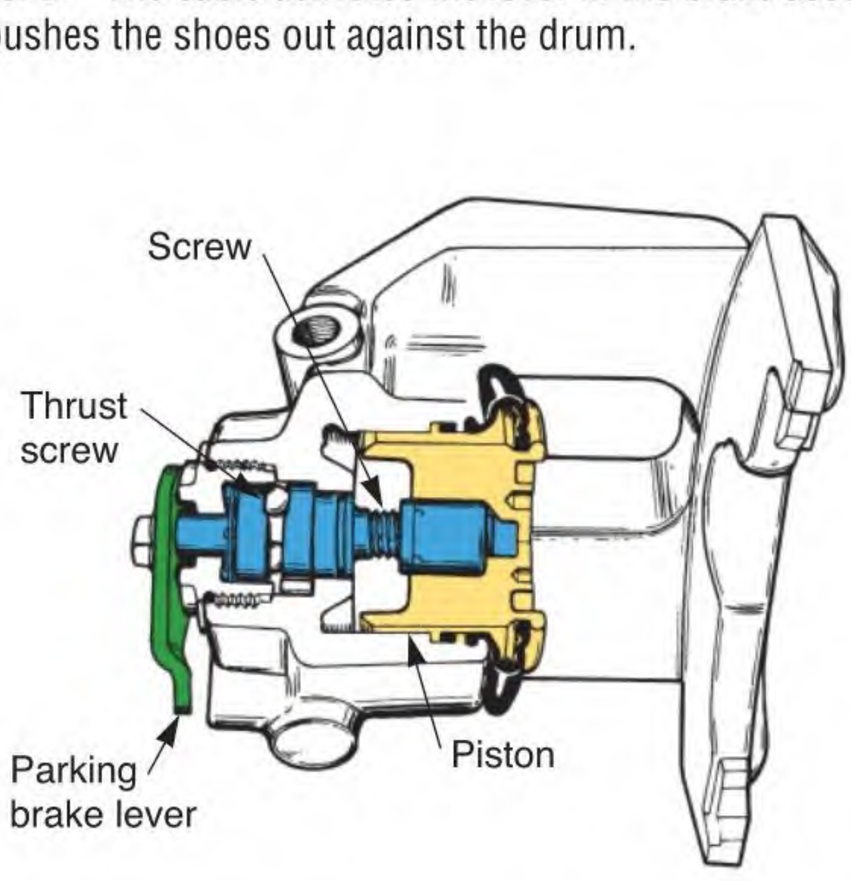
Volatile organic compounds (VOCs) are toxic substances that evaporate into the atmosphere. VOCs may develop into such environmental hazards as smog, but they are also harmful if kept indoors. VOCs are associated with mild and severe health concerns. VOCs may be found in substances like cleaning solutions, as well as paints or coatings. You can reduce your VOC output by choosing alternatives to VOC-containing products. For example, you can use more environmentally friendly VOC-free brake cleaning solutions.

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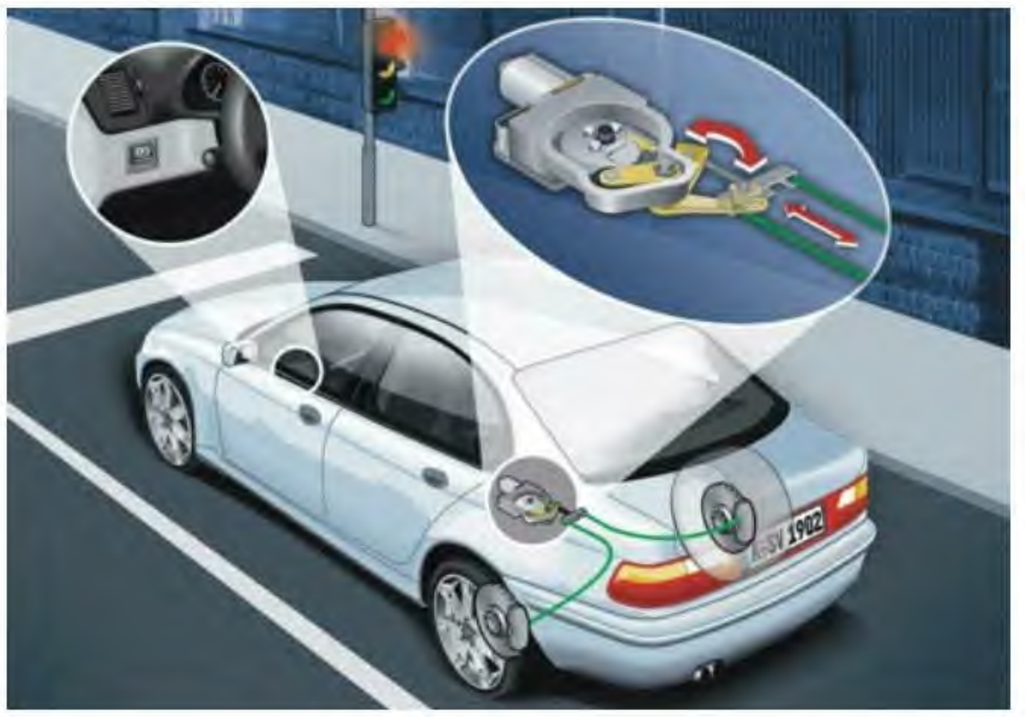
Chrysler; Ford

Figure 80-35. Parts of a parking brake system. A—Foot-operated parking brake pedal. Note the latch and the release handle. B—The cable activates the lever in the brake assembly that pushes the shoes out against the drum.



Bendix

Figure 80-36. Cross-sectional view of a caliper that has a parking brake mechanism. A cable rotates the parking brake lever. The lever turns a screw that pushes the piston outward to apply the brake.



Siemens

Figure 80-37. This electric emergency brake system uses a servo motor to pull on short steel cables that apply and hold the rear brakes.

Summary

- Automotive brakes provide a means of using friction to either slow down, stop, or hold the wheels of the vehicle.
- A brake pedal assembly is a foot lever for operating the master cylinder and power booster.
- A master cylinder is a hydraulic piston-type pump that develops pressure for the brake system.
- A brake booster is a vacuum or power steering operated device for assisting brake pedal application.
- Brake lines are metal tubing and rubber hose for transmitting pressure to wheel brake assemblies.
- Wheel brake assemblies are devices that use system pressure to produce friction for slowing or stopping wheel rotation.
- Braking ratio refers to the comparison of front wheel to rear wheel braking effort.
- A hydraulic system is basically a system that uses a liquid to transmit motion or pressure from one point to another.
- The cup and piston in the master cylinder are used to pressurize the brake system.
- The dual master cylinder, also called a tandem master cylinder, has two separate hydraulic pistons and two fluid reservoirs.
- Power brakes use a booster and either engine vacuum, electric pump, or hydraulic pressure to assist brake pedal application.

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- Brake fluid is a specially blended hydraulic fluid that transfers pressure to the wheel cylinders.
- Brake lines and hoses transfer fluid pressure from the master cylinder to the wheel cylinders.
- The piston seal in the caliper prevents pressure leakage between the piston and cylinder.
- The floating caliper disc brake is mounted on two bolts supported by rubber bushings.
- The bleeder screw provides a means of removing air from the brake system.
- The primary brake shoe is the front shoe. It normally has a slightly shorter lining than the secondary shoe.
- The secondary brake shoe is the rear shoe. It has the largest lining surface area.
- A metering valve is designed to equalize braking action at each wheel during light brake applications.
- A proportioning valve is also used to equalize braking action with front disc and rear drum brakes.
- A combination valve is a single unit that functions as a brake warning light switch, a metering valve, and/or a proportioning valve.
- Emergency brakes, also called parking brakes, provide a mechanical means (cable and levers) of applying the brakes.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

anti-rattle clips
atmospheric suspended brake booster
automotive brakes
bleeder screw
brake backing plate
brake booster
brake caliper
brake disc
brake drum
brake fluid
brake hoses
brake lines
brake pads
brake pad linings
brake pedal assembly
brake rotor
brake shoe adjusters
brake shoes
brake warning light switch
braking ratio
caliper
caliper cylinder
combination valve
compensating port
cup
cup expanders
diagonally split
disc brake assembly
disc brake pads
drum brake assembly
drum brake shoe assemblies
dual master cylinder
electric parking brake
emergency brakes
fixed caliper
floating caliper
hold-down springs
hybrid brakes
hydra-booster
hydraulic booster
hydraulic brakes
hydraulic system
hydro-boost
inertia
intake port
longitudinally split
low-fluid warning light switch
master cylinder
master cylinder reservoir
metering valve
pad-wear sensor
parking brakes
piston
piston boot
piston seal
power brakes
pressure differential valve
primary brake shoe
primary piston
proportioning valve
residual pressure valves
retracting springs
rotor
rubber boot
runout
secondary brake shoe
secondary piston
self-energizing action
servo action
sliding caliper
star wheel
stoplight switch
tandem master cylinder
vacuum booster
vacuum suspended brake booster
wheel brake assemblies
wheel cylinder
wheel cylinder assembly
wheel cylinder boots
wheel cylinder cups
wheel cylinder housing
wheel cylinder pistons
wheel cylinder spring

Activities

1. Identify the type of brake system—disc or drum—on a vehicle assigned by your instructor.
2. Examine the calipers of a disc brake system and identify the type: floating or fixed.
3. Using **Figure 80-1**, explain to your class the function of the various parts of a brake system.
4. Using a small hydraulic jack, explain and demonstrate the principle of the hydraulic brake.

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Review Questions

Answer the following questions using the information provided in this chapter.

1. List and explain the six basic parts of a brake system.
2. Describe the four major parts of a disc brake assembly.
3. Which of the following is *not* part of a drum brake assembly?
   (A) Wheel cylinder.
   (B) Booster.
   (C) Shoes.
   (D) Drum.
4. A(n) _____ system uses a liquid to transmit motion or pressure from one part to another.
5. What are four functions of a master cylinder?
6. Why is a dual master cylinder used?
7. A certain automotive brake system's residual pressure valve maintains residual fluid pressure of 9 psi. What is the purpose of this residual pressure?
   (A) To keep the brakes partially engaged at all times.
   (B) To prevent contaminants from entering the system.
   (C) To equalize braking action at each wheel.
   (D) To prevent wheel lockup during heavy brake applications.
8. A power brake vacuum _____ uses engine vacuum to apply the hydraulic brake system.
9. A hydro-boost power brake system uses pressure from the power steering pump. True or False?
10. In a diagonally split brake system, each master cylinder cup and piston assembly operates a brake assembly on opposite sides and corners of the vehicle. True or False?
11. Which of the following is *not* part of a brake caliper?
    (A) Piston seal.
    (B) Bleeder screw.
    (C) Piston boot.
    (D) Cup expander.
12. What causes a brake caliper piston to retract away from the disc after brake application?
13. Why are floating and sliding calipers more common than fixed calipers?
14. The _____ _____ provides a means of removing air from the wheel cylinder after repairs.
15. Explain the difference between a primary brake shoe and a secondary brake shoe.
16. The brake _____ _____ _____, also called the _____ _____ _____, warns the driver of a pressure loss on one side of a dual brake system.
17. Why is a metering valve used?
18. How does a proportioning valve equalize braking action?
19. Describe a combination valve.
20. How does the parking brake work?

ASE-Type Questions

1. Technician A says an automotive master cylinder is a device that uses brake system pressure to produce friction for stopping wheel rotation. Technician B says an automotive master cylinder holds the wheel cylinder piston and brake pads. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Technician A says certain automobiles are equipped with disc brakes on all four wheels. Technician B says disc brakes are most commonly used on an automobile's rear wheels. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. All of the following are basic components of an automotive disc brake assembly, *except:*
   (A) rotor.
   (B) brake drum.
   (C) brake pads.
   (D) caliper.
4. Technician A says a caliper cylinder holds the piston on a drum brake assembly. Technician B says a caliper cylinder holds the piston on a disc brake assembly. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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5. Technician A says a hydraulic system uses air to transmit motion or pressure from one point to another. Technician B says a hydraulic system uses a liquid to transmit motion or pressure from one point to another. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Technician A says a manual master cylinder normally bolts to the side of the engine. Technician B says a manual master cylinder normally bolts to the engine firewall. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. Technician A says a push rod connects the brake pedal to the master cylinder piston. Technician B says a steel plate connects the brake pedal to the master cylinder piston. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. Technician A says an automotive master cylinder keeps the brake system full of fluid as the brake linings wear. Technician B says an automotive master cylinder maintains a slight amount of pressure to keep contaminants from entering the brake system. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Technician A says a master cylinder's cup and piston are used to release brake system pressure. Technician B says a master cylinder's cup and piston are used to pressurize the brake system. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. Technician A says a dual master cylinder's rear piston assembly is called the primary piston. Technician B says a dual master cylinder's rear piston assembly is called the secondary piston. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
11. Technician A says certain automotive power brake systems use engine vacuum to assist brake pedal application. Technician B says certain automotive power brake systems use a vacuum pump to assist brake pedal application. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
12. Technician A says an automotive brake booster is a piston-type pump that develops pressure for the vehicle's brake system. Technician B says an automotive brake booster is a vacuum or power steering–operated device that assists brake pedal application. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
13. Technician A says an atmospheric suspended vacuum brake booster works on both sides of the diaphragm or piston. Technician B says a vacuum suspended booster works on both sides of the piston or diaphragm. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
14. Technician A says a "longitudinally split" brake system has each master cylinder piston operating the brake assemblies on opposite corners of the vehicle. Technician B says a "longitudinally split" brake system has one master cylinder piston operating the front wheel brake assemblies and the other piston operating the rear wheel brake assemblies. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
15. A combination valve functions as all of the following, *except:*
    (A) proportioning valve.
    (B) warning light switch.
    (C) fluid level sensor.
    (D) metering valve.

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Chapter 81
Brake System Diagnosis, Service, and Repair

After studying this chapter, you will be able to:

- Diagnose common brake system problems.
- Inspect and maintain a brake system.
- Explain how to service a disc brake assembly.
- Explain how to service a drum brake assembly.
- Describe basic procedures for servicing a master cylinder and a brake booster.
- Describe the procedures for manual, pressure, and vacuum bleeding of a brake system.
- Cite the safety rules that should be followed when servicing brake systems.
- Correctly answer ASE certification test questions about the diagnosis and repair of brake systems.

The brake system is the most important system on a vehicle from a safety standpoint. The customer trusts the technician to do every service and repair operation correctly because his or her life may depend upon it.

When working on a brake system, always keep in mind that a brake system failure could result in a deadly automobile accident. It is up to you to make sure the vehicle's brake system is in perfect operating condition before releasing the vehicle to the customer.

This chapter will explain the most important procedures to follow when servicing automotive brakes, including pads, shoes, discs, drums, wheel cylinders, calipers, and hydraulic valves. The next chapter explains the operation, diagnosis, and repair of anti-lock brake systems.

Brake System Problem Diagnosis

Use brake symptoms (noises, smells, abnormal brake pedal movements, improper braking action, etc.) when diagnosing brake system problems. Listen to the customer's complaints or the service writer's explanation. Then, inspect the brake system or test-drive the vehicle.

It is important that you be able to interpret the symptoms. You can then decide what adjustments or repairs are needed. Refer to **Figure 81-1**.

Almost all brake system problems can be sorted into the following basic categories: brake pedal vibration, grabbing brakes, excessive brake pedal effort, pulling brakes, spongy brake pedal, dropping brake pedal, low brake pedal, dragging brakes, no brake pedal, illuminated brake warning light, and braking noise.

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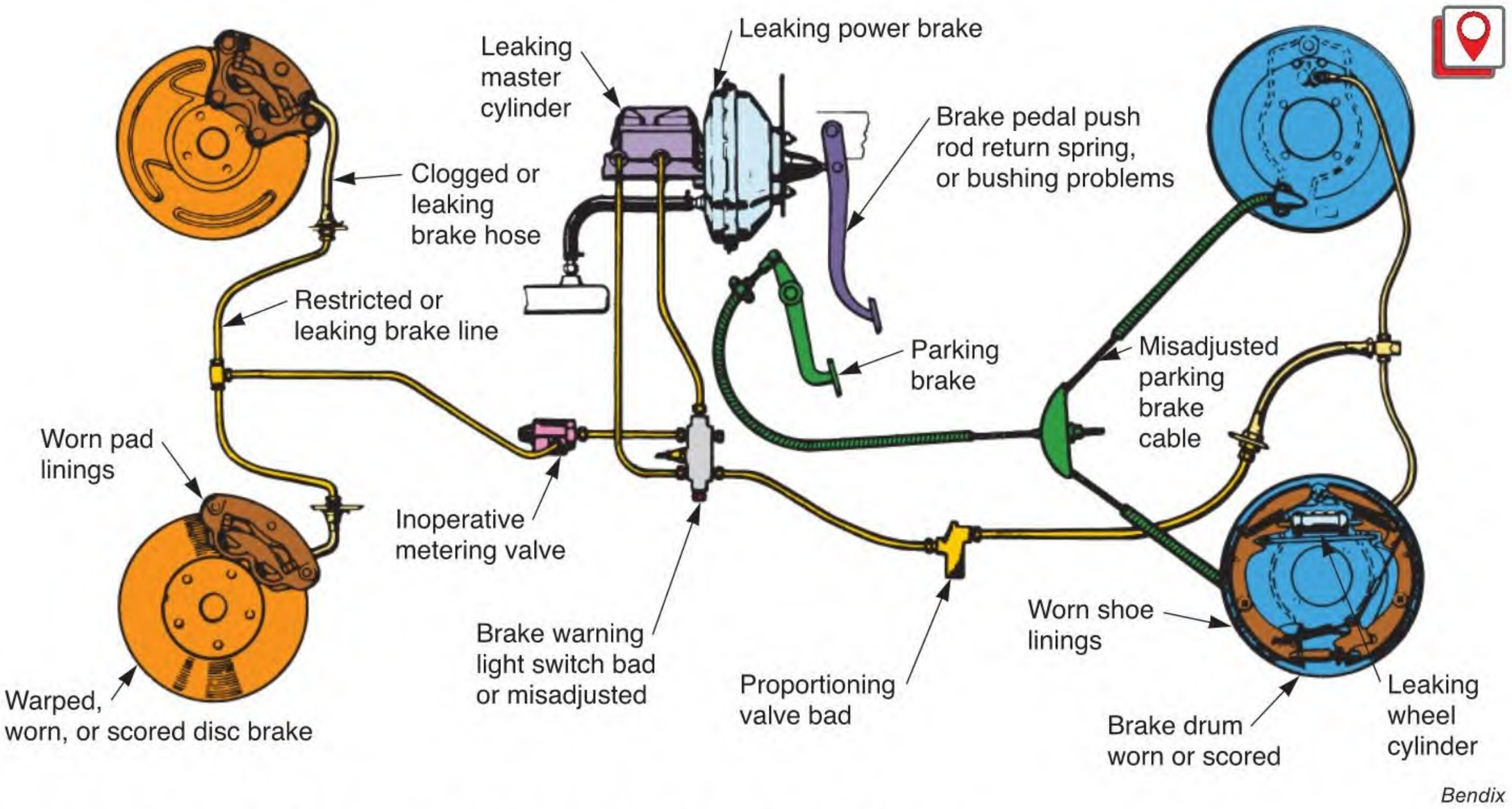


Figure 81-1. Note some of the common problems that can develop in a brake system.

Brake System Diagnostics

Modern brake systems, primarily those with anti-lock brake systems, have self-diagnostic capabilities. If the brake control module detects an abnormal operating condition in a circuit, it will store one or more diagnostic trouble codes and illuminate a malfunction indicator light in the dash. You can then scan the brake system to retrieve the stored trouble codes. These codes will indicate which brake circuit or component is causing the problem.

Tech Tip

Remember that vibration problems caused by a defective tire or a bent wheel are present whenever the vehicle is moving and are usually more pronounced at a specific speed. Brake vibration problems, on the other hand, are only present when the brakes are applied.

Brake Vibration

Brake vibration shows up as a chatter, pulsation, or shake problem when the brake pedal is pressed. The vibration may be felt mostly in the steering wheel (front brake assembly problems) or in the brake pedal itself (could be problems at any wheel). When problems are severe, the whole chassis and body (hood and fenders) may vibrate when braking. Brake vibration is usually caused by a warped brake disc or an out-of-round brake drum. Hard spots on the disc or drum can also cause vibration.

Grabbing Brakes

Grabbing brakes apply too quickly, even with light brake pedal application. If the brakes are grabbing, it will be very difficult to stop slowly.

Grabbing is usually caused by a malfunctioning brake booster, brake fluid or grease on the linings, worn brake linings, a faulty metering valve, or a mechanical problem in the wheel brake assembly.

Excessive Brake Pedal Effort

Excessive brake pedal effort is a noticeable increase in the amount of foot pressure needed to apply the brakes. It can be caused by a variety of problems, such as a frozen wheel cylinder or caliper

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piston, a clogged brake hose or line, a faulty master cylinder, contaminated linings, a disconnected brake booster vacuum line, or a defective brake booster.

Pulling Brakes

Pulling brakes cause the vehicle to veer to the right or left when the brakes are applied. When the problem is in the front brakes, a strong pulling force will be noticed on the steering wheel. Rear brake pull is only noticeable during very hard braking—one of the rear brakes will lock up, causing tire skid and squeal.

Brake pull is usually caused by a frozen caliper or wheel cylinder piston, a grease- or fluid-coated lining, a leaking cylinder, a faulty automatic adjuster, or a buildup of brake lining dust. Incorrect front end alignment can also make the vehicle pull to one side during braking.

Spongy Brake Pedal

A ***spongy brake pedal*** feels like it is connected to a spring or a rubber band. The brakes will apply, but the pedal does not feel solid. It will travel farther toward the floor before full braking action occurs.

This condition is usually caused by air in the brake system. The air is compressing, so it takes up less space. A spongy pedal can also result from faulty residual pressure check valves in the master cylinder or maladjusted brake shoes.

Dropping Brake Pedal

A ***dropping brake pedal*** slowly moves all the way to the floor when steady pressure is applied to it. This condition usually shows up when the driver is stopped at a stoplight. The brake may apply normally at first. However, while holding the brakes, the pedal steadily creeps downward. Pumping usually restores pedal height momentarily.

A dropping brake pedal is usually caused by an internal leak in the master cylinder. Pressure is slowly leaking past the piston cups. Since fluid returns to the reservoir, the fluid level will not drop.

A fluid leak anywhere else in the system can also cause the same symptom. If fluid is leaking out, however, the fluid level in the master cylinder will drop.

Low Brake Pedal

A ***low brake pedal*** travels too far toward the floor before braking. The pedal is not spongy, and braking is normal once the pedal applies the brakes.

A low brake pedal can be caused by inoperative brake adjusters, a maladjusted master cylinder push rod, or a mechanical problem in the wheel brake assemblies.

Dragging Brakes

Dragging brakes remain partially applied when the brake pedal is released. The brakes will overheat if the vehicle is driven very far. To detect dragging brakes, feel each wheel assembly. The dragging brake or brakes will be abnormally hot.

Dragging brakes can be caused by frozen wheel cylinder pistons, an overadjusted parking brake, weak return springs, an overadjusted master cylinder push rod, brake fluid contamination, or a master cylinder problem.

No Brake Pedal

No brake pedal is a dangerous condition in which the brake pedal moves to the floor with no braking action. Pumping the brakes does not help.

Lack of braking action is usually caused by a hydraulic problem. A system leak may have emptied the master cylinder reservoir.

With today's dual master cylinders, a complete loss of braking is unlikely. However, it can occur from driver neglect.

Brake Warning Light On

When the ***brake warning light*** is on, it indicates either an internal leak (master cylinder) or an external leak (brake line, hose, wheel cylinder) in the hydraulic system. Unequal pressure in the dual master cylinder system has caused the warning light switch (usually part of combination valve) to shift to one side. Inspect the system for leaks and check the action of the master cylinder.

Braking Noise

Braking noise can be grinding sounds, squeaks, rattles, and other abnormal noises. Use your understanding of system operation to determine the cause of braking noise.

A brake grinding sound is a metal-on-metal noise that occurs only when braking may be due to worn brake linings. The shoe or pad may be rubbing on the metal drum or brake disc.

A squeak when braking may be caused by glazed (hardened) brake linings, an unlubricated brake drum

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backing plate, foreign material embedded in the linings, or a wear indicator rubbing on a rotor.

A brake rattle may be due to a missing anti-rattle clip or disconnected spring on the brake caliper assembly. Loose or disconnected parts in the drum brake assembly can also cause a rattle from inside the brake assembly.

Brake System Inspection

Most automobile manufacturers recommend a periodic inspection of the brake system. The inspection is a form of preventive maintenance that helps ensure safety. During a brake system inspection, you should:

- Check the fluid level in the master cylinder. Low brake fluid indicates excessive pad and/or brake disc wear or fluid leaking out of the system.
- Check brake pedal action while parked and while driving.
- Check for abnormal sounds when braking.
- Inspect the brake lines, hoses, and wheel brake assemblies, **Figure 81-1**.

Checking Brake Pedal Action

A fast and accurate way of checking many components of the brake system is the ***brake pedal check***. This is done by applying the brake pedal and comparing its movement to specifications. There are three brake pedal application specifications (distances): pedal height, pedal free play, and pedal reserve distance.

Brake pedal height is the distance from the pedal to the floor with the pedal fully released. Incorrect pedal height is usually caused by problems in the pedal mechanism. There may be worn pedal bushings, a weak return spring, or a maladjusted master cylinder push rod.

Brake pedal free play is the amount of pedal movement before the beginning of brake application. It is the difference between the "at rest" position and the initially applied position.

Brake pedal free play is needed to prevent brake drag. If pedal free play is not correct, check the adjustment of the master cylinder push rod. A worn pedal bushing or a bad return spring can also increase pedal free play.

Brake pedal reserve distance is measured from the vehicle's floor to the brake pedal when the brakes are applied. Typically, brake pedal reserve distance should be 2″ (51 mm) for manual brakes and 1″ (25 mm) for power brakes. See **Figure 81-2**.

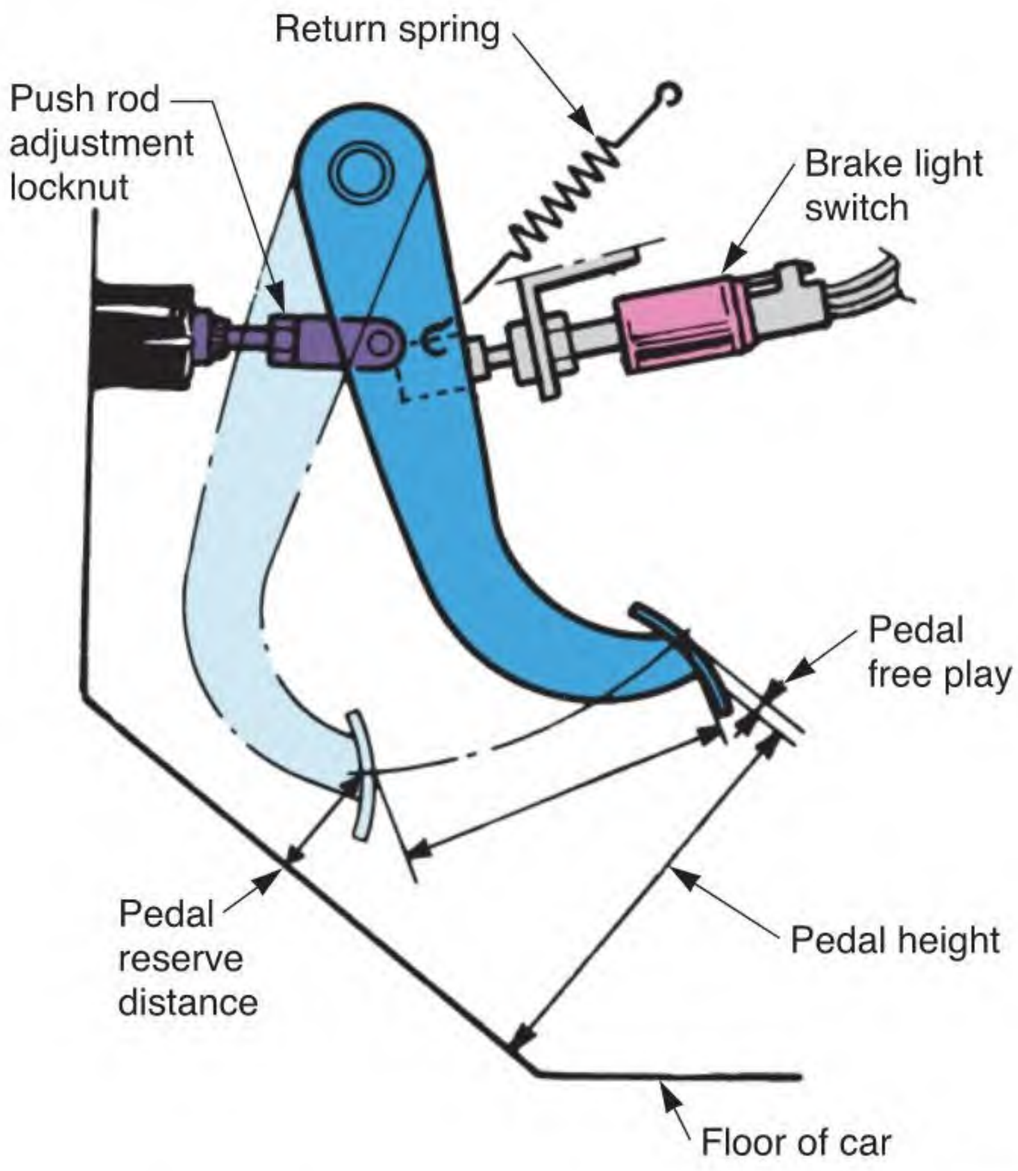
If brake pedal reserve distance is incorrect, check push rod adjustment. Also, check for air in the system or inoperative brake adjusters. Numerous other problems can cause incorrect pedal reserve distance.

When checking brake pedal action, apply and hold the brake pedal firmly for about 15 seconds. The engine should be running if the vehicle has power brakes. Try to detect any system leakage, which would cause the pedal to slowly move toward the floor. Also, make sure the pedal is firm and that it returns properly.

While checking the brake pedal, you should also make sure the brake lights are operating. If they do not work, check the bulbs, the fuses, and the switch.

Checking Brake Fluid

An important part of a brake system inspection involves checking the level and condition of the brake fluid. To check the fluid, remove the master cylinder cover. Pry off the spring clips and lift off the lid or cover. Be careful not to drip brake fluid on the car's paint. Wipe off brake fluid spills right away or they will dissolve the paint and require a major auto body repair.



Honda

Figure 81-2. Note the basic brake pedal measurements. Brake pedal height, reserve distance, and free play are important. Some vehicles have an adjustable push rod. Also note the location of the brake light switch.

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Typically, the ***brake fluid level*** should be 1/4″ (6 mm) from the top of the master cylinder reservoir. Add the correct type of brake fluid as needed.

Tech Tip

Only use the manufacturer's recommended type of brake fluid. Also, keep oil, grease, and other substances out of the brake fluid. Contamination can cause rapid deterioration of the master cylinder cups, resulting in a sudden loss of braking ability.

Checking for Brake System Leaks

When the fluid level in the master cylinder is low, you should inspect the brake system for leaks. Check all brake lines, hoses, and wheel cylinders for wetness and the smell of brake fluid. Brake fluid leakage will show up as a darkened, damp area around brake hoses and line fittings, master cylinder, metering valves, wheel cylinders (bottom of drums), or calipers (at piston boots).

Checking the Parking Brake

Apply the parking brake. The pedal or lever should not move more than 2/3 of full travel. The parking brake should keep the vehicle from moving with the engine idling and the transmission in drive.

The parking brake cables and linkage should also be inspected. The cables should not be frayed. The linkage should be tight, undamaged, and well lubricated.

Checking Wheel Brake Assemblies

When inspecting a brake system, remove one front wheel and one rear wheel. This will let you inspect the condition of the brake linings and other wheel brake assembly components.

When inspecting disc brakes, check the thickness of the brake pad linings. Pads should be replaced when the thinnest (most worn) part of the lining is no thicker than the metal shoe (approximately 1/8″ or 3 mm). **Figure 81-3** shows common disc brake problems. Study them closely.

Check the caliper piston for fluid leakage and inspect the brake disc for damage. The disc should not be scored, cracked, or ***heat checked*** (small hardened and cracked areas caused by overheating). The wheel bearings should be adjusted properly. To check for rattles, strike the caliper with a rubber mallet. Repair any problems according to service manual instructions.

When inspecting drum brakes, you must remove the brake drum. This will expose the brake shoes, the wheel cylinder, the braking surface of the drum, the adjuster mechanism, and other parts, **Figure 81-4**.

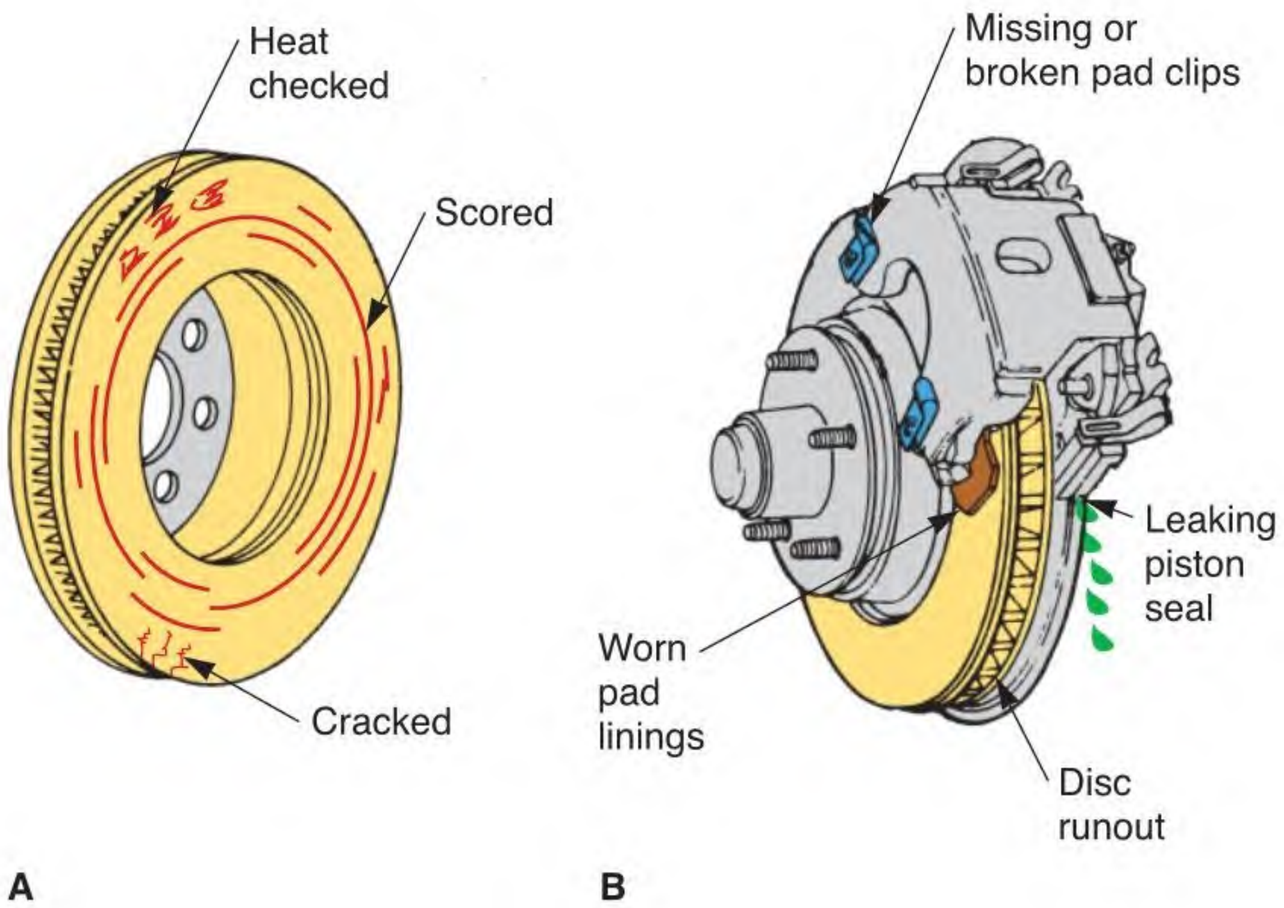
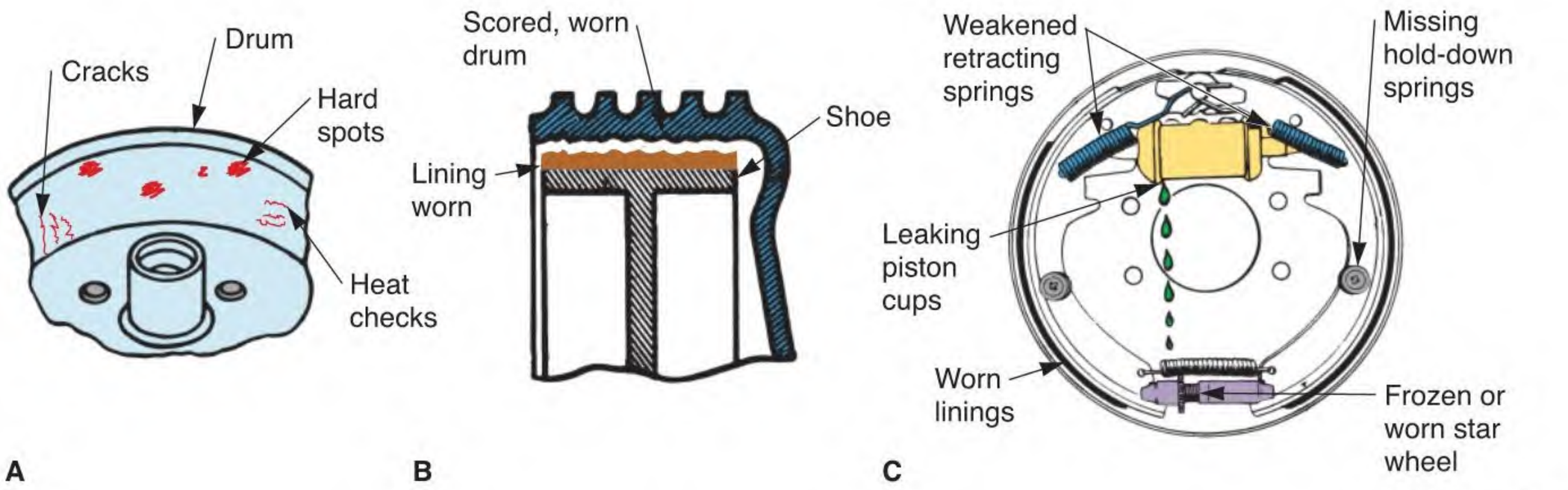


Figure 81-3. Study these disc brake problems. A—Check the rotor for heat checking, cracks, and scoring. B—Also check for a leaking piston seal, worn pad linings, and missing clips.

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Bendix and FMC

Figure 81-4. Study these common drum brake problems. A—Check the drum for cracks, heat checks, and hard spots. B—A badly scored drum must be machined. If the drum is worn too much, it must be replaced. C—Check for a leaking wheel cylinder, worn linings, and missing or damaged parts.

The brake shoe linings must never be allowed to wear thinner than approximately 1/16″ (1.5 mm). The shoes should not be glazed or coated with brake fluid, grease, or differential fluid. Any of these problems requires lining replacement. If the linings are contaminated with brake fluid or other substances, the cause of the contamination must be corrected before the linings are replaced.

Pull back the wheel cylinder boots and check for leakage. If the boot is full of fluid, the wheel cylinder should be rebuilt or replaced. Also, check the automatic adjuster, the return springs, and the brake drum. The brake drum should not be scored, cracked, heat checked, or worn beyond specifications.

Warning

Take every precaution to avoid breathing brake lining dust. If needed, wear an approved filter mask over your nose and mouth. Never use compressed air to blow brake dust off a wheel brake assembly. Use a special brake vacuum and a clean rag to remove the dust. Older brake linings were made of asbestos, a known cancer-causing substance. Newer linings are made from safer materials, but the brake dust created by these substances can be harmful to your health.

Vacuum Booster Service

If a vehicle has vacuum-type power brakes, you should inspect the brake booster and the vacuum hose. Make sure the vacuum hose from the engine is in good condition. It should not be hardened, cracked, or swollen. Also, check the hose fitting in the booster.

To test the vacuum booster, pump the brake pedal several times to remove any vacuum from the booster. Then, press down lightly on the brake pedal as you start the engine. If the vacuum booster is functioning, the brake pedal will move downward slightly as soon as the engine starts.

Many shops do not rebuild vacuum brake boosters. Instead, they install a new or factory rebuilt unit. Some boosters are sealed and cannot be disassembled. **Figure 81-5** shows the parts that must be removed when replacing a vacuum booster.

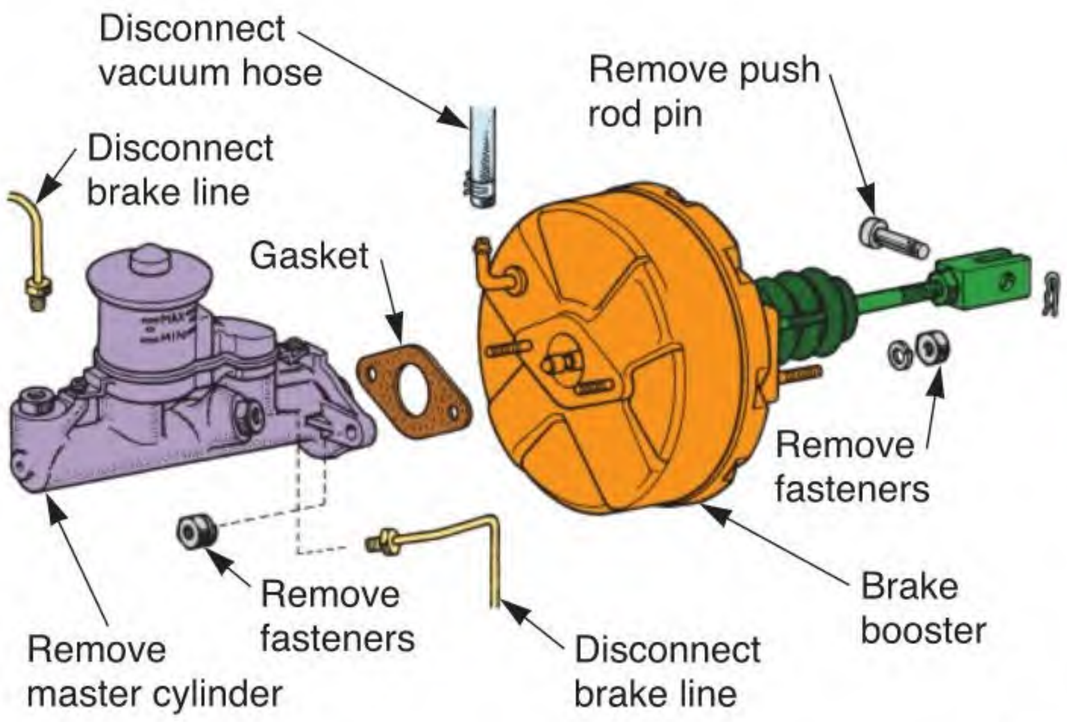
A vacuum brake booster rebuild normally involves replacing the diaphragm, the valves, and other plastic or rubber parts. Refer to a service manual for exact procedures for a particular booster.

Hydraulic Booster Service

A hydraulic brake booster should be checked when inspecting a brake system. Check all the hydraulic lines for signs of leakage. Tighten connections or replace any line that leaks.

If the booster is inoperative, check the fluid level in the power steering pump. A low fluid level can prevent hydro-boost operation. When the hydraulic booster is found to be faulty, it should be replaced. Most types are not repairable.

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Toyota

Figure 81-5. These components may need to be removed for service of the master cylinder and brake booster.

Master Cylinder Service

A faulty master cylinder usually leaks fluid past the rear piston or leaks internally. When fluid is leaking past the rear piston, you should find brake fluid in the rear boot or on the firewall. When the leak is internal, the brake pedal will slowly sink to the floor as pressure is applied. Inoperative valves in the master cylinder are also a reason for service.

Master Cylinder Removal

To remove a master cylinder, disconnect the brake lines from the master cylinder using a tubing wrench. Then, unbolt the master cylinder from the brake booster or the firewall. Sometimes, the push rod must be disconnected from the brake pedal assembly.

Master Cylinder Rebuild

Many shops simply replace a faulty master cylinder with a new or factory rebuilt unit. A replacement cylinder may be cheaper than the cost of labor and parts for an in-shop rebuild. Further, the new or factory rebuilt master cylinder will have a remachined cylinder and a guarantee.

To rebuild a master cylinder, drain the fluid from the reservoir. Then, completely disassemble the unit, following the manufacturer's instructions. Basically, you must hone the cylinder and replace the piston cups and valves. Clean the parts in brake fluid before reassembly.

Caution

Do not clean the hydraulic parts of a brake system with conventional parts cleaners. These cleaners can destroy the special rubber cups in the brake system. Use only brake fluid or a manufacturer-suggested cleaner (denatured alcohol for example).

After cleaning, measure the piston-to-cylinder clearance. Use a telescoping gauge and an outside micrometer or a strip-type feeler gauge. The cylinder must not be tapered or worn beyond specifications. Also, make sure the cylinder is not corroded, pitted, or scored. Replace the master cylinder if the cylinder is not in perfect condition after honing.

Blow all parts dry with compressed air. Blow out the ports and check that they are unobstructed. Lubricate the parts with brake fluid. Assemble the unit according to the manufacturer's instructions.

Bench Bleeding a Master Cylinder

Bench bleeding removes air from inside the master cylinder. This must be done before installing the unit on the vehicle.

Mount the master cylinder in a vise. Install short sections of brake line and bend them into each reservoir. Fill the reservoirs with approved brake fluid. Then, pump the piston in and out by hand until air bubbles no longer form in the fluid, as shown in **Figure 81-6**.

Installing a Master Cylinder

To install a master cylinder, replace the reservoir cover after bench bleeding. Bolt the master cylinder to the firewall or booster. Check the adjustment of the push rod if a means of adjustment is provided.

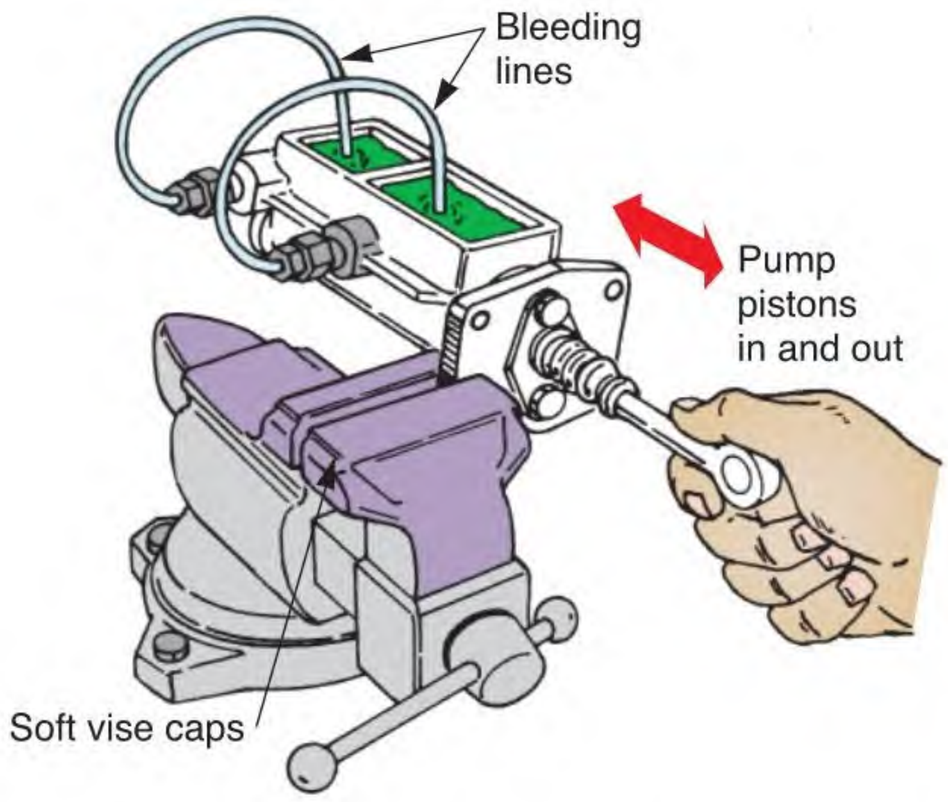
Without cross-threading the fittings, screw the brake lines into the master cylinder. Lightly snug the fittings. Then, bleed (remove air from) the system.

Tighten the brake line fittings. Top off the reservoir with fluid and check brake pedal feel. Test-drive the vehicle to verify your repairs.

Brake System Bleeding

The brake system must be free of air to function properly. Air in the system will compress, causing a spongy brake pedal. Air can enter the system any time a hydraulic component (brake line, hose, master cylinder, wheel cylinder, etc.) is disconnected or removed.

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EIS

Figure 81-6. Before installing a new or rebuilt master cylinder, bench bleed the unit. Fill the reservoir with brake fluid and install bleeding lines. Then pump the piston in and out until no air bubbles are visible in the reservoir.

Brake system bleeding involves the use of fluid pressure to force air out of the brake line connections or wheel cylinder bleeder screws. There are three methods of bleeding brakes: manual bleeding, pressure bleeding, and vacuum bleeding.

Manual Bleeding

Manual bleeding is accomplished by using master cylinder pressure to force fluid and trapped air out of the system.

Service Procedure

To manually bleed a brake system:

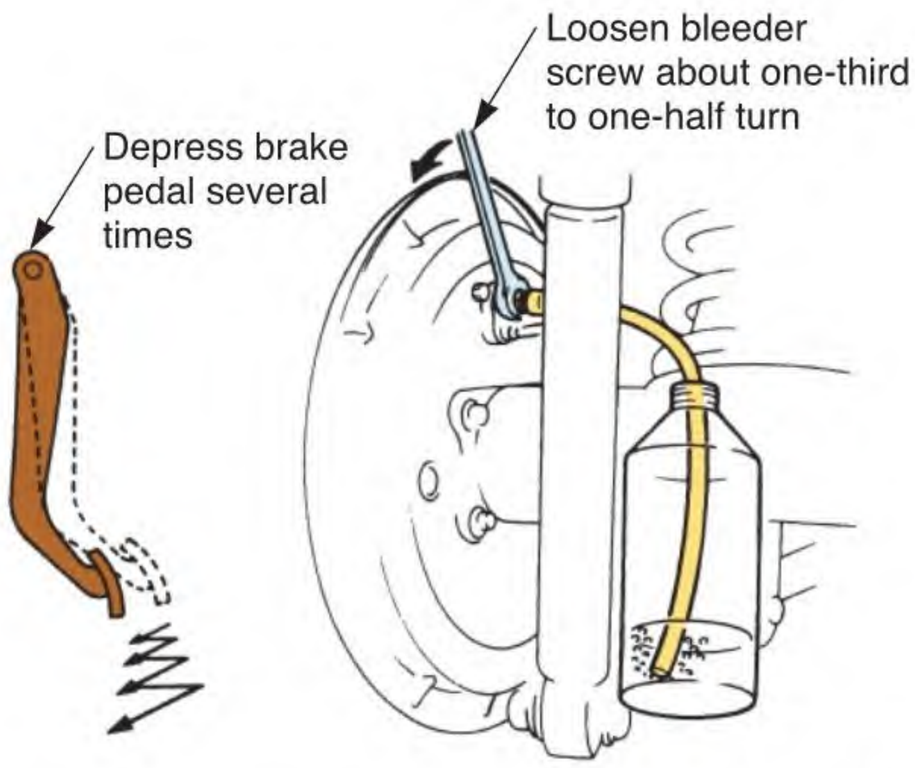
1. Attach one end of a hose to the bleeder screw.
2. Place the other end of the hose in a jar partially filled with clean brake fluid. Make sure the end of the hose is submersed in the fluid.
3. Have another technician gently depress the brake pedal.
4. Open the bleeder screw or fitting on the caliper or wheel cylinder while watching for air bubbles at the hose.
5. Close the bleeder screw or fitting and tell your helper to release the brake pedal.
6. Repeat steps 3–5 until no air bubbles come out of the hose.
7. Perform this operation on the other wheel brake assemblies or at brake line connections, if needed.

Typically, start bleeding at the wheel brake assembly farthest from the master cylinder and work your way toward the master cylinder. Some brake systems require special procedures when bleeding. When in doubt, refer to the vehicle's service manual. See **Figure 81-7**.

Brake line fittings that are higher than the bleeder screws can sometimes trap air. By loosening these line fittings, you can bleed more air out of the system.

Tech Tip

Check the manufacturer's instructions for details when in doubt. For example, for certain systems you may need to push or pull out the metering valve stem before bleeding the brake system.



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Figure 81-7. If you are not using a pressure bleeder, you can have a helper pump the brake pedal up and down lightly to build system pressure. Then, crack open the bleeder screw to purge air from the system. A container of brake fluid will keep air from being pulled back into the system.

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Pressure Bleeding

Pressure bleeding a brake system is done using a pressure bleeder tank, which contains brake fluid under pressure. Pressure bleeding is quick and easy because you do not need a helper to work the brake pedal.

A special adapter is installed over the master cylinder reservoir. A pressure hose connects the master cylinder and the pressure tank. A valve in the hose controls flow. See **Figure 81-8**.

Pour enough brake fluid in the bleeder tank to reach the prescribed level. Charge the tank with 10–15 psi (69–103 kPa) of air pressure. Fill the master cylinder with brake fluid. Install the adapter and hose on the master cylinder. Open the valve in the hose. You are now ready to bleed the brakes.

Attach one end of a hose to a bleeder screw and place the other end of the hose in a jar containing clean brake fluid. Open the screw. As soon as the fluid entering the jar is clear, close the screw. Repeat the bleeding operation on the other wheel brake assemblies in the proper order.

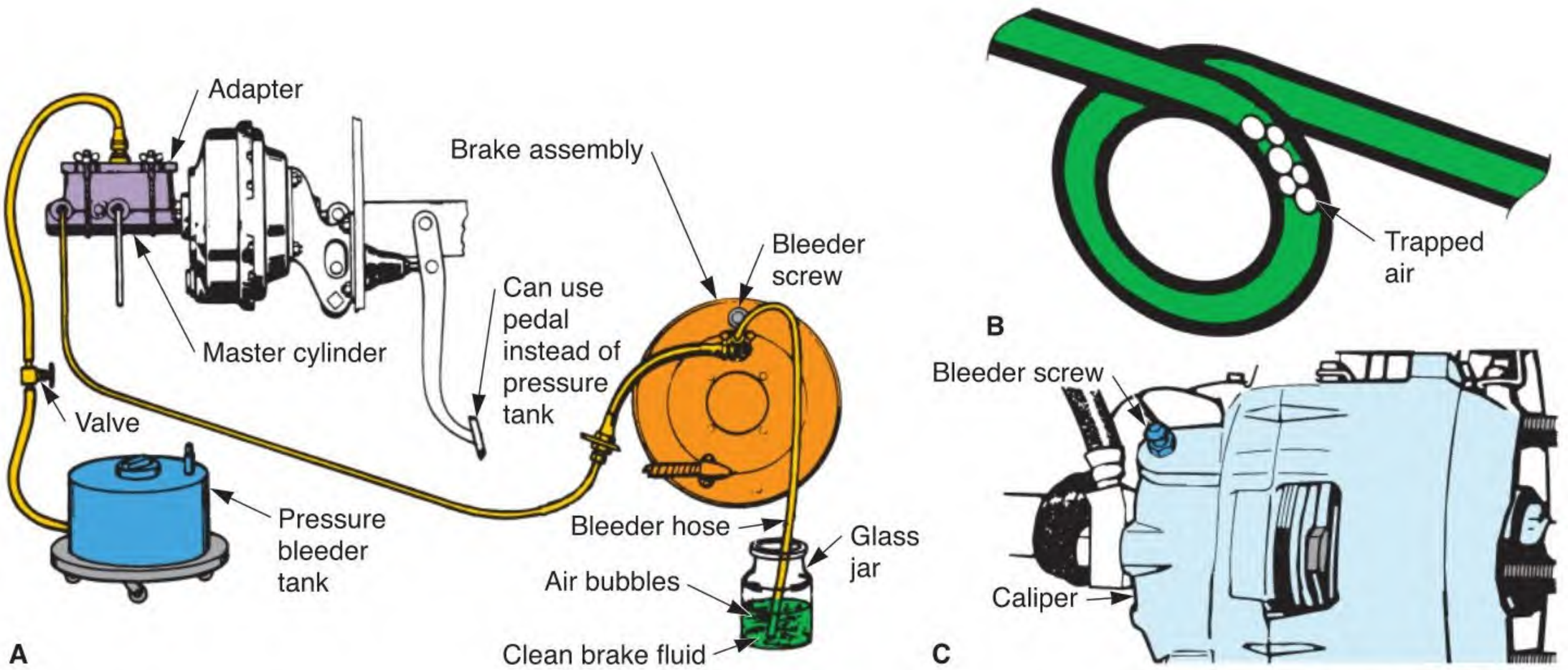
Tech Tip

A special pressure bleeding adapter is needed on master cylinders using a plastic reservoir. Use an adapter that seals over the ports in the bottom of the master cylinder. This will prevent reservoir damage.

Vacuum Bleeding

Vacuum bleeding involves using a vacuum device to pull brake fluid through the hydraulic system for flushing or bleeding. A ***vacuum bleeder tool*** uses shop air pressure and the Venturi effect to produce suction in a brake fluid container and a small plastic hose connected to the brake bleeder screw. A knob on the top of the vacuum brake bleeder allows you to adjust airflow and vacuum applied.

An automatic ***master cylinder filling tool*** is used to keep the fluid reservoir full of brake fluid while bleeding or flushing. It has a float valve or ball in its neck that only opens when the fluid in the master cylinder drops too low.



Bendix and Chrysler

Figure 81-8. Pressure bleeding a brake system involves forcing brake fluid through the lines and the wheel brake assemblies. This forces air out of the system. Note how a pressure bleeder is connected to the master cylinder. With pressure in the system, open each bleeder screw until the air is purged from the system. A—Complete setup. B—Trapped air. C—Bleeder screw location.

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Service Procedure

To vacuum bleed a brake system:

1. Fill the master cylinder filling tool with brake fluid and install it on the reservoir, **Figure 81-9A**.
2. Remove protective plastic cap over brake bleeder screw (if applicable) and loosen the screw, **Figure 81-9B**.
3. Install one end of the clear plastic hose over the loosened brake bleeder screw, **Figure 81-9C**, and the other end to the vacuum bleeder tool, **Figure 81-9D**.
4. Connect a shop air hose to the vacuum bleeder tool. Adjust the knob on the tool until brake fluid starts flowing through the clear hose. When new fluid is seen passing steadily through the clear vacuum hose (usually 25–30 seconds), air has been removed from the system.
5. After bleeding a caliper or wheel cylinder, tighten the bleeder screw.
6. Repeat steps 2–5 for each wheel brake assembly following the order given in the service information. Many technicians like to final bleed all air from the system after vacuum bleeding by pressing the brake pedal while cracking open the bleeder screws.

Flushing a Brake System

Brake system flushing is done by pressure bleeding all the old fluid out of the system. Flushing is needed when the brake fluid is contaminated (filled with dirt, rust, corrosion, oil, or water). Bleed each wheel cylinder until clean fluid flows from the bleeder screw or fitting.

Brake Line and Hose Service

Brake lines and hoses can become damaged or deteriorated after prolonged service. When replacing a brake line, use approved double-wall steel tubing. Brake lines normally use double-lap flares. Some common tools and procedures used when servicing brake lines and hoses are shown in **Figure 81-10**.

Disc Brake Service

Complete ***disc brake service*** typically involves four major operations:

- Replacing worn brake pads.
- Rebuilding the caliper assembly.
- Turning (machining) the brake discs.
- Bleeding the system.

Depending on the condition of the disc brake assembly, the technician may need to do one or more of these operations. Service manual procedures and shop policies vary. In any case, you must make sure the brake assembly is in sound operating condition. Refer to **Figure 81-11**.

Replacing Brake Pads

Service Procedure

To replace worn brake pads in a floating caliper:

1. Loosen the wheel lug nuts.
2. Place the vehicle on jack stands or secure it on a lift.
3. Use an impact wrench and socket to remove the tire-and-wheel assemblies.
4. Use a large C-clamp or caliper tool to push each piston back into its cylinder, **Figure 81-12A**.
5. Unbolt the calipers and slide them off the brake discs, **Figure 81-12B**.
6. Hang the calipers by a piece of wire (if the caliper is not to be removed). See **Figure 81-12C**.

Tech Tip

To prevent brake hose damage, do not allow the heavy calipers to hang on their hoses. A metal hose end can cut through the rubber and cause a dangerous pressure leak.

7. Remove the old brake pads from the calipers.
8. Install anti-rattle clips on the new pads. If required, install any adhesive or insulator compound to the recommended surfaces on the metal areas of the pads.

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A



B



C

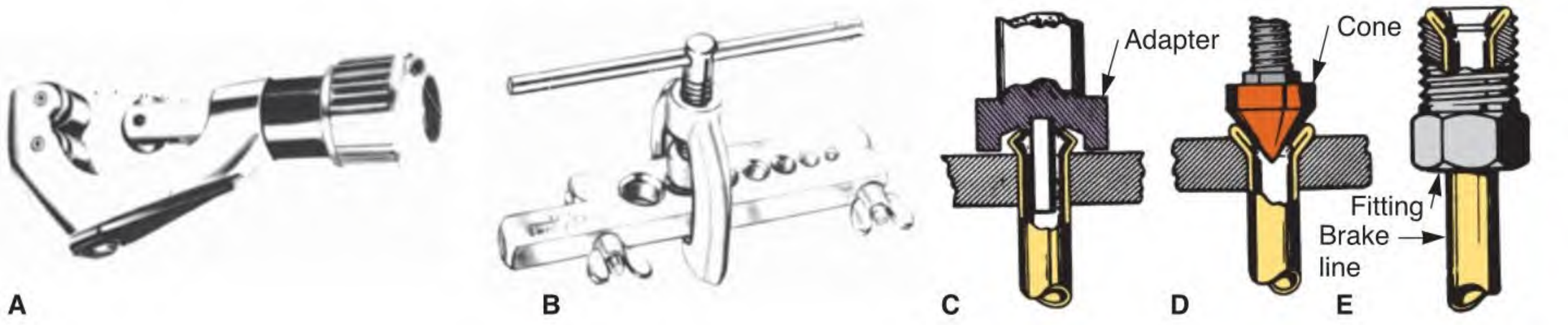


D

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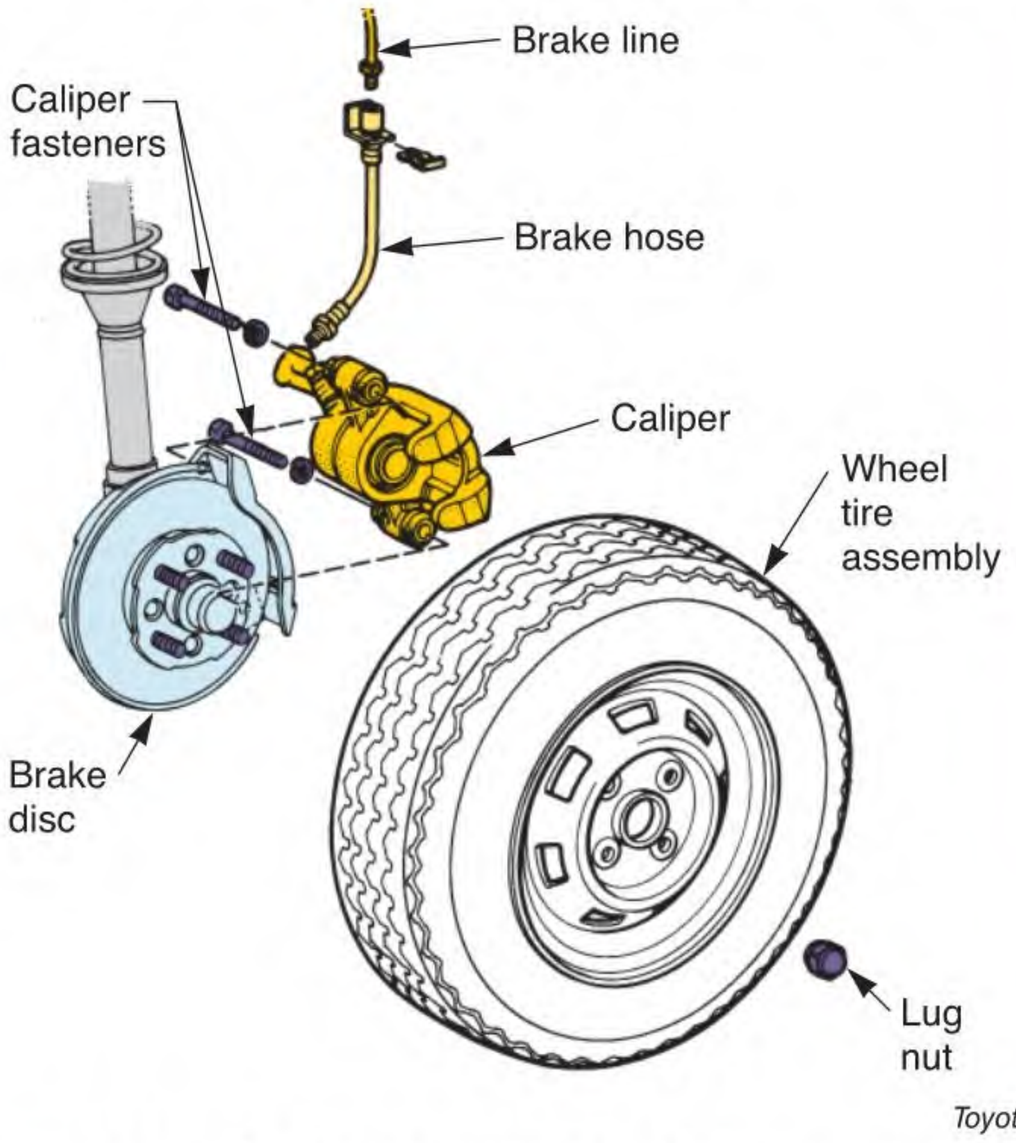
Figure 81-9. The major steps for vacuum bleeding a hydraulic brake system. A—Attach a master cylinder filling tool to the brake fluid reservoir. B—Loosen the bleeder screw on the wheel brake assembly. C—Fit one end of the clear hose over the bleeder screw. D—Connect the other end of the clear vacuum hose to the vacuum bleeder tool, along with a shop air hose.

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Bendix and Snap-on Tool Corp.

Figure 81-10. Proper service of brake lines and hoses is critical to vehicle safety. A—Tubing cutter. B—Flaring tool for forming ends on tubing. C—Using an adapter to fold the tubing inward. D—Using a cone on a flaring bar to form a double-lap. E—The fitting slides up to the double-lap flare. The fitting must be slid onto the brake line before the flare is formed. F—Clips are commonly used to secure the ends of a brake hose. G—Two wrenches are normally needed to loosen or tighten this type of tubing-to-hose connection. H—Use a tubing or a line wrench on fitting nuts. An open-end wrench will hold the flats of some fittings.



Toyota

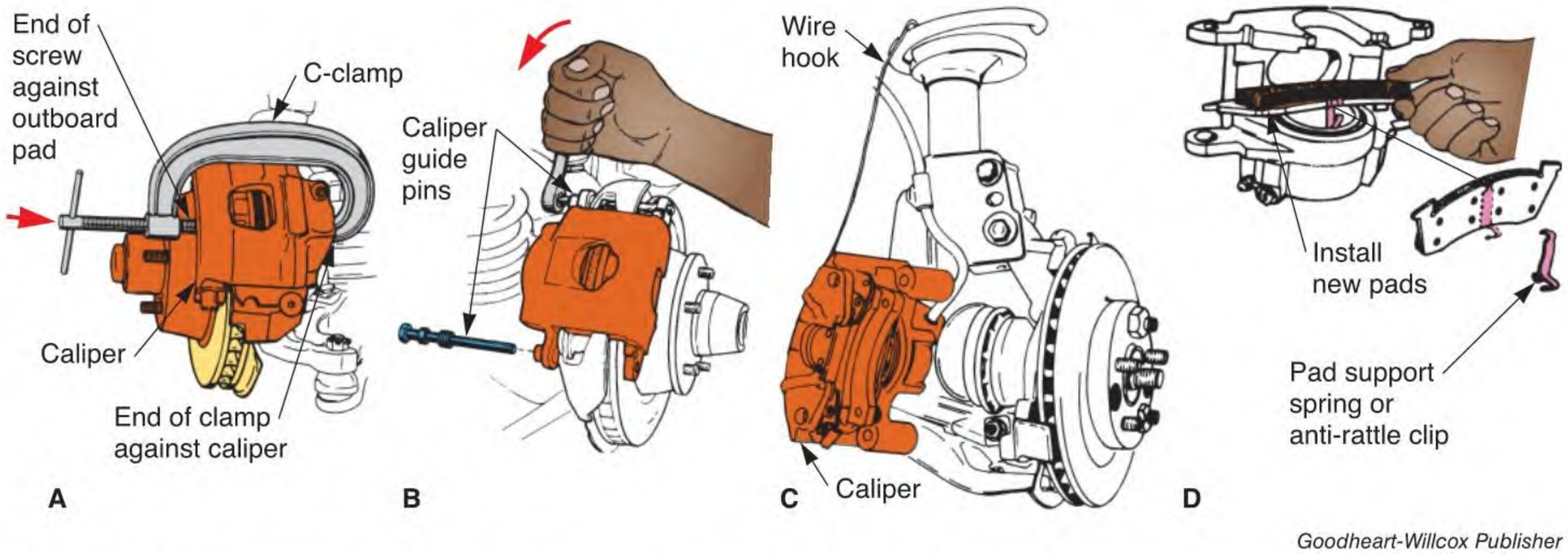
Figure 81-11. On modern vehicles, two bolts commonly hold the caliper on the steering knuckle. The brake hose connects the metal brake line to the caliper.

9. Fit the new pads into the calipers, **Figure 81-12D**. Install any retainer clips on the brake pads during installation.
10. With their pistons fully retracted (pushed inward), slide the caliper assemblies down over the brake discs.
11. Assemble the caliper mounting hardware in reverse order of disassembly.
12. Use a torque wrench to make sure all bolts are torqued properly.
13. Install the wheels and torque the lug nuts or bolts to specifications.
14. Test-drive the car to verify your repairs.

Tech Tip

It is acceptable to service only the front or rear brakes. However, never service only the right or left brake assemblies. This could cause dangerous brake pull.

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Figure 81-12. Study basic steps for floating caliper pad service. A—Use a C-clamp or a large screwdriver to force the piston back into the caliper. This will open the caliper wide enough for the new, thicker pad linings. B—Use a six-point socket or an Allen socket to unscrew the bolts holding the caliper. C—Lift the caliper off the knuckle and support it on a piece of wire. Do not let the unit hang by the brake hose, or the hose could be damaged. D—Remove the old pads. Note the position of the anti-rattle clips. The clips can be reused if they are in good condition. New pads can be installed without caliper service if the vehicle has low mileage and if the boot and seals are in good condition.

Rebuilding a Caliper Assembly

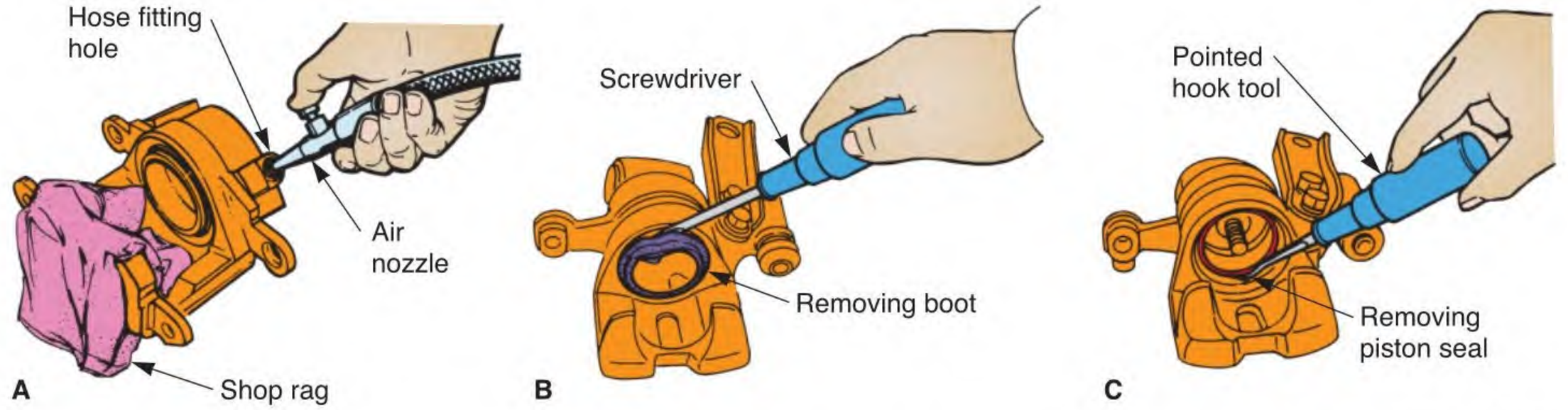
When a caliper piston is frozen, leaking, or has extremely high mileage, it must be rebuilt or replaced. Remove the caliper from the vehicle and take it to a clean work area.

To remove the piston from the caliper, apply just enough air pressure in the hose fitting hole to push the piston out of its cylinder, **Figure 81-13A**. Some automakers recommend using brake system hydraulic pressure to force the piston out of the caliper.

Warning

Keep your fingers out of the way when using compressed air to remove a caliper piston. A stuck piston could fly out with tremendous force. Serious hand injuries could result.

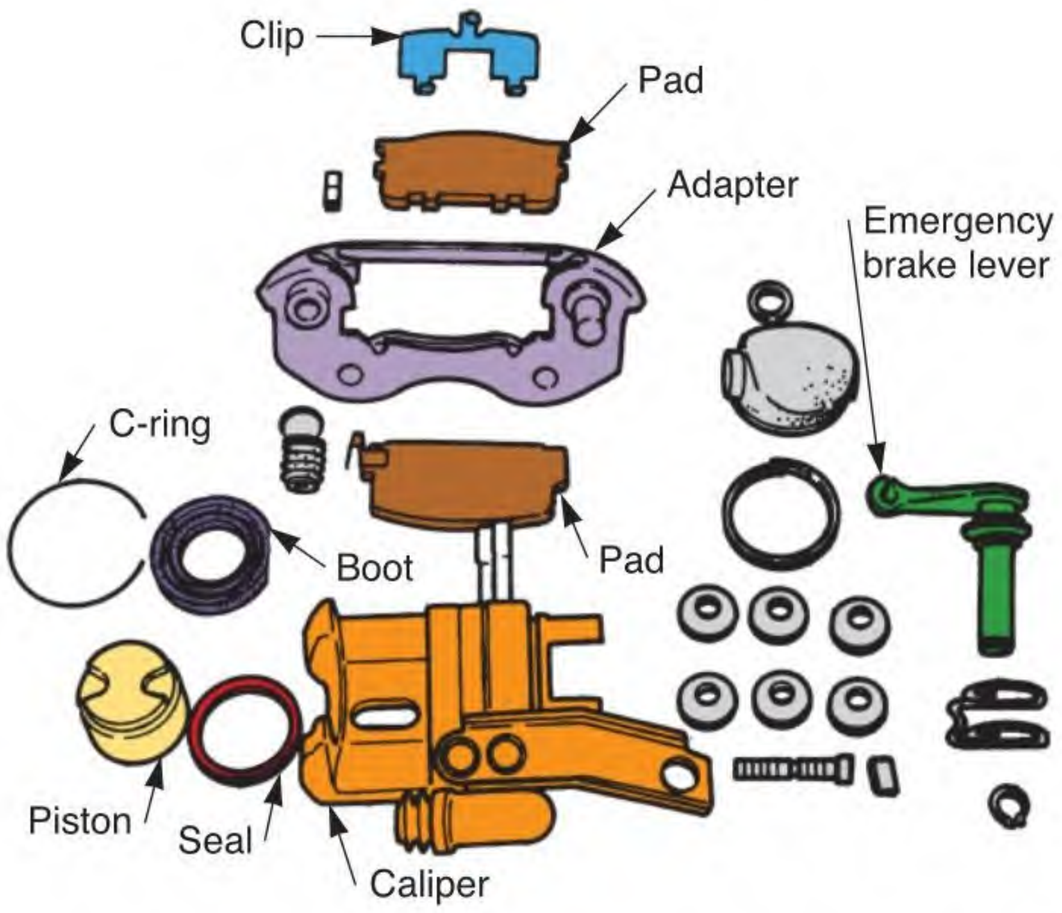
After piston removal, pry the old dust boot and the seal out of the caliper, **Figures 81-13B** and **81-13C**. Keep all parts organized on your workbench. Do not mix up right and left or front and rear parts. See **Figure 81-14**.



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Figure 81-13. Note the fundamental steps for caliper disassembly. A—Use air pressure or brake system pressure to push the piston out of the caliper. Place a thick rag or a block of wood in the caliper and keep your hands out of the way. B—Use a screwdriver or a similar tool to pry the old boot out of the caliper. C—A pointed hook-type tool will make removal of the old seal easy. The seal is positioned inside the groove in the cylinder.

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Subaru

Figure 81-14. When servicing calipers, keep all parts organized on a workbench. Do not mix parts from the right and left sides of the caliper. Inspect all parts closely for signs of wear or damage.

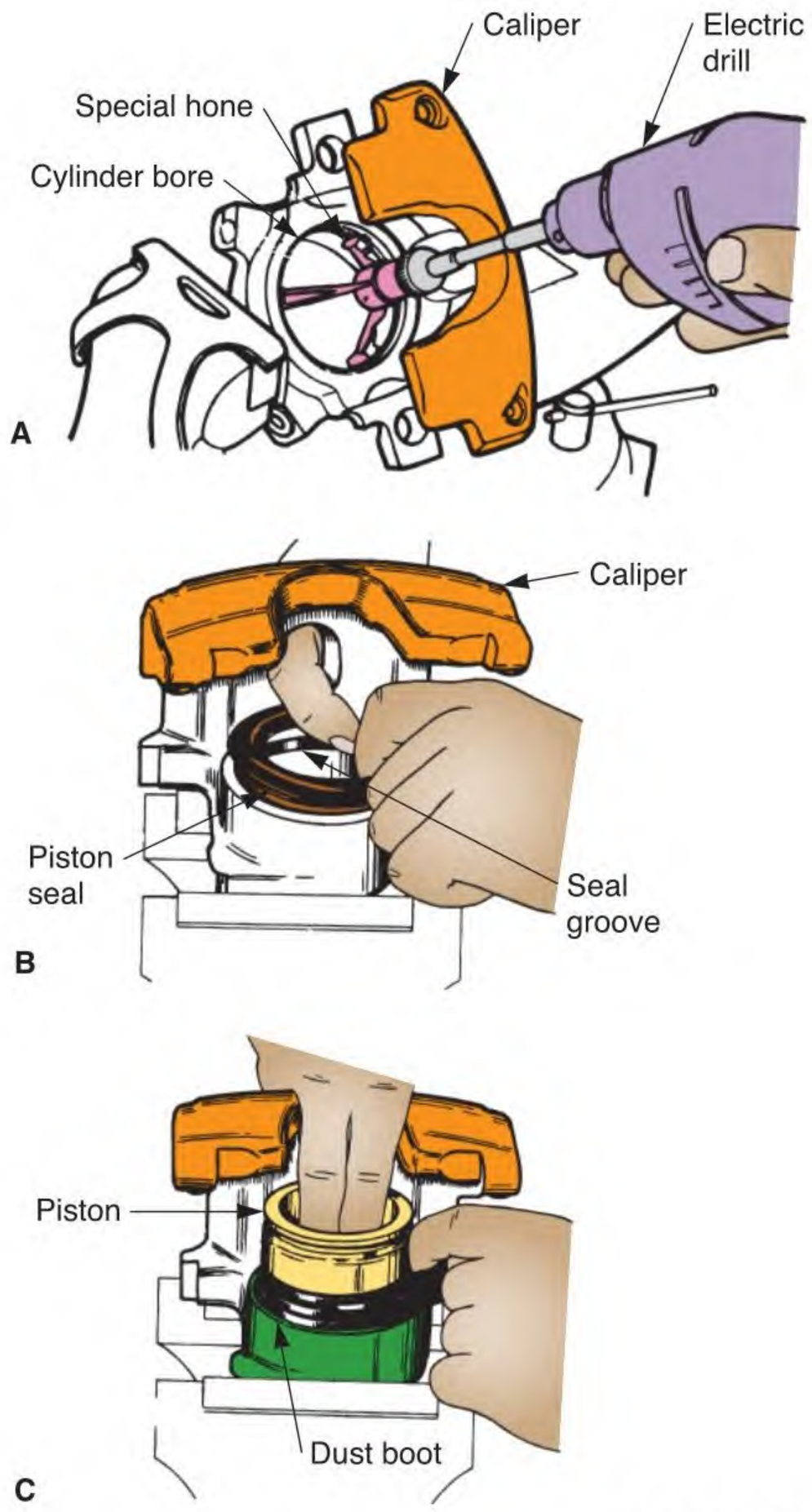
Check the caliper cylinder wall for wear, scoring, or pitting. Light surface imperfections can be cleaned up with a cylinder hone. See **Figure 81-15A**. Use brake fluid to lubricate the hone. If excessive honing is needed, replace the caliper.

Also, check the caliper piston for wear or damage. Install a new piston if you find any problems. The piston and the cylinder are critical and must be in perfect condition.

Clean all the caliper parts with an approved cleaner. Wipe the parts clean with a clean shop rag. Then, coat them with brake fluid.

Assemble the caliper in the reverse order of disassembly. Typically, work the new seal into the cylinder bore groove with your fingers, **Figure 81-15B**.

Then, install the new boot in its groove. Coat the piston with more brake fluid. Spread the boot with your fingers and slide the piston into the cylinder, **Figure 81-15C**.



Chrysler and Bendix

Figure 81-15. Proper honing and reassembling are critical to a caliper rebuild. A— Electric drill spins a special hone inside the caliper cylinder. This removes minor surface flaws. B—Fit the new seal and boot into position. The seal must be down in its groove. Sometimes, it is easier to install the boot after installing the piston. C—Slide the piston into the cylinder squarely. Make sure the seal does not come out of its groove. Fit the boot into the groove on the outside of the piston.

Brake Disc (Rotor) Service

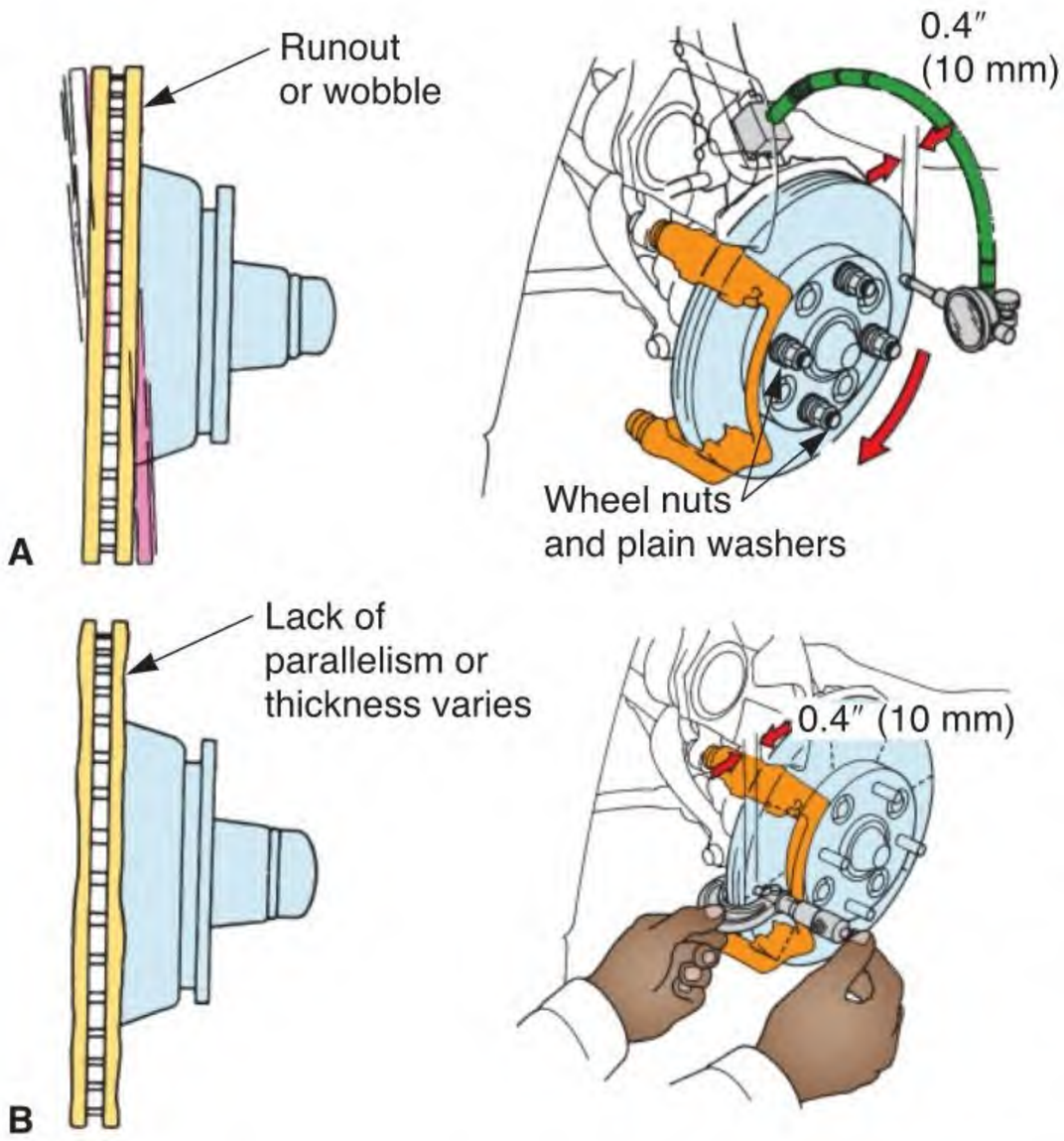
When servicing a disc brake system, it is important to check the condition of the brake disc. Automakers provide specifications for maximum disc runout (wobble) and minimum disc thickness. Also, the brake disc must not be scored, cracked, or heat checked.

Brake Disc Measurements

Brake disc runout is the amount of side-to-side movement measured near the outer edge of the disc's friction surface. A dial indicator is used to measure brake disc runout. See **Figure 81-16A**.

Compare your indicator reading to factory specifications. Typically, runout should not exceed 0.004″

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EIS and Honda

Figure 81-16. Checking for rotor runout and thickness variations is important. A—Mount a dial indicator as shown to measure disc runout, or wobble. Rotate the disc by hand and read the indicator. If runout is greater than specifications, the rotor should be turned or replaced. B—An outside micrometer can be used to detect any thickness variations. Take thickness measurements at several places around the disc. If readings are not the same, or if they are not within specifications, turn or replace the disc.

(0.10 mm). If runout is beyond specifications, turn (machine) the disc on a brake lathe to true its friction surfaces.

Brake disc thickness is measured across the two friction surfaces in several locations. Variation in disc thickness indicates wear.

To measure disc thickness, use an outside micrometer. Measure in several places around the disc. Compare your measurements to specifications, as in **Figure 81-16B**.

Minimum disc thickness will sometimes be printed on the side of the brake disc. If it is not, refer to a manual or brake specification chart. If brake disc thickness is under specifications, replace the brake disc.

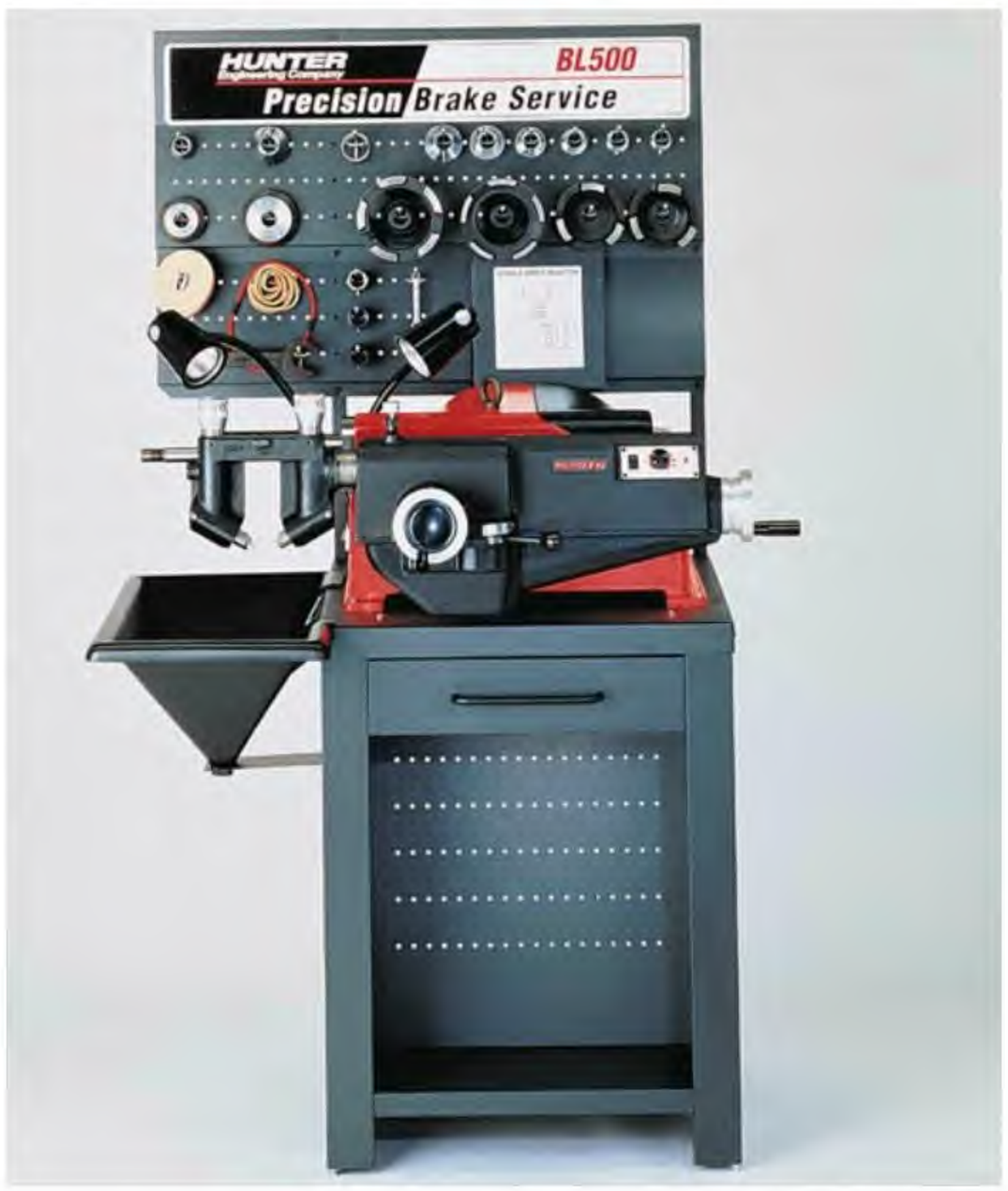
Tech Tip

A thin brake disc cannot dissipate heat properly and may warp or fail in service. A warped brake disc can cause severe vibration upon braking. Complete failure of the brake disc may severely damage other parts.

Resurfacing a Brake Disc

Brake disc resurfacing refers to machining a disc's friction surfaces on a brake lathe, **Figure 81-17**. Disc resurfacing is needed to correct runout, thickness variation, or scoring.

When a brake disc is in good condition, most manufacturers do not recommend resurfacing. Only machine a disc when it is absolutely necessary.



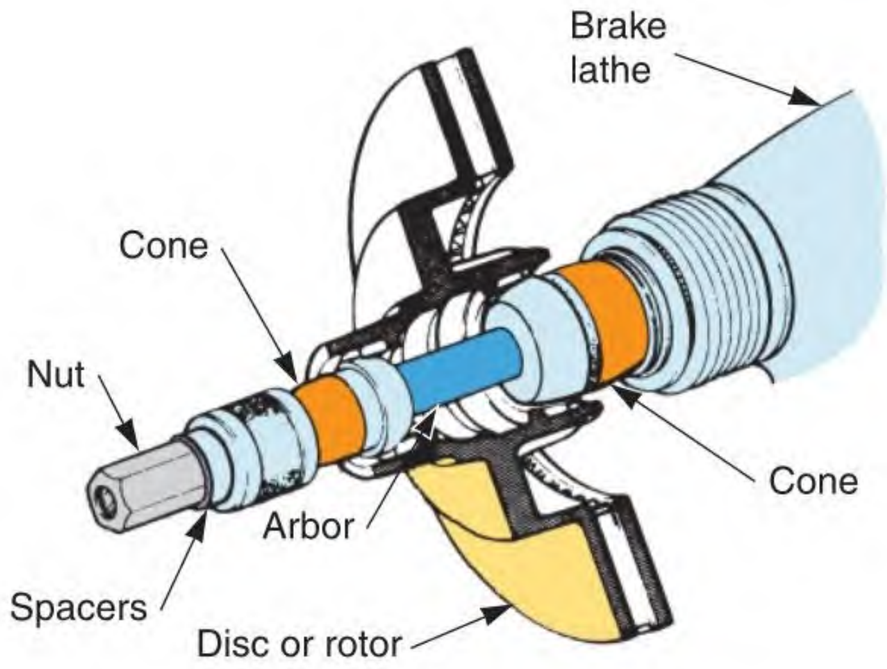
Hunter Engineering

Figure 81-17. Always read the operating manual before trying to use a brake lathe. Note the controls.

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Warning

Do not attempt to operate a brake lathe without first obtaining proper training. The machine could be damaged or you could be injured by incorrect operating procedures. Look at **Figure 81-18**.



EIS

Figure 81-19. Special cones are used to mount the rotor on a brake lathe. The cones must contact the bearing races. Spacers and a nut then lock the assembly on the arbor.

Service Procedure

To resurface a brake disc:

1. Mount the brake disc on the brake lathe. Use the appropriate spacers and cones to position the disc true on the machine's arbor. Follow the directions provided with the brake lathe. See **Figure 81-19**.
2. Tighten the large shaft nut on the machine so the brake disc is held firmly on the arbor. The nut must clamp the cones and spacers tightly against the bearing races.
3. Wrap a ***vibration damper*** (spring or rubber damper) around the disc to prevent high-frequency vibration and squeal, **Figure 81-20**.
4. While wearing eye protection, start the machine and adjust the cutting tools until they just contact the friction surfaces on the disc. Adjust the cutting tools very slowly so they barely touch the brake disc surface.
5. With the machine feeds and controls set properly, engage the auto feed mechanism to machine both smooth surfaces on the disc. Remove only enough metal to true the disc.

Tech Tip

Minimizing the depth of cut and feed speed will produce the longest lasting, smoothest finish on the surface of the brake disc. Overcutting and cutting too quickly is a common mistake that affects repair longevity.

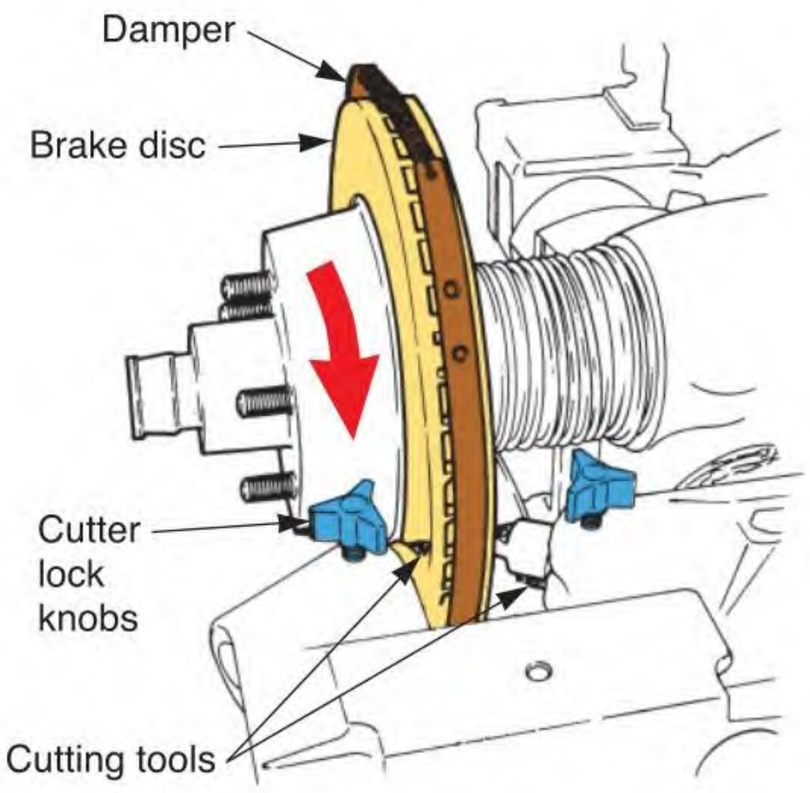
6. Without touching the machined surfaces with your fingers, remove the disc from the lathe.
7. Double-check disc thickness and install the disc on the vehicle.



Ammco

Figure 81-18. This brake lathe has a large guard, or cover, that should be closed during operation. It protects you and others in the shop from flying debris if something goes wrong.

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Chrysler

Figure 81-20. After installing a damper to prevent vibration, small cutters are fed into the rotor a prescribed depth. Then, the controls are set so the cutters advance over the rotor's surface automatically.

On-Car Brake Lathes

Some European and Asian front-wheel-drive vehicles have brake discs that are difficult to remove. With these vehicles, an on-car disc lathe (grinder) is a time-saver because you do not have to remove the disc to machine it. The lathe mounts on the vehicle's steering knuckle. A large electric motor turns the disc during the machining process. See **Figure 81-21**.

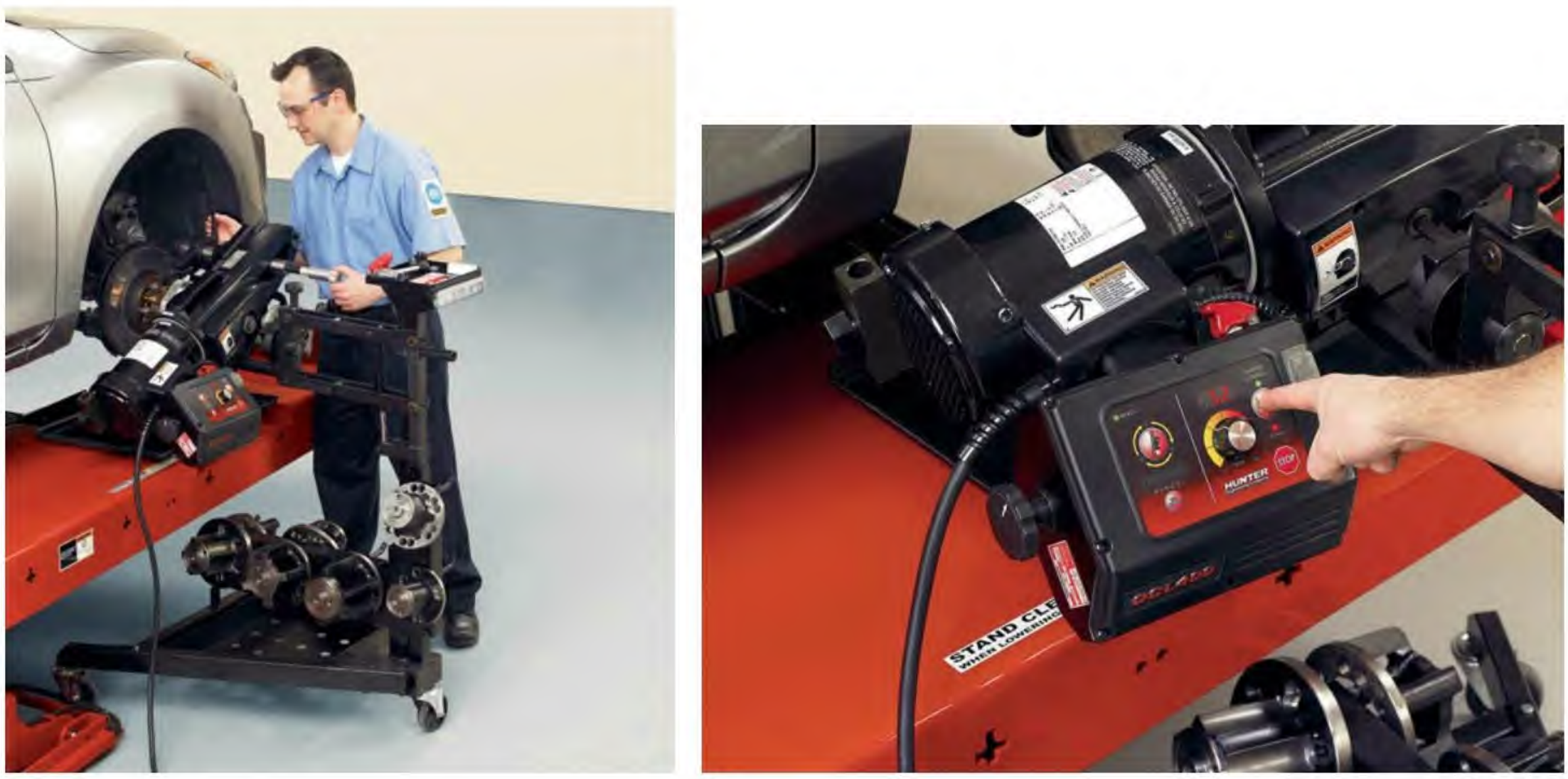
Disc Brake Reassembly

Reassemble the disc brake in the opposite order of disassembly, **Figure 81-22**.

After installing the brake disc, fit the caliper assembly into place. Make sure the new pads are properly installed. In some cases, high-temperature silicone is used on the backs of the pads to help prevent brake rattle and squeal.

If recommended, apply a small amount of grease to the caliper mounting bolt threads. This will ensure proper tightening and secure mounting of the caliper, **Figure 81-23**. Torque all caliper fasteners to specifications.

During assembly, keep your hands off the surface of the disc and the brake pad linings. Grease will burn and harden on the friction lining, causing brake squeak. Refer to **Figure 81-24**.

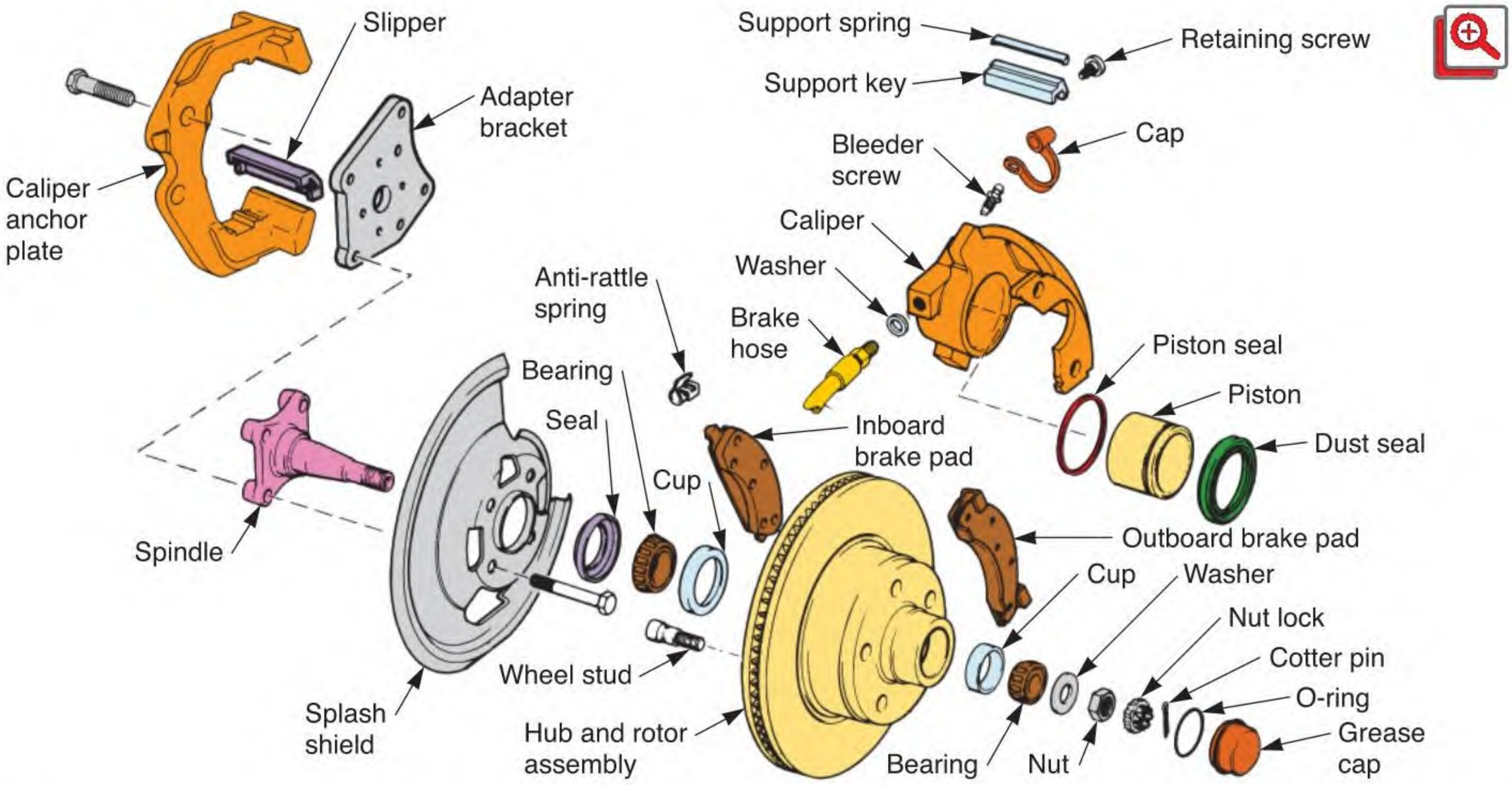


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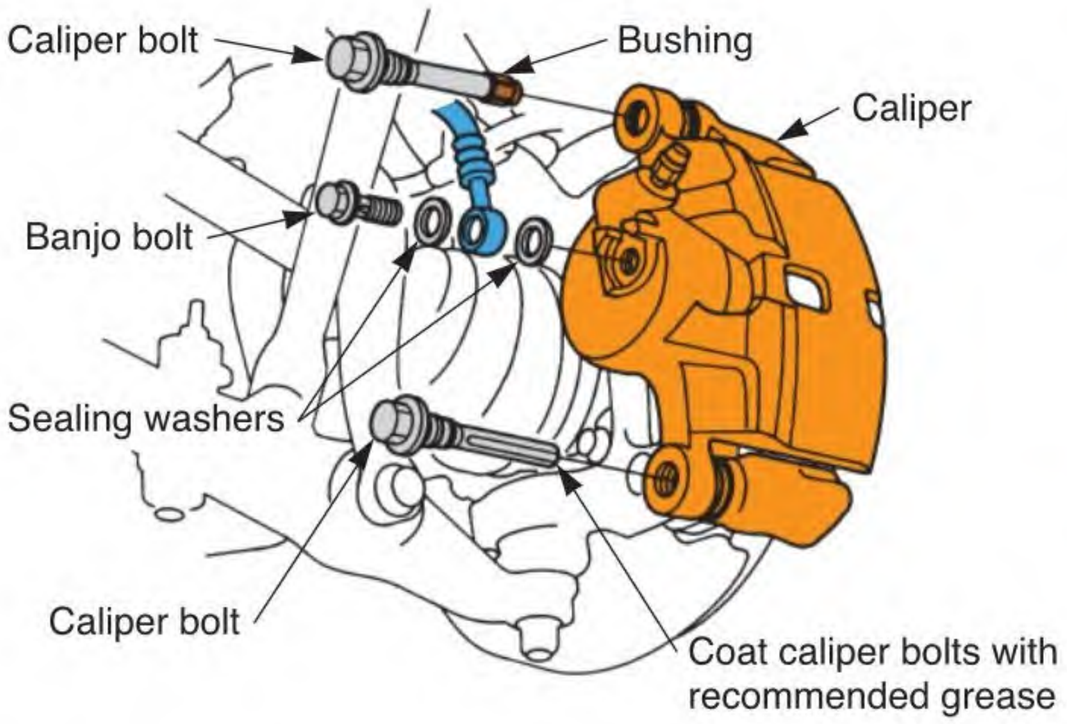
Figure 81-21. An on-car brake lathe is handy when rotors are difficult to remove from a vehicle. A—Mount the hub adapter on the vehicle. Move lathe into position and adjust its height so that the adapter engages the drive head on the machine squarely. Then adjust cutters up against the disc for machining. B—The on-car lathe assembly has controls for feeding cutters into the disc surface. Understand all of the control functions before operating the machine.

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Chrysler

Figure 81-22. Study parts of a disassembled disc brake assembly. Study how the parts fit together.



Honda

Figure 81-23. When reinstalling a caliper, lubricate the bolt threads. Make sure the special washers are in place on the brake hose, if used.

Tech Tip

Some disc brake rotors have their fins arranged to pull air through the inside of the rotor in only one direction. The spinning action of the rotor aids cooling. With these designs, the rotors are different on the right and left sides of the vehicle. If you accidentally reverse sides or purchase a rotor for the wrong side, rotor overheating and damage can result. Not enough air will be pulled through the rotor to prevent heat-related warpage during hard braking.

Drum Brake Service

Although specific procedures vary, you should understand the most important methods for servicing a drum brake. Service is needed anytime your diagnosis finds faulty drum brake components. A leaking wheel cylinder, worn or contaminated linings, scored drum, or other troubles require immediate repairs.

Complete ***drum brake service*** typically involves:

- Removing parts from the backing plate.
- Cleaning and inspecting the parts.
- Replacing the brake shoes.
- Replacing or rebuilding the wheel cylinders.
- Turning (resurfacing) the brake drums.
- Lubricating and reassembling the brake parts.
- Preadjusting, bleeding, and testing the brakes.

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Volvo

Figure 81-24. Rotor and lining surfaces should be perfectly clean after repairs are complete. If you accidentally get greasy fingerprints on the rotor, wipe off the surfaces with an approved solvent.

Figure 81-25 shows some special brake service tools.

Drum Brake Disassembly

To disassemble drum brakes, remove the tire-and-wheel assemblies and the brake drums, **Figure 81-26**.

If the drum is rusted to the axle flange, light taps with a hammer may be needed. Hammer on the outside edge of the drum. Do not hammer on the inner lip of the drum, or it can break. You may also need to back off the adjuster if the drum is worn. This is shown in **Figure 81-27**.

Use a brake spring tool to remove the upper shoe return springs, **Figure 81-28A**. Organize the springs so that they can be installed in the same location. The primary and secondary springs are usually a different color and tension. Use a hold-down spring tool to remove the hold-down springs, **Figure 81-28B**.

Lift the brake shoes off the backing plate. Remove the automatic adjuster mechanism. See **Figure 81-29**.

Before disassembling the wheel cylinder, clean the backing plate. Wipe off the plate with a shop rag. If the backing plate is coated with brake fluid or axle lubricant, wash the plate with an approved cleaner.

Servicing Wheel Cylinders

Pull back the wheel cylinder boots. The wheel cylinder should be rebuilt or replaced if it shows signs of leakage or sticking. In fact, many shops service the wheel cylinders anytime the linings are replaced, **Figure 81-29**.

To service a wheel cylinder, remove the boots, the pistons, the cups, and the spring. Usually, the wheel cylinder can be serviced while bolted to the backing plate. Sometimes, however, the wheel cylinder must be removed before disassembly.

A ***wheel cylinder rebuild*** normally involves honing the cylinder and replacing the rubber cups and boots.

It is very important that the inside of the cylinder be in good condition. Cylinders that are deeply scratched, scored, or pitted must be replaced.

To hone a wheel cylinder, mount the small hone in an electric drill. Insert the hone in the cylinder. Turn on the drill while moving the hone back and forth in the cylinder. Keep the hone lubricated with brake fluid.

Warning

When honing a wheel cylinder, do not pull the hone out of the cylinder. The spinning hone could fly apart. Wear eye protection!

After honing, wash the wheel cylinder thoroughly with brake fluid or an approved cleaning solvent. Dry the cylinder with clean shop rags. Make sure the cylinder is clean and in perfect condition before reassembly. The slightest bit of grit or roughness could cause cup leakage.

Make sure the new wheel cylinder cups are the same size as the old ones. Cup size is normally printed on the face of the cup. Coat the parts with brake fluid and fit them into the cylinder.

Brake Drum Resurfacing

Brake drum resurfacing, also called ***turning***, involves machining the friction surface of the drum on a brake lathe. Look at **Figure 81-30**.

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A



Snap-on Tool Corp.; Nilfisk

Figure 81-25. A—Special tools and equipment are available for servicing drum brakes. Small brake tools make the work fast and easy. B—A brake vacuum is used for cleaning off brake assemblies. It helps prevent you from breathing brake lining dust, which can contain asbestos—or a similar heat-resistant material—a possible cancer-causing agent.

Resurfacing is needed when the drum is scored, out-of-round, or worn unevenly. Some shops machine a drum anytime the brake linings are replaced. Other shops only resurface the drum when needed. Refer to auto manufacturer suggestions when in doubt.

To resurface a brake drum, mount the drum on the lathe. Follow the operating instructions for the particular lathe. Wrap a silencing band (rubber or spring strap) around the outside of the drum. The band will prevent vibration that could affect drum surface smoothness, **Figure 81-31**.

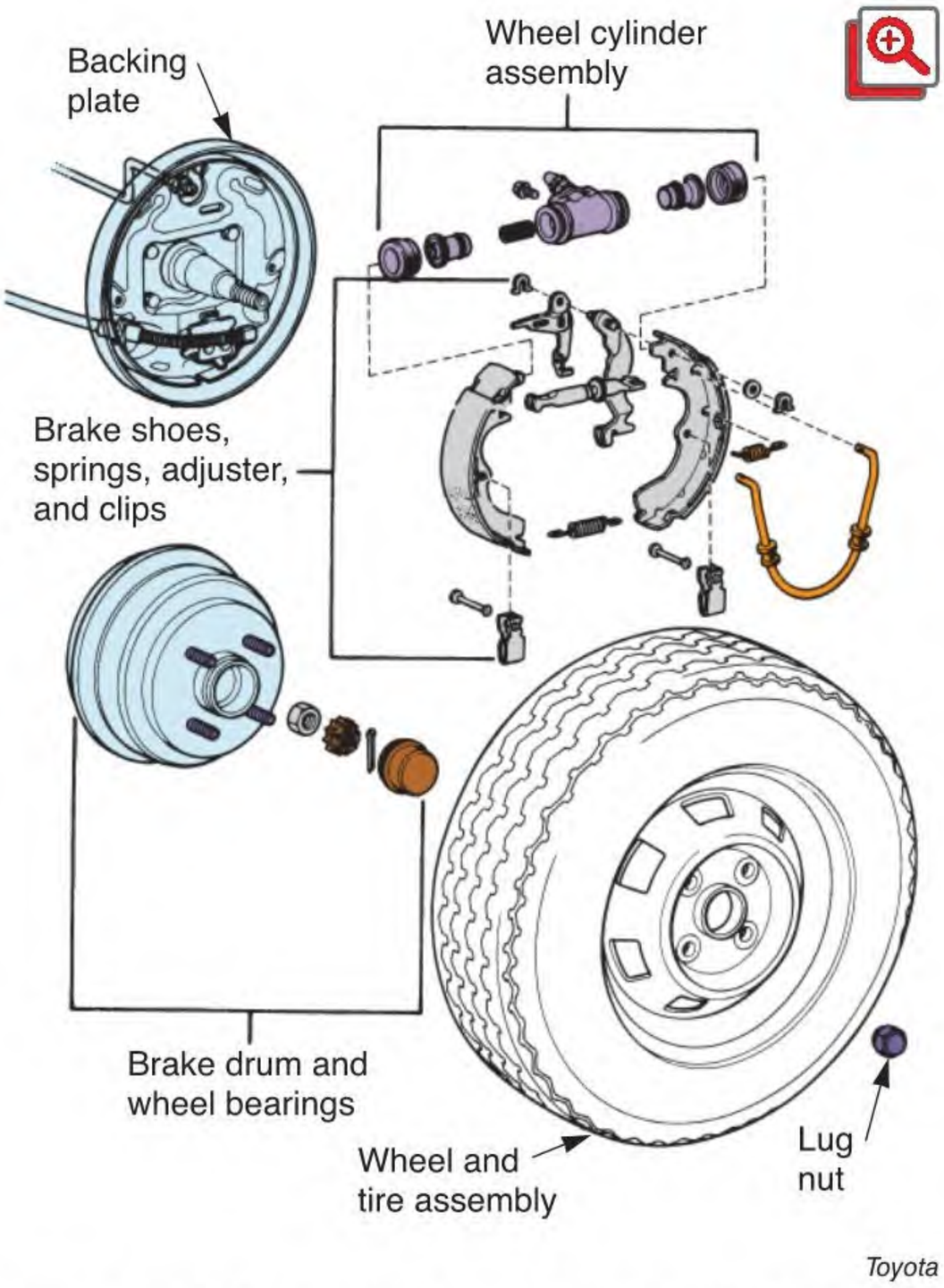
Wearing eye protection, feed the cutting tool against the inner surface of the drum. Adjust the depth of the cut to lathe specifications and activate the automatic feed.

When resurfacing a drum, remove as little material as possible. Resurfacing thins the metal around the friction surface. As a result, the drum is more prone to overheating and warping.

Machine the right- and left-hand drums to the same diameter. This will help ensure even, straight-line braking.

A conventional cutting tool will not remove metal from hardened areas of the brake drum. A high spot will remain on the friction surface, and brake vibration will result. ***Brake drum grinding*** is sometimes needed to remove this hardened metal and to true the friction surface. The grinder is mounted on the lathe in place of the cutter arm.

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Toyota

Figure 81-26. Disassembled drum brake assembly. Note the part relationships.

Measuring Brake Drum Diameter

Typically, a brake drum should not be more than 0.060″ (1.5 mm) oversize. Look at **Figures 81-32A** and **81-32B**. For example, a drum that is 9″ (229 mm) in diameter when new must not be over 9.060″ (230 mm) in diameter after resurfacing. If larger in diameter, the drum is dangerously thin.

To measure brake drum diameter, use a special brake drum micrometer. It will measure drum diameter quickly and accurately, **Figure 81-32C**.

Replace the drum if it is worn beyond specifications. Sometimes, maximum diameter is stamped on the side of the brake drum.

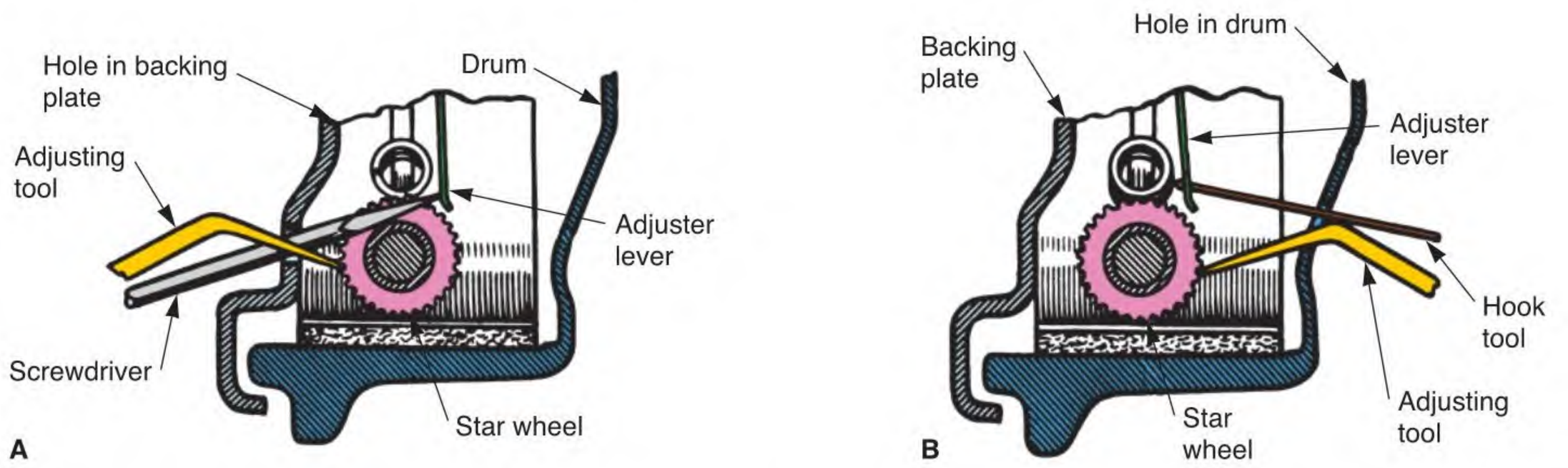
Drum Brake Reassembly

Before reassembling drum brakes, clean the wheel bearings and inspect them for wear or damage. Then, pack the bearings with grease and install new grease seals.

Lubricate the small pads or bumps on the backing plate. This will keep the shoes from squeaking. Avoid using too much lubricant, or the linings can become contaminated and ruined, **Figure 81-33**. Also, lubricate the threads on the star wheel screw, if there is one.

Before installing the new shoes, check their fit inside the brake drum. There should be a small clearance between the ends of the lining and the drums. The shoes should rock slightly when moved in the drum. If the centers of the linings are not touching the drum, the linings should be arced (ground).

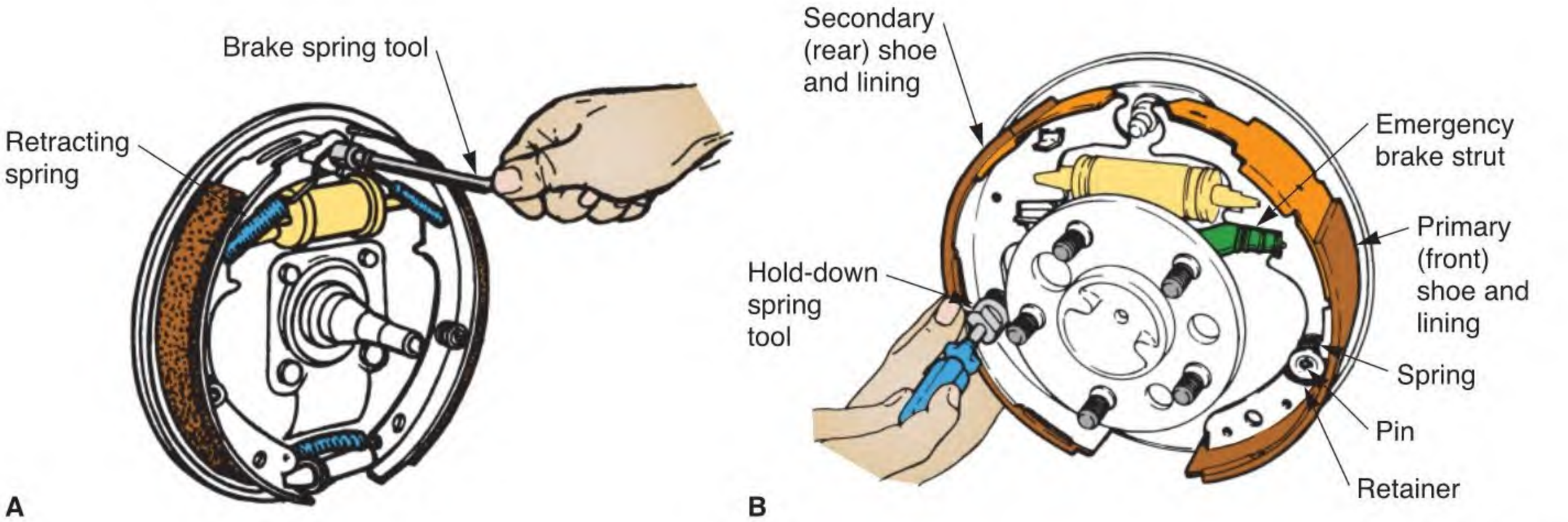
When arcing brake shoe linings, follow the instructions provided by the equipment and vehicle manufacturer. Basically, you must grind the linings so that they are 0.35″ (0.89 mm) smaller in diameter than the drum. Without this clearance, the linings could chatter and vibrate when returned to service.



Bendix

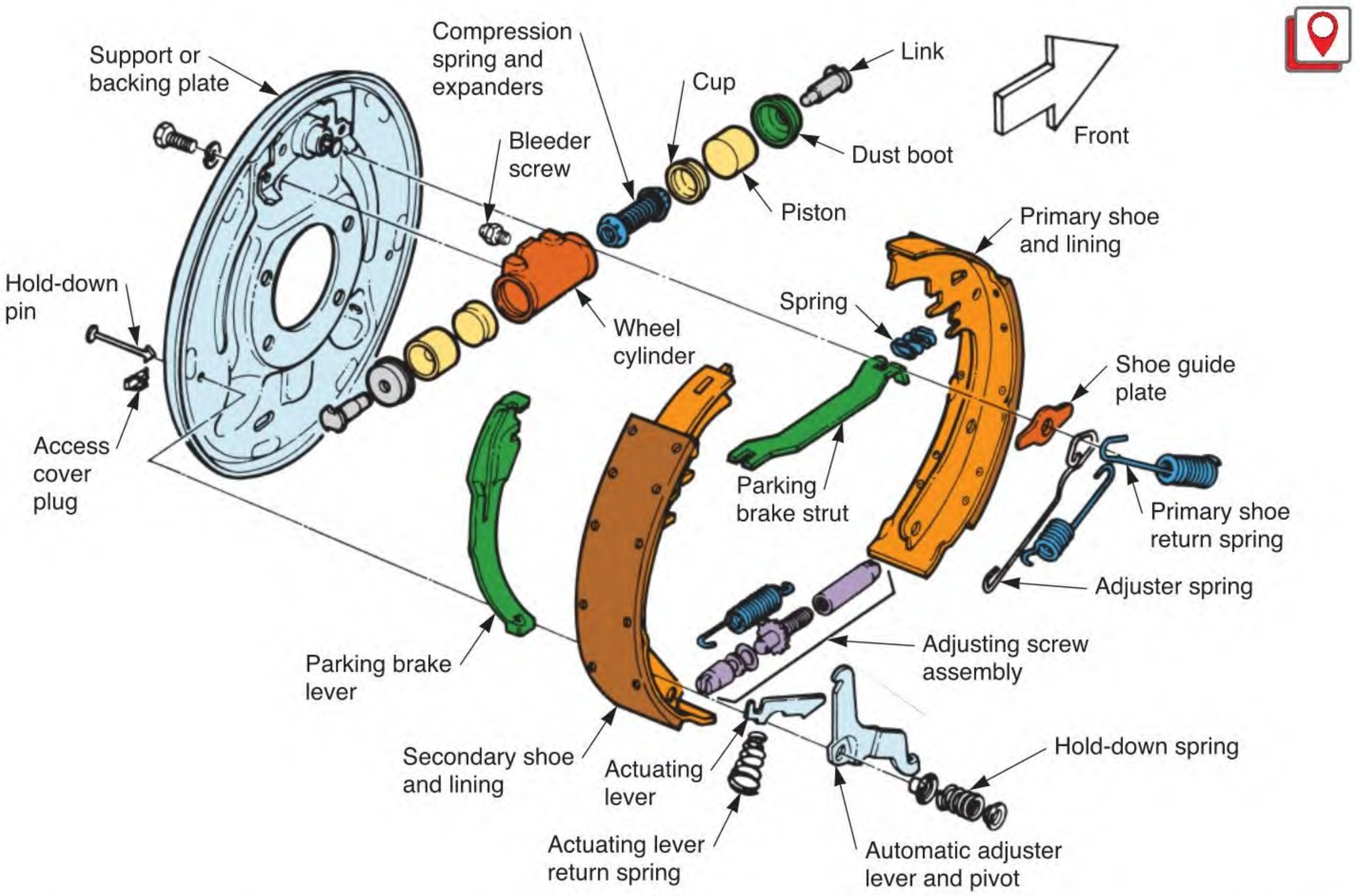
Figure 81-27. Backing off the star wheel will allow drum removal. A—When the access hole is in the backing plate, hold the lever and turn the star wheel as shown. B—Turning the star wheel when the access hole is in the drum.

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Bendix and Chrysler

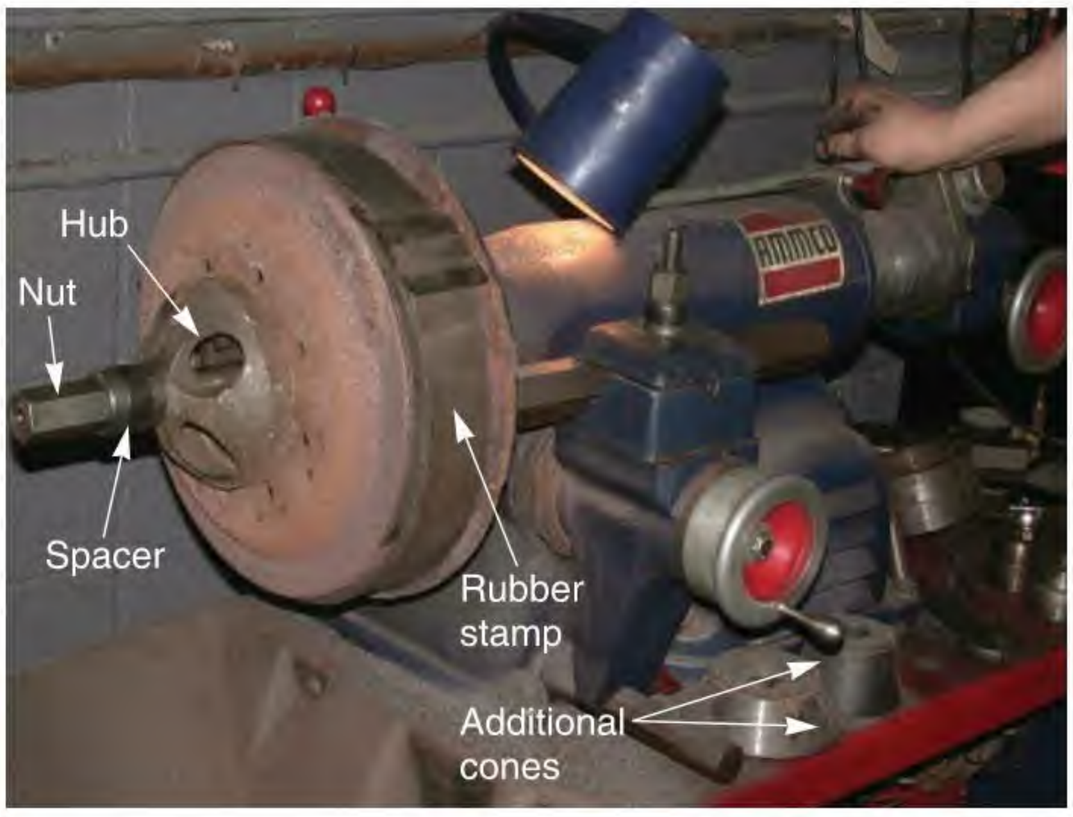
Figure 81-28. Note how to service springs. A—Brake retracting spring tool can be turned to pry springs off the anchor pin. B—A hold-down spring tool can be pushed in and turned to free the spring from the pin. Use your finger to hold the pin from the rear of the backing plate.



Chrysler

Figure 81-29. Study this disassembled view of a typical drum brake unit.

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Figure 81-30. When installing a brake drum on a lathe (similar to a rotor), you must use the correct cones, spacers and hubs. The cone is slid on the lathe shaft ahead of the drum and rests against the inner side of the drum. These parts will safely secure the drum to the lathe shaft.

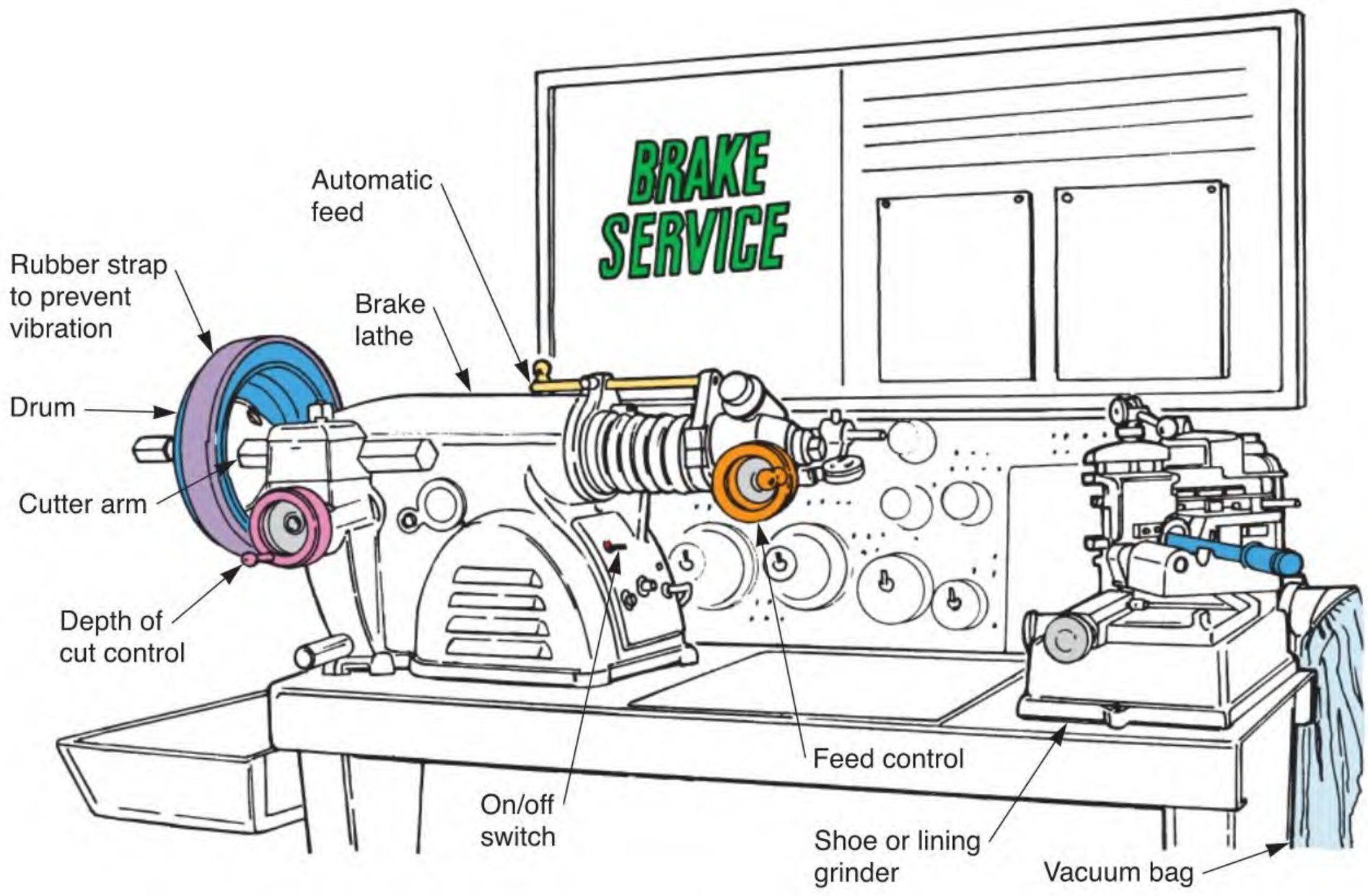
Warning

Make sure the vacuum system on the lining grinder is working properly. Remember that asbestos brake lining dust can cause cancer. Even dust from non-asbestos brake linings is unhealthy to breathe. At a minimum, wear a dust respirator mask when working on friction brakes.

Install the new shoes and the adjuster mechanism on the backing plate. Make sure all the parts are positioned correctly, **Figure 81-34**.

Ask yourself the following brake service questions:

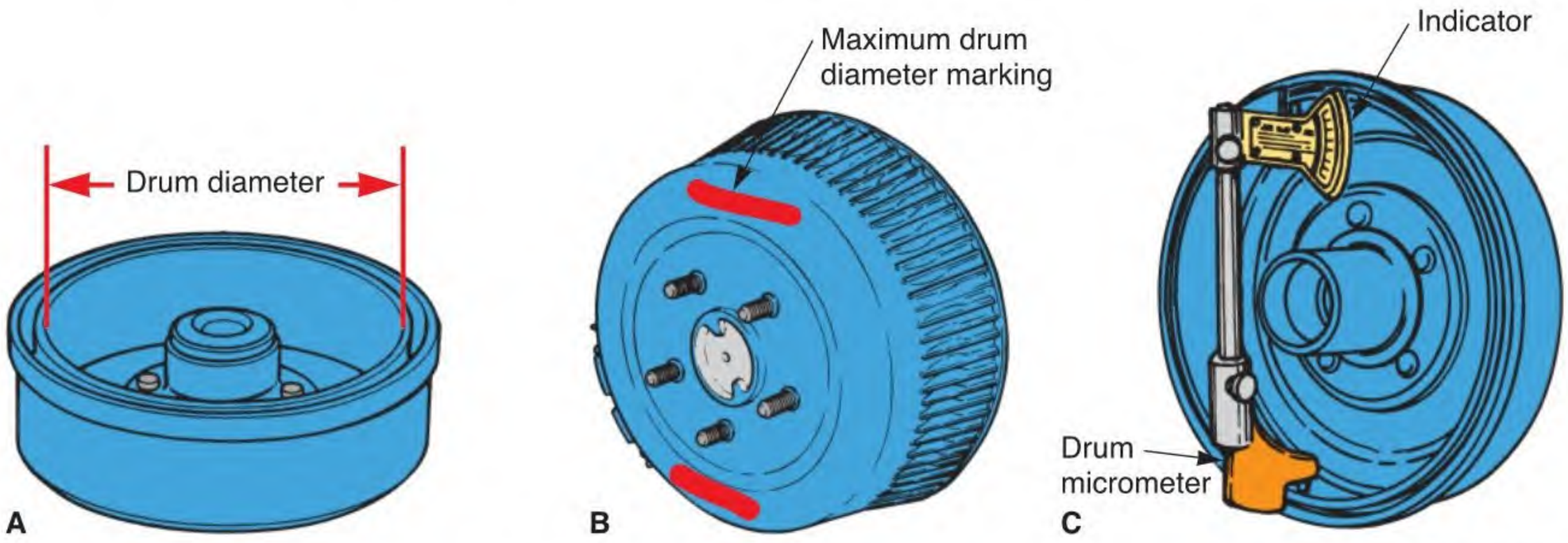
- Are the wheel cylinders in perfect condition and assembled properly?
- Did I lubricate the backing plate and the star wheel?
- Is the primary (smaller) lining facing the front of the vehicle and the secondary (larger) lining facing the rear of the vehicle?



EIS

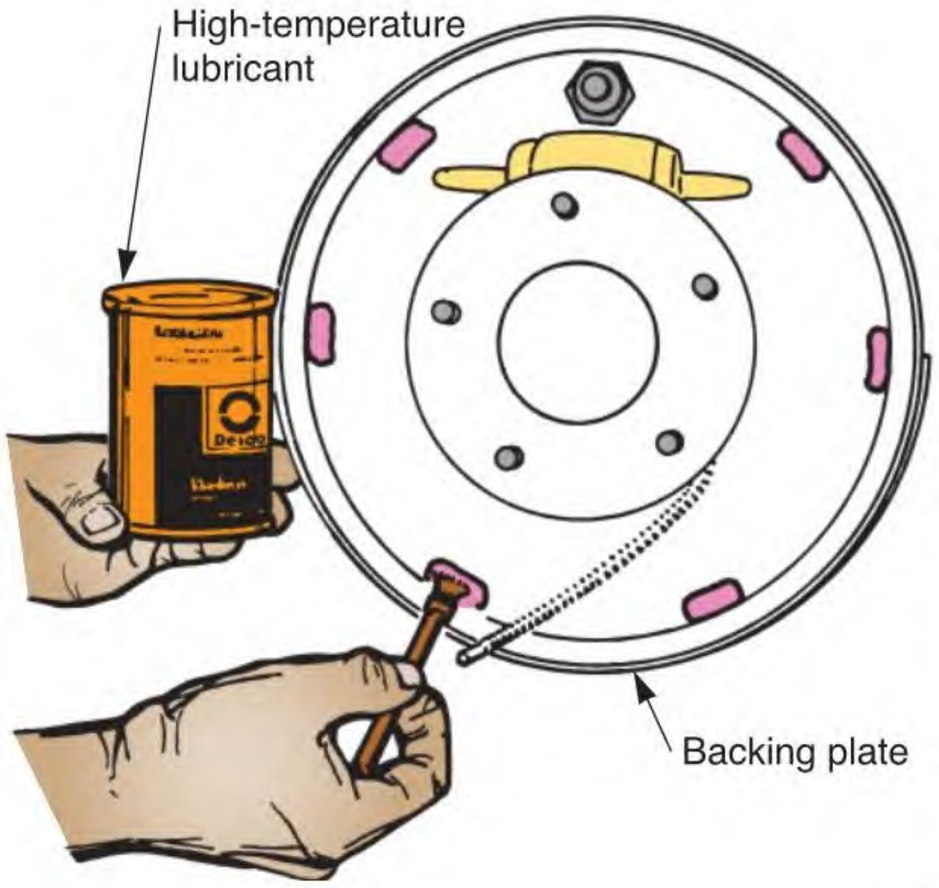
Figure 81-31. Note how this drum is mounted on the brake lathe. A shoe grinder is also shown.

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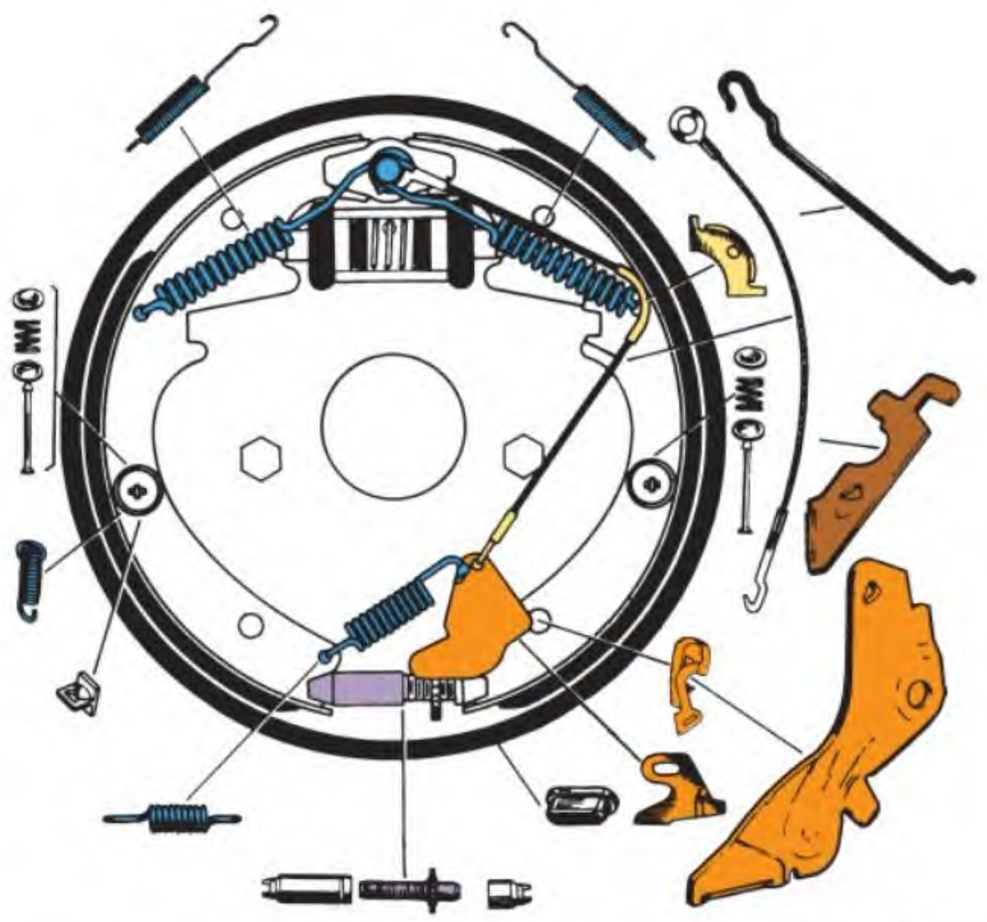
Toyota; Chrysler; FMC

Figure 81-32. Note how to check brake drum wear. A—Drum diameter is the distance across the inside friction surface. B—Drum diameter is normally stamped on the outside of the drum. Oversize limits may also be given. C—A special drum micrometer will quickly and accurately measure drum diameter and wear. Generally, drums should not be more than 0.060″ (1.5 mm) oversize.



Bendix

Figure 81-33. Wipe high-temperature grease on the raised pads on the backing plate and on the star wheel threads.



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Figure 81-34. When assembling brakes, make sure every part is in the proper location. This illustration shows the locations for one specific unit.

- Are the shoes centered on the backing plate?
- Are the shoes contacting the anchor correctly?
- Are all the springs installed properly?
- Does the automatic adjuster work?
- Are the lining surfaces perfectly clean (sand if needed)?
- Do I need to bleed the brakes?

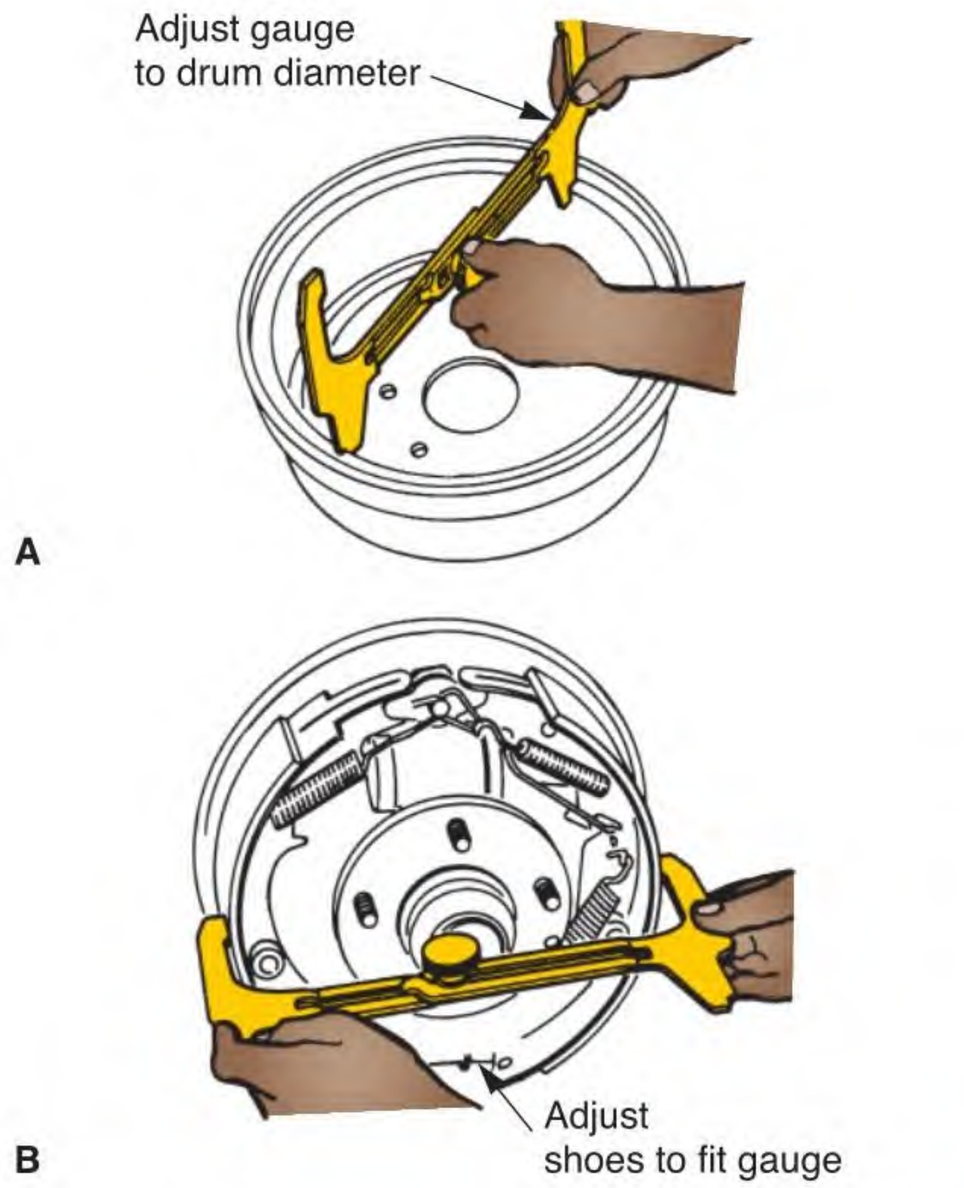
Your service manual will have assembly illustrations for the particular brake design being serviced. Use them to help position the parts on the backing plate correctly.

Preadjusting Drum Brakes

Even though modern brakes have automatic adjusters, you should preadjust the brake shoes. This will ensure proper initial brake system operation.

To preadjust the brake shoes, fit a brake adjusting gauge into the brake drum, **Figure 81-35A**. Set the gauge for the inside diameter of the drum. Tighten the lock on the gauge.

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Figure 81-35. Study drum brake preadjustment. A—Fit the gauge into the brake drum and adjust it against the inside diameter of the drum. Lock the unit into position. B—Fit the gauge around the outside of the brake shoes. Adjust the shoes outward until they just touch the gauge.

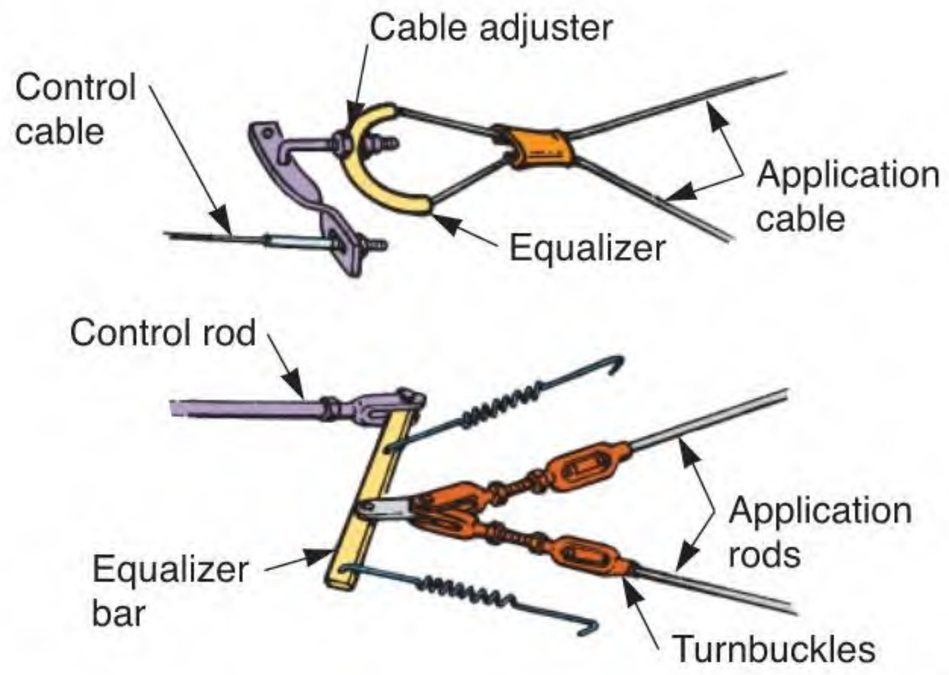
Next, fit the gauge over the brake shoes, **Figure 81-35B**. Then, turn the star wheel or move the adjuster arm until the linings touch the gauge. This will ensure that the linings are the correct distance from the inside of the drum.

Another way to preadjust drum brakes involves the use of a brake spoon (star wheel tool) to turn the star wheel. Turn the wheel until the brake drums drag lightly when rotated by hand.

Parking Brake Adjustment

To adjust the parking brake, you must normally tighten an adjustment nut on the cable mechanism. Refer to **Figure 81-36**.

During adjustment, release the parking brake lever or pedal. Lubricate cables and linkages. To prevent over adjustment, engage the parking brake lever or pedal one notch. Then, turn the cable adjuster to remove excess slack. Operate the parking brake and make sure the brakes are not dragging when released.



FMC

Figure 81-36. Note how to adjust parking brake. Simply turn the threaded fastener or the turnbuckle until excess slack is out of the cable. Do not overtighten the parking brake, or the brakes can drag and overheat.

Diagnostic Case Study

Concern: Mr. Jenson brings his 2012 Ford F-150 pickup to the shop and says that his brake pedal goes all the way to the floor at stoplights. He says that new brake pads were installed only a few weeks earlier.

Cause: Duff checks the fluid level in the master cylinder and finds it to be normal. He tests the brake pedal action and finds that it feels soft and bleeds down to the floor with constant foot pressure. Since fluid is not leaking from the system, this indicates internal leakage in the master cylinder. Duff turns the repair over to the shop's brakes specialist.

Correction: The technician removes the old master cylinder. She fills the new master cylinder with brake fluid and bench bleeds it before installing it on the vehicle. After the new master cylinder is installed in the vehicle, the technician uses a pressure bleeder to bleed air out of the entire brake system. She checks the brakes for proper operation and then releases the vehicle to the customer.

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Summary

- Use symptoms (noises, smells, abnormal brake pedal movements, improper braking action) when diagnosing brake system problems.
- Modern brake systems, primarily those with anti-lock brake systems, have self-diagnostic capabilities.
- Brake vibration shows up as a chatter, pulsing, or shake. It happens only when the brake pedal is applied.
- Grabbing is a condition in which the brakes apply too quickly, with only light brake pedal application.
- Pulling brakes is a symptom in which the vehicle veers to the right or left when braking.
- A spongy brake pedal is a condition which causes the brake pedal to feel like it is connected to a spring or rubber band.
- A dropping brake pedal is a symptom in which the brake pedal slowly moves all the way to the floor when steady pressure is applied to it.
- Dragging brakes are brakes that remain partially applied even though the brake pedal is released.
- Brake pedal height is the distance from the pedal to the floor fully released.
- Brake pedal free play is the amount of pedal movement before the beginning of brake application.
- Typically, the brake fluid level should be 1/4″ (6 mm) from the top of the reservoir.
- When the fluid level in the master cylinder is low, you should inspect the brake system for leaks.
- When inspecting disc brakes, check the thickness of the brake pad linings. Pads should be replaced when the thinnest (most worn) part of the lining is no thicker than the metal shoe (approximately 1/8″ or 3 mm).
- A faulty master cylinder usually leaks fluid past the rear piston or leaks internally.
- A master cylinder is bench bled to remove air from inside the cylinder.
- Brake system bleeding is the use of fluid pressure to force air out of the brake line connections or wheel cylinder bleeder screws.
- Pressure bleeding a brake system is done using a pressure bleeder tank which contains pressurized brake fluid.
- Vacuum bleeding a brake system requires a special vacuum tool connected to shop air pressure and to the bleeder screw of each wheel brake assembly.
- Brake disc runout is the amount of side-to-side movement measured on the outer friction surface of the rotor.
- Brake disc thickness is measured across the two friction surfaces in several locations.
- A wheel cylinder rebuild normally involves honing the cylinder and replacing the rubber cups and boots.
- Parking brake service includes inspecting, adjusting, and lubricating the mechanical cables and linkages of the system.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

bench bleeding
brake disc resurfacing
brake disc runout
brake disc thickness
brake drum grinding
brake drum resurfacing
brake fluid level
brake pedal check
brake pedal free play
brake pedal height
brake pedal reserve distance
brake system bleeding
brake system flushing
brake vibration
brake warning light
braking noise
disc brake service
dragging brakes
dropping brake pedal
drum brake service
excessive brake pedal effort
grabbing brakes
heat checked
low brake pedal
manual bleeding
master cylinder filling tool
no brake pedal
pressure bleeding
pulling brakes
spongy brake pedal
turning
vacuum bleeder tool
vacuum bleeding
vibration damper
wheel cylinder rebuild

Activities

1. Demonstrate the safe method of removing asbestos laden dust from a brake assembly.
2. Bleed a set of brakes and explain your procedure.

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3. Using a flat rate manual and a parts catalog, prepare a bill for a brake job.
4. Using a labor rate set by your instructor and a price list for parts, add up the cost of the brake job. Fill in the price on the bill prepared in Activity 3.

Review Questions

Answer the following questions using the information provided in this chapter.

1. What usually causes brake pedal vibration?
2. _____ brakes apply too quickly, even with light pedal application.
3. _____ brakes cause the vehicle to steer to the right or left when braking.
4. A spongy brake pedal is normally caused by air in the brake system. True or False?
5. A driver complains that the brake pedal slowly moves toward the floor when the vehicle is stopped at traffic lights. Pumping the pedal temporarily returns the pedal to the proper height. Also, the brake fluid has been checked and is at a normal height in the reservoir. Technician A says that a bad master cylinder could be the cause of the problem. Fluid could be leaking internally in the cylinder. Technician B says that a leaking wheel cylinder could be allowing pressure to drop. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. List and explain three types of brake noise.
7. Which of the following is *not* a brake pedal measurement?
   (A) Brake pedal free play.
   (B) Brake pedal pressure.
   (C) Brake pedal height.
   (D) Brake pedal reserve distance.
8. How much fluid should typically be in a master cylinder?
9. How do you check brake pad lining wear and brake shoe lining wear?
10. How do you quickly test the basic operation of a vacuum brake booster?
11. Most technicians replace faulty master cylinders with new or factory rebuilt units. True or False?
12. Cleaning hydraulic brake system parts in cold soak solvent is recommended. True or False?
13. A master cylinder should be _____ before installation to remove air from the unit.
14. What are the three methods for bleeding a vehicle brake system?
15. List the four major operations done during disc brake service.
16. _____ is the amount of side-to-side movement measured near the outer friction surface of a disc.
17. What can happen if a brake disc is too thin?
18. List the seven major steps for drum brake service.
19. Typically, a brake drum should *not* be _____ oversize, or it can warp or break.
20. Summarize the preadjustment procedure for drum brakes.
21. A technician determines that an automobile's front brake pad linings are 0.025″ thick. Specifications call for a minimum thickness of 0.020″. How much are the pads in or out of specifications?
   (A) 0.005″ out of specifications.
   (B) 0.005″ within specifications.
   (C) 0.045″ out of specifications.
   (D) 0.045″ within specifications.

ASE-Type Questions

1. A service writer says a customer's car has a brake system problem. Technician A road tests the car to detect any strange noises. Technician B checks the car around the master cylinder, brake lines, and wheel assemblies for any unusual odors. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. A customer complains that his car vibrates when the brake pedal is applied. Technician A looks for a warped disc. Technician B checks for "hard spots" on the brake disc. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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3. A car is brought into the shop with grabbing brakes. Technician A looks for worn brake linings. Technician B looks for a faulty metering valve. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. A customer tells the shop service writer that there has been a noticeable increase in the amount of foot pressure needed to apply the brakes on her car. Technician A checks for a frozen wheel cylinder. Technician B checks the car's front end alignment. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. A car veers to the right when the brakes are applied. Technician A checks the vehicle's front end alignment. Technician B looks for a frozen caliper. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. An automobile's brake system has a soft, spongy pedal. Technician A checks the fluid level in the master cylinder. Technician B checks the operation of the brake caliper pistons. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. An automobile has a dropping brake pedal. Technician A looks for an internal master cylinder leak. Technician B checks for a scored or gouged brake rotor. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. A car has a low brake pedal problem. Technician A inspects the brake adjusters. Technician B looks for a maladjusted master cylinder push rod. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. An automobile's brakes are dragging. Technician A checks the parking brake adjustment. Technician B checks for a master cylinder malfunction. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. A small pickup truck is brought into the shop with a no-brake-pedal condition. Technician A checks the hydraulic system for problems. Technician B checks the wheel cylinder return springs. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
11. An automobile has a metal-on-metal grinding sound when the brakes are applied. Technician A inspects the brake linings. Technician B looks for a leaking wheel cylinder. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
12. An automobile's brake system needs to be inspected. Technician A checks the system's brake pedal action. Technician B checks the system's master cylinder fluid level. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
13. Brake dust has accumulated on an automobile's wheel brake assemblies. Technician A uses a brake vacuum machine to remove this dust. Technician B uses compressed air to remove this dust. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
14. An automobile has a spongy brake pedal. Technician A checks to see if the brake pad linings are too thin compared to specs. Technician B bleeds the brake system. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
15. An automotive brake disc has 0.001″ runout. Technician A wants to replace the brake disc. Technician B says this amount of runout is normally within specifications. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Chapter 82
Anti-Lock Brakes, Traction, and Stability Control

After studying this chapter, you will be able to:

- Identify the major parts of a typical anti-lock brake system.
- Describe the operation of anti-lock brake systems.
- Compare anti-lock brake design variations.
- Describe the purpose and operation of traction control and stability control systems.
- Diagnose problems in anti-lock brake systems.
- Repair anti-lock brake systems.
- Diagnose and repair traction control and stability control systems.
- Correctly answer ASE certification test questions requiring knowledge of anti-lock brake systems, traction control systems, and stability control systems.

Anti-lock brake systems, or ***ABS***, are standard equipment on economy cars, luxury cars, minivans, and even pickup trucks. The major parts of a modern anti-lock brake system are illustrated in **Figure 82-1**.

ABS increases safety by reducing stopping distances compared to manual brakes on both wet and dry pavement. The ABS control module can cycle hydraulic pressure to each caliper or wheel cylinder to prevent wheel lockup. When a wheel locks up, its tire begins to skid and the coefficient of friction between the tire's tread and the road surface is diminished.

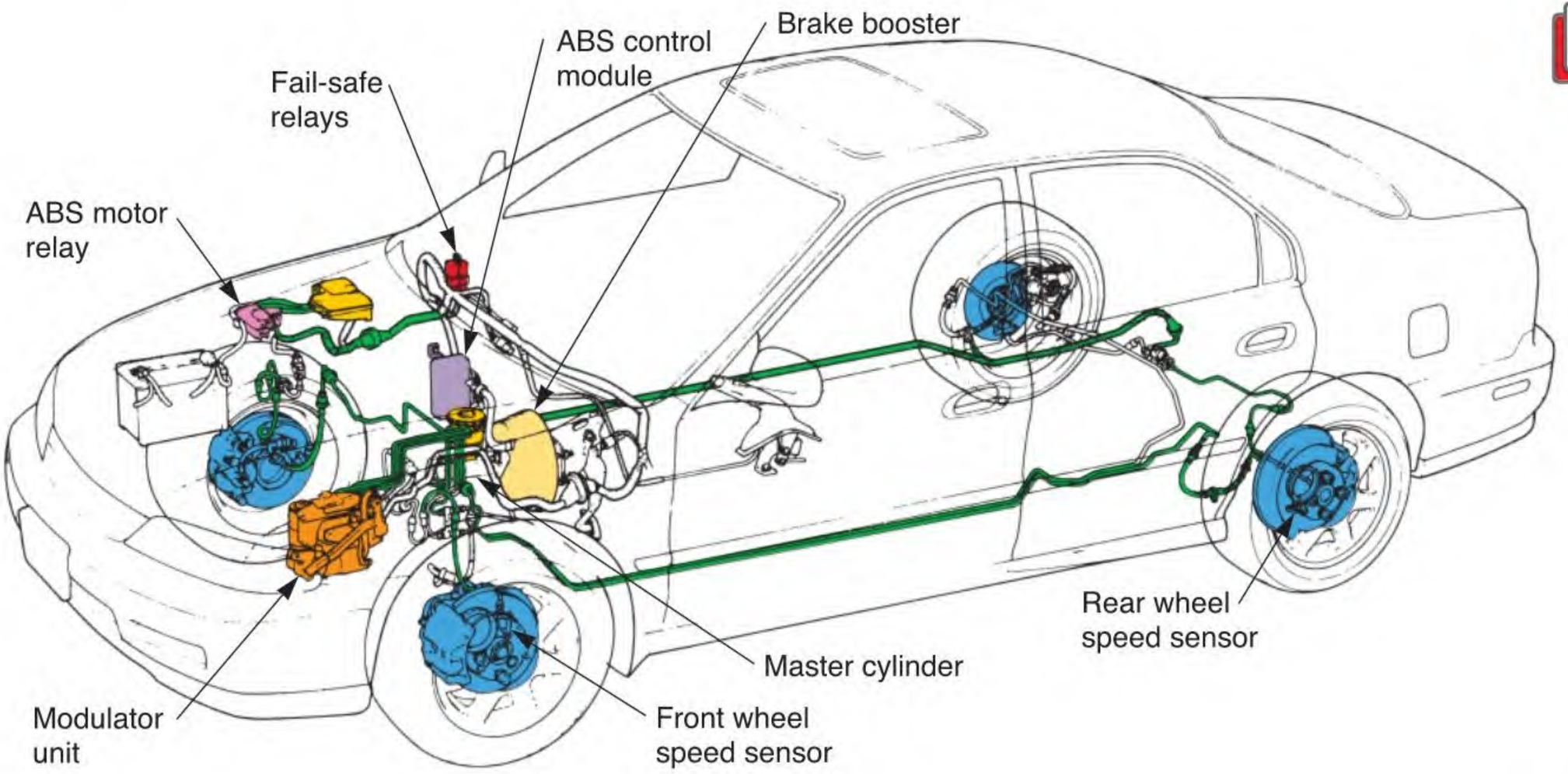
Traction control systems (TCS) electronically control the brakes, differential, engine, and transaxle to help reduce tire spin upon acceleration on slippery pavement. Again, when a tire skids on a road surface, it loses traction or adhesion. By preventing a wheel and tire from spinning too rapidly, a car with a TCS can drive up a snowy hill better than a car with rapidly spinning, skidding tires.

Stability control systems electronically link the steering, suspension, braking, and traction control systems together to prevent a loss of vehicle control and skidding when cornering at high speed. Almost every sensor on the car will provide feedback on the car's performance: vehicle speed, transmission gear selection, braking force applied to pedal, degree and speed of steering wheel rotation, etc. Various control modules can then adjust shock stiffness, sway bar tension, brake application at each wheel, engine power output, transmission operation, and even differential lockup to keep the vehicle level and stable when braking and cornering.

This chapter will build on the information you learned in previous chapters. It will introduce the additional parts needed to provide computer control of the complete chassis and driveline.

The chapter also summarizes the operation and repair of traction control and stability control systems.

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Honda

Figure 82-1. A modern anti-lock brake system uses a control module (computer), sensors, and a modulator to aid panic stops or stops on slick pavement. Also, note the locations of the relays.

These systems often use parts of the anti-lock brake system to help prevent tire spin and skidding to increase driver safety during emergency maneuvers.

Anti-Lock Brake Systems (ABS)

ABS uses wheel speed sensors, an ABS control module (computer), an electro-hydraulic brake actuator, and conventional hydraulic brake circuits to prevent wheel lockup during hard braking.

If a wheel locks up and the tire skids on the road surface, braking distance will increase and steering control can be lost. In a panic stop situation, the driver will often press down hard on the brake pedal to try to avoid a collision. This will normally send too much hydraulic pressure to the wheel cylinders, locking the wheels on vehicles without ABS. The tires will begin to squeal as they slide over the road surface. When the tires skid, they actually lose traction or friction with the road surface. This can increase stopping distance and reduce vehicle control in some situations.

On dry pavement, good drivers only apply enough pedal pressure to almost reach tire skid. They will release pedal pressure slightly when the squeal of tire skid is heard or felt. On slick pavement (water, snow, or ice on road surface), good drivers might pump the brake pedal manually to reduce skidding and stopping distance.

This is the principle of anti-lock brakes. For maximum stopping power, you want the tires to almost, but not quite, skid. When the tire skids, its friction with the road surface drops and stopping distance increases, which could cause an accident.

The anti-lock brake system improves driver and passenger safety by reducing stopping distances and increasing directional stability under panic stop conditions.

Figure 82-2 shows the advantages of ABS. In this example, one side of the road is very slippery and the other side is dry. This poses a problem if a panic stop is required.

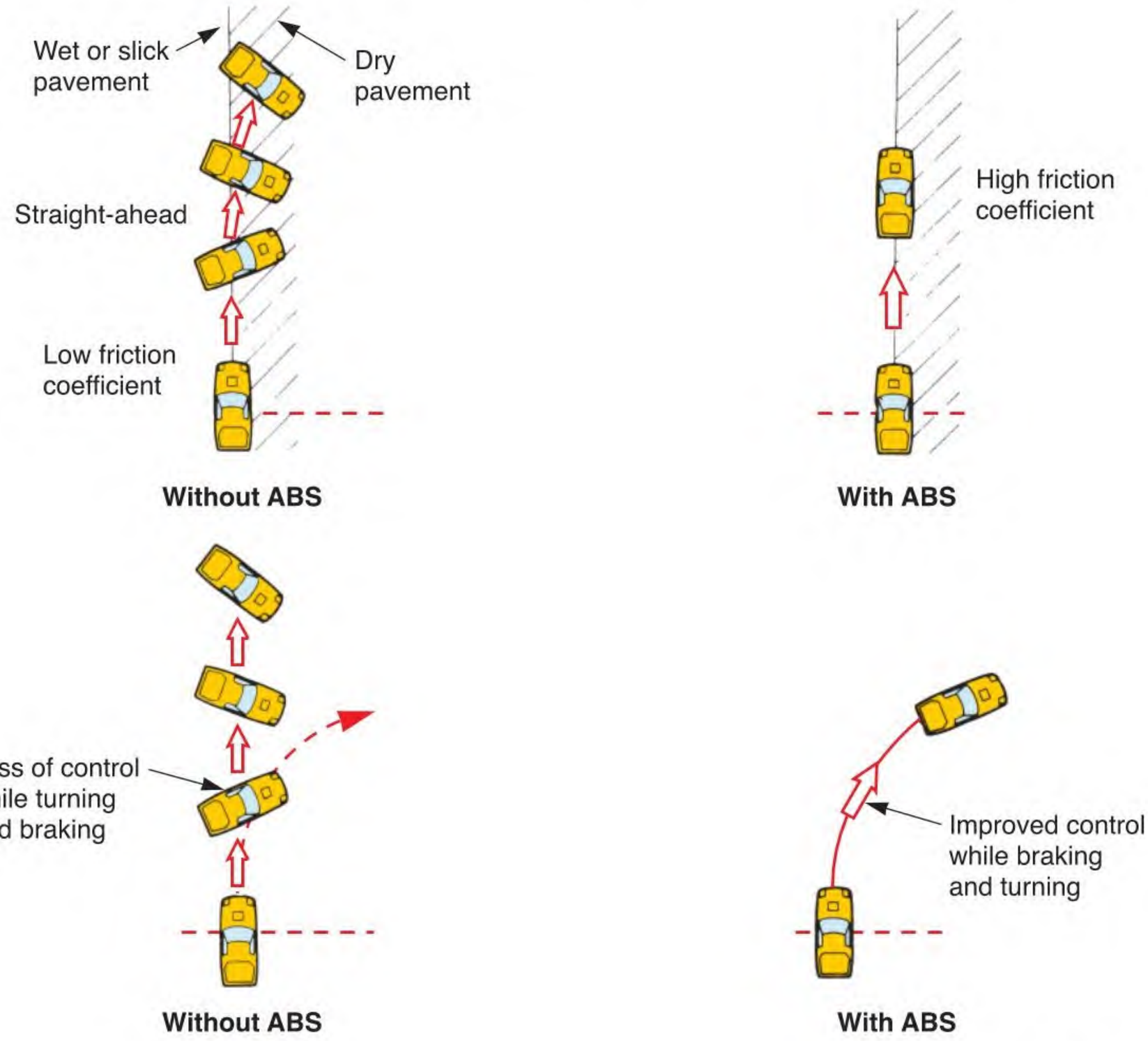
Without ABS, the car would tend to skid to the right because of higher tire adhesion on the right. With ABS, the car would still travel straight-ahead with hard braking. The brake units would be cycled to prevent tire skid and a loss of control. Also note that the car can be steered while braking with ABS.

ABS Components

The major parts of an anti-lock braking system, **Figure 82-3**, include:

- Wheel speed sensors—The wheel speed sensors are magnetic pickups for detecting the rotating speed of each tire and wheel assembly.
- Sensor trigger wheels—Sensor trigger wheels are toothed wheels that rotate at the same speed as the wheel and tire.

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Figure 82-2. Without ABS, tires can lock up and lose adhesion with the road. This can cause a loss of control during hard braking or when braking and trying to steer. Even if one side of the road is slick, the brakes will be cycled so that none of the tires skid. Maximum braking results when tires are just about ready to skid; traction is reduced if the wheels lock up.

- ABS control module—This module is a small computer, or processor, that uses sensor inputs to control the electro-hydraulic modulator.
- Electro-hydraulic modulator—The electro-hydraulic modulator is a control module-operated solenoid valve and electric pump module that cycles pressure to each wheel brake cylinder if its speed begins to slow down too much, indicating tire skid or wheel lockup.
- Brake warning light—This light, which is located in the instrument cluster, informs the driver of problems in the anti-lock brake system circuits.

Wheel Speed Sensors

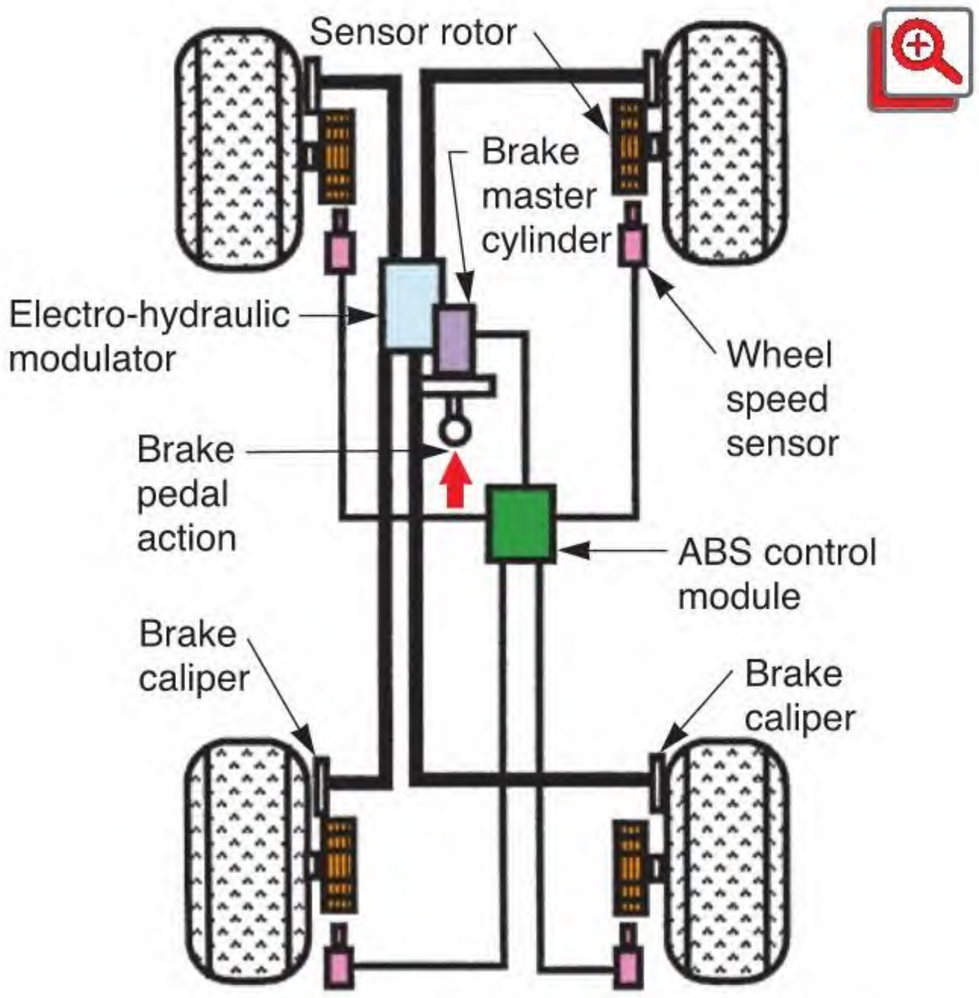
The ***wheel speed sensors*** produce ac signals that correspond to wheel and tire speed. These signals are fed into the ABS control module. With rear-wheel anti-lock brakes, wheel speed sensors are only used on the rear wheels. With four-wheel anti-lock brakes, wheel speed sensors are needed on all wheels. Refer to **Figure 82-4**.

The ***sensor rotor***, or ***trigger wheel***, is a toothed ring that rotates with the wheel hub. The magnetic sensor tip is located next to the sensor rotor teeth. Only a small ***air gap*** separates the sensor tip from the spinning teeth.

As the tire and wheel rotates, the sensor rotor spins. As each rotor tooth passes the sensor, the magnetic field around the sensor is affected. This induces a weak ac signal in the wheel sensor coil, **Figure 82-4**.

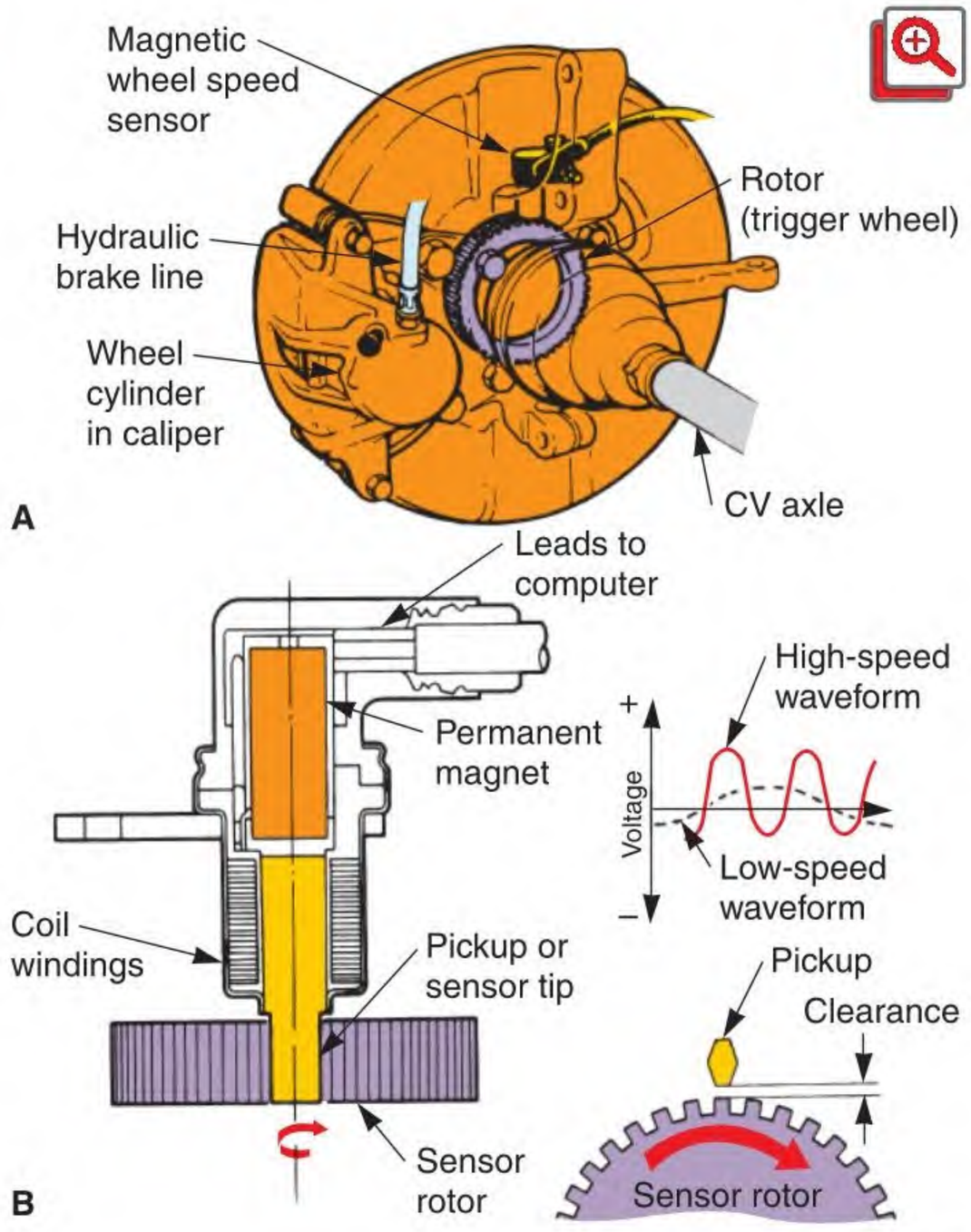
The frequency of this wheel speed sensor's ac signal depends on tire and wheel speed. As the tire rotates faster, a higher frequency signal is sent back to the ABS control module. If tire rotation slows, a lower frequency signal is almost instantly fed to the ABS control module.

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Figure 82-3. Note basic parts of an anti-lock brake system. Sensor rotors are mounted on each spindle. Magnetic sensor coils produce an ac signal that equals wheel speed. The ABS control module can detect if one or more wheels are skidding because the sensor signal will decrease in frequency. The control module can then trigger the electro-hydraulic modulator to cycle hydraulic pressure to keep the tires from skidding and losing traction.



Saab

Figure 82-4. Study how a wheel speed sensor generates weak ac signal for the ABS control module. A—Wheel speed sensor is mounted next to the sensor rotor. As the tire rotates, teeth on the rotor make the magnetic sensor produce a 1.5-volt ac signal for the ABS control module. B—Current is induced in the sensor windings as teeth pass the sensor. Note the waveform. Specific clearance is needed between the sensor and rotor teeth if the sensor is to generate the proper voltage signal.

The ac signal is used by the ABS control module to check for tire skid. A rapid decrease in sensor ac signal frequency would indicate that a tire is starting to lock up and skid. The control module would then send an electrical signal to the electro-hydraulic modulator to pulsate hydraulic pressure to the affected wheel cylinder. Study **Figure 82-5**.

ABS Control Module

The ***ABS control module*** is a small computer that uses wheel speed sensor inputs to control the operation of the electro-hydraulic modulator. It is constructed and operates like the other control modules discussed in this book. See **Figure 82-6**.

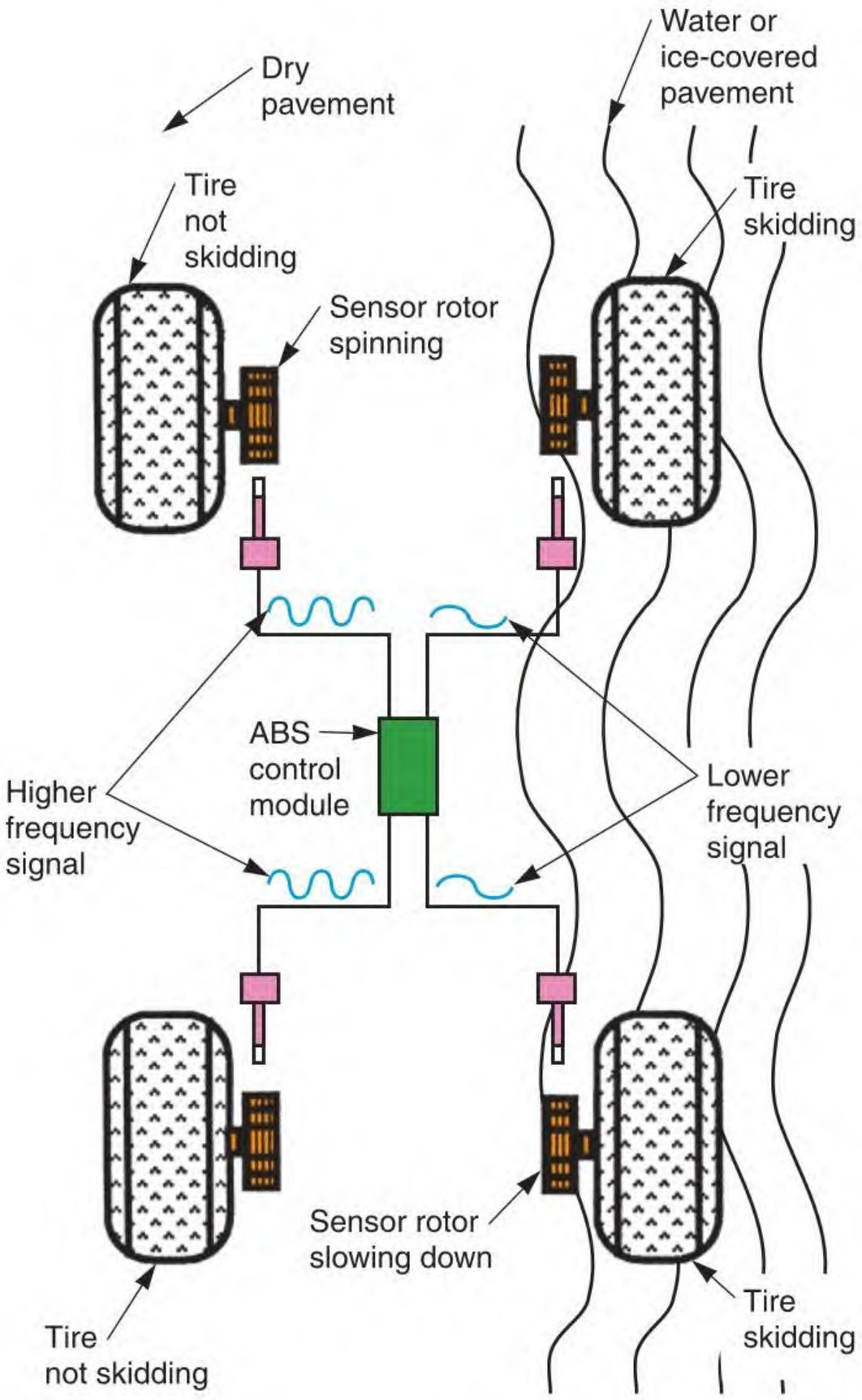
ABS Electro-Hydraulic Modulator

The ***ABS electro-hydraulic modulator***, also called an ***ABS actuator***, regulates the fluid pressure applied to each wheel brake assembly during periods of hard braking. The modulator is controlled by the ABS control module. It is often mounted on the firewall in the engine compartment or somewhere in the passenger compartment, **Figure 82-7**.

The following are major parts of an ABS modulator:

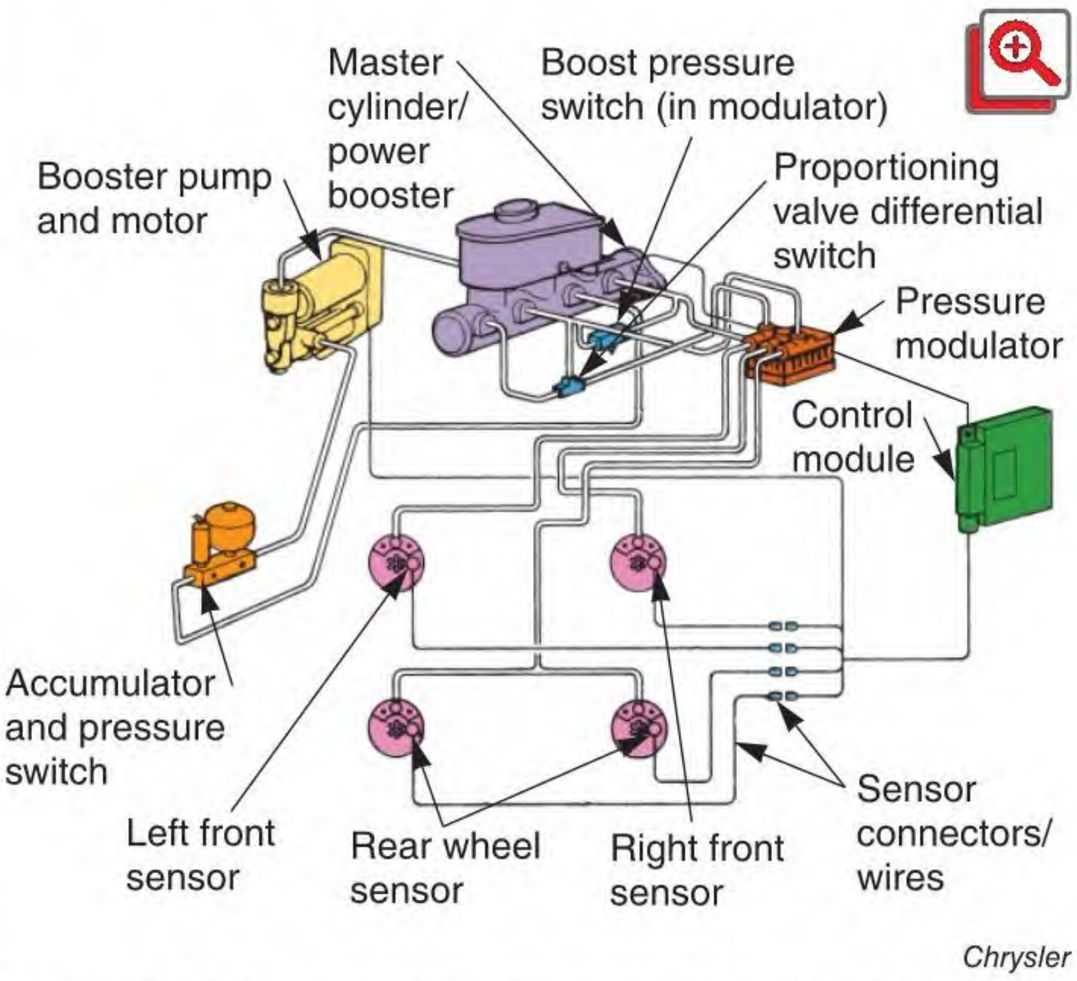
- ***Brake fluid reservoir***—The brake fluid reservoir is a container for holding an extra supply of brake fluid. See **Figure 82-8**.
- ***Brake solenoid valve block***—The brake solenoid valve block is an electro-hydraulic device that contains coil-operated valves that control brake fluid flow to each wheel brake cylinder.
- ***Brake accumulator***—The brake accumulator is a chamber for storing extra fluid under high pressure.
- ***Brake fluid pump and motor***—The brake fluid pump is a high-pressure pump operated by a small electric motor; it provides brake fluid pressure for the ABS system.
- ***Brake pressure switch***—The brake pressure switch is a sensor that monitors brake fluid pres-

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Figure 82-5. Study how the frequency of the signal from the skidding tires is lower than the frequency from the tires that are rotating on dry pavement. This is how the ABS control module detects when a tire or tires are skidding to control hydraulic pressure to those wheel cylinders.



Chrysler

Figure 82-6. An accumulator stores an extra supply of fluid under pressure to increase fluid cycling rates and volume. An electric motor–driven pump produces pressure assist for this ABS system.



Snap-on Tool Corp.

Figure 82-7. ABS modulator, or electro-hydraulic unit, in an engine compartment. Note the wire connections and the brake fluid reservoir.

sure and controls operation of the electric motor for the hydraulic pump.

- ***Brake master cylinder-booster assembly***—The brake master cylinder-booster assembly is a conventional master cylinder with power assist for operating brakes under normal conditions, **Figure 82-9**.

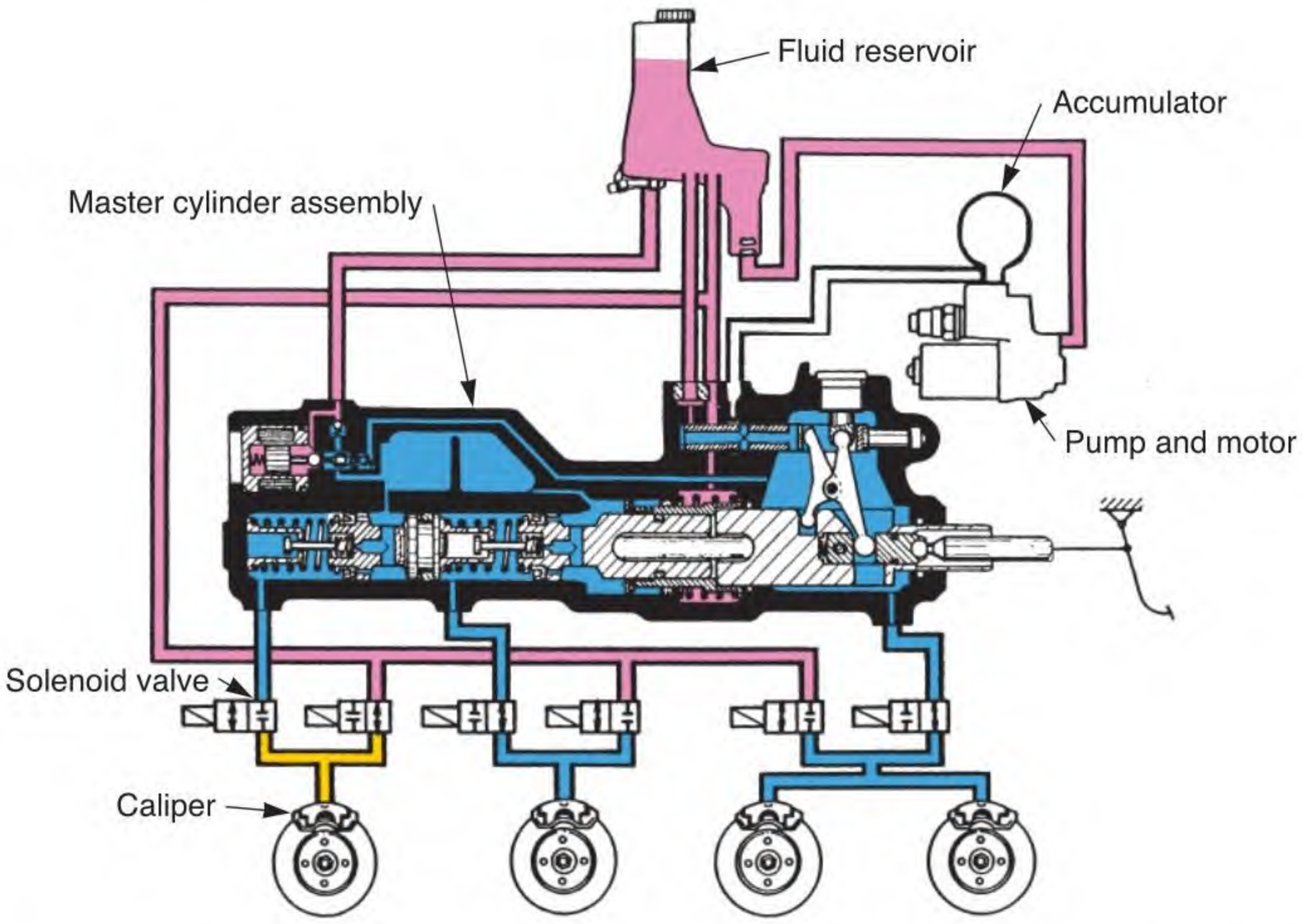
ABS systems and hydraulic modulators vary with the specific make and model of car, van, or truck. However, their operating principles are very similar.

The primary purpose of the electro-hydraulic modulator is to produce hydraulic pressure pulses, or modulations.

An ***integrated ABS*** combines the power booster, master cylinder, and modulator units into one assembly. All these units are mounted together.

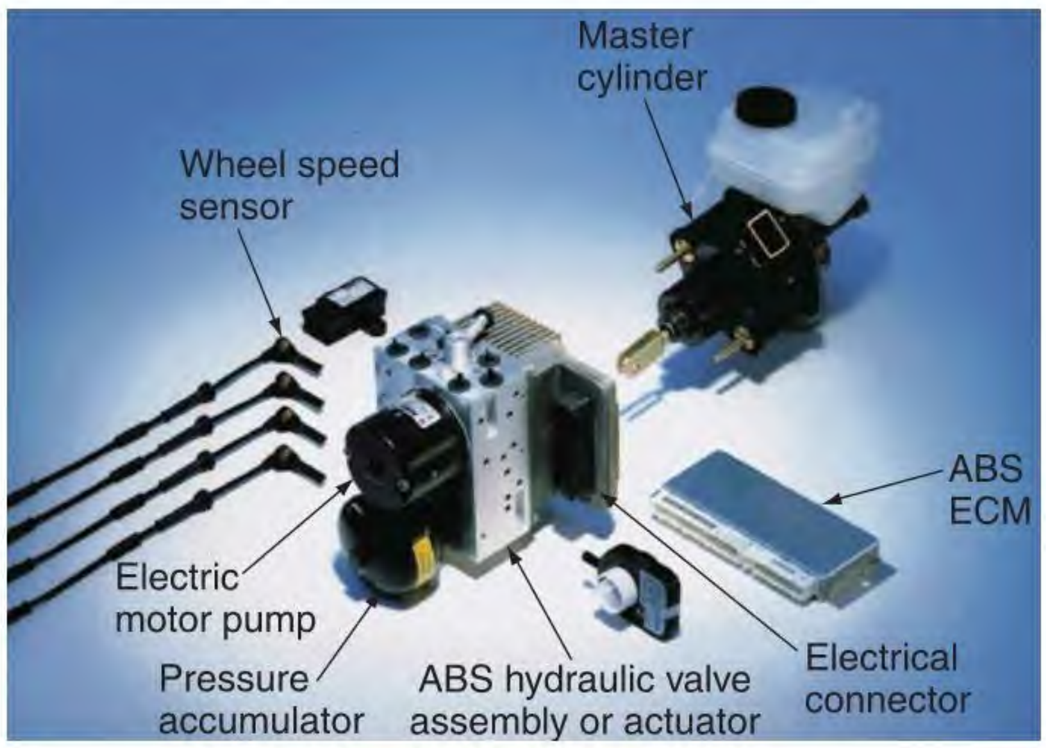
In a ***nonintegrated ABS***, the major units are separated. A conventional booster and master cylinder are used with a separate electro-hydraulic modulator.

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Saab

Figure 82-8. Study this variation of an ABS system. Note how the system is blocking pressure to one of the wheel cylinders to keep the brakes from locking and causing the tires to skid. Solenoid valves are positioned in the brake lines to the wheel cylinders.



Bosch

Figure 82-9. Study the major parts of an anti-lock brake system. The hydraulic actuator has solenoid-operated valves that can reduce pressure to each wheel brake assembly. It is frequently mounted on the brake master cylinder assembly.

Hydraulic pressure modulation refers to the electro-hydraulic unit's ability to rapidly cycle pressure to the wheel cylinders or calipers on and off, preventing wheel lockup and skidding. Anti-lock systems can modulate the brakes about 15 to 20 times per second.

There are three modes of ABS pressure modulation: the isolation mode, the dump mode, and the reapply mode. In the ***isolation mode***, the ABS control module detects that a tire is starting to skid and energizes the modulator to isolate that hydraulic circuit from the other brake lines. The nonskidding wheel circuits work normally, but the ABS takes over the one hydraulic circuit with the slowing wheel.

In the ***dump mode***, the ABS releases hydraulic pressure to one or more of the brake wheel cylinders or calipers. This is done to stop tire skidding. Wheel circuits work normally, but the ABS takes over. The ECM will energize a solenoid that redirects brake fluid pressure away from the wheel brake assembly.

In the ***reapply mode***, the ABS applies hydraulic pressure to one or more of the wheel brake assemblies. This is done to reapply the brakes during pressure modulation.

These three control modes (isolation, dump, and reapply) happen in milliseconds (thousandths of a second). Several brake pumping cycles occur each second. This is much faster than a human could manually pump the brakes.

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Tech Tip

With hydraulic pressure modulation, the driver can actually feel and sometimes hear the brake pedal pulsing up and down or vibrating. This is caused by the modulator unit cycling pressure on and off, trying to reduce tire skid. This is a basic way to check to see if the system is functioning.

ABS Warning Light

An ***ABS warning light*** is mounted in the dash. This light is used to alert the driver to an ABS malfunction. It is important to note that the light generally glows during engine cranking and stays on for several seconds after the engine starts. This lets you know that the system is armed and functioning.

ABS Channels

An ABS ***channel*** is a separate hydraulic circuit that feeds out to one or more wheel cylinders or caliper pistons. Anti-lock brake systems can have from one to four channels.

A ***one-channel ABS*** normally operates the rear wheel brakes together. Only one channel is provided for both rear wheels. The front wheel brakes are not controlled by the ABS in a one-channel system. This was one of the earliest types of ABS.

A ***two-channel ABS*** has two separate hydraulic circuits controlled by the electro-hydraulic modulator. For example, with rear-wheel ABS, each rear brake has its own hydraulic control circuit. Pickup trucks sometimes use two-channel ABS, because the rear of the vehicle is considerably lighter than the front. Help is needed to keep the rear wheels from skidding because there is less weight pressing down on the rear tires.

A ***four-channel ABS*** has a separate hydraulic control circuit for each wheel. This is the most effective and common anti-lock brake system found on late-model vehicles. It can keep any one of the four tires from skidding.

ABS Operation

Under normal braking conditions, ABS is not used. The master cylinder reacts to brake pedal movement. It sends fluid pressure to each wheel cylinder without ABS intervention. A proportioning valve, like the one found in conventional braking systems, is commonly used to reduce pressure to the rear brakes.

If the brakes are applied in a panic stop and a wheel begins to lock up, the ABS is activated. The wheel sensor on the slowing wheel instantly reduces the frequency of the ac signal sent to the ABS control module. The control module detects that the wheel is slowing down more than the others and is getting ready to slide or skid. The module then sends an electrical current to the correct solenoid on the electro-hydraulic modulator assembly to bleed pressure from that channel.

With many designs, when current is sent to the solenoid, the solenoid opens a valve to reduce the pressure to the brake cylinder with the slowing wheel. The ABS control module quickly cycles the current to the solenoid on and off, artificially "pumping the brakes" to keep the tire from skidding and losing traction.

When ABS takes over, the brake pedal will usually rise or drop and vibrate slightly. This is due to the pressure entering the system from the accumulator or pump and from the cycling of the solenoid valves. This is normal and will stop when ABS is no longer functioning.

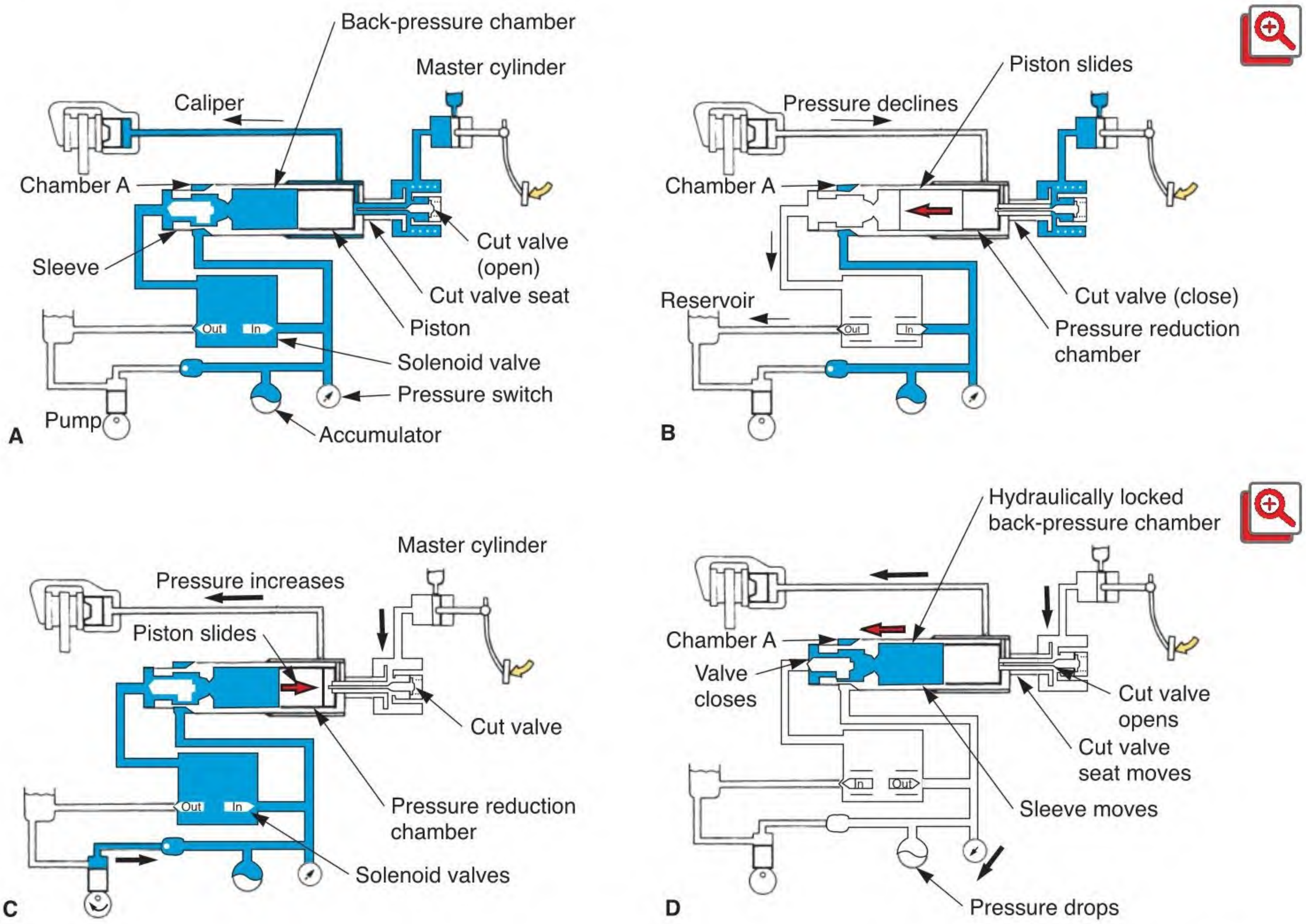
When hydraulic pressure in the system drops below a specific point, the pressure switch closes and energizes the electric motor. This drives the pump to build pressure back up. Once pressure is normal, the pressure switch opens and the motor and pump shut off.

If an ABS component malfunctions, the ABS control module will detect an abnormal condition. It will then light the ABS warning light in the dash and deactivate the ABS. The brake system will still function normally, but without the anti-lock feature. The operation of an anti-lock brake system is shown in **Figure 82-10**.

Tech Tip

Warn new drivers that they should not pump the brake pedal on a vehicle equipped with ABS. This can prevent the system from functioning. Instruct them to apply hard, steady pedal pressure so that the ABS can modulate, or "pump," the brakes. For the experienced driver, this can take time to learn.

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Honda

Figure 82-10. Study the operation of an anti-lock brake system. A—ABS is not functioning. Master cylinder pressure flows to the caliper normally. B—ABS starts working to avoid a skid. The system operates the solenoid valve to close the inlet valve and open the outlet valve. High pressure is released to the reservoir. This reduces pressure to caliper, allowing that wheel to turn and not skid. C—ABS increases caliper pressure to maintain stopping action. The solenoid inlet valve is opened and the outlet valve is closed. High-pressure brake fluid is then sent to the back-pressure chamber and the piston slides to increase pressure to brake caliper. D—The ABS control unit monitors pressure in the high-pressure passage by means of a pressure switch. The control unit turns on the ABS warning light. The sleeve moves and hydraulically locks the back-pressure chamber. This connects the master cylinder to the caliper for normal braking again.

Traction and Stability Control Systems

As mentioned, traction control systems are designed to prevent the vehicle's wheels from spinning and losing traction under hard acceleration. Most traction control systems work with the anti-lock brake system to cycle hydraulic pressure to the wheel spinning the fastest. The control module is capable of applying one wheel brake at a time. Some systems also reduce engine power output to reduce skidding.

An indicator light comes on anytime the traction control system is activated. This warns the driver that the tires are losing traction and slipping on the road surface. He or she then knows that the traction control system is trying to limit or prevent this problem.

A stability control system is an advanced system that reduces tire spin upon acceleration and prevents tire skid when cornering too quickly. This system uses more input signals from various sensors to provide greater control over vehicle handling under severe cornering, braking, and acceleration conditions. It is designed to make the vehicle more stable under

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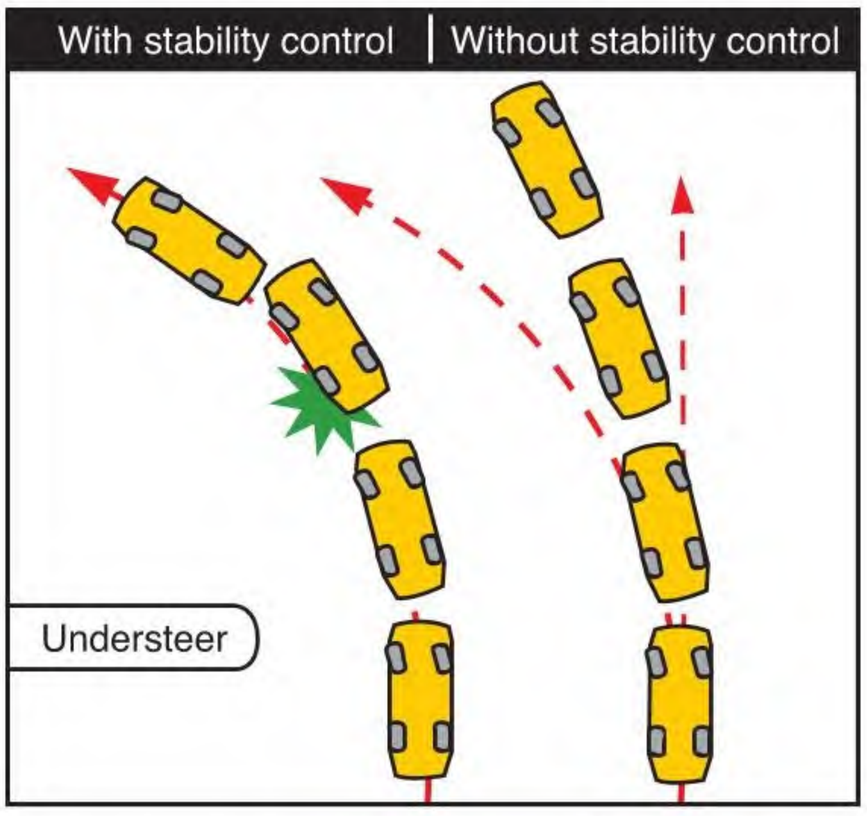
emergency handling situations, such as when trying to avoid a collision.

If ***understeer*** is detected (front tires lose adhesion with the road in a turn), the control module will apply braking force to the inside rear wheel. This will help bring the front of the vehicle back under control for making the turn. See **Figure 82-11**.

If the stability control system detects ***oversteer*** (rear tires lose adhesion with the road surface and slide sideways), additional braking force is automatically applied to the outside front wheel. This helps correct the oversteer so the rear of the vehicle does not spin out or slide sideways in a sharp turn. Refer to **Figure 82-12**.

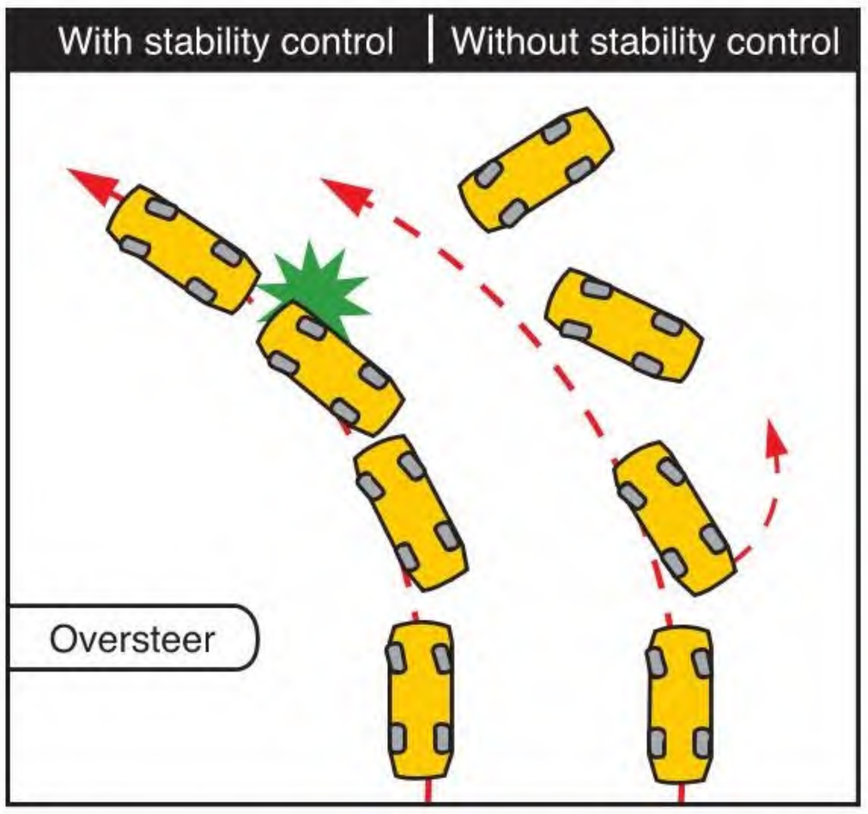
In addition to the wheel speed sensors, a stability control system may use inputs from the following sensors:

- ***Steering angle sensor***—The steering angle sensor measures how sharply the steering wheel is rotated to the right or left.
- ***Lateral acceleration sensor***—The lateral acceleration sensor measures how much side force is generated by a turn.
- ***Yaw sensor***—This sensor measures the direction of the thrust generated by vehicle movement.
- ***Throttle position sensor***—The throttle position sensor measures how far the driver has pressed down on the accelerator to control engine power output.
- ***Brake pressure sensor***—This sensor measures the amount of hydraulic pressure produced by the driver pressing on the brake pedal.



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Figure 82-11. With an understeer problem, the stability control system might apply the left rear brake to keep the front of the vehicle from sliding or drifting to the right in a left-hand turn.



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Figure 82-12. With an oversteer problem, the stability control system can apply the right front brake to keep the rear of the vehicle from sliding around in a left-hand turn.

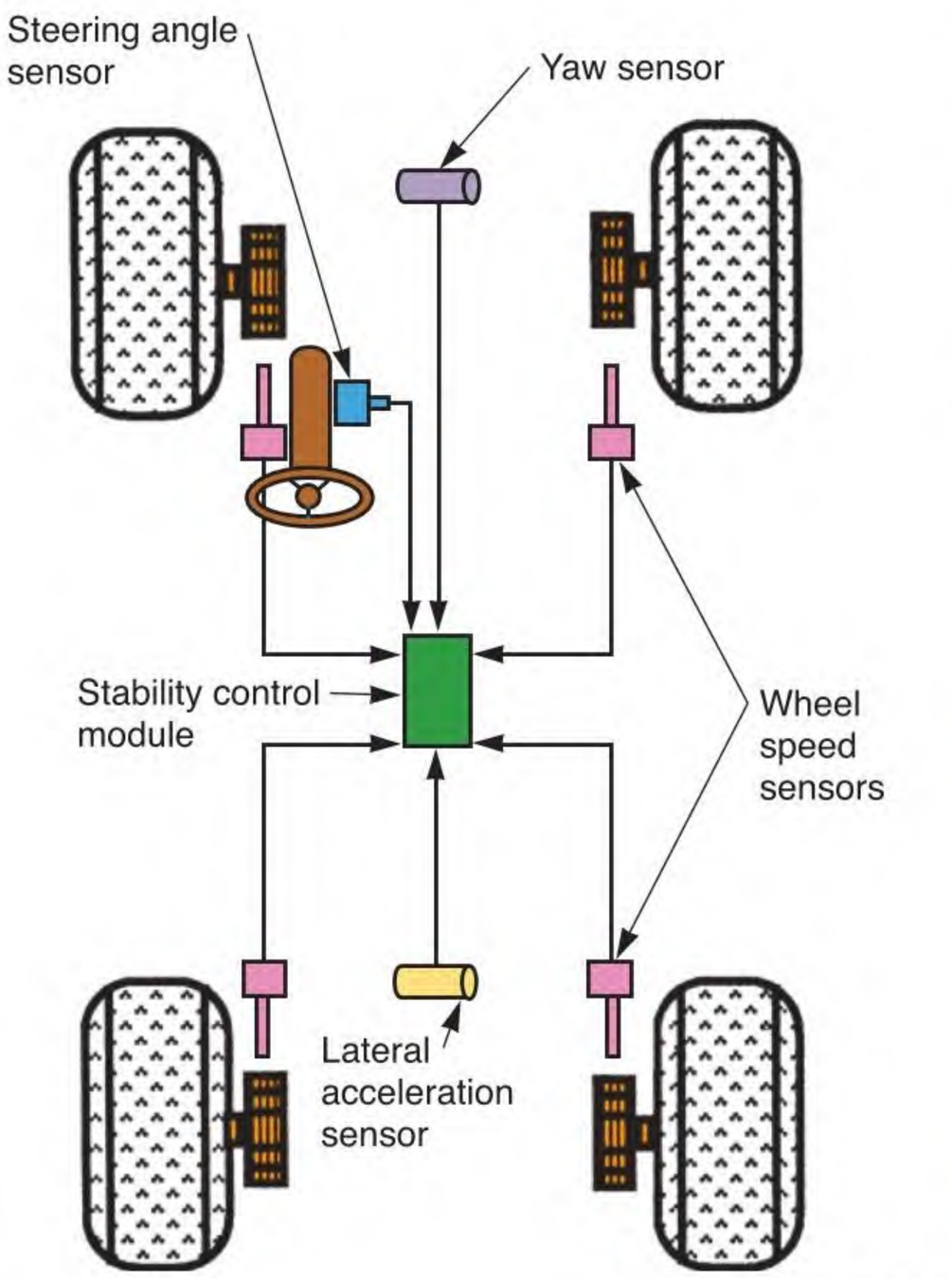
- ***Other sensors***—These sensors give the control module information about the driver's actions and the resulting vehicle motion.

These sensors help the control module determine if the vehicle is skidding out of control, so corrective action can be taken. The control module is programmed to know when the vehicle is near its maximum rate of directional change. If this limit is reached, the system activates, **Figure 82-13**.

The control module is preprogrammed to apply one or more of the wheel brakes. It can also decrease or increase engine power to maintain vehicle control. If the driver rotates the steering wheel hard right for a sharp turn, the steering angle sensor signals the stability control module. The control module calculates how fast each wheel should be turning. The inside wheels should be spinning more slowly than the outside wheels because they are traveling less distance in the turn.

For example, the control module can use sensor signals to determine if the vehicle is following its intended direction of travel. The module calculates the frequency that each speed sensor should produce as the steering wheel is turned. If one or more of the wheels are not spinning at the right speed (skidding on road surface), the control module can react within 40 milliseconds to take corrective action. It might cut engine power slightly and apply one of the wheel brake calipers to reduce skidding.

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Figure 82-13. Note the extra sensors that are used in a stability control system.

Tech Tip

When driving a vehicle equipped with a stability control system, a common mistake is to try to counter-steer the vehicle out of a skid when turning. This often causes overcorrection. It is best to continue steering in the desired direction of travel, allowing the system to correct the skid. This is similar to getting used to driving a vehicle with anti-lock brakes.

ABS Service

Before servicing an anti-lock brake system, you should be familiar with how a normally operating system works and feels. Become familiar with the pedal pulsations that occur when the ABS is activated. Test-drive known good vehicles with the same type of ABS. Memorize how the pedal bumps when ABS is first activated and how it vibrates as the system modulates. This will let you quickly detect some problems because you will know when the system in question does not "feel right."

You should also be familiar with the exact type of ABS being repaired. Since designs and repair procedures vary, read the service manual for the vehicle at hand. This will give you the information needed (diagnosis charts, part locations, specifications, procedures, etc.) to perform competent repair work.

Warning

ABS systems can retain high hydraulic pressure even when the vehicle is shut off. To prevent injury, you must relieve this pressure before disconnecting any part of the hydraulic system! Many manufacturers recommend pumping the brake pedal a minimum of 40 times with the ignition key in the off position to release the pressure. Other manufacturers require the use of a dedicated tool to relieve system pressure. Refer to the service manual for factory recommended procedures.

ABS Inspection

To begin anti-lock brake system diagnosis, make a visual inspection of all the major parts. Look for obvious problems that could affect braking action. In addition to inspecting for conventional troubles, check for the following:

- ABS indicator light on.
- Low or contaminated brake fluid.
- Brake fluid leaks, especially at the modulator seals, gaskets, and lines.
- Worn or damaged brake pad linings and rotors.
- Tires that will not rotate freely.
- Loose or worn wheel bearings, which could affect wheel speed sensor operation.
- Badly worn tires or tires of unequal size, which could upset ABS operation.
- Damaged or improperly mounted speed sensors and trigger wheels.

Based on your findings, determine what step should be taken next. If the fluid level is low, check more closely for leaks. If one set of brake pads is worn down, make sure that the corresponding wheel is not dragging. Use common sense and your knowledge of ABS operation to help find the source of the trouble.

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Scanning ABS

Late-model anti-lock brake systems have very sophisticated on-board diagnostics. Manufacturers have developed these elaborate self-test capabilities so the technician can troubleshoot and repair ABS with minimum difficulty. A typical ABS diagnostic system can produce over 50 trouble codes to help you find the cause of a malfunction.

When the ignition key is turned, an ABS warning light should glow for several seconds after the vehicle is started and then go off. This lets you know that the system is armed and functioning.

If the ABS light stays on, the ABS control module has detected an abnormal operating condition. This would signal you to use a scan tool to analyze the system and read trouble codes.

On some older vehicles, manufacturers may have specialized testers, or scanners, for their anti-lock brake systems. Follow the operating and service manual instructions when using these tools.

First, use the scan tool to check for a ***code history*** (list of stored codes with the number of times each has occurred). This will let you know how often the problem occurs. It will also let you determine how many different codes have been set in the past.

Next, review all the trouble codes. This may help you quickly find the bad ABS component or circuit. Trouble codes are provided for all major electrical-electronic parts in the system. The scan tool will normally indicate problems with the following:

- Wheel speed sensor circuits.
- ABS warning light circuit.
- System relays.
- Low system voltage.
- Modulator motors.
- Solenoid circuits.
- Brake switch circuit.
- Calibration memory in the ABS control module.
- Other circuits and components.

With many late-model anti-lock brake systems, the scan tool can be used to perform several manual and automatic tests. You can use the scan tool to manually control motors, relays, solenoids, and other ABS parts. The automatic tests are used to check the operation of the modulator. This will let you make sure every part is functioning properly.

You can also use the scan tool to obtain system values (voltage, current, resistance). However, this is only done when a problem is difficult to locate. You can check to see if any value is almost out of specification, but not tripping a trouble code. This will narrow down your diagnosis on "borderline" circuits and components that are causing intermittent problems.

ABS Pinpoint Tests

If your scan tool indicates a malfunction, you must still use pinpoint tests to determine the exact source of the problem. Use a multimeter to check the circuit or component. Compare your meter readings to factory specifications to verify the trouble.

The service manual will give electrical values for all major ABS circuits and components. One example is given in **Figure 82-14**.

ABS Speed Sensor Service

If your scan tool points to a problem with a wheel speed sensor, make sure the sensor is mounted securely. Check that all wire connectors are tight. Also check for chipped or broken trigger wheel teeth. Road debris and improper repair methods can damage the trigger wheel.

If applicable, check the air gap between the speed sensor and its trigger wheel. Use a nonmetal feeler gauge of the specified thickness. See **Figure 82-15**.

A handheld scope will let you check the exact signal output from a suspicious wheel speed sensor. Unplug the wiring to the sensor and connect the scope to the sensor's output leads. To generate a waveform, spin the wheel by hand. Compare the actual sensor waveform to a known good waveform, **Figure 82-16**.

Tech Tip

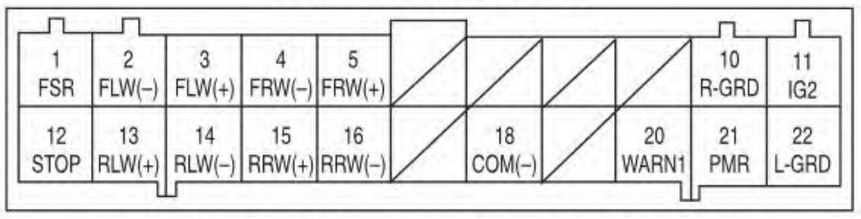
If a pinpoint test of a wheel speed sensor shows no problem but the scan tool indicates a problem, check the wiring between the sensor and the ABS control module. If the wiring is not faulty, suspect the control module.

If the sensor is bad, replace it. Small bolts usually secure the sensor to the suspension knuckle. Clips may be used to secure the sensor wire to the body to prevent wiring damage, **Figure 82-17**.

After installing the new wheel speed sensor, adjust its air gap, if needed, using a brass or plastic feeler gauge. Speed sensor trigger wheels often require major part removal for service.

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22P CONNECTOR



TERMINAL SIDE OF MALE TERMINALS

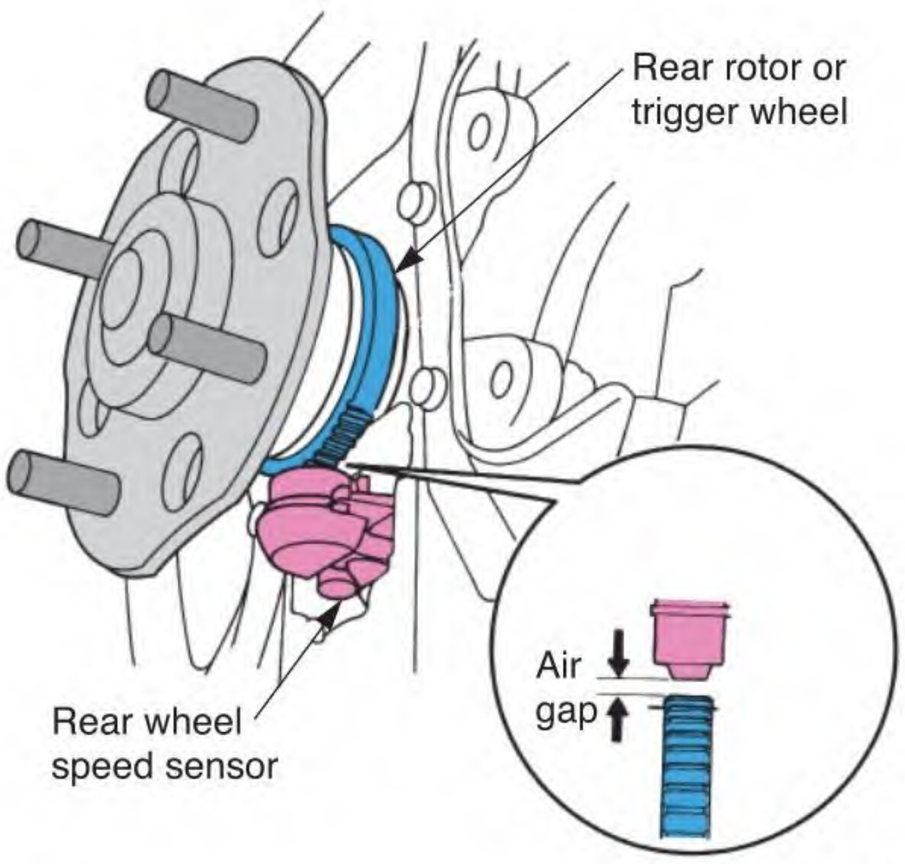
22P Connector NOTE: Standard voltage is 12 V

Terminal number	Wire color	Terminal name	Description	Signal	
1	YEL/GRN	FSR (Fail-safe relay)	Drives fail-safe relay. (Fail-safe relay is turned OFF to shut off the power source to the solenoid when problem occurs.)	ON: 12 V OFF: 0 V	
2	BRN	FLW (–) (Front-left wheel sensor, negative)	Detects left-front wheel speed. (Ground level)	No. 2 - 3 terminals	When the wheel is turned at 1 turn/second: 70 mV or above on digital tester (AC range) (Reference) 200 mVP-P or above on oscilloscope
3	GRN/BLU	FLW (+) (Front-left wheel sensor, positive)	Detects left-front wheel speed.		
4	GRN	FRW (–) (Front-right wheel sensor, negative)	Detects right-front wheel speed. (Ground level)	No. 4 - 5 terminals	
5	GRN/BLK	FRW (+) (Front-right wheel sensor, positive)	Detects right-front wheel speed.		
10	BLK	R-GND (Rear solenoid valve ground)	Ground for rear inlet and outlet solenoid valves.		
11	YEL/BLK	IG2 (IG2 power source)	Detects ignition switch IG2 signal. (When IG2 is input, +B2 power source is switched to the power source for the ABS control unit (Vcc). Also IG2 monitors P-SW and MCK lines, and drives fail-safe relay.)	ON: 12 V OFF: 0 V	
12	GRN/WHT	STOP (Foot brake)	Detects brake switch signal. (Prevents unnecessary ABS operation when the brake pedal is not depressed.)	ON: 12 V OFF: 0 V	
13	LT BLU	RLW (+) (Rear-left wheel sensor, positive)	Detects left-rear wheel speed.	No. 13 - 14 terminals	When the wheel is turned at 1 turn/second: 70 mV or above on digital tester (AC range) (Reference) 200 mVP-P or above on oscilloscope
14	GRY	RLW (–) (Rear-left wheel sensor, negative)	Detects left-rear wheel speed. (Ground level)		
15	GRN/YEL	RRW (+) (Rear-right wheel sensor, positive)	Detects right-rear wheel speed.	No. 15 - 16 terminals	
16	BLU/YEL	RRW (–) (Rear-right wheel sensor, negative)	Detects right-rear wheel speed. (Ground level)		
18	BLK/ORN	COM (–) (Common negative)	Ground for ALB checker when it is connected.		
20	BLU/WHT	WARN 1 (Warning lamp)	Drives ABS indicator light. (Shuts off the indicator light ground circuit inside the ABS control unit to turn off the light when the system is normal.)	Light ON: 0 V Light OFF: 12 V	
21	YEL/RED	PMR (Pump motor relay)	Drives pump motor relay. (Pump motor relay is turned ON to drive the pump motor when P-SW OFF signal is detected.)	ON: 0 V OFF: 12 V	
22	BLK	L-GND (Logic ground)	Ground for the ABS control unit control circuits.		

Honda

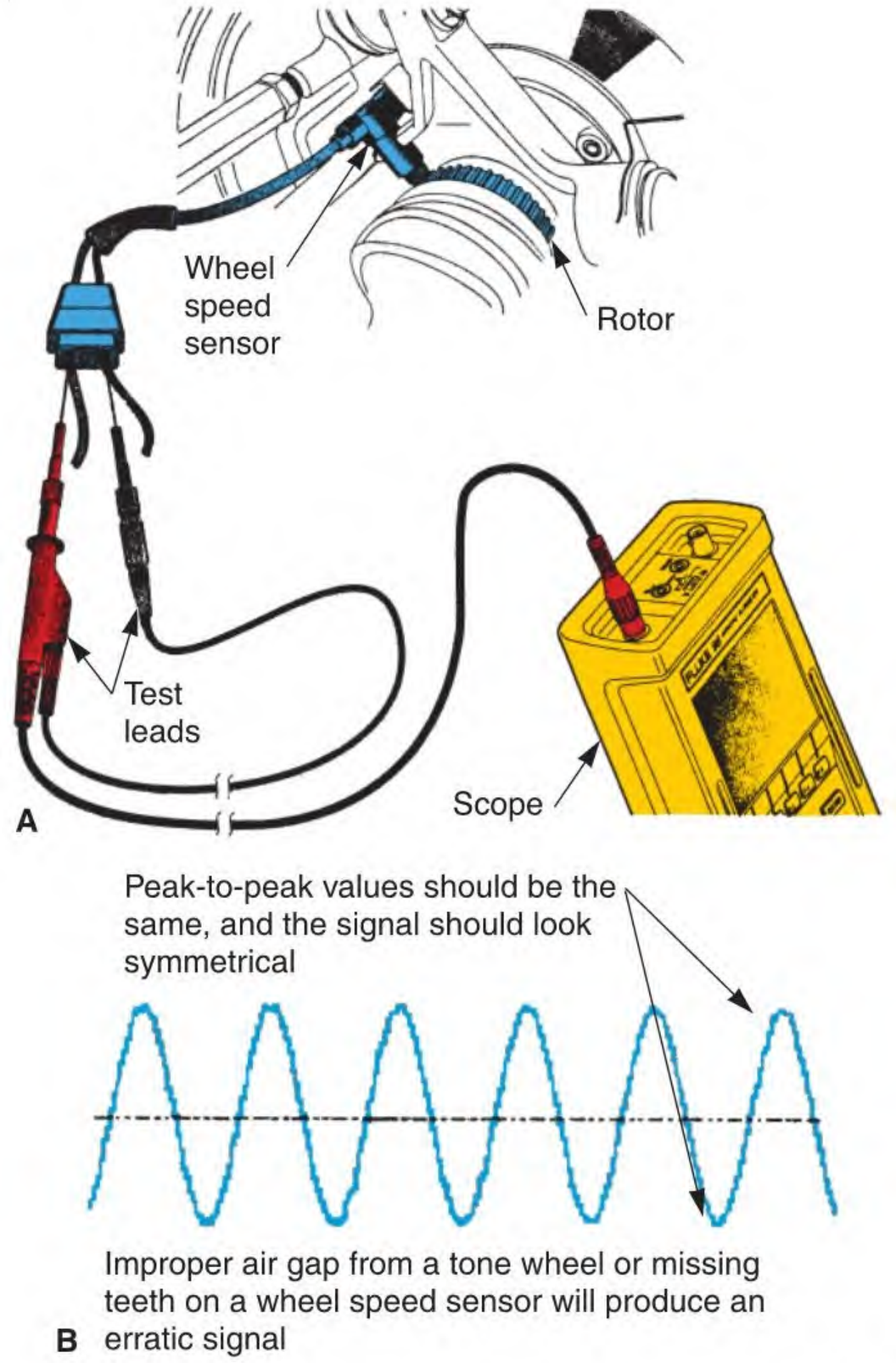
Figure 82-14. A service manual will normally give charts for doing pinpoint tests. Note how this chart gives electrical connector pin numbers, wire color codes, terminal names, circuit descriptions, and terminal specifications.

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Honda

Figure 82-15. Some wheel speed sensors require adjustment of the air gap. The correct size nonmetallic feeler gauge should fit snugly between the sensor tip and the trigger wheel tooth.



Fluke

Figure 82-16. A handheld scope will measure the signal leaving a wheel speed sensor. A—Typical sensor hookup. B—Output signal from a speed sensor. The output should match the reading from the scan tool. If not, a wiring or control module problem is indicated.

Tech Tip

When working on anti-lock brakes, be careful not to damage the wheel speed sensor trigger wheels. When pulling off calipers, axles, and related parts, it is easy to hit and chip one or more of the small teeth on the trigger wheel. When the vehicle is driven again, this would activate a trouble code and require trigger wheel replacement.

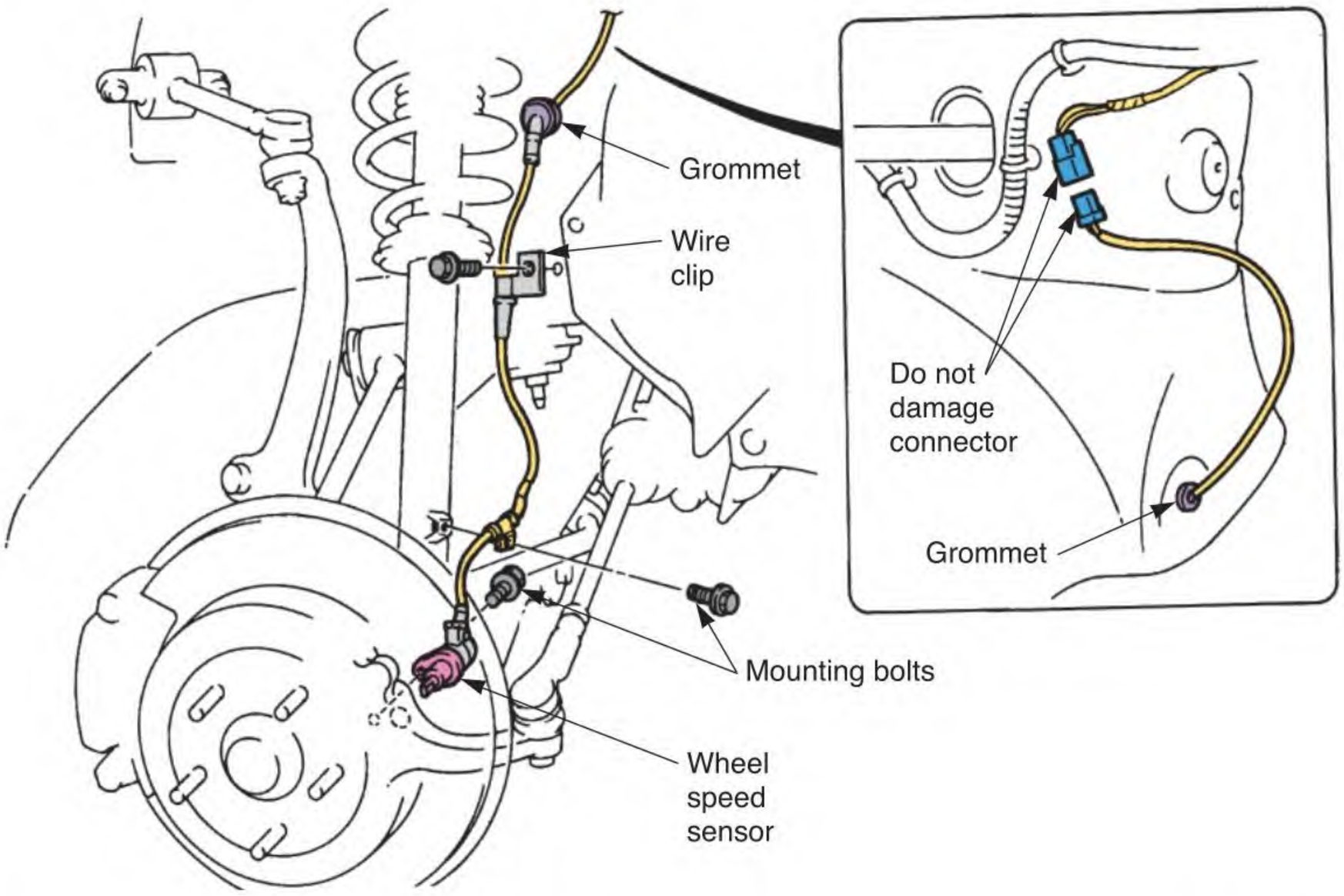
ABS Modulator Check

Service Procedure

Most ABS modulator problems will show up when scanning. However, some automakers allow you to check the modulator in the following manner.

1. Place the vehicle on jack stands so all four tires are equally off the ground, **Figure 82-18A**.
2. Release the parking brake.
3. Rotate each wheel by hand. Make sure none of the wheels are dragging. A dragging wheel indicates that the system might not be releasing hydraulic pressure normally. Brake drag can also be caused by a frozen wheel cylinder, a restricted brake line or hose, and similar sources discussed in the previous chapter.
4. Connect a jumper wire to the correct terminals on the vehicle's diagnostic connector or use the scan tool to energize the modulator to apply hydraulic pressure to one of the wheels, **Figure 82-18B**.
5. Press down and hold the brake pedal while you have a helper make sure that the wheel will not rotate.
6. Using service manual instructions, energize the modulator to dump pressure to the wheel. Make sure the modulator relieves pressure from the wheel cylinder so the tire will rotate freely, **Figure 82-18C**.
7. Repeat steps 4–6 on the other wheels.

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Mazda

Figure 82-17. When replacing a wheel speed sensor, do not damage the electrical connectors and replace any clips that hold the wiring on the body.

This test will check the operation of the modulator, brake tubing, brake hoses, solenoids, relays, ECM, and other major parts. Remember, these are general procedures. Refer to the service manual and scan tool manual for specific instructions.

ABS Modulator Service

If the ABS modulator is faulty, most shops install a new or factory-rebuilt unit. Modulators are very complex and time-consuming to rebuild.

If the vehicle is under warranty, some dealerships repair or rebuild modulators in-house. Make sure the proper rebuild kit is available before starting. Also, compare cost of rebuilding the modulator to the cost of a new or factory rebuilt unit to determine the best course of action.

To remove an ABS modulator, disconnect all wires between the vehicle and unit. See **Figure 82-19**. Then, use a tubing wrench to loosen the brake lines going to the modulator. Remove the bolts that hold the modulator on its brackets. Then, lift the unit out of the engine compartment.

If you are installing a new or rebuilt unit, transfer any necessary parts from the old unit to the new one. These parts might include the combination valve, reservoir, master cylinder (integral units), and brackets. Coat O-ring seals with clean brake fluid to ensure a leakproof seal. Some units have numbered dip-switches (tiny lever switches) that must be set correctly for the make and model car.

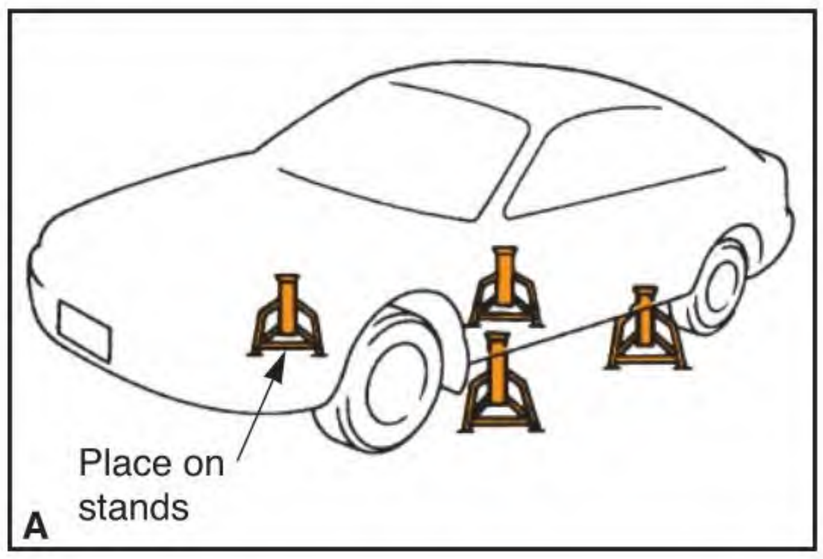
General rules to keep in mind when repairing or replacing an ABS modulator include:

- Always install all parts included in the rebuild kit.
- If a new unit is being installed, make sure it has the correct part number.
- Always lubricate rubber parts with clean brake fluid of the appropriate type.
- Work on a clean, uncluttered workbench to avoid contamination.
- Avoid using compressed air on hydraulic parts. Oil from the compressor may deteriorate rubber parts.
- Prevent brake fluid from contacting electrical connections, painted surfaces, and electronic parts.
- Use correct torque values when tightening fasteners.
- Refer to the service manual for detailed procedures, specifications, and safety precautions.

Regenerative Braking Safety

When servicing regenerative braking systems on hybrid and all-electric drive trains, always keep the

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Mazda

Figure 82-18. Some automakers recommend testing an ABS modulator by energizing the unit and rotating each tire by hand. A—Place the vehicle in level position on jack stands. B—Energize the modulator to free or lock up each wheel as directed in the service manual. C—Rotate each tire by hand to make sure the modulator frees and holds the brake as designed.

12-volt and HV battery disconnected from the ABS control circuit. Pull out the HV battery disconnect; disconnect the 12-volt battery negative cable; and pull off the ABS control module connector, and remove related fuses or circuit breakers to keep all sources of power from reaching the ABS control module.

If you accidentally reconnect battery power to the ABS control circuit, it might perform an automatic pressure test to check for brake fluid leakage. During a pressure test, the ABS pump motor applies full hydraulic pressure to all four brake calipers. If the computer control system performs a pressure test while brake parts are being serviced, high-pressure brake fluid will shoot out any disconnected line or blow out any piston not still over its brake disc. Your fingers could be crushed if the hydraulic piston shoots from its bore at full brake line pressure!

ABS Bleeding

Bleeding an anti-lock brake system of air bubbles can be similar to bleeding conventional brakes or it might require special procedures and tools.

When servicing a master cylinder that is separate from the modulator, plug the brake lines to keep out as much air as possible. Bench bleed the new master cylinder. Then, re-bleed the master cylinder at its lines once it is mounted on the vehicle.

When the master cylinder is formed as an integral part of the modulator, you may need to use a very specific bleeding procedure. An electrical break-out box and an electronic unit might be required to properly energize the solenoids when bleeding some systems. Refer to the service manual when in doubt. See **Figure 82-20**.

ABS Wet Pavement Test

Warning

When test-driving a vehicle that has a malfunctioning or newly repaired ABS, drive slowly and stay out of traffic. Make sure you have adequate braking action before driving on public streets.

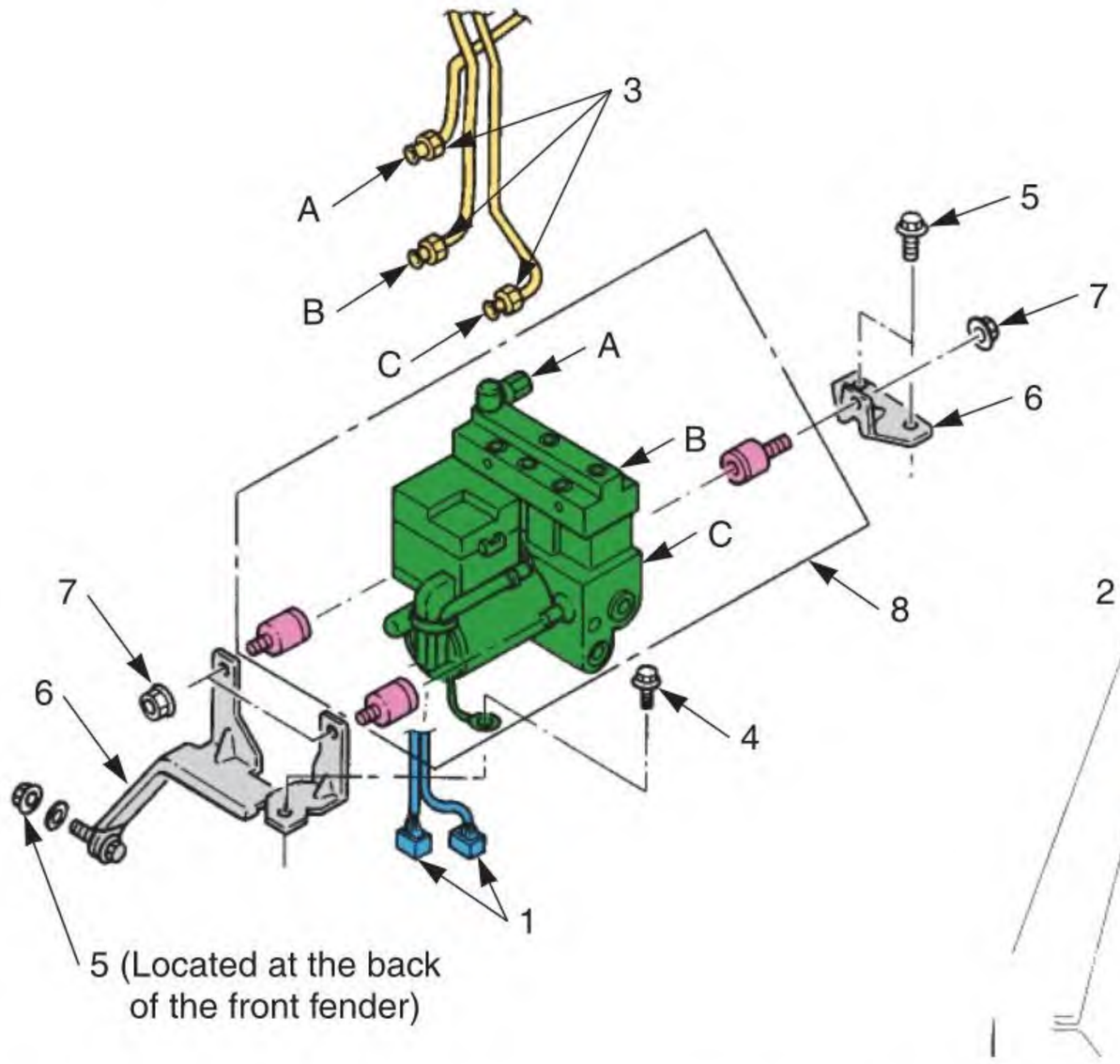
A ***wet pavement test*** can be done to check your repair work or to help pinpoint a problem when all other methods of diagnosis have been exhausted. It verifies the operation of the ABS electronics, as well as all mechanical parts associated with normal braking.

The wet pavement test is performed with two tires on wet pavement and the other two tires on dry pavement. Make sure the vehicle has enough stopping power before testing.

Use a garden hose to wet a small strip of pavement about a foot wide and 20 feet long in an open parking lot. Make sure the lot is large enough to provide ample stopping room if the brakes fail to work normally.

Position the vehicle so that only the right or left tires ride on the wet area. Drive the vehicle across the strip of wet pavement at about five miles per hour. Then, hit the brakes hard to try to make the tires skid on the pavement. Ask a helper to watch the tire contact on the wet pavement and to let you know if either

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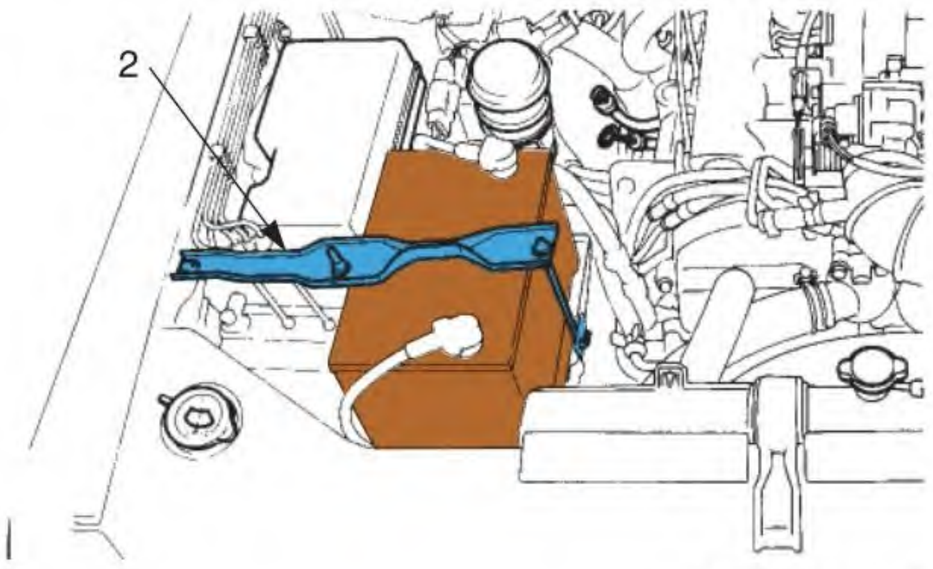


Removal steps

1. Harness connector
2. Battery mounting bar
3. Brake pipes
4. Ground cable bolt
5. Bracket fixing bolt and nut
6. Bracket
7. Hydraulic unit fixing nuts
8. Hydraulic unit

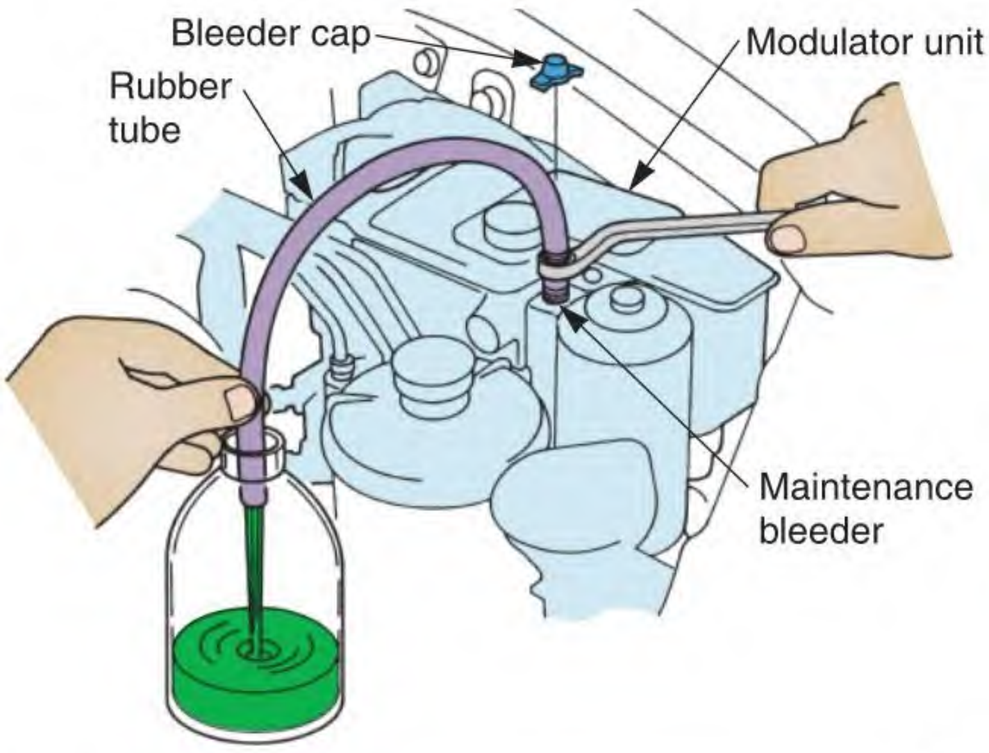
Installation steps

To install, follow the removal steps in the reverse order.



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Figure 82-19. Note the parts that must be disconnected to service a typical ABS modulator.



Honda

Figure 82-20. Special procedures may be needed to bleed all the air from an anti-lock brake system. Follow the manufacturer's instructions for the specific make and model vehicle.

tire is totally locking up or not modulating upon hard brake application. This will let you determine if any wheel is not being controlled by the ABS.

As you brake and two of the tires try to skid, you should feel the pedal modulate. The helper should not see the tires lock up or continue to rotate freely. The ABS system should modulate hydraulic pressure so the tires almost skid.

Repeat this test with the other set of tires on the wet strip of pavement. This will allow you to check modulation on all four wheels.

This test will provide you with useful information about the condition and operation of the ABS. Make sure the ABS indicator light stays off before releasing the vehicle to the customer.

Traction and Stability Control System Service

The diagnosis and repair procedures for traction and stability control systems are similar to the methods described for ABS. You would use an initial inspection and your scan tool to find any obvious problems or trouble codes. If you have trouble codes, use pinpoint tests to verify the problem. After repairs are made, re-scan the system to check your work.

If needed, test-drive the vehicle while scanning to check the action of the traction control system. This should be done in your shop's parking lot or somewhere away from pedestrians and traffic. A gravel surface or wet pavement is best because you can intentionally make the vehicle try to skid upon acceleration. If needed, use a garden hose to wet down an area in your parking lot.

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When on the slick surface, accelerate the vehicle and try to make the drive tires spin. This should activate the traction control or stability control system. You can then use scanner data about the wheel speed sensors, hydraulic unit, engine control module (ECM), and other components to help isolate the problem.

Tech Tip

When the traction control or stability control system energizes, the indicator light should come on and you should usually hear a rapid buzzing or clicking sound from the modulator.

Final System Check

Before releasing a vehicle after ABS, traction control, or stability control system repairs, you should:

- Clear trouble codes and re-scan the system for problems.
- Check the brake fluid level in the system.
- Test-drive the vehicle in an area without traffic.
- Simulate a panic stop several times in a large parking lot.
- Make sure the ABS indicator light stays off.

Diagnostic Case Study

Concern: Mrs. Peterson brings her 2013 Chevrolet Cruze to the shop. She says that her ABS warning light is glowing, but the brakes still seem to be working normally.

Cause: Duff test-drives the vehicle to verify the problem. As Mrs. Peterson explained, the ABS light stays on after the car is started, but the brakes seem to be working properly. Duff connects a scan tool to the vehicle. The trouble code retrieved (DTC C1175) indicates a problem with the speed sensor circuit at the left-rear wheel. Duff turns the repair over to one of the shop's brake technicians.

The technician removes the left-rear wheel to gain access to the sensor. The wires are still connected to the sensor and appear to be in good condition. The technician disconnects the sensor from the harness and uses a scope to check the sensor's output as the hub is rotated. The waveform produced by the sensor is erratic, indicating a problem with the sensor itself or the trigger wheel. Since the sensor and trigger wheel are integral parts of the hub assembly, the technician must replace the entire assembly.

Correction: The technician removes the brake drum and the hub assembly. He installs the new hub assembly and reassembles the other parts in the reverse order of disassembly. After a test-drive to ensure the car's problem has been corrected, the technician releases the vehicle to its owner.

Summary

- ABS uses wheel speed sensors, an ABS control module (computer), an electro-hydraulic brake actuator, and conventional hydraulic brake circuits to prevent wheel lockup during hard braking.
- When the tires skid, they actually lose traction or friction with the road surface. This can increase stopping distance and reduce vehicle control in some situations.
- The wheel speed sensors produce ac signals that correspond to wheel and tire speed.
- The ABS control module is a small computer that uses wheel speed sensor inputs to control the operation of the electro-hydraulic modulator.
- The ABS electro-hydraulic modulator, also called an ABS actuator, regulates the fluid pressure applied to each wheel brake assembly during periods of hard braking.
- Hydraulic pressure modulation refers to the electro-hydraulic unit's ability to rapidly cycle pressure to the wheel cylinders or calipers on and off, preventing wheel lockup and skidding.
- An integrated ABS combines the power booster, master cylinder, and modulator units into one assembly. All these units are mounted together.
- In a nonintegrated ABS, the major units are separated. A conventional booster and master cylinder are used with a separate electro-hydraulic modulator.
- In the dump mode, the ABS releases hydraulic pressure to one or more of the brake wheel cylinders or calipers.
- In the reapply mode, the ABS applies hydraulic pressure to one or more of the wheel brake assemblies.
- A four-channel ABS has a separate hydraulic control circuit for each wheel.

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- Traction control systems are designed to prevent the vehicle's wheels from spinning and losing traction under hard acceleration.
- A stability control system is an advanced system that reduces tire spin upon acceleration and prevents tire skid when cornering too quickly.
- You should also be familiar with the exact type of ABS being repaired. Since designs and repair procedures vary, read the service manual for the vehicle at hand.
- To begin anti-lock brake system diagnosis, make a visual inspection of all the major parts.
- Late-model anti-lock brake systems have very sophisticated on-board diagnostics.
- If the ABS light stays on, the ABS control module has detected an abnormal operating condition.
- With many late-model anti-lock brake systems, the scan tool can be used to perform several manual and automatic tests.
- If your scan tool indicates a malfunction, you must still use pinpoint tests to determine the exact source of the problem.
- If applicable, check the air gap between the speed sensor and its trigger wheel. Use a non-metal feeler gauge of the specified thickness.
- Most ABS modulator problems will show up when scanning. However, some automakers allow you to check the modulator by rotating each wheel by hand while energizing the unit.
- If the ABS modulator is faulty, most shops install a new or factory-rebuilt unit. Modulators are very complex and time-consuming to rebuild.
- Bleeding an anti-lock brake system of air bubbles can be similar to bleeding conventional brakes or it might require special procedures and tools.
- The wet pavement test is performed with two tires on wet pavement and the other two tires on dry pavement.
- The diagnosis and repair procedures for traction control systems are similar to the methods described for ABS.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

ABS
ABS actuator
ABS control module
ABS electro-hydraulic modulator
ABS warning light
air gap
anti-lock brake systems
brake accumulator
brake fluid pump and motor
brake fluid reservoir
brake master cylinder-booster assembly
brake pressure sensor
brake pressure switch
brake solenoid valve block
channel
code history
dump mode
four-channel ABS
hydraulic pressure modulation
integrated ABS
isolation mode
lateral acceleration sensor
nonintegrated ABS
one-channel ABS
other sensors
oversteer
reapply mode
sensor rotor
stability control systems
steering angle sensor
throttle position sensor
traction control systems (TCS)
trigger wheel
two-channel ABS
understeer
wet pavement test
wheel speed sensors
yaw sensor

Activities

1. Inspect the ABS system on several different vehicles. Write down any problems you found on each. Also summarize any differences in part locations or part designs for a class discussion.
2. Scan a late-model ABS system. Unplug some of the wiring connectors in the system and note the scanner readout. Make a report of what you learned.

Review Questions

Answer the following questions using the information provided in this chapter.

1. A(n) _____ system prevents wheel lockup during hard braking.
2. What happens when a tire skids or slides during hard braking?
3. In addition to the brake warning light in the instrument cluster and the sensor trigger wheels, list and describe the four major parts of an anti-lock brake system.
4. In addition to reducing stopping distances, ABS improves driver and passenger safety by increasing _____ under panic stop conditions.
5. The wheel speed sensors produce ac _____ that correspond to wheel and tire speed.

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6. What should a technician do before servicing a regenerative brake system on a hybrid or all-electric vehicle?
7. List and summarize the six major parts of an ABS modulator.
8. Describe the three operating modes of an ABS modulator.
9. Technician A says that most traction control systems work with the anti-lock brake system to cycle hydraulic pressure to the wheel spinning the fastest. Technician B says that stability control systems use more input signals from various sensors to provide greater control over vehicle handling under severe cornering, braking, and acceleration conditions. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. A scan tool is commonly used to troubleshoot a modern ABS. True or False?

ASE-Type Questions

1. For maximum stopping power with anti-lock brakes, you want the tires to:
   (A) skid until the vehicle stops.
   (B) almost, but not quite, skid.
   (C) lock up until the vehicle stops.
   (D) turn alternately left and right until vehicle stops.
2. Technician A says a scan tool will usually test the action of major ABS components by energizing them. Technician B says that a scan tool does not have this capability. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. A car enters the shop with the ABS light glowing. Technician A says to inspect the system for obvious troubles. Technician B says to also use a scan tool to help find the problem. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. All of the following sensors may send inputs to the vehicle's stability control system to determine vehicle skidding and body movement *except:*
   (A) throttle position sensor.
   (B) oxygen sensor.
   (C) brake pressure sensor.
   (D) yaw sensor.
5. Which of the following *cannot* be checked with a scan tool?
   (A) Trouble code history.
   (B) Present trouble codes.
   (C) Brake lining condition.
   (D) Wheel speed sensor circuits.
6. Technician A says that you must set the sensor air gap on some vehicles. Technician B says that the air gap between the sensor and trigger wheel needs to be increased each year the vehicle is in service. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. A scan tool shows a problem with the right front wheel speed sensor circuit. Technician A says that after servicing the sensor, the ABS control module must be reprogrammed. Technician B says to replace the brake master cylinder. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. A new ABS modulator is being installed on a vehicle. Technician A says you may have to transfer the old combination valve to the new unit. Technician B says to coat all rubber parts with clean brake fluid. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. A scan tool shows a problem with the modulator pump motor. Technician A says to check for power to the motor from the ABS control module. Technician B says if no power is reaching the motor to check the wiring between the control module and the motor. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. After completing repairs on a stability control system, you should do all of the following *except:*
   (A) clear trouble codes and re-scan for problems.
   (B) recheck brake fluid level in system.
   (C) test-drive the vehicle slowly in an area without traffic.
   (D) reprogram the control module.

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Section 14

Heating and Air Conditioning Technology

Chapter 83
Heating and Air Conditioning Fundamentals

Chapter 84
Heating and Air Conditioning Diagnosis, Service, and Repair

To the vehicle owner, the heating and air conditioning systems are vital. On a cold winter morning or a hot summer day, these systems keep the passenger compartment comfortable for the vehicle's occupants. If the heating or air conditioning system is not working properly, the passenger compartment can become very unpleasant and so can the customer.

This section explains the operation, service, and repair of heating and air conditioning systems. It details state-of-the-art methods for repairing these systems without damaging our environment. It will also help you pass the ASE Test A7, *Heating and Air Conditioning*.



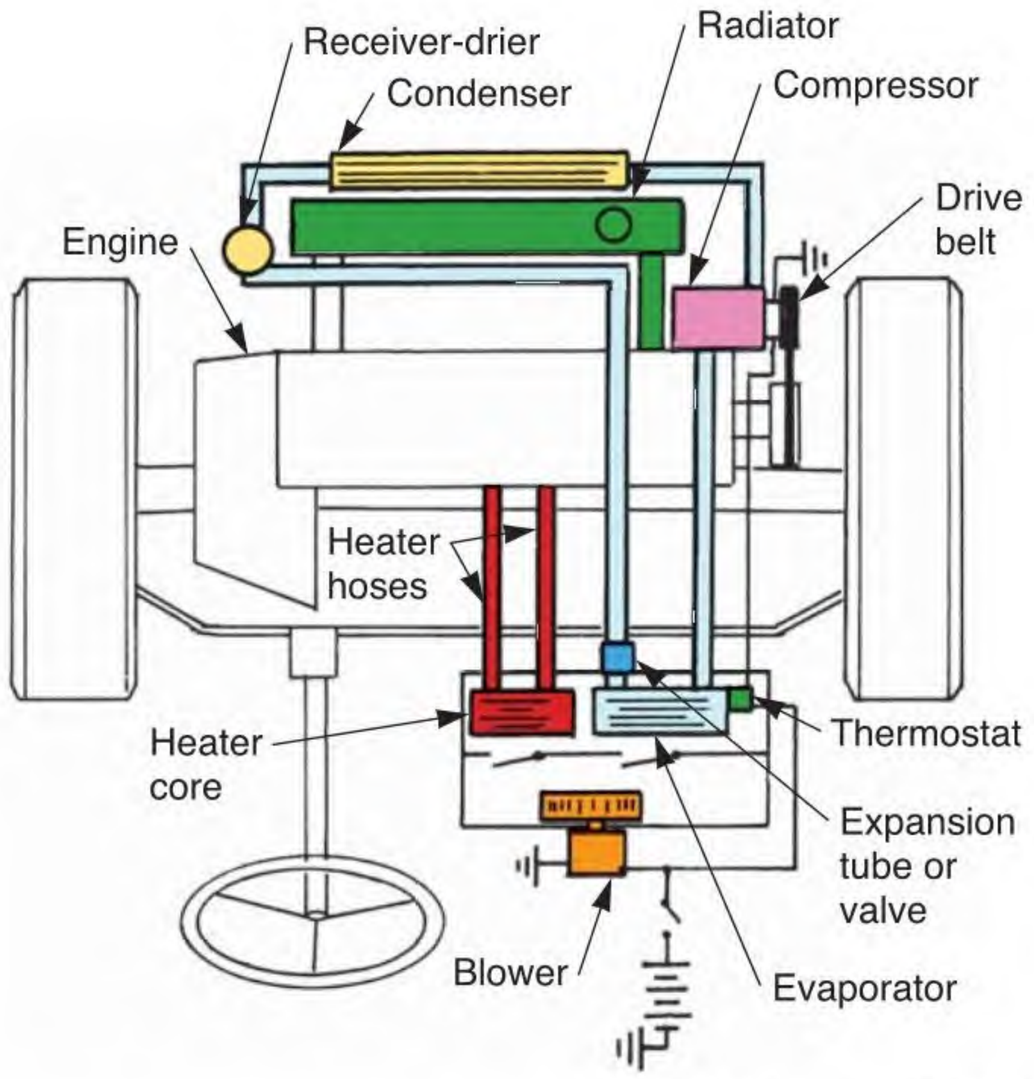
Chapter 83
Heating and Air Conditioning Fundamentals

After studying this chapter, you will be able to:

- Explain the principles of refrigeration.
- Describe the four cycles of refrigeration.
- Describe the high and low sides of an air conditioning system.
- Explain the basic function and construction of each major part of a typical heating and air conditioning system.
- Summarize the operation and interaction of heating, ventilation, and air conditioning systems.
- Describe safety precautions to be observed when working on heating and air conditioning systems.
- Correctly answer ASE certification test questions requiring a knowledge of modern heating and air conditioning systems.

The term "air conditioning" generally means to control the temperature, humidity, and flow of air in the passenger compartment of a vehicle. An automotive ***air conditioning system*** uses a refrigerant system, a heating system, and a ventilation system to provide a comfortable environment in all weather conditions, **Figure 83-1**.

The ***refrigerant system*** uses a confined gas to provide cool, dehumidified (dried) air. The ***heating system*** uses heat from the engine cooling system to supply warm air. The ***ventilation system*** carries fresh outside air into the vehicle. These three systems work together to provide air conditioning.



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Figure 83-1. This top view shows the major parts of an air conditioning system. The heating, ventilation, and refrigerant systems work together to provide passenger comfort.

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Tech Tip

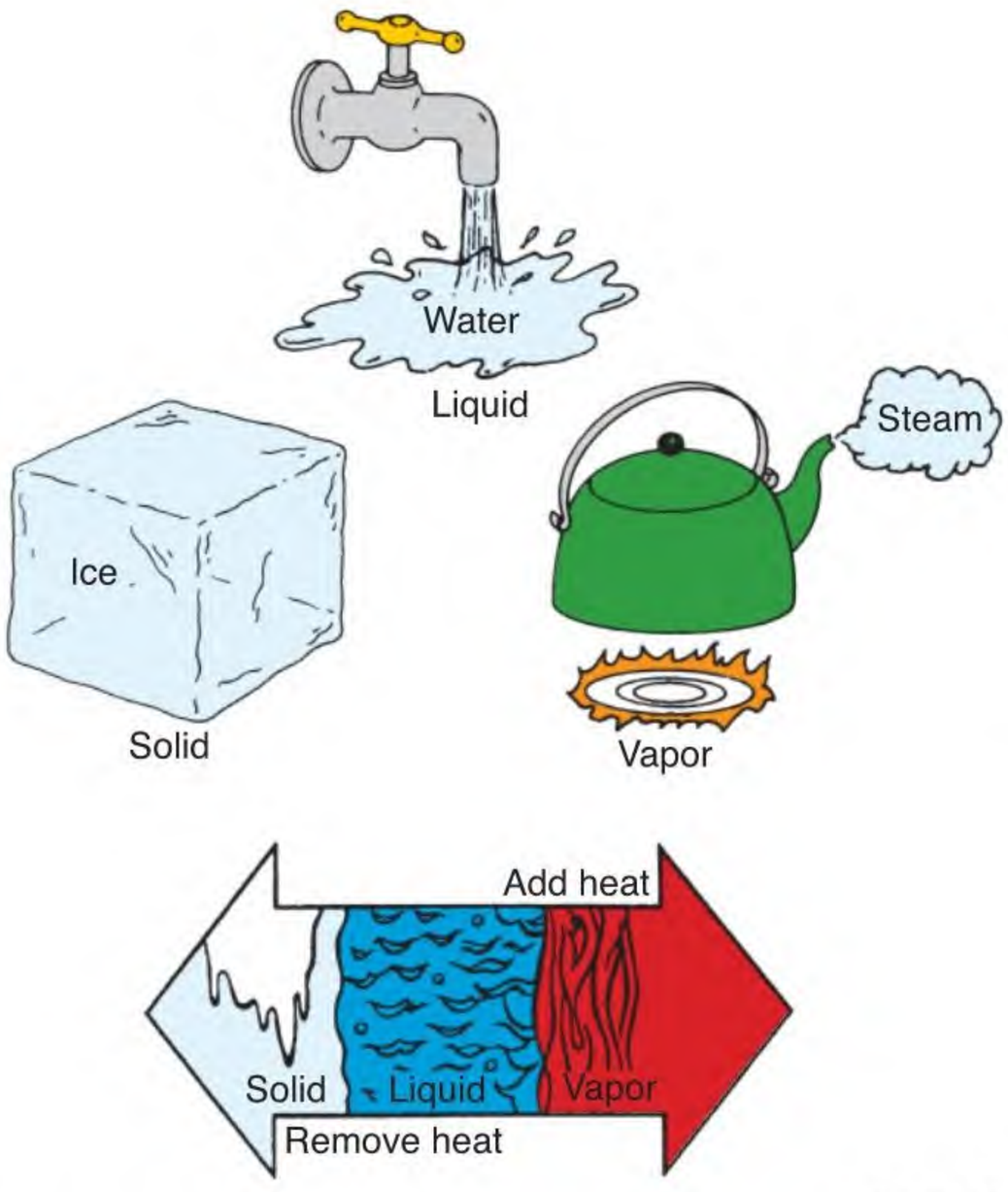
In the trade, the term "air conditioning" is often used to refer to the refrigerant system. Actually, this term refers to all three systems that help control the passenger compartment environment.

Principles of Refrigeration

An automotive refrigerant system (air conditioning) uses the same principles found in a home refrigerator. For this reason, you should understand a few rules that apply to refrigeration before studying actual automotive systems.

States of Matter

There are three basic ***states of matter***: vapor, liquid, and solid. For example, water can exist as a *vapor* (steam), a *liquid* (water), or a *solid* (ice). The temperature of the water controls its state. Look at **Figure 83-2**.



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Figure 83-2. These are the three fundamental states of matter. As temperature changes, the state of matter changes.

Heat and Matter

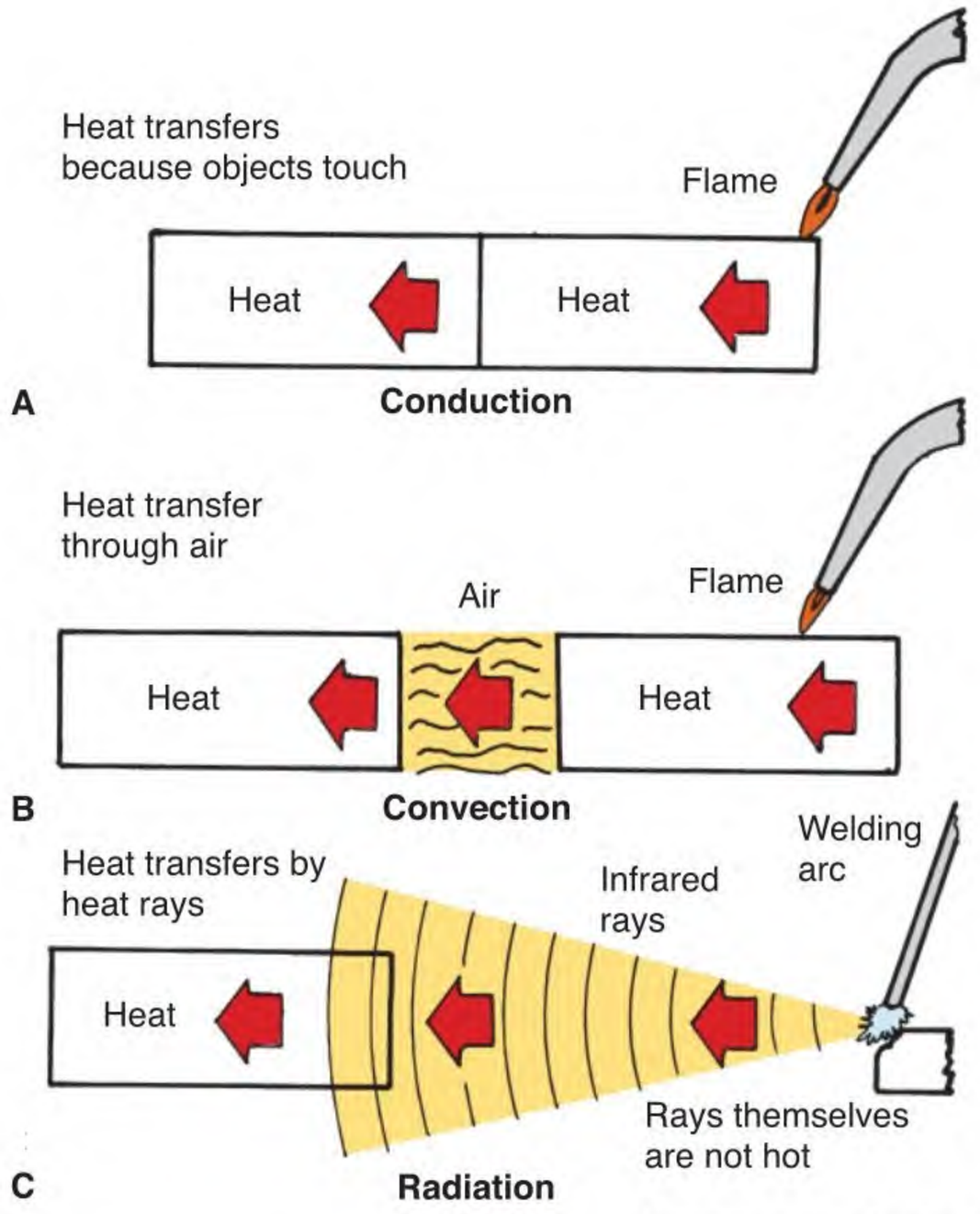
As you can see with the three states of water, heat is a controlling factor in the state of matter. Heat causes increased molecular motion inside a substance. The hotter an object, the faster its molecules move. The colder an object, the slower its molecules move.

At room temperatures, hydrogen and oxygen molecules are fluid and form a liquid. When water is hot enough, its molecules move fast enough to separate, forming a vapor. When water is cold enough, the molecules move slowly enough to join and form a solid chunk of ice.

Methods of Heat Transfer

There are three methods of heat transfer: conduction, convection, and radiation.

Conduction is heat transfer through objects that are touching each other, **Figure 83-3A**. For example, engine combustion heat is conducted into the water jackets through the block and cylinder head. The metal parts of the engine carry or *conduct* heat.



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Figure 83-3. Three means of heat transfer: conduction, convection, and radiation.

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Convection is heat transfer caused by the air surrounding objects. For instance, when air blows through a radiator, heat is convected into the air. Air is the medium of heat transfer, **Figure 83-3B**.

Radiation, the third method of heat transfer, is commonly carried out by infrared waves (rays from the sun, for example). See **Figure 83-3C**. When the sun shines through the windows of a vehicle, interior parts (seats, steering wheel) can become very hot because of heat radiation. Radiant energy moves through space in waves. When the waves strike a solid object, the energy is absorbed by the object. The internal energy in the object's molecules increases, and the temperature of the object rises.

Heat Movement

Heat is caused by rapid molecule movement or excitation. Heat energy always moves from a hotter object to a colder object. Technically, when you hold a piece of ice, the ice does not really cool your hand. Instead, it removes heat energy from your hand. This makes your hand feel cold.

Cold is an absence of heat. Hot and cold are relative (dependent on each other). When one object is colder than another, the colder object simply contains less heat.

Heat Measurement

The ***British thermal unit (Btu)*** is the unit of measure for heat transfer from one object to another. For example, when the temperature of one pound of water increases one degree Fahrenheit at sea level pressure, one Btu of heat has moved into the water. The cooling potential of home air conditioning units is normally rated in Btus.

Vaporization and Evaporation

Mentioned briefly, ***vaporization*** and ***evaporation*** generally refer to a liquid changing into a vapor (gas) state. For instance, boiling water changing into steam (vapor) demonstrates vaporization. Water slowly changing to a vapor while sitting in the hot sun is evaporation. Heat is *absorbed* by the liquid as it changes into a vapor.

Condensation

Condensation occurs when a vapor changes back into a liquid (opposite of vaporization). For example, when water collects on the outside of a cold soft drink bottle on a warm day, moisture has condensed out of the air. Heat is *given off* when a vapor changes into a liquid.

Pressure and Temperature

When pressure is placed on a substance, the temperature of the substance increases—the substance gives off heat. When pressure is removed from a substance, the temperature of the substance drops. The substance absorbs heat (cools). Look at **Figure 83-4**.

Pressure also affects change of state. When a liquid is placed in a closed container and pressurized, its boiling (vaporizing) point increases. For example, the boiling point of water at sea level pressure (14.7 psi [101 kPa]) is 212°F (100°C). However, when the pressure is increased, water's boiling point increases. If pressure is decreased, the boiling point decreases. This principle is true for all substances.

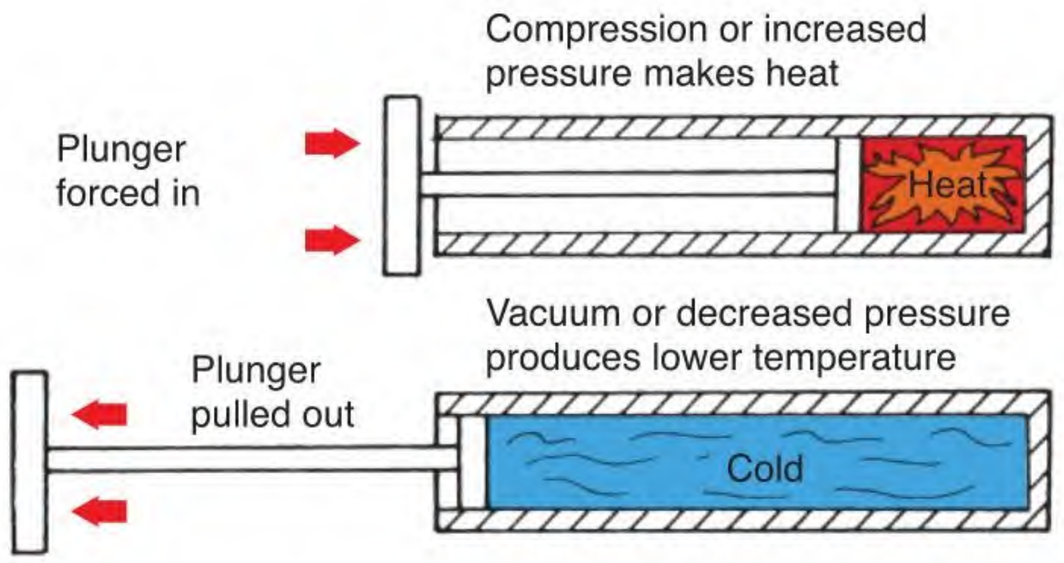
Refrigerant

A ***refrigerant*** is a substance with a very low boiling point. It is circulated through a refrigeration, or air conditioning, system. See **Figure 83-5**.

Refrigerant-12, also called ***R-12*** or ***Freon***, used to be the most common refrigerant. It has a boiling point of 22°F (–6°C) and vaporizes at room temperature and pressure. However, it was determined that R-12 is dangerous to the environment due to a chemical reaction with the atmosphere. R-12 has been phased out and newer vehicles no longer use this type refrigerant.

The ***R-134a*** refrigerant replaced R-12 because it is less damaging to the ozone layer around the earth. Newer cars, vans, and trucks are equipped with refrigerant systems that require the use of R-134a.

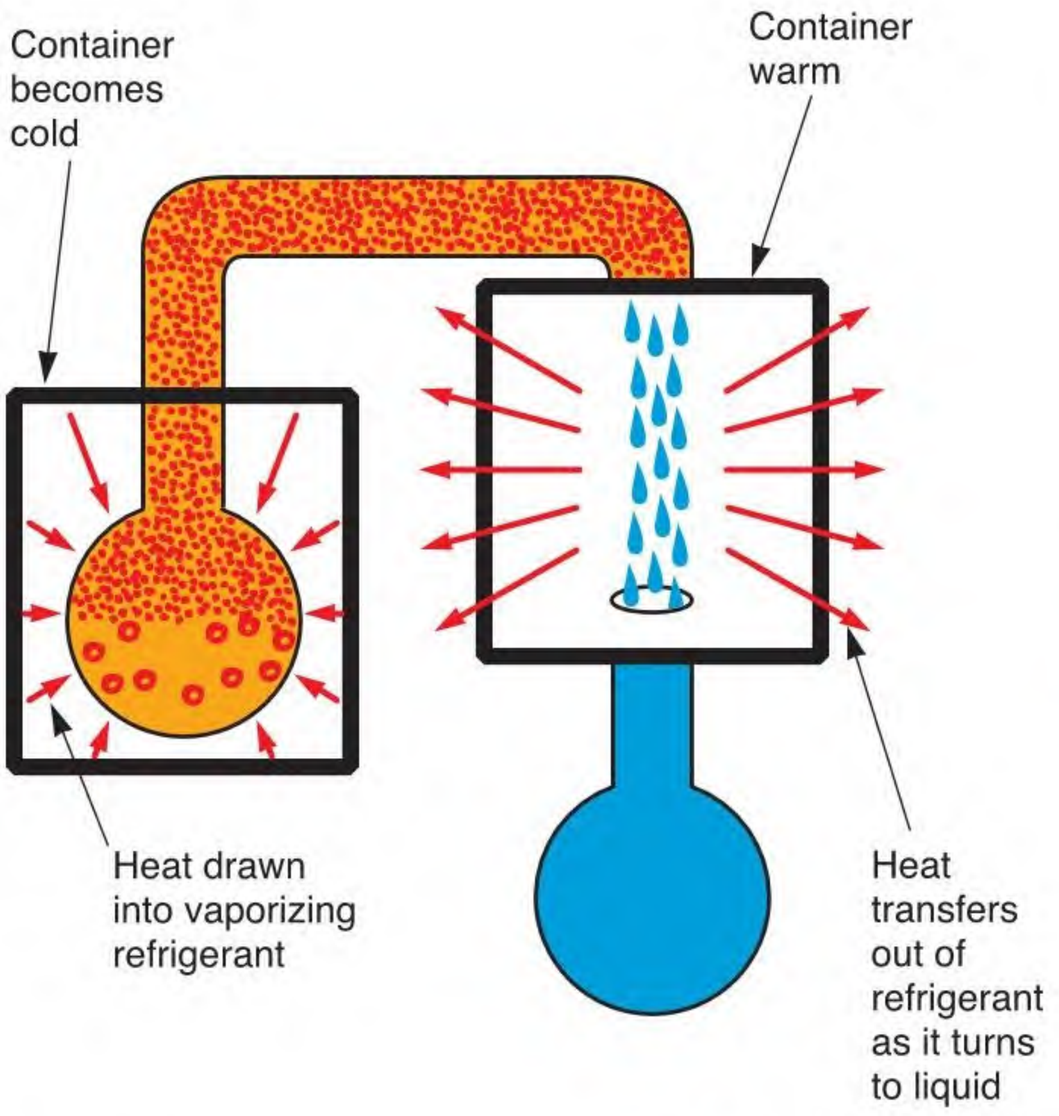
As discussed in the next chapter, several system parts, controls, sensors, tools, and procedures have changed with the newer, environmentally-safe refrigerant.



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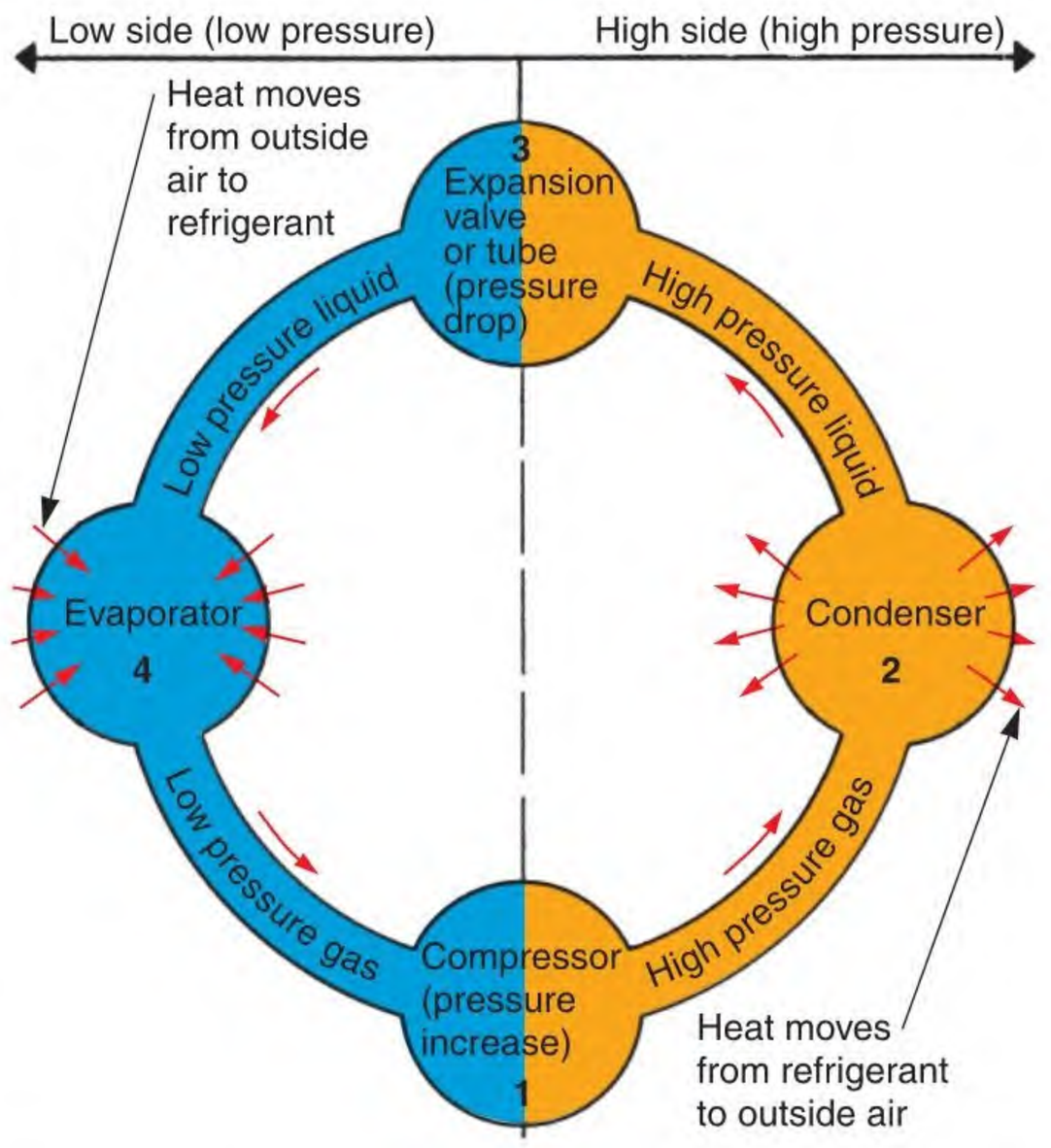
Figure 83-4. Study the relationship between pressure and temperature.

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Figure 83-5. Refrigerant can be used to cool object when it vaporizes. It releases gathered heat when it condenses.



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Figure 83-6. Study this diagram showing the basic refrigeration cycle.

Basic Refrigeration Cycle

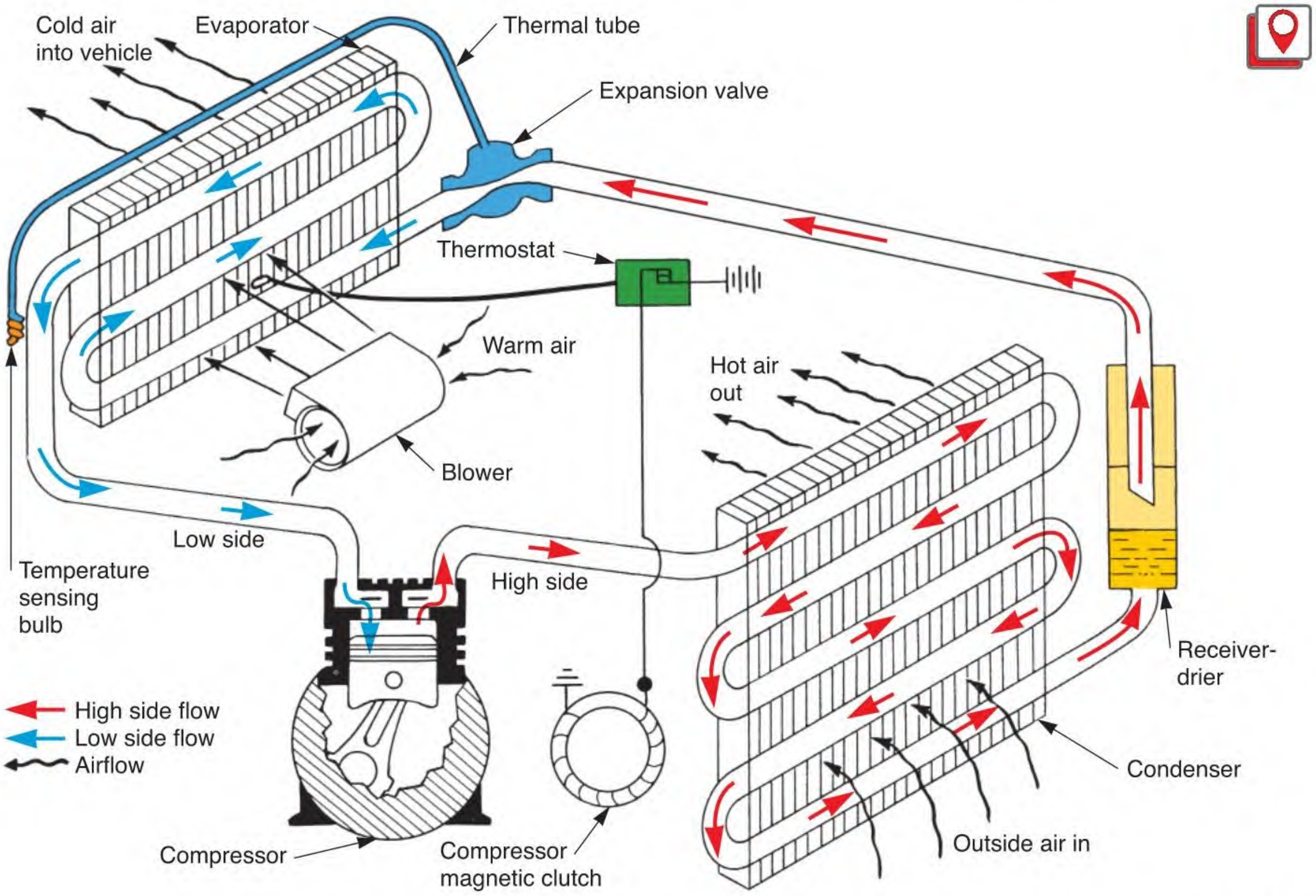
In the ***basic refrigeration cycle***, the refrigerant goes through four phases: compression, condensation, expansion, and vaporization. See **Figure 83-6**. When the refrigerant condenses, heat transfers out of it and into the surrounding air. Then, when the refrigerant evaporates, it absorbs heat to cool the air in the surrounding area.

Figure 83-7 illustrates the operation of a refrigeration system. The eight basic parts of a typical refrigeration system include:

- Refrigerant—Refrigerant is a substance, usually R-134a, that carries heat through the system to lower the air temperature in the vehicle.
- Compressor—The compressor is an engine-driven or electric pump that pressurizes refrigerant and forces it through the system.
- Condenser—The condenser causes refrigerant to change from a gaseous state to a liquid state, causing it to give off its stored heat.
- Flow-control device—A flow-control device, usually an expansion valve or tube, causes refrigerant pressure and temperature to drop, cooling the evaporator.
- Evaporator—An evaporator uses the cooling action of vaporizing refrigerant to cool the air inside the vehicle.
- Receiver-drier or accumulator—A receiver-drier or accumulator removes moisture from and stores refrigerant.
- Blower—The blower is a fan that forces air through the evaporator and into the passenger compartment.
- Thermostatic switch—Thermostatic switch shuts the compressor off when the evaporator temperature nears freezing.

Refrigerant circulates inside the system. The compressor pressurizes the refrigerant and forces it into the condenser, where it condenses into a liquid. Heat is transferred into the condenser and then into the outside air. Liquefied refrigerant then flows to a flow-control restriction (orifice tube or expansion valve). As it passes through the restriction, its pressure suddenly drops. This makes the refrigerant turn into a vapor as it enters the evaporator. The refrigerant absorbs heat from the evaporator, and the evaporator becomes very cold.

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Figure 83-7. The fundamental parts and action of an automotive air conditioning system.

Since the blower forces air through the evaporator, cold air blows into the area to be cooled. The refrigerant vapor is then pulled back into the compressor for another cycle.

Automotive Air Conditioning System

An automotive air conditioning system (A/C system) performs four basic functions—it cools, dehumidifies (dries), cleans, and circulates the air in the vehicle. Additional components (valves, ducts, flaps, and switches) increase system efficiency and dependability, **Figure 83-8**.

High and Low Sides

There are two major divisions of an air conditioning system: the high side and the low side, **Figure 83-9**.

The ***high side***, or ***discharge side***, of an A/C system consists of the parts between the output of the compressor and the flow-control restriction. All the lines and other parts operating on high pressure are in the high side of the system.

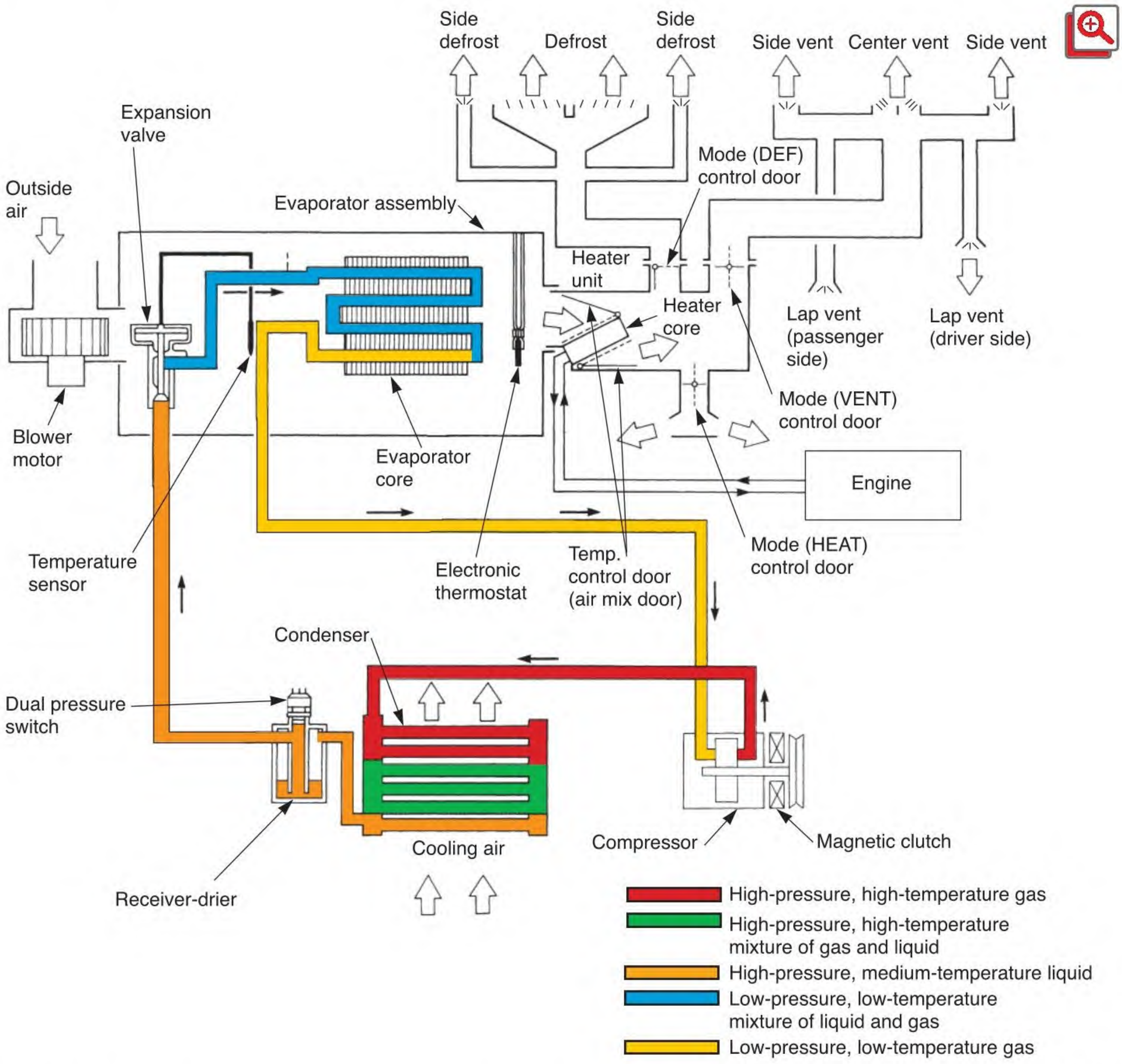
The ***low side***, or ***suction side***, of an A/C system consists of the parts between the flow-control restriction and the inlet of the compressor. All these parts operate on low pressure.

Air Conditioning Compressor

An ***air conditioning compressor*** is a refrigerant pump that is bolted to the front of the engine. It is normally driven by a V-belt or a ribbed-type belt from the engine crankshaft pulley, **Figure 83-10**. Although exact designs vary, an A/C compressor operates as shown in **Figure 83-11**.

In a piston-type compressor, a piston is forced to slide up and down in a cylinder. This produces an intake (suction) stroke when the piston moves down

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Figure 83-8. Trace the flow of refrigerant liquid and vapor through the system. Also study airflow through the vents.

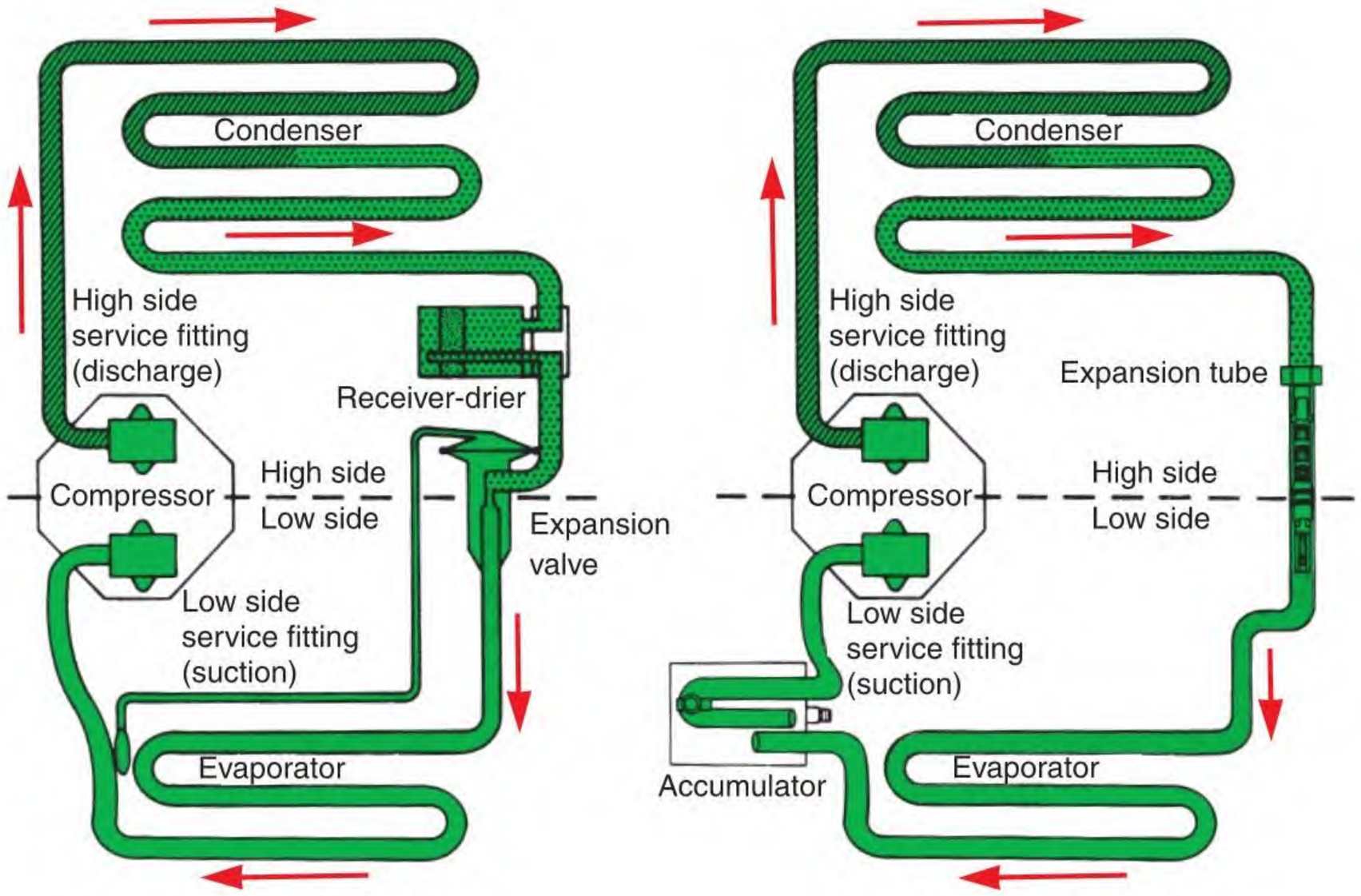
and an output (pressure) stroke when the piston moves up.

A ***reed valve*** is simply a thin piece of metal that bends to open and close an opening. Reed valves are normally used as check valves to produce flow through the compressor and system, **Figure 83-12**.

A ***magnetic clutch*** is used to engage and disengage the air conditioning system compressor. A magnetic clutch typically consists of an electric coil, a pulley, and a front clutch plate. These parts bolt around or on the compressor shaft. See **Figure 83-13**.

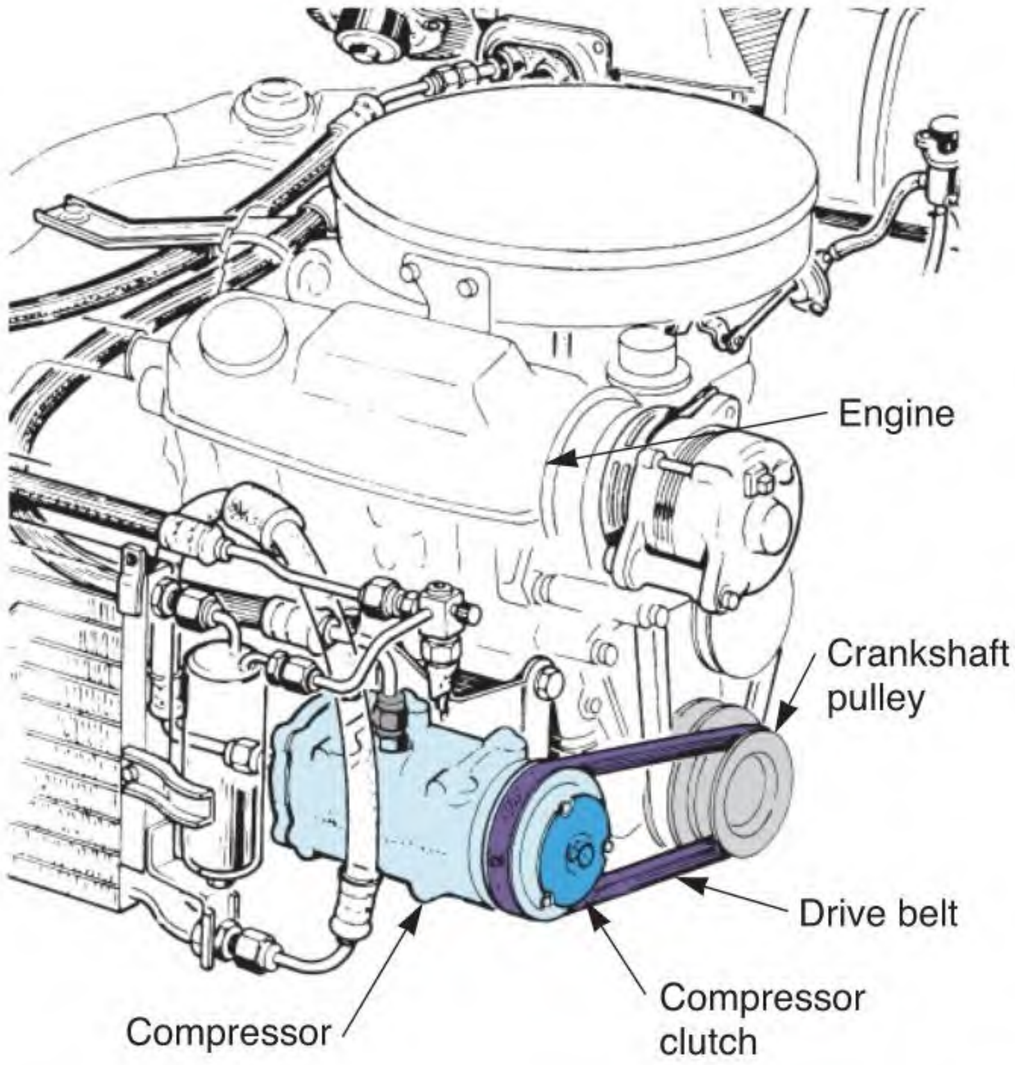
When current is passed through the compressor coil, a strong magnetic field develops. The magnetic field pulls the front clutch plate into contact with the compressor pulley. This locks the clutch plate and pulley together. The compressor shaft then rotates to operate the internal parts of the compressor, **Figure 83-14**.

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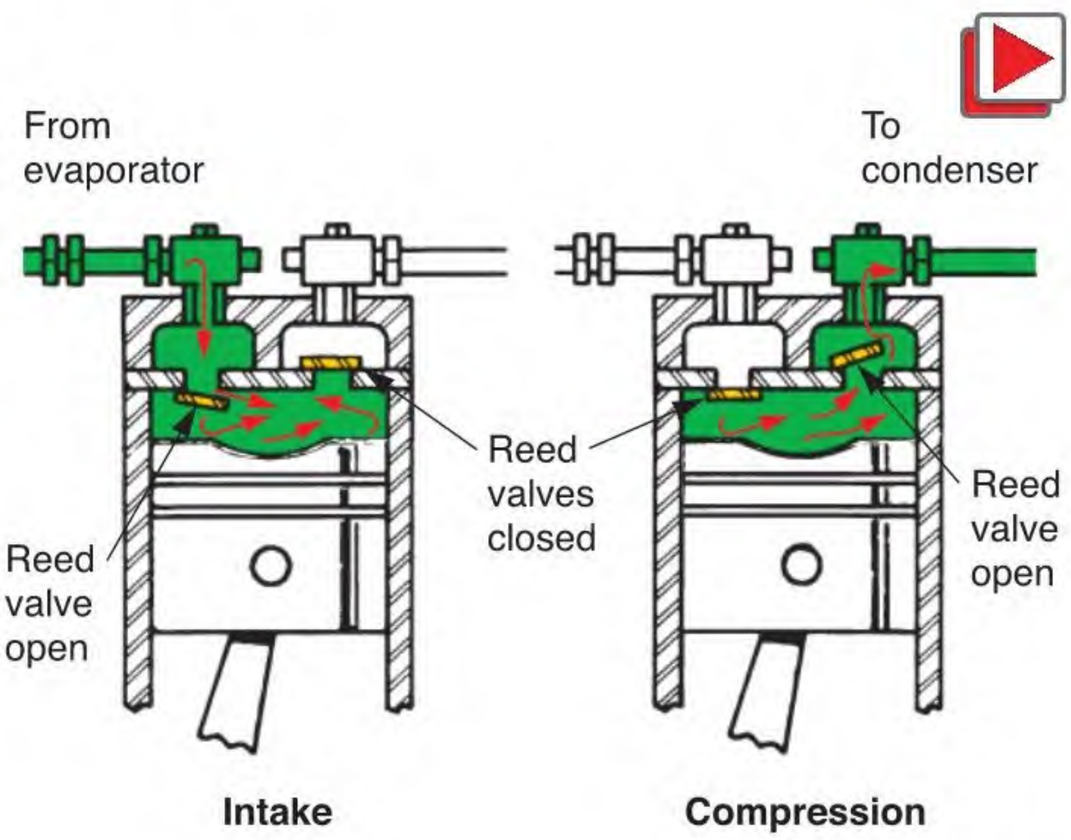
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Figure 83-9. Note the parts in high and low sides of a typical air conditioning system.



Honda

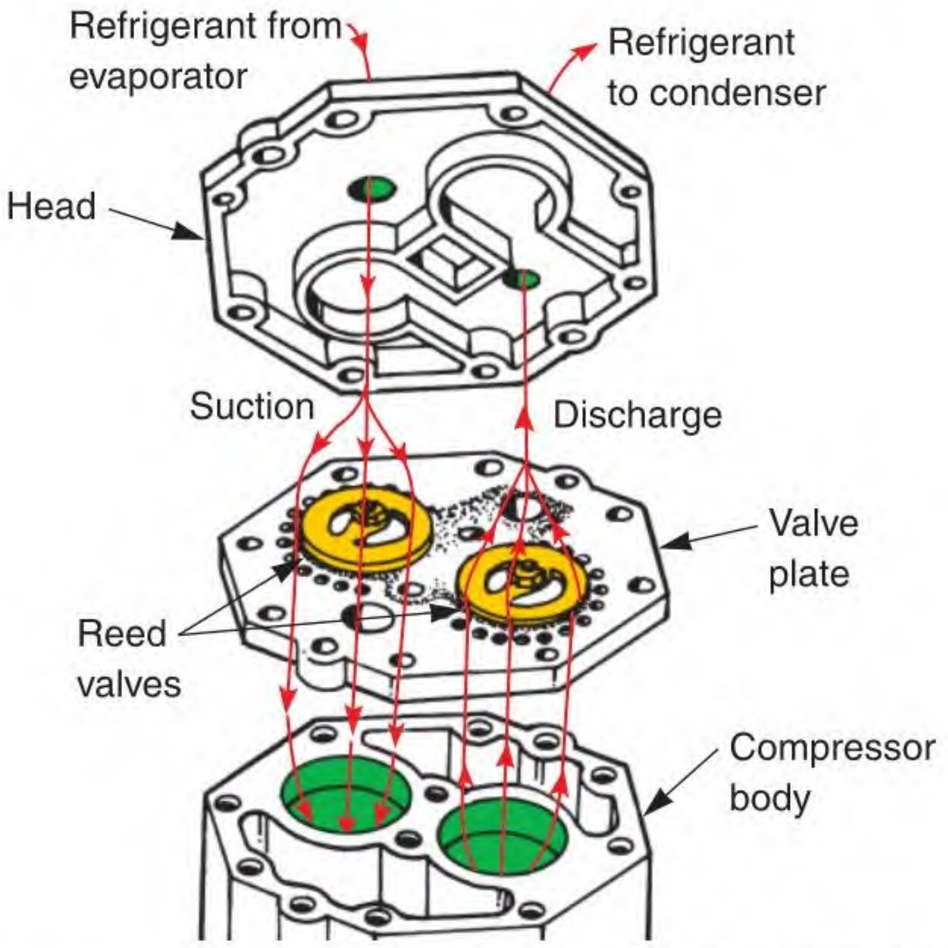
Figure 83-10. An air conditioning compressor is normally belt-driven off the front of the engine. This engine is transverse mounted in car.



Ford

Figure 83-11. The basic operation of a compressor. During the intake stroke, the piston slides down and pulls vapor into the cylinder. On the compression stroke, the piston slides up and forces vapor through the system.

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Figure 83-12. Compressor reed valves control flow in and out of the compressor. Note how they mount in the unit.

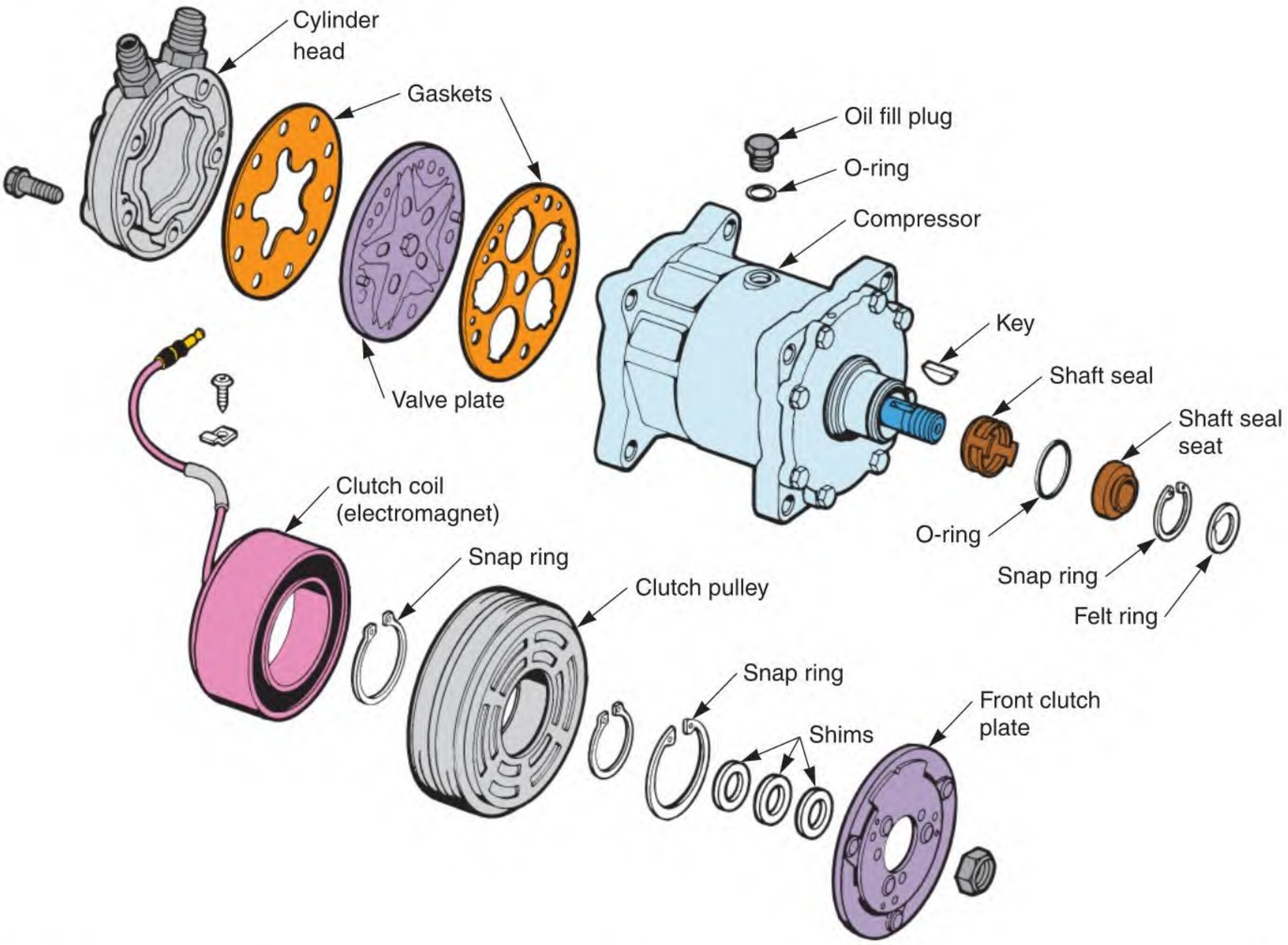
When current to the compressor coil is shut off, the clutch plate is released from the compressor pulley. This lets the pulley freewheel, so the compressor doesn't function.

Compressor Types

There are five types of automotive air conditioning compressors:

- Crank compressor (inline or V-type), **Figure 83-15**.
- Axial compressor, **Figure 83-16**.
- Radial compressor, **Figure 83-17**.
- Rotary vane compressor, **Figure 83-18**.
- Scroll compressor, **Figure 83-19**.

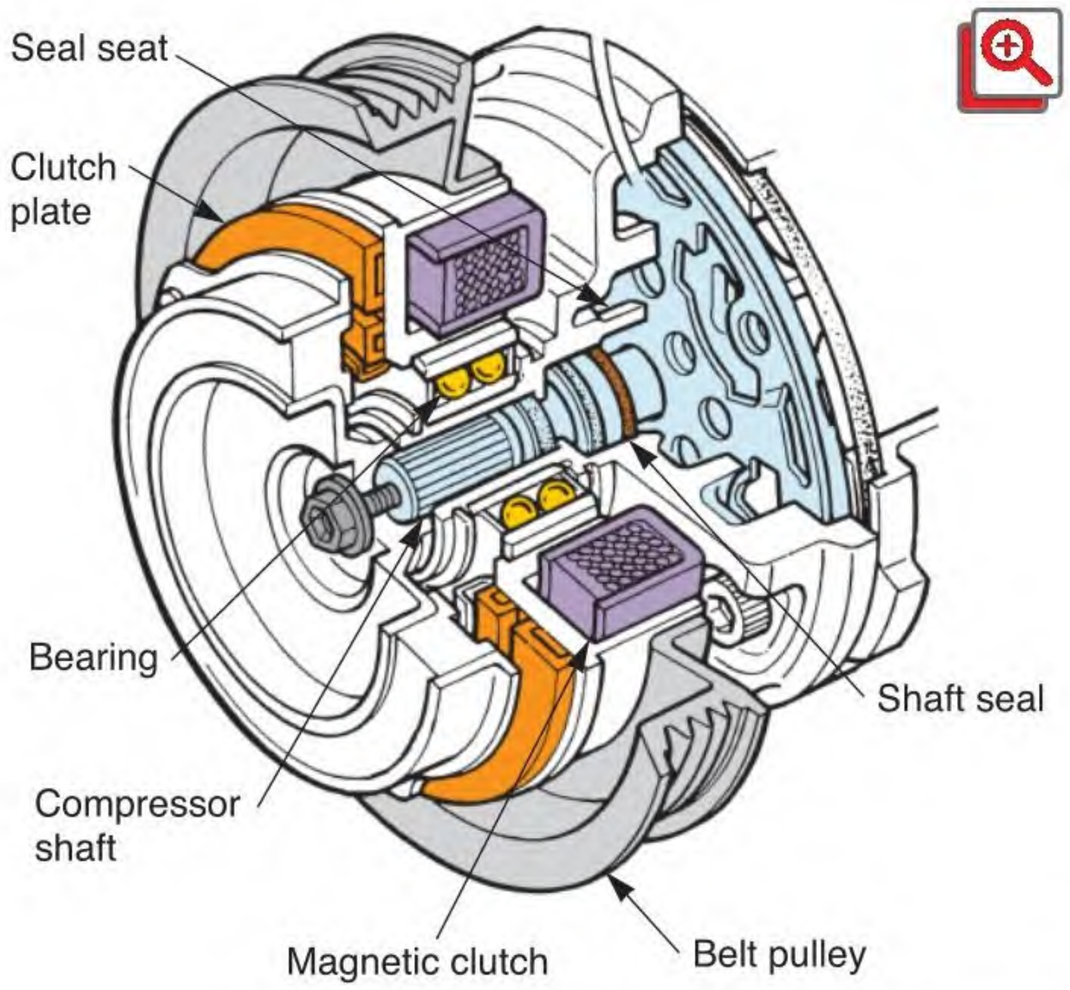
Compare the shape and construction of each type. Note that three of the five types use pistons, cylinders, and reed valves to produce system pressure. The main difference is the position of these parts.



Chrysler

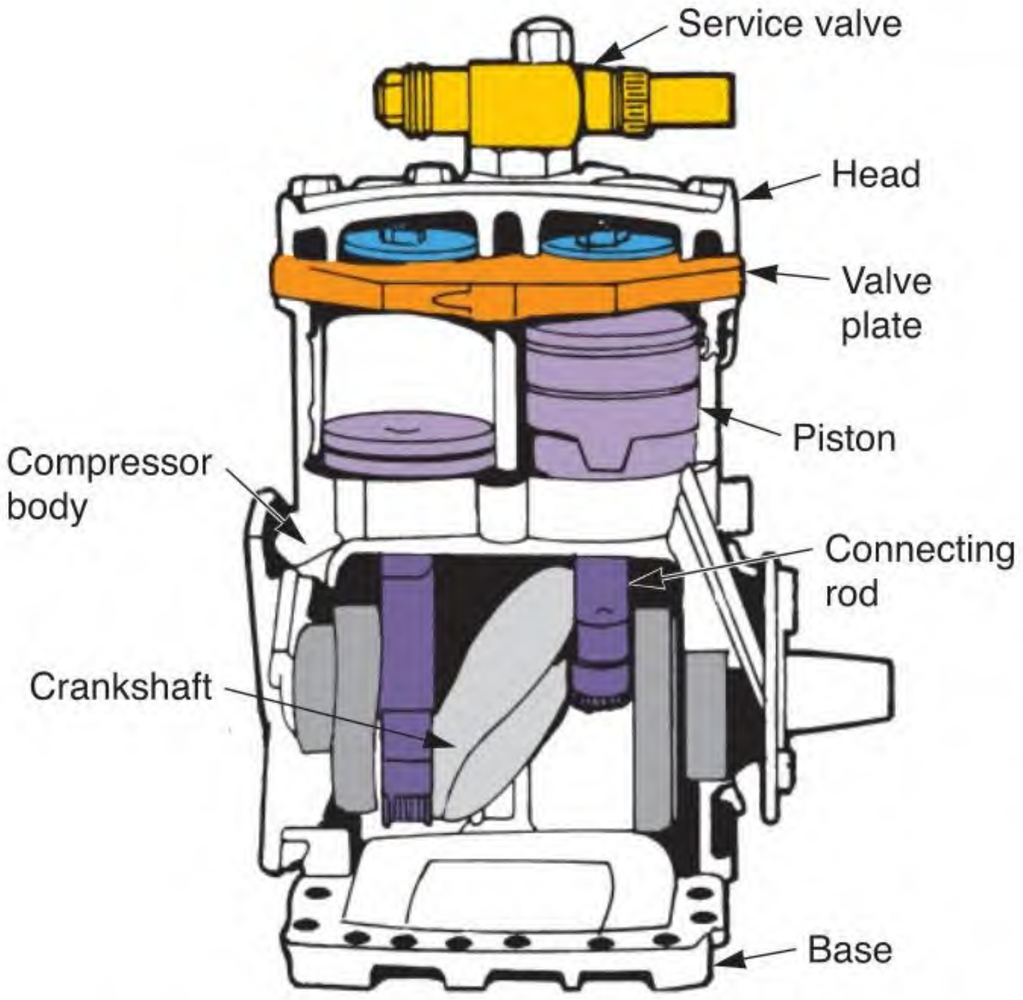
Figure 83-13. This exploded view of a compressor shows how the valve plate and clutch mount on the main body of the compressor.

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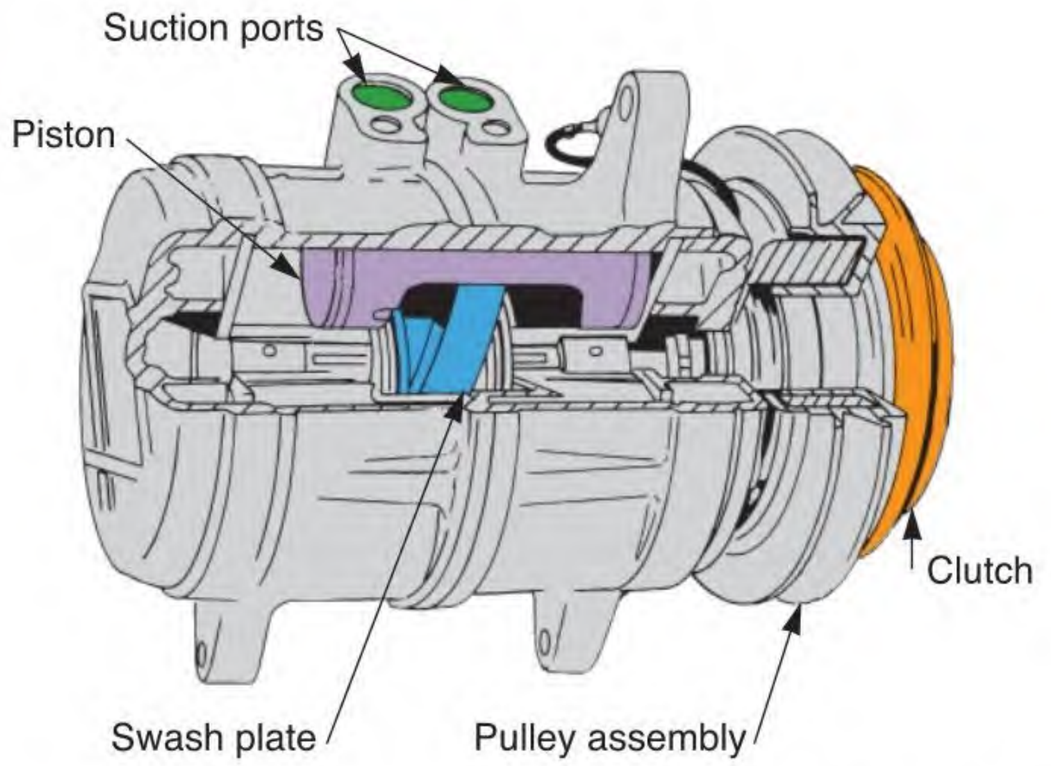
Honda

Figure 83-14. This cutaway of a compressor clutch shows the electromagnetic coil that pulls the clutch plate into the hub, locking the assembly together to rotate the input shaft.



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Figure 83-15. A crank-type compressor is similar to a small gasoline engine. The crankshaft, connecting rods, and pistons make up the reciprocating assembly.



Mitchell Manuals

Figure 83-16. An axial compressor has pistons moving lengthwise in its body. The swash plate moves the pistons.

The crank compressor uses a *crankshaft* that is similar to the crankshaft used in an automotive engine. The axial compressor uses a *swash plate* to produce piston motion. A *shaft eccentric* (egg-shaped component) causes piston movement in a radial compressor.

Vanes (blades), similar to those found in oil or power steering pumps, pressurize the refrigerant in a rotary vane compressor. A scroll compressor uses two scrolls—one movable and one stationary—to pressurize the refrigerant.

Refrigerant Oil

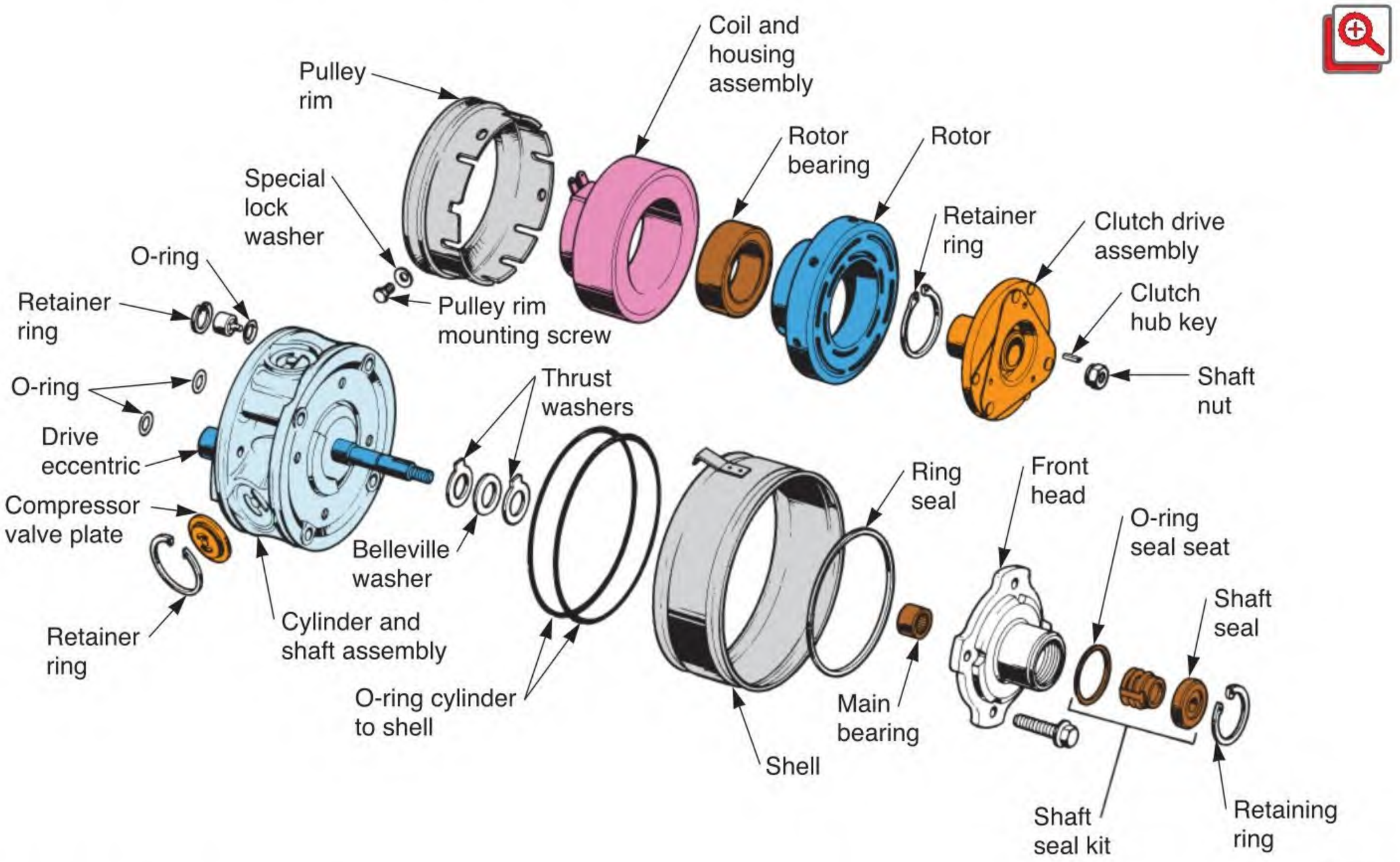
Refrigerant oil is high-viscosity, highly refined (pure) oil used to lubricate the parts of the air conditioning system, especially the compressor. Because the refrigerant oil and the refrigerant mix, oil droplets are carried throughout the system. The refrigerant oil also splashes around inside the compressor to reduce friction and wear.

Refrigerant Hoses

Refrigerant hoses carry refrigerant to each air conditioning system component and back to the compressor. These special high-pressure hoses are designed to withstand compressor pressures as high as 250 psi (1725 kPa). See **Figure 83-20**.

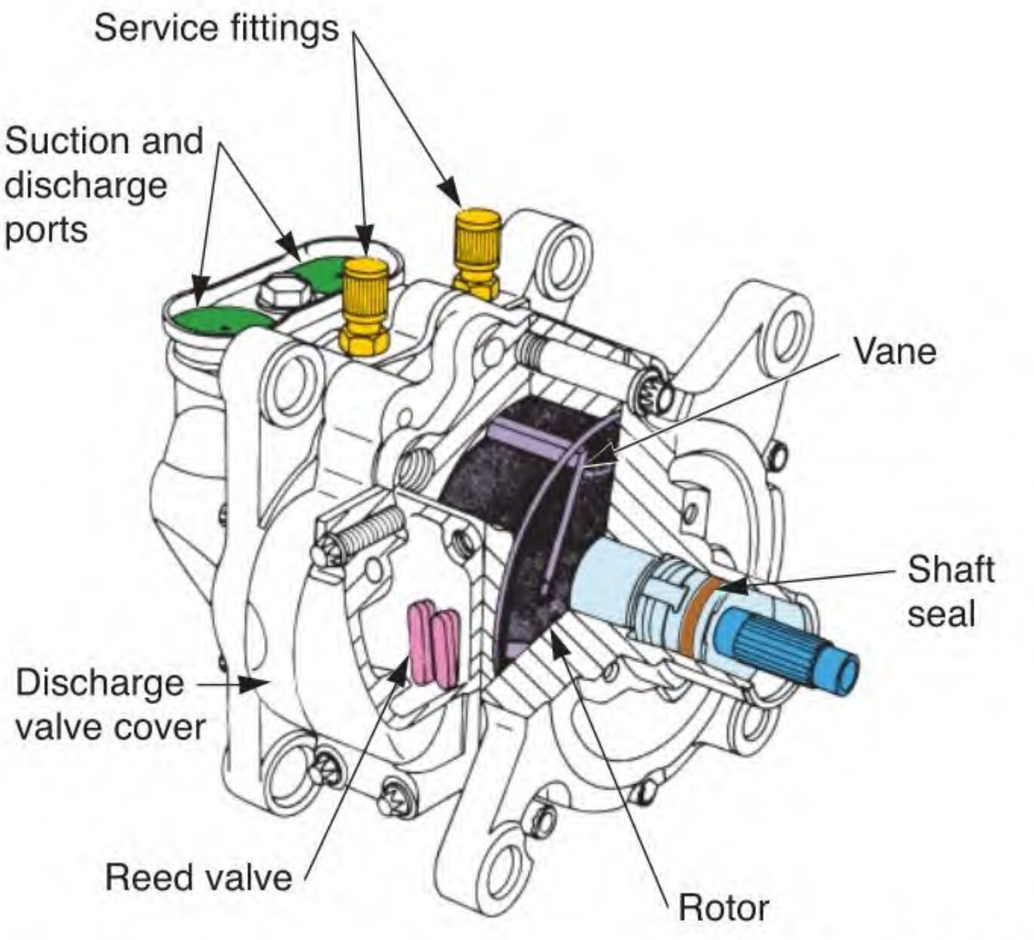
Special fittings are used on the ends of refrigerant hoses. O-ring seals, hose clamps, or flared tube ends are used on the fittings to prevent leakage. Look at **Figure 83-21**.

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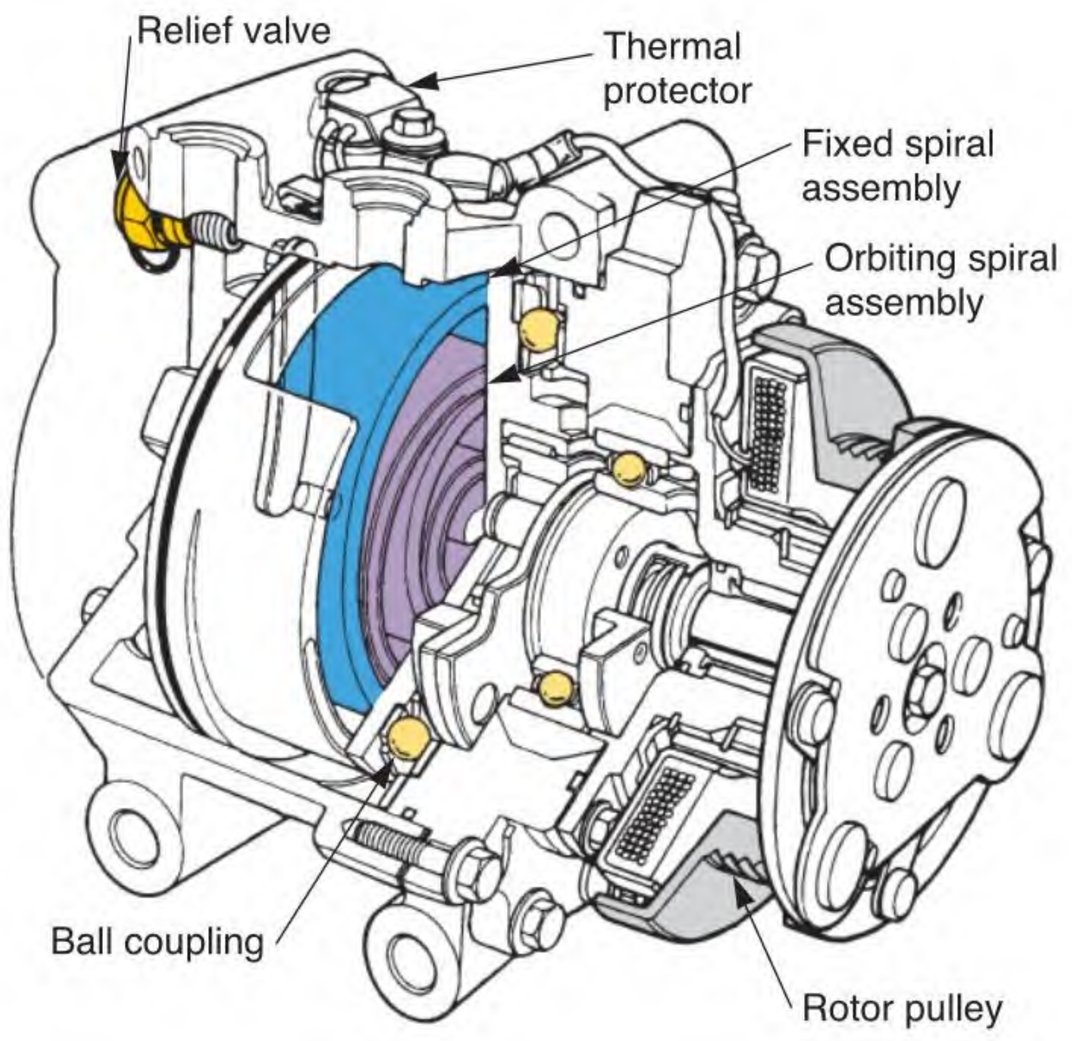
Chrysler

Figure 83-17. A radial compressor has a shaft-mounted eccentric that moves the pistons in and out. The pistons are arranged in a circle around the shaft.



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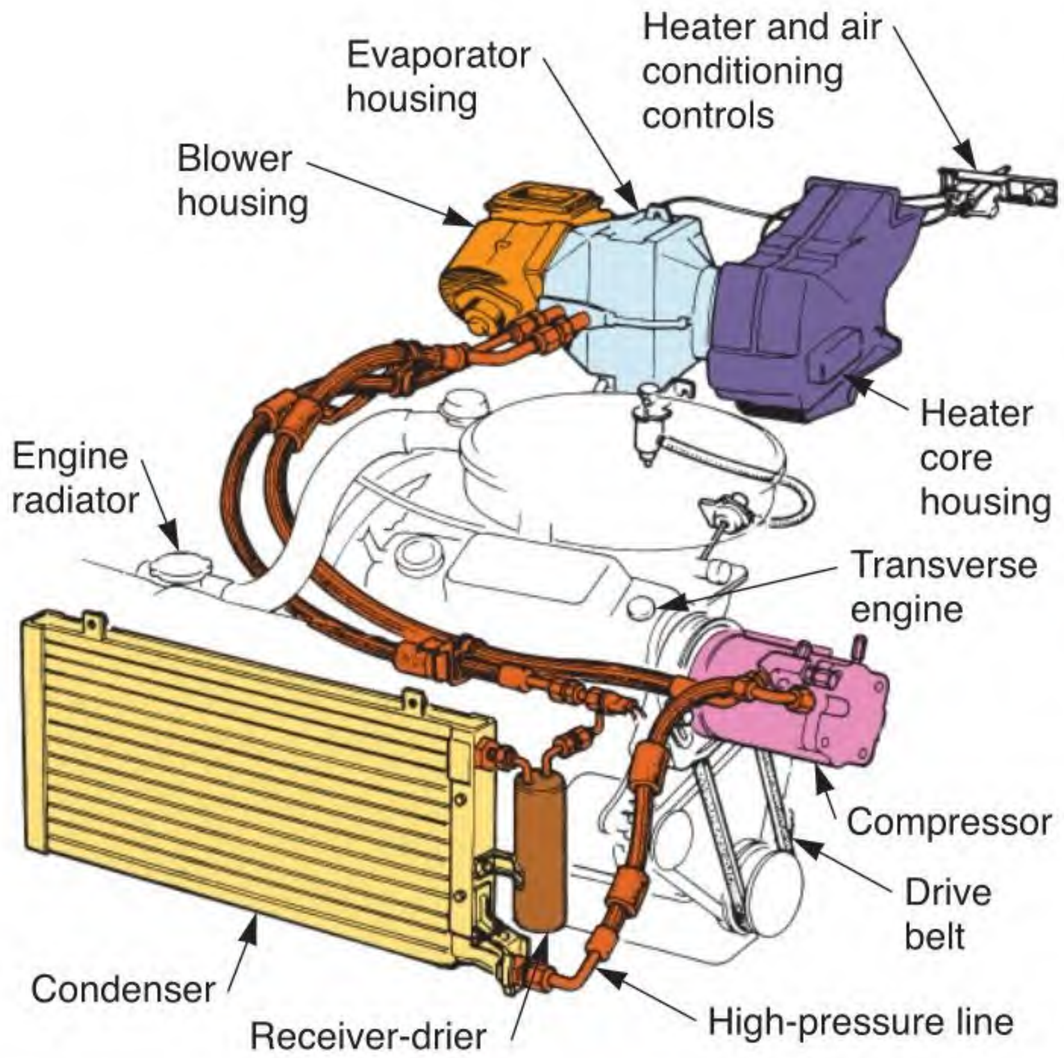
Figure 83-18. A rotary vane compressor works like an oil or air injection pump. Blades spin inside the housing to pressurize the refrigerant.



Honda

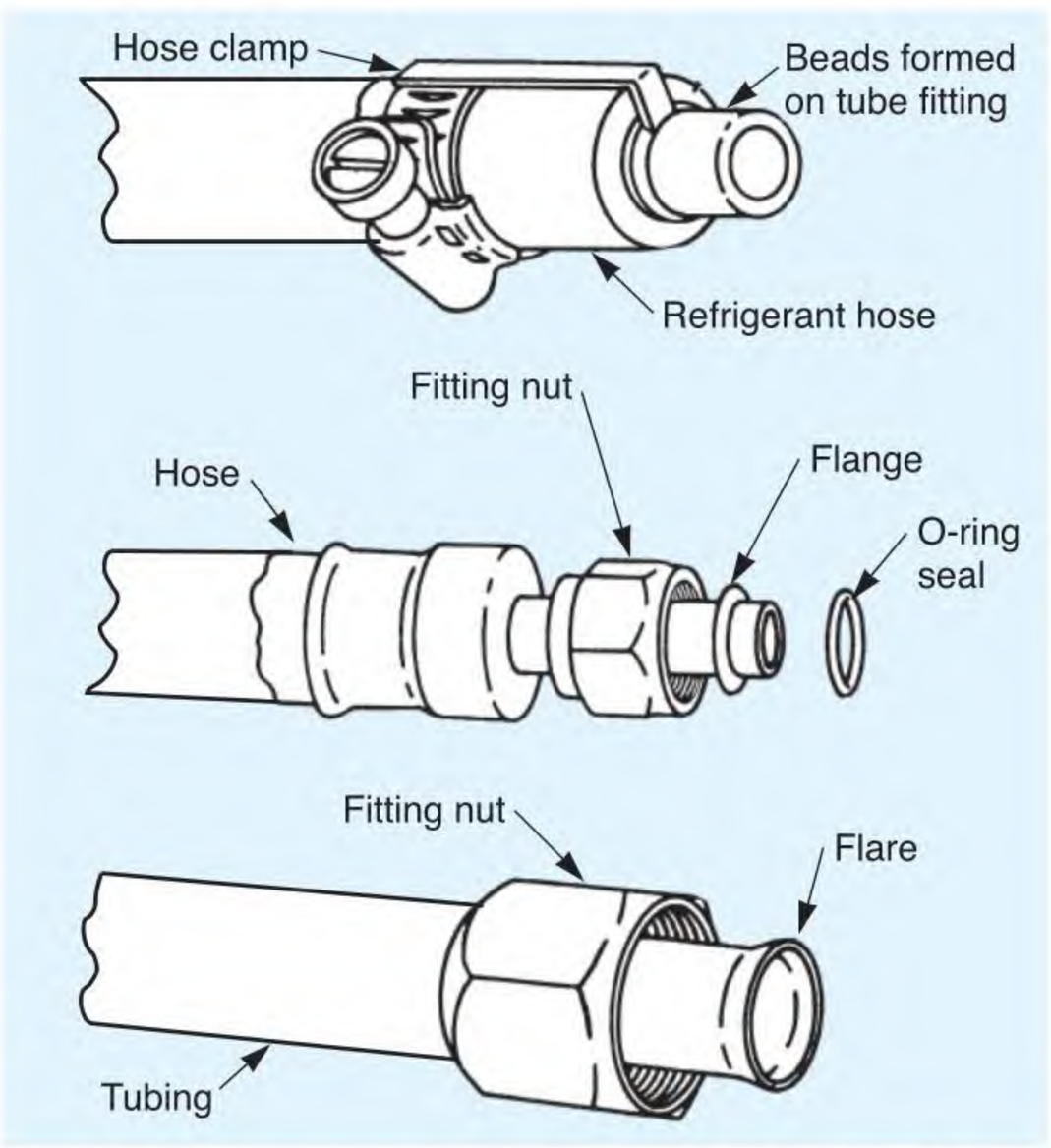
Figure 83-19. A cutaway view of a scroll compressor.

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Honda

Figure 83-20. High-pressure refrigerant hoses and lines carry refrigerant through the system.



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Figure 83-21. Note the common types of fittings found in automotive air conditioning systems.

Air Conditioning Condenser

An ***air conditioning condenser*** is a radiator-like device that transfers heat from the refrigerant to the outside air. It normally bolts in front of the cooling system radiator, as shown in **Figure 83-20**.

The condenser is simply a long metal tube wound back and forth between hundreds of metal fins. The fins increase the condenser's surface area, improving heat transfer.

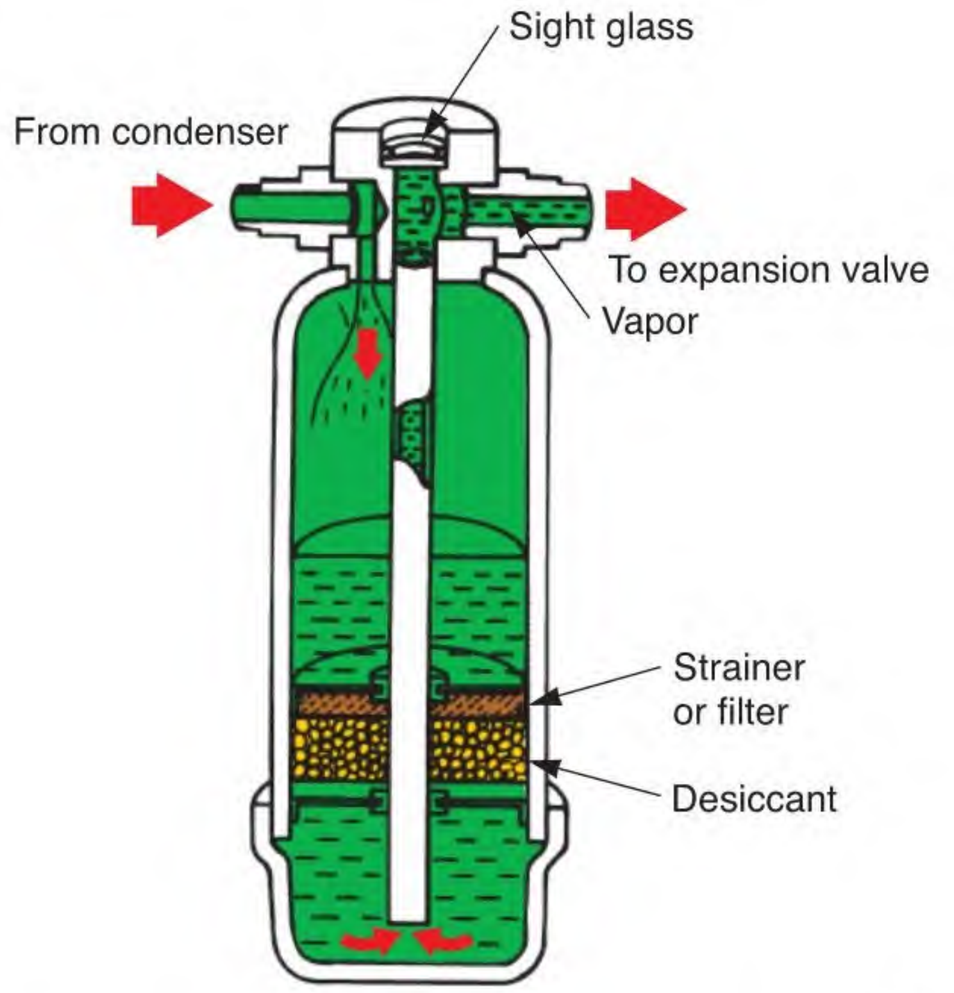
Receiver-Drier

A ***receiver-drier*** removes moisture from the system and stores extra refrigerant. It is normally located in the high side of the system. A cutaway view of a typical receiver-drier is shown in **Figure 83-22**. Note that the unit contains a *desiccant* (drying agent), which removes water from the refrigerant.

A ***sight glass*** may be located in the top of the receiver-drier to show the amount of refrigerant in the system. If the system is low on refrigerant, bubbles will show up in the sight glass. The sight glass can also be located in one of the refrigerant lines.

Accumulator

An ***accumulator*** performs the same function as a receiver-drier: it stores and dries the refrigerant.



Nissan

Figure 83-22. The receiver-drier, or dehydrator, removes moisture from the air conditioning system.

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However, it is normally on the system's low side (at the evaporator outlet). Look at **Figure 83-23**.

The accumulator keeps liquid refrigerant from entering the compressor. The compressor can be damaged by liquid refrigerant because liquids do *not* compress. The construction of receiver-driers and accumulators varies.

Muffler

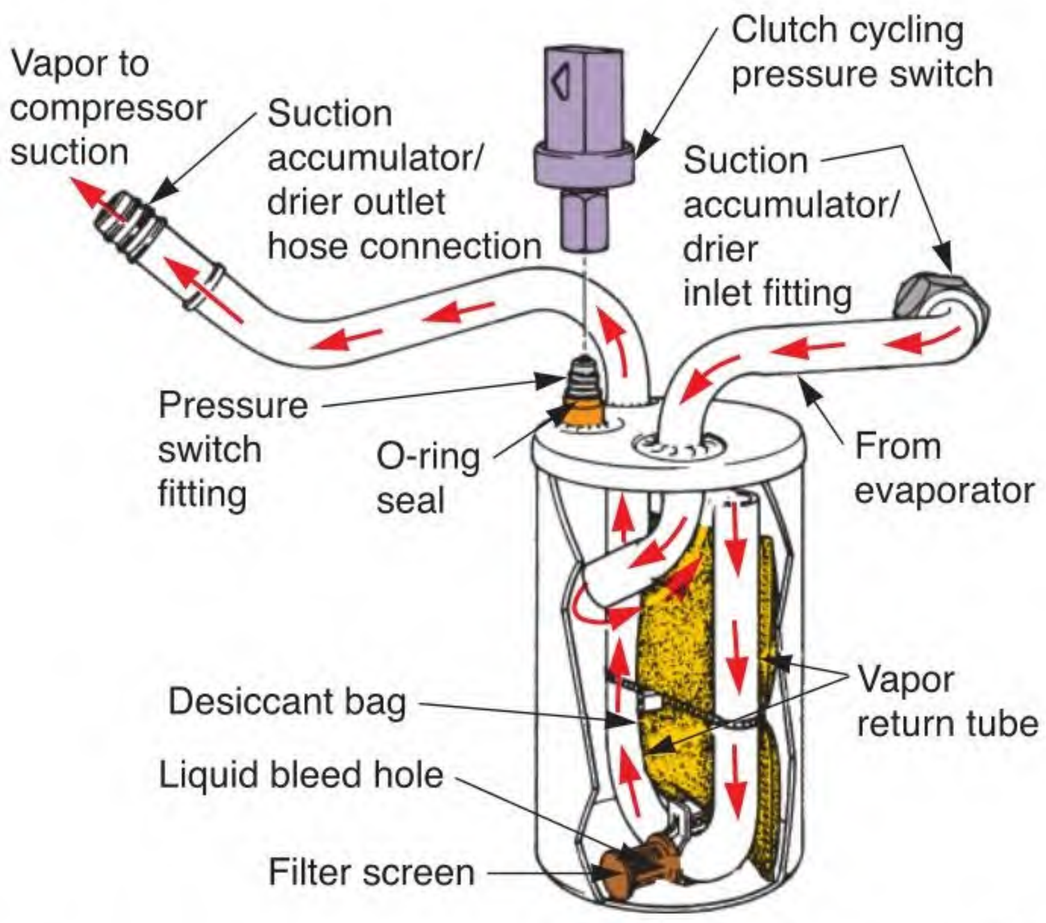
A ***muffler*** is a hollow container that quiets the pumping sounds produced by the compressor. It is usually a metal can formed into the high-pressure, or compressor discharge, refrigerant line.

Evaporator

The ***evaporator***, like the condenser, is a refrigerant coil mounted in cooling fins. The evaporator is usually mounted on the right side of the vehicle. It fits inside the blower housing, either on the outside or inside of the firewall.

Air Conditioning System Controls

All A/C systems use a compressor, a condenser, an evaporator, a drier, and/or an accumulator. However, many different devices are used to control the operation of the compressor and to meter the flow of refrigerant.



Ford

Figure 83-23. An accumulator serves as a reservoir and a moisture trap. Note how the clutch cycling switch mounts on the accumulator.

For example, the two most common types of air conditioning systems are:

- Expansion tube A/C system (cycling clutch system).
- Thermostatic expansion valve A/C system.

Over the years, other systems have been used. However, these two represent the most typical and easiest to understand A/C systems found on today's vehicles.

Expansion Tube A/C System

An ***expansion tube A/C system***, or ***cycling clutch system***, controls refrigerant flow and evaporator temperature by cycling the compressor on and off. This system is one of the simplest. Look at **Figure 83-24**.

The ***expansion tube*** (also called ***orifice tube***) has a fixed opening that meters the refrigerant flowing into the evaporator. The expansion tube usually fits near or in the evaporator inlet. It is usually a straight tube made of plastic or sintered metal, **Figure 83-25**.

Cycling Switches

Two types of ***compressor cycling switches*** can be used in an expansion tube A/C system: thermostatic cycling switches and pressure cycling switches.

A ***thermostatic cycling switch*** turns the compressor on and off to maintain the correct evaporator temperature (approximately 32°F or 0°C).

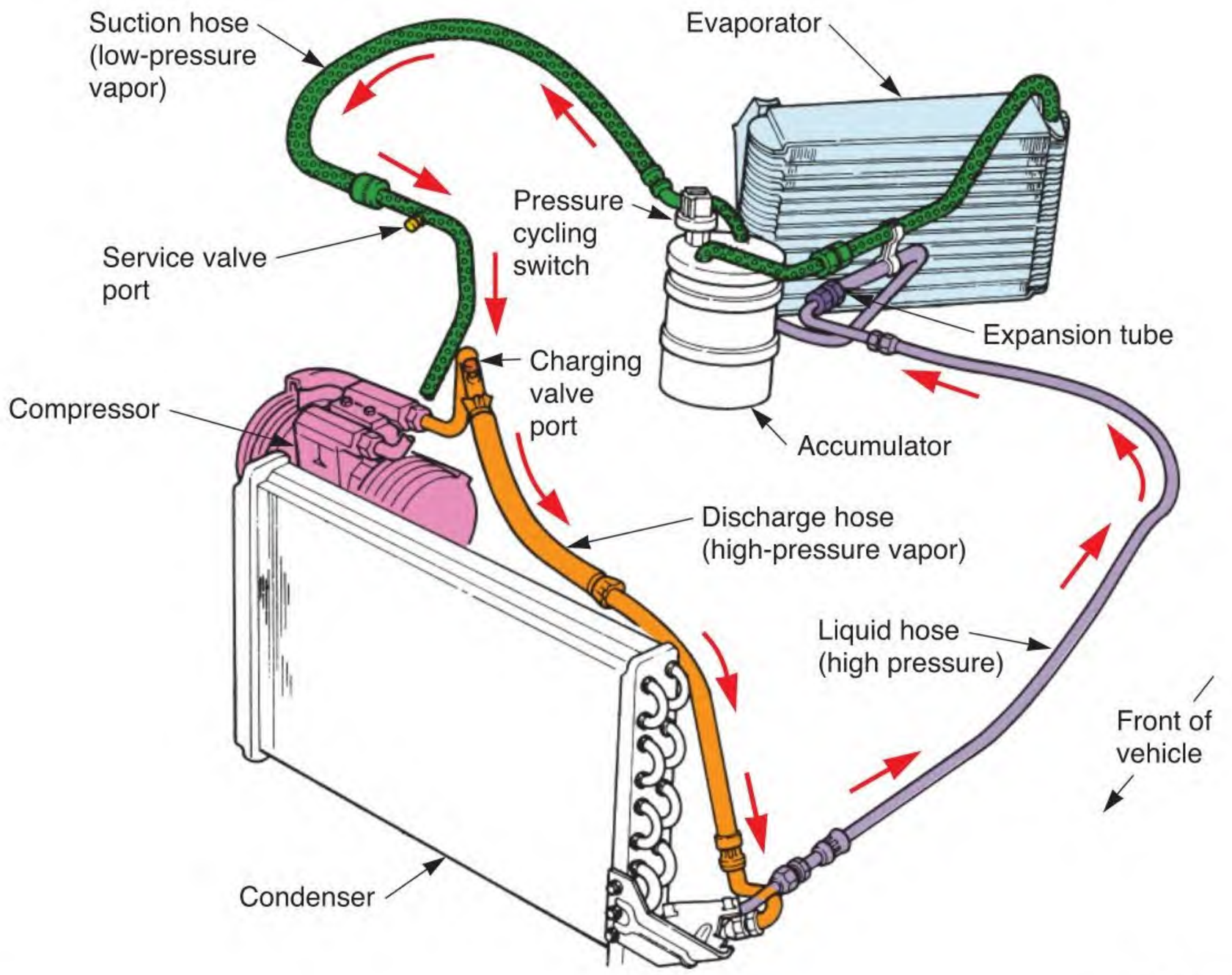
When the evaporator is warm, the switch is closed and current flows to the compressor clutch coil. This causes the compressor to function, cooling the evaporator. Then, when the evaporator becomes cold enough (near freezing point), the cycling switch opens the circuit to the compressor clutch. This allows the evaporator temperature to increase as needed.

Since evaporator pressure determines evaporator temperature, a ***pressure cycling switch*** can be used in place of or in conjunction with a thermostatic switch to maintain the correct evaporator temperature. Note the location of the pressure cycling switch in **Figure 83-24**.

Expansion Valve A/C System

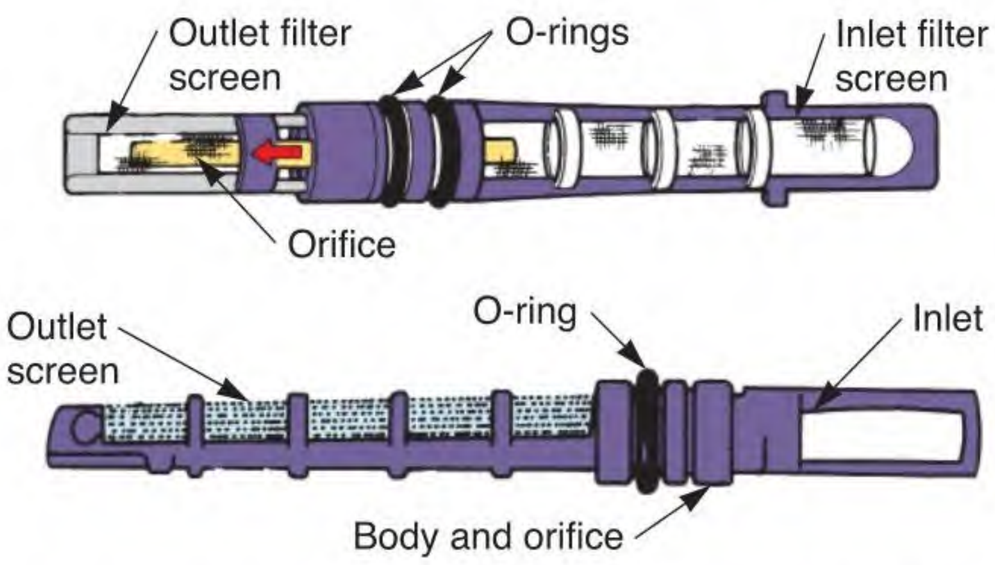
An ***expansion valve*** is a temperature-sensitive valve that controls refrigerant flow and the evaporator temperature. See **Figure 83-26**. Basically, an expansion

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Figure 83-24. The expansion tube system turns the compressor on and off to control amount of refrigerant flowing through the evaporator. This provides a simple method of maintaining temperature.



Mitchell Manuals

Figure 83-25. The expansion tube has a metering orifice that allows a specific amount of refrigerant to enter the evaporator.

valve consists of a thermostatic bulb and tube, a diaphragm, actuating pins, a valve and seat, a metering orifice, and a spring. The compressor is not cycled on and off to control evaporator temperature—it runs all the time. So, the expansion valve can open and close to meter the right amount of refrigerant into the evaporator.

When the temperature of the evaporator and bulb is too warm, expansion in the thermostatic bulb places pressure on the diaphragm. This flexes the diaphragm, pushing the expansion valve open. More refrigerant then flows into the evaporator to provide more cooling. When the system becomes too cold, bulb pressure drops. When bulb pressure drops, the spring in the expansion valve closes the metering orifice to reduce refrigerant flow and cooling action, **Figure 83-27**.

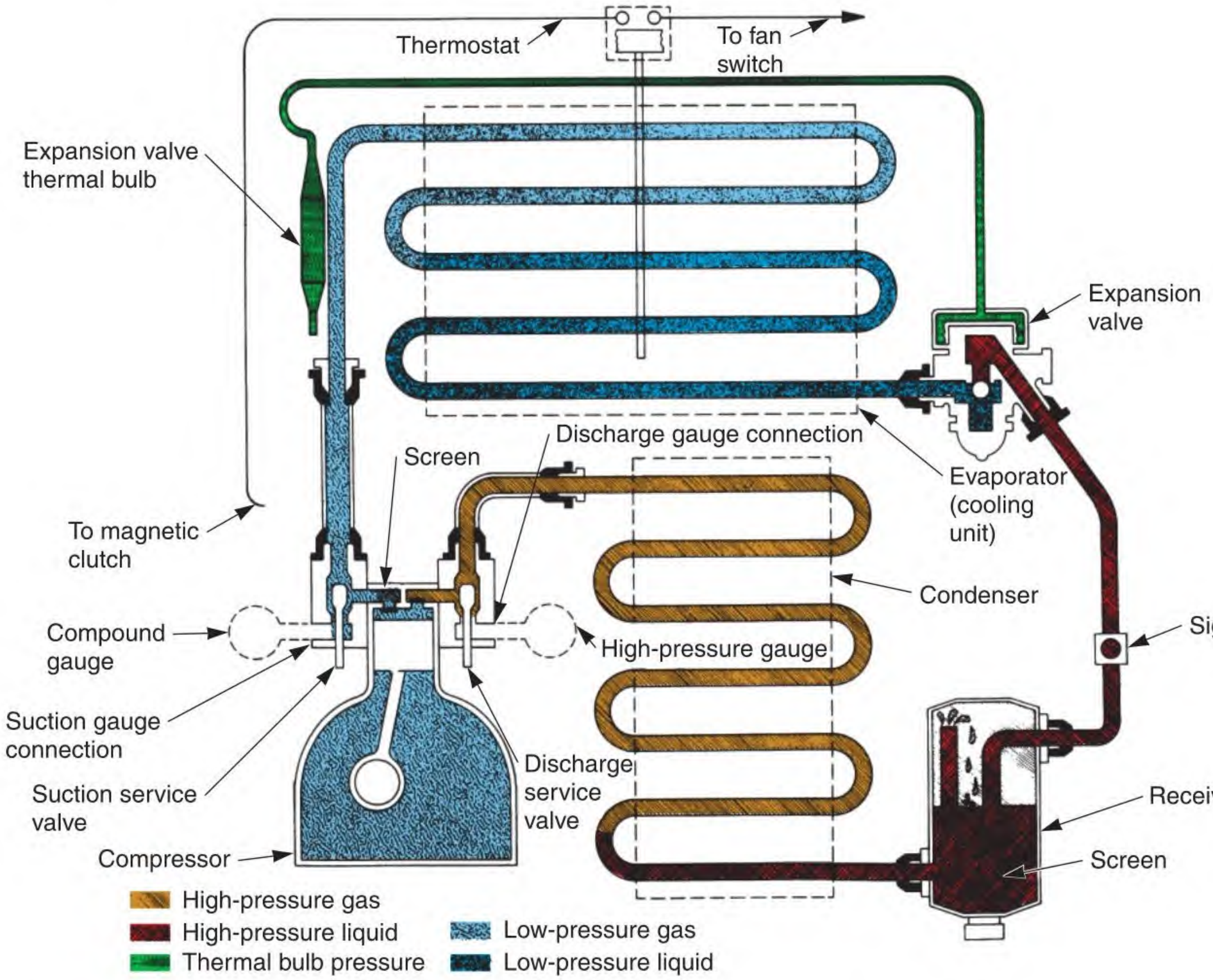
Other A/C System Controls

Aside from the thermostatic cycling switch, the pressure cycling switch, and the expansion valve, other controls are needed to increase system efficiency and provide additional protection.

An ***ambient temperature switch*** can be used to keep the compressor from operating when the outside (ambient) air temperatures are very cold. This helps prevent seal, gasket, and reed valve damage.

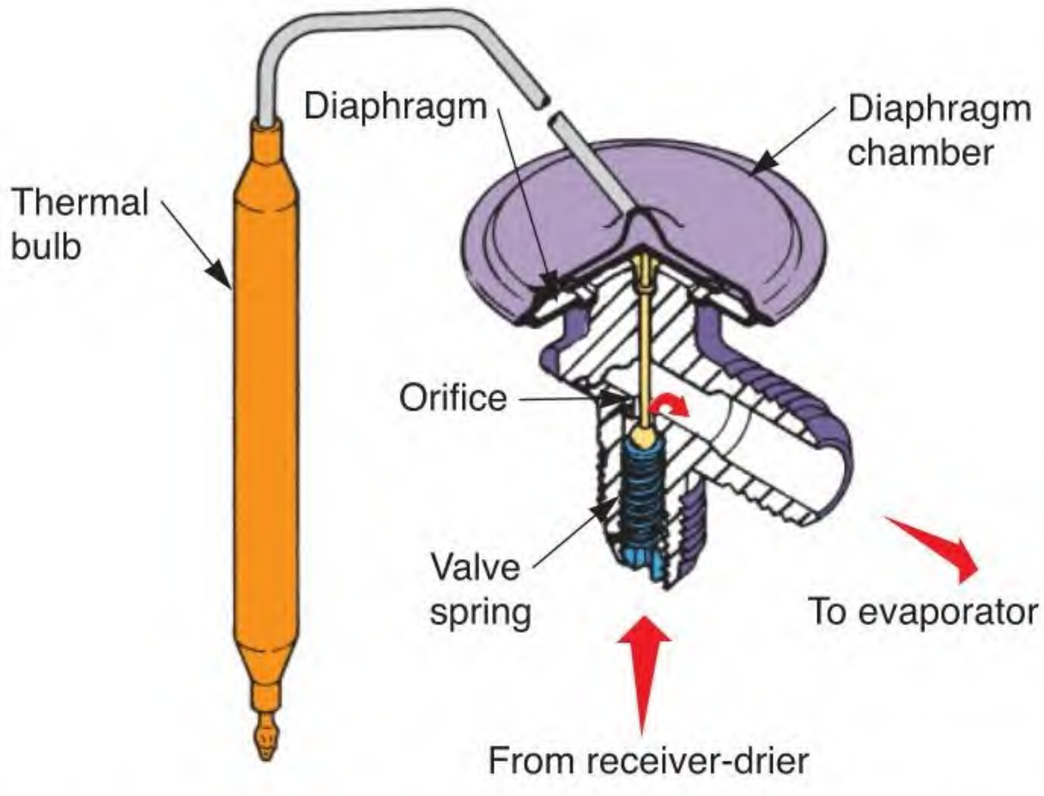
A ***low-pressure cutout switch*** shuts off the compressor when system pressure drops below a certain point to prevent compressor damage. Low

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Chrysler

Figure 83-26. This A/C system uses a thermostatic expansion valve. A thermal bulb senses evaporator outlet temperature and can open or close the expansion valve to maintain temperature.



Nissan

Figure 83-27. The expansion valve opens and closes with temperature changes to regulate the amount of refrigerant entering the evaporator.

system pressure can result from a refrigerant leak. The low-pressure cutout switch interrupts the circuit to the compressor clutch. If the compressor continues operating without refrigerant circulation, it could overheat and lock up.

A ***high-pressure cutout switch*** opens the compressor coil circuit when discharge pressure is too high. The switch opens when pressure reaches approximately 375 psi (2584 kPa). The high-pressure cutout switch is normally located in the service fitting of the discharge muffler. Like the low-pressure cutout switch, it prevents compressor damage from abnormal operating conditions.

A ***thermal limiter*** and a ***superheat switch*** can prevent compressor damage when the refrigerant level or the oil level is too low. The superheat switch senses low system pressure and high compressor temperature, and sends current to the thermal

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limiter. Current flow melts a fusible link in the thermal limiter and stops current to the compressor clutch. **Figure 83-28** shows these protection devices.

A ***pressure relief valve*** bleeds off excess pressure to prevent compressor damage. It is a pop-off (spring-loaded) valve located on the receiver-drier, compressor, or other component in the high side of the system.

The ***wide open throttle (WOT) switch*** shuts off the compressor during rapid acceleration to save power. This switch is used on cars with small gasoline or diesel engines. It is normally located on the accelerator linkage, carburetor, or throttle body, **Figure 83-28**.

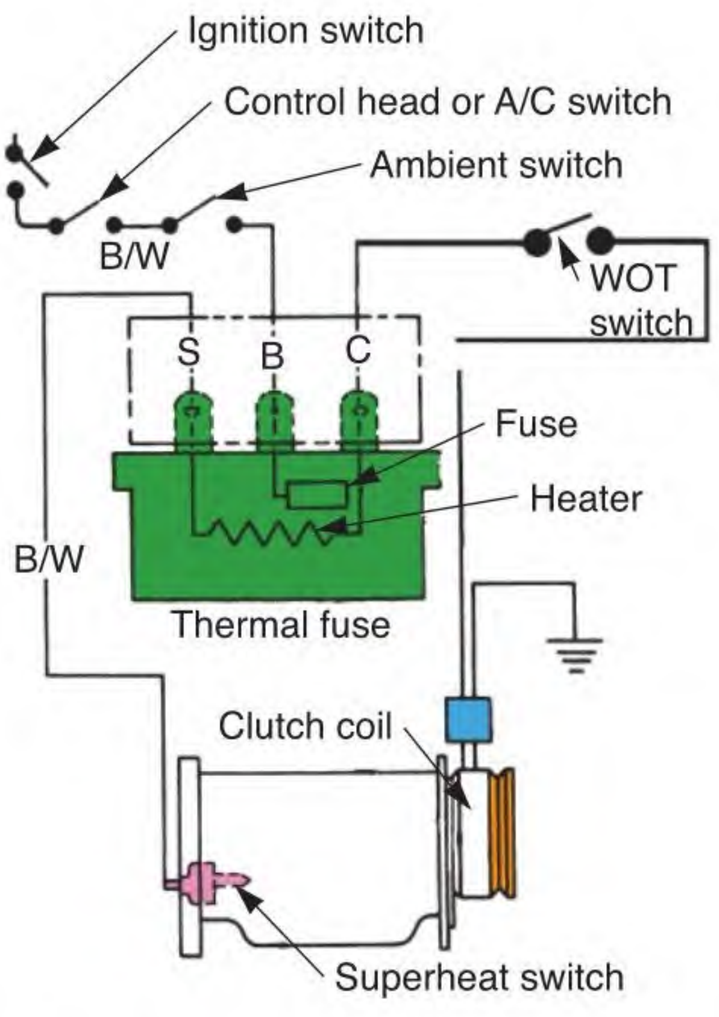
The ***A/C switch*** is the driver-operated switch in the car's dash that feeds current to the compressor clutch and other electric components. The A/C switch provides a manual means of controlling system operation.

Service Valves

Service valves are basically provided to allow refrigerant installation and removal, as well as pressure gauge tests of the A/C system.

The ***discharge service valve*** is located at the output from the compressor, in the system high side.

The ***suction service valve*** is located at the inlet to the compressor, in the system low side.



AC-Delco

Figure 83-28. Study how switches are wired in an A/C system circuit.

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Tech Tip

The service valves on older vehicles are different from those used on new vehicles. This helps prevent the accidental use of the wrong type of refrigerant (R-12 instead of R-134a).

Heating System

The heating system uses the engine's cooling system heat to warm the passenger compartment in cold weather. A heating system typically consists of two heater hoses, a heater core, a blower (fan), and a control mechanism. See **Figure 83-29**.

Heater hoses are small-diameter hoses that carry engine coolant to the heater core. Hot engine coolant flows through one heater hose, through the heater core, and back into the engine through another heater hose. A vacuum-operated valve may be used in one of the heater hoses to control coolant flow to the heater core.

The ***heater core*** is a small, radiator-like unit that provides a large surface area for heat dissipation into the passenger compartment. It is made of a series of tubes surrounded by fins. As air passes through the tubes and fins, heat is transferred into the air.

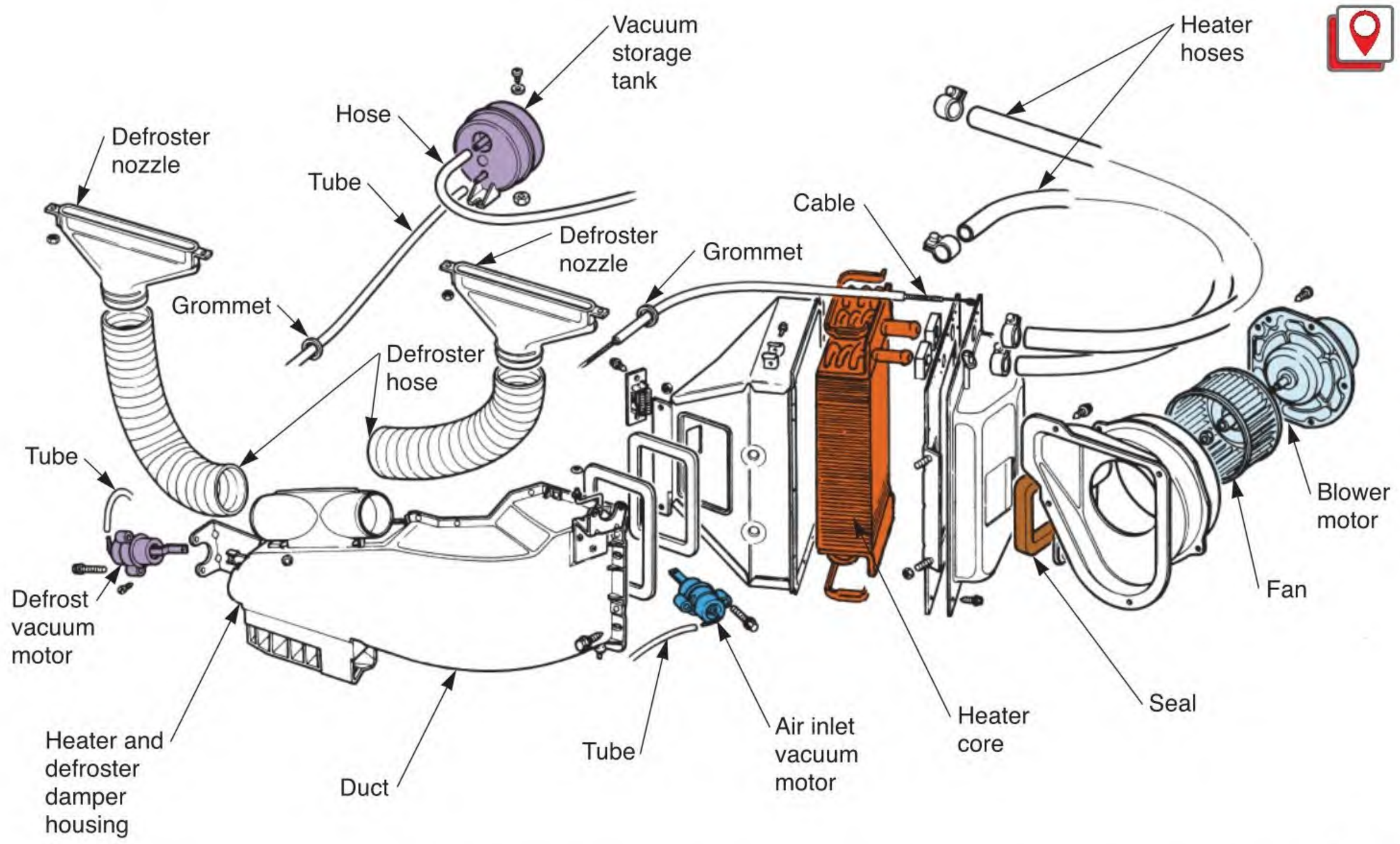
The ***blower*** is an electric motor and fan assembly. When current is fed to the electric motor, the fan spins to force air through the heater core or the air conditioning evaporator. The blower mounts in a housing that surrounds the heater core, the evaporator (if used), and the air doors.

Heater controls can be set to move the duct flaps so that cool outside air is mixed with hot heater core air. This permits control of the passenger compartment temperature, **Figure 83-30**.

Heating and Air Conditioning Controls

The driver uses levers, buttons, or switches in the instrument panel to control the operation of the heating and air conditioning systems. When the driver activates one of the instrument panel controls, one of four methods may be used to operate the system components:

- An electric switch may operate (usually through relays) the blower motor, the compressor clutch, and other electric components.



Chrysler

Figure 83-29. Exploded view of vent and heat components that mount under the dash of a car. Note the vacuum motors, the heater core, and the blower.

- Mechanical levers and cables can operate air doors (air flaps) over the heater core, evaporator, and ducts.
- A vacuum switch can operate vacuum motors (vacuum diaphragms) that open and close the air doors.
- An electronic control unit (computer) and sensors can operate the heating and air conditioning systems automatically.

Manual Temperature Control

Manual controls for the heating and air conditioning systems are driver controlled. The driver must select the blower speed and air door positions to control the heating or cooling temperatures.

Push-pull cables use a stiff steel cable that slides back and forth in its housing. This design, after prolonged service, tends to bind when pushed. A ***pull-pull cable*** loops cable in its housing so that it always pulls when activated. Like a movable clothesline, turning the dash knob pulls the cable in both directions for smoother operation. A typical cable-type manual control for a heater is shown in **Figure 83-30**.

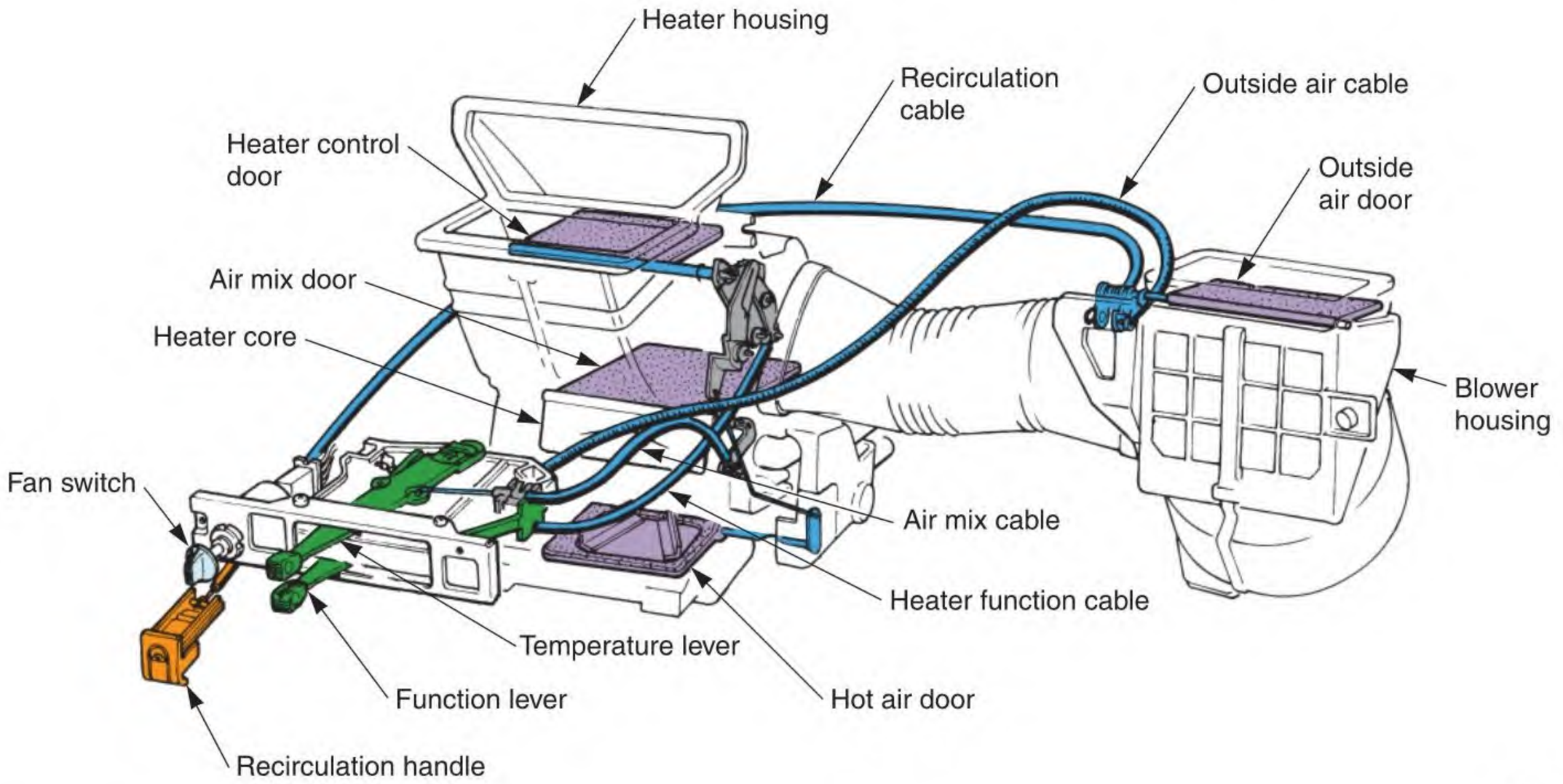
A manual control system can also use ***vacuum motors*** (sealed rubber diaphragms) to operate the air doors. If used, the control panel will contain a ***vacuum switch*** to route engine vacuum to the correct vacuum motor. The vacuum motors then move the air doors.

Figure 83-31 shows how air can be mixed to control the temperature of the air entering the passenger compartment.

Automatic Temperature Control

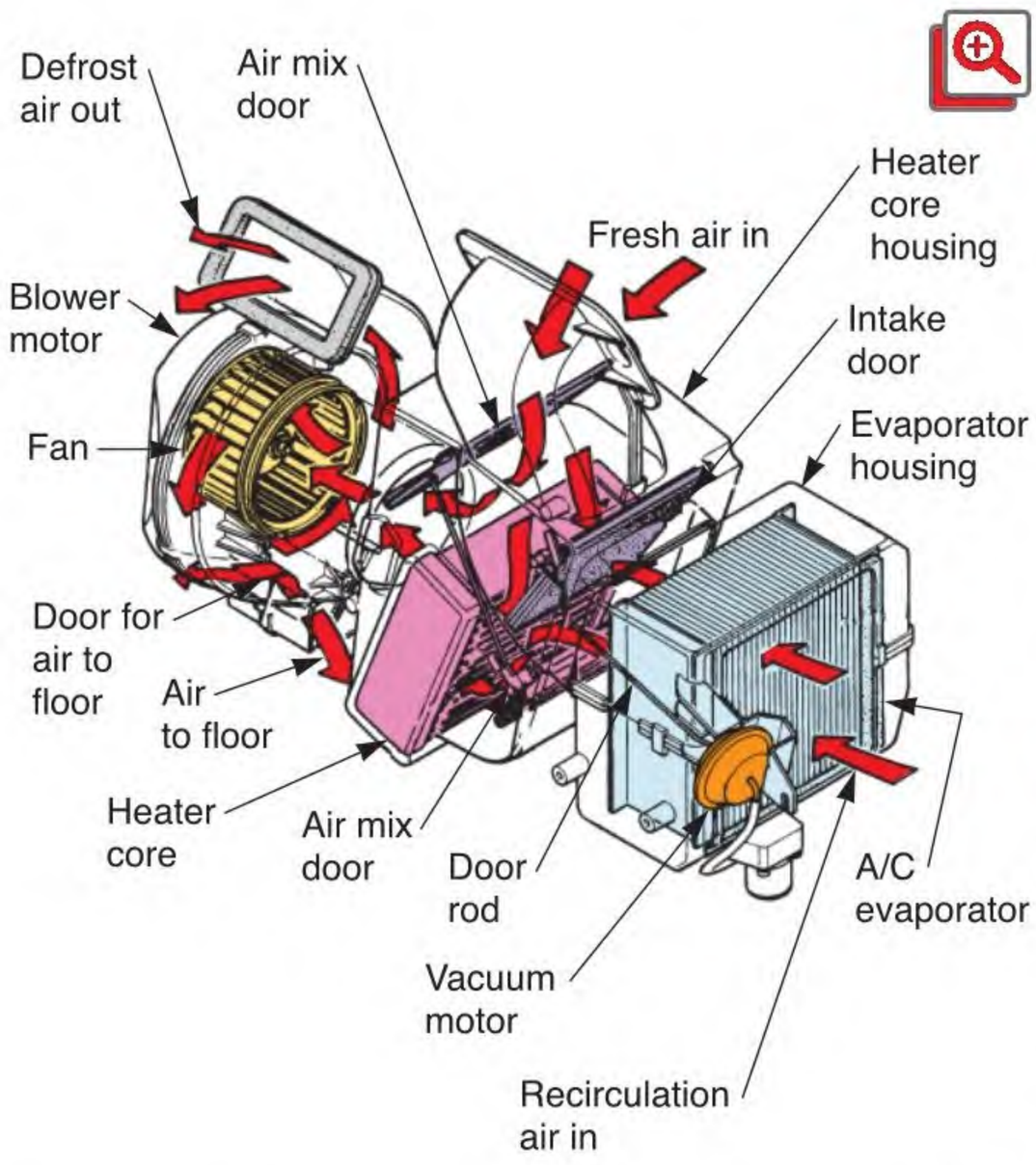
Automatic temperature control systems use various pressure and temperature sensors and a control module (computer) to maintain a preset passenger compartment temperature. See **Figure 83-32**. The driver sets the instrument panel controls to a specified temperature; then the heating and air conditioning systems automatically keep the vehicle's passenger compartment at this temperature.

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Honda

Figure 83-30. Driver's dash levers can be moved to operate cables to the air control doors. Doors then open or close the ducts to route warmed or cooled air to the passenger compartment.



Nissan

Figure 83-31. Trace the airflow through the heater core and air conditioning evaporator. Hot and cold air blend when needed to maintain a comfortable temperature output.

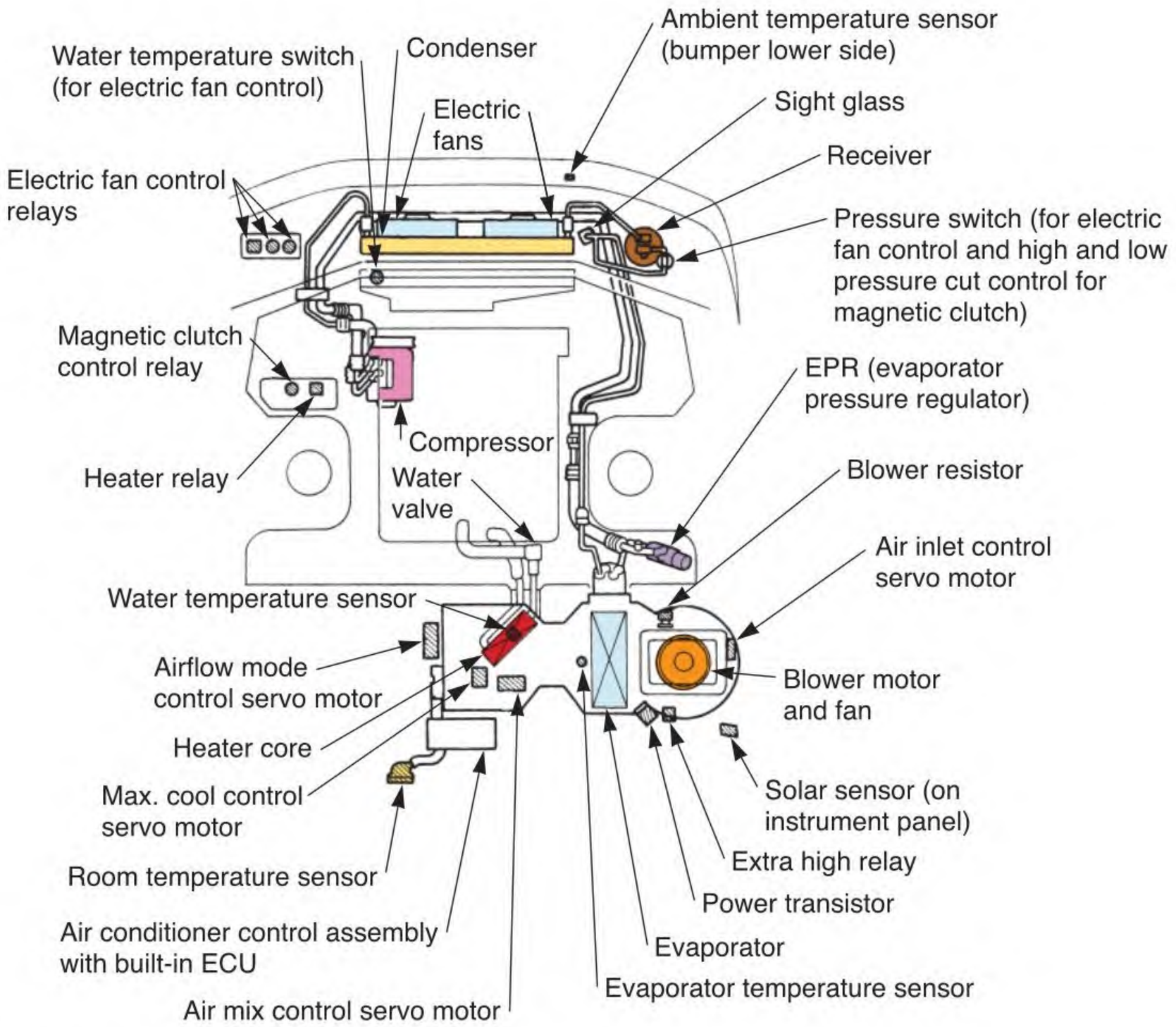
An automatic temperature control system can use three temperature sensors: an in-car sensor, a duct sensor, and an ambient (outside) air sensor. These temperature sensors may be thermistors. A ***thermistor*** is an electrical device that changes resistance with a change in temperature. For example, the in-car sensor's (thermistor's) internal resistance may drop when the passenger compartment temperature drops. The increased current flow could be used by the electronic control unit to turn on the heater or to turn off the air conditioning system. In this way, the system maintains the preset temperature.

Ducts and Vents

Ducts are plastic tubes of various shapes that carry air over the evaporator and the heater core, as well as to the vents. See **Figure 83-33**.

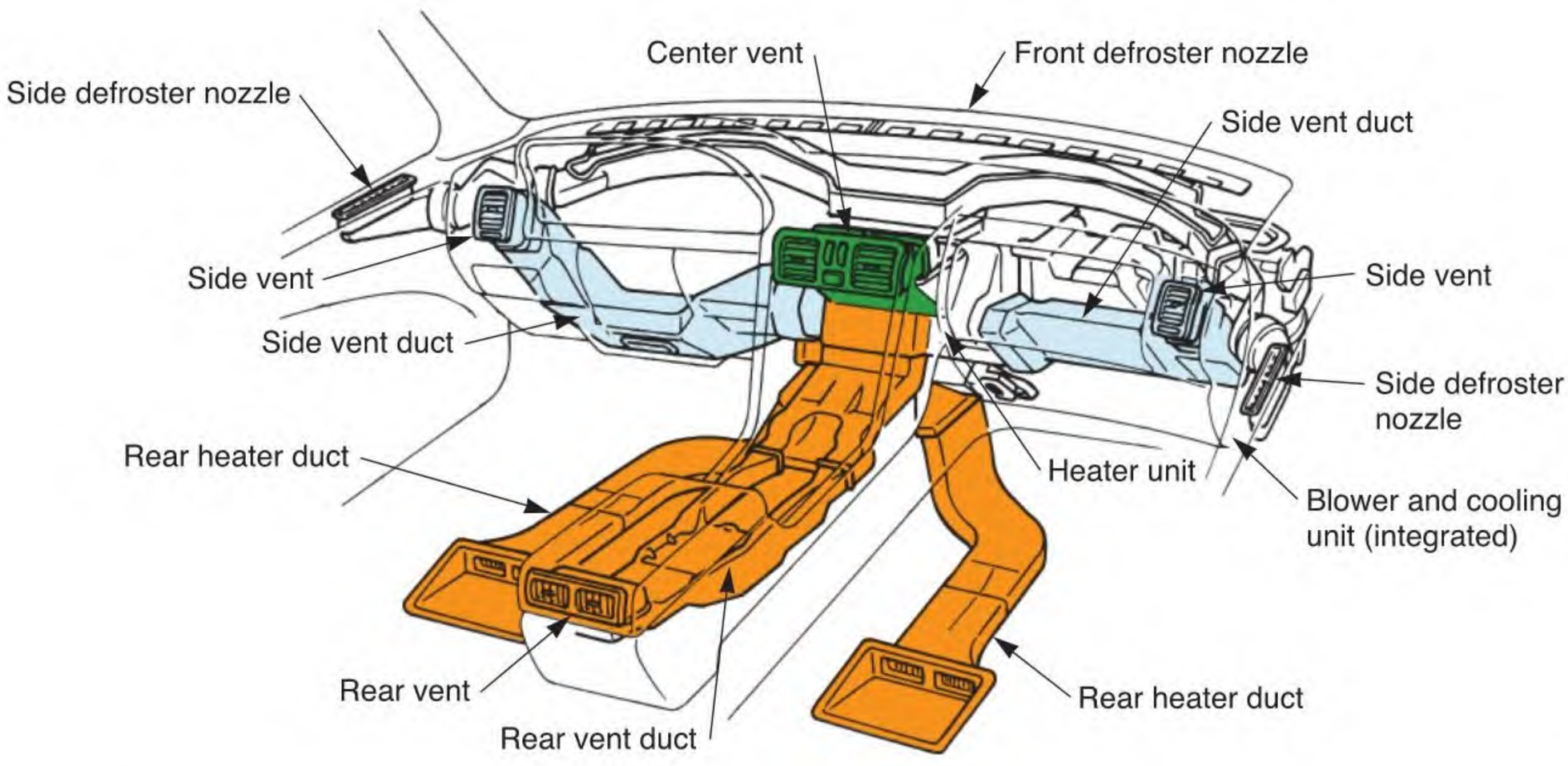
Air blows into the passenger compartment through ***vents*** (louvered openings). Adjustable grills are provided to open and close the vents and to change the direction of airflow.

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Lexus

Figure 83-32. Study the general layout of this automatic temperature control system. The in-car temperature sensor is the primary controller of the system.



Lexus

Figure 83-33. Note how the ducts and vents route air into the passenger compartment.

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Passenger Compartment Filters

Some climate control systems use a ***high-efficiency air filter*** to clean the air entering the passenger compartment. This filter helps people with allergies by trapping pollen and other particles in the air.

Electronic air filters use electrically-produced ion action to help remove small particles, such as dust and pollen, from the air entering the passenger compartment. An electrically-charged, plastic micron filter traps particles as small as 5 microns (0.0002″ or 0.005 mm). The electrical charge (ion action) on the polyester-polycarbonate plastic filter causes these microscopic particles to stick to the surfaces of the element and not enter the passenger area through the climate control system.

Solar Ventilation

A ***solar ventilation system*** uses energy from sunlight to operate the blower. The major parts of a solar ventilation system include:

- ***Solar ventilation switch***—The solar ventilation switch allows the system to be manually turned on and off.
- ***Ambient temperature switch***—The temperature switch turns the blower on if the interior temperature is high enough.
- ***Ventilation fan***—A small, low power consumption fan circulates outside air through the interior.
- ***Solar cell***—The solar cell is a solar panel that converts sunlight into electricity.
- ***Solar ventilation ECM***—A small computer monitors and controls the operation of the solar ventilation system.

The solar cell is usually located in the roof or the moon roof of the vehicle. The solar cell converts sunlight directly into electrical energy, which is used to operate the blower. The blower circulates cool air to lower the temperature in the passenger compartment in hot weather. The solar cell can also be used to recharge the battery if needed. See **Figure 83-34**.

Hybrid Systems

In some hybrid vehicles, the gasoline engine powers the air conditioning compressor. This makes it difficult for the air conditioning system in these vehicles to maintain a constant temperature because the compressor stops turning when the gasoline engine shuts down—during stops or during all-electric operation. However, switching to the maximum A/C setting keeps the engine running at all times for efficient cooling.

On many hybrid vehicles, the compressor is turned by an electric motor powered by the battery pack. Therefore, the compressor operates even when the gasoline engine is off.

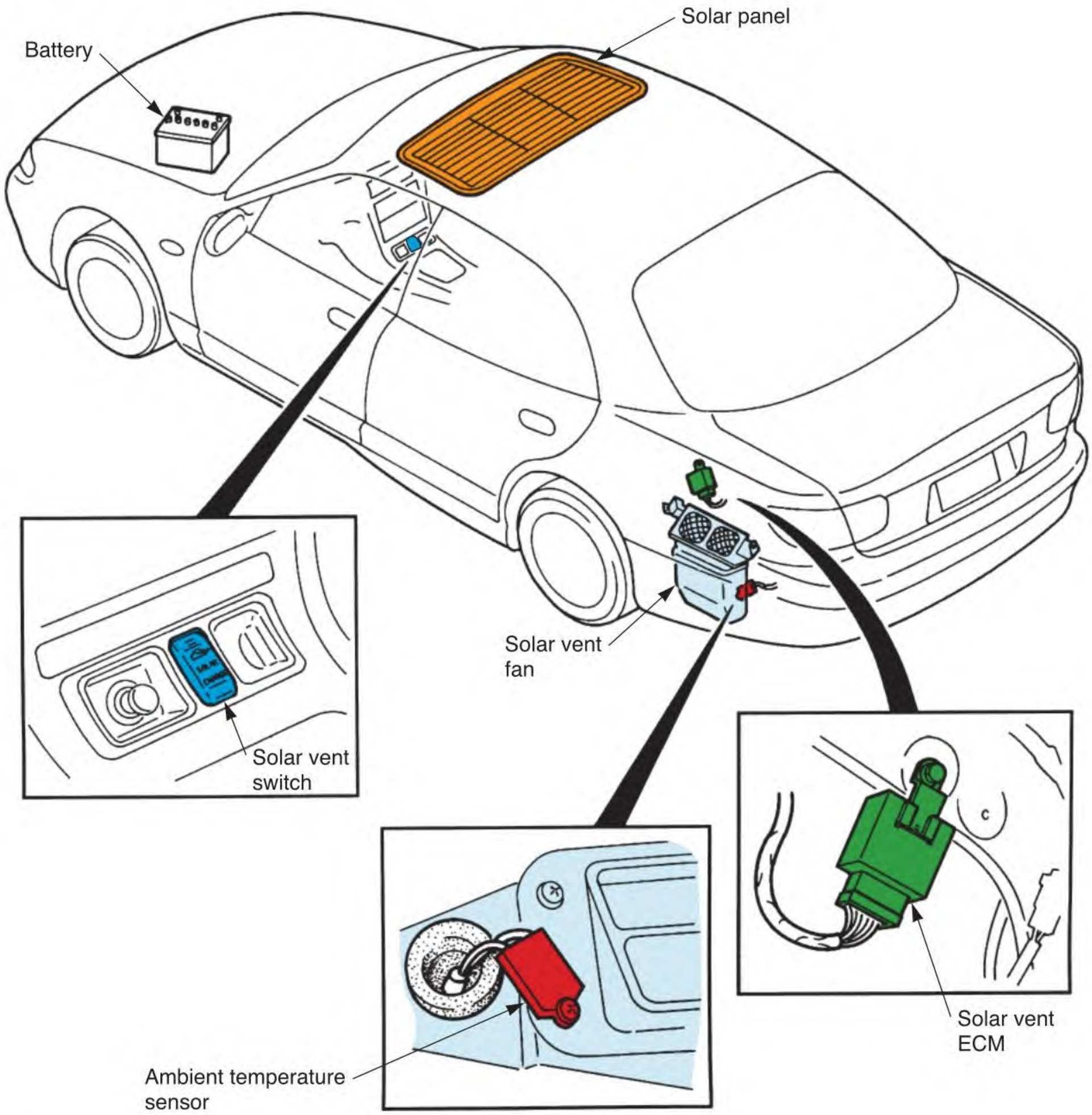


Green Tech

Aerosol Spray Cans

Aerosol spray cans may be used in various areas of automotive repair, such as paint touch-ups or for cleaning. Many aerosol sprays use chlorinated compounds, which emit volatile organic compounds (VOCs) into the atmosphere. Another concern with aerosol spray cans is the product contained within. When disposing of these cans, they must be completely empty or they can be considered hazardous waste. The containers themselves pose a threat to the environment if they are not recycled. To combat the dangers caused by aerosol spray cans, green shops can use water-based products over chlorinated products. To help reduce the amount of empty cans produced, use refillable spray bottles for aqueous solutions.

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Mazda

Figure 83-34. These are the basic parts of a solar ventilation system. This system helps keep the interior cool in very hot, sunny weather.

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Summary

- The term *air conditioning* generally means to control the temperature, humidity, and flow of air in the passenger compartment.
- There are three basic states of matter: vapor, liquid, and solid.
- Conduction is heat transfer through objects that are touching each other.
- Convection is heat transfer caused by the air surrounding objects.
- Radiation is carried out by infrared rays.
- Cold is actually an absence of heat.
- The British thermal unit, abbreviated Btu, is the unit of measurement for heat transfer from one object to another.
- Condensation occurs when a vapor changes into a liquid.
- A refrigerant is a substance with a very low boiling point. It is circulated through a refrigeration, or air conditioning, system.
- R-134a is currently being used because it is less damaging to the ozone layer than R-12.
- The high side, or discharge side, of an A/C system consists of the parts between the output of the compressor and the flow-control restriction.
- The low side, or suction side, of an A/C system consists of the parts between the flow-control restriction and the inlet of the compressor.
- An air conditioning compressor is a refrigerant pump that is bolted to the front of the engine.
- A reed valve is simply a thin piece of metal that bends to open and close an opening.
- A magnetic clutch is used to engage and disengage the air conditioning system compressor.
- Refrigerant oil is a high-viscosity, highly refined (pure) oil used to keep the parts of the air conditioning system lubricated.
- An air conditioning condenser is a radiator-like device that transfers heat from the refrigerant to the outside air.
- A receiver-drier removes moisture from the system and stores extra refrigerant.
- The evaporator, like the condenser, is a refrigerant coil mounted in cooling fins.
- The expansion tube, or orifice tube, has a fixed opening that meters the amount of refrigerant flowing into the evaporator.
- An expansion valve is a temperature-sensitive valve that controls refrigerant flow and the evaporator temperature.
- The heating system uses the engine's cooling system heat to warm the passenger compartment in cold weather.
- The heater core is a small, radiator-like unit that provides a large surface area for heat dissipation into the passenger compartment.
- Automatic temperature control systems use temperature sensors and a control module (computer) to maintain a preset passenger compartment temperature.
- Ducts are plastic tubes of various shapes that carry air over the evaporator, the heater core, and the vents.
- The vents are the louvered openings where air blows into the passenger compartments.
- Some climate control systems use a high-efficiency air filter to clean the air entering the passenger compartment.
- A solar ventilation system uses energy from sunlight to operate the blower.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

A/C switch
accumulator
air conditioning compressor
air conditioning condenser
air conditioning system
ambient temperature switch
automatic temperature control systems
basic refrigeration cycle
blower
British thermal unit (Btu)
compressor cycling switches
condensation
conduction
convection
cycling clutch system
discharge service valve
discharge side
ducts
evaporation
evaporator
expansion tube
expansion tube A/C system

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expansion valve
Freon
heater core
heater hoses
heating system
high side
high-efficiency air filter
high-pressure cutout switch
low side
low-pressure cutout switch
magnetic clutch
muffler
orifice tube
pressure cycling switch
pressure relief valve
pull-pull cable
push-pull cables
R-12
R-134a
radiation
receiver-drier
reed valve
refrigerant
refrigerant hoses
refrigerant oil
refrigerant system
Refrigerant-12
service valves
sight glass
solar cell
solar ventilation ECM
solar ventilation switch
solar ventilation system
states of matter
suction service valve
suction side
superheat switch
thermal limiter
thermistor
thermostatic cycling switch
vacuum motors
vacuum switch
vaporization
ventilation fan
ventilation system
vents
wide open throttle (WOT) switch

Activities

1. Make a sketch (by hand or using a computer graphics/drawing program) of a basic refrigeration system. Create a presentation from your sketch and use it to explain the refrigeration cycle to the class.
2. Obtain a junked automotive air conditioning compressor and disassemble it. Identify the type of compressor and the basic parts. Then, reassemble the compressor.
3. Research R-12 and other CFC refrigerants to find out why they are dangerous to the environment. Write a short report (1–2 pages) on the problem and the action being taken to solve it.
4. Demonstrate the procedure for removing and installing the passenger compartment filter, or cabin filter, on a vehicle of your choice. Inspect the filter and, if possible, determine when it was last replaced. Discuss with your classmates the issues caused by neglecting to change the cabin filter according to the vehicle manufacturer's recommendations.

Review Questions



Answer the following questions using the information provided in this chapter.

1. The three basic states of matter are _____, _____, and _____.
2. Explain the three methods of heat transfer.
3. Heat always moves from the colder object to the warmer object. True or False?
4. What is a Btu?
5. _____, the opposite of _____, occurs when a vapor changes back into a liquid.
6. This substance circulates inside an air conditioning system.
   (A) Refrigerant.
   (B) R-12.
   (C) R-134a.
   (D) All of the above.
7. List and explain the eight basic parts of a refrigeration system.
8. Which of the following is *not* a function of an air conditioning system?
   (A) Cools air.
   (B) Circulates air.
   (C) Humidifies air.
   (D) Cleans air.
9. Describe the high and low side of an air conditioning system.
10. How does an air conditioning compressor turn on and off?
11. Name the five types of air conditioning compressors.
12. _____ _____ is used in the A/C system to keep the compressor lubricated.
13. How does the expansion tube A/C system control output temperature?
14. How does the thermostatic expansion valve A/C system control outlet temperature?

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15. Why are service valves provided?
16. The suction service valve is located at the inlet to the compressor, in the system low side. True or False?
17. The _____ _____ is a small radiator-like device that provides a large surface area for heat dissipation into the passenger compartment.
18. Explain four methods used to operate heater components.
19. Define the term *thermistor*.
20. How does a solar ventilation system work?

ASE-Type Questions

1. Technician A says the operating principles of an automotive air conditioning system are completely different than those of a home refrigerator. Technician B says an automotive air conditioning system operates on the same principles as a home refrigerator. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Technician A says vapor is one of the basic states of matter. Technician B says a molecule is one of the basic states of matter. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. Technician A says "conduction" is heat transfer through objects that are touching each other. Technician B says "conduction" is heat transfer caused by the air surrounding objects. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. Technician A says heat always transfers from a hotter object to a colder object. Technician B says heat always transfers from a colder object to a hotter object. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
5. Technician A says "evaporation" normally refers to a liquid changing into a vapor state. Technician B says "evaporation" normally refers to a vapor changing into a solid. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Technician A says "condensation" occurs when liquid changes back into a vapor. Technician B says "condensation" occurs when a vapor changes back into a liquid. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. Technician A says when pressure is placed on a substance, the temperature of the substance increases. Technician B says when pressure is placed on a substance, the temperature of the substance decreases. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. Technician A says a "refrigerant" is a substance with a very low boiling point. Technician B says a "refrigerant" is a substance with a very high boiling point. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Technician A says the refrigerant R-134a has been found dangerous to the environment and its production was ceased in 1995. Technician B says the refrigerant R-12 has been found dangerous to the environment and its production was phased out. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. Technician A says in a basic refrigeration cycle, the refrigerant goes through a compression phase. Technician B says in a basic refrigeration cycle, the refrigerant goes through a vaporization phase. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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11. Technician A says an automotive air conditioner's condenser causes refrigerant to change from a gaseous state into a liquid state. Technician B says an automotive air conditioner's condenser causes refrigerant to change from a liquid state into a gaseous state. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
12. Technician A says the "high side" of an automotive air conditioning system is known as the "discharge side." Technician B says the "high side" of an automotive air conditioning system is known as the "suction side." Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
13. Technician A says a "crank-type" compressor is used on certain automotive air conditioning systems. Technician B says a "rotary vane type" compressor is used on several automotive air conditioning systems. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
14. Technician A says an automotive air conditioner's accumulator forces air through the evaporator and into the passenger compartment. Technician B says an automotive air conditioner's accumulator keeps liquid refrigerant from entering the compressor. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
15. All of the following are basic components of an automotive heating system, *except:*
    (A) blower.
    (B) heater core.
    (C) receiver-drier.
    (D) ducts.

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Chapter 84
Heating and Air Conditioning Diagnosis, Service, and Repair

After studying this chapter, you will be able to:

- Visually inspect a heating and air conditioning system and locate obvious troubles.
- Diagnose common heating and air conditioning problems.
- Describe the functions and uses of air conditioning test equipment.
- Locate air conditioning and heating system leaks.
- Explain how to replace major heating and air conditioning components.
- Describe the general procedures for evacuating and charging an air conditioning system.
- Demonstrate safe working practices when servicing heating and air conditioning equipment.
- Correctly answer ASE certification test questions about the diagnosis and repair of heating and air conditioning systems.

Heating and air conditioning systems are prone to failure. Even the smallest leak (refrigerant or coolant) will eventually prevent either system from working properly. As you will learn, correct service methods not only keep the vehicle operating normally, but also help protect our environment from damage caused by refrigerant gases and antifreeze spillage.

Inspecting an Air Conditioning System

When an air conditioning system does not cool properly, visually inspect the entire system. Look for obvious signs of trouble, including:

- Loose or missing compressor drive belt.
- Inoperative compressor clutch.
- Disconnected or damaged wiring or vacuum hoses.
- Refrigerant leaks (wetness) around lines or fittings.
- Blockage (leaves, mud) in the condenser fins.
- Inoperative air control doors.

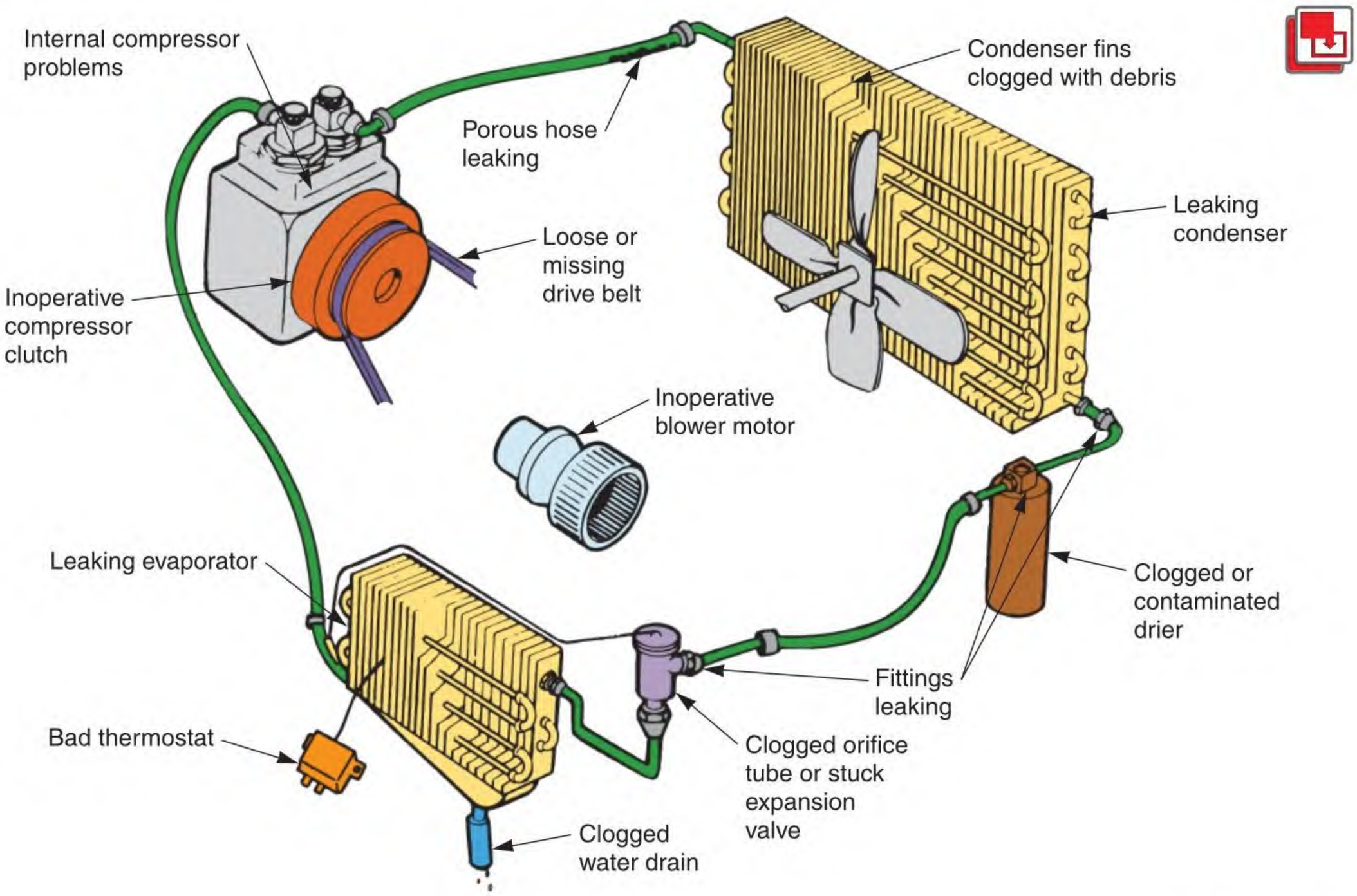
Some common air conditioning system problems are illustrated in **Figure 84-1**.

Scanning the A/C System

Late-model climate control systems produce trouble codes if the on-board diagnostic system detects an abnormal circuit value or condition. If the indicator light in the dashboard glows, connect a scan tool to the vehicle. The scan tool might indicate problems with air conditioning system circuits and components, such as:

- Radiator fan circuit
- A/C clutch circuit

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Figure 84-1. Note the types of problems that develop in a typical air conditioning system.

- A/C pressure circuit (low, high, or out of range)
- Outside temperature sensor circuit
- Interior temperature circuit
- Solar sensor circuit
- Blower motor circuit
- A/C high side and low side temperature sensors
- Compressor relay circuit
- Airflow control circuit
- Control head circuit
- Climate control ECM

Modern OBD systems monitor almost every circuit in a climate control system, which makes the task of troubleshooting very efficient.

Checking Line Temperatures

To check the basic action of an A/C system, start the engine. Turn the air conditioning system on high and allow it to run for about ten minutes. Feel the refrigerant lines or aim a laser thermometer at both high- and low-pressure lines to check their temperatures.

The *high-side* (discharge) line should be warm or hot. The *low-side* (suction) line should be cool. If this is the case, you know that refrigerant is moving through the system.

When the low-side line is cold but the system does *not* cool the passenger compartment, there might be a problem with the air control doors or the instrument panel controls.

If the high-side line is *not* warm and the low-side line is *not* cold, a problem exists in the refrigeration section of the system. You must perform other tests to pinpoint the problem source.

Inspecting the Sight Glass

Check the air conditioning system sight glass (if used) during your visual inspection of the system. It can give you information on the condition of the

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system. The sight glass may be located in the top of the receiver-drier or in a refrigerant line. **Figure 84-2** shows how to read an A/C system sight glass.

A ***clear sight glass*** usually indicates that the A/C system has the correct charge of refrigerant. However, it can also indicate an empty system. If the low-side line is cool, there is refrigerant in the system. If the sight glass is clear and the low-side line is warm, the system could have a refrigerant leak.

A ***bubbling sight glass*** indicates that the A/C system is low on refrigerant and air is in the system. However, an occasional bubble during clutch cycling or system start-up may be normal.

An ***oil-streaked sight glass*** denotes a low refrigerant level. In this case, excessive compressor oil is circulating through the system.

A ***cloudy sight glass*** may indicate that the desiccant (drying agent) in the receiver-drier or the accumulator has broken down and is circulating through the system. You probably need to replace the unit or the desiccant bag.

Sight glass readings can be used only as indicators of system problems. They are not totally accurate. You must perform other tests to verify problems.

Refrigerant Safety Precautions

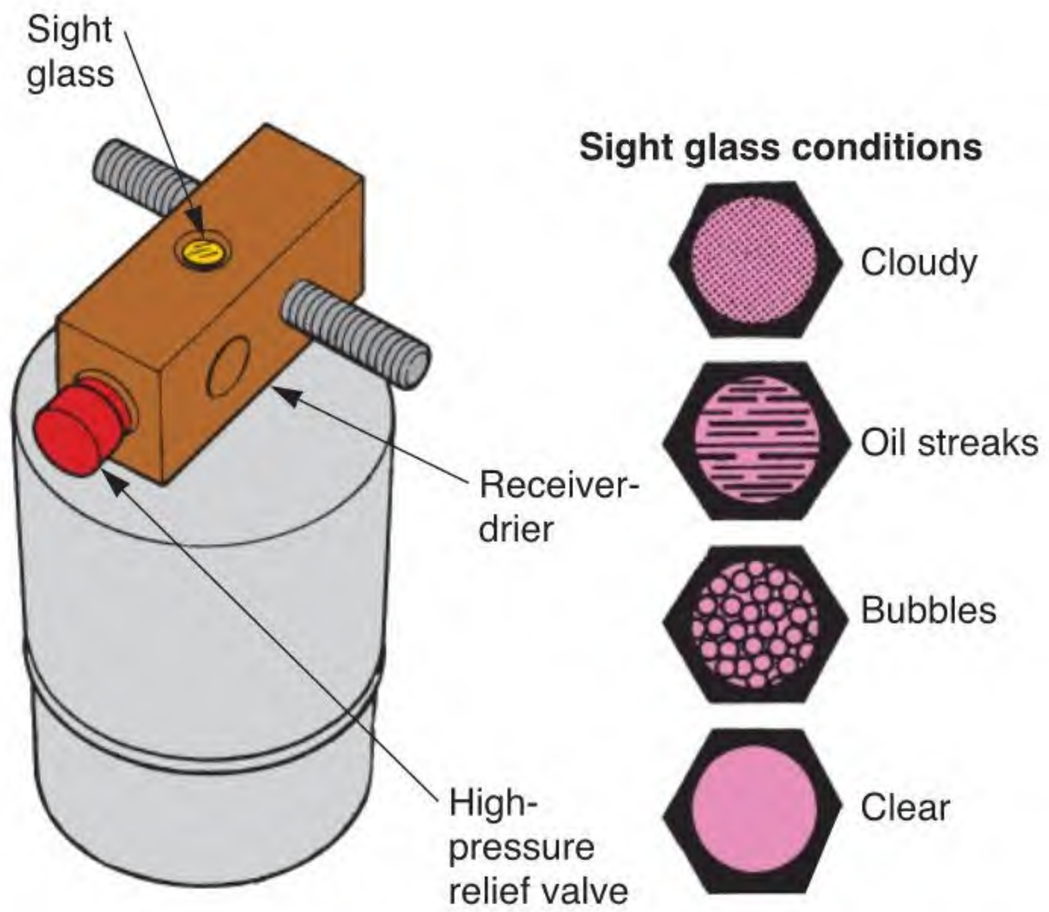
To avoid injury, observe the following safety precautions when working with refrigerant:

- Refrigerant can cause severe *frostbite* if it contacts your skin. Be careful when opening a line in the air conditioning system. Place a rag around the fitting before loosening the connection.
- Always wear safety glasses when working with refrigerant—it can cause *blindness* if it sprays into your eyes. If refrigerant sprays into your eyes, flush them with water, without rubbing. Always consult a doctor.
- Store refrigerants away from excessive heat. Pressure in a refrigerant container increases as temperature rises. High heat could make the tank explode, shooting metal fragments and refrigerant into your face or hands. Store refrigerant at temperatures below 104°F (40°C).
- Keep refrigerant away from an open flame. When burned, refrigerant turns into phosgene gas, a highly *toxic poison*. When using a torch-type leak detector, carefully follow directions and make sure the work area is well ventilated.
- Never discharge refrigerant into the air. To prevent environmental damage, all refrigerant must be reclaimed or recycled. Also, discharging any vapor in a confined space, where it could displace air, may cause *suffocation*.
- Improper refrigerant storage poses a danger to those working in the shop and to the environment. In addition to causing physical injury such as frostbite, refrigerants allowed to escape from storage containers can damage the Earth's ozone layer.
- Refrigerants should be stored in approved containers that are in good condition. Replace containers exhibiting signs of corrosion or damage. If a container is designed to accept a safety cap, secure the cap when the container is not in use.
- Store refrigerant containers in a location away from mechanical work so they are not accidentally damaged during vehicle repair operations. Accidentally striking or knocking over a container could cause the release of refrigerant into the atmosphere.

R-134a Service Differences

R-134a refrigerant systems require the use of special tools, fittings, and service procedures. See **Figure 84-3**.

- Never use a flammable refrigerant, like OZ-12, in a system designed for R-134a or R-12. If a crash or collision occurs, this type refrigerant could catch fire and kill someone.



Chrysler

Figure 84-2. If used, inspect the sight glass. It will indicate the condition of the A/C system. The sight glass may be in the top of the receiver-drier or in the line.

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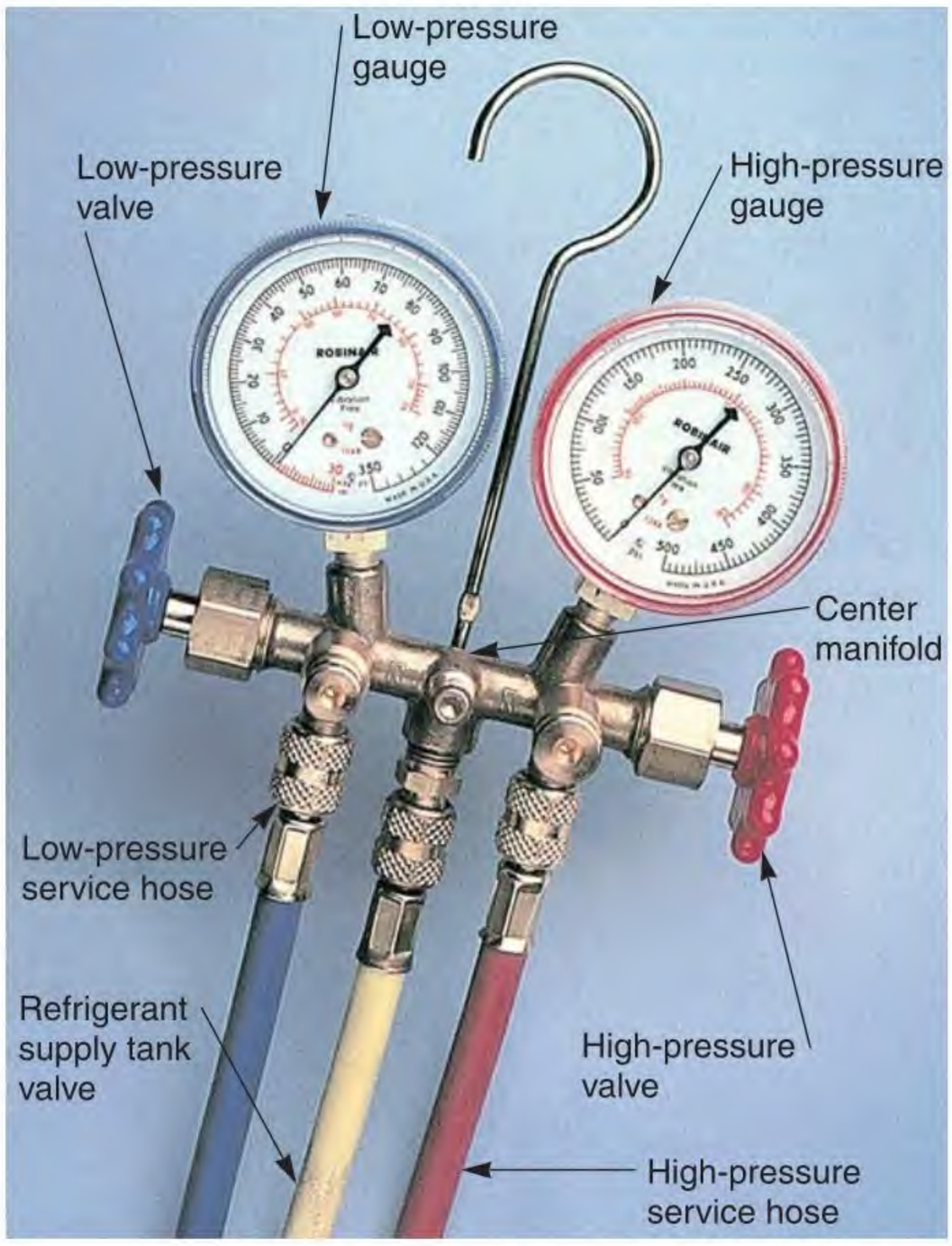
Service Tools			
Part/tool	**R–12 system**	**R–134a system**	**Remarks**
Tool joints	Inch threads	Metric threads	Threads standards for tool joints have been changed to avoid confusing R-12 system tools with R-134a system tools.
Charging valve joints	Screw-on type HI: 3/8–24 UNF LO: 7/16–20 UNF	Quick-connect–type HI: 16 mm (0.6 in) dia. LO: 13 mm (0.5 in) dia.	The shape of the charging valve joints differ for each system to avoid confusion. The quick-connect–type charging-valve joint prevents refrigerant from leaking when the charging hose is connected to the valve.
Manifold gauge	High-pressure side maximum reading: 2.9 MPa (30 kgf/cm^2, 430 psi)	High-pressure side maximum reading: 3.5 MPa (35 kgf/cm^2, 500 psi)	R-134a requires a higher pressure to condense than R-12.
Gas leak tester	Gas type Electric type	Electric type	A gas leak tester reacts with chlorine in R-12 to indicate the location of a leak. This kind of tester does not work with an R-134a system, however, because R-134a has no chlorine. Two kinds of electric testers are available: those that work exclusively with one system or the other, and those that work with both. A tester built only for R-12 systems cannot be used with R-134a systems.
Refrigerant	Chlorofluorocarbon–12 (CFC–12) (CCl_2F_2)	Hydrofluoro-carbon–134a (HFC–134a) (CH_2FCF_3)	If the refrigerants are mixed or one refrigerant is used in a system that requires the other, the compressor oil will separate from the refrigerant and not circulate within the system. This can damage the A/C compressor and cause abnormal A/C compressor vane noise. In addition, mixing R-134a with R-12 or using R-134a instead of R-12 in an R-12 system can lower the durability of the NBR O-ring and dissolve the fluorine rubber O-rings. If the fluorine rubber O-rings are dissolved, refrigerant may leak.
Compressor oil	Mineral oil	Polyalkylene glycol oil (PAG oil) (ATMOS GU10)	Special compressor oils for R-134a air conditioning systems are developed by each air conditioning vendor. Therefore, use only the specified oil for each model vehicle. If a PAG oil other than the specified type is used, the A/C compressor and refrigerant system can be damaged. If the compressor oils are mixed or one compressor oil is used in a system that requires the other, the refrigerant will separate from the compressor oil and not circulate within the system. This can damage the A/C compressor and cause abnormal A/C compressor vane noise. Mixing PAG oil with mineral oil or using PAG oil instead of mineral oil in an R-12 system can lower the durability of the NBR and fluorine rubber O-rings.
O-ring	Nitrile butadiene rubber (NBR) Fluorine rubber	High-circulated nitrile butadiene rubber (HNBR)	If an NBR O-ring is used in an R-134a system, the PAG oil and R-134a will lower the durability of the O-ring. If a fluorine rubber O-ring is used in an R-134a system, the R-134a will dissolve the O-ring and cause the refrigerant to leak.
Charging valve	Screw-on type HI: 3/8–24 UNF LO: 7/16–20 UNF	Quick-connect–type HI: 16 mm (0.6 in) dia. LO: 13 mm (0.5 in) dia.	The shape of the charging valve differs for each system to avoid confusion. The quick-connect–type charging valve prevents refrigerant from leaking when the charging hose is connected to the valve.

Mazda

Figure 84-3. Chart compares R-12 and R-134a parts and tools. Study the differences closely.

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- The refrigerant tank for R-134a is normally blue, while R-12 is normally stored in a white tank.
- Tool fittings on R-12 systems use US Customary threads, while R-134a fittings have metric threads.
- R-134a service fittings are male, while R-12 service fittings are female.
- R-12 systems use screw-on fittings on charging valve joints; R-134a systems use quick-disconnect fittings on charging valve joints.
- Pressure gauges must read higher values when testing R-134a systems.
- Never mix R-12 and R-134a. Mixing these will make the refrigerant oil separate out of the refrigerant gas, resulting in severe compressor damage. Mixing refrigerants can also deteriorate O-ring seals and cause leakage.
- Only use the refrigerant oil recommended by the manufacturer. Like refrigerants, mixing R-12 (organic) oil and R-134a (synthetic) oil will cause separation and damage to the compressor and O-ring seals.
- Only use O-ring seals designed for the type of refrigerant and oil in the system. R-134a will dissolve the seals designed for R-12.



Imperial

Figure 84-4. A gauge set is commonly used when charging an A/C system with refrigerant gas.

Testing an Air Conditioning System

If your initial inspections and other checks do not find the source of the trouble, test the air conditioning system using pressure gauges. By comparing the high- and low-side pressures to specifications, you can determine the possible causes of the problem.

Pressure Gauge (Manifold) Assembly

A ***pressure gauge assembly***, or ***manifold gauge assembly***, typically consists of two pressure gauges, a manifold, two on-off valves, and three service hoses, **Figure 84-4**. The pressure reading on these gauges is affected by the outside temperature.

The low-pressure gauge measures suction, or low-side pressure. In cold weather, the low-side pressure reading may be only 31 psi. In hot weather, the low-side pressure reading for the same A/C system might be 45 psi because greater pressure is needed to sufficiently cool the evaporator. The high-side pressure gauge is used to measure compressor discharge pressure, or high-side pressure. A lower pressure reading of 150 psi may register in cold weather. Higher readings, nearing the 300 psi maximum, might be produced in weather nearing 100°F. See **Figure 84-5**.

The two outer service hoses connect to fittings on the air conditioning system. The center service hose is commonly connected to a recovery or recycling unit for cleaning or evacuating or to a refrigerant container for charging (filling) the system.

Service Valves

Service valves provide a means of connecting the pressure gauge assembly for testing, discharging, evacuating, and charging (filling) the air conditioning system. Most systems have two service valves; a few have three. The service valves may be located on the compressor fittings or in the refrigerant lines.

There are two basic types of service valves: Schrader valves and stem valves. These two types also vary for R-12 and R-134a systems.

A ***Schrader service valve*** is a spring-loaded valve, similar to the air valve in a tire. The service

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Low-side Gauge



High-side Gauge

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Figure 84-5. A/C pressure gauges give normal operating high- and low-side pressures for R-134a systems. The low-side gauge should read between 25–45 psi. The high-side gauge should read 150–300 psi.

hoses on the pressure gauge set have depressors that open these valves. This is the most common type of service valve found on late-model vehicles. See **Figure 84-6**.

An R-134a service valve has a quick-disconnect fitting that accepts a corresponding fitting on the R-134a gauge set service hose. Before connecting these fittings, make sure the thumb screw on the hose fitting is turned all the way out. Pull back the sleeve on the hose fitting while pushing the hose fitting onto the service valve fitting. Release the sleeve to lock the fittings together. Finally, tighten down the thumb screw to depress the valve. An R-12 service valve has a threaded male fitting that accepts the female fitting on the R-12 service hose. This is shown in **Figure 84-6**.

Dust caps screw over the Schrader service valves to keep out debris and to prevent accidental opening of the spring-loaded valves. Dust caps should always be reinstalled after A/C system service, **Figure 84-7**.

Caution

Never operate an air conditioning system when stem-type valves are in the frontseated position. Excessive pressure could build in the compressor, causing part overheating and damage.

Connecting A/C Pressure Gauges

With the engine stopped and safety glasses on, remove the dust caps from the service valves. Make sure the pressure gauge valves are both closed.

Connect the high-side line first. Screw the *red* (high-side) hose fitting on the high-side service valve. Then screw the *blue* (low-side) hose fitting over the low-side service valve, **Figure 84-8**.

If you have stem-type service valves, turn them 1 1/2 turns clockwise. You can then measure air conditioning system pressures and cooling temperatures as a means of testing the system. This setup will also let you discharge or charge the system.

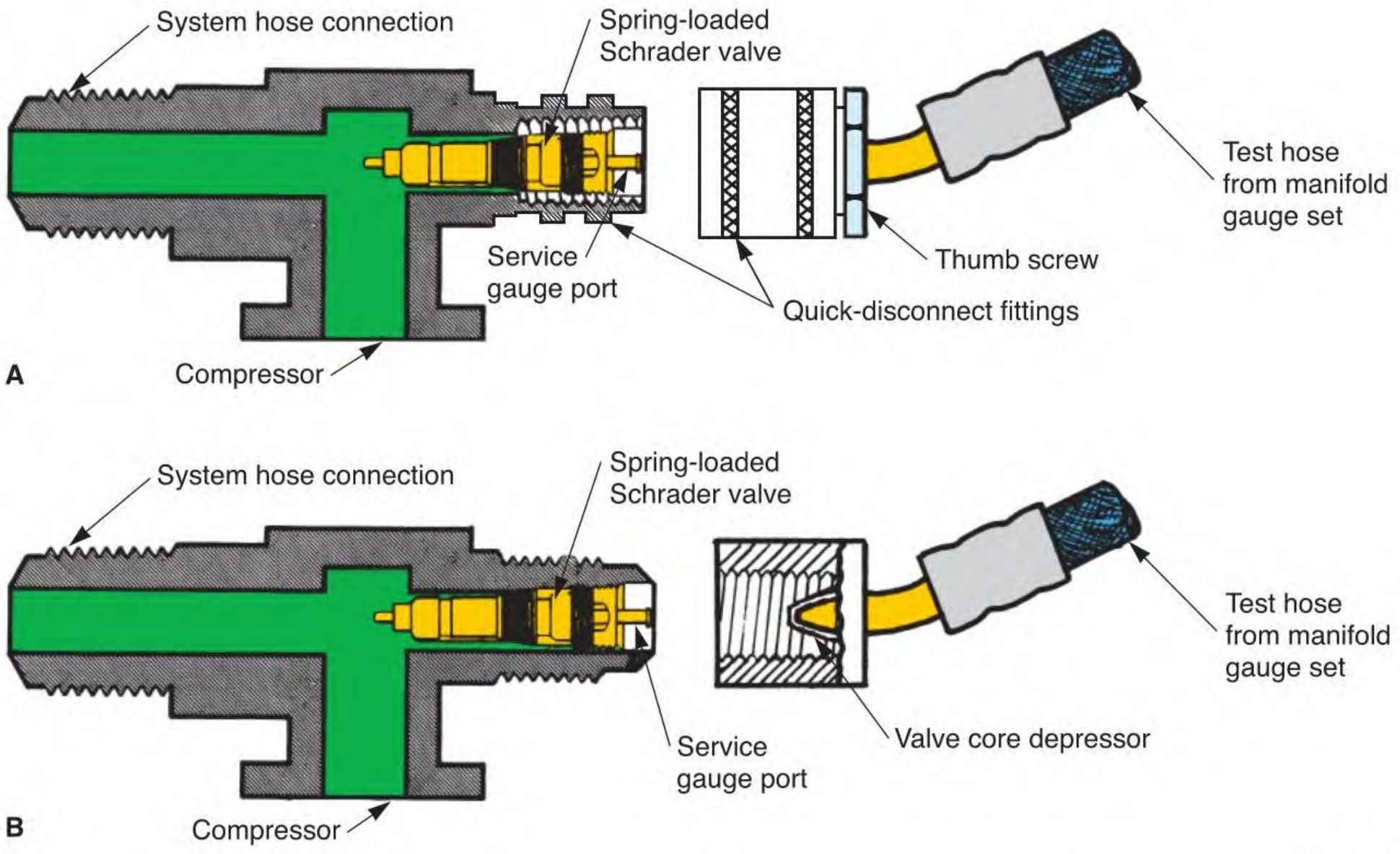
Static A/C Pressure Reading

A ***static A/C pressure reading*** indicates how much refrigerant is in the system. With the engine *off*, read the high-side pressure gauge. If the high pressure gauge shows approximately 50 psi (345 kPa), the system should have an adequate charge. If the pressure gauge reads below 50 psi (345 kPa), some of the refrigerant charge has leaked out and the system should *not* be operated. Correct any leaks and add refrigerant before making other tests.

Performance Testing A/C System

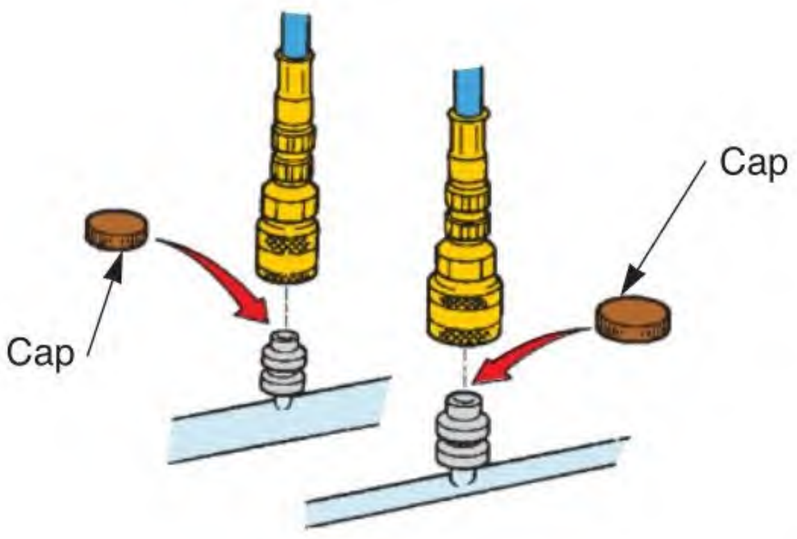
A ***performance test*** indicates air conditioning system condition by measuring cooling vent temperatures as well as system pressures with the engine running.

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Snap-on Tool Corp.

Figure 84-6. A Schrader service valve has a valve core that is similar to one used in a car tire. When the pressure gauge hose is connected to the valve, the valve is pushed open to allow gas flow. A—Quick-disconnect fittings are used in R-134a systems. B—Service fittings for R-12 systems will have male threads.



Mazda

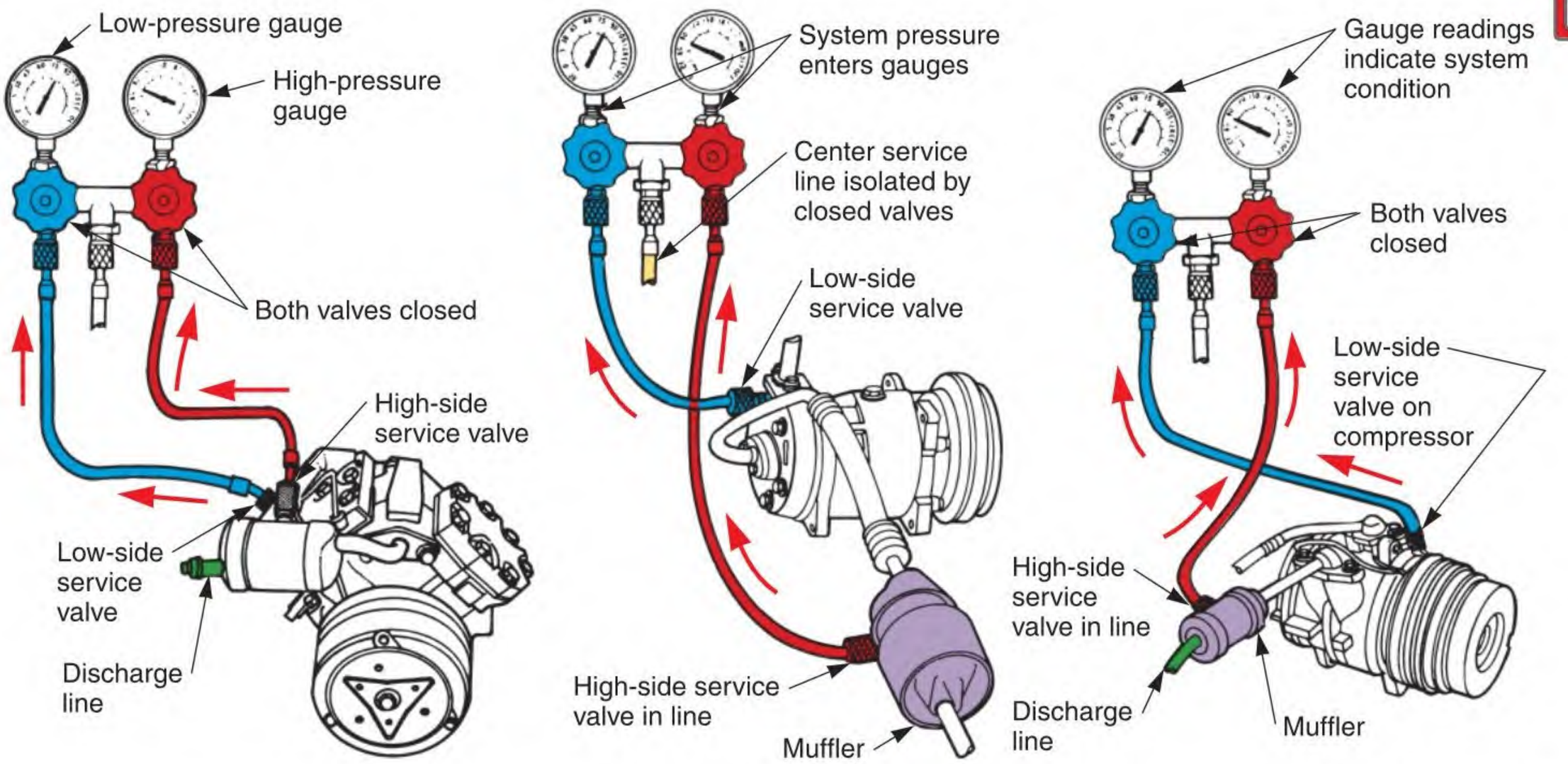
Figure 84-7. Dust caps protect Schrader valves from being filled with dirt and from accidental opening. Always reinstall the plastic caps on the service fittings.

Service Procedure

To conduct an A/C system performance test:

1. Connect an exhaust vent hose over the car's tailpipe.
2. Start the engine.
3. Set the system for maximum cooling and make sure the compressor is spinning.
4. Allow the A/C system to operate for about 10 minutes to allow pressures to stabilize.
5. Place a temperature gauge in a center air outlet in the passenger compartment. Slide the metal shaft on the temperature gauge fully down into the vent, **Figure 84-9**.
6. Close the vehicle's doors and windows. Leave the hood fully open.
7. If it is hot outside (above 85°F or 29°C), aim a large shop fan at the condenser to improve heat removal.

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Figure 84-8. Study how a pressure gauge is connected. The manifold valves are kept closed, so that refrigerant cannot flow out the center hose on the manifold.



A B

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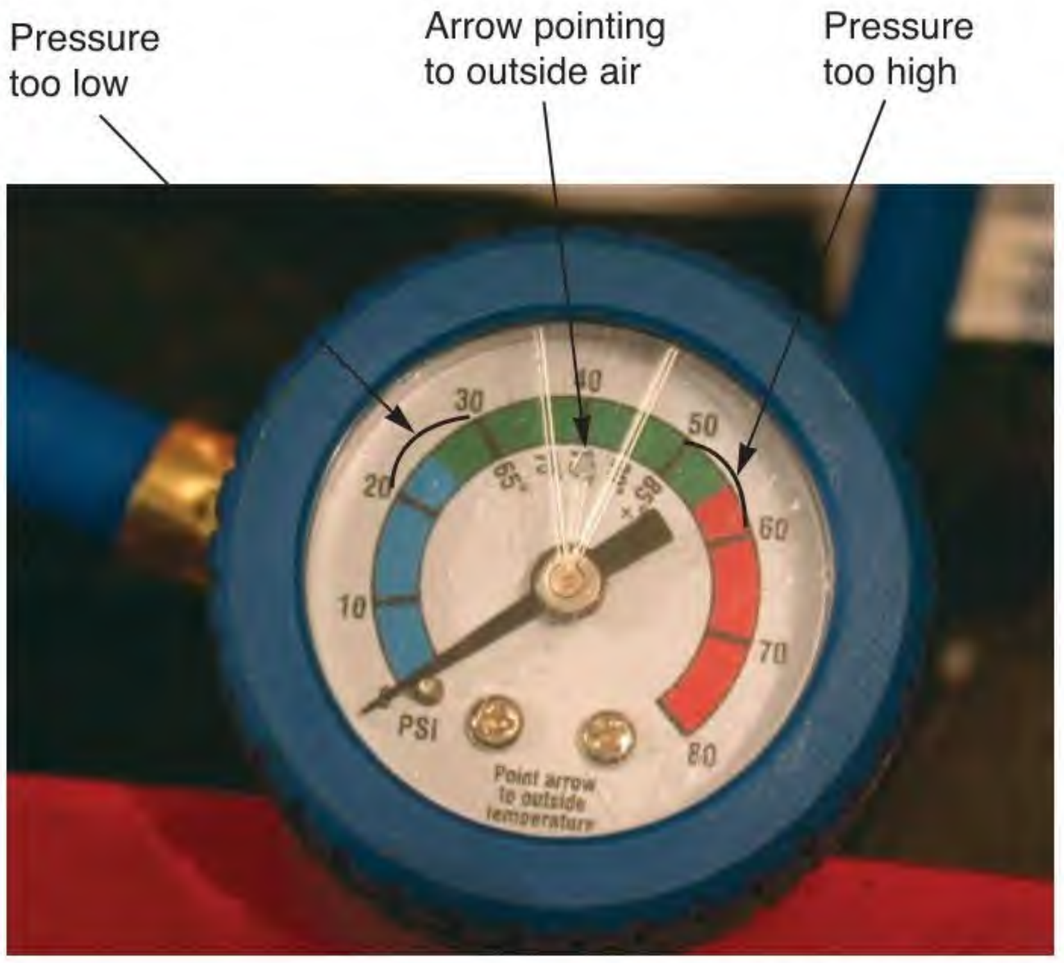
Figure 84-9. Use a temperature gauge to get a reading in a passenger compartment air vent. A—Remove the plastic sleeve to expose the metal shaft. B—Insert the thermometer shaft fully into the center vent in the dash.

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8. Place another temperature gauge at the condenser to measure ambient (outside) air temperature. See **Figure 84-10**. Both temperatures are usually needed to fully analyze system performance.
9. With R-134a, some manufacturers also require you to measure wet- and dry-bulb temperature at the blower inlet. Use a chart to find the relative humidity, which affects system operation and pressures. See **Figure 84-11**.
10. Compare pressure and temperature readings, as well as relative humidity, to factory specs.

The dash vent temperature reading should be approximately 38–60°F. In hot weather nearing 100°F ambient temperature, air at 57°F blowing out the vents will feel quite cool. In less extreme heat, the center vent temperature should be around 40°F. Note that pressure gauge readings vary with ambient air temperature, humidity, and system design.

If your pressure gauge readings are not within factory specs, there is a problem in the system.



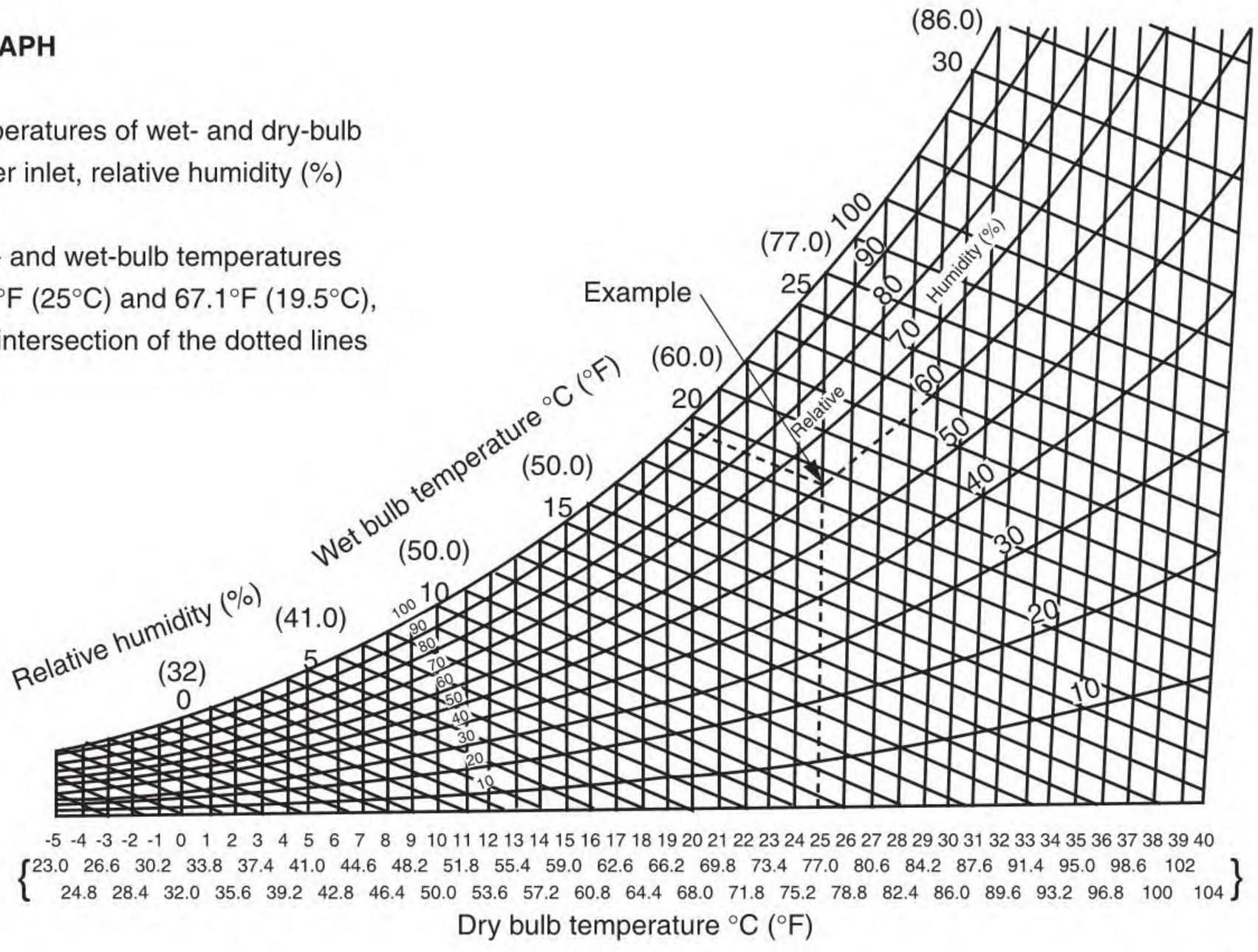
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Figure 84-10. Notice the outside temperature arrow on this low-side pressure gauge. Aim the arrow at the outside or ambient temperature of the shop. The reference lines then note the pressure range for a properly functioning A/C system.

HOW TO READ THE GRAPH

After measuring the temperatures of wet- and dry-bulb thermometer at the blower inlet, relative humidity (%) can be obtained.

Example: Supposing dry- and wet-bulb temperatures at the blower inlet are 77°F (25°C) and 67.1°F (19.5°C), respectively, the point of intersection of the dotted lines in the graph is 60%.



Mazda

Figure 84-11. A chart like this will help you convert wet- and dry-bulb thermometer readings into humidity. Note the directions in the upper-left corner.

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You must use the gauge readings, other symptoms, service manual diagnosis charts, and your knowledge of system operation to pinpoint the problem. A few examples of improper gauge readings are pictured in **Figure 84-12**.

Locating A/C System Leaks

An air conditioning system is considered leaking (needing repairs) when more than one-half pound of refrigerant must be added per year. There are several methods used to locate leaks.

An ***internally charged detector*** is a colored agent that can be charged into the system. Any leak shows up as a bright color spot (usually orange-red) at the point of leakage.

A ***bubble detector*** is a solution applied on the outside of possible leak points. The leaking refrigerant will make bubbles or foam in the leak-detecting solution.

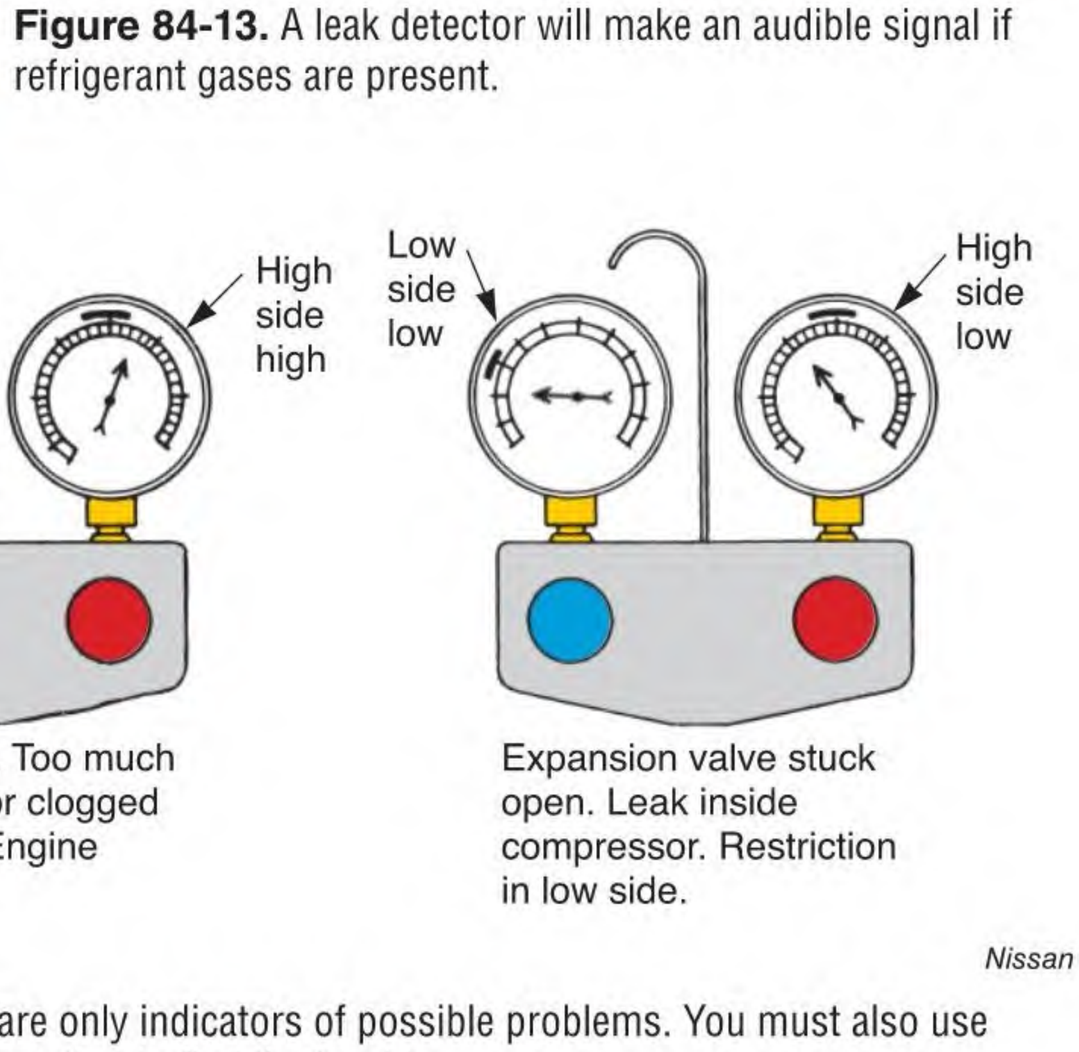
A ***torch detector*** uses a gas flame to indicate A/C leaks. Leaking refrigerant is drawn into and changes the color of the flame. If the flame does not change color, refrigerant is not present. This type of detector has been phased out for the safer electronic leak detector.

Warning

When some refrigerants are burned, a very toxic phosgene gas is produced. If it is necessary to use a torch detector, use only in a ventilated area. Keep your face away from the detector to avoid inhaling fumes.

An ***electronic leak detector*** uses a special sensor and an electronic amplifier to locate A/C leaks. It produces a sound or light signal when refrigerant is detected. See **Figure 84-13**.

An electronic leak detector is the fastest, safest method of locating system leaks. To use an electronic leak detector, move the tester's probe around possible leakage points, such as service ports, line fittings and connections, condenser, compressor seals, valves, and evaporator. Check under the fittings and seals



Snap-on Tool Corp.

Figure 84-13. A leak detector will make an audible signal if refrigerant gases are present.

Nissan

Figure 84-12. Basic gauge readings, whether too high or too low, are only indicators of possible problems. You must also use information on system design and your knowledge of A/C system operation to find the trouble.

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since cold gas tends to settle downward in a warm shop. When the tester buzzes or lights up, you have found the leaking component.

Tech Tip

Loose refrigerant line fittings are one of the most common sources of A/C system leaks. Tighten leaking fittings and retest them for leaks, **Figure 84-14**. If tightening does not correct the leak, replace the hose or line if needed.

Recovering Refrigerant

Technicians must use a ***refrigerant recovery machine*** to capture, store, filter, and recycle all used R-134a gas from repaired vehicles. See **Figure 84-15**. According to federal law, it is illegal to allow used refrigerant gas to escape into the shop area during repairs. The refrigerant gas that is drawn out of the vehicle's A/C system must be stored and recycled.

The recovery machine automatically filters the used R-134a and prepares the gas to be reused in another vehicle, **Figure 84-16**. Oil is separated from the refrigerant gas before circulating the gas through filter-driers to remove acids, moisture, and other contaminants. After filtering out water and other impurities, the clean R-134a gas can be charged into an empty vehicle A/C system.

Tech Tip

An automotive technician from St. Louis, Missouri, was the first person convicted of a crime for releasing automotive refrigerant into the atmosphere. The technician admitted to the offense and was prosecuted under a federal law written to protect the earth's atmosphere from further damage.

Never allow automotive refrigerant to escape into the atmosphere. Although you may not get caught, releasing refrigerant into the atmosphere contributes to our environmental problems. If everyone ignored this law, future generations could suffer serious consequences from ozone layer depletion and global warming



Snap-on Tool Corp.

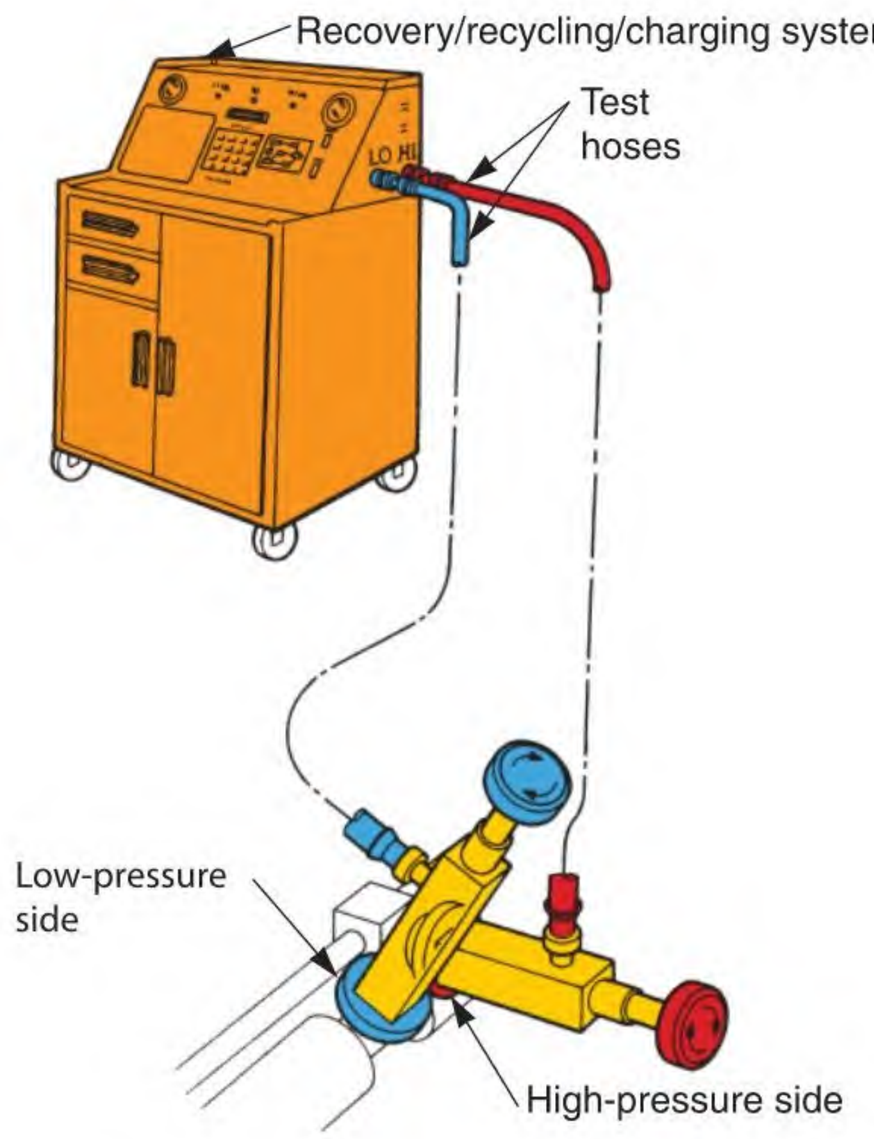
Figure 84-14. If a fitting is leaking, try tightening it. Use two wrenches or one wrench and a torque wrench, if possible.



Snap-on Tool Corp.

Figure 84-15. This typical charging station includes a recovery unit to withdraw refrigerant from an air conditioning system. The refrigerant is stored in a refillable container for reuse or recycling.

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Snap-on Tool Corp.

Figure 84-16. The charging station connects to the vehicle like a pressure gauge set. A vacuum pump evacuates the system and a refillable container holds old, captured refrigerant.

R-12 and other older refrigerants can be recycled, as well. Recycling has become increasingly important as the reserve of R-12 and other CFC refrigerants is depleted. Environmentally safer refrigerants (such as R-134a) are used in new vehicles, but the A/C systems in many older cars and trucks still require R-12.

If your A/C recovery machine is not set up for R-12, connect an empty pressure tank to the vehicle's A/C system using your pressure gauge set. Open the gauge valves and the valve on the vacuum tank. Tank suction or vacuum will pull most of the old refrigerant into the tank. Start the engine and the compressor will pump almost all of the remaining R-12 gas and oil out of the vehicle for recycling. To prevent compressor damage, do not let the engine run very long without refrigerant and oil in the A/C system.

Tech Tip

Retrofit kits are available for converting A/C systems designed for R-12 to operate with R-134a refrigerant. The cost of these kits and the amount of labor involved in completing the retrofit varies. Check with the vehicle manufacturer and your parts supplier.

Common A/C Component Problems

When your performance (pressure) tests indicate faulty components, remove and replace or repair the defective parts. This section outlines typical symptoms, problems, and service procedures for common air conditioning components. Refer to a service manual for special procedures and tools.

Tech Tip

Some air conditioning systems use spring-loaded connectors at the ends of refrigerant lines. A special plastic disconnect tool is required to properly disengage these high-pressure line connectors without damaging the fitting, **Figure 84-17**. The connector tool must be the right diameter and design to disengage a spring-loaded, R-134a high-pressure line.

Evaporator Problems

With a bad evaporator, the trouble normally shows up as inadequate cooling. An evaporator can develop leaks that show up when testing with a leak detector around the evaporator case.

If leaking, the evaporator must be removed for replacement. Sometimes, the evaporator is removed from under the dash or it may come out on the engine compartment side of the firewall. Refer to a service manual for details.

A clogged ***evaporator drain*** often causes water to leak onto the carpet in the vehicle under the evaporator housing. The evaporator drain normally allows water to flow from the evaporator housing out of the vehicle, to the ground under the vehicle. The evaporator drain or hose can become clogged with debris. When this occurs, water may slosh around in the housing and may leak onto the floor of the passenger compartment. Additionally, the air conditioning system may produce a musty odor, as mold spores grow in the trapped water.

To clear a clogged evaporator housing drain hose, insert a long piece of mechanic's wire into the end of the housing drain hose to clean out any debris. Water will begin to flow and drip from the hose when the drain is clean. Some manufacturers recommend using compressed air to clear the drain. When using compressed air, be careful not to blow the hose out of the housing.

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A



B

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Figure 84-17. To disconnect spring-loaded connectors on the ends of refrigerant lines requires a special tool. A—A/C line tools must be the right size for the spring-loaded fitting. These tools are color-coded by size. B—After removing the clip that surrounds the spring-loaded fitting, seat the tool around the fitting and squeeze while pulling to disconnect refrigerant line.

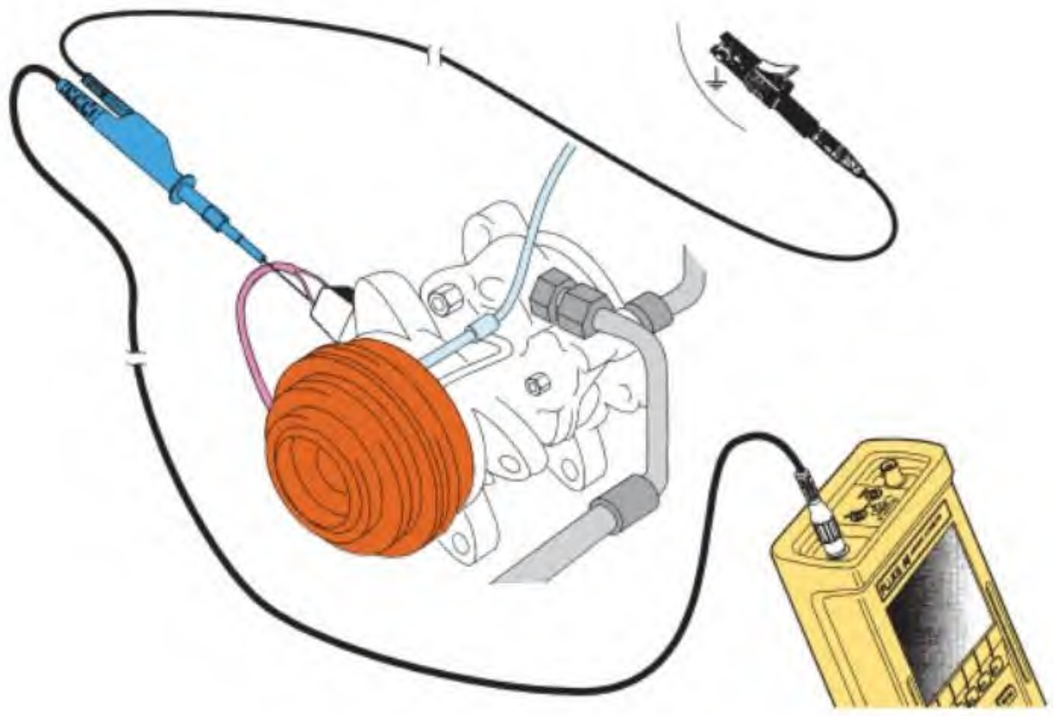
Compressor Problems

Compressor problems appear as abnormal noises, seizure, leakage, or high inlet or low discharge pressures. Some pumping noise is normal. However, if a loud rattling or knocking noise comes from the compressor, faulty parts may be indicated.

A bad ***compressor shaft seal*** is a common wear problem that allows refrigerant to leak past the compressor shaft and compressor end housing. Always check the compressor seal closely during your leak tests. The seal can sometimes be replaced without compressor removal.

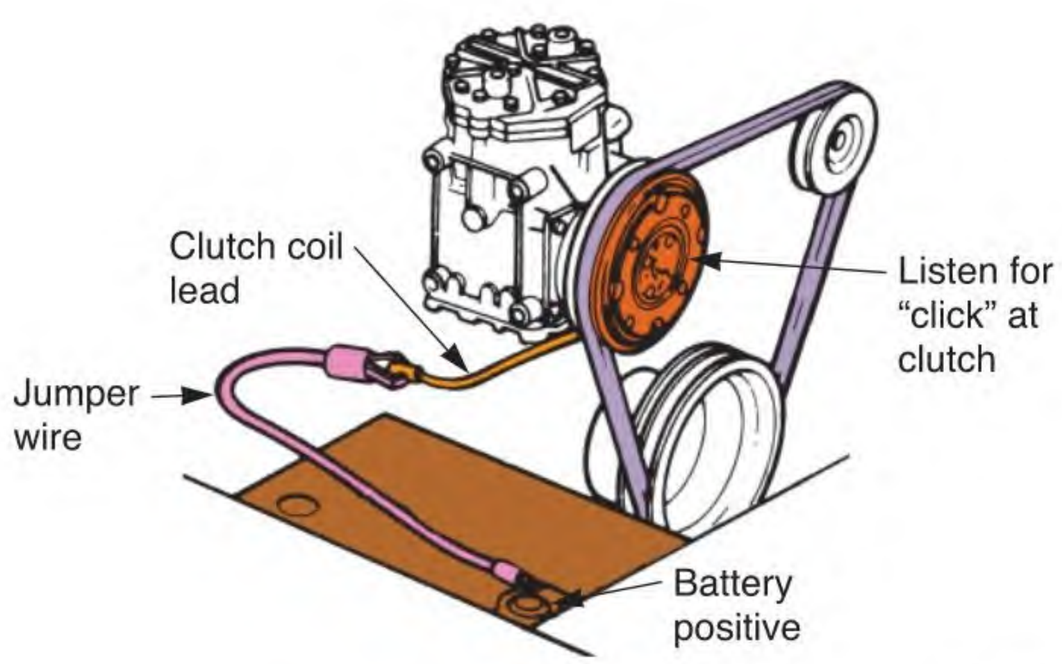
To check the ***compressor clutch***, check for voltage being applied to the clutch magnet. If you are not getting voltage to the clutch wire, find the open in the circuit, **Figure 84-18**. There may be a blown fuse or disconnected wire.

You can also connect battery voltage directly to the clutch. This should produce a clicking sound. If you start and idle the engine, the compressor plate and pulley should lock together to spin the compressor shaft and pump refrigerant through the system. See **Figure 84-19**. This tells you that there is a voltage feed problem to the compressor.



Fluke

Figure 84-18. A multimeter can be used to check for current and voltage to the compressor clutch. If no voltage is reaching the magnetic clutch, check the wiring and the controller.



Chrysler

Figure 84-19. If the compressor fails to turn on, check the clutch by applying battery voltage to the clutch coil. This should make the clutch kick in.

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If the clutch does not engage, the compressor coil may be open or shorted and need replacement. If the clutch engages when connected to battery voltage, there may be a problem in the circuit supplying voltage to the compressor clutch. Trace the circuit and locate the problem (bad switch, wire connection, broken wire, burned relay points, etc.).

Follow the instructions provided in the service manual during compressor service. The manual outlines procedures for compressor removal, disassembly, overhaul, and reassembly. Special tools and procedures are required.

Tech Tip

Air conditioning compressors are complicated to the inexperienced technician. Never attempt to overhaul a compressor without proper training and supervision. Most technicians replace bad compressors with new or rebuilt units.

Condenser Problems

A bad condenser can leak refrigerant or become restricted internally. A restricted condenser causes a high pressure reading in the discharge (high) side of the system. A partial condenser restriction can cause ice or frost to form on the outside of the condenser. During normal condenser operation, the outlet tube is slightly cooler than the inlet tube.

The condenser is fairly simple to replace, as it often mounts in front of the radiator. Its fittings must be loosened and removed. Use tubing wrenches to prevent fitting nut damage. Screws or small bolts often hold the condenser to the vehicle's radiator core (metal framework across the front of the body). During installation, make sure you start the fitting nuts by hand to prevent crossthreading. Be careful not to hit and bend the soft aluminum fins on the new condenser. Bent fins will reduce heat transfer and cooling efficiency in hot weather.

Receiver-Drier Problems

Receiver-drier problems are very common. The receiver-drier is one of the most frequently replaced air conditioning components. The desiccant (drying agent) can become contaminated or the unit may become internally restricted. A restricted receiver-drier alters system pressures, causing the outlet fitting on the unit to become abnormally cold.

A receiver-drier is typically replaced when:

- The sight glass is cloudy.
- System fittings have been left open for more than an hour.
- The system has been leaking and been operated on a partial charge.
- The system has been opened and serviced for the third time.
- Moisture is found in the system.
- A restriction is indicated in the unit.

Expansion Valve or Tube Problems

A faulty expansion valve usually shows up as low pressure readings on either the low side (suction) or the high side (discharge) of the system. The failure is often due to the power element (bulb) not operating the valve properly. A less common failure of the expansion valve is due to a clogged inlet screen (corrosion particles, loose desiccant beads, etc.).

A restriction in the expansion valve increases high-side pressure and decreases low-side pressure. A valve that is stuck open decreases pressure on the high-side and increases pressure on the low-side.

A clogged orifice tube will produce symptoms similar to those caused by a restricted expansion valve. Contaminants can fill and clog the orifice tube or the tube screen, blocking refrigerant flow through the system.

Refer to a service manual for detailed procedures for diagnosing and replacing these and other flow control valves. **Figure 84-20** shows the special tool needed to replace one type of orifice (expansion) tube.

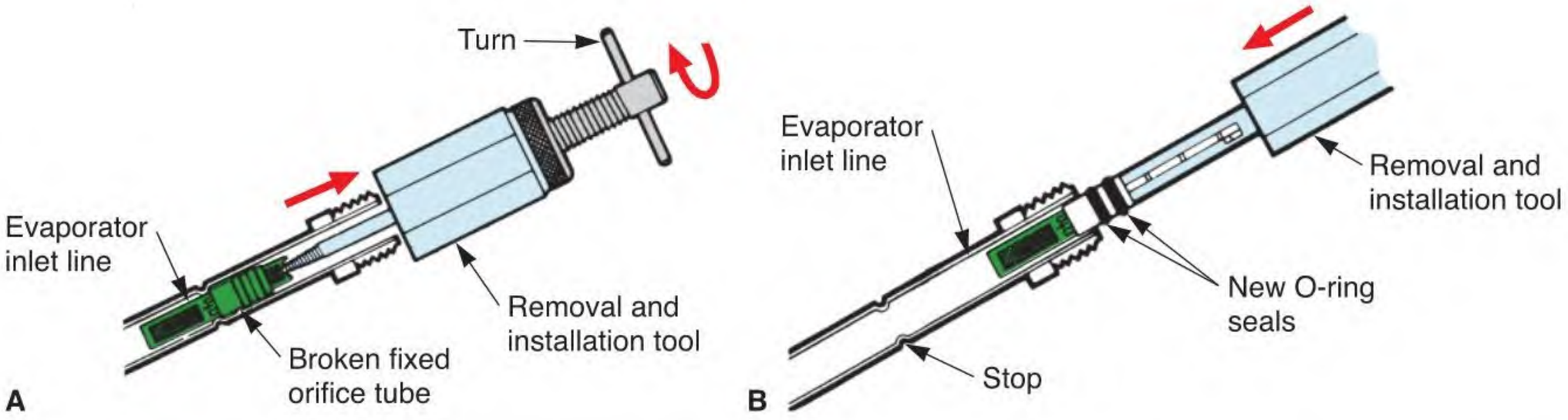
Thermostat Problems

A bad thermostat will usually keep the compressor clutch from engaging. This prevents the system from cooling. If the compressor clutch will not engage during normal system operation but engages when connected to battery voltage, test the thermostat. It may not be sending current to the clutch coil when needed.

Refrigerant Line Problems

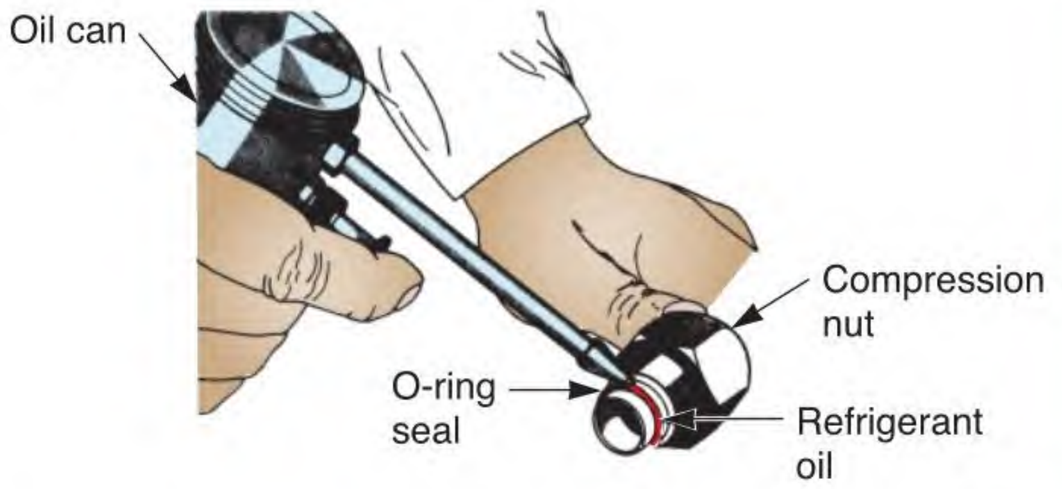
Defective refrigerant lines may leak, harden, crack, and restrict refrigerant flow. Replace any refrigerant lines that are faulty. When installing a line using an O-ring seal, coat the seal with refrigerant oil. This will help prevent the seal from leaking, **Figure 84-21**.

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Ford

Figure 84-20. In this illustration, a special tool is used to service a broken orifice tube. A—Thread the screw into the broken tube. Then tighten to pull out the unit. B—Forcing a new orifice tube into place.



Chrysler

Figure 84-21. Lubricate all A/C system O-rings and seals with refrigerant oil. This will help seal them and prevent leaks.

Evacuating an Air Conditioning System

A/C system evacuation involves using a vacuum pump to remove air and moisture from the inside of the vehicle's refrigerant system, **Figure 84-22**. Evacuation is needed anytime the air conditioning system has been discharged or opened to the atmosphere.

Service Procedure

To evacuate an A/C system:

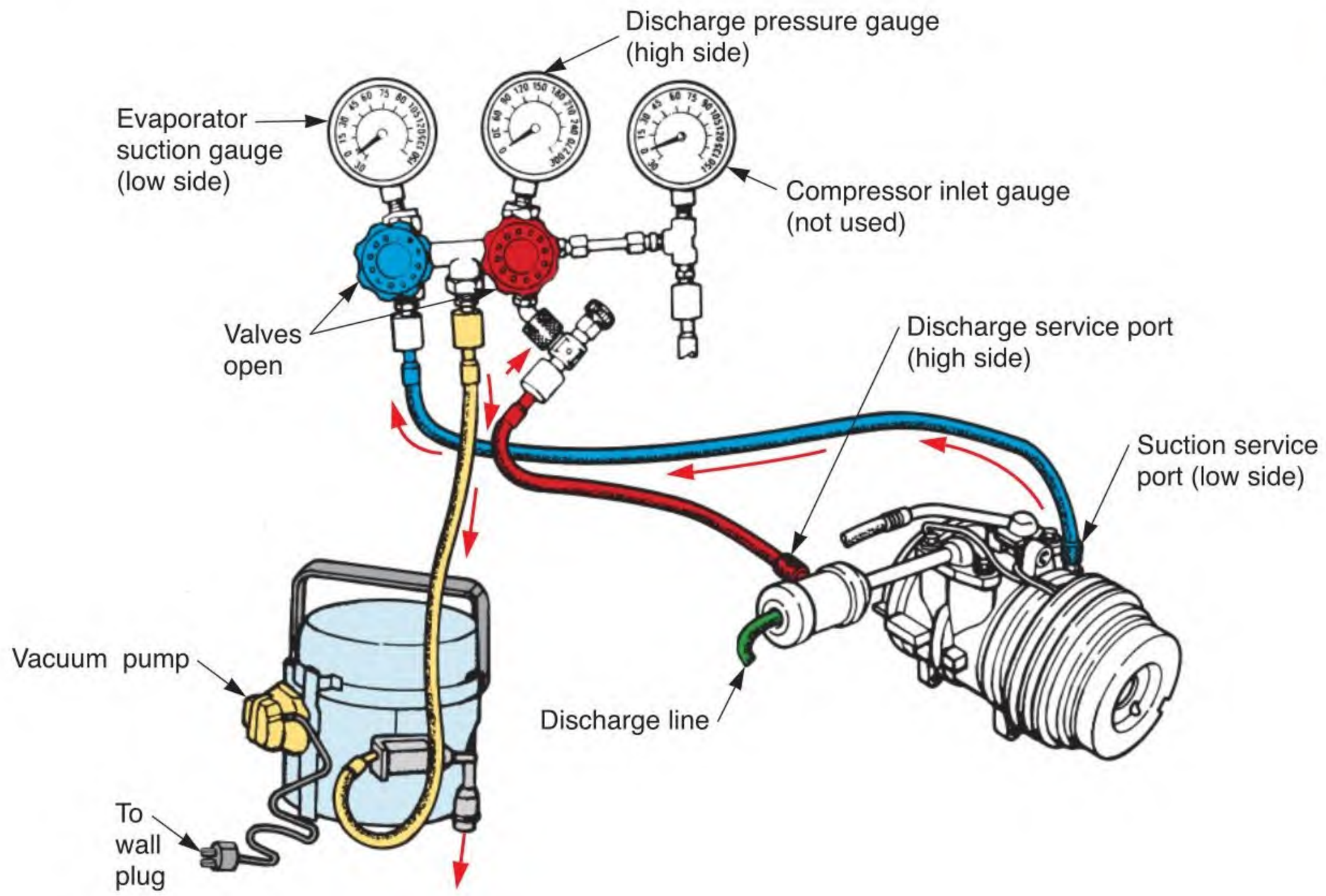
1. Connect the pressure gauges to the system.
2. Connect the vacuum pump to the center service hose on the gauge set.
3. If necessary, open the compressor valves (stem type).
4. Open the valves on the pressure gauge set.
5. Plug in and turn on the vacuum pump.
6. Operate the vacuum pump until the pressure gauges read approximately 26–28 inches of mercury (in. Hg) at sea level.
7. After reaching the necessary pressure reading, run the pump another 5 or 10 minutes to ensure complete removal of air and moisture.
8. If you cannot draw the amount of vacuum recommended by the service manual, check the operation of the pump and examine the system for leaks. This is an easy way to detect major leaks before installing refrigerant.
9. After evacuating the system, shut off the vacuum pump and close both gauge valves.

   The system vacuum should not drop more than 2–3 in. Hg in a five-minute period. If it does, a small system leak is indicated. You must leak-test the system as described earlier.

Charging an Air Conditioning System

A/C system charging involves filling the system with the correct amount and type of refrigerant. See **Figure 84-23**. The system should be charged only after it has been leak-tested and evacuated. Most shops use 10- to 30-pound containers of refrigerant. However, larger bulk containers are also used.

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Figure 84-22. Connect the vacuum pump as shown to evacuate the system.



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Figure 84-23. This 12-ounce can of refrigerant is often called a "pound can of refrigerant," even though it is not 16 ounces.

Service Procedure

To charge an A/C system:

1. Leave the pressure gauge set attached to the A/C system after evacuation.
2. Remove the center hose from the vacuum pump and connect it to the refrigerant container or charging station.
3. With the gauge valves closed, connect the center hose to the refrigerant container, **Figure 84-24**.
4. Open the center valve of the manifold gauge set and the service valve on the refrigerant container. This will transfer control of refrigerant flow to the gauge valves.
5. To charge the system, open the gauge suction (low-pressure) valve but leave the gauge discharge (high-pressure) valve closed. See **Figure 84-25**.
6. Start the engine and adjust the A/C system to maximum cooling. Compressor suction will then draw refrigerant into the system.

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Figure 84-24. A special spike fitting on the dispenser hose must puncture the sealed top on a pound can of refrigerant.

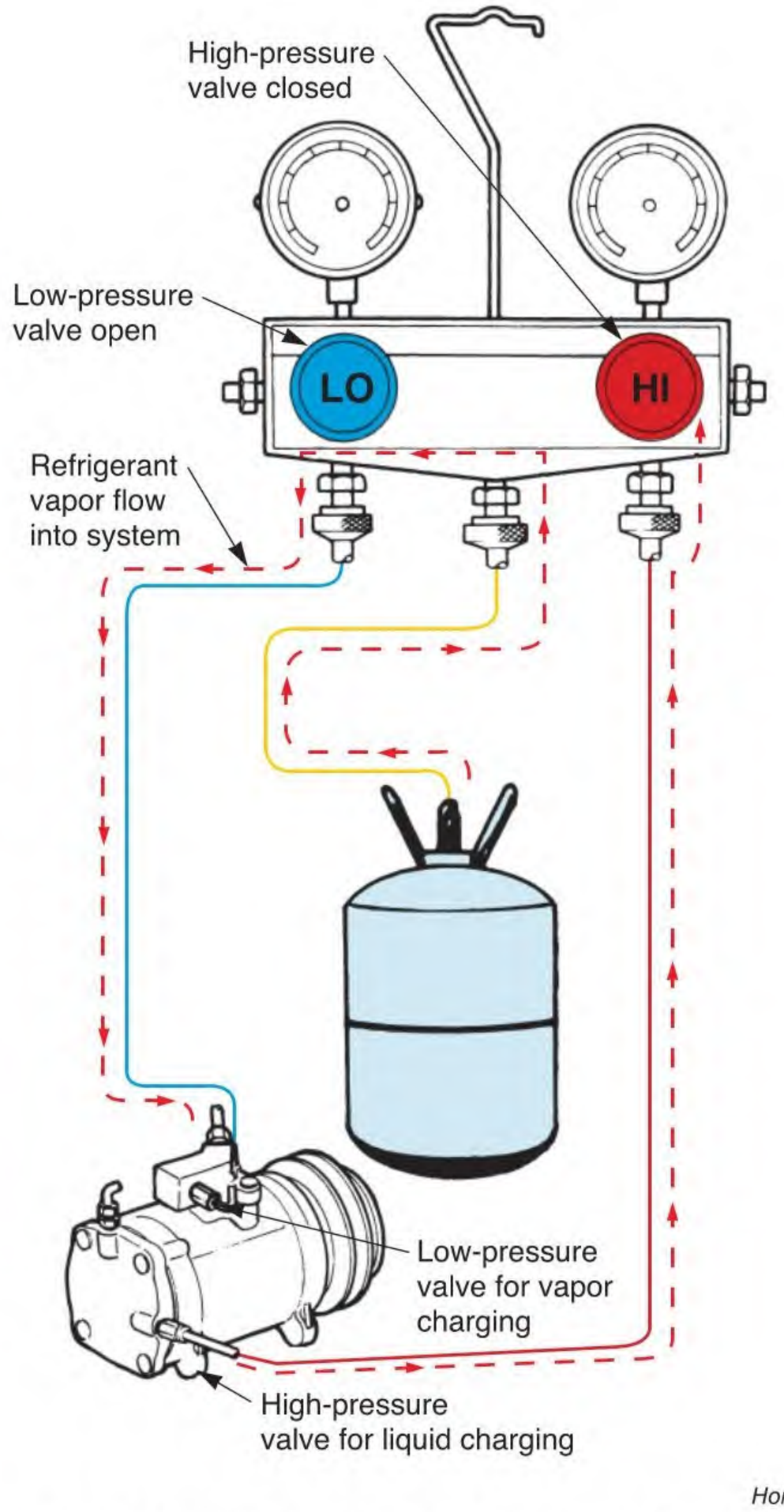
7. Adjust the gauge suction valve so that gauge pressure does *not* exceed 50 psi (345 kPa). This will ensure that liquid refrigerant does not enter and damage the compressor.

Tech Tip

You may want to place the refrigerant container in warm water—not hotter than 125°F (52°C). This will expand the refrigerant, helping it to flow into the system.

Keep the refrigerant container right-side up when charging. This will ensure that only refrigerant vapor, not liquid refrigerant, enters the system.

After charging the A/C system, double-check system pressures and temperatures. Make sure the high- and low-side pressures are satisfactory. Also, use a thermometer to measure the temperature of the air blowing from the passenger compartment vents. If these checks are within specs, the air conditioning system is ready to be returned to service.



Honda

Figure 84-25. Attach the refrigerant container to the center hose. Open the lower pressure valve and allow refrigerant to flow into the low side of the system with the engine running.

Charging Station

A ***charging station*** usually contains a vacuum pump, a pressure gauge set, an oil injection cylinder, and a charging tank of refrigerant. A charging station can be used to evacuate and charge the system without disconnecting the service hose. The general procedures for using a separate vacuum pump, refrigerant container, and test gauge set should be followed when using a charging station. Remember to follow the directions for the specific type of equipment.

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Adding Refrigerant Oil

The refrigerant oil level should be checked anytime you add or replace refrigerant. Before checking the refrigerant oil, operate the system for 10–15 minutes. Then, isolate the compressor by closing the stem-type service valves. If Schrader valves are used, you must discharge the system to check the oil level.

Refer to a service manual for detailed procedures for checking the refrigerant oil level. Follow instructions for the type of compressor you are servicing.

If the oil is low, add the specified amount and type of refrigerant oil. Do not overfill the compressor, or system efficiency will be reduced. If the refrigerant oil is dirty, the system should be evacuated, flushed, and refilled.

Tech Tip

Make sure you use the right type of compressor oil. R-12 and R-134a oils are different. Mixing them will cause separation and lack of lubrication in the compressor.

A/C System Service Rules

When servicing an air conditioning system, remember to follow these basic rules:

- Inspect the system for obvious problems (loose or missing belt, clogged condenser fins, disconnected wires, inoperative compressor clutch, etc.).
- Check the sight glass to see if the system has a refrigerant charge.
- Feel hose temperatures to determine if the compressor pump is moving refrigerant through the system.
- Leak test the system.
- Wear safety glasses and gloves when servicing a refrigerant system.
- Discharge the system into a recovery unit, never into the air.
- Make sure the system is fully discharged before attempting to remove any pressurized component.
- After disconnecting fittings, cap them to prevent moisture from entering the system.
- Coat all O-rings with refrigerant oil before installation. Add oil to the system as needed.
- Torque all fittings to specifications.
- Evacuate the system and check for leakage (vacuum drop) before charging.
- Charge the system with the correct amount and type of refrigerant.
- Add refrigerant to the suction side of the system with engine running. Do not let liquid refrigerant enter the compressor.
- Use service manual instructions and specifications for system test pressures, temperatures, capacities, and other information.
- Recheck system operation after service.

Heater Service

Heater problems typically show up either as coolant leaks or as insufficient warming of the passenger compartment. The heater hoses can harden, break, or leak, especially when they are routed near the hot engine. The heater core can rust and develop leaks, allowing coolant to drip on the car's floor or carpet.

When the system does not produce heat, the heater core may be clogged, a heater hose valve may be inoperative, or the air control doors may not be functioning properly.

Checking Heater Coolant Flow

To check heater coolant flow, let the engine and the heater hoses cool. Then, start the engine and operate it at a fast idle. Turn the heater on high.

As the engine coolant warms, feel both the inlet and outlet heater hoses. Feel the hose on both sides of the heater flow control valve, if used.

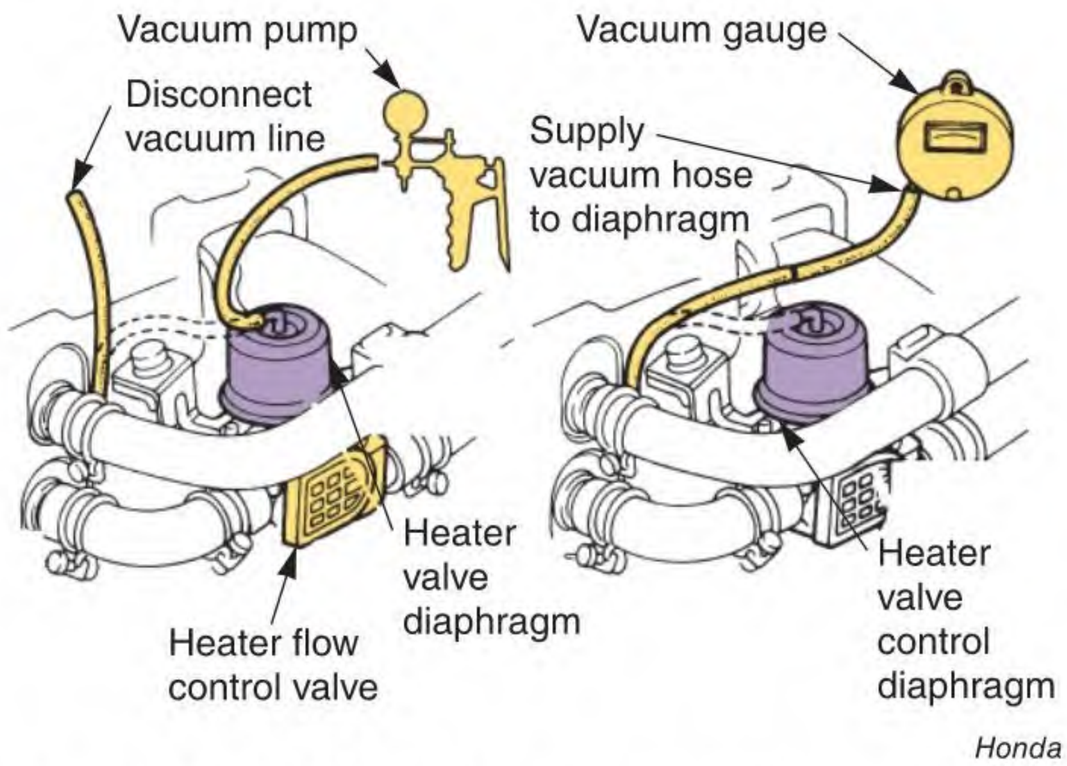
If both heater hoses are about the same temperature, coolant is passing through the heater core and valve. If one hose is hot and the other is cool, there is blockage in the system. The heater core may be clogged or the flow valve may be stuck closed.

To check the operation of a heater flow valve, use a hand vacuum pump to apply suction to the diaphragm. When vacuum is applied, the valve should activate. If the valve does not move or the diaphragm does not hold vacuum, replace it. If the valve and diaphragm are good, use a vacuum gauge or your finger to check that vacuum is reaching the unit through the supply line. See **Figure 84-26**.

Flushing the Heater Core

The heater core can become clogged with rust deposits, which prevents coolant from circulating and reduces heater efficiency. This problem can result from a poorly serviced engine cooling system.

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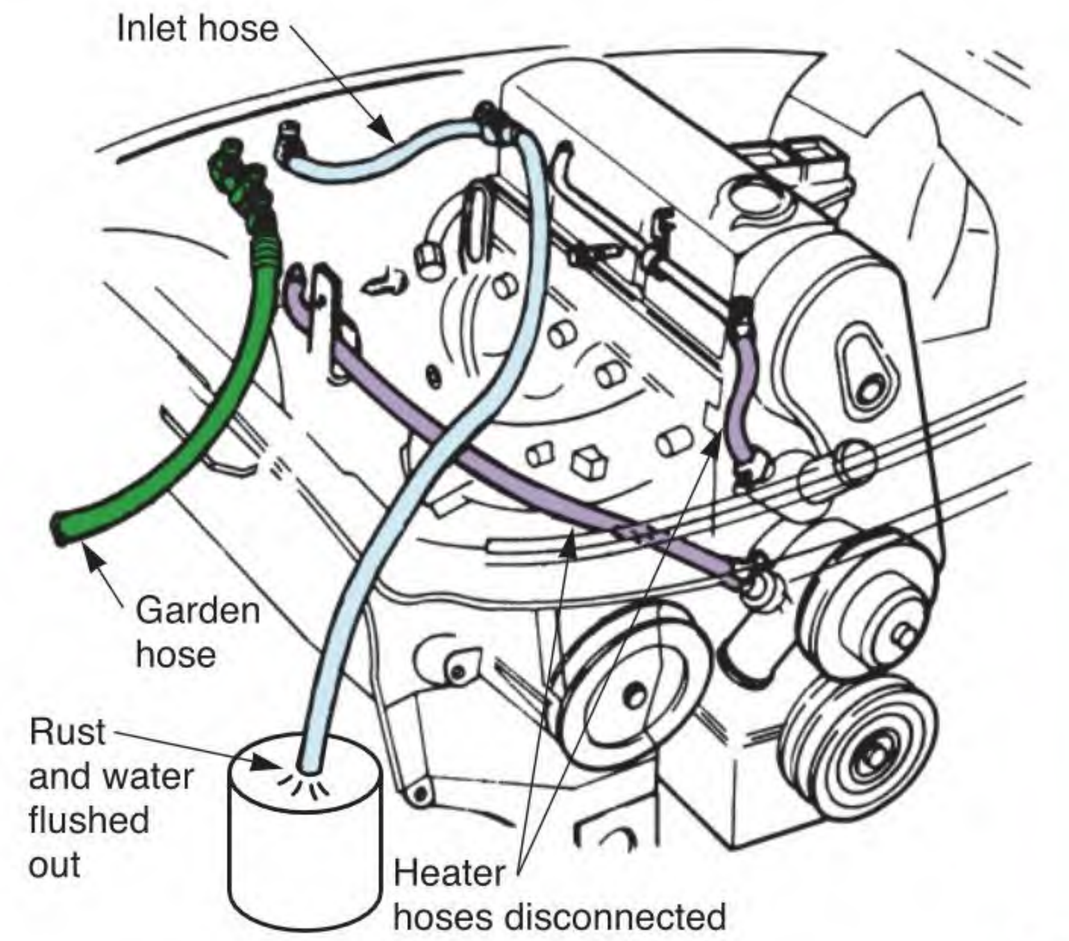
Honda

Figure 84-26. The heater flow valve can stick open or closed and the vacuum diaphragm can rupture. A—Use a vacuum pump to check valve operation. B—Also check that vacuum is being fed to the diaphragm from the vacuum line.

To flush the heater core, remove both heater hoses. Connect a garden hose to the outlet heater hose. Turn the hose on and let water force rust out of the core for about five minutes, **Figure 84-27**.

Heater Core Replacement

A clogged or leaking heater core must be replaced. Before removing a heater core, drain the cooling system to a level below the heater core. Then, remove the heater hoses from the heater core. Some heater cores come out from under the dash, while others are removed from the firewall through the engine compartment. Small clips or screws usually secure the housing around the heater core. Some heater cores can be difficult to reach, and a light and mirror are needed to find them. Refer to service literature for exact heater core replacement procedures for the vehicle being serviced.



Ford

Figure 84-27. A clogged heater core is common. Remove the heater hoses. Attach a garden hose to the outlet heater hose and force water through the core and flush out rust.

Blower Motor Replacement

A bad blower motor does not properly circulate air through the passenger compartment, and may produce dry bearing whining or screeching sounds.

Service Procedure

To replace a blower motor:

1. Disconnect the battery to prevent short circuits, as well as injuries caused by accidentally energizing the fan.
2. Refer to the service data to find out if the blower motor is removed from under the dash or from outside the firewall.
3. If the blower motor is mounted under the dash, remove inner trim pieces, ducts, and hoses to gain access to the motor mounting screws. You may have to remove the dash glove box or the whole dash panel to get at some blower motor and fan assemblies.
4. On a full-size truck, the blower motor is often removed from inside the engine compartment. The blower motor is held onto the cowl or firewall with machine screws. See **Figure 84-28**.
5. Unplug the harness and remove the blower mounting screws.
6. Lift the blower motor out of its plastic housing.
7. If needed, remove the fan from the old blower motor and install it on the new motor. Make sure the plastic fan is not cracked or broken. A friction clip usually secures the plastic fan to the motor shaft. Make sure the fan is tight and secure on its shaft to prevent it from coming loose.
8. Snug down the blower motor mounting screws and reconnect the wiring.
9. Operate the blower fan at all speeds to make sure it operates quietly. If you hear a loud grinding noise, the fan is not centered on its mount and is rubbing inside its housing.

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Figure 84-28. On this pickup truck, the blower motor is easily accessed in the engine compartment.

Checking Air Control Doors

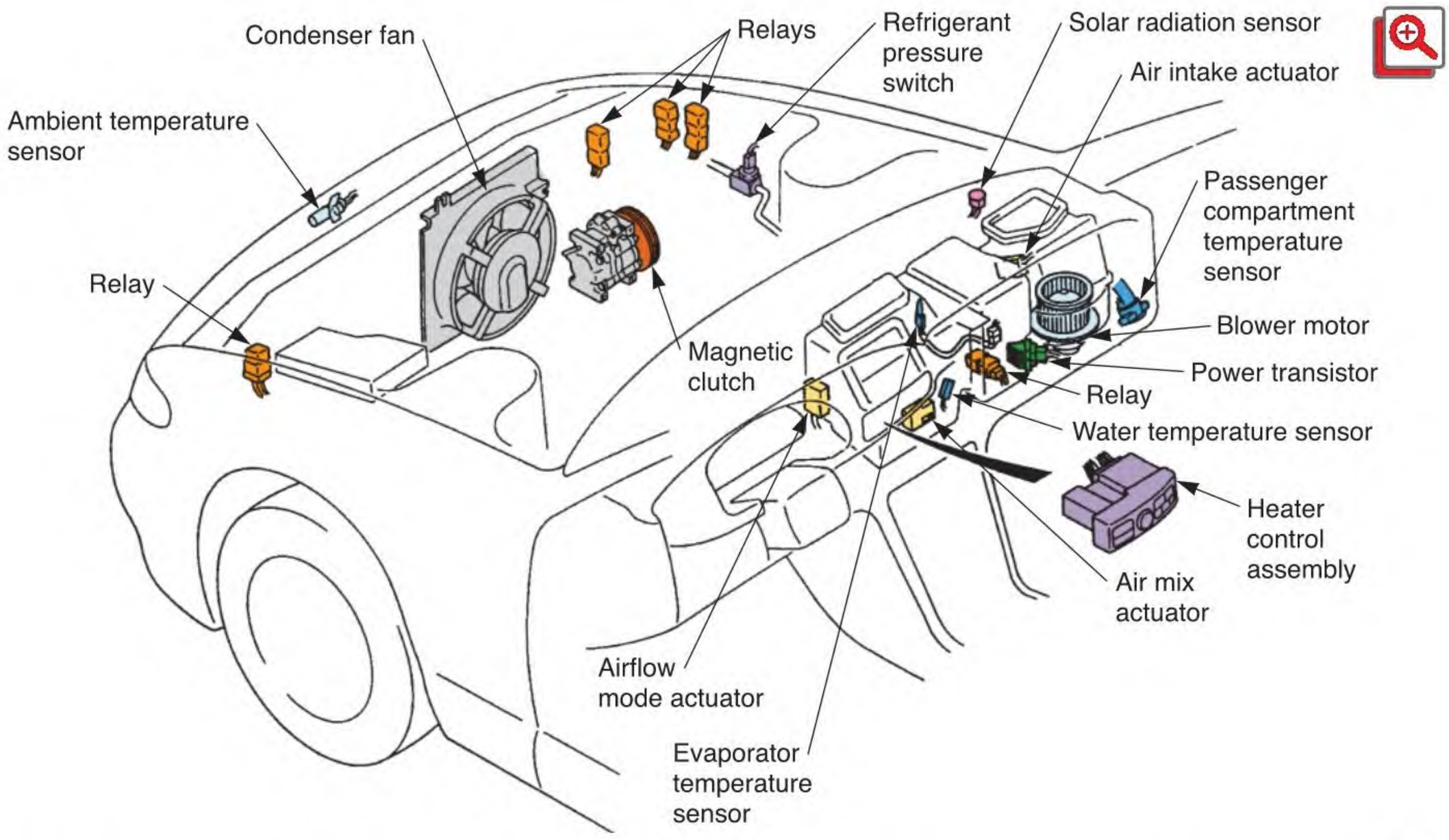
Inoperative air control doors prevent both cool and warm air from flowing through the desired vents. Use service manual diagrams of the doors to determine which ones are not working normally. You can sometimes lay under the dash and watch the air door shaft turn to check operation. If needed, adjust the air control door arm or cable until it closes and opens as needed.

Electronic Climate Control Service

Electronic climate control service can be challenging because there are so many design variations. Again, the service manual will give essential service information.

A ***component location drawing*** shows which parts affect heating and A/C operation and gives the general location of these parts on the vehicle. See **Figure 84-29**.

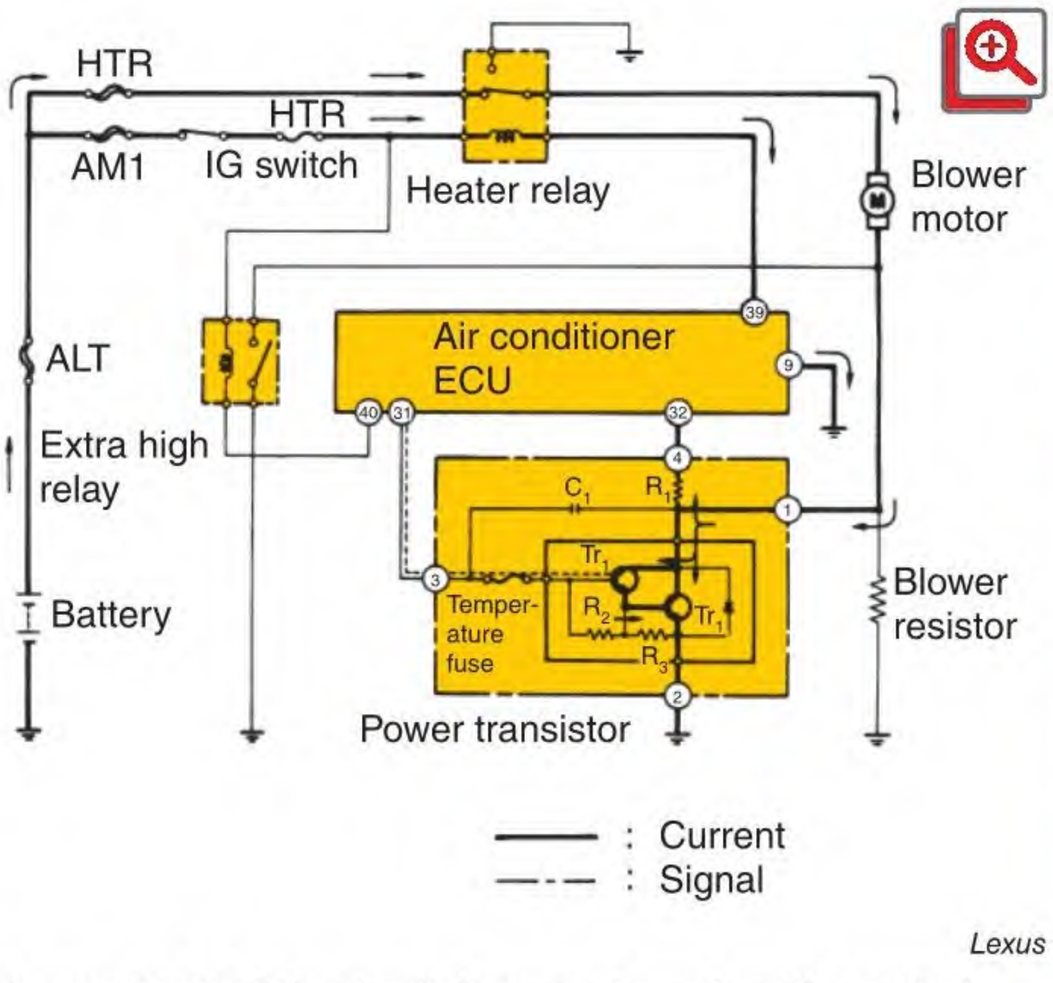
Wiring diagrams are also needed to troubleshoot electronic climate controls. These diagrams let you trace wires from component to component, **Figure 84-30**.



Mazda

Figure 84-29. A component location drawing shows the location of all major parts in climate control system. This can save time when troubleshooting.

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Lexus

Figure 84-30. This circuit diagram shows how the control module can control blower speed. This principle is used in other system designs.

The control module is the brain of modern electronic climate control systems. To check its condition, you must determine if the unit is producing the right outputs for known inputs. For example, if you move the controls to the maximum heat position, the module should produce an output to move the correct air control door to route warm air into the passenger compartment.

The control module must also produce the correct readouts in the digital display. Various sensors provide feedback so that the module can control the climate control system and produce meaningful displays, **Figure 84-31**.

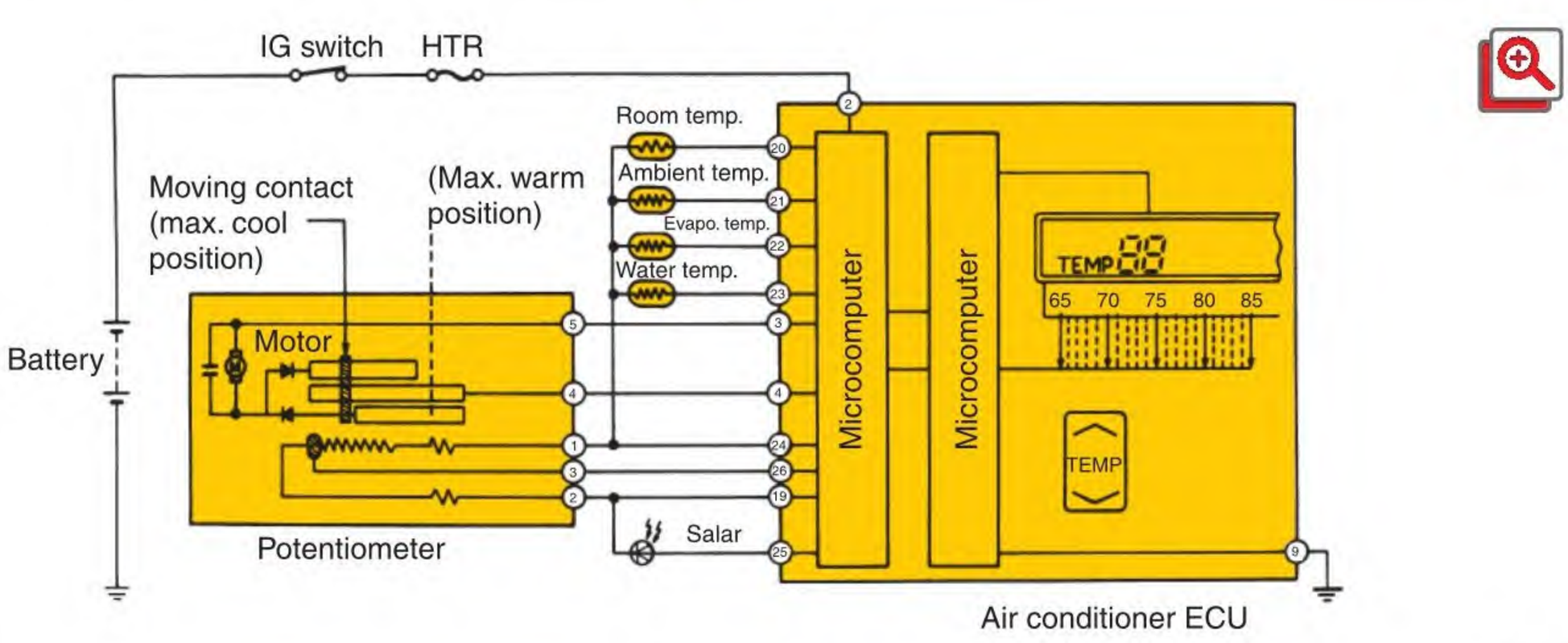
A wiring diagram for a complete climate control system is shown in **Figure 84-32**. Refer to this type of diagram when diagnosing and repairing hard-to-find problems.

Diagnostic Case Study

Concern: Mr. Watt brings his 2004 Impala to the shop. He states that his air conditioning system is not blowing as cold as usual.

Cause: Duff starts the engine and sets the air conditioner controls to high cool. He notes that the air coming from the vents is not as cool as it should be. Looking under the hood, Duff sees that the compressor belt is intact, but the compressor is turning on and off rapidly. Duff then checks the temperature of the air conditioner lines. The low side feels warm, while the high side feels cooler than it should. Duff shuts off the engine and turns the vehicle over to the shop's air conditioning technician.

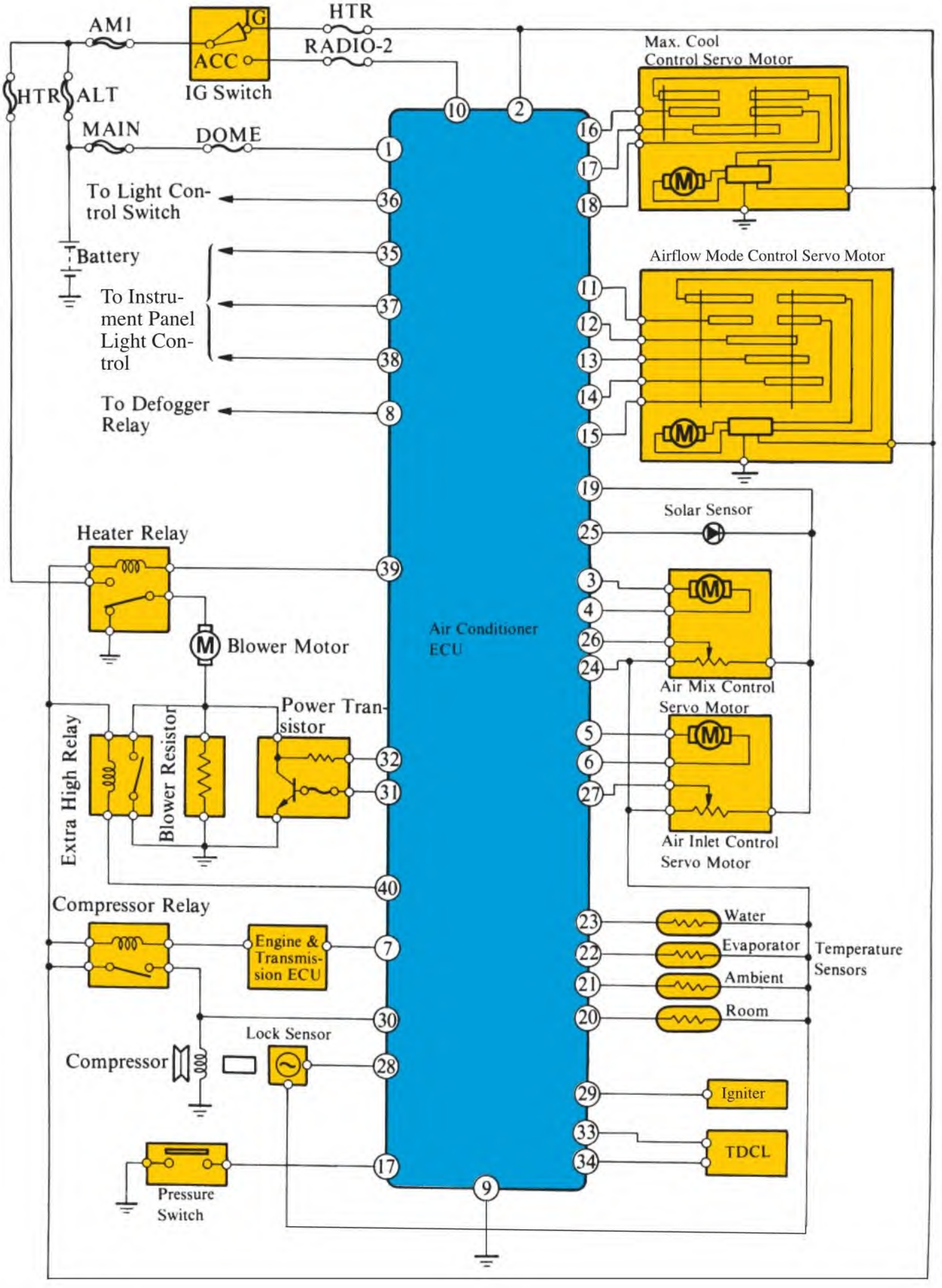
After allowing the vehicle to sit for about an hour, the technician connects a pressure gauge set to the vehicle's service valves to measure static pressure. The gauge shows approximately 30 psi (210 kPa), which indicates that some refrigerant has leaked from the system. The technician uses an electronic leak detector to search for leakage points. The detector sounds off near the compressor's front seal. The technician sweeps the entire system and finds only the leak at the compressor seal.



Lexus

Figure 84-31. This circuit shows how two microprocessors are used to operate the digital display and to analyze inputs from various sensors and switches.

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Lexus

Figure 84-32. Wiring diagram for a modern climate control system. Note the various inputs from sensors and outputs to motors and displays.

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Correction: The technician connects the refrigerant recovery system to the vehicle and pulls the refrigerant from the system. He replaces the front seal in the compressor and then evacuates the system, which holds vacuum for an hour.

The technician charges the system with the correct amount of refrigerant. He sets the air conditioning controls to high cool and closes the windows. He places a thermometer in the center vent of the dash. After a few minutes of operation, the thermometer reads approximately 50°F (10°C). The car is released to the owner.

Summary

- Late-model climate control systems produce trouble codes if the on-board diagnostic system detects an abnormal circuit value or condition.
- To check the basic action of the A/C system, start the engine. Turn the air conditioning system on high and allow it to run for about ten minutes. Then, feel the refrigerant lines.
- During visual checks of the A/C system, be sure to inspect the sight glass (if used).
- Refrigerant can cause severe *frostbite* if it contacts your skin.
- Always wear safety glasses when working with refrigerant.
- Keep refrigerants away from excessive heat.
- Keep refrigerant away from an open flame.
- Never discharge refrigerant into the air.
- A pressure gauge assembly typically consists of two pressure gauges, a manifold, two on-off valves, and three service hoses.
- A Schrader service valve is a spring-loaded valve, similar to the air valve in a tire.
- An R-134a service valve has a quick-disconnect fitting that accepts a corresponding fitting on the R-134a gauge set service hose.
- A performance test indicates air conditioning system condition by measuring cooling vent temperatures as well as system pressures with the engine running.
- With R-134a, some manufacturers require you to measure wet- and dry-bulb temperatures at the blower inlet. This will let you use a chart to find the relative humidity, which affects system operation and pressures.
- An electronic leak detector uses a special sensor and an electronic amplifier to locate refrigerant leaks.
- Since refrigerant can no longer be discharged into the air when servicing air conditioning systems, technicians must use a refrigerant recovery unit.
- The compressor shaft seal is a common refrigerant leakage point.
- A bad condenser can leak refrigerant or it can become restricted internally.
- A faulty expansion valve will usually show up as low suction (low-side) or discharge (high-side) pressure readings.
- A clogged orifice tube will produce symptoms similar to those caused by a restricted expansion valve.
- A bad thermostat will usually keep the compressor clutch from engaging and prevent the A/C system from cooling.
- A/C system evacuation involves using a vacuum pump to remove air and moisture from the inside of the vehicle's refrigerant system.
- A/C system charging involves filling the system with the correct amount and type of refrigerant.
- A charging station usually contains a vacuum pump, a pressure gauge set, an oil injection cylinder, and a refrigerant container.
- Make sure you are using the right type of compressor oil. R-12 and R-134a oils differ.
- Heater problems typically show up as coolant leaks or as insufficient warming of the passenger compartment.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

A/C system charging
A/C system evacuation
bubble detector
bubbling sight glass
charging station
clear sight glass
cloudy sight glass
component location
drawing
compressor clutch
compressor shaft seal
dust caps
electronic leak detector
evaporator drain
internally charged detector
manifold gauge assembly

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oil-streaked sight glass
performance test
pressure gauge assembly
refrigerant recovery machine
Schrader service valve
service valves
static A/C pressure reading
torch detector

Activities

1. Talk to the owners of several shops that service auto air conditioners. Ask if they convert R-12 systems to R-134a and what is involved. Report the findings to your class.
2. Demonstrate the proper connections and use of a gauge manifold set for making a static pressure reading on an A/C system.
3. Create a video demonstrating the proper use of an electronic refrigerant leak detector.
4. Locate the refrigerant storage containers in your shop. Are they in good condition and stored in an appropriate location? Write a short report summarizing your findings and explaining the environmental and physical dangers posed by improper refrigerant storage.

Review Questions

Answer the following questions using the information provided in this chapter.

1. List six check points when inspecting an air conditioning system.
2. How can feeling line temperatures help you when inspecting an air conditioning system?
3. Which of the following sight glass conditions could indicate system troubles?
   (A) Clear sight glass.
   (B) Bubbling sight glass.
   (C) Cloudy sight glass.
   (D) All of the above.
   (E) None of the above.
4. Explain five important safety precautions for air conditioning system service.
5. What is a pressure gauge assembly, or manifold assembly?
6. _____ valves provide a means of connecting the pressure gauge assembly for testing, discharging, evacuating, and charging the system.
7. Describe a Schrader valve.
8. A static A/C pressure reading will indicate whether the compressor is in good condition. True or False?
9. Why is an electronic leak detector safer than a torch type detector?
10. Give a reason why you should not discharge (empty) an A/C system into the air.

ASE-Type Questions

1. An automotive air conditioning system is not cooling properly. Technician A checks for a loose compressor drive belt. Technician B looks for blockage in the condenser fins. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. An automobile's air conditioning is running on high. Technician A says the refrigerant lines on the high-side of this system should be warm or hot. Technician B says the refrigerant lines on the high-side of this system should be cool. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. An automobile air conditioning's low-side line is cold, but the system does not cool. Technician A says this problem may be caused by faulty air control doors. Technician B says this problem may be caused by an instrument panel control malfunction. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. The condition of a car's air conditioning refrigerant needs to be checked through the system's sight glass. Technician A says the sight glass may be located on top of the receiver-drier. Technician B checks to see if the sight glass is located in a refrigerant line. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.

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5. An automotive air conditioning system's sight glass is clear. Technician A says a clear sight glass normally indicates that the system has the correct charge of refrigerant. Technician B says a clear sight glass may indicate an empty system. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Bubbles are visible in an air conditioning system's sight glass. Technician A adds refrigerant to the system. Technician B removes some of the refrigerant from the system. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
7. The sight glass on an auto air conditioning system appears to be "cloudy." Technician A checks the condition of the system's receiver-drier. Technician B says the system is operating properly. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. A car's A/C system is being serviced. Technician A places a shop rag around the fitting before removing a refrigerant line. Technician B wears safety glasses while removing a refrigerant line. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Technician A uses the high-pressure gauge on a manifold assembly to measure the compressor discharge pressure. Technician B uses the high-pressure gauge on a manifold assembly to measure the A/C's suction-side pressure. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
10. During a static A/C pressure test, the manifold assembly's high-pressure gauge shows approximately 50 psi. Technician A says this reading indicates a very low refrigerant level in the system. Technician B says this reading indicates an adequate amount of refrigerant in the system. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
11. All of the following are used to detect automotive A/C system leaks, *except*:
    (A) Bubble detector.
    (B) Torch detector.
    (C) Electronic leak detector.
    (D) Tube detector.
12. Moisture is found in an automotive air conditioning system. Technician A replaces the receiver-drier. Technician B removes refrigerant from the system. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
13. A car's air conditioning system is not operating properly. Pressure gauge readings show a low high-side pressure and a high low-side pressure. Technician A says the expansion valve may be restricted. Technician B says the expansion valve may be stuck in the open position. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
14. An automotive air conditioning system needs to be charged. Before charging this system, Technician A tests the system for leaks. Before charging this system, Technician B evacuates the A/C system. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.
15. An automobile's heater system will not operate. Technician A checks for a clogged heater core. Technician B checks the operation of the heater hose valve. Who is right?
    (A) A only.
    (B) B only.
    (C) Both A and B.
    (D) Neither A nor B.

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Climate Control System Diagnosis		
Condition	**Possible Causes**	**Correction**
No cooling.	1. Low refrigerant. 2. Refrigerant leak. 3. Bad compressor. 4. Compressor not engaging. 5. Missing drive belt. 6. Bad control circuit.	1. Add refrigerant. 2. Repair leak and recharge. 3. Replace compressor. 4. Repair clutch or sensors. 5. Install belt. 6. Test and repair circuit.
Poor cooling.	1. Low refrigerant. 2. Blower will not work on high. 3. Bad air control system. 4. Debris in condenser. 5. Belt slippage.	1. Add refrigerant. 2. Repair blower circuit. 3. Repair air flap system. 4. Clean condenser fins. 5. Tighten compressor belt.
No heating.	1. Blown blower fuse. 2. Open blower switch. 3. Bad blower motor. 4. Fan loose on shaft. 5. Open wiring. 6. Inoperative flow valve.	1. Replace fuse. 2. Replace switch. 3. Replace blower. 4. Repair fan. 5. Repair wiring. 6. Repair or replace coolant valve at heater hose.
Poor heating.	1. Clogged heater core. 2. Inoperative flow valve. 3. Blower will not work on high. 4. Open thermostat. 5. Low engine coolant level. 6. Air in cooling system. 7. Airflow doors inoperative.	1. Flush or replace core. 2. Repair or replace coolant valve at heater hose. 3. Repair blower circuit. 4. Replace thermostat. 5. Add coolant. 6. Bleed out air. 7. Repair controls and doors.
Inadequate defrost.	1. Air flap problem. 2. Disconnected ducts. 3. Blockage in ducts.	1. Adjust air flaps or repair control circuit. 2. Reinstall ducts. 3. Remove debris.
Defrost fogs windshield.	1. AC not working. 2. Leaking heater core. 3. Leaking windshield seal.	1. Repair AC. 2. Replace heater core. 3. Replace or caulk glass.
Abnormal noise.	1. Bad compressor. 2. Too much refrigerant. 3. Belt slippage. 4. Compressor cycling. 5. Loose parts. 6. Bad blower bearings. 7. Loose fan.	1. Replace compressor. 2. Install correct charge. 3. Adjust belt tension. 4. Add refrigerant or repair control circuit. 5. Tighten hold-downs. 6. Replace blower motor. 7. Install or replace blower fan.
Low-side pressure high.	1. Bad expansion valve. 2. Moisture in system. 3. Compressor problems. 4. Restricted suction line.	1. Replace expansion valve. 2. Replace desiccant and recharge system. 3. Replace compressor. 4. Replace line.

Continued

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Climate Control System Diagnosis

Condition	Possible Causes	Correction
Low-side pressure low.	1. Low refrigerant. 2. Low airflow. 3. Restricted liquid line. 4. Restricted suction line. 5. Compressor not disengaged.	1. Charge system. 2. Clean condenser fins and check blower operation. 3. Replace line. 4. Replace line. 5. Repair frozen clutch, bad sensor, or control circuit.
High-side pressure high.	1. Low refrigerant, air in system. 2. System overcharged. 3. Clogged condenser core. 4. Engine overheating. 5. Refrigerant system restriction.	1. Evacuate and charge. 2. Properly charge system. 3. Replace condenser. 4. Repair cooling system. 5. Replace parts as needed.
High-side pressure low.	1. Low refrigerant charge. 2. Expansion valve open. 3. Bad compressor.	1. Charge system. 2. Replace valve. 3. Replace compressor.
Water on floor.	1. Leaking heater core. 2. Loose heater hose clamps. 3. Evaporator drain clogged.	1. Replace core. 2. Tighten clamps. 3. Clean out drain tube.

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Section 15

Safety Systems and Future Technologies

Chapter 85
Restraint System Technology

Chapter 86
Restraint System Service

Chapter 87
New and Future Technology

Every year, automakers strive to incorporate features into their vehicles that improve safety, efficiency, and convenience. These features include highly effective restraint systems that protect a vehicle's occupants during an accident.

It is critical that you understand the operation and repair of the restraint systems found on late-model vehicles. Chapters 85 and 86 cover the operation, diagnosis, service, and repair of various restraint systems, including seat belt systems and air bag systems.

Chapter 87 details many of the cutting-edge technologies used in late-model vehicles. It also discusses exciting high-tech systems that may become common in the not-too-distant future.



Chapter 85
Restraint System Technology

After studying this chapter, you will be able to:

- Explain how vehicle body and frame construction works with restraint systems to protect a vehicle's occupants.
- Describe the purpose of restraint systems.
- Identify and locate the most important parts of vehicle restraint systems.
- Describe restraint system design variations.
- Correctly answer ASE certification test questions requiring a knowledge of restraint system operation and construction.

Restraint systems hold a vehicle's occupants in their seats, protecting them from injury during an automobile accident. These systems include the seat belts and air bags. Restraint system designs are affected by the strength and collapsibility of the vehicle's body structure, frame members, roof pillars, steering column, and dashboard.

The ability of a properly functioning restraint system to save lives makes it very important that you understand the operation and repair of these systems. Understanding how restraint systems work will help you diagnose problems when a system malfunctions.

Vehicle Collisions

Vehicle collisions, or ***accidents***, normally result from driver error that causes the car or truck to hit other objects (vehicles, trees, retaining walls, etc.). Tremendous force is generated when the vehicle, which can weigh almost two tons, crashes to a halt in a few feet (or meters) of travel. Automobile manufacturers design their vehicles to absorb this force in a controlled manner. Refer to **Figure 85-1**.

Crush zones located at the front and rear of the body-frame assembly are designed to collapse during a severe impact. As the crush zones collapse, they absorb some of the collision forces rather than transferring them to the passenger compartment. The passenger compartment is stiffer and stronger than these crush zones, so the occupants are protected from the forces of the accident. See **Figure 85-2**.

Side-impact beams, made of high-strength steel or carbon fiber, are mounted in the vehicle's doors to help prevent intrusion into the passenger compartment.

Body pillars are the metal beams that extend vertically to support the roof panel. Front pillars, or

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Chrysler

Figure 85-1. When a passenger vehicle hits a large, stationary object, a tremendous amount of energy is absorbed to bring the vehicle to an abrupt, but controlled, halt.

A-pillars, extend from outside edges of the cowl to the front corners of the roof panel and form the vertical members of the windshield frame. Center pillars, or B-pillars, are found between the front and rear doors on four-door vehicles. Rear pillars, which are commonly called C-pillars on four-door vehicles, run between the rear quarter panels and the rear corners of the roof panel. The rear pillars form the vertical sections of the rear window frame. Body pillars are made of multiple layers of high-strength steel or titanium to protect the passenger compartment, especially in the event of a rollover.

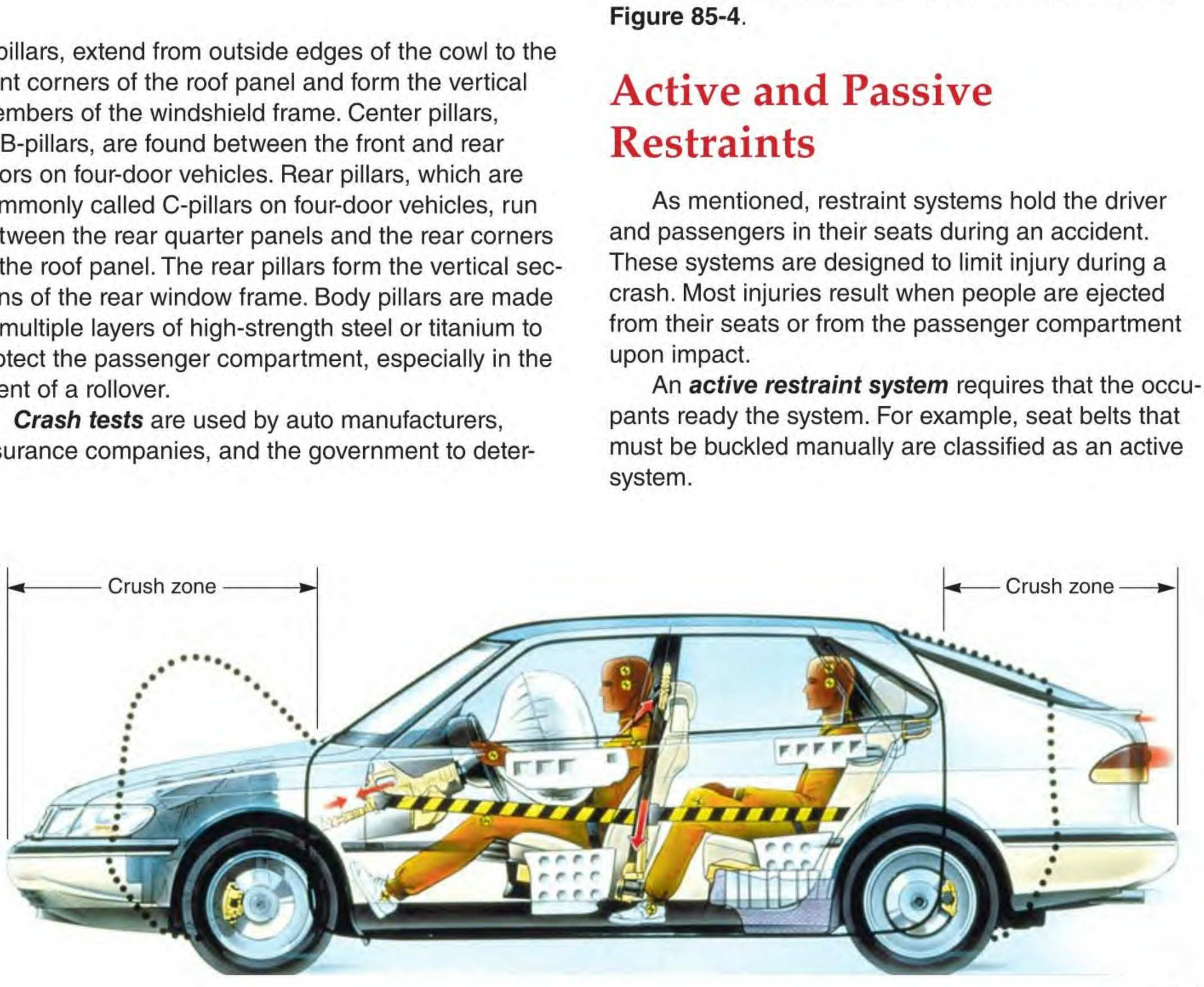
Crash tests are used by auto manufacturers, insurance companies, and the government to determine how well a vehicle's body-frame structure and restraint systems will protect its occupants in the event of a major collision. Vehicles are crashed into stationary walls or other vehicles to measure how the vehicles and their occupants withstand and react to the impact forces. Crash tests are performed from the front, side, and rear of the vehicle. This allows the effects of major impact forces from each direction to be studied. See **Figure 85-3**. Vehicles are rated as good, acceptable, marginal, or poor based on front and side crash tests, as well as rollover tests.

Crash test dummies are used to measure the impact forces that would act on the human body during a crash test. Inertia sensors in the test dummies record the forces acting on vital parts of the body. This allows the manufacturer to estimate how badly people will be injured during similar crash conditions. Study **Figure 85-4**.

Active and Passive Restraints

As mentioned, restraint systems hold the driver and passengers in their seats during an accident. These systems are designed to limit injury during a crash. Most injuries result when people are ejected from their seats or from the passenger compartment upon impact.

An ***active restraint system*** requires that the occupants ready the system. For example, seat belts that must be buckled manually are classified as an active system.



Saab

Figure 85-2. Crush zones are built into the front and rear areas of the vehicle's body and frame. These areas collapse more easily than the passenger compartment, increasing occupant safety. Dotted lines show how the body deforms during a major collision.

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A



B



C

Saab

Figure 85-3. Automakers perform extensive crash tests to analyze the safety of new car and truck designs. A—Frontal-impact crash test propels the vehicle straight into a barrier. B—In a side-impact crash test, a test sled hits the side and doors of the test vehicle. C—In a rear-impact crash test, the test sled is propelled into rear bumper and trunk area.



Volvo

Figure 85-4. A crash test dummy is designed to measure the forces that would act on the human body during an auto accident. Damage to the dummy indicates how badly people would be injured in a similar accident.

A ***passive restraint system*** operates without driver or passenger activation. Air bags and automatic seat belts are passive restraint systems. Refer to **Figure 85-5**.

Seat Belt Systems

Seat belts are strong nylon straps that hold people in their seats during a collision. ***Lap belts*** extend across a person's lap. ***Shoulder belts*** extend over a person's shoulder and chest.

The ***seat belt buckle*** allows you to engage and disengage the belt around your body. ***Seat belt anchors*** provide a means of bolting the seat belt to the car's body and frame structure. A large steel bolt normally secures the seat belt anchors to the structural members in the rocker panels and floor panel. Look at **Figure 85-6**.

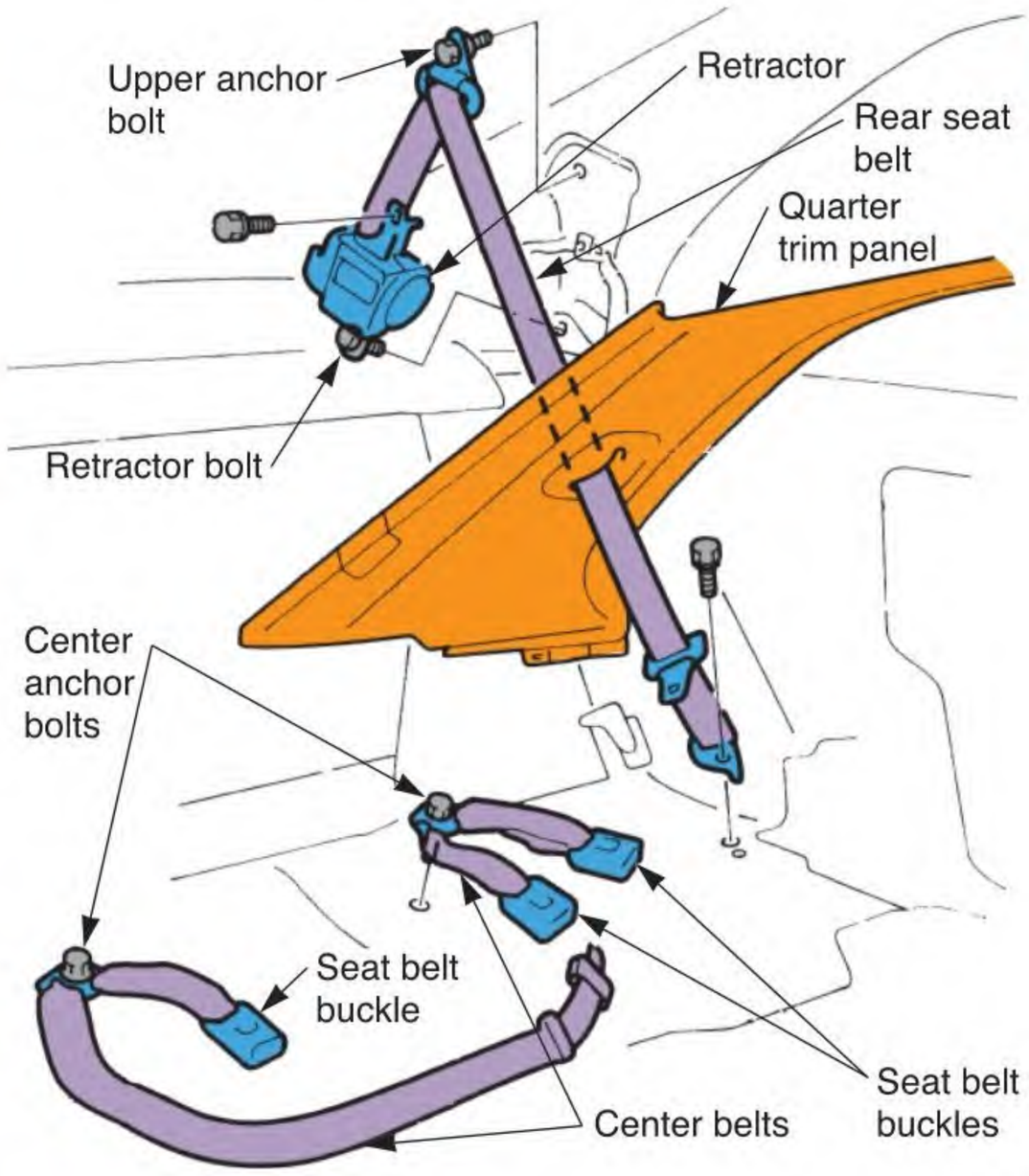
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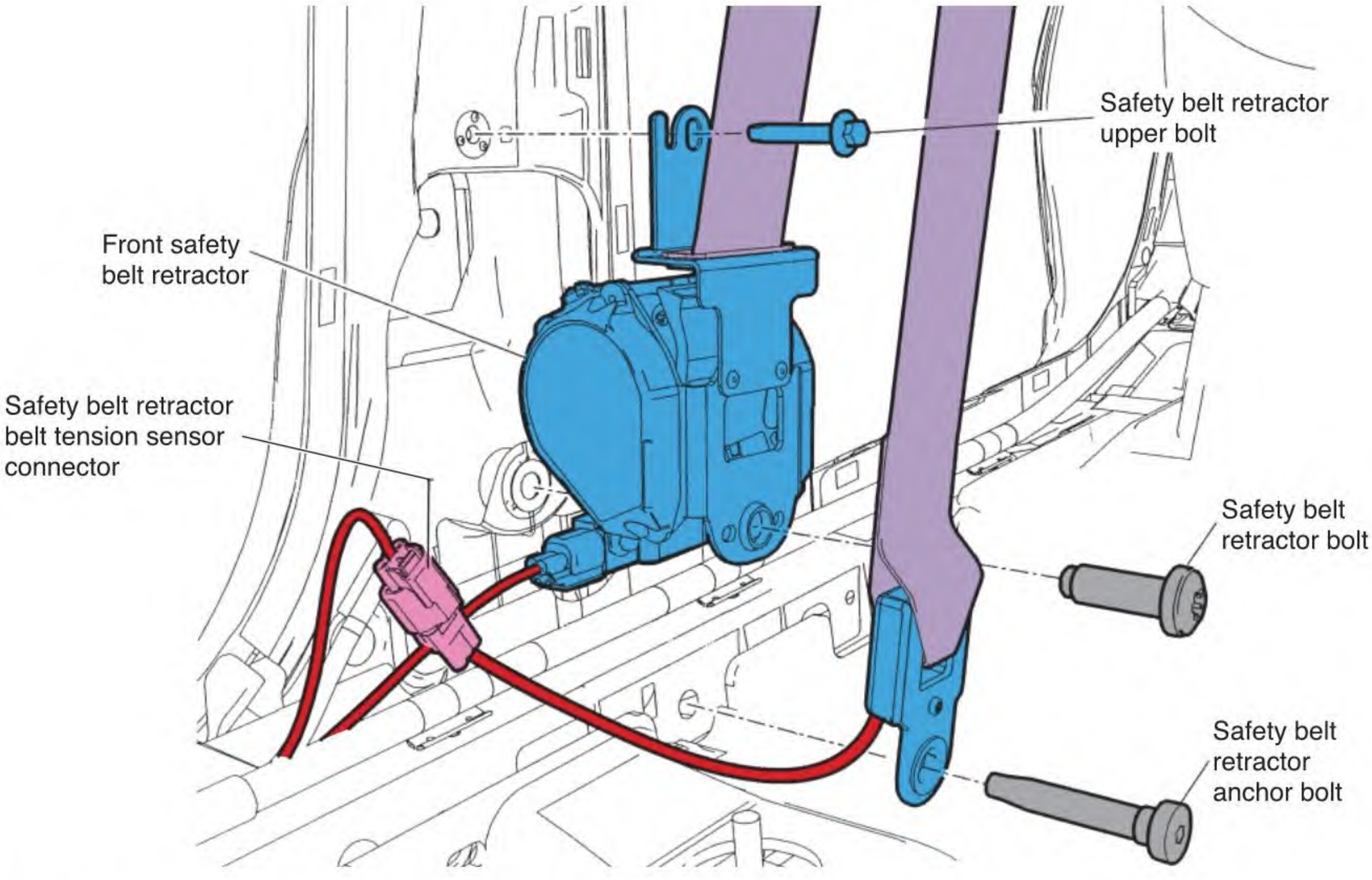
Figure 85-5. Modern vehicles are much safer than those produced in the past. Besides stronger passenger compartments, seat belts and air bags help protect the driver and passengers from injury during collisions.

A ***belt retractor*** takes the slack out of the seat belt so the belt fits snugly around the body. Designs vary. Most pull the belt tight during rapid deceleration, such as when the driver slams on the brakes. See **Figure 85-7**.



Honda

Figure 85-6. Note the basic parts of a seat belt assembly.



Ford

Figure 85-7. A seat belt retractor pulls the seat belt tight around a person's body during rapid deceleration. Large anchor bolts are used to secure the seat belt assembly to the frame or unibody of the vehicle.

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A ***seat belt reminder system*** activates a dash light and generates an audible tone to warn the vehicle's occupants to buckle their seat belts.

Knee Diverter

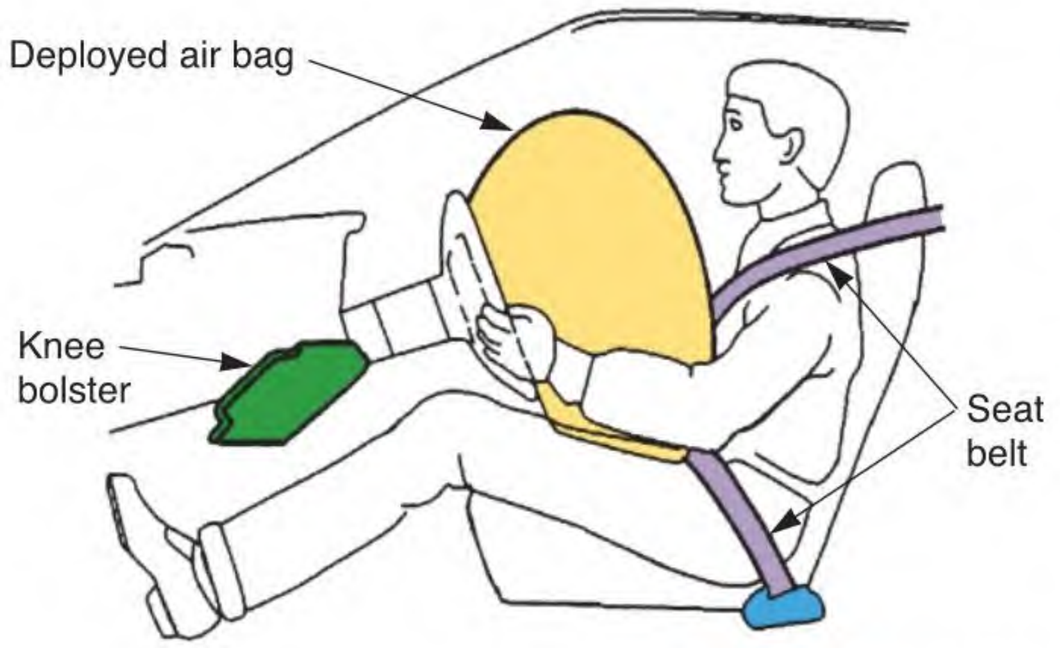
A ***knee diverter***, or ***knee bolster***, is formed into the lower part of the dash to protect the driver's and the front passengers' knees from being injured on the metal frame of the dash. The diverter also prevents the driver and passengers from sliding under the air bag during a collision. It is usually a thick plastic panel that covers the metal frame of the dash. Refer to **Figure 85-8**.

Air Bag Systems

An ***air bag system*** deploys inflatable nylon bags to help protect a vehicle's occupants during a collision, **Figure 85-9**. The air bags inflate in about 1/20th of a second, well before a body can fly forward during a collision. The tough nylon bags can easily absorb the forward inertia of a human body. This helps protect both the driver and the passengers. The air bag system is designed to supplement the protection provided by seat belts.

Typical air bag system parts include the following:

- Air bag module—An air bag module contains the inflator mechanism and the nylon air bag that expands to protect the vehicle's occupants during the collision.
- Air bag controller—An air bag controller is a computer that operates the system and detects faults.



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Figure 85-8. This drawing shows the three primary restraint devices: the seat belt, air bag, and knee bolster.



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Figure 85-9. This vehicle is equipped with a driver's-side air bag, a passenger-side air bag, side-impact air bags, and side curtain air bags.

- Impact sensors—Air bag impact sensors are inertia sensors that signal the controller in the event of a collision. When at least two impact sensors are energized, the controller activates the air bag module.
- Clock spring—The clock spring is mounted in the steering column and provides a continuous electrical connection between the driver's-side air bag module and the air bag wiring harness in the steering column.
- Dash warning lamp—The dash warning lamp contains a bulb that glows when the vehicle is started and remains on until the system is armed (approximately 5 seconds). The bulb will also glow if the controller has detected a problem in the system.

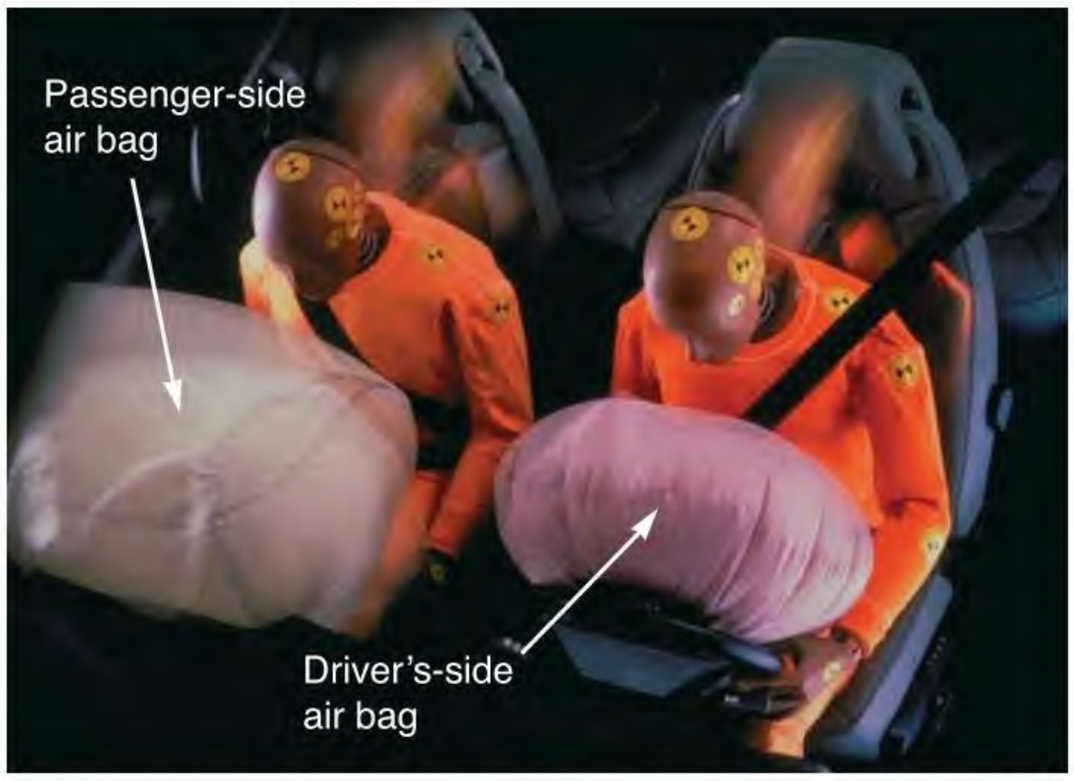
Air Bag Types

The ***driver's-side air bag*** is located inside the steering wheel and protects the driver from head and chest injury during a high-speed frontal collision. Older vehicles may have a driver's-side air bag only. All late-model vehicles are equipped with dual air bags: a driver's-side air bag and a ***passenger-side air bag***. See **Figure 85-10**.

The passenger-side air bag deploys from the right side of the dash. It is much larger than a driver's-side air bag, since it is relatively far from the passengers and may have to protect two humans simultaneously.

The driver's- and passenger-side air bags will only deploy during frontal impacts. Steering wheel

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Saab

Figure 85-10. Both driver's-side and passenger-side air bags are shown here. Note that the passenger-side air bag is considerably larger than the driver's-side air bag.

and dash-mounted air bags may not deploy in side impacts, rear impacts, or rollover situations. A collision must occur within about 30° of the vehicle's centerline for these air bags to inflate.

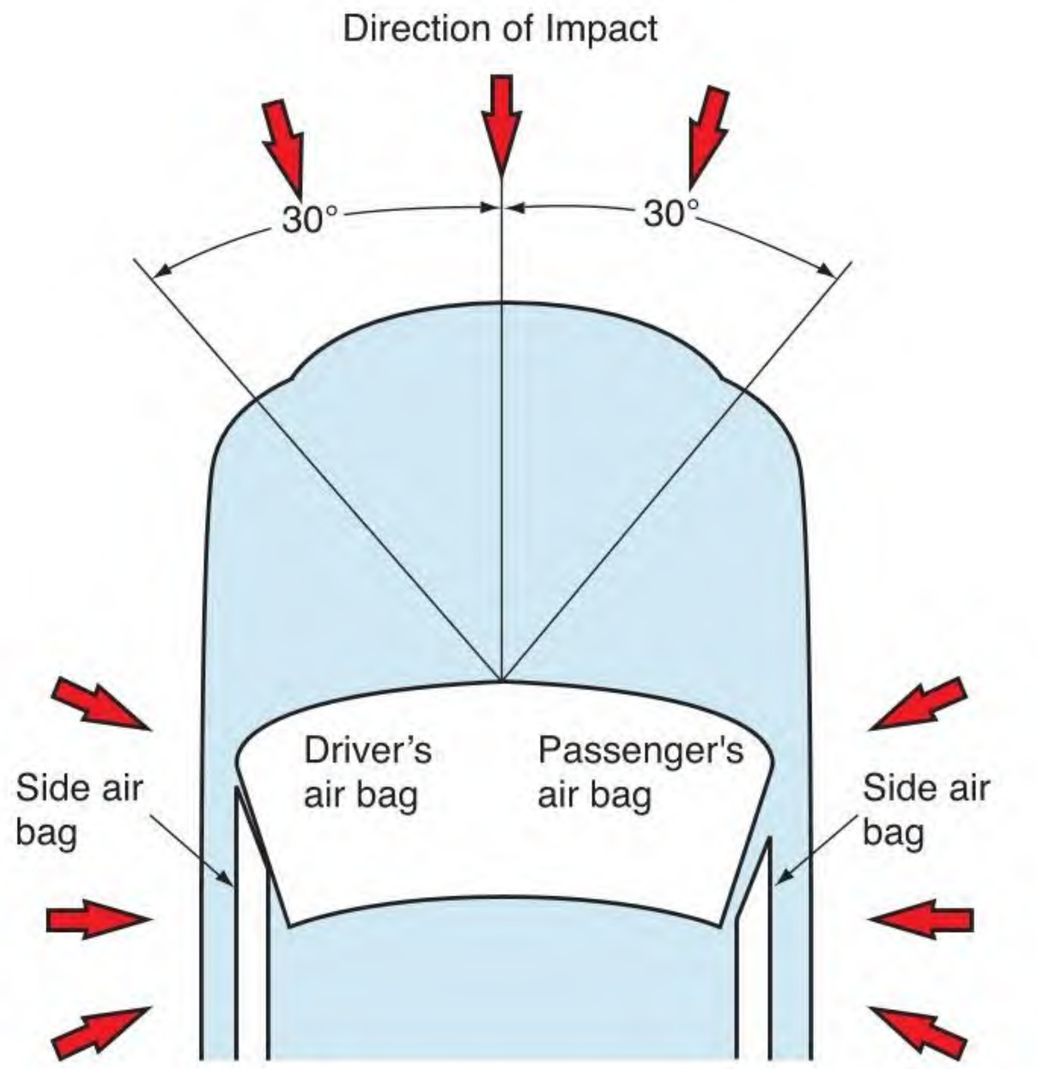
Side-impact air bags can be located in the door panels or on the outside edge of each front seat. These small air bags deploy when the vehicle is hit from the side. They generally do not deploy during a frontal impact. See **Figure 85-11**.

When a vehicle is hit from the side, injury usually results when the occupant's shoulder and head fly through the side window glass. A side-impact air bag system senses the side thrust of the impact and deploys a small air bag to cushion the person as he or she is propelled sideways, **Figure 85-12**.

Side curtain air bags are designed to drop down like "curtains" over the side window glass. This helps protect the occupants from head and facial injuries caused by impact with the window glass. See **Figure 85-13**.

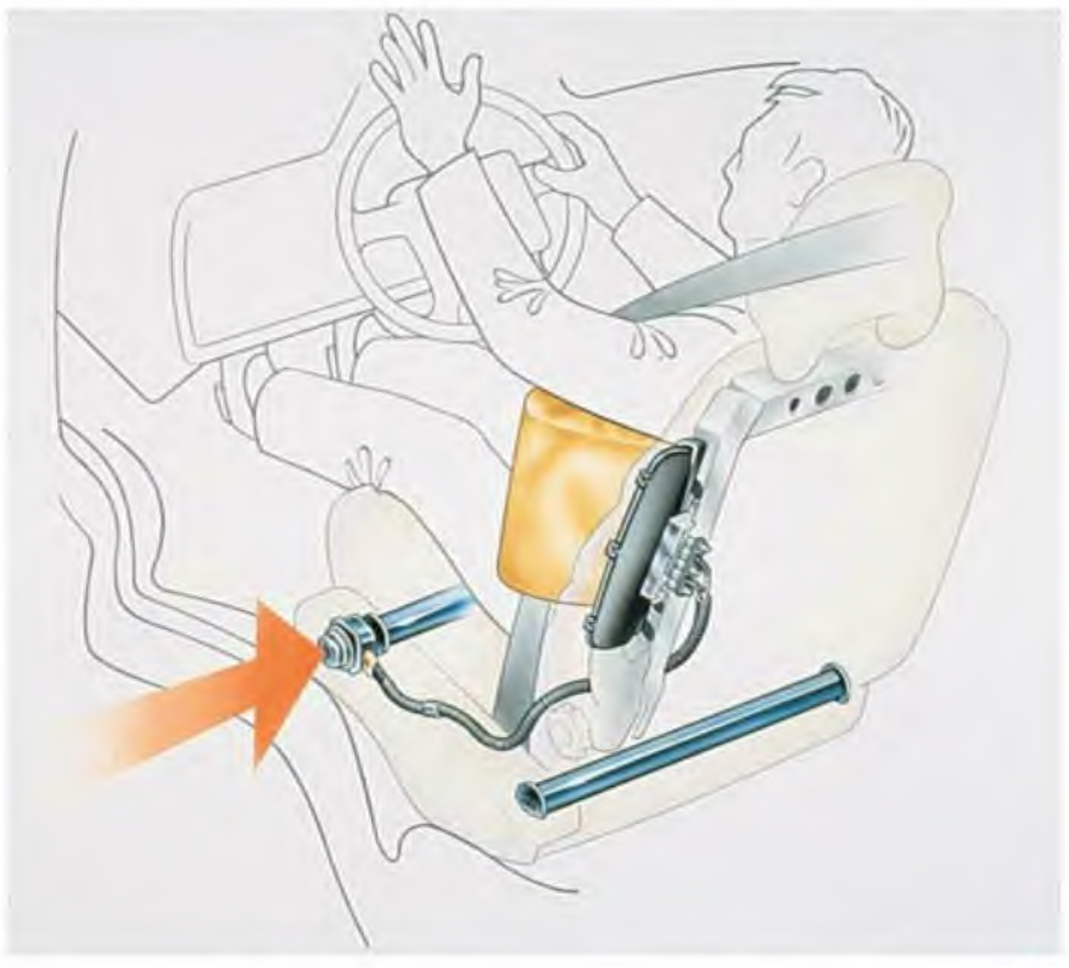
Rear seat air bags fit into the rear cushion of the front seats. They inflate to protect the passengers in the rear seat from injury during a frontal collision. Although not very common, they can be found in a few luxury cars.

Inflatable seat belts use small air bags located in the shoulder harness straps. During a frontal impact, the air bag module can fire a small gas charge to inflate the air bag, increasing the surface area of the shoulder harness. See **Figure 85-14**. This causes the harness to more effectively hold the occupant in the



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Figure 85-11. Driver's-side and passenger-side air bags will normally deploy if impact is within 30° of a vehicle's centerline. Impacts on doors or sides may fire the side-impact air bags independently of frontal air bags.



Volvo

Figure 85-12. Side-impact air bags normally use their own sensors to detect side-impact forces. They only deploy when the impact force would tend to throw the body sideways and into the door.

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Volvo

Figure 85-13. Note how side curtain air bags protect the head and face from being cut by side glass during a side impact from another vehicle. Side air bags and curtains also protect against neck lacerations caused by the shoulder harness during a severe side impact.



Ford

Figure 85-14. Inflatable seat belts use small air bags located in the shoulder harness straps to more effectively hold the occupant in the seat.

seat. It also spreads crash forces over a larger area, preventing the nylon shoulder harness strap from injuring the occupant's shoulder and chest.

Air Bag Module

The ***air bag module*** consists of a nylon bag and an igniter-inflator unit enclosed in a metal and plastic housing. The driver's-side air bag module is mounted in the center of the steering wheel. The passenger-side air bag module is mounted under a small door formed in the right side of the dash pad. Look at **Figure 85-15**.

The ***air bag*** itself is a strong, reinforced nylon sack attached to the metal frame of the module. It is tightly folded for storage in the steering wheel pad, the dash, the door panel, or the side of the seat. ***Air bag vent holes*** allow for rapid deflation of the air bag after deployment. These small holes are formed around the outer edge or back of the bag.

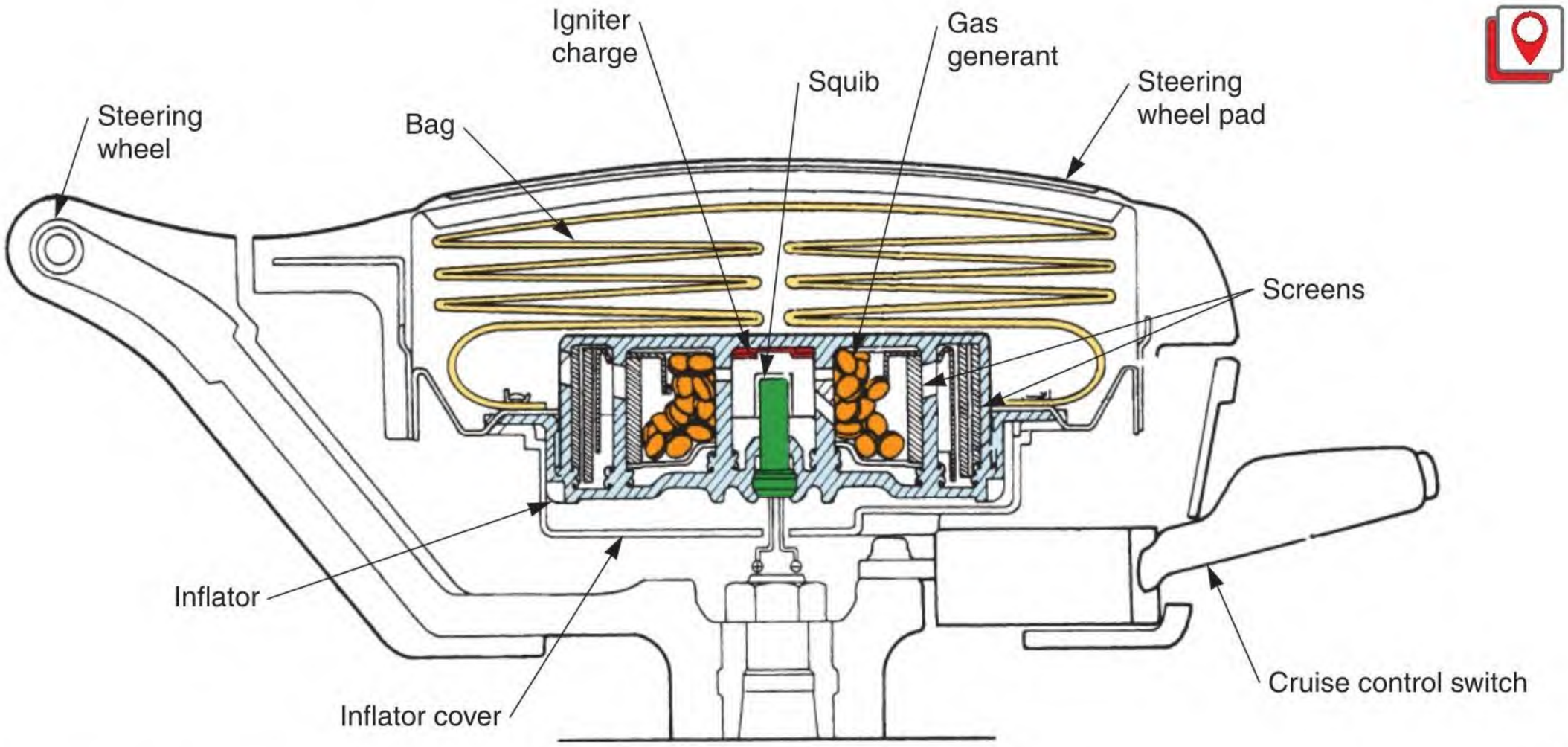
The ***air bag igniter*** generates a small electric arc when an electrical signal is sent to it from the air bag controller. The arc forms across two small pins in the igniter and fires an igniter charge. This flash of the igniter charge causes the gas-generating pellets to burn, generating a huge volume of expanding gas. See **Figure 85-16**.



Breed Automotive Corporation

Figure 85-15. This cutaway shows the inside of an air bag module. The flexible fabric air bag is folded neatly under the steering wheel cover. The air bag igniter generates a small electric arc across two metal pins when an electrical signal is sent to the igniter from the controller. The arc fires an igniter charge, causing the gas-generating pellets to burn. The burning pellets generate a rapidly expanding gas that inflates the air bag.

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Toyota

Figure 85-16. This illustration shows the details of a common air bag module. Study the part names and locations carefully.

The air bag's ***propellant charge***, or expanding gas, is usually produced by the burning of sodium azide pellets in the air bag module. The burning pellets form nitrogen gas, which inflates the air bag.

The large volume of nitrogen gas can inflate the air bag in a fraction of a second. This forces the steering wheel cover to split open, and the air bag shoots out at about 200 miles per hour (320 kilometers per hour). This is fast enough to cushion the forward thrust of the human body as it flies forward after the collision. The air bags also protect the driver's and passengers' heads from flying objects resulting from the accident.

Immediately after the air bag is inflated, the gas is vented out the small holes on the sides or rear of the bag. This prevents the occupants from being pinned in their seats. It also allows the driver to see out of the windshield right after deployment. Study the stages of air bag deployment shown in **Figure 85-17**.

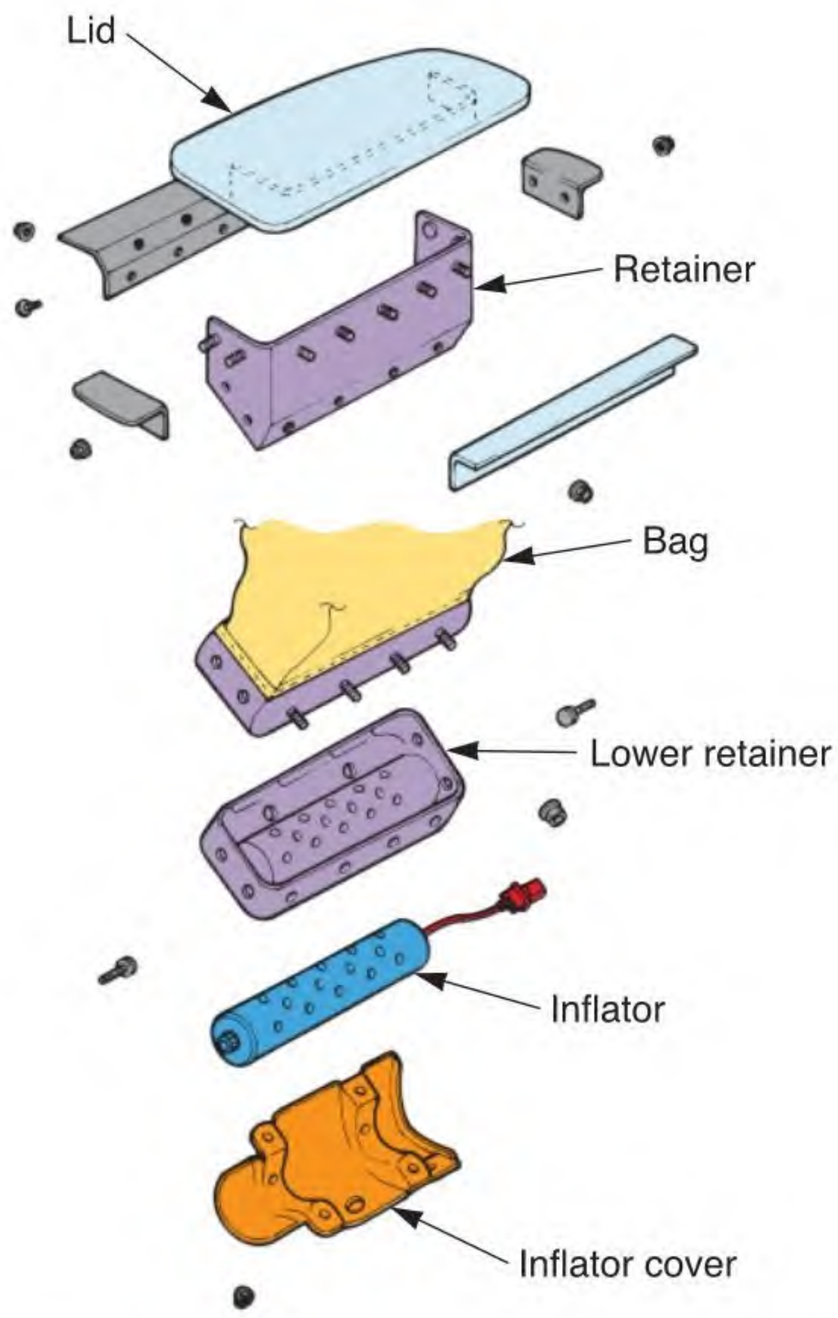
Passenger-side and side-impact air bags are very similar in design. The passenger-side air bag is much larger than a side-impact bag and, therefore, requires more gas for proper inflation. An exploded view of a passenger-side air bag is shown in **Figure 85-18**.



Chrysler

Figure 85-17. Note the stages of air bag deployment. A—During initial deployment, the air bag expands and tears through the plastic cover on the steering wheel pad. B—An air bag inflates at a tremendous speed because it must be fully inflated before the driver hits the bag when thrown forward by the collision force. C—Once the air bag is fully inflated, vent holes allow the bag to slowly deflate so the driver can get out of the vehicle after the accident.

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Honda

Figure 85-18. Exploded view shows the major parts of a passenger-side air bag, which fits in the right side of the dash.

Hybrid Air Bags

A ***hybrid air bag*** uses two methods to inflate the air bag: a small explosive charge and a pressurized gas cartridge. The pressurized gas is much safer and easier to control than the hot nitrogen gas produced by burning sodium azide pellets. The small, metal ***gas cartridge*** contains inert argon gas pressurized to 3000 psi (20,700 kPa).

When the air bag controller sends current to a thin wire heating element, the element heats up and fires a small amount of pyrotechnic material (rapidly burning substance) that forces a "plastic bullet" through the end of the gas cartridge. The cool, pressurized gas then flows out to inflate the air bag.

A hybrid air bag is designed to help prevent minor skin burns that can result from the hot nitrogen gas used to inflate a conventional air bag. Refer to **Figure 85-19**.

Air Bag Sensors

Air bag sensors detect a collision by measuring vehicle deceleration during a collision. They are inertia sensors that detect a rapid change in speed or velocity. One or more sensors are commonly incorporated into air bag systems. The trend is to use fewer sensors than in the past.

Impact sensors are mounted in the front and, in some cases, on the sides of a vehicle to detect a collision. Front impact sensors are often located in the engine compartment, on or near the radiator support. See **Figure 85-20**. Side impact sensors are mounted in the doors or in the B-pillars (pillars behind the front doors).

A ***safing sensor***, or ***arming sensor***, is a backup sensor designed to ensure that the vehicle is actually in a collision. It provides a fail-safe system to prevent accidental bag deployment. For the inflation of the air bags, the safing sensor and at least one impact sensor must be closed.

Magnet-and-Ball Sensors

A ***magnet-and-ball sensor*** is used in some air bag systems as the impact sensor. A small permanent magnet is used to hold a steel ball away from the electrical contacts in the sensor. During a severe collision, the rapid deceleration throws the steel ball forward, overcoming the force of the magnet. The ball rolls forward and strikes electrical contacts. This closes the sensor circuit to signal the controller of a possible collision requiring air bag deployment. See **Figure 85-21**.

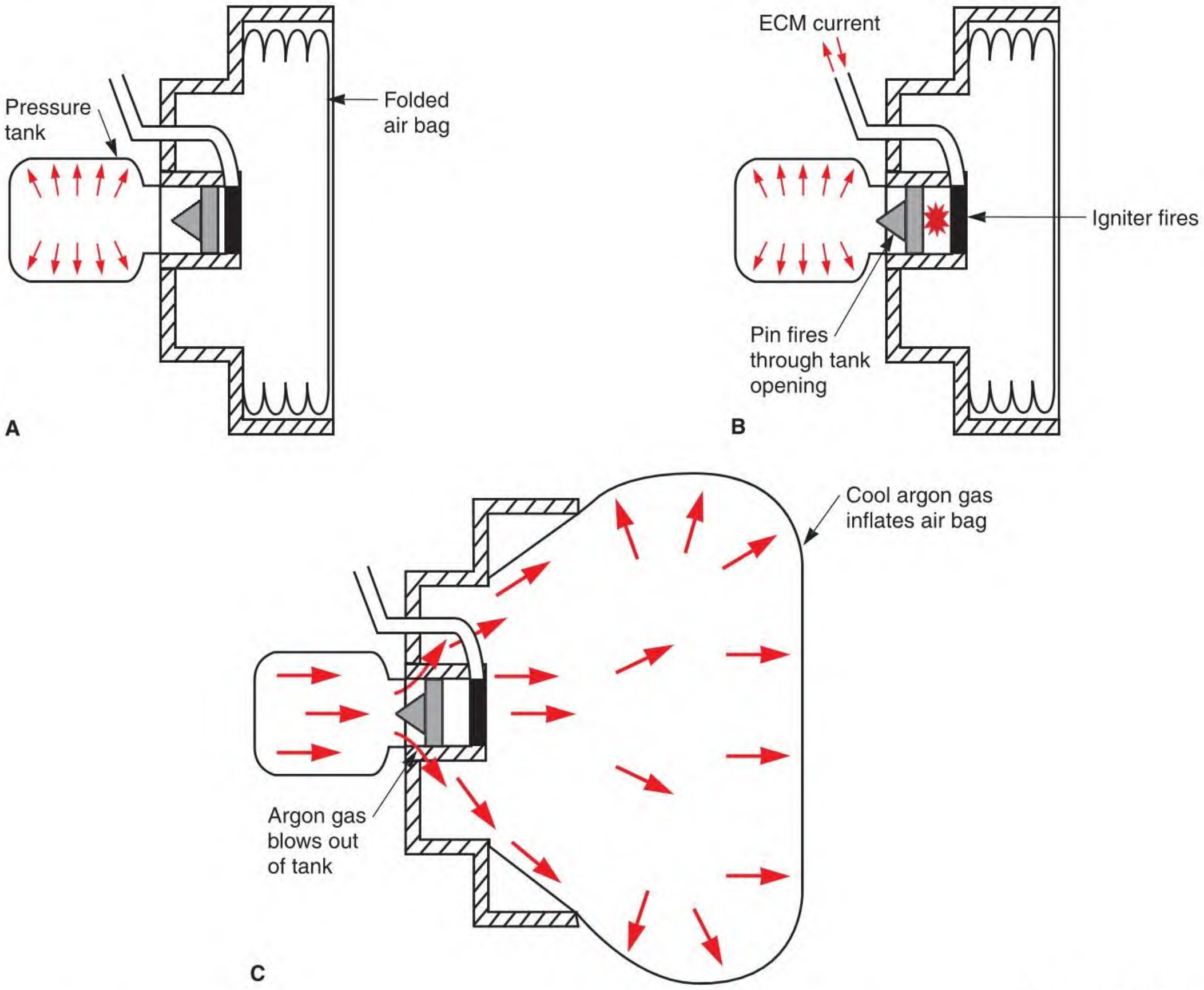
Coil Spring Sensors

A ***coil spring sensor*** uses a small metal weight attached to a metal coil spring. During a severe frontal impact, the weight is thrown forward with enough force to overcome spring tension. The weight touches the sensor contacts and closes the circuit to the air bag controller.

Seat Cushion Sensors

Seat cushion sensors detect the weight of a person sitting in the passenger seat. If no one is sitting in the passenger seat, the air bag system may not deploy the passenger-side air bag. This saves the considerable cost of replacing an air bag without it protecting someone. If a small child is in the passenger seat, the air bag will inflate with less force to protect the child from injury. See **Figure 85-22**.

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Figure 85-19. A hybrid air bag uses both pyrotechnic material and a container of pressurized gas to cause air bag inflation. A—The metal tank is filled with argon gas. The igniter is mounted on one end of the tank. The air bag is folded inside the steering wheel cover. B—The controller detects a collision and sends current to the igniter. The igniter fires, forcing a plastic projectile through the end of the tank. C—A hole formed in the end of the tank allows cool argon gas to blow out and inflate the air bag.

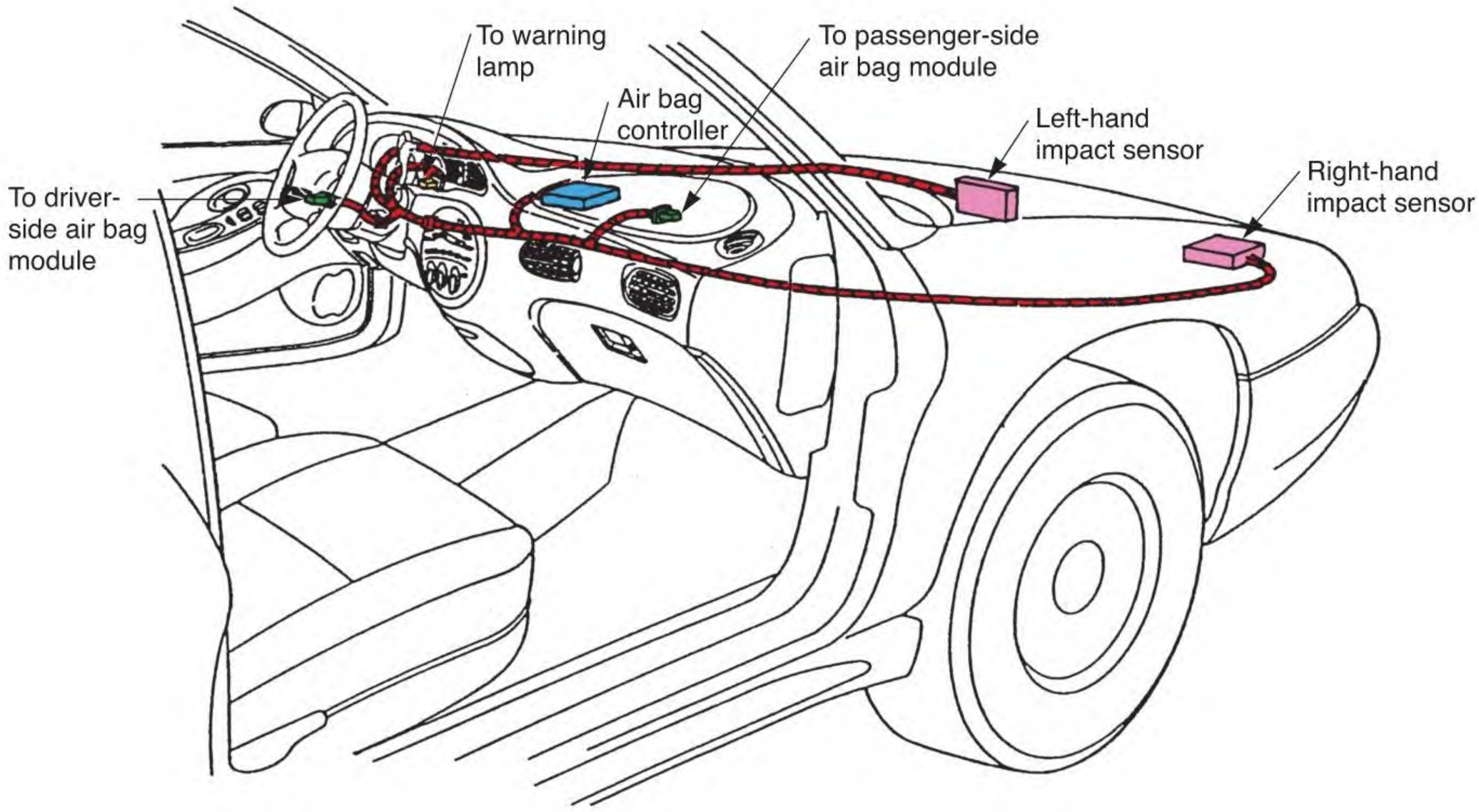
Accelerometer Sensors

Many late-model vehicles are equipped with one central ***accelerometer*** (inertia sensor) instead of separate impact and safing sensors. The accelerometer measures changes in motion or deceleration and is sometimes mounted in the air bag controller. Some accelerometers contain a thin wafer of semiconductor material that is deflected and warped by rapid deceleration. The bending of the semiconductor produces a piezo-electric, or pressure-generated, electrical signal that fires the air bag.

Decibel Impact Sensors

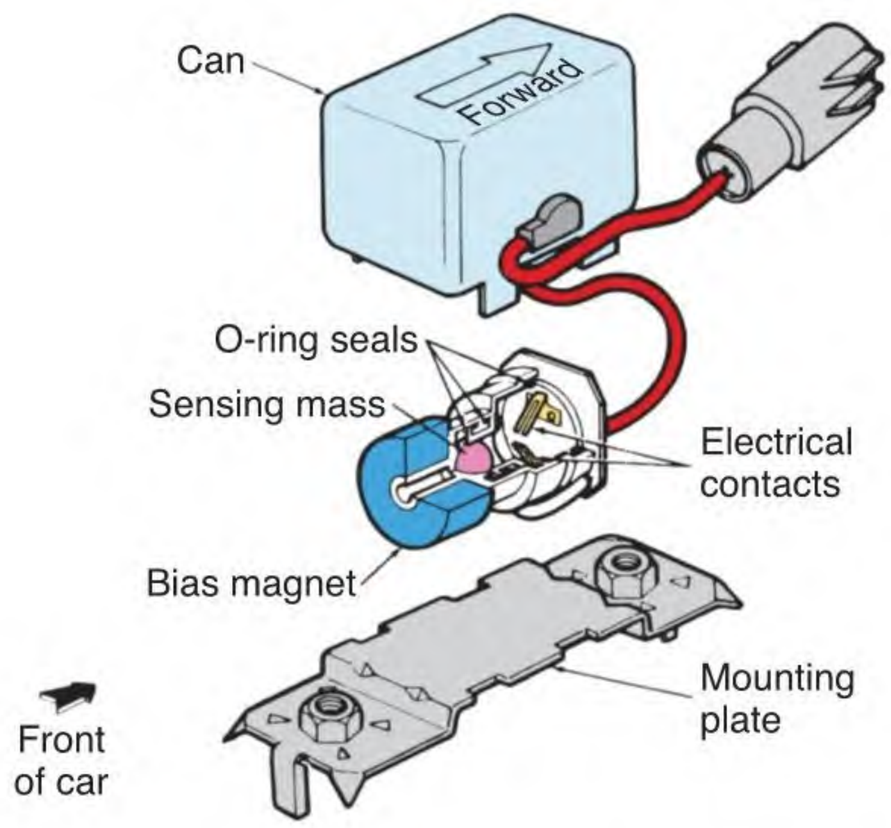
A ***decibel impact sensor*** can measure the amount of sound produced by a major collision. A minor impact will produce less sound and a weaker sensor signal than a major impact. This allows the air bag ECM to deploy the air bags more slowly in a minor accident. In a major, potentially deadly impact, the ECM can use decibel sensor signals to deploy the air bags at maximum speed to better protect people from injury. See **Figure 85-23**.

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Ford

Figure 85-20. Typical location of the air bag impact sensors. They are often mounted near the radiator support.



Ford

Figure 85-21. An air bag system sensor closes when exposed to rapid deceleration forces. This sensor uses a magnet to hold a steel ball. If impact is great enough, the steel ball is thrown away from the magnet and into the two metal contacts. This closes the circuit and signals the controller that the vehicle is in a collision. Note that contacts can be plated with pure gold to ensure a good electrical contact after years of service.

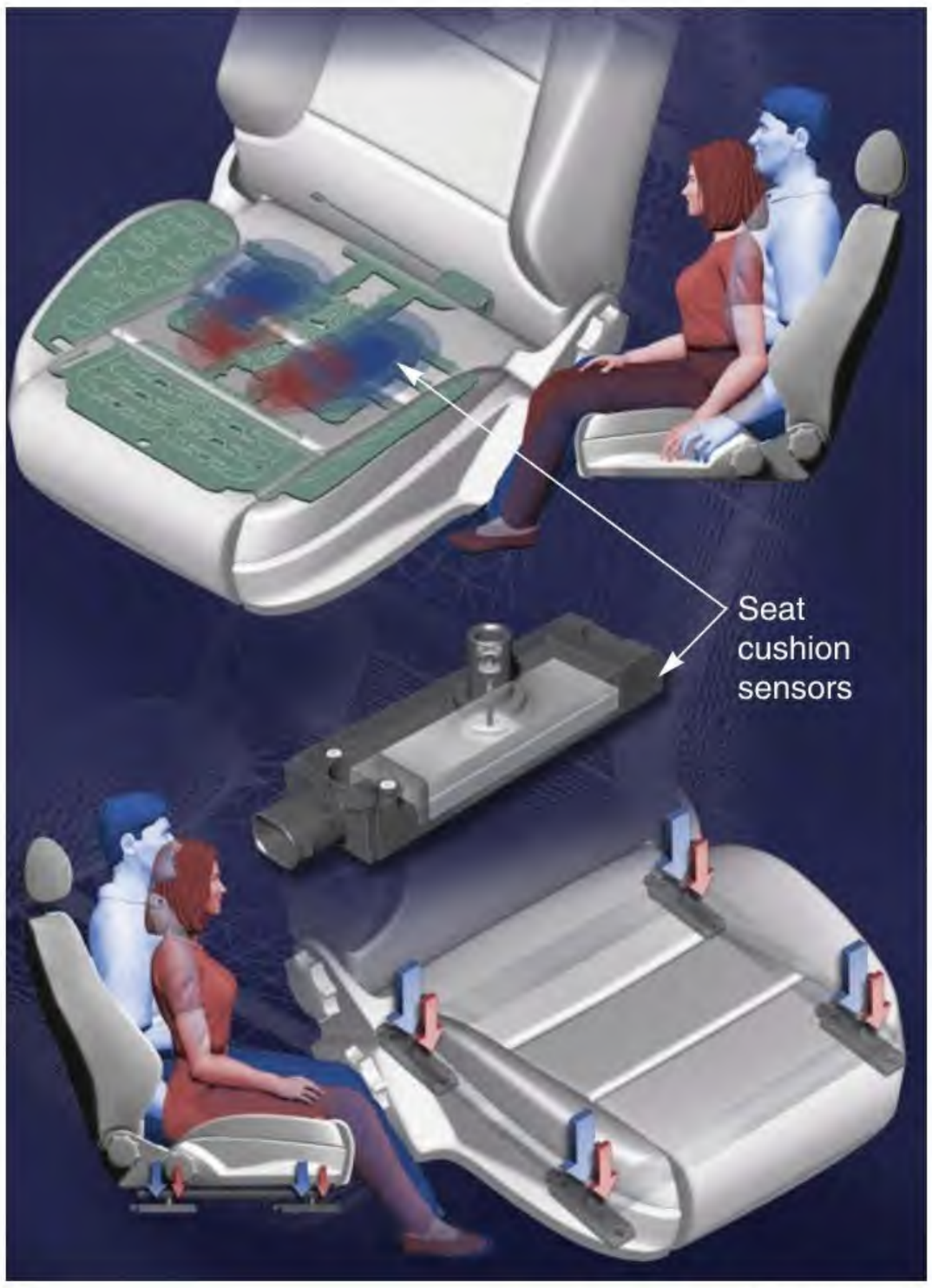
Air Bag Controller

The ***air bag controller***, or ***air bag control ECM***, uses inputs from the impact and safing sensors to determine if air bag deployment is needed. If at least one impact sensor and the safing sensor are closed, the controller sends a high current pulse to the air bag module. The pulse produces a small electric arc in the air bag module, igniting the pyrotechnic material to produce gas expansion and bag inflation, **Figure 85-24**.

The air bag controller also generates trouble codes and energizes a warning lamp if it detects something wrong with the system. Refer to **Figure 85-25**.

A ***smart restraint system*** uses additional inputs to affect the operation of the air bags. It uses conventional impact sensor inputs, as well as data from the seat sensors, side door impact sensors, yaw sensors, wheel speed sensors, seat belt sensors, and even collision-predicting sensors. This allows the smart system to adjust the speed and pressure applied to the air bags to better protect the vehicle's occupants from injury.

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Mercedes-Benz

Figure 85-22. Signals from seat cushion sensors can be used by the air bag controller to control the speed and force of air bag deployment.

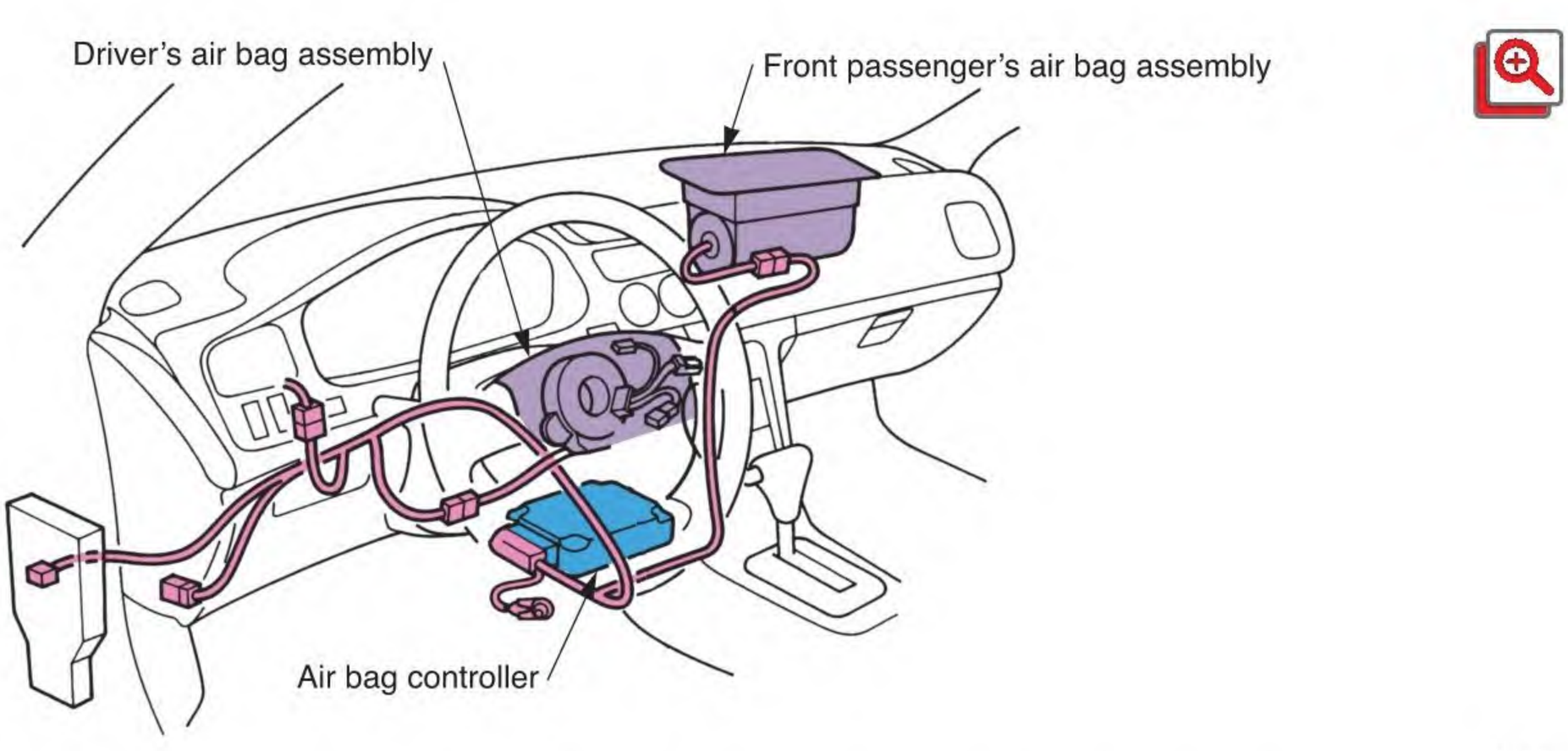


Siemens

Figure 85-23. This air bag system uses a decibel impact sensor that measures the severity of the collision. The louder the crash, the stronger the signal the impact sensor sends to the air bag controller. This allows the controller to inflate the air bag slowly in a minor collision or more quickly in a major collision.

Event Data Recorder

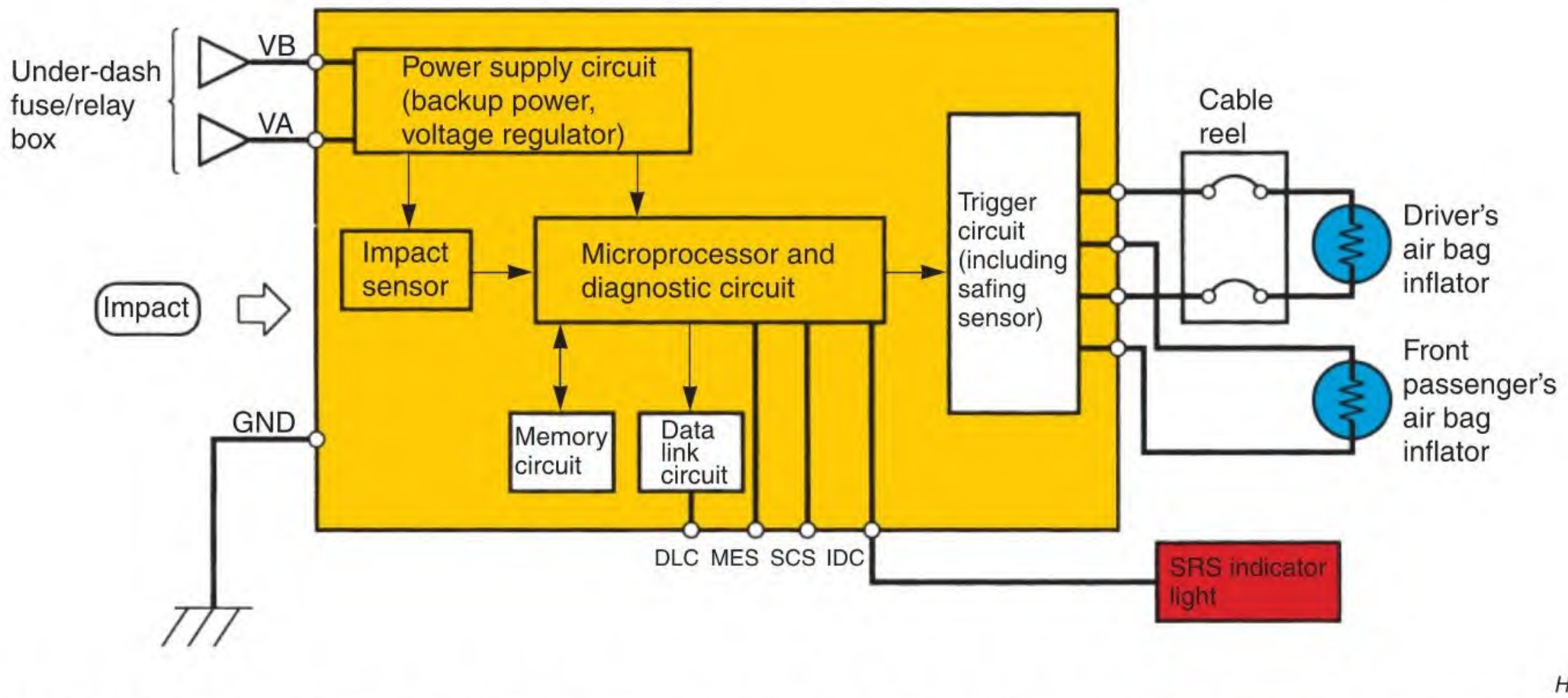
An ***event data recorder***, or flight recorder, monitors and records vehicle operating conditions and stores them in memory. Dealerships and insurance companies can unlock and retrieve this data to determine if a driver was speeding or driving erratically right before a major auto accident. On most new passenger vehicles, the event data recorder is built into the air bag controller or the engine control module (ECM).



Honda

Figure 85-24. Study the general arrangement of the parts in this air bag system. Note the location of the controller.

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Honda

Figure 85-25. This diagram shows how the air bag controller operates. Note that the controller has self-diagnostic capabilities and will generate a trouble code if any component in the system has abnormal voltage, resistance, or current levels.

Industry Trend

The technology found in typical late-model vehicles helps to prevent thousands of highway deaths each year. Many high-speed accidents, which were often fatal in yesterday's lower-tech cars, now result in only minor injuries. This improved safety record is primarily due to the superior structural body/frame designs and advanced restraint systems found in today's vehicles. Air bags, front and rear crush zones, stronger pillars, and reinforced passenger compartments have all contributed to improved vehicle safety.

Summary

- Crush zones, located at the front and rear of the body-frame assembly, are designed to collapse during a severe impact.
- Crash tests are used by the auto manufacturer to measure how well the body-frame structure will protect the driver and passengers in a major collision.
- Crash test dummies are used to measure the forces acting upon the human body during a collision.
- Seat belts are strong nylon straps that hold people in their seats during a collision.
- A knee diverter is formed into the lower part of the dash to prevent the driver's and front passengers' knees from being injured on the metal frame of the dash.
- An air bag system automatically inflates a large nylon bag immediately after the start of a major collision.
- All late-model vehicles are equipped with dual air bags: a driver's-side air bag and a passenger-side air bag, which deploys from the right side of the dash.
- Side-impact air bags can be located in the door panels or on the outside edges of the front seats.

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- The air bag module consists of a nylon bag and an igniter-inflator unit enclosed in a metal-plastic housing.
- A hybrid air bag uses a small explosive charge and a pressurized container of gas to inflate the air bag.
- Air bag sensors detect a collision by measuring vehicle deceleration.
- A safing sensor, or arming sensor, is a backup sensor designed to ensure that the vehicle is actually in a collision.
- A smart restraint system uses additional inputs to affect the operation of the air bag system.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

accelerometer
accidents
active restraint system
air bag
air bag control ECM
air bag controller
air bag igniter
air bag module
air bag sensors
air bag system
air bag vent holes
arming sensor
belt retractor
body pillars
coil spring sensor
crash test dummies
crash tests
crush zones
decibel impact sensor
driver's-side air bag
event data recorder
gas cartridge
hybrid air bag
impact sensors
inflatable seat belts
knee bolster
knee diverter
lap belts
magnet-and-ball sensor
passenger-side air bag
passive restraint system
propellant charge
rear seat air bags
safing sensor
seat belt anchors
seat belt buckle
seat belt reminder system
seat belts
seat cushion sensors
shoulder belts
side curtain air bags
side-impact air bags
side-impact beams
smart restraint system
vehicle collisions

Activities

1. Visit a local salvage yard. Ask to inspect deployed air bags in wrecked vehicles. Write a report on the amount of damage to the vehicle.
2. Read service manual literature on air bags.
3. Visit the library and look up articles in periodicals on air bags. Give a presentation to the class about interesting facts found in these articles.

Review Questions

Answer the following questions using the information provided in this chapter.

1. A(n) _____ _____ helps hold the driver and passengers in their seats to prevent them from being injured during a collision.
2. What are *crush zones*?
3. The _____ takes the slack out of the seat belt, so it fits around the body snugly.
   (A) anchor
   (B) buckle
   (C) retractor
   (D) propellant
4. Name the major parts of an air bag system.
5. The largest air bag in a dual air bag system is the _____.
   (A) driver's-side air bag
   (B) passenger-side air bag
   (C) side-impact air bag
   (D) rear seat air bag
6. Describe the air bag module.
7. How fast can an air bag travel during deployment?
   (A) 100 mph (160 km/h).
   (B) 150 mph (240 km/h).
   (C) 200 mph (320 km/h).
   (D) 300 mph (480 km/h).
8. Explain the operation of a hybrid air bag system.
9. Air bag sensors detect a collision by measuring _____ of the vehicle during a collision.
10. The trend is to replace several air bag sensors with a central _____.

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ASE-Type Questions

1. Technician A says manual seat belts are passive restraints. Technician B says air bags are active restraints. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Which of the following tests is used to analyze how well the vehicle structure protects the driver and passengers?
   (A) Beam test.
   (B) Crush zone test.
   (C) Crash test.
   (D) Dummy test.
3. Which of the following parts helps prevent leg injuries?
   (A) Knee diverter.
   (B) Pedal cushions.
   (C) Tilt wheel.
   (D) Padded dash.
4. With most systems, how many sensors must be energized before the air bag will deploy?
   (A) One.
   (B) Two.
   (C) Three.
   (D) Four.
5. Technician A says that the driver's-side air bag may not deploy if the direction of impact is more than about 30° from the vehicle's centerline. Technician B says that side air bags may not deploy during a frontal impact. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. All of the following are found in motor vehicles, *except:*
   (A) rear seat air bags.
   (B) knee air bags.
   (C) side-impact air bags.
   (D) side curtain air bags.
7. Technician A says that the air bag controller is usually located on the vehicle's steering wheel. Technician B says that the driver's-side air bag module is located in the steering wheel. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
8. Technician A says that hybrid air bags use a small explosive charge to inflate the air bag. Technician B says hybrid air bags use a pressurized gas cartridge. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
9. Which of the following is *not* an air bag sensor?
   (A) Arming sensor.
   (B) Safing sensor.
   (C) Accelerometer sensor.
   (D) Proximity sensor.
10. Front impact air bag sensors are usually located in the:
    (A) engine compartment.
    (B) passenger compartment.
    (C) doors.
    (D) trunk.

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Kim D. Lyman/Shutterstock.com

Even a relatively minor collision may result in the need to replace multiple air bags.

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Chapter 86
Restraint System Service

After studying this chapter, you will be able to:

- Explain how to inspect and repair seat belts and their retracting mechanisms.
- Use a scan tool to diagnose and repair restraint systems.
- Describe safety rules for working with air bags.
- Safely disconnect 12-volt and, if necessary, HV battery power from restraint system circuit before working on the system.
- Summarize the procedure for air bag replacement and disposal.
- Explain how to replace air bag sensors.
- Correctly answer ASE certification test questions about the diagnosis and repair of restraint systems.

The proper operation of seat belts and air bags is critical to the safety of the driver and his or her passengers. If you make the slightest mistake when servicing these important safety devices, you will endanger the people who trust your work.

An air bag also has the potential to cause serious injury to you and others in the shop if handled improperly. Air bags "pack a powerful punch" when deployed, expanding outward at a speed up to 200 mph (320 km/h). This chapter will summarize the most important procedures for correctly servicing air bags and seat belts. Study it carefully.

Warning

Warn customers of the danger of placing children in front seats of vehicles equipped with dual air bags. Air bags have been blamed for the deaths of several small children. Children should be placed in the rear seats of the vehicles. They should be buckled into an approved child seat until they are tall enough to be restrained properly by a seat belt.

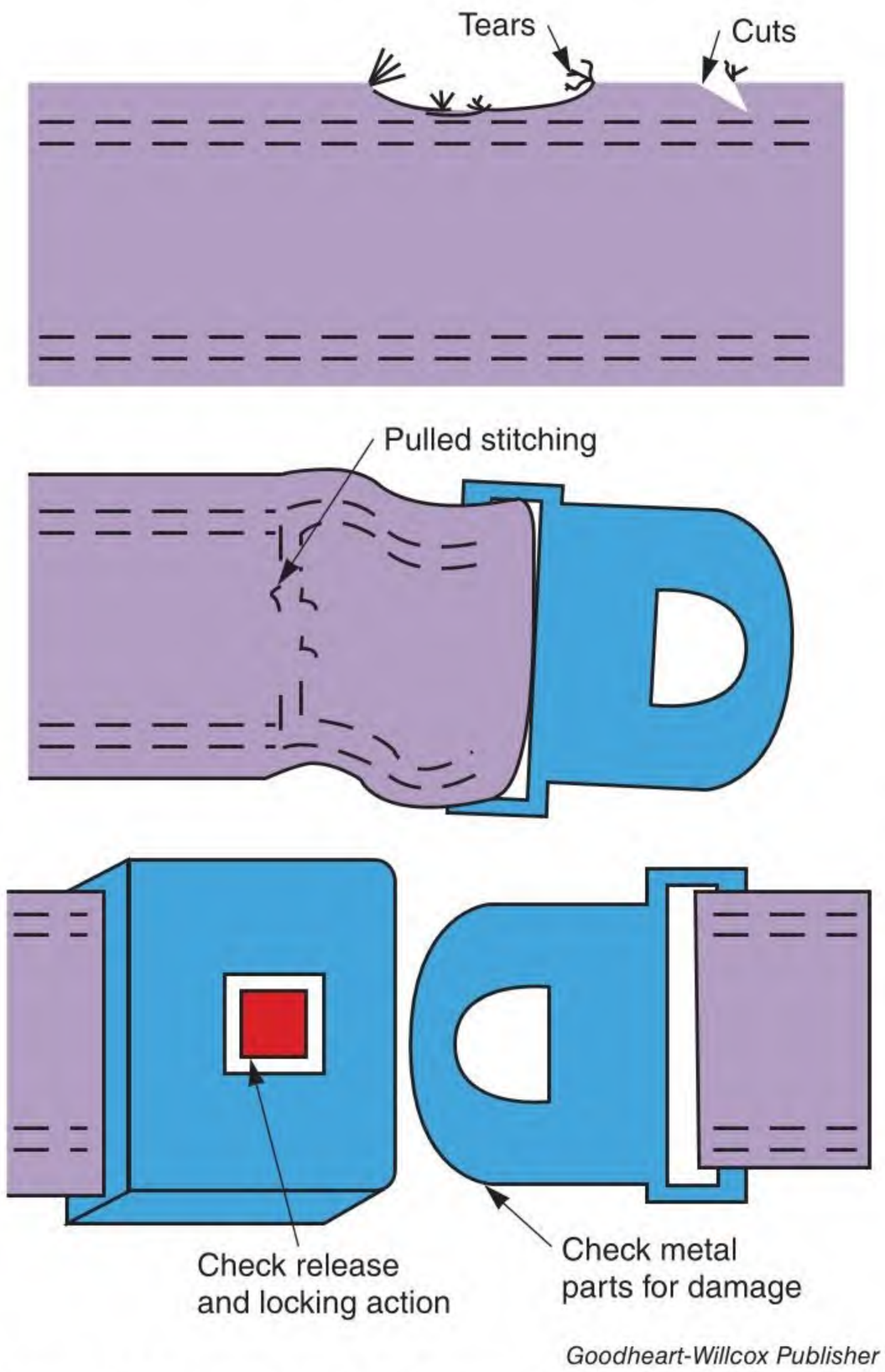
Seat Belt Service

Seat belts can be damaged by the force of a collision and their cloth fabric can deteriorate over time. Therefore, seat belt mechanisms and the belts themselves should be inspected after an accident or prolonged use, **Figure 86-1**.

Seat Belt Inspection

To inspect a seat belt for damage, pull the belt all the way out of its retractor. Inspect the belt fabric, or webbing, for cuts, pulled threads, broken thread loops, color fading, and fabric deterioration. Look for twisted

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Figure 86-1. Inspect seat belt assemblies for these types of problems.

webbing, which could make the belt stick in its retractor or guide plates. If necessary, untwist the belt so it moves freely in and out of the retractor and guides.

Fit the two ends of the seat belt buckle together. Listen for a solid click. Then, try to pull the buckle apart by pulling sharply on the belt. The two ends must not disengage. Make sure the belt buckle will release with normal finger pressure. Inspect the belt anchors for problems (bent, cracked, loose, etc.).

Replace the seat belt assembly if problems are found. Repeat this procedure on all other seat belts.

Seat Belt Service

Seat belt service generally involves removing the damaged belt and replacing it with a new seat belt assembly. When replacing a seat belt, remember the following precautions:

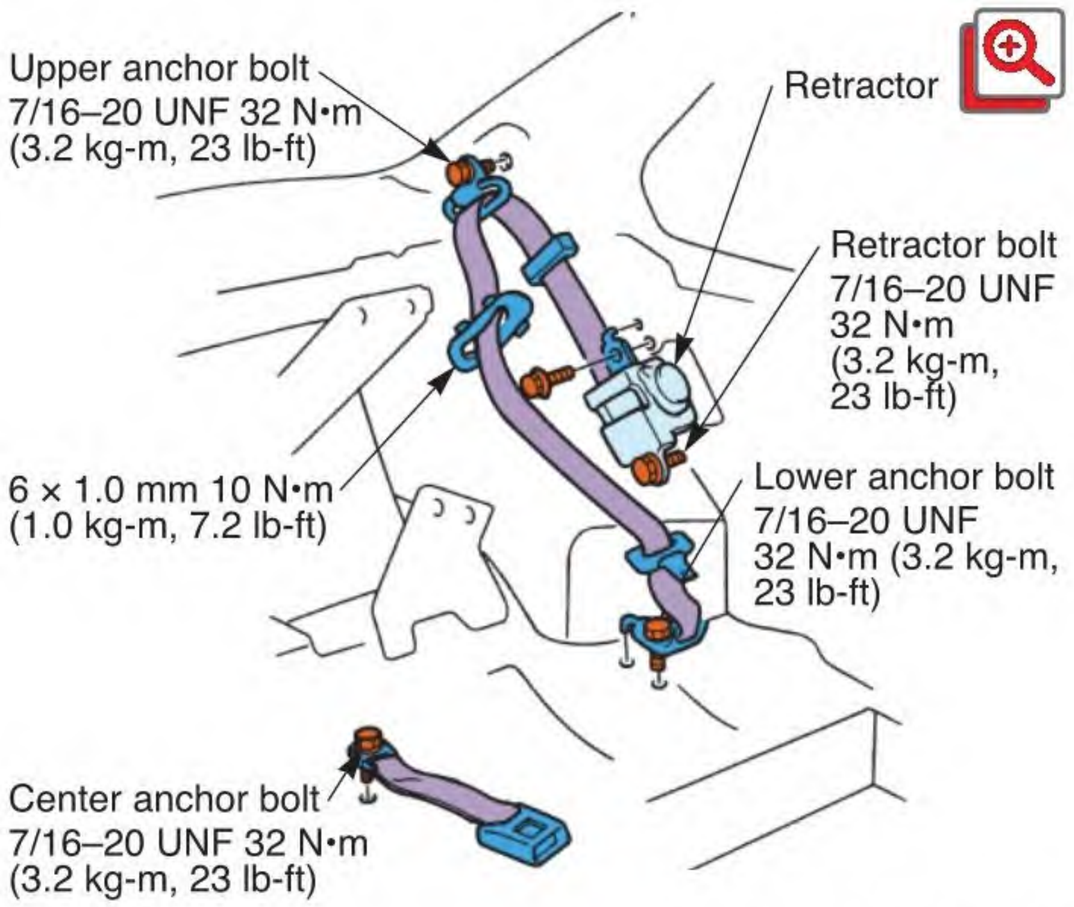
- Sharp edges on sheet metal body parts and on tools can damage seat belts. Even small cuts can weaken the belt webbing, causing it to snap during a collision.
- Never attempt to straighten any portion of the belt buckle, latch plate, or anchor plate. If bent, the components should be replaced.
- Inspect seat belt anchors for bending, cracking, or looseness. When replacing anchors, use the correct grade case-hardened bolts. If common low-strength steel bolts are used, they could break during an accident, allowing the occupant to be ejected from the seat.
- Use a torque wrench to tighten all seat belt anchor bolts to factory specifications. See **Figure 86-2**.

Belt Retractor Service

Seat belts commonly use one of two belt retractor mechanisms: a centrifugal retractor or a pendulum retractor.

A ***centrifugal belt retractor*** uses centrifugal force to keep the belt from extending. If you pull on the belt hard enough, the rapid centrifugal force engages the locking mechanism so the belt holds the driver or passenger in the seat.

To check the action of this type belt, simply pull out on the belt quickly. It should lock, and you should not be able to extend the belt further. Pulling slowly should allow free lengthening of the belt out of the retractor.



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Figure 86-2. Always tighten seat belt anchor bolts and retractor bolts to specifications.

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A ***pendulum belt retractor*** uses the inertia of a small hinged metal weight to engage the seat belt's locking mechanism during vehicle deceleration. When the vehicle brakes or stops quickly, a small pendulum in the retractor is thrown forward, causing the belt locking mechanism to engage.

To test this type of belt, find an open road or an empty parking lot. Drive the vehicle at approximately 10 mph and then hit the brakes hard. The belt should lock up as the vehicle comes to a stop. If the belt still does not lock, the retractor should be replaced.

Tech Tip

Most manufacturers recommend that certain seat belt system parts be replaced after a major collision. For example, many manufacturers recommend replacing seat belt retractors and inertia sensors after a collision, as these components can be mechanically damaged by the rapid deceleration.

Air Bag System Service

Air bag service is needed after deployment or when the dash malfunction light indicates a problem. For your safety and the safety of the people relying on the air bags, proper repair methods must be followed.

Warning

Remember to be cautious to prevent accidental air bag deployment when working. An air bag has enough force to break bones and cause serious injury. Always disconnect the battery before beginning work. Keep your head and arms to one side of the air bag when testing, removing, and installing a new module. Never place your head close to the steering wheel or reach through the wheel spokes during service.

Scanning an Air Bag System

If the air bag indicator light glows and the bag is not deployed, use a scan tool to analyze the system. Connect the scan tool to the vehicle's diagnostic connector and read any trouble codes. These codes will tell you where circuit problems might exist for further testing.

Tech Tip

Warn customers of the danger of placing items such as jewelry, keys, cell phones, etc., on their dash or hanging objects from their rear view mirrors. These items pose a safety risk to a vehicle's occupants.

Even in minor accidents, people have been seriously injured when the air bags deploy and propel items in their path directly at the vehicle's occupants. In one case, a car's passenger had just set a cell phone on the dash when the driver rear-ended another vehicle at only 30 mph. The passenger was seriously injured when the air bag deployed and propelled the cell phone at her head, causing face and neck lacerations Remember that anything hanging in front of or placed in the path of an air bag can become a potentially deadly projectile. Make sure all items are removed from the dash before you repair a vehicle.

Air Bag Module Service

The air bag module must be serviced when it is deployed, defective, or damaged. You must often remove or disable the module when working on the steering column. It is important that specific procedures be followed to ensure personal safety and proper air bag operation.

Disarming an Air Bag

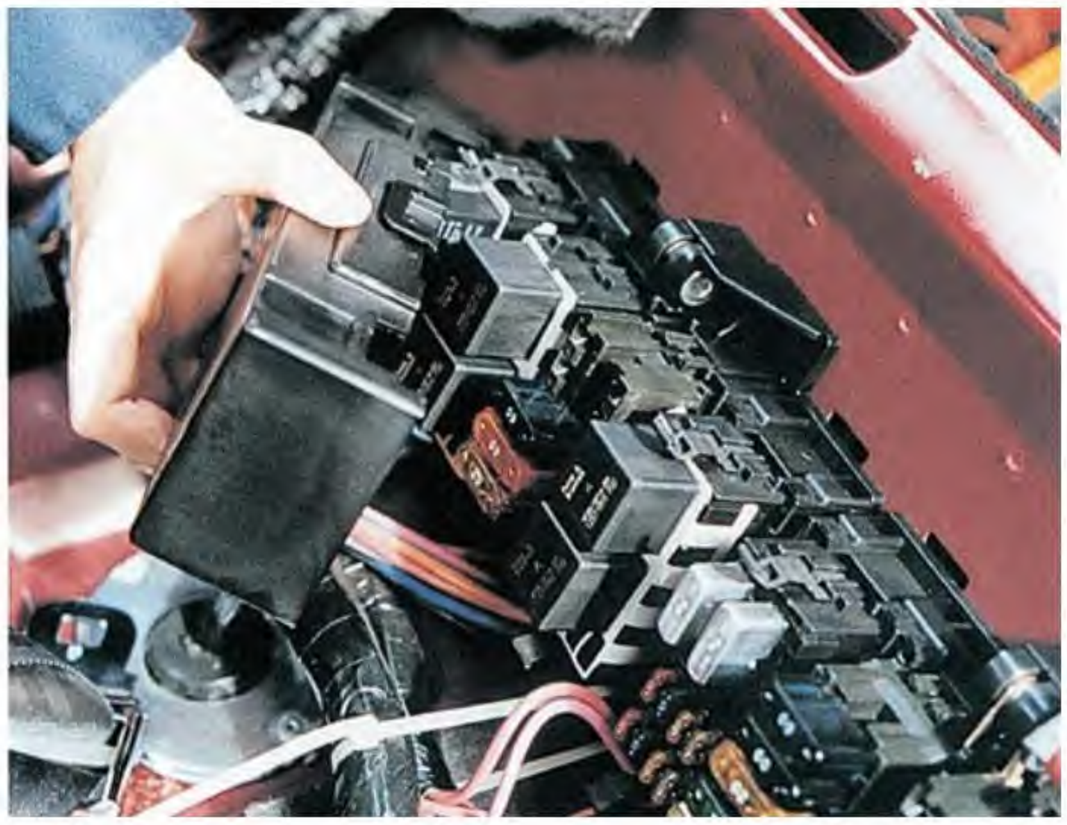
Before servicing a vehicle equipped with an air bag, the system must be disarmed. To disarm an air bag system, all sources of electricity for the igniter must be disconnected from the air bag module. This would include disconnecting the 12-volt battery and, on hybrid vehicles, disconnecting the HV battery by removing the high-voltage disconnect. Procedures vary with the vehicle make and model.

Manufacturers may also specify the removal of a specific system fuse or disconnection of the controller. Always refer to the service manual for exact procedures for disarming the system. This will help prevent electrical system damage and accidental deployment, **Figure 86-3**.

Warning

Air bag systems are often equipped with an ***energy reserve module,*** which can deploy the air bag after a power failure. The energy reserve module must be disconnected or allowed to discharge for up to 30 minutes after disconnecting the battery. Refer to the service manual for details.

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Figure 86-3. Follow service manual instructions to disable the air bag system. You may have to follow a specific sequence. For example, you may be instructed to pull a fuse, disconnect the module, and then disconnect the battery.

Manual Air Bag Deployment

Manual air bag deployment is done by connecting a voltage source to the air bag module wires to "fire" the air bag. Manual deployment is needed if the vehicle is to be scrapped at a salvage yard (total loss from accident) or if the air bag module is damaged or defective. Used air bags are not recommended for reuse in another vehicle for safety reasons.

Warning

Never deploy a passenger-side air bag unless the vehicle is being scrapped for salvage. Passenger-side air bag deployment can break the windshield and damage dash components.

Service Procedure

To manually deploy an air bag:

1. Disconnect the wires between the controller and air bag. Most manufacturers recommend that the air bag remain mounted securely in the vehicle.
2. Connect long jumper wires to the wires going into the air bag igniter. The jumper wires must be long enough to reach to the rear of the vehicle. Wrap the other ends of the jumper wires together to short them and prevent accidental deployment.
3. With everyone clear of the area, connect the other ends of the jumper wires to an automotive battery. The air bag should deploy with a loud pop, and the deployed bag should be visible.
4. During deployment, the air bag becomes extremely hot and can cause serious burns. Wait at least thirty minutes before touching the deployed air bag assembly.

Warning

Never connect the jumper wires to the battery before connecting them to the air bag module. This will make the bag deploy as soon as the jumper wires are connected to the module, usually resulting in serious injury to the technician.

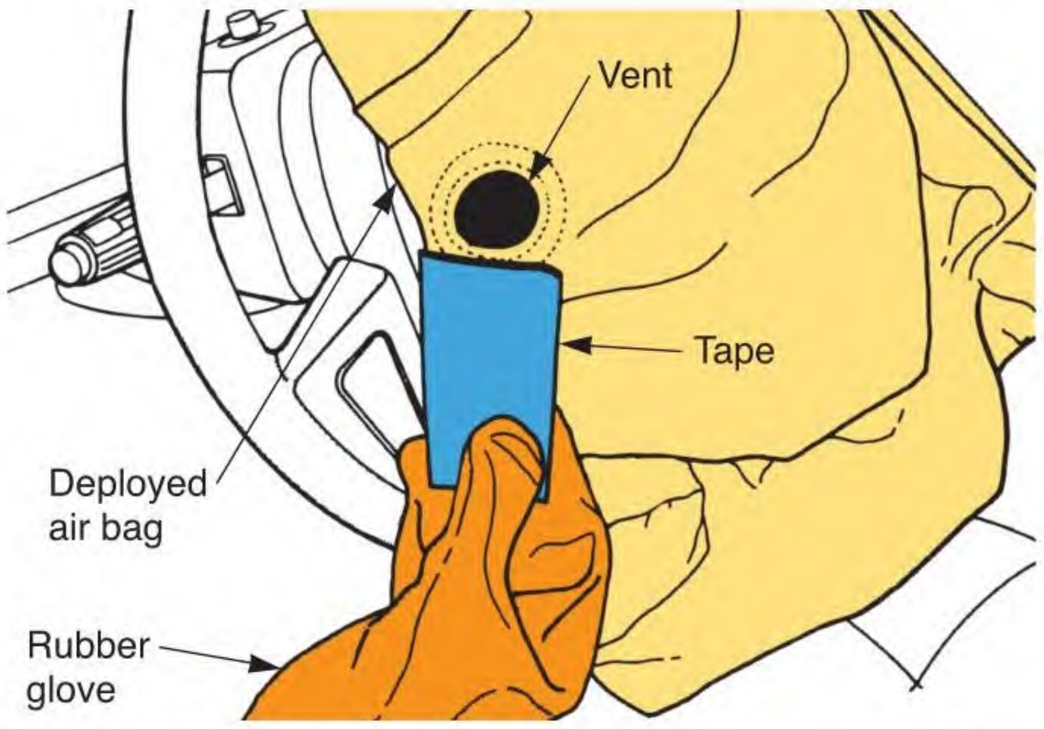
Air Bag Disposal/Recycling

Service Procedure

After deployment, the air bag must be removed and disposed of properly. Follow all disposal information to avoid breaking federal law.

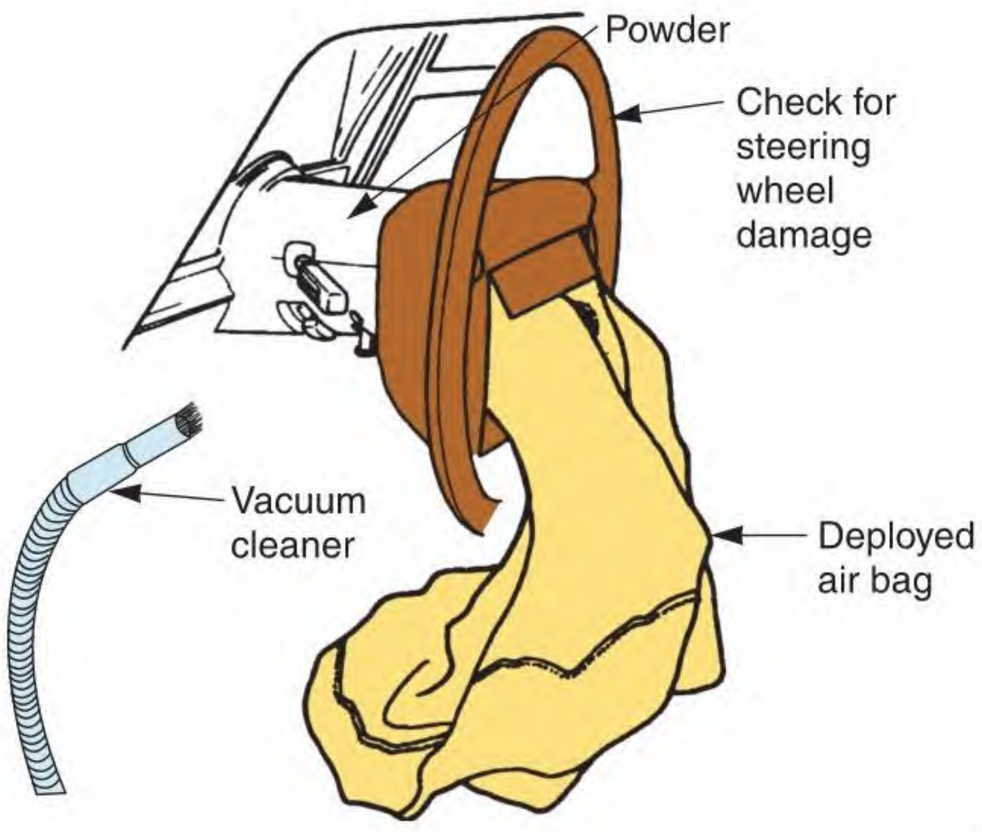
1. Wear rubber or plastic gloves, a respirator, and safety glasses when handling a deployed air bag.
2. ***Air bag powder***, usually sodium hydroxide, is a skin, eye, and throat irritant that may blow out of the air bag upon deployment. Place pieces of tape over the vent holes in the air bag. This will help keep residual powder from leaking out the vents during bag removal, **Figure 86-4**.
3. To remove the deployed air bag, remove the screws from the rear of the steering wheel. Lift the module out and disconnect the wires.
4. Use a shop vacuum to clean up any air bag powder in the passenger compartment. The air bag powder can be an eye and skin irritant. Vacuum the dash, vents, seats, carpet, and other surfaces contaminated with this powder. Refer to **Figure 86-5**.

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Chrysler

Figure 86-4. Place tape over the air bag vent holes to keep powder from leaking out during removal.



Ford

Figure 86-5. After air bag deployment, use a vacuum cleaner to pick up any powder. Wear safety goggles, rubber gloves, and a respirator. The powder is a skin and eye irritant.

5. Inspect the steering wheel, steering column, and related parts for damage. Parts that have visible damage should be replaced. Damage to the wiring may require wiring harness replacement.
6. Dispose of the air bag as instructed by the manufacturer. In all cases, seal the deployed bag in a large plastic bag, **Figure 86-6**.
7. Wash your hands after being exposed to the air bag powder.
8. A prepaid postage label is usually included with the new air bag. Use this label to ship the deployed air bag to its approved disposal station.

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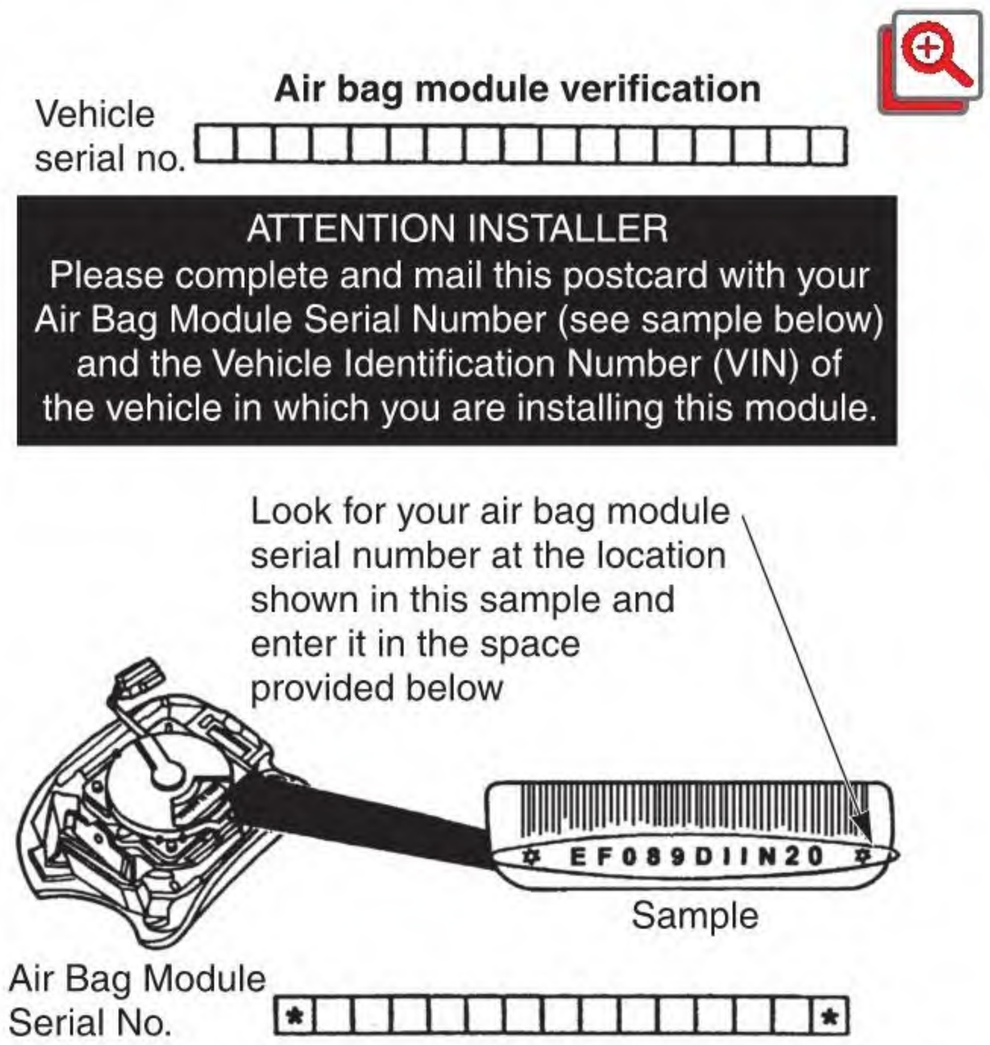


Honda

Figure 86-6. After removal, place deployed air bag in plastic bag. Use the label inside new air bag box to ship the old air bag to an approved recycling or disposal center. Never throw the old air bag into the trash.

Air Bag Installation

Obtain the correct replacement air bag module. Make sure the part number on the new air bag is correct. Although air bag modules may look similar, they often have different internal designs. Look at **Figure 86-7**.



Ford

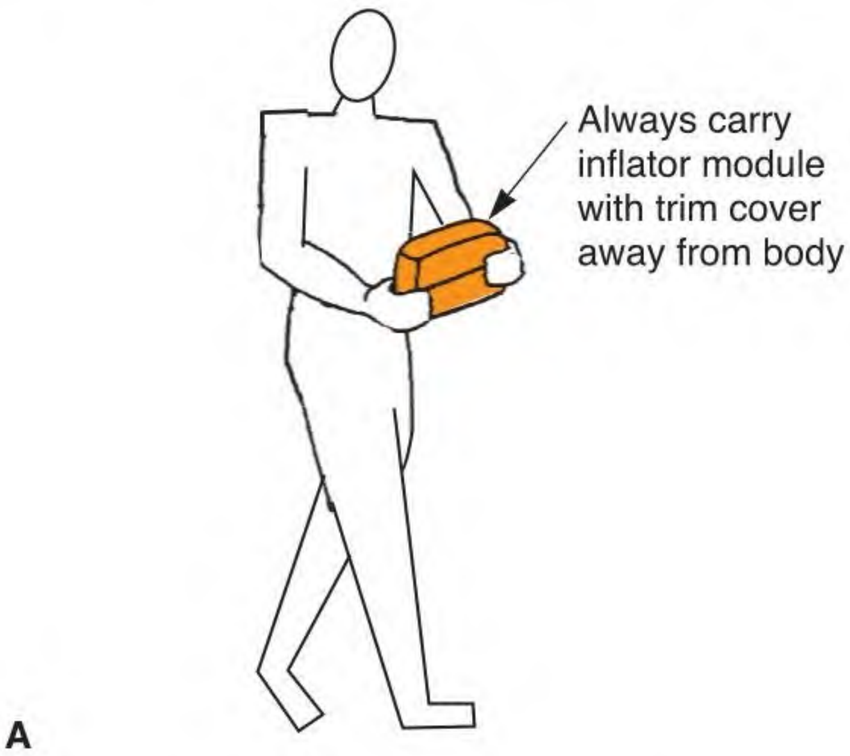
Figure 86-7. Compare part numbers to make sure you have the correct replacement air bag.

Warning

Keep your arms out of the steering wheel spokes and your head to one side of the steering wheel when working on an undeployed air bag. An air bag can shatter bones if accidentally deployed.

When carrying a live (undeployed) air bag module, aim the trim cover or bag away from your body. The metal housing should face your body. This will reduce the chance of injury if the bag accidentally deploys.

When placing the air bag module on a workbench, the bag and trim cover must face up. This will help prevent the module from flying violently through the shop if the bag suddenly inflates. See **Figure 86-8**.



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Figure 86-8. A—When carrying a "live" air bag, the trim cover should face away from your body. The metal housing should face your body. B—When placing an air bag on a workbench, the metal housing should face down and the trim cover should face upward.

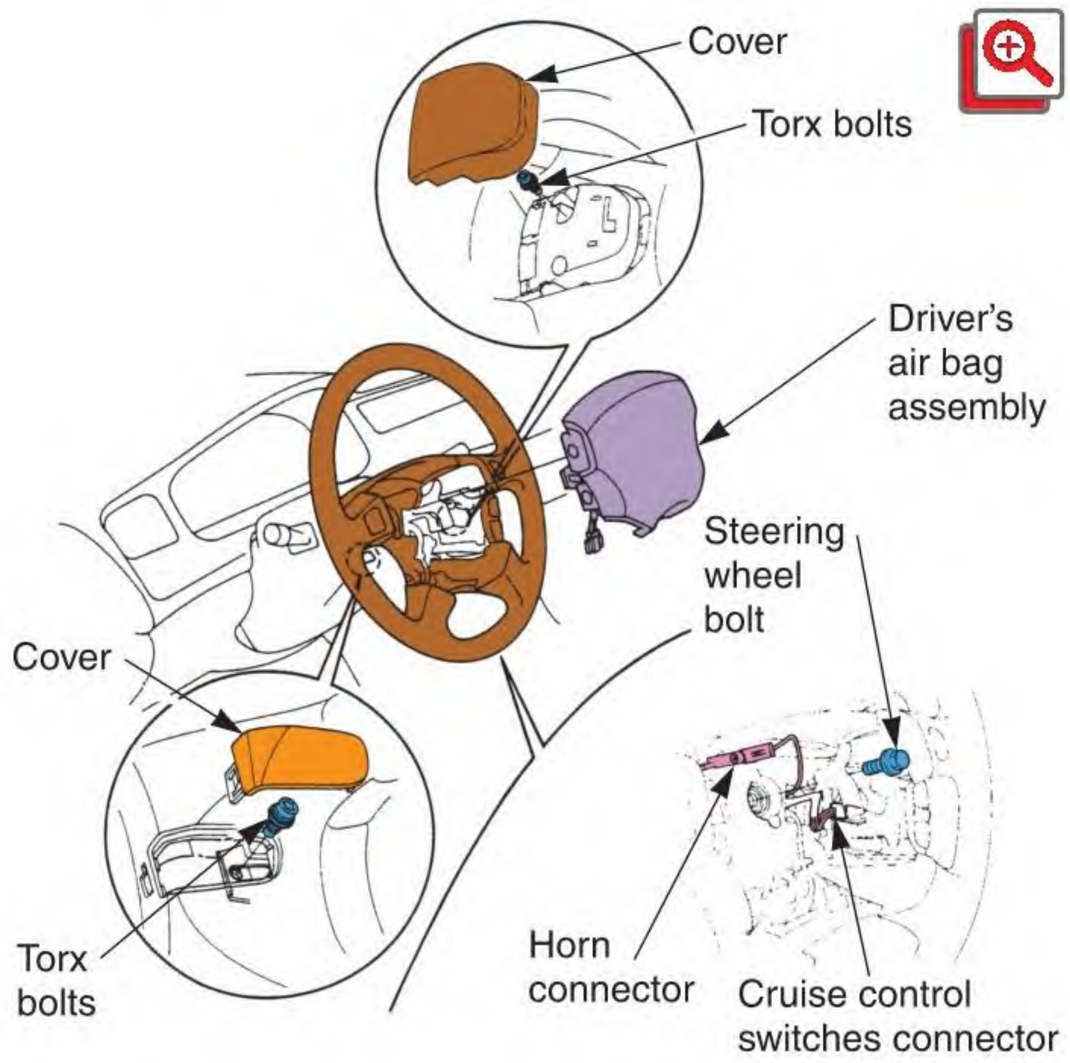
If needed, service the clock spring that connects voltage to the air bag module through wiring in the steering column. In some cases, the steering wheel must be removed to access the clock spring. A wheel puller is normally needed to force the steering wheel off its shaft.

If a clock spring is to be reused, it may have to be centered before it is reinstalled. Failure to properly center the clock spring will result in damage to the internal clock spring wiring. Refer to an appropriate service manual for specific clock spring service procedures.

Before installing the new air bag module, double-check that all sources of voltage are disconnected. You do not want the air bag to deploy when you reconnect its wires in the steering column.

You can then install the new air bag module. While keeping your head to one side of the bag, reconnect its wires. Fit the unit down into the steering wheel. Then, install the small screws that secure the module. Most manufacturers recommend using new screws, since the old ones might have been damaged by deployment. See **Figure 86-9**.

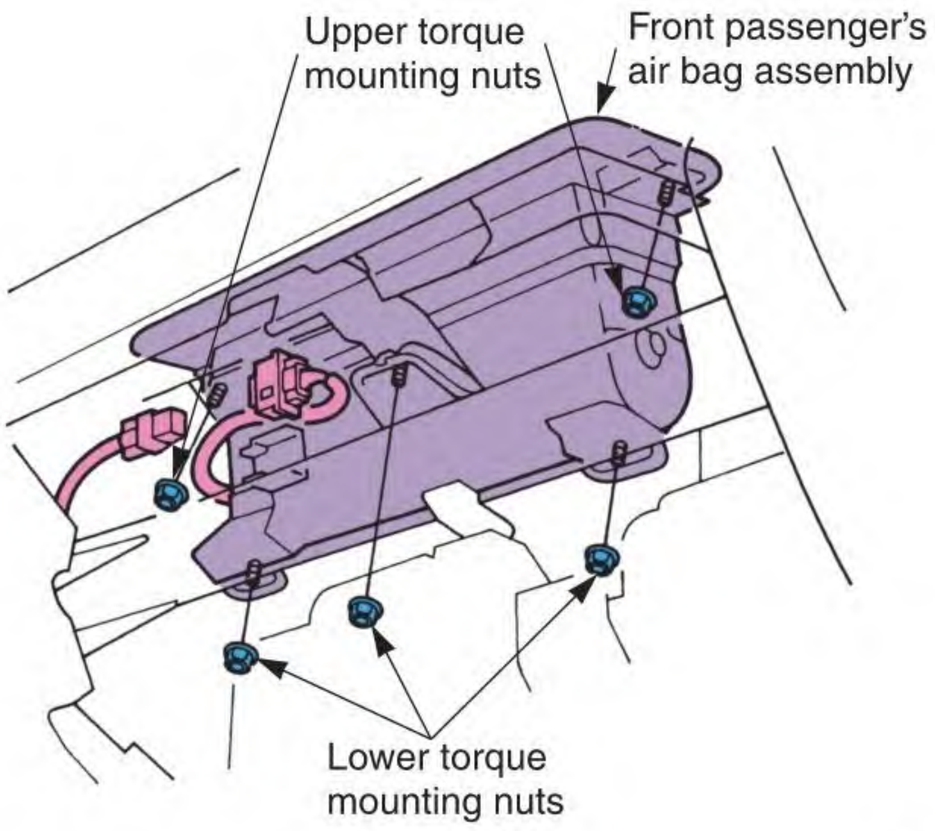
This procedure also applies to the passenger-side air bag. It must usually be secured from under the right side of the dash. Tighten the mounting bolts or nuts to specifications. When reconnecting the wiring harness, keep your body away from the front of the air bag, **Figure 86-10**.



Honda

Figure 86-9. Before installing an air bag module, make sure the source of electricity is disconnected. Then, fit new air bag module into place. Use new fasteners to bolt unit into the steering wheel, if needed. Torque the fasteners to specifications.

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Honda

Figure 86-10. A passenger-side air bag must usually be installed from under the dash. Tighten the nuts to specifications before reconnecting the harness.

Just like driver- and passenger-side air bags, the side-impact air bags found on many vehicles require replacement after deployment or malfunction. The basic steps for replacing a seat-cushion-mounted side air bag are shown in **Figure 86-11**.

Air Bag Sensor Service

After deployment from a collision, some manufacturers recommend replacement of all air bag sensors. By replacing all sensors, you ensure that none are damaged. If you do not replace all sensors, some sensors may remain closed and fire the replacement air bag as soon as power is reconnected.

Refer to the service manual if in doubt. It will give you critical service information: sensor locations, wiring diagrams, and specifications. Air bag sensors are usually located in the front of the engine compartment and under the dash or console in the passenger compartment.

Before replacing any air bag system sensors, make sure the system is disarmed. If you try to remove an air bag sensor with the system armed, the air bag could accidentally deploy—a costly, dangerous mistake.

Disconnect the wiring from the sensor first. Then, remove the screws holding the sensor to the vehicle. Make sure you have the correct replacement sensor.

Any arrow stamped or printed on the sensor must point toward the front of the vehicle. If you install a sensor backwards, the air bag will not deploy during a frontal impact. Tighten the sensor screws properly and reconnect the wiring connector. Refer to **Figure 86-12**.



A



B

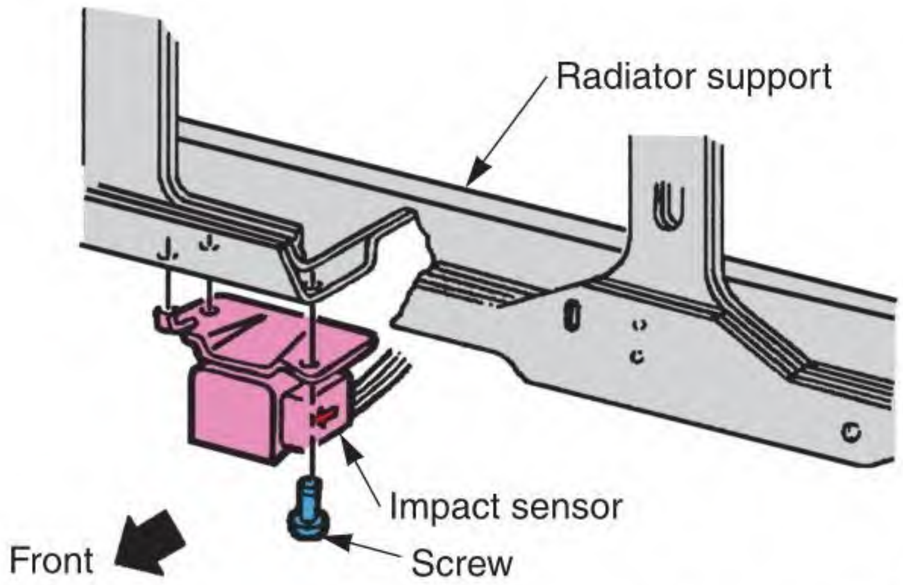


C

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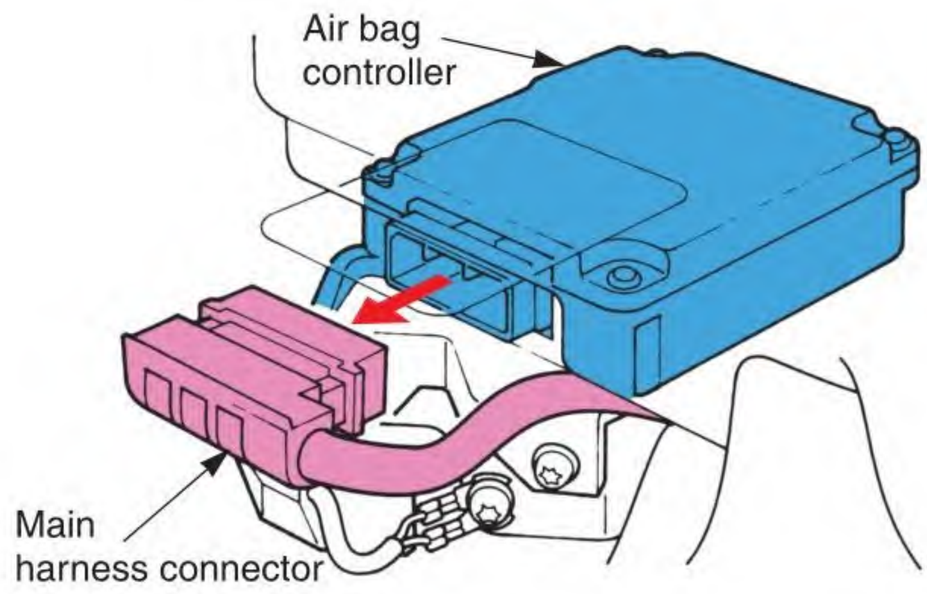
Figure 86-11. A trouble code indicated a bad side-impact air bag. A—A side air bag is typically installed inside the door panel or inside the cushion on the outside edge of each front seat, as shown here. First, remove Velcro or clips from the back of the seat to access the air bag module. B—Disconnect the vehicle battery before carefully unplugging the connection from the old module and plugging in the new one. Before reinstalling the seat upholstery, use a scan tool to make sure you have fixed the problem. C—Correctly position the new side air bag into the slot cut into the seat cushion. Finally, reinstall the upholstery.

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Figure 86-12. When replacing sensors, make sure the air bag is disabled so it does not accidentally deploy. Also make sure any arrow on the sensor points toward the front of the vehicle. If you install the sensor backward, the air bag will not work properly.



Honda

Figure 86-13. Follow the service manual instructions when replacing an air bag controller. Some units contain the impact sensor, which can deploy the air bag. Do not damage the connections and be sure to secure the new unit properly.

Air Bag Controller Service

If symptoms or scan tool readings indicate problems with the controller, it should be replaced. Again, make sure the air bag system is disarmed before starting.

Some controllers contain the main impact sensor for the air bag. If you move or jar this type of controller, the air bag could accidentally deploy.

First, disconnect the wiring harness from the controller. Do not force the connector from the controller. Fully release the connector clip and wiggle the plug back and forth while pulling. Do not pull too hard or pry on the connector or you could damage the connector and its pins. Remove the screws that secure the air bag controller to the body panel or bracket. Install the correct replacement controller in reverse order of removal. See **Figure 86-13**.

With everyone out of the vehicle and away from the air bags, rearm the system. Reconnect all harness connectors, install any removed fuses or circuit breakers, and reconnect the battery. On some late-model vehicles, you must reset the air bag system using a scan tool or a special programming tool. In some cases, you must upload new software into the new controller after installation. Follow the manufacturer's instructions.

To check your work, use your scan tool to make a final sweep for trouble codes. Make sure the system is in perfect working order before releasing the vehicle to the customer.

Diagnostic Case Study

Concern: Emmett's Auto Body sends a car over to have the air bag system serviced after a major front-collision repair. The two front air bags deployed during the collision, but the side air bags did not deploy.

Cause: Emmett, the body shop's owner, tells Duff that the impact sensors were replaced when the vehicle was disassembled for repairs. Additionally, the wiring harness near the point of impact was inspected and repaired as needed. Duff relays this information to one of the shop's master technicians. He asks the technician to replace the deployed air bags and make any other repairs needed to return the system to proper operating condition.

Correction: The technician removes the two front air bags and sends them out for proper disposal. She vacuums the passenger compartment to remove the air bag powder residue. She then installs new front air bags and replaces the deployment module according to the service information instructions.

The technician connects a scan tool to the diagnostic connector and verifies that everything is working normally. Since no trouble codes are detected, she releases the vehicle to the body shop.

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Summary

- The proper service of seat belts and air bags is critical to the safety of the vehicle's occupants.
- Seat belt mechanisms should be inspected after an auto accident or after prolonged service.
- A centrifugal belt retractor uses centrifugal force to keep the belt from extending.
- A pendulum belt retractor uses the inertia of a vehicle deceleration to engage the belt locking mechanism.
- Air bag service is needed after deployment or when the air bag indicator light is illuminated.
- Take care to prevent accidental air bag deployment when working.
- If the indicator light glows but the bag is not deployed, use a scan tool to analyze the system.
- To disarm an air bag, all sources of electricity for the igniter module must be disconnected from the air bag module.
- Manual air bag deployment is done by connecting a source of voltage to the air bag module wires to "fire" the air bag.
- After deployment, the air bag must be serviced and disposed of properly.
- Keep your arms out of the steering wheel spokes and your head to one side of the module when working on an undeployed air bag.
- When carrying a live (undeployed) air bag module, aim the trim cover or bag away from your body.
- When placing the air bag module on a workbench, the bag and trim cover must face up.
- After deployment caused by a collision, some manufacturers recommend the replacement of all air bag sensors.
- Any arrow on the air bag sensor must point toward the front of the vehicle.
- If symptoms or scan tool readings indicate problems with the controller, it must usually be replaced.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

air bag powder
centrifugal belt retractor
energy reserve module
manual air bag deployment
pendulum belt retractor

Activities

1. Visit a salvage yard and locate several vehicles with front-end collision damage. While wearing a respirator, safety goggles, and gloves, look for steering wheel and steering column damage. Compare the steering wheel and column damage found on air bag–equipped vehicles to the damage found on vehicles without air bags.
2. Use a service manual to find the locations of impact sensors on different makes and models of vehicles.

Review Questions

Answer the following questions using the information provided in this chapter.

1. Warn customers of the danger of placing _____ in front seats if air bags are installed.
2. Describe the process for inspecting seat belts.
3. List two of the four precautions that should be taken when replacing a seat belt.
4. How do you check the action of a centrifugal seat belt retractor?
5. How do you test the operation of a pendulum-type seat belt retractor?
6. How do you disable an air bag system?
7. Air bag systems are often equipped with an energy reserve module, which can deploy the air bag up to _____ minutes after power is disconnected.
8. How do you manually deploy an air bag?
9. After deployment from a collision or accident, some manufacturers recommend replacement of all air bag sensors. True or False?
10. What will happen if you install an air bag sensor backward?

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ASE-Type Questions

1. Technician A says that it is acceptable to place your arms through the steering wheel spokes when installing a new air bag. Technician B says to place your face directly in front of the air bag during installation. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. An air bag indicator light shows a problem with the air bag system. Technician A says to use a scan tool to help determine the source of the trouble. Technician B says to replace the air bag sensors. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. After air bag deployment, which of the following should *not* be done?
   (A) Force excess powder out of air bag with hand pressure.
   (B) Wear a respirator, goggles, and rubber gloves.
   (C) Place tape over air bag vent holes.
   (D) Vacuum the passenger compartment.
4. When carrying a live (undeployed) air bag module, how should you aim the trim cover?
   (A) Upward.
   (B) Toward your body.
   (C) Toward the floor.
   (D) Away from your body.
5. Technician A says that you may have to replace all the sensors after air bag deployment. Technician B says that the air bag sensor arrow must point toward the front of the vehicle. Who is right?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
6. Some air bag controllers contain:
   (A) azide pellets.
   (B) the malfunction indicator light.
   (C) the main impact sensor.
   (D) an igniter module.

Restraint System Diagnosis

Condition	Possible Causes	Correction
Indicator does not work.	1. Burned out dash bulb. 2. Circuit problem. 3. Open in inflator module. 4. Controller failure.	1. Replace bulb. 2. Test and repair wiring. 3. Replace module. 4. Replace controller.
Air bag will not deploy during a collision.	1. Failed sensors. 2. Failed air bag module. 3. Bad controller. 4. Wiring problems.	1. Replace sensor. 2. Replace module. 3. Replace controller. 4. Test and repair wiring.
Air bag deploys accidentally.	1. Loose impact sensors. 2. Controller failure. 3. Shorted wires. 4. Moving or hitting sensors while key is on.	1. Tighten sensors, test system. 2. Replace controller. 3. Test and repair wiring. 4. Use approved procedures.
Indicator light comes on.	1. Controller failure. 2. Circuit problem. 3. Bad air bag module.	1. Replace controller. 2. Repair wiring. 3. Replace air bag module.
Seat belt will not engage.	1. Broken spring in retractor. 2. Worn retractor. 3. Failed retractor motor. 4. Circuit problem.	1. Replace retractor. 2. Replace retractor. 3. Replace motor. 4. Repair wiring.
Seat belt will not retract.	1. Twisted belt. 2. Bad retractor. 3. Debris in retractor.	1. Straighten belt. 2. Replace retractor. 3. Remove debris.

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Chapter 87
New and Future Technology

After studying this chapter, you will be able to:

- Summarize developments in vehicle security technology.
- Explain how servo motors have been incorporated into vehicle operation.
- Describe how kinetic energy storage systems work.
- Discuss the various alternate power sources in use and in development for vehicles.
- Explain how composite plastics and metals may be used in future vehicle construction.

This chapter looks to the future of automotive engineering and technology. Automotive technology has seen tremendous change over the years, and more exciting changes are on the horizon. What will the future bring to the passenger vehicle? See **Figure 87-1**. What will happen if we run out of crude oil? What alternate forms of energy could we use? This chapter will address these and other questions.

Security Technologies

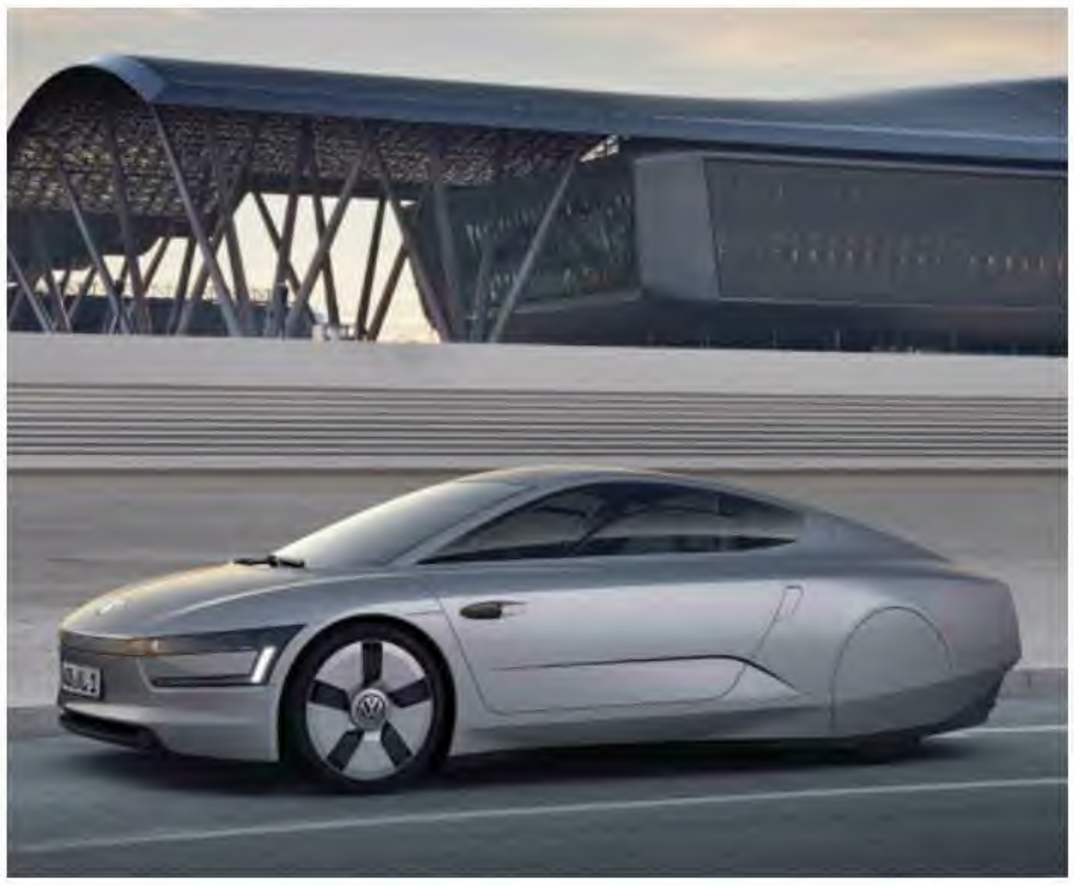
Advancements in electronics and computer technology have enabled many on-vehicle security features. For example, consider that civilian access to GPS satellites was granted in the 1990s. In no time, GPS technology was incorporated into our everyday lives, including cell phones, tracking devices, and vehicle and pedestrian navigation applications.

Vehicle Tracking Systems

A ***vehicle tracking system*** is a security system that can track the location of a car or truck if it is stolen. One system uses an on-board security control module, a miniature transmitter and receiver, the global positioning satellite (GPS) system, and a 24-hour monitoring/response center, **Figure 87-2**.

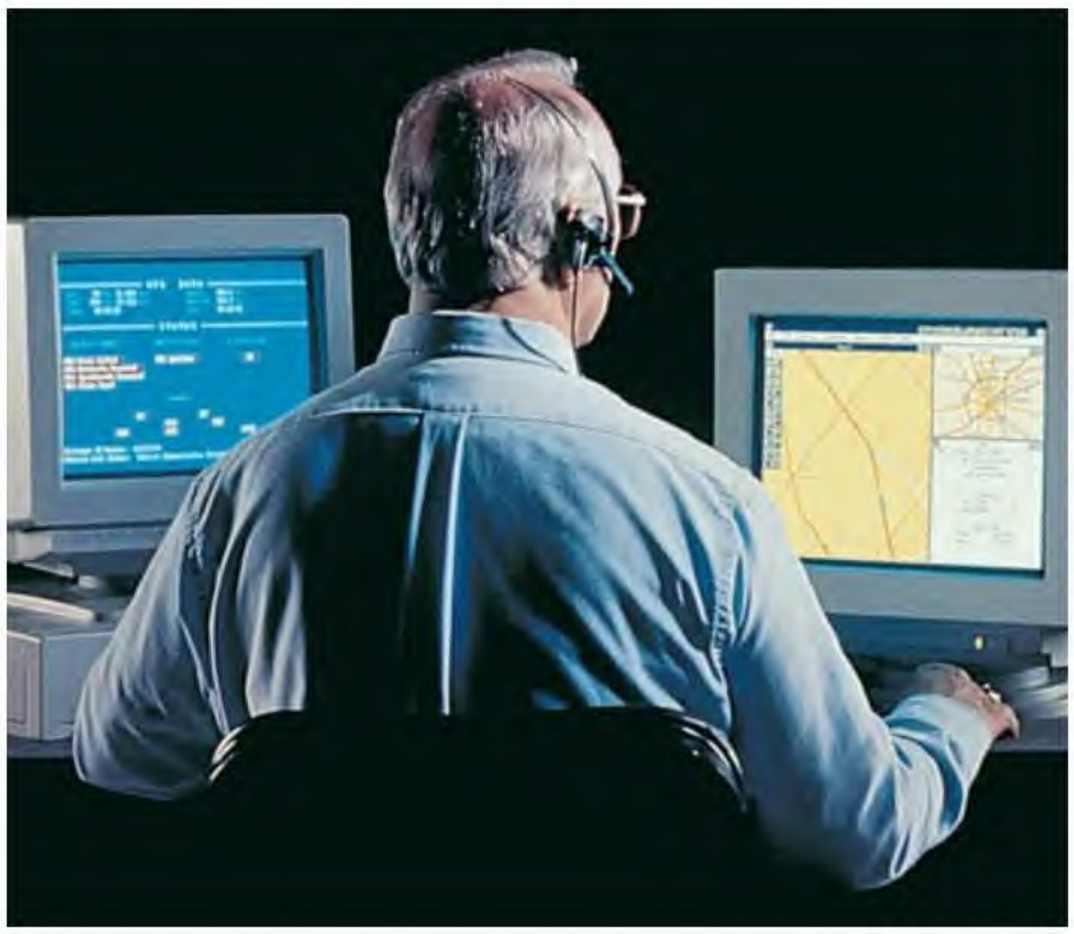
If a vehicle with this type of system is stolen, the monitoring center is notified and they transmit a signal to activate the tracking system. Once activated, the control module uses information received from the GPS system to pinpoint the vehicle's location. The system then transmits the location of the vehicle to the monitoring center.

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Volkswagen

Figure 87-1. Changes in the materials used to build and power vehicles, as well as the overall design, can make cars, SUVs, and trucks lighter and more streamlined. These changes will provide a great improvement in fuel/energy economy.



ATX Research

Figure 87-2. A vehicle tracking system includes trained operators available 24 hours a day. If a vehicle is stolen or a driver is in distress, the GPS tracks and locates the vehicle, and the monitoring/response center contacts emergency services with an accurate location of the vehicle.

This type of vehicle tracking system is usually small and self-contained, allowing it to be easily hidden on the vehicle. The tracking system usually incorporates a backup battery, which allows the system to continue receiving and transmitting signals after the vehicle's battery dies or is removed.

Some tracking systems also provide added security for the driver during a carjacking or kidnapping. The driver can press an emergency call button on the key ring, which allows the people at the response center to listen to conversation in the vehicle and to take action as needed. The response center can call the police and tell them the exact location and description of the vehicle. Other systems enable the vehicle to be remotely disabled.

Night Vision Systems

Night vision systems use an infrared camera and monitor system to help the driver's view in fog, snow, rain, and other vision-impairing atmospheric conditions. The camera could be mounted in the front grille. When activated in bad weather or at night, the camera produces an image on the dash-mounted monitor or on a heads-up display on the windshield. This lets the driver see longer distances through outside conditions, like fog, to detect oncoming vehicles, people, curves in the road, and other dangers.

Vehicle Operation Technologies

Advancements in both electronics technology and environmental consciousness have prompted changes in how a vehicle operates, as well as features offered to consumers.

Electric Brake Calipers

An ***electric brake caliper*** uses one or more servo motors to force the brake pads into the rotating brake disc to slow and stop the vehicle. This type of caliper eliminates the need for the brake system hydraulic components (master cylinder, brake lines, hoses, etc.).

When the driver presses the brake pedal, a sensor on the brake pedal sends a signal to the braking computer. The computer then sends an electric control current to each electric brake caliper to turn on the servo motor actuator(s). When the servo armature rotates, it turns a screw-type mechanism to force the inner plate and brake pad into the rotor. The rotor pulls the pad and inner plate in the direction of rotation, wedging the rollers between the inner plate and the stationary outer plate. The wedging action then forces the brake pads tighter against the spinning

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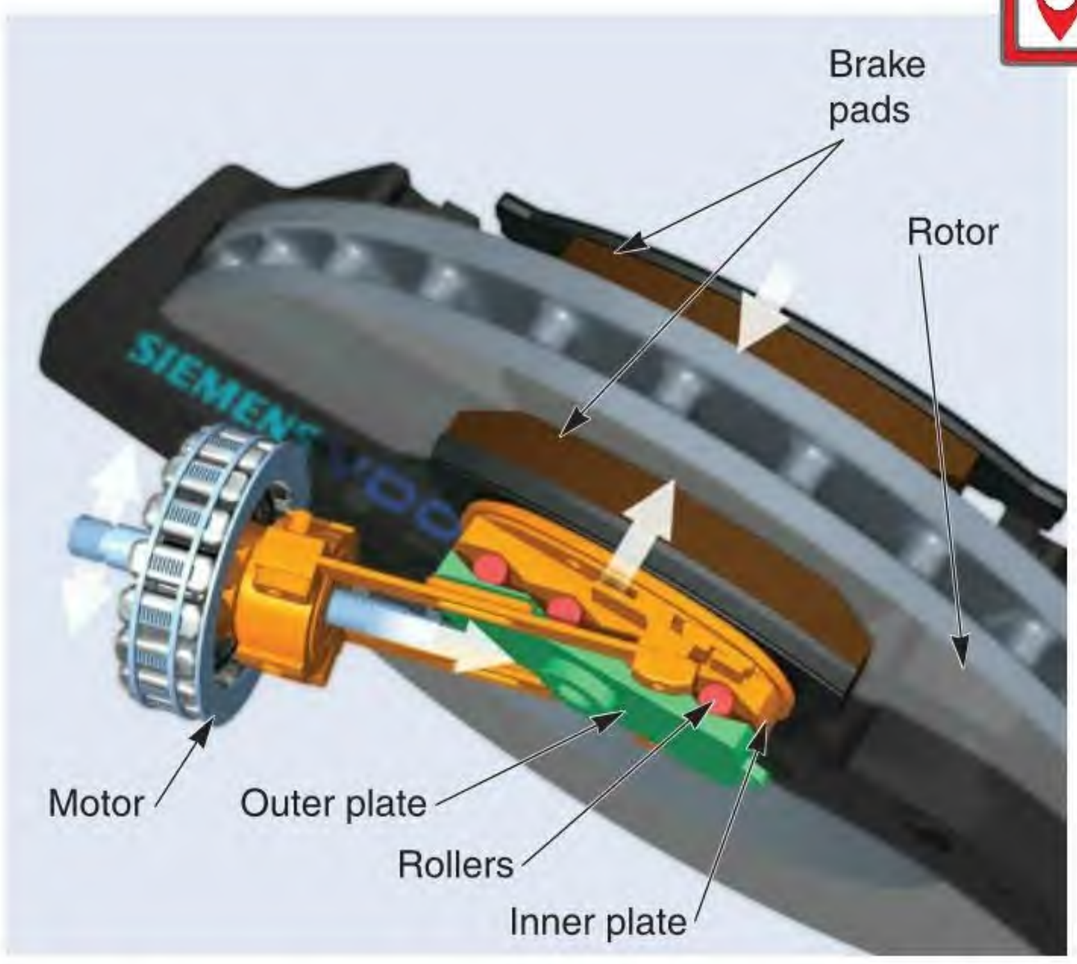
rotor to increase friction and decrease speed. See **Figure 87-3**.

When the brake pedal is released, the computer reverses servo motor rotation to release clamping force on the rotor. The ECM can apply different amounts of electrical current to each wheel to control how much braking force is applied at each wheel.

Total electronic control of brake system is ideal for ABS, stability control, collision avoidance, and other computer-controlled systems. Electronic brake systems are much lighter than hydraulic brakes, helping to reduce fuel consumption, **Figure 87-4**.

Electric Parking Brake

An ***electric parking brake***, or electric emergency brake, uses a dash-mounted switch and an electric servo motor to mechanically apply the rear brake. When the parking brake servo motor is energized, it rotates a worm gear that acts on a lever mechanism to pull on a mechanical arm and cable mechanism. The cable mechanism forces the brake pads or shoes into the rotors or drums to keep the vehicle from rolling. When the parking brake is shut off, the servo motor reverses to allow the brake pads or shoes to retract so the vehicle can be driven.



Siemens

Figure 87-3. An electric brake caliper. The servo motor forces the inner plate and brake pad into the rotor. The spinning rotor moves the pad and inner plate in the direction of rotation, wedging the rollers between the inner and outer plates.



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Figure 87-4. Auto manufacturers are developing all-electric brakes for vehicles. Electric brakes provide shortened application times, more precise clamping force, reduced unsprung weight, and other benefits of a computer control system.

Kinetic Energy Recovery System (KERS)

A ***kinetic energy recovery system (KERS)*** can capture kinetic energy generated during vehicle braking and store the energy to assist in vehicle acceleration from a standstill. These types of systems use either a flywheel mechanism (mechanical) or a battery (electrical) to store the energy captured until it is needed.

In the mechanical KERS design, the kinetic energy generated during vehicle braking spins a composite steel flywheel mounted in the vehicle's hub at speeds up to 100,000 rpm. When an acceleration boost is needed, the spinning energy of the flywheel is connected to the rear wheels of the vehicle to temporarily supplement engine power. See **Figure 87-5**.

In an electrical KERS design, the system converts the kinetic energy generated during vehicle braking to electrical energy. The electrical energy is stored in a battery until it is released/engaged by the driver.

Automatic Tire Wear Adjustment

Future vehicles might have automatic tire wear adjustment systems, which could eliminate the need to rotate the tires. Automotive engineers could use the anti-lock brake sensors to monitor tire and wheel speed. If one

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Volvo

Figure 87-5. An experimental drive axle-mounted KERS. A special transmission is used to transfer torque from the flywheel to the CV-drive axles.

tire is worn, it would be slightly smaller in diameter than the others. The computer would detect a higher signal frequency from the wheel sensor monitoring the rotation of the worn tire. The computer could then adjust the differential solenoids to apply more pressure to one side of the differential clutch pack upon acceleration. This would lower tread loss on the worn tire. More torque could be applied to the tire or tires with more tread to progressively even out tire wear.

Alternate Power Sources

Alternate power sources are other methods of producing energy (other than from gasoline and diesel oil) to propel a motor vehicle. The most promising include electric vehicles, hybrid vehicles, hydrogen fuel engines, and flexible-fuel vehicles.

Electric Vehicles

An electric vehicle uses a large, high-efficiency electric motor and large storage batteries to power the automobile and reduce air pollution from burning fossil fuels. They provide a viable, alternate means of vehicle propulsion for short trips. The driver simply plugs the electric car into a recharging station to re-energize the storage batteries and ready the car for another commute, **Figure 87-6**.



Audi

Figure 87-6. Power companies and large corporations are working together to provide electric vehicle charging stations in convenient locations.

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Lithium polymer batteries can be formed into almost any shape for saving space in a vehicle's design. The lithium polymer cells are made from flexible laminate film that can measure as little as 100 microns thick. The laminate is made of metal foil, electrolyte, cathode, anode, and insulator layers. This battery design offers high energy density and low manufacturing costs.

One drawback involved with electric vehicles is the large number of power generating stations needed to recharge the millions of batteries every night. Building all the generating stations would create environmental pollution from burning much more coal, oil, or nuclear power. Battery recharging itself can also cause some pollution from the battery gases generated.

Flywheel Generator Hybrids

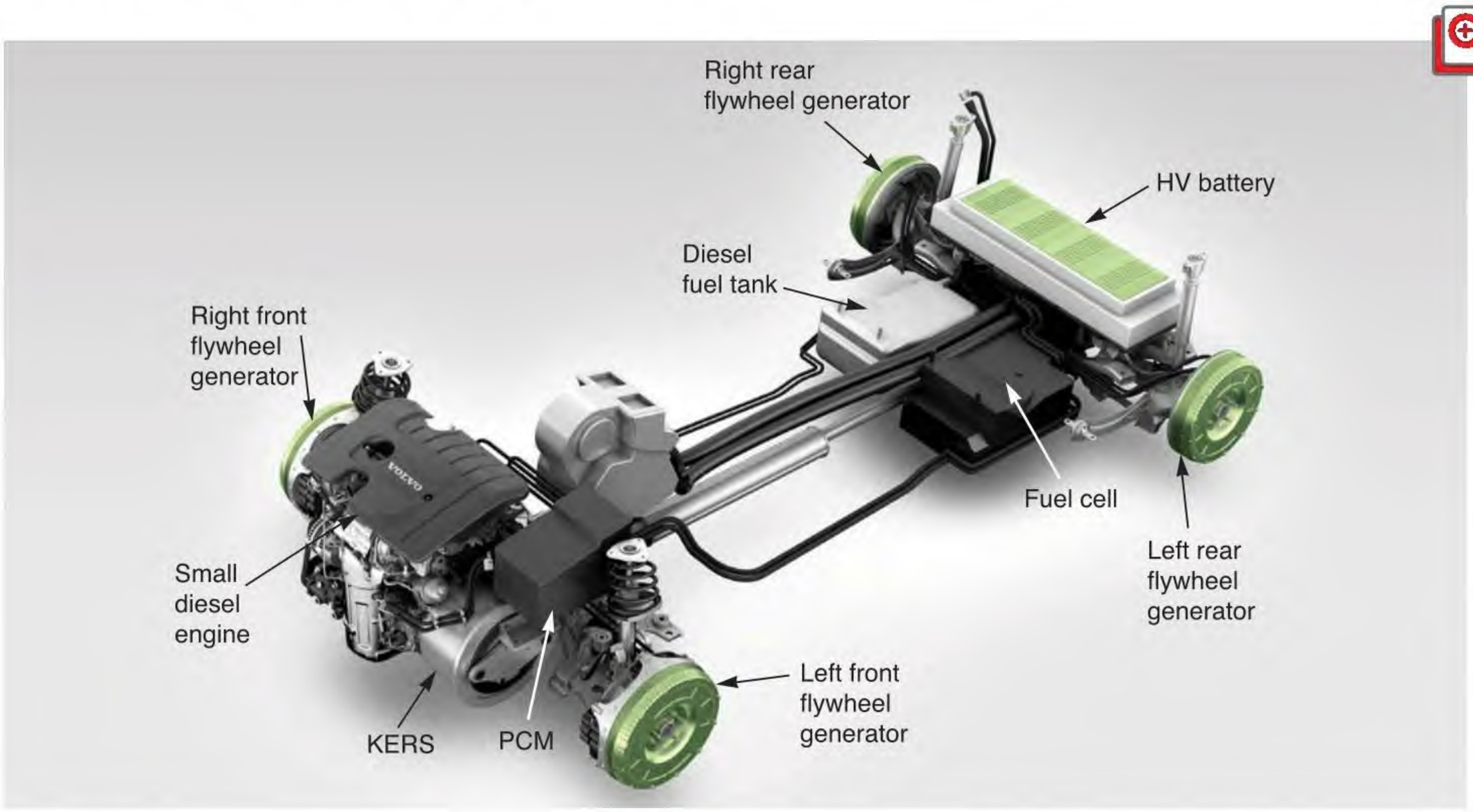
A flywheel generator drive system is a direct electric wheel drive design that eliminates the power lost from having to spin or rotate the transmission gearset and a differential assembly in heavy gear oil. Electromagnetic coils are mounted on the bearing hubs with permanent magnets embedded in the spinning wheel. Four flywheel generators are used to rotate or stop the four wheels and tires directly. This system eliminates the need for friction brake pads and large rotors that waste the energy needed to bring the car to a stop by generating heat. Refer to **Figure 87-7**.

The problem with flywheel generator drive systems is that they increase the unsprung weight and ride harshness on rough roads. Since the four flywheel generators add weight to the outer ends of the suspension control arms, the vehicle body/frame shudders or shakes more when the flywheel generators move up and down with road surface imperfections.

Solar Vehicles

A ***solar vehicle*** uses solar panels to generate electricity for propulsion. A large surface area of the vehicle body is covered with solar panels, which convert sunlight directly into electric current. The current powers an electric motor, which powers the vehicle.

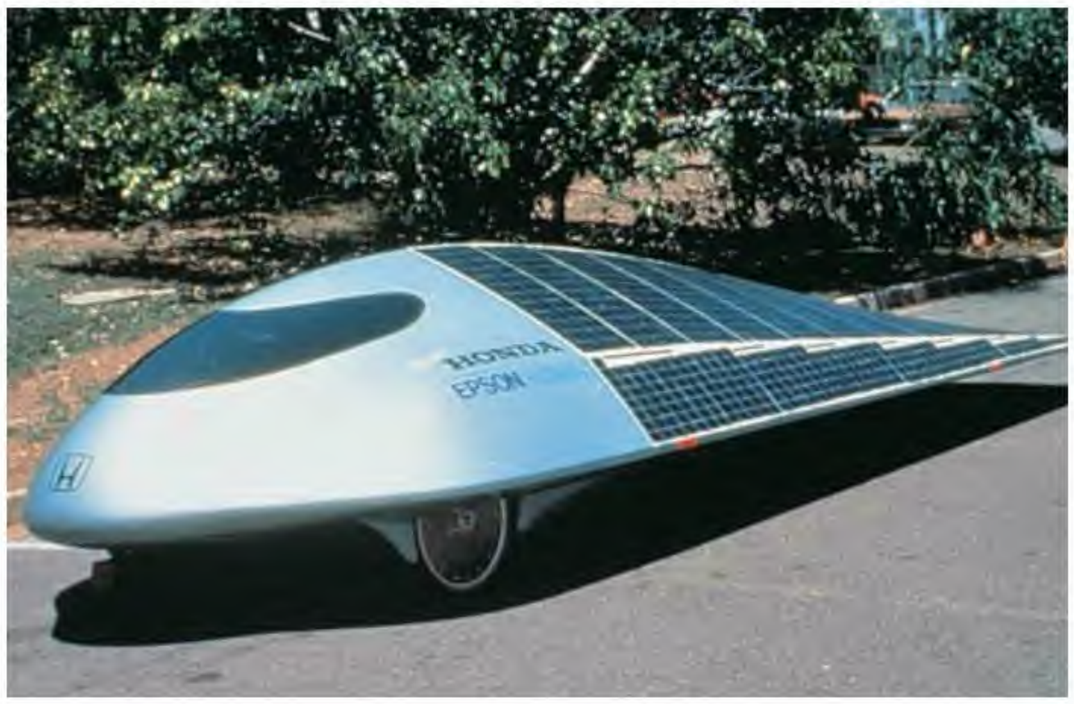
Someday, maybe the whole surface of the hood, roof, and trunk could be covered with solar panels that are coated with a painted clear coat. See **Figure 87-8**. The electric current from the solar panels could be stored in the HV battery. The hybrid PCM could step up the low solar cell voltage into high voltage for recharging the HV battery. This would eliminate the need to recharge the vehicle at a charging station. So, the battery would charge for free.



Volvo

Figure 87-7. This experimental powertrain uses a small diesel fuel engine, a KERS, fuel cell, four flywheel generators, and an HV battery.

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Honda

Figure 87-8. A solar vehicle is powered completely by sunlight. This technology could someday be incorporated into a hybrid vehicle.

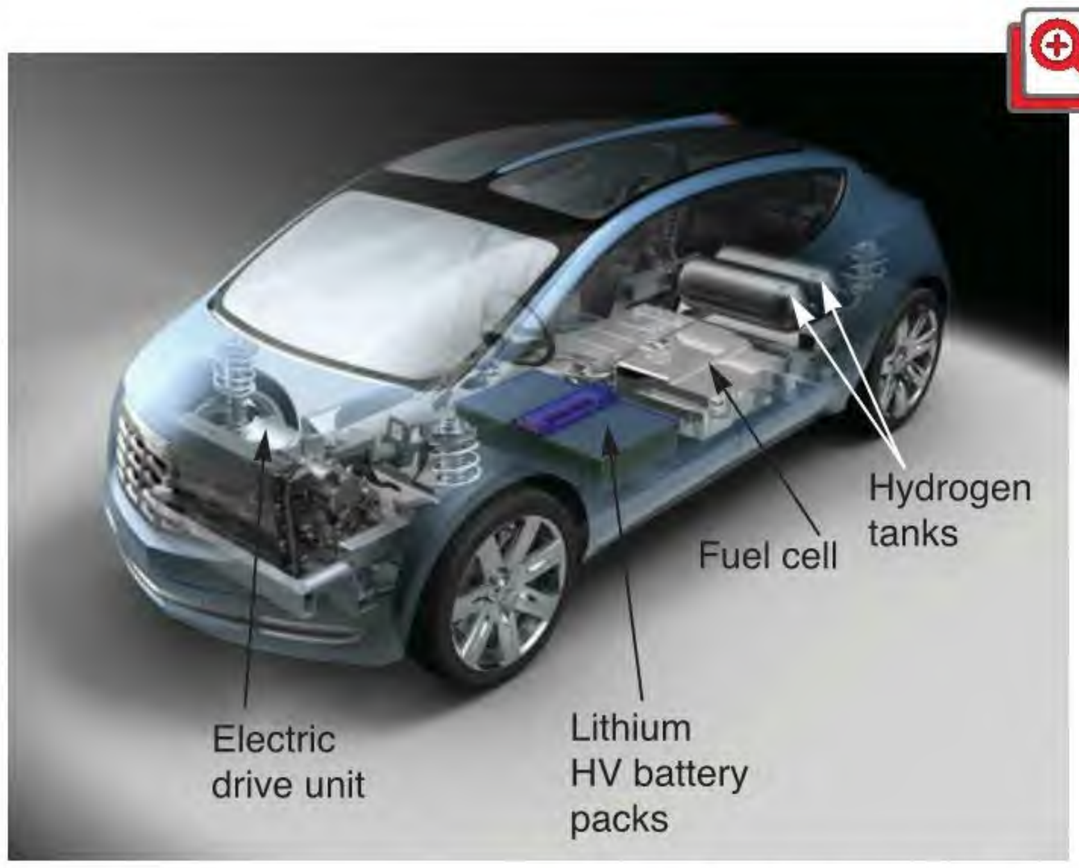
Hydrogen Fuel

Hydrogen burns with no harmful emissions—water vapor is the only by-product of combustion. The process of electrolysis can be used to convert ocean salt water into pure hydrogen and oxygen. ***Electrolysis*** sends electric current through water (H_2O), which separates the two atoms of hydrogen (H) from one atom of oxygen (O) into separate gases. If ignited, the hydrogen and oxygen atoms will burn and vibrate at high temperatures while changing back into water vapor.

Producing hydrogen fuel is currently too expensive using conventional sources of energy. However, hydrogen fuel production using low-cost wind or solar energy to process salt water would give us a very desirable new fuel source. With a hydrogen storage and gas metering system, engines would be just as powerful, but would operate much more cleanly, with no adverse effects on our atmosphere and climate. See **Figure 87-9**.

Fuel Cell

A ***fuel cell*** combines hydrogen and oxygen to produce electrical energy. It is electrolysis in reverse. A fuel cell is made of a plastic, gas-permeable membrane coated with a catalytic platinum foil. This membrane is sandwiched between two electrode plates. Hydrogen gas flows through the anode plate and the membrane, while compressed air flows the other way. The catalyst causes the hydrogen gas to separate into positive hydrogen ions (protons) and electrons.



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Figure 87-9. This hybrid crossover vehicle uses a small turbine engine, an electric motor, lithium HV battery, and hydrogen gas tanks for a fuel cell battery to produce a tremendously powerful propulsion system that can operate for hundreds of miles before refueling or recharging.

This causes a potential difference of electrical energy across the anode and cathode. When current is drawn out of the fuel cell, oxygen molecules separate and combine with hydrogen ions to form water and heat.

Flexible-Fuel Vehicles

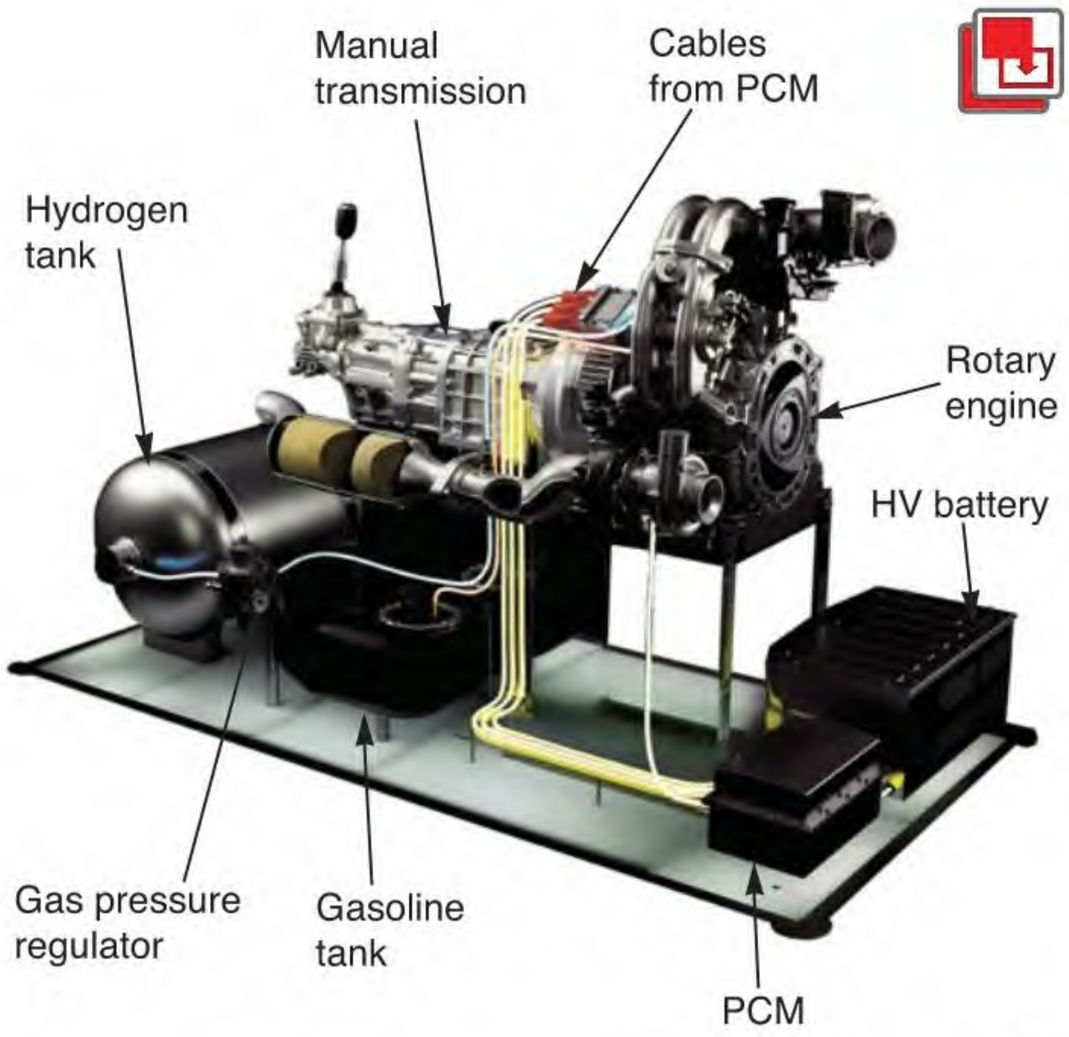
Flexible-fuel vehicles (FFV) are designed to operate on different types of fuel. Sensors monitor the contents of the fuel through measurement of combustion efficiency, and engine functions are adjusted for maximum efficiency for the type of fuel being consumed. A flex fuel rotary engine (no reciprocating pistons) is shown in **Figure 87-10**.

Gas Turbine

Gas turbines are alternate types of engines that can burn a wide variety of fuels: gasoline, kerosene, or oil. A gas turbine can produce tremendous power for its size. Because of the spinning action, its power output is very smooth.

Gas turbines are not currently in use due to high manufacturing costs and poor fuel efficiency. They require many special metals, ceramic parts, and precision machining and balancing. Someday, with improvements in efficiency through engineering advances, the gas turbine may be a very common automotive engine.

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Figure 87-10. This hybrid propulsion system uses a smooth running, high-speed rotary engine (no reciprocating pistons) and a motor generator to operate a manual transmission in a sports car.

Plant Fuels and Lubricants

As the world's petroleum reserves dwindle, the prices of petroleum-based fuels are bound to rise. This has prompted many researchers to consider fuels derived from plant life. Since plant life is relatively abundant and renewable, many consider this a promising area of research.

Plant fuel research has led to the development of biodiesel fuel. Biodiesel can be created from animal fats or vegetable oils (including waste oils and grease from restaurants). Biodiesel can be used in current diesel engines without modification. This fuel has the benefit of coming from a renewable source. It is also cleaner burning than petroleum diesel fuel.

Ethanol is another plant fuel that is already in wide use. Currently, small quantities of ethanol are blended with gasoline to increase its octane and reduce emissions. However, car manufacturers are developing flexible fuel cars that can run on fuel containing a much higher concentration of ethanol.

Synthetic motor oil has been created from farm-grown plants and vegetables, and performs as well as crude oil-based lubricants. Tests show that motor oil made from natural plant or vegetable oils can be formulated to have equal or better high and low temperature lubricating performance as carbon- or petroleum-based oils.

Future Vehicle Construction

Vehicle curb weight reduction is the most important factor in further improving fuel economy. In the future, almost every part of a passenger vehicle will contain light and strong composite plastics and metals. For example, engine block strength is increased by casting composite webbing into cast iron and aluminum parts. The synthetic netting is placed inside the mold for the part.

Body panels on cars are now being made of lightweight aluminum, fiberglass, or carbon fiber. A-pillars on the side of the windshield can be made of high-strength steel with carbon fiber core tubes for added stiffness during a vehicle roll-over accident.

Tech Tip

Do not overtighten fasteners on carbon fiber or plastic parts. Only a few foot pounds of torque are required to secure plastic and carbon fiber parts.

Some automakers are experimenting with ***inflatable door impact beams***. A powerful pyrotechnic charge is used to expand the metal beam so it balloons out to a larger diameter. This larger beam diameter can withstand more violent collisions from the side without intrusion into the driver or passenger seat area.

Future Systems

What automotive design changes will we see in the next century or two? Just look at the advances the human race has made in the last 100 years! We have gone from the horseless carriage to the hybrid passenger vehicle, and from experimenting with human flight to traveling beyond the moon in one human lifetime. Since human progress is increasing exponentially, we should see even more rapid technical progress in the future. As a result, your job as a professional auto technician will become even more important and in-demand.

We have the technology to reduce the impact of passenger vehicles on the environment and atmosphere. The change from R-12 refrigerant to R-134a has reduced the negative effect on Earth's atmosphere.

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In the future, regulations could require another change from R-134a refrigerant to the naturally occurring atmospheric gas, CO_2. Carbon dioxide has proven to be a very efficient refrigerant and is more "ecofriendly" when compared to other non-ozone-depleting refrigerants. Hybrid gas/electric propulsion systems are also a big step in the right direction for the future of our planet and our driving experience.

In addition, recycling is becoming more standard in practice in the automotive industry. It may increase to the point that we build whole car bodies out of recycled aluminum cans. A car body made out of "old soda pop cans" will be a strong, lighter vehicle that resists corrosion much better than steel.

Industry Trend

The fuel cell vehicle offers a glimpse into the future of automotive technology. Several major automobile and truck manufacturers are experimenting with fuel cell technology. The fuel cell is highly efficient and emits very few or no toxic emissions, depending on the fuel used. Learn all you can about fuel cell technology. There is a good chance you will be servicing fuel cell vehicles sometime in the future.

Summary

- Advancements in electronics and computer technology have enabled many on-vehicle security features, including vehicle tracking systems and night vision systems.
- The use of servo motors in an electric brake caliper eliminates the need for the brake system hydraulic components.
- A dash-mounted switch energizes the electric parking brake servo motor to mechanically apply the rear brake.
- Kinetic energy recovery systems can capture kinetic energy generated during vehicle braking and store the energy to assist in vehicle acceleration.
- Alternate power sources are other methods of producing energy (other than from gasoline and diesel oil) to propel a motor vehicle.
- Electric vehicles use an electric motor and storage batteries to power the automobile and reduce air pollution from burning fossil fuels.
- A flywheel generator drive system is a direct electric wheel drive design that eliminates the need for friction brake pads and large rotors.
- A solar vehicle uses solar panels to generate electricity for propulsion.
- Hydrogen burns with no harmful emissions—water vapor is the only by-product of combustion.
- A fuel cell combines hydrogen and oxygen to produce electrical energy.
- A flexible-fuel vehicle (FFV) is designed to operate on different types of fuel.
- Plant fuel research has led to the development of biodiesel fuel, ethanol, and synthetic motor oil.
- Vehicle curb weight reduction is the most important factor in further improving fuel economy.
- Since human progress is increasing exponentially, we should see even more rapid technical progress in the future.

Technical Terms

Write the definitions for the following terms on a separate sheet of paper.

alternate power sources
electric brake caliper
electric parking brake
electrolysis
flexible-fuel vehicles (FFV)
fuel cell
inflatable door impact beams
kinetic energy recovery system (KERS)
night vision systems
solar vehicle
vehicle tracking system

Activities

1. Research articles and other information on future automotive technologies. Create a presentation to report your findings.
2. Research the production of hydrogen gas from saltwater. Write a report on the current state of production. Include information on the potential use of solar energy in production.

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Review Questions

Answer the following questions using the information provided in this chapter.

1. Describe the operation of a typical vehicle tracking system.
2. Night vision systems use a(n) _____ camera and monitor to help the driver's view during vision-impairing weather conditions.
3. What is the function of servo motors in relation to an electric brake caliper?
4. Describe the role of servo motors in an electric parking brake.
5. How does a KERS assist in vehicle acceleration?
6. A(n) _____ battery offers high energy density and low manufacturing costs.
7. How is electrolysis used to produce hydrogen fuel?
8. Automobiles designed to operate on different types of fuel are called _____.
9. _____ is an alternative fuel created from animal fats or vegetable oils and used in current diesel engines without modification.
10. Describe how composite plastics and metals can be used to improve fuel economy.

ASE-Type Questions

1. Technician A says advancements in electronics technology have led to changes in how a vehicle operates. Technician B says that increased environmental consciousness has prompted changes in how a vehicle operates. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
2. Technician A says all kinetic energy recovery systems use a flywheel mounted in the vehicle's hub. Technician B says kinetic energy recovery system designs can be either mechanical or electrical. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
3. Technician A says lithium polymer cells are made from incredibly thin flexible laminate film. Technician B says lithium polymer cells are made of metal foil, electrolyte, cathode, anode, and insulator layers. Who is correct?
   (A) A only.
   (B) B only.
   (C) Both A and B.
   (D) Neither A nor B.
4. The process of _____ can be used to convert ocean saltwater into pure hydrogen and oxygen.
   (A) conversion
   (B) combustion
   (C) electrolysis
   (D) vaporization
5. Which of the following is blended with gasoline to increase its octane and reduce emissions?
   (A) Ethanol.
   (B) Lubricants.
   (C) Biodiesel.
   (D) Hydrogen.

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Fraction, Decimal, and Metric Equivalents

INCHES		MILLI-METERS	INCHES		MILLI-METERS
FRACTIONS	DECIMALS		FRACTIONS	DECIMALS	
	.00394	.1	15/32	.46875	11.9063
	.00787	.2		.47244	12.00
	.01181	.3	31/64	.484375	12.3031
1/64	.015625	.3969	1/2	.5000	12.70
	.01575	.4		.51181	13.00
	.01969	.5	33/64	.515625	13.0969
	.02362	.6	17/32	.53125	13.4938
	.02756	.7	35/64	.546875	13.8907
1/32	.03125	.7938		.55118	14.00
	.0315	.8	9/16	.5625	14.2875
	.03543	.9	37/64	.578125	14.6844
	.03937	1.00		.59055	15.00
3/64	.046875	1.1906	19/32	.59375	15.0813
1/16	.0625	1.5875	39/64	.609375	15.4782
5/64	.078125	1.9844	5/8	.625	15.875
	.07874	2.00		.62992	16.00
3/32	.09375	2.3813	41/64	.640625	16.2719
7/64	.109375	2.7781	21/32	.65625	16.6688
	.11811	3.00		.66929	17.00
1/8	.125	3.175	43/64	.671875	17.0657
9/64	.140625	3.5719	11/16	.6875	17.4625
5/32	.15625	3.9688	45/64	.703125	17.8594
	.15748	4.00		.70866	18.00
11/64	.171875	4.3656	23/32	.71875	18.2563
3/16	.1875	4.7625	47/64	.734375	18.6532
	.19685	5.00		.74803	19.00
13/64	.203125	5.1594	3/4	.7500	19.05
7/32	.21875	5.5563	49/64	.765625	19.4469
15/64	.234375	5.9531	25/32	.78125	19.8438
	.23622	6.00		.7874	20.00
1/4	.2500	6.35	51/64	.796875	20.2407
17/64	.265625	6.7469	13/16	.8125	20.6375
	.27559	7.00		.82677	21.00
9/32	.28125	7.1438	53/64	.828125`	21.0344
19/64	.296875	7.5406	27/32	.84375	21.4313
5/16	.3125	7.9375	55/64	.859375	21.8282
	.31496	8.00		.86614	22.00
21/64	.328125	8.3344	7/8	.875	22.225
11/32	.34375	8.7313	57/64	.890625	22.6219
	.35433	9.00		.90551	23.00
23/64	.359375	9.1281	29/32	.90625	23.0188
3/8	.375	9.525	59/64	.921875	23.4157
25/64	.390625	9.9219	15/16	.9375	23.8125
	.3937	10.00		.94488	24.00
13/32	.40625	10.3188	61/64	.953125	24.2094
27/64	.421875	10.7156	31/32	.96875	24.6063
	.43307	11.00		.98425	25.00
7/16	.4375	11.1125	63/64	.984375	25.0032
29/64	.453125	11.5094	1	1.0000	25.4001

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Conversion Chart

METRIC/U.S. CUSTOMARY UNIT EQUIVALENTS

Multiply:	by:	to get:	Multiply:	by:	to get:
ACCELERATION					
feet/sec²	× 0.3048	= meters/sec² (m/s²)	× 3.281		= feet/sec²
inches/sec²	× 0.0254	= meters/sec² (m/s²)	× 39.37		= inches/sec²
ENERGY OR WORK (watt–second = joule = newton–meter)					
foot–pounds	× 1.3558	= joules (J)	× 0.7376		= foot–pounds
calories	× 4.187	= joules (J)	× 0.2388		= calories
Btu	× 1055	= joules (J)	× 0.000948		= Btu
watt–hours	× 3600	= joules (J)	× 0.0002778		= watt–hours
kilowatt–hrs.	× 3.600	= megajoules (MJ)	× 0.2778		= kilowatt-hrs
FUEL ECONOMY AND FUEL CONSUMPTION					
miles/gal	× 0.42514	= kilometers/liter (km/L)	× 2.3522		= miles/gal
Note:					
235.2/(mi/gal) = liters/100km					
235.2/(liters/100 km) = mi/gal					
LIGHT					
footcandles	× 10.76	= lumens/meter² (lm/m²)	× 0.0929		= footcandles
PRESSURE OR STRESS (newton/sq meter = pascal)					
inches Hg(60 F)	× 3.377	= kilopascals (kPa)	× 0.2961		= inches Hg
pounds/sq in	× 6.895	= kilopascals (kPa)	× 0.145		= pounds/sq in
inches H_2O(60 F)	× 0.2488	= kilopascals (kPa)	× 4.0193		= inches H_2O
bars	× 100	= kilopascals (kPa)	× 0.01		= bars
pounds/sq ft	× 47.88	= pascals (Pa)	× 0.02088		= pounds/sq ft
POWER					
horsepower	× 0.746	= kilowatts (kW)	× 1.34		= horsepower
ft–lbf/min	× 0.0226	= watts (W)	× 44.25		= ft–lbf/min
TORQUE					
pounds–inches	× 0.11298	= newton–meters (N-m)	× 8.851		= pound–inches
pound–feet	× 1.3558	= newton–meters (N-m)	× 0.7376		= pound–feet
VELOCITY					
miles/hour	× 1.6093	= kilometers/hour (km/h)	× 0.6214		= miles/hour
feet/sec	× 0.3048	= meters/sec (m/s)	× 3.281		= feet/sec
kilometers/hr	× 0.27778	= meters/sec (m/s)	× 3.600		= kilometers/hr
miles/hour	× 0.4470	= meters/sec (m/s)	× 2.237		= miles/hour

COMMON METRIC PREFIXES

mega	(M)	= 1 000 000	or 10^6	centi	(c)	= 0.01	or 10^{-2}
kilo	(k)	= 1 000	or 10^3	milli	(m)	= 0.001	or 10^{-3}
hecto	(h)	= 100	or 10^2	micro	(μ)	= 0.000 001	or 10^{-6}



METRIC/U.S. CUSTOMARY UNIT EQUIVALENTS

Multiply:	by:	to get:	Multiply:	by:	to get:
LINEAR					
inches	× 25.4	= millimeters (mm)	× 0.03937		= inches
feet	× 0.3048	= meters (m)	× 3.281		= feet
yards	× 0.9144	= meters (m)	× 1.0936		= yards
miles	× 1.6093	= kilometers (km)	× 0.6214		= miles
inches	× 2.54	= centimeters (cm)	× 0.3937		= inches
microinches	× 0.0254	= micrometers (μm)	× 39.37		= microinches
AREA					
inches²	× 645.16	= millimeters²(mm²)	× 0.00155		= inches²
inches²	× 6.452	= centimeters²(cm²)	× 0.155		= inches²
feet²	× 0.0929	= meters²(m²)	× 10.764		= feet²
yards²	× 0.8361	= meters²(m²)	× 1.196		= yards²
acres²	× 0.4047	= hectares (10^4m²)			
			ha × 2.471		= acres
miles²	× 2.590	= kilometers² (km²)	× 0.3861		= miles²
VOLUME					
inches³	× 16387	= millimeters³ (mm³)	× 0.000061		= inches³
inches³	× 16.387	= centimeters³ (cm³)	× 0.06102		= inches³
inches³	× 0.01639	= liters (L)	× 61.024		= inches³
quarts	× 0.94635	= liters (L)	× 1.0567		= quarts
gallons	× 3.7854	= liters (L)	× 0.2642		= gallons
feet³	× 28.317	= liters (L)	× 0.03531		= feet³
feet³	× 0.02832	= meters³ (m³)	× 35.315		= feet³
fluid oz	× 29.57	= milliliters (mL)	× 0.03381		= fluid oz
yards³	× 0.7646	= meters³ (m³)	× 1.3080		= yards³
teaspoons	× 4.929	= milliliters (mL)	× 0.2029		= teaspoons
cups	× 0.2366	= liters (L)	× 4.227		= cups
MASS					
ounces (av)	× 28.35	= grams (g)	× 0.03527		= ounces (av)
pounds (av)	× 0.4536	= kilograms (kg)	× 2.2046		= pounds (av)
tons (2000 lb)	× 907.18	= kilograms (kg)	× 0.001102		= tons (2000 lb)
tons (2000 lb)	× 0.90718	= metric tons (t)	× 1.1023		= tons (2000 lb)
FORCE					
ounces—f (av)	× 0.278	= newtons (N)	× 3.597		= ounces—f (av)
pounds—f (av)	× 4.448	= newtons (N)	× 0.2248		= pounds—f (av)
kilograms—f	× 9.807	= newtons (N)	× 0.10197		= kilograms—f

TEMPERATURE



°Celsius = 0.556 (°F – 32)

°F = (1.8° C) + 32



Bolt Torquing Chart

SAE Standard/Foot-Pounds						
Grade of Bolt	***SAE 1 & 2***	***SAE 5***	***SAE 6***	***SAE 8***		
Min. Tensile Strength	64,000 P.S.I.	105,000 P.S.I.	133,000 P.S.I.	150,000 P.S.I.		
Markings on Head					Size of Socket or Wrench Opening	
U.S. Standard	Foot Pounds				U.S. Regular	
Bolt Dia.					Bolt Head	Nut
1/4	5	7	10	10.5	3/8	7/16
5/16	9	14	19	22	1/2	9/16
3/8	15	25	34	37	9/16	5/8
7/16	24	40	55	60	5/8	3/4
1/2	37	60	85	92	3/4	13/16
9/16	53	88	120	132	7/8	7/8
5/8	74	120	167	180	15/16	1.
3/4	120	200	280	296	1-1/8	1-1/8

METRIC STANDARD						
Grade of Bolt	***5D***	***.8G***	***10K***	***12K***		
Min. Tensile Strength	71,160 P.S.I.	113,800 P.S.I.	142,200 P.S.I.	170,679 P.S.I.		
Grade Markings on Head	5D	.8G	10K	12K	Size of Socket or Wrench Opening	
Metric		Foot Pounds			Metric	
Bolt Dia.	U.S. Dec Equiv.				Bolt Head	
6mm	.2362	5	6	8	10	10mm
8mm	.3150	10	16	22	27	14mm
10mm	.3937	19	31	40	49	17mm
12mm	.4720	34	54	70	86	19mm
14mm	.5512	55	89	117	137	22mm
16mm	.6299	83	132	175	208	24mm
18mm	.709	111	182	236	283	27mm
22mm	.8661	182	284	394	464	32mm

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Wire Size Chart

The selection of the correct gage primary wire is very important for automotive and other low-voltage applications to ensure safe and reliable performance.

When too small a gage primary wire is used, a voltage drop occurs due to electrical resistance. On lighting equipment there is also a loss of candlepower (visible light measurement).

The two factors that should always be considered in selecting an adequate gage primary wire are (1) the total amperage the circuit will carry and (2) the total length of wire used in each circuit, including the return.

Select the correct gage wire from the wiring diagram and primary wiring guide below. Allowance for the return circuits, including grounded returns, has been computed on the recommendations below. The length cable should be determined by totaling both wires in a two-wire circuit.

Total Approx. Circuit Amperes	Total Circuit Watts	Total Candle-power	Wire Gage (for length in feet)											
12V	**12V**	**12V**	**3'**	**5'**	**7'**	**10'**	**15'**	**20'**	**25'**	**30'**	**40'**	**50'**	**75'**	**100'**
1.0	12	6	18	18	18	18	18	18	18	18	18	18	18	18
1.5		10	18	18	18	18	18	18	18	18	18	18	18	18
2	24	16	18	18	18	18	18	18	18	18	18	18	16	16
3		24	18	18	18	18	18	18	18	18	18	18	14	14
4	48	30	18	18	18	18	18	18	18	18	16	16	12	12
5		40	18	18	18	18	18	18	18	18	16	14	12	12
6	72	50	18	18	18	18	18	18	16	16	16	14	12	10
7		60	18	18	18	18	18	18	16	16	14	14	10	10
8	96	70	18	18	18	18	18	16	16	16	14	12	10	10
10	120	80	18	18	18	18	16	16	16	14	12	12	10	10
11		90	18	18	18	18	16	16	14	14	12	12	10	8
12	144	100	18	18	18	18	16	16	14	14	12	12	10	8
15		120	18	18	18	18	14	14	12	12	12	10	8	8
18	216	140	18	18	16	16	14	14	12	12	10	10	8	8
20	240	160	18	18	16	16	14	12	10	10	10	10	8	6
22	264	180	18	18	16	16	12	12	10	10	10	8	6	6
24	288	200	*18	18	16	16	12	12	10	10	10	8	6	6
30			18	16	16	14	10	10	10	10	10	6	4	4
40			18	16	14	12	10	10	8	8	6	6	4	2
50			16	14	12	12	10	10	8	8	6	6	2	2
100			12	12	10	10	6	6	4	4	4	2	1	1/0
150			10	10	8	8	4	4	2	2	2	1	2/0	2/0
200			10	8	8	6	4	4	2	2	1	1/0	4/0	4/0

*18 AWG indicated above this line could be 20 AWG electrically—18 AWG is recommended for mechanical strength.

How to use chart

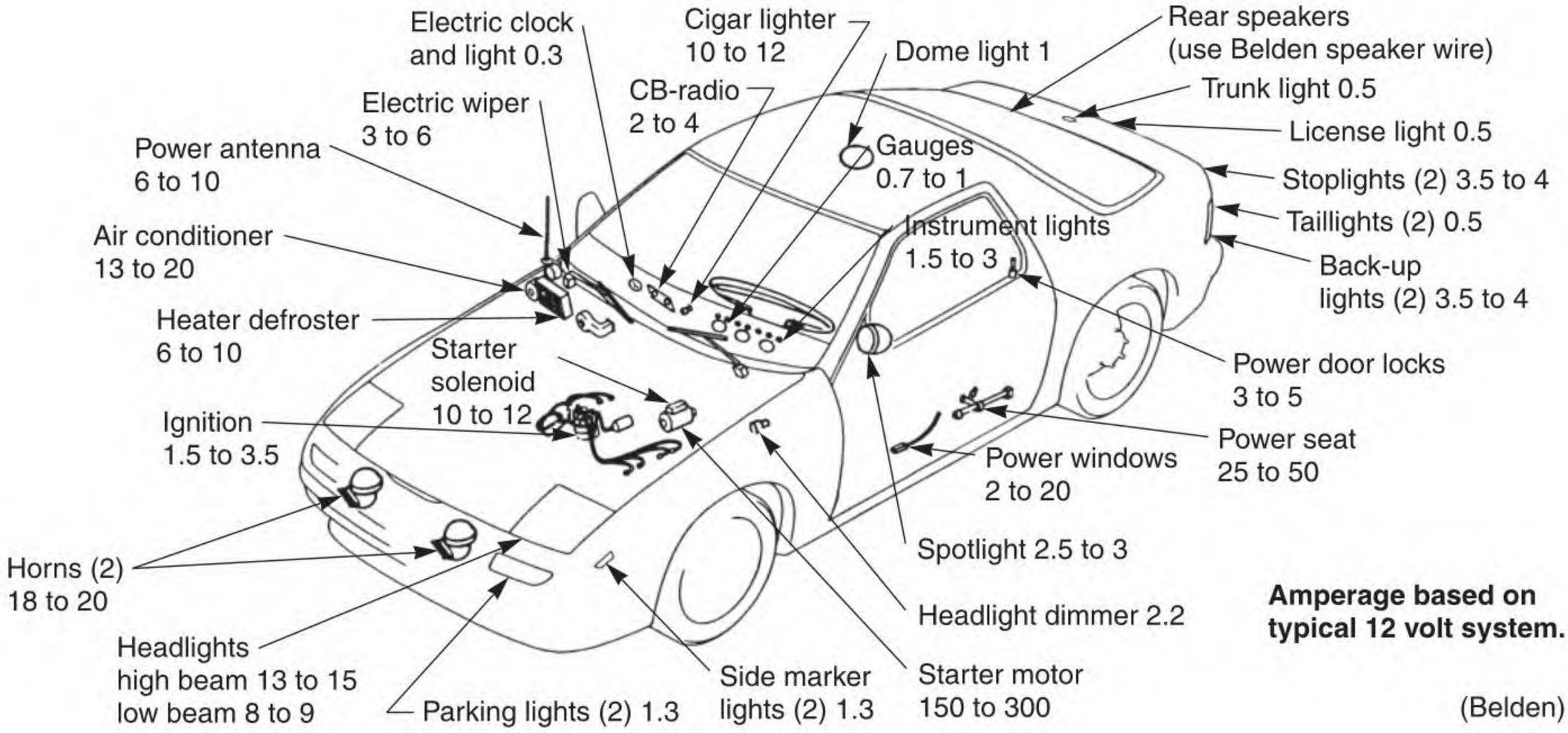
1
Measure Length of Wire in Circuit—chart applies to ground return. Two-wire circuits will be total of both wire lengths. Be sure to indicate both vehicles on auto and trailer applications.

2
Find the total amperes, watts, or candlepower and choose nearest value in proper column.

3
Move horizontally to proper footage column and find nearest wire gage.

4
For 6 volt applications, use two wire sizes larger. Example: If chart shows 16 ga. for 12 volt system, use 14 ga. on 6 volt system.

Based on maximum of 10% voltage drop



Amperage based on typical 12 volt system.

(Belden)

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SAE-Recommended Abbreviations/Acronyms

Term	Abbreviation/ Acronym
Accelerator Pedal	AP
Air Cleaner	AC
Air Conditioning	A/C
Automatic Transmission	A/T
Automatic Transaxle	A/T
Barometric Pressure	BARO
Battery Positive Voltage	B+
Camshaft Position	CMP
Carburetor	CARB
Charge Air Cooler	CAC
Closed Loop	CL
Closed Throttle Position	CTP
Clutch Pedal Position	CPP
Continuous Fuel Injection	CFI
Continuous Trap Oxidizer	CTOX
Crankshaft Position	CKP
Data Link Connector	DLC
Diagnostic Test Mode	DTM
Diagnostic Trouble Code	DTC
Direct Fuel Injection	DFI
Early Fuel Evaporation	EFE
EGR Temperature	EGRT
Electronically Erasable Programmable Read Only Memory	EEPROM
Electronic Ignition	EI
Engine Control	EC
Engine Control Module	ECM
Engine Coolant Level	ECL
Engine Coolant Temperature	ECT
Engine Modification	EM
Engine Speed	RPM
Erasable Programmable Read Only Memory	EPROM
Evaporative Emission	EVAP
Exhaust Gas Recirculation	EGR
Fan Control	FC
Flash Electrically Erasable Programmable Read Only Memory	FEEPROM
Flash Erasable Programmable Read Only Memory	FEPROM
Flexible Fuel	FF
Fourth Gear	4GR
Fuel Pump	FP
Fuel Trim	FT
Generator	GEN
Governor Control Module	GCM
Ground	GND
Heated Oxygen Sensor	HO2S
Idle Air Control	IAC
Idle Speed Control	ISC
Ignition Control	IC
Ignition Control Module	ICM
Indirect Fuel Injection	IFI
Inertia Fuel Shutoff	IFS
Intake Air	IA
Intake Air Temperature	IAT
Knock Sensor	KS
Malfunction Indicator Lamp	MIL
Manifold Absolute Pressure	MAP
Manifold Differential Pressure	MDP
Manifold Surface Temperature	MST
Manifold Vacuum Zone	MVZ
Mass Airflow	MAF
Mixture Control	MC
Multiport Fuel Injection	MFI
Nonvolatile Random Access Memory	NVRAM
On-Board Diagnostic	OBD
Open Loop	OL
Oxidation Catalytic Converter	OC
Oxygen Sensor	O2S
Park/Neutral Position	PNP
Periodic Trap Oxidizer	PTOX
Positive Crankcase Ventilation	PCV
Power Steering Pressure	PSP
Powertrain Control Module	PCM
Programmable Read Only Memory	PROM
Pulsed Secondary Air Injection	PAIR
Random Access Memory	RAM
Read Only Memory	ROM
Relay Module	RM
Scan Tool	ST
Secondary Air Injection	AIR
Sequential Multiport Fuel Injection	SFI
Service Reminder Indicator	SRI
Smoke Puff Limiter	SPL
Supercharger	SC
Supercharger Bypass	SCB
System Readiness Test	SRT
Thermal Vacuum Valve	TVV
Third Gear	3GR
Three Way + Oxidation Catalytic Converter	TWC+OC
Three Way Catalytic Converter	TWC
Throttle Body	TB
Throttle Body Fuel Injection	TBI
Throttle Position	TP
Torque Converter Clutch	TCC
Transmission Control Module	TCM
Transmission Range	TR
Turbocharger	TC
Vehicle Speed Sensor	VSS
Voltage Regulator	VR
Volume Airflow	VAF
Warm Up Three Way Catalytic Converter	WU-TWC
Wide Open Throttle	WOT

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Glossary

12-volt battery: Electrochemical device that produces and stores electricity. An automotive battery is a 12-volt battery with six cells, which produce 12.6 volts to power the vehicle's 12-volt main electrical system.

12-volt starting system: System using a 12-volt battery and an electric motor to turn the engine crankshaft for engine operation.

A

A/C switch: Driver-operated switch in the car's dash that feeds current to the compressor clutch and other electric components of a vehicle's air conditioning system.

abbreviations: Letter combinations that stand for words. Abbreviations are used extensively in the automotive industry.

abnormal combustion: Problem that occurs when combustion happens too quickly or too slowly. The resultant flame does not spread evenly and smoothly through the combustion chamber.

abrasive pad: A cleaning tool with a surface of coarse material. It can be attached for use in an air or electric drill and is helpful in removing old gasket material.

ABS: Abbreviation for Anti-lock Braking System.

ABS actuator: See *ABS electro-hydraulic modulator.*

ABS control module: An ECM that uses wheel speed sensor inputs to control the operation of the electro-hydraulic modulator.

ABS electro-hydraulic modulator: Regulates the fluid pressure applied to each wheel brake assembly during periods of hard braking. It is also called an ABS actuator.

ABS warning light: Amber indicator lamp mounted in the instrument cluster. It illuminates when there is a problem with the anti-lock brake system.

absorbed glass mat battery: Type of sealed lead-acid battery that contains fiber matting which absorbs liquid electrolyte and holds it between the battery plates. It is also called an ABG battery.

ac generator: Machine that produces electricity using a spinning magnetic field (rotor) within a stationary set of windings (stator). As the rotor turns one-half turn, the polarity of the windings reverses. This continuous change of winding polarity creates alternating current.

acceleration sensor: Sensor that provides acceleration data to the computer in an electronic suspension system.

acceleration test: See *ignition load test.*

accelerator pedal sensor: Sensor that feeds an electric signal to the ECM that corresponds to pedal position.

accelerometer: An inertia sensor, sometimes mounted in a vehicle's air bag, that measures changes in motion or deceleration.

accessory system: Systems that are not vital to a vehicle's operation, including the air conditioner, sound system, power seats, and rear window defogger.

accident: See *vehicle collision.*

accumulator: Device that is used in the apply circuit of a band or clutch in an automatic transmission to dampen hydraulic pressure surges by temporarily absorbing some pressure. *Also,* a receiver-drier combination used to remove moisture and store additional refrigerant in a vehicle A/C system.

acid-core solder: A type of solder that has an internal core of acid flux. This type of solder is not to be used for electrical repairs.

active restraint system: A restraint system that requires the occupants to ready the system. For example, seat belts that must be buckled manually are classified as an active system.

active sensor: Computer sensor that generates its own voltage signal in response to a change in a condition.

active suspension system: A suspension system that uses computer-controlled hydraulic rams instead of conventional suspension system springs and shock absorbers. The hydraulic rams support the weight of the car and also react to the road surface and different driving conditions.

actuator: Type of motor that converts an electronic signal into movement or motion.

actuator diagnostic test: Test that enables a technician to check if actuators are working. It uses a scan tool to order a vehicle's computer to energize specific output devices with the engine on or off.

adapter: On a scan tool, an adapter is a connector that allows the scan tool connector to fit a vehicle's data link connector if pin configurations differ.

adaptive cruise control system: Type of cruise control system that can alter vehicle speed automatically when approaching another vehicle too quickly from behind.

adaptive strategy: Feature in an ECM that allows it to adjust its operation to compensate for sensor, actuator, or vehicle deterioration.

addition: Arithmetic process of combining two or more numbers to find the total quantity.

adhesive: High-strength glue used for holding parts and other automotive items together.

adjustable shock absorber: Shock absorber that has a means of changing shock stiffness, either manually with an adjustment knob or automatically with a computer.

adjustable wrench: Wrench with movable jaws for fitting different size bolt and nut heads. It is also called a Crescent wrench.

adjusting nut: A nut on a worm-type steering gearbox that is used to set worm shaft bearing preload.

adjusting screw: A screw on a worm-type steering gearbox that is used to set the sector shaft clearance.

aerodynamics: Study of the motion of air as it interacts with a moving object. Aerodynamics is a major concern for automotive designers when creating a vehicle body.

after-running: See *dieseling.*

afterburner: On a catalytic converter, an afterburner is a device that reheats or re-burns exhaust fumes.

AGM battery: See *absorbed glass mat battery.*

air bag: A strong, reinforced nylon sack attached to the metal frame of the air bag module. It is tightly folded for storage in the steering wheel pad, the dash, the door panel, or the side of the seat.

air bag control ECM: See *air bag controller.*

air bag controller: Uses inputs from the impact and safing sensors to determine if air bag deployment is needed. It is also called an air bag control ECM.

air bag igniter: Air bag module component that generates a small electric arc when an electrical signal is sent to it from the air bag controller. Its flash causes a huge volume of expanding gas.

air bag module: A nylon bag and an igniter-inflator unit enclosed in a metal and plastic housing.

air bag powder: A powder, usually sodium hydroxide, that may blow out of the air bag on deployment.

air bag sensor: Inertia sensor that signals the control ECM in the event of a collision by detecting a rapid change in speed or velocity.

air bag system: A protective device that deploys inflatable nylon bags to help protect a vehicle's occupants during a collision.

air bag vent hole: Small hole around the air bag that allows for rapid deflation of the air bag after deployment.

air blowgun: Handheld tool that attaches to a compressed air system to blow off small bits of dirt, solvent, water, and other debris and to blow out bolt holes, coolant passages, and oil passages.

air chisel: See *air hammer.*

air chuck: Pressurized air hose attachment designed to depress the pin of a tire valve core with the purpose of opening the valve for tire inflation or deflation.

air cleaner: See *air filter.*

air cleaner carbon element: Air filter that may be used to absorb fuel vapors when an engine is shut off.

air compressor: A pump that forces air, under pressure, into a storage tank.

air conditioning compressor: A refrigerant pump, bolted to the front of the engine, that pressurizes refrigerant and forces it through the cooling system.

air conditioning condenser: A radiator-like device that transfers heat from the refrigerant to the outside air.

air conditioning system: Set of components that lowers passenger compartment temperature and humidity. It is combined with the heating system.

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air cooling system: Circulation of airflow over the cooling fins on engine cylinders to remove heat from the cylinders and prevent overheating.
air distribution manifold: Part of an air injection system that directs a stream of air toward each engine exhaust valve.
air dome: A hump formed in the top of a fuel tank as part of a vehicle EVAP system to allow for fuel expansion and tank filling without spillage.
air drill: Compressed-air tool with a tool attachment at the tip. Power output and speed adjustment capabilities make it a versatile tool. With specific attachments, air drills can drill holes, grind, polish, and clean parts.
air filter: Vehicle part that removes foreign matter (dirt and dust) from the air entering the engine intake manifold. It is also called an air cleaner.
air gap: Clearance that separates the wheel speed sensor tip from the spinning teeth of the sensor rotor.
air hammer: Compressed-air tool featuring different cutting and hammering attachments that are very rapidly struck against a part or surface. It is also called air chisel.
air hose: A flexible, high-pressure hose that carries a source of air pressure for tools and equipment throughout an automotive shop.
air induction system: Subsystem of an electronic vehicle fuel injection system. It filters, routes, and controls outside air flowing into engine cylinders.
air injection pump: Low-pressure pump driven by an engine and used to force air into an exhaust manifold.
air injection system: A method of reducing hydrocarbons and carbon monoxide emissions by forcing fresh air into the exhaust ports of an engine by means of an air pump. It is also called an Air Injection Reaction system or AIR.
air jet combustion chamber: Combustion chamber designed with a small, extra valve that allows a stream of air to enter the combustion chamber to aid swirl and combustion efficiency.
air ratchet: A special compressed-air wrench with limited turning power designed for working in tight spaces.
air shock: Shock absorber that uses air pressure, rather than springs, to maintain vehicle height.
air spring: Air-filled rubber cylinder that is lighter than an equivalent coil spring; can provide a smoother ride compared to a coil.
air supply system: Subsystem of a vehicle fuel system. It allows clean, filtered air to flow into the engine's combustion chambers.
air test: Test that forces pressurized air through transmission passages to detect leaks, stuck parts, or blocked passages.
air tool: Tool that uses compressed air for operation.
air wrench: See *impact wrench*.
air-fuel ratio: Ratio by weight between the air and fuel that makes up an engine's fuel charge.
airflow sensor: Sensor measuring the quantity of air entering an engine.
alcohol: Clean-burning alternative automotive fuel that is not widely used outside of the racing industry due to its high expense to use and produce.
alignment: Term for the positioning of an object in a straight line.
alignment equipment software: Software that contains computer instructions, information for using the alignment equipment, alignment specifications for various makes and models of vehicles, and other helpful information.
alignment head: Part of a wheel alignment machine that mounts on the vehicle wheels and is used to check caster, camber, and toe.
alignment machine: Machine used to correctly align a vehicle's wheels. Consists of the rack, console, and related parts.
alignment rack: Fixture onto which the vehicle is driven for alignment measurement and adjustment.
Allen wrench: A hexagonal wrench, usually "L" shaped, designed to fit into a hexagonal hole.
all-wheel drive system: Type of drive system that transmits power to all four wheels at all times. A special internal clutch in the transfer case diverts more or less power to the front wheels depending on road conditions.
all-wheel drive train: Configuration with the engine in the front and twin differentials to distribute engine/electric power to all four wheels and tires.
alphanumeric: A system that uses letters and numbers to denote tire characteristics and limits.
alternate power source: A method of producing energy, other than gasoline and diesel oil, to propel a motor vehicle.
alternating current (ac): An electrical current that moves in one direction and then the other.
alternative fuel: Term used to categorize any vehicle fuel other than gasoline and diesel fuel. Some examples are alcohol, methane gas, and hydrogen.
alternator: An ac generator that uses mechanical (engine) power to produce electricity.
alternator bearing: Grease-packed bearing used to produce a low-friction surface to support the rotor shaft as the shaft spins inside the stator and alternator housing.
alternator brush: Brush that feeds battery current into the slip rings by means of creating a sliding electrical connection with them.
alternator drive belt: Belt that links the engine crankshaft pulley with the alternator pulley to power the alternator.
alternator fan: Fan mounted on the front of the rotor shaft that draws air through and over the alternator to prevent overheating.
alternator pulley: Circular, grooved disk attached to the front of the rotor shaft providing a means of spinning the rotor using a belt.
alternator rectifier: An assembly that uses diodes to convert stator current (alternating current) to direct current through full-wave rectification. It is also called a diode assembly.
alternator rotor assembly: Consists of two claw-shaped pole pieces surrounding field coil windings, all mounted on the rotor shaft. Opposing north/south poles on each claw produce an alternating current as the rotor spins.
alternator slip ring: Ring mounted on the rotor shaft that connects each end of the rotor's field windings to provide dc current.
alternator stator: Produces the electrical current of the alternator with three sets of windings wrapped around a laminated iron core. The windings connect to the rectifier.
alternator warning light: Light wired to the charging system that glows when alternator output falls to a certain level.
aluminum cylinder block: Engine block used in many late-model vehicles due to its lighter weight, ability to increase fuel economy, and better heat dissipation properties than a cast iron block.
AM radio: Radio designed to pick up radio signals that vary in amplitude (strength). It operates on a frequency of 530 to 1610 kilohertz (kHz).
ambient temperature switch: Temperature sensitive switch that is designed to prevent air conditioner operation when outdoor temperatures are below a set point.
American Wire Gage (AWG) system: A system used to indicate the diameter of conductors. A smaller number, or wire gage, denotes a larger conductor diameter, and vice versa.
ammeter: Instrument used to measure the flow of electric current in a circuit in amperes. It is normally connected in series in a circuit.
ammeter indicator: Instrument cluster display that measures current output of the alternator.
ampere: The unit of measurement for the flow of electric current.
amp-hour rating: Measurement of how much current a battery can produce for 20 hours at 80°F (27°C) with battery voltage staying above 10.5 volts.
amplitude: Measure between the highest part of a waveform and the lowest part of a waveform, which can be negative.
analog instrument: Instrument that uses rotating needles or dials to indicate vehicle operating conditions.
analog multimeter: Multimeter that uses a needle or pointer to show electrical readings. In addition to measuring constant values, it can detect changes in voltage, current, or resistance.
analog scope pattern: Oscilloscope readout that has a smooth, gradual change in voltage over time.
analog signal: A signal that can have a continuous range of strengths.
antenna: Device that picks up a broadcast signal and feeds it through the antenna lead to the radio. Some antennas are a very fine piece of wire in the windshield glass. Other antennas are a metal mast (rod) mounted in the car body.

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antifreeze: A liquid, usually ethylene or propylene glycol, that is added to water in a vehicle's cooling system. This mixture serves as the engine's coolant.

antifriction bearing: A bearing that uses balls or rollers between a journal and bearing surface to decrease friction.

antiknock additive: Extra chemical added to gasoline that slows down the burning of gasoline to prevent engine ping, or knock.

anti-lock brake system (ABS): A computer-controlled system that is part of the base brake system. The system cycles the brakes on and off to prevent wheel lockup and skidding.

anti-rattle clip: Clip that snaps onto a brake pad to keep it from vibrating and rattling.

armature: The core and shaft of an electric motor or alternator, consisting of electromagnets (known as field coils) and contacts (known as the commutator). As the armature rotates, the field coils change polarity to keep it rotating.

armature core: Indented iron piece within the starter armature that holds the windings in place. Iron is used to strengthen the magnetic field produced by the windings.

armature motor shaft: Pole that extends the length of the starter armature supporting the spinning armature on one end and the starter pinion gear/pinion drive unit on the other.

arming sensor: See *safing sensor.*

ASE-certified automobile technician: Technician who has passed a specific ASE test and completed the work requirement to achieve ASE-certification in that automotive area.

ASE-certified master automobile technician: Title awarded to a technician who has passed all the ASE Automobile & Light Truck Certification Tests (A1-A8, A9 is not required) and completed the work requirement.

aspect ratio: The ratio between tire section height and section width.

asphyxiation: A condition in which the body is deprived of oxygen, which can result in dead tissue, unconsciousness, and death.

aspirator valve: Type of valve that allows air or liquid flow in only one direction, opening and closing based on pressure pulses. It is also known as a check, gulp, or reed valve.

assembly: A set of fitted parts designed to complete a specific function.

assembly line diagnostic link (ALDL): See *data link connector (DLC).*

assist hybrid: See *mild hybrid.*

asymmetric tire: Type of tire that has a different tread pattern on its inner edge than its outer edge. The outer tread pattern is designed to improve cornering on dry surfaces, while the inner tread pattern is designed to improve traction on wet surfaces.

atmospheric engine: See *normally aspirated engine.*

atmospheric pressure: Pressure formed by the air surrounding Earth. At sea level, the atmosphere exerts 14.7 psi (103 kPa) of pressure on everything.

atmospheric suspended brake booster: This system has atmospheric pressure on both sides of the diaphragm or piston when the brake pedal is released. As the brakes are applied, a vacuum is formed on one side of the booster. Atmospheric pressure then pushes on and moves the piston or diaphragm.

atom: A microscopic particle that cannot be broken into smaller pieces without losing its properties.

attitude: Height ratio between the front and rear of a vehicle's body.

auto parts specialist: An individual with a general knowledge of the components and systems of a vehicle, and is capable of using auto industry tools to quickly and accurately find needed parts.

auto ranging: Feature of a digital multimeter that automatically changes to the correct range. All that has to be set on the meter is the knob for volts, amps, or ohms.

auto salesperson: A professional who promotes automobiles or automotive parts and equipment in an attempt to sell said products.

automated manual transmission: Transmission that uses computer control and sensors to allow shifting gears without clutch pedal disengagement. Computer control synchronizes the speed of the engine with the transmission so that no load is sent through the transmission while shifting.

automatic clutch adjuster: A quadrant and pawl device attached to the top of a clutch pedal. When the clutch is depressed, the pawl locks on a certain tooth of the quadrant to eliminate play from the clutch cable.

automatic engine clutch: Assembly that uses computer control and several control modules to operate a conventional clutch or a set of wet clutches.

automatic headlight dimmer system: System that uses a light sensor, amplifier, and relay to control the high and low beam headlights.

automatic locking hub: Type of locking hub in a four-wheel-drive vehicle that electrically locks the hubs at the front wheels to the front axles when the driver shifts into four-wheel drive.

automatic manual clutch: Type of manual transmission that uses driver-operated shift buttons and a computer to electronically control manually shifting gears.

automatic parking system: System that uses computer control with proximity sensors and/or vehicle cameras to back up, steer, and brake a car into a parallel parking space.

automatic suspension leveling system: Suspension system that uses air shocks or air springs, height sensors, and a compressor to maintain curb height. Changes in vehicle load are counteracted with an automatic increase/decrease in suspension air pressure.

automatic temperature control system: System that uses various pressure and temperature sensors and a control module (computer) to maintain a preset passenger compartment temperature.

automatic transaxle: A combination of an automatic transmission and a differential in a front-wheel-drive vehicle. It consists of a torque converter, an oil pump, a valve body, pistons and servos, bands and clutches, planetary gearsets, and differential.

automatic transmission: A transmission that uses fluid pressure to shift itself. Shift points and range are determined by road speed, engine loading, altitude, and throttle position. Late-model automatic transmissions are computer-controlled.

automatic transmission fluid (ATF): Mineral oil with special additives to make it compatible with clutch and band materials and to prevent foaming and breakdown.

automatic transmission slippage: Slight to severe problem that occurs when the gearsets within a transmission engage only partially, causing the vehicle to hesitate during shifts.

automobile: Term derived from the Greek word "autos," which means self, and the French word "mobile," which means moving. Modern "self-moving" vehicles combine engineering and technology in a safe, reliable means of transportation.

automotive brake: Mechanism that provides a means of using friction to either slow, stop, or hold the wheels of a vehicle.

automotive clutch: Assembly of discs and other parts that is used to connect and disconnect an engine from a manual transmission or transaxle.

automotive designer: An individual with strong artistic abilities and engineering knowledge who can imagine and create sketches or models of new body and part designs.

automotive engineer: A highly paid, college-trained individual who uses math, physics, and other advanced technologies to design new and improved automobiles, automotive systems, and parts. A complete working knowledge of automobiles is required.

automotive instructor: An experienced technician capable of sharing his/her knowledge effectively to students. Most instructors are also required to have a college degree.

automotive technician: Individual with the skills to diagnose, service, and repair automobiles for a living.

auto-off headlamp system: System that automatically turns the headlamps off after a short delay period, once the engine is turned off.

auxiliary audio input: Terminal that allows a digital audio player to be connected to the vehicle's stereo system.

auxiliary chain: Chain powering additional vehicle components; driven by an extra sprocket, usually located in front of the crankshaft timing chain sprocket.

axle end play: Lengthwise movement of a drive axle that should meet specifications to avoid mechanical problems.

axle gear: Side gear in a differential that transfers motion to the drive axles.

axle housing: A metal enclosure for drive axles and differential. It is partially filled

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with differential fluid and other additives as needed.

axle locknut: See *hub locknut.*

axle retainer plate: Metal plate that bolts to the outside of the axle tube to hold the axle and axle bearing to the axle tube.

axle shaft: Shaft or shafts used to transmit driving force to the wheels of a vehicle.

axle shim: Flat, metal ring or plate placed between the axle retainer plate and axle housing to adjust the bearing preload to control axle end play.

axle washer: Special washer installed between a wheel driving hub and hub locknut.

B

backfiring: Condition caused by unburned air-fuel mixture igniting in the intake manifold or exhaust system. A loud bang or pop sound can be heard when the mixture ignites.

backup light switch: Electric switch that closes the circuit to illuminate the reverse lamps when initiated by the reverse gear shift linkage, solenoid, or servo.

balanced valve: See *shift valve.*

balancer shaft: One or more offset shafts geared to either the crankshaft or camshaft, used to counterbalance crankshaft vibration. Also called a silent shaft.

balancing coil gauge: Type of dash gauge that uses two electric coils to cause needle deflection.

ball-and-trunnion joint: A type of constant velocity universal joint that has ball bearings situated on a trunnion pin that fits through a hole on the drive shaft. Springs hold the shaft centered and the balls allow, but limit, shaft movement.

ballast: Transformer used in high energy discharge lightbulbs.

ball bearing (antifriction): A bearing consisting of an inner and outer hardened steel race separated by a series of hardened steel balls.

ball guide: Channels that route extra ball bearings in and out from between the worm and ball nut in a recirculating-ball gearbox.

ball joint: A flexible joint with a ball and socket-type construction. It is used primarily in steering linkage and steering knuckle pivot support. The ball joint is designed to allow the suspension to move up and down while allowing the steering knuckle to turn.

ball joint separator: Puller tool used to pry a ball joint from a steering knuckle.

ball joint wear indicator: Device on a ball joint that recesses into the joint to display the amount/degree of wear on the joint.

ball nut: Grooved nut that rides on the ball bearings and the worm gear in a recirculating-ball gearbox. The moving ball bearings force the nut up and down the worm gear without turning.

ball peen hammer: Type of hammer with a flat face for general striking and a round end for shaping metal parts.

band: Holding member with a friction material coating in an automatic transmission. It is used to stop clutch rotation in certain transmission gear ranges.

band adjustment: Process of tightening an adjustment screw to specifications when setting the clearance between a band and clutch drum in an automatic transmission.

band adjustment screw: Screw used to change clearance between the band and clutch drum in an automatic transmission.

band and clutch: Devices that use clamping pressure to apply planetary gears in an automatic transmission/transaxle. Different bands and clutches can be activated to operate different units in gearsets.

bare cylinder head: A machined cylinder head casting without any parts installed.

barrel: Small cylinder that holds a plunger of an inline diesel injection pump.

base line: The reference line, or zero volts on an oscilloscope display.

base voltage: Battery voltage with the engine off.

basic circuit problem: Circuit trouble that increases or decreases current, resistance, or voltage within the circuit.

basic refrigeration cycle: The refrigerant goes through four phases: compression, condensation, expansion, and vaporization.

battery: Source of electrical energy within a vehicle.

battery acid: See *electrolyte.*

battery bank: See *HV battery.*

battery cable connection test: Test that uses a voltmeter to check for high resistance between a battery cable end connector and a battery post.

battery cables: Wires, usually #10 gage to #1 gage copper conductor with plastic insulation and metal terminals, that connect the battery terminals to the vehicle's electrical system.

battery cap: Plastic piece that snaps into the hole above each battery cell to prevent electrolyte from spilling out of a battery and gases inside a battery from igniting.

battery carrier: Adjustable handheld clamp that tightens two forceps across the width of a battery allowing for easy removal from the battery tray.

battery case: High-quality plastic housing divided into compartments that hold the battery elements and electrolyte. It is designed to handle extreme conditions and corrosive elements.

battery cell: Battery division made up of a negative and positive plate, container, and electrolyte. An HV battery uses an acidic lithium paste or gel, while a lead-acid battery uses liquid sulfuric acid as an electrolyte.

battery charge indicator: Device designed into the battery cover that provides a visible sign of the general charge condition of the battery. It is also called a battery eye or test indicator.

battery charger: Machine that forces current back through a battery to restore the charge on the cell plates and reenergize it from a discharged state.

battery cover: Plastic piece that is bonded to the top of the battery case to seal it.

battery cycling: Amount of time between the discharging and charging of battery cells.

battery drain test: Test designed to check for an abnormal current draw (high parasitic load) that is discharging a battery while the ignition key is off.

battery eye: See *battery charge indicator.*

battery heat shield: Cover or plate that fits over the battery or between the engine and battery to protect it from excess engine heat.

battery hold-down: See *retainer.*

battery leakage test: Test designed to determine if electrical energy is draining and discharging across the top of a battery case. A dirty battery top can cause leakage.

battery load test: Test that places a battery under full-current load to measure the current and voltage output and the overall performance of the cells.

battery pack fuse: Fuse that will burn open to isolate a failed battery pack from the rest of the battery if current flow is too high.

battery pack voltage: Between 7.2–9.2 volts, depending on the number and types of battery cells.

battery pack warning light: A light in a hybrid vehicle instrument cluster that illuminates if the HV battery pack's state of charge is below normal limits or for other mild battery problems.

battery plate: Stiff mesh framework each grouped in a battery cell and coated with porous lead that allows penetration of electrolyte to aid the chemical reaction of electricity production within the battery.

battery post: Round metal terminal that protrudes from the battery cover and serve as male connections for the female battery cable ends.

battery service life: The acceptable period of use in service of a battery. A 12-volt battery is 3-5 years. An HV battery is more dependable and can last an average of about 150,000 miles.

battery stack: See *HV battery.*

battery strap(s): Band with two ends that attach to opposite battery terminals creating a handle to lift and carry a battery. *Also,* within a 12-volt battery, lead bars that connect the positive and negative battery plates into similar groups. They are also called connectors.

battery temperature sensor: Sensor found in many late-model vehicles that monitors battery temperature, providing the ECU with data on when to vary the battery charging rate.

battery terminal: Two top post or two side links that provide a means of connecting the battery plates to the vehicle's electrical system.

battery terminal test: Test that checks for a poor electrical connection (high voltage drop) between the battery cables and battery terminals on post-type batteries.

battery thermistor: Device mounted on the positive battery cable that rests against the battery to measure its temperature. It allows the charging system to alter charging output, as needed.

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battery tray: Plate on which the battery sits, usually found in the engine compartment. The retainer fastens to the tray to help securely hold the battery in place.

battery voltage test: Test to determine battery condition and general state of charge by measuring static battery voltage.

bead: The steel-reinforced edge of a tire that engages the wheel rim.

bead breaker: Pneumatic arm tool and bar on a tire changing machine that is used to force a tire bead away from or onto the wheel rim as the tire spins.

bearing crush: A split-type bearing is machined to sit slightly taller than its bore so both halves clamp against each other when bearing caps are tightened. It is used to help prevent a bearing from spinning inside its bore during engine operation.

bearing housing: Enclosure around the turbo shaft that contains bearings, seals, and oil passages.

bearing insert: A removable piece of metal that fits into the main bearing bores.

bearing locating lug: A small flange on a split-type engine bearing used to position the bearing in its bore. The lug fits into a recess machined in the bore or cap.

bearing oil hole: Hole in engine bearings that allows oil flow through an engine block to a clearance between a bearing and a journal.

bearing packer: Handheld tool designed to properly fill a bearing cage with grease.

bearing spread: The difference in the distance across the parting line of a split-type bearing compared to that of the bearing bore. This provides alignment and support after assembly as well as helps a bearing insert stick in its bore during assembly.

bearing support: Suspension part that holds the wheel bearings, axle stub shaft, and hub.

bell housing: See *clutch housing.*

bellcrank: Part in a clutch linkage mechanism designed to convert clutch pedal downward motion into a pulling motion for the release rod and clutch fork.

belt: Tire component installed between the tread and body plies. It strengthens the body plies and stiffens the tread. Belts can be made of various materials, including steel, nylon, rayon, polyester, aramid, Kevlar, or fiberglass.

belt-driven oil pump: Type of pump used with dry sump lubrication systems. Oil pump is driven by the crankshaft or off another accessory pulley that is driven by the crankshaft.

belt retractor: Device that takes the slack out of the seat belt so the belt fits snugly around the body.

belt squeal: Loud screeching or squeaking noise made by a slipping or worn vehicle belt.

belt tension gauge: Tool used to measure the tightness, or tension, of different vehicle belts after installation.

belt tensioner: Spring-loaded or hydraulic pulley that is used to keep tension and adjustment on serpentine belts.

belted bias tire: Tire construction method using crisscrossed plies with additional belts under the tread area.

bench bleeding: Removes air from inside the master cylinder. This must be done before installing the unit on the vehicle.

bench grinder: Bench-mounted machine with two wheels (an abrasive grinding wheel and a soft wire wheel) used for grinding, cleaning, or polishing operations.

bias ply tire: Tire construction method in which the plies run at an angle from bead to bead, with the angle reversed from ply to ply.

bimetal gauge: Type of dash gauge that uses two dissimilar types of metal bonded together to cause gauge needle deflection.

binary numbering system: A number system that uses two numbers (0 and 1) arranged in different sequences to represent other numbers, letters, words, computer input data, computer output data, or a condition.

bio-based oil: Oils, especially vegetable-based motor oils, developed as more environmentally friendly lubricating products.

bipolar junction transistor (BJT): An electronic component that is made by joining three semiconductor materials. It can act as a switch for electronic signals or serve as a current amplifier.

black diesel smoke: Smoke that indicates an injection system problem, or low compression is keeping fuel from burning.

black engine smoke: Smoke caused by an extremely rich air-fuel mixture.

bleeder screw: Screw that allows air to be removed from a hydraulic brake system. When the screw is loosened, hydraulic pressure can be used to force fluid and air out of the system.

bleeding: Process of using a pressure bleeder or manually pressurizing/depressurizing a vehicle system to purge air bubbles and any fluid out of the system.

block and head tester: Test tool that determines if combustion gases are present in engine coolant. It is also called a block tester or combustion leak tester.

block boring: Machining process that uses a single-point cutting bit to enlarge the diameter of engine cylinders.

block diagram: A diagram that uses boxes and symbols to illustrate components and lines to represent wires and hoses. This type of diagram simplifies a system or circuit so you can easily understand how an area of the system operates and how major components interact.

block girdle: A one-piece cap that fits over the bottom of the engine block, securing the main bearings and holding any balancer shafts. It is also called the main bearing bedplate or unit main cap.

block heater: A heating device installed in place of one of the block's freeze plugs. It is used to heat an engine during cold weather.

block ring ridge: A small lip or metal ridge formed at the tops of cylinder walls where the rings do not wear away metal. It is a sign of cylinder wear.

block tester: See *block and head tester.*

blocking ring: Toothed brass or copper ring that acts as a clutch to speed up or slow down the mating gears to match the speed of the output shaft.

blowby: Oil vapors and other emissions that leak past piston rings into an engine crankcase or form in an engine bottom end from heating of oil.

blower: An electric motor and fan assembly that forces air through the evaporator and into the passenger compartment.

blower intercooler temperature: Must be kept cooler than the engine's operating temperature by the supercharger cooling system.

blowgun: Compressed-air tool used to blow off small bits of dirt, solvent, water, and other debris and to blow out bolt holes, coolant passages, and oil passages.

blowout: Term for the instantaneous rupture and air loss of a vehicle tire.

blue diesel smoke: Smoke that indicates engine oil is entering combustion chambers and being burned.

blue-gray engine smoke: Smoke this color indicates that engine oil is entering combustion chambers.

bob weight: Weight installed on a crankshaft during crankshaft balancing to replicate the reciprocating weight.

body: A steel, aluminum, fiberglass, plastic, or composite (carbon fiber) skin forming the outside of a vehicle.

body control area network (B-CAN): A group of computers that work together to operate relay modules, entry lights, exterior lights, the horn, interlocking system, key-in reminder, keyless entry, power door locks, seat belt reminder, security alarm, turn and hazard signals, wiper-washer system, and other functions. B-CAN communicates at a data rate of about 33 kbps (kilobits per second).

body dive: Term for a vehicle body that tilts down in the front, as during vehicle braking.

body-over-frame construction: Vehicle design in which the body is installed over the frame and held in place by large bolts. This design is still used on some large passenger cars, larger vans, pickup trucks, and sport utility vehicles.

body pillar: A metal beam that extends up from the bottom of the windshield to the roof panel.

body plies: Rubberized fabric and cords wrapped around the beads. They form the carcass, or body, of the tire.

body roll: Term for a vehicle body that leans to one side, as when turning a corner.

body squat: Term for a vehicle body that tilts down in the rear, as during vehicle acceleration.

bolt: An externally threaded rod with a head on one end.

bolt head marking: Markings of lines or numbers that specify the tensile strength of a bolt.

bolt tightening sequence: The order in which a set of fasteners on a part must be tightened to prevent leaks, warping, or other problems from uneven tightening. It is also called torque pattern.

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boost charger: See *fast charger.*
boost pressure: Increased intake air pressure provided by a supercharger or turbocharger to an engine. Most production superchargers and turbochargers provide a boost pressure of 4–10 psi (30–70 kPa) above atmospheric pressure inside the intake manifold plenum.
boot: Insulated cap that fits over each end of the secondary wires to protect the metal connectors from corrosion, oil, and moisture.
boring bar: A machine shop tool that cuts a thin layer of metal out of a worn engine cylinder to make it larger in diameter.
bottom dead center (BDC): The point of travel where a piston is at its lowest point in the cylinder.
bowl fuel filter: Type of fuel filter found in modern diesel engines that is shaped to trap water out of fuel.
brake accumulator: A chamber in an ABS modulator used for storing extra fluid under high pressure.
brake backing plate: Metal plate that holds the shoes, springs, wheel cylinder, and other parts inside the brake drum. It also helps keep road dirt and water off the brakes.
brake booster: A vacuum, electric, or power steering operated device that assists brake pedal application.
brake caliper: Disc brake component that forms the cylinder and houses the piston and brake pads. It produces the clamping action on the rotating disc to stop the vehicle.
brake disc: The brake disc uses friction from the brake pads to slow or stop wheel rotation. It is normally made of cast iron and is also called a rotor or brake rotor.
brake disc resurfacing: Refers to machining a disc's friction surfaces on a brake lathe. Disc resurfacing is needed to correct runout, thickness variation, or scoring.
brake disc runout: The amount of side-to-side movement measured near the outer edge of the disc's friction surface.
brake disc thickness: The thickness of the disc measured across the two friction surfaces in several locations.
brake drum: Brake drums provide a rubbing surface for the brake shoe linings.
brake drum grinding: Procedure to remove a high spot from the drum to true the friction surface.
brake drum resurfacing: Involves machining the friction surface of the drum on a brake lathe.
brake fluid: A specially blended hydraulic fluid used to transfer power and motion from the brake pedal to the wheel cylinders and brakes.
brake fluid level: Ideal amount of brake fluid contained in the master cylinder. It should be 1/4″ (6 mm) from the top of the master cylinder reservoir.
brake fluid pump and motor: A high-pressure pump operated by a small electric motor; it provides brake fluid pressure for an ABS system.
brake fluid reservoir: A container in an ABS modulator used for holding an extra supply of brake fluid.
brake horsepower (bhp): The usable horsepower delivered to an engine crankshaft.
brake hose: Hose that transfers fluid pressure from the master cylinder to the wheel brake assemblies.
brake inspection: Process of visually examining the brake pads and rotors with the tires removed from a vehicle.
brake light switch: Switch used to operate the brake lights, installed on the brake pedal linkage. It also signals the control module to shut off the cruise control when the brakes are applied.
brake light system: Lighting system commonly made up of a fuse, brake light switch, two rear lamps, and related wiring. The brake light switch is normally mounted on or near the brake pedal.
brake line: Metal tubing and rubber hose for transmitting pressure to wheel brake assemblies.
brake master cylinder-booster assembly: A conventional master cylinder with power assist for operating brakes under normal conditions.
brake pad: Friction unit that is pushed against the disc by the action of the master cylinder, caliper cylinder, and piston.
brake pad lining: Friction material surface that contacts the rotor or drum.
brake pedal assembly: A foot-operated lever for actuating the master cylinder and power booster.
brake pedal check: A fast and accurate way of checking many components of the brake system. This is done by applying the brake pedal and comparing its movement to factory recommended specifications.
brake pedal free play: The amount of pedal movement before the beginning of brake actuation.
brake pedal height: The distance from the pedal to the floor with the pedal fully released.
brake pedal reserve distance: The distance measured from the vehicle's floor to the brake pedal when the brakes are applied.
brake pedal switch: Switch that illuminates vehicle brake lights, disengages cruise control, and, in hybrid vehicles, starts regenerative braking.
brake pressure sensor: Measures the amount of hydraulic pressure produced by the driver pressing on the brake pedal.
brake pressure switch: A sensor that monitors brake fluid pressure and controls operation of the electric motor for the hydraulic pump.
brake rotor: See *brake disc.*
brake sensor: Sensor that monitors braking in an electronic suspension system. It can alter suspension stiffness to prevent body dive during hard braking.
brake shoe: Friction unit that is pushed against the rotating brake drum by the action of the hydraulic wheel cylinder.
brake shoe adjuster: Mechanism used to maintain the correct drum-to-lining clearance as the brake linings wear.
brake solenoid valve block: An electro-hydraulic device that contains coil-operated valves. The valves control brake fluid flow to each wheel brake cylinder.
brake system: A collection of components that work together to stop a vehicle.
brake system bleeding: Involves the use of fluid pressure to force air out of the brake line connections or wheel cylinder bleeder screws.
brake system flushing: Pressure bleeding all the old brake fluid out of the system.
brake vibration: Shows up as a chatter, pulsation, or shake problem only when the brake pedal is pressed.
brake warning light: Red warning light used to inform driver of a brake problem or that the parking brake has been applied. It typically indicates either an internal leak (master cylinder) or an external leak (brake line, hose, wheel cylinder) in the hydraulic system.
brake warning light switch: Pressure-sensitive switch that warns a driver of a pressure loss on one side of a hydraulic brake system. It is also called a pressure differential valve.
brake warning light system: A lighting system that informs the driver of a problem in the hydraulic brake system.
braking noise: Grinding sounds, squeaks, rattles, and other abnormal noises often can be used to trace the cause of a braking problem.
braking ratio: A comparison of the front wheel to rear wheel braking effort.
break-away torque: In a limited-slip differential, the amount of torque needed to make one axle rotate the clutches.
breakout box: Diagnostic tool with numbered test terminals that connect to an ECM connector or system wiring harness. A multimeter can then be used to check the appropriate terminals in order to measure circuit values.
British thermal unit (Btu): The unit of measurement for heat transfer from one object to another. It is equal to near 1055 joules.
broken-surface rod: Rough, irregular mating surfaces between a piston connecting rod and cap when the rod is scored and broken off during the manufacturing process. These surfaces match perfectly to prevent shifting during engine operation.
brush spring: Small spring that holds the alternator brushes in contact with the slip rings to allow current flow.
brushes: Copper pieces that slide on the commutator to carry battery current to the spinning winding.
bubble balancer: Type of tire balancer that static balances a wheel and tire assembly. After the wheel is mounted on the machine, weights are added to parts of the wheel to bring the bubble indicator to the balanced, center crosshair.
buffer: A device that can serve as a temporary storage area for data and prevent improper data from entering internal computer chips.
burn-off oven: See *heat-cleaning oven.*
burned transmission fluid: A black or dark brown-colored transmission fluid with a burned odor. It is commonly the result of slipping or overheating band and clutch friction material.

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bus configuration: Computer network configuration in which several of the vehicle's computers are wired to a single conductor, or bus.
butt splice: A splice in which wires that are to be connected together are placed end-to-end, without overlap.
bypass circuit: Supplies direct battery voltage to the ignition system during starting motor operation.
bypass thermostat: Thermostat with an additional valve that blocks off the bypass for routing all the hot coolant through the radiator, not just most of the hot coolant.
bypass valve: Valve used to permit coolant flow when the thermostat is closed.

C

cable: Term referring to a wire with a large-diameter conductor. The outside diameter of a cable is generally much larger than that of a wire, and cables can contain one or more conductors.
calibration: In reference to measuring tools, involves adjusting the needles or digital readouts to measure accurately. Calibration procedures differ from tool to tool.
calibration gas: A test gas used to zero an exhaust gas analyzer's scales.
caliper: A brake assembly part that holds a hydraulic cylinder, piston, seals, and brake pads.
caliper cylinder: A machined hole in the caliper; the piston fits into the caliper cylinder.
cam-ground piston: A piston machined a few thousandths of an inch larger in diameter perpendicular to the piston pin centerline. This compensates for different rates of piston expansion due to heat and differences in metal wall thickness.
cam phaser hydraulic valve: Valve that reacts to electric solenoid action to redirect oil flow into and out of camshaft phaser(s).
camber: The inward or outward tilt of the wheel and tire assembly when viewed from the front of the vehicle.
camshaft: A shaft with offset lobes used to operate the valve train.
camshaft bearing: Insert pressed into the block or cylinder head; meant to reduce the friction of camshaft rotation. The camshaft journals ride in the cam bearings.
camshaft bearing clearance: The oil lubrication gap between a camshaft bearing and a camshaft journal.
camshaft bearing wear: Damage to camshaft bearings that can cause increased part clearance and may reduce engine oil pressure. It can be determined by measuring a bearing's inside diameter and subtracting this from specifications.
camshaft cover: An acoustically dampening lid over the top of a camshaft housing found on overhead camshaft engines.
camshaft drive: Mechanisms designed to smoothly transfer the rotational motion of a crankshaft to the camshaft(s) at one-half of engine speed. There are three types: timing gears, a timing chain and sprockets, or a timing belt and pulleys.
camshaft duration: Amount of time the valves stay open. It is determined by the shape of the cam lobe nose and flank.
camshaft end play: The front-to-rear movement of the camshaft in its bores.
camshaft grinding: Machine grinding done to restore camshaft lobe and journal dimensions to specifications.
camshaft housing: A casting mounted on top of a cylinder head to hold the engine camshaft(s) on overhead camshaft engines.
camshaft journal wear: Reduction in the size of the camshaft journal that results in increased part clearance and may reduce engine oil pressure.
camshaft lift: The distance a valve opens, calculated by subtracting the cam base diameter from the cam lobe height.
camshaft lobe: The offset, polished portion of a camshaft consisting of a nose, flank, heel, and base diameter. As the lobe turns on the camshaft, it imparts motion to other parts of a valve train.
camshaft lobe wear: Reduced lift or duration resulting from friction wearing off some of the camshaft lobe.
camshaft phaser: Replaces the fixed chain or belt sprocket with a hydraulic camshaft timing sprocket, or cam actuator. Each camshaft phaser uses high-engine oil pressure to rotate the camshaft in relation to its drive sprocket.
camshaft positioning tool: Tool used to hold dual-overhead camshafts in correct alignment during timing belt replacement or installation.
camshaft position sensor (CPS): A sensor used by a computer control system to reference camshaft position in order to adjust spark timing, fuel, etc.
camshaft position sensor indexing: Process during engine reassembly of installing the camshaft position sensor with the number one piston at TDC on the compression stroke. This base alignment will allow the sensor to correctly tell the vehicle ECM which cylinder is on its compression stroke.
camshaft service: Maintenance service that involves measuring camshaft lobe and journal wear, as well as measuring camshaft end play and bearing clearance.
camshaft solenoid: Solenoid that opens and closes phaser oil passages to retard or advance the camshafts in relation to crankshaft position.
camshaft straightness: A measure to determine if a camshaft is bent or warped.
camshaft thrust plate: Metal plate bolted to the front of a block or cylinder head to limit the front-to-rear movement, or end play, of a camshaft.
canister fuel filter: Type of fuel filter housed inside a metal container mounted on a fuel line.
canister vent solenoid: Electrically operated vacuum valve that replaces the fresh air vent used on older canisters.
cap screw: A bolt threaded into a part instead of a nut.
capacitor: An electrical component that absorbs voltage spikes by storing electrons, or electrical energy, thus protecting other vehicle electrical equipment.
carbon-core wire: See *secondary resistance wire.*
carbon monoxide (CO): A toxic by-product of partial burning of fuel. It is a deadly colorless, odorless gas.
Cardan universal joint: See *cross-and-roller joint.*
carrier bearing: See *case bearing.*
cartridge oil filter: Filter with a separate element that fits in an engine mounted housing.
case bearing: Bearing that fits between the outer ends of a differential case and the carrier. It is also called a carrier bearing.
case bearing preload: The force pushing differential case bearings together to eliminate excess play and clearance. Depending on the differential design, it can be adjusted by loosening or tightening an adjusting nut or using shims.
caster: Basically, the forward or rearward tilt of a steering knuckle (spindle support) when viewed from the side of the vehicle.
caster-camber gauge: Gauge used with the turning radius gauge to measure caster and camber in degrees.
casting number: Number formed into parts during manufacturing. They can be found on major components, such as an engine block and camshafts.
cast iron cylinder block: A heavy and strong engine block designed to withstand the high load forces found in high horsepower diesel and gasoline engines.
catalyst: Any substance that speeds a chemical reaction without itself being changed.
catalyst monitor: Name given to any oxygen sensor that is mounted after a catalytic converter. It is used in OBD II vehicles.
catalytic converter: An emissions control device that uses the elements platinum, palladium, and rhodium as catalysts to reduce harmful exhaust emissions.
catalytic converter temperature check: Test to quickly identify an inoperative converter catalyst by measuring the difference in exhaust temperature as it enters and leaves a catalytic converter.
C-clamp: Type of clamp with one clamping surface fixed at the end of a C-shaped body and the other at the end of an adjustable screw that passes through the clamp body to tighten.
C-clip type axle: Type of axle that uses a C-clip positioned in a groove on the axle shaft to hold the axle in place inside the differential assembly. This design is frequently used with an integral rear axle carrier.
cell voltage test: Test measuring the voltage of each cell designed to find if a battery is defective or just discharged.
center link: Steel bar used to connect the pitman arm to the tie-rods in a parallelogram steering system. It is also called a relay rod.
center support bearing: A bearing used to mount and support a two-piece Hotchkiss drive shaft.
center terminal (center electrode): The center terminal in a spark plug that conducts electricity into the combustion chamber.
centrifugal belt retractor: Part of a vehicle restraint system that uses centrifugal force to keep the seat belt from extending.

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If you pull on the belt hard enough, the rapid centrifugal force engages the locking mechanism so the belt holds the driver or passenger in the seat.

ceramic insulator: Keeps the high voltage at the plug wire from shorting to ground before producing a spark in the engine cylinder.

cetane rating: Number given to diesel fuels that indicates the fuel's cold starting ability. The higher the number, the easier the engine will start and run in cold weather.

chain guide: Metal plates shaped to prevent chain slap on long lengths of chain. Guides have a metal body with a plastic, nylon, or Teflon face, allowing a chain to slide with minimum wear.

chain slap: Noise that occurs when a chain shakes because of excessive slack in the chain.

chain tensioner: Spring-loaded or hydraulic device that pushes on the unloaded side of a chain to keep it tight and remove excess slack in the chain.

channel: A single system of ABS sensor input and hydraulic output. There are a maximum of four channels, one for each wheel. One-, two-, and three-channel systems are also used.

charcoal canister: Metal or plastic canister filled with activated charcoal granules that absorb fuel vapors. It stores fuel vapors when the engine is not running.

charge indicator: One of three types of instrument cluster devices that informs the driver of the operating condition or output of the vehicle charging system.

charge voltage: Load voltage minus base voltage. This value should be at least 0.5 volts with the vehicle engine at warm idle.

charging: Current flowing back into battery cells from a charging system that can be stored until needed. This is a conversion of electrical energy into chemical energy by the battery.

charging system: System that consists of a battery, alternator, drive belt, voltage regulator, charge indicator, and charging harness. The job of the system is to reenergize the battery as the engine is running and provide electricity to the various vehicle electrical systems.

charging system analyzer: Electronic device that quickly measures charging system voltage to determine alternator operation.

charging system harness: Wiring setup electrically connecting the components of a vehicle charging system together.

charging system load test: Measures alternator/regulator current and voltage output under its maximum load.

charging system test: Test that quickly determines the operating condition of the charging system performed when symptoms point to low alternator current and voltage.

charging voltage: Alternator output voltage (13–15 volts) held by the regulator. Since this is higher than battery voltage (12.6 volts), current flows back into the battery and recharges it.

chassis: The framework of a vehicle without its body panels.

chassis dynamometer: A machine used to measure engine power at a vehicle's drive wheels.

chassis grease: An all-around vehicle body lubricant. It is applied on easy-to-reach vehicle hinges and latches.

chassis ground: A method of grounding a circuit that uses the metal part of a component to attach to ground.

chassis hertz: A numerical measurement of the stiffness of a vehicle's structure.

chassis stiffness: The amount of give or flexibility in a vehicle chassis. It is a primary factor affecting the quietness and smoothness of a vehicle's ride—the stiffer the chassis, the better.

chattering clutch: See *grabbing clutch*.

check valve: Valve that allows fluid to flow through it in only one direction.

chemical burn: A burn caused when a corrosive substance, such as solvents or battery acid, come into contact with skin.

chisel: A tool used for cutting off damaged or badly rusted fasteners and rivet heads. A hammer blow to the top of a chisel supplies the necessary force to remove such parts.

circuit: A source, resistance, and path to carry a flow from the source to the resistance and back to the source.

circuit breaker: Device that interrupts current if a circuit is overloaded or a short occurs. Unlike a fuse, it can be reset.

circuit resistance tests: Tests used to locate wiring problems in a charging system such as a loose connection, corroded terminal, partially burned wire, or other similar types of troubles.

circuit sensing: A system that uses a computer instead of dedicated sensors to monitor current flow through various components and circuits.

circular mil: Equals the area of a circle that has a 0.001 inch diameter.

classroom: Room within an automotive shop in which instructors teach students and other technicians the knowledge and skills needed to succeed in the automotive service industry.

cleaning tool: A tool, such as a scraper or a brush, used for removing carbon, rust, dirt, grease, old gaskets, and dried oil from parts.

closed cooling system: Type of cooling system that uses an overflow bottle and a radiator cap with pressure and vacuum valves.

closed loop: In reference to an electronic fuel injection system, information looping from the ECM, through the fuel system, into the exhaust system, and back to the ECM is used to determine efficient air-fuel mixture.

closed PCV system: Type of PCV system that uses a sealed oil filler cap, a sealed oil dipstick, ventilation hoses, and either a PCV valve or a flow restrictor to keep engine blowby from entering the atmosphere.

cloud point: Temperature at which paraffin (wax) separates out of diesel fuel. At this point, the paraffin can clog fuel filters and prevent diesel engine operation.

cluster gear: A cluster of gears that are all cut on one long gear blank. The cluster gears ride in the bottom of a manual transmission, providing a connection between the transmission input and output shaft.

cluster gear assembly: The input or output shaft gears in a manual transaxle transmission.

cluster gear shaft: See *countershaft*.

clutch: In a manual transmission, a friction disc assembly that engages and disengages the engine flywheel to transfer power through gearsets. In an automatic transmission, an assembly that uses a clamping pressure to transfer engine torque through the planetary gearset(s).

clutch adjustment: Process of setting the correct amount of free play in the type of clutch release mechanism designed in the clutch assembly.

clutch apply piston: Metal plunger that applies or releases pressure against the clutch discs within a clutch assembly.

clutch arm: See *clutch fork*.

clutch cable mechanism: Arrangement of cables inside a flexible housing that transfers motion from the clutch pedal to the clutch fork.

clutch cylinder: See *clutch drum* for automatic transmissions. See *clutch master cylinder* for manual transmissions/hydraulic clutch release mechanism.

clutch disc: Friction disc with an inner edge splined to the transmission input shaft. The face is held against or pulled away from the flywheel as the clutch operates and gears are shifted. It is also termed a friction disc.

clutch drum: Metal case that holds the clutch apply piston, pressure plate, discs, and other clutch assembly parts. It is also referred to as a clutch cylinder.

clutch fork: Lever that forces a release bearing into a pressure plate assembly for disengagement of the clutch. It is also called a release arm, clutch arm, or throw-out lever.

clutch housing: Cast iron or aluminum case that bolts to the rear of an engine to surround a flywheel and clutch mechanism. On hybrid vehicles, it may also house a motor-generator. It is sometimes called a bell housing.

clutch hub: Part of a multiple disc clutch assembly that meshes against the driving disc notches and fits inside the clutch drum.

clutch linkage mechanism: Arrangement of levers, rods, cables, or hydraulic lines that transfer motion from the clutch pedal to the clutch fork.

clutch master cylinder: Piston mounted in a sealed cylinder that produces the hydraulic pressure needed to operate the clutch. It is also called a clutch cylinder.

clutch pack: Set of friction discs and steel plates sandwiched together inside most types of limited-slip differentials.

clutch release mechanism: Mechanism that lets a driver operate a clutch in a manual transmission. It includes a clutch pedal assembly (mechanical linkage, a cable, or a hydraulic circuit), the clutch fork, and sometimes the release bearing.

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clutch release spring: Spring that pushes the clutch discs apart during clutch disengagement.
clutch shaft: See *manual transmission input shaft.*
clutch shell: See *driving shell.*
clutch slippage: Problem that occurs when a clutch disc does not grip, or loosely grips, the flywheel and pressure plate. Instead of locking to transfer torque, the clutch disc slips against the flywheel and pressure plate.
clutch start switch: Switch that prevents current from reaching the starter solenoid to start an engine unless the clutch pedal is depressed (switch closed).
clutch switch: Switch in a cruise control system that signals the control module to deactivate the cruise control when the clutch pedal is depressed.
coaxial cable: A type of cable that has a center conductor surrounded by a metal shield with insulation separating the two. This keeps magnetic pulses from inducing unwanted voltage pulses. It is also called coax or shielded wire.
code history: A list of stored codes with the number of times each has occurred in a vehicle with onboard diagnostics.
coefficient of drag (Cd): Numerical value that represents the resistance of an object through air or water.
coil: An electrical component that consists of insulated wire wound into tightly-spaced loops to create an electromagnetic field. Coils are usually wrapped around an iron core to strengthen the electromagnetic properties. It is also called a choke or inductor.
coil oscillations section: See *intermediate section.*
coil pack: A device in the ignition system that consists of several ignition coils combined into one assembly. A coil pack is used in distributorless ignition systems.
coil pack ignition: An ignition system design that uses multiple ignition coils, a coil control unit, engine sensors, and a computer (engine control module) to operate the spark plugs.
coil spring: Length of spring steel rod wound into a spiral. Powerful coil springs are commonly used in vehicle suspension assemblies.
coil spring compressor: Screw-type tool used to compress coil springs during removal and installation.
coil spring pressure plate: Type of pressure plate that uses coil springs and release levers located behind the plate face to move the plate during clutch operation.
coil spring sensor: An air bag sensor that uses a small metal weight attached to a metal coil spring. The weight touches the sensor contacts and closes the circuit to the air bag controller.
cold cleaning tank: Tank used for removing oil and grease from parts. It is also called a cold-solvent tank.
cold cranking rating: Amount of current (in amperes) the battery can deliver for 30 seconds at 0°F (–18°C), while maintaining terminal voltage of 7.2 volts (1.2 volts per cell).
cold-solvent tank: Shop equipment made up of a pump, reservoir, and solvent. It is used to apply solvent to remove grease and oil from parts.
cold spark plug: A spark plug that has a short insulator tip and operates at a cooler temperature than a hot spark plug. It is used in engines operated at high speeds. The cooler tip helps prevent tip overheating and preignition.
cold-start fuel injector: Additional fuel injector used in some early indirect injection models that richens fuel mixture in an engine manifold to aid in starting a cold engine.
collapsible steering column: Type of steering column that crumples or slides together when forced forward during a collision to help prevent driver chest and face injury.
collision avoidance system: System that measures the distance between the front of a vehicle and any object in its path and automatically controls the braking and engine speed control systems to prevent an accident.
combination meter: Hybrid vehicle in-dash instrument cluster that contains a speedometer, odometer, and other vehicle gauges as well as the hybrid power display and drive ready light.
combination square: A tool with a sliding square mounted on a steel rule commonly used when a rule must be held precisely parallel to the item being measured.
combination valve: A single unit that functions as a brake warning light switch, a metering valve, and/or a proportioning valve in a brake system. *Also,* valve that combines both the expansion valve and the suction throttling valve into one assembly for controlling evaporator temperature in a vehicle A/C system.
combustion: Chemical reaction that occurs when a fuel is burned with an oxidant (oxygen).
combustion chamber: Area at the top of the cylinder where a spark plug ignites the compressed air-fuel mixture.
combustion efficiency: Measure of how well combustion consumes all the fuel's heat energy for maximum cylinder pressure and minimum exhaust by-products.
combustion leak test: Test that checks for the presence of combustion gases in engine coolant.
combustion leak tester: See *block and head tester.*
comeback: A repair that returns to be done over because the problem was not initially fixed.
commission: Pay system in which the technician obtains a set percentage of the flat rate charged to the customers.
commission plus parts: A variation of the commission pay system in which a technician being paid on commission also receives a small commission for the parts installed during a repair.
commutator: Segmented, sliding electrical connection between the armature windings and the brushes.
compact disc (CD) player: Device that plays music by reading plastic compact discs holding digitally stored music files.
compact spare tire: Type of vehicle spare tire that is smaller than the normal tire used on the vehicle. It is also referred to as a space saver spare.
compensating port: Releases extra pressure when the piston returns to the released position. Brake fluid can flow back into the reservoir through the compensating port.
component: See *part.*
component location chart: Diagram that shows the location of various parts on a vehicle. This type of chart is valuable for engine compartment repairs.
compound: A substance composed of molecules containing two or more elements.
compound planetary gearset: Gearset that combines two planetary units in a single housing or ring gear. It can have a second sun gear and can provide more gear ratios than a single planetary unit.
compression distance: The distance from the centerline of a piston pin hole to the top of the piston.
compression gauge: Pressure gauge used to measure the internal pressure developed by an engine cylinder on the compression stroke.
compression ignition engine: Type of internal combustion engine that squeezes air in the combustion chamber until it is hot enough to ignite the fuel. A diesel engine is an example of this type of engine.
compression limiter: Metal insert that allows enough bolt torque for proper sealing without deformation around bolt holes in plastic parts.
compression pressure: Amount of pressure produced in an engine cylinder on the compression stroke. It is measured in pounds per square inch (psi) or kilopascals (kPa).
compression ratio: The relationship of cylinder volumes with the piston at TDC and at BDC.
compression ring: The top set of piston rings designed to seal between the piston and cylinder to prevent escape of gases from the combustion chamber.
compression stroke: The portion of the piston's movement devoted to compressing the fuel mixture in the cylinder.
compression test: Method of testing engine cylinder(s) by determining how much compression pressure is developed. It is commonly performed any time symptoms point to cylinder pressure leakage.
compressor assembly: A motor-powered air pump that produces pressure for an electronic suspension system.
compressor cycling switch: One of two (thermostatic and pressure) cycling switches used in an expansion tube A/C system for operating the compressor to maintain correct evaporator temperature.
compressor housing: Part of the turbo housing that surrounds the compressor wheel. Its shape helps pump air into the engine.
compressor wheel: Driven fan that forces air into the engine intake manifold under pressure.
computer: A complex set of electrical circuits that, in an automobile, produce programmed electrical control currents for

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actuators after receiving specific input signals from sensors.

computer-based service information: Service information stored or retrieved electronically using a personal computer. Data can be accessed quickly off a hard drive, computer network, CDs, DVDs, or via the Internet.

computer-controlled diesel system: System that uses a computer, sensors, and actuators to increase the efficiency of mechanical diesel injection.

computer control system: Subsystem of an electronic vehicle fuel injection system in which an ECM responds to sensor signals to control operation of a fuel injector and properly meter the precise amount of fuel into the engine.

computer network: Series of computers that each control specific systems, but communicate and work as one to improve overall vehicle efficiency.

computer signal: Electrical impulse or frequency used to carry electronic data.

computer system: Electric and electronic devices that control specific vehicle systems.

computer system block diagram: Simple service manual drawing that uses shapes (squares, rectangles) and lines to display the interaction of sensors, actuators, and a computer.

computer voltage regulator circuit: Circuit located in a power train control module that can precisely control the charging system by monitoring system output and reacting to changes in operating conditions.

computerized emission control system: System that uses various engine, exhaust, and fuel system sensors, a three-way catalytic converter, and dual-bank O_2 sensors to reduce pollution levels emitted from a vehicle.

concentricity: A measure of how closely two circular cross sections share a common axis. It is used to check the accuracy of valve seats after repair.

condensation: The changing of a gas (vapor) to a liquid.

conditioner: Device that changes signals for use by other chips and circuits in a computer. It can be used to transform an analog sensor signal into a digital signal that a computer would understand.

conduction: Heat transfer through objects that are touching each other.

conductor: Any material that allows the flow of free electrons. Metals (gold, silver, copper, aluminum, etc.) make good conductors.

cone clutch differential: Type of limited-slip differential that uses the friction produced by cone-shaped axle gears and centrifugal force to provide improved traction.

connecting rod: The connecting link between the crankshaft and the pistons.

connecting rod bearing: Inserts that fit into the connecting rods and rides on the crankshaft journals.

connecting rod bearing knock: A light, regular, rapping noise with the engine running at a constant speed above idle. It is caused by wear and excessive bearing-to-crankshaft clearance.

connecting rod number: Number marked or etched on each connecting rod to ensure its proper placement in an engine. They also ensure each rod cap is installed and orientated correctly on each rod body.

connecting rod side clearance: Distance between the side of a connecting rod and the cheek of the crankshaft journal or side of another rod.

connector: Plastic or rubber device with metal terminals or connection points for joining the ends of two or more wires. *Also,* see *battery strap(s).*

connector diagram: A diagram that shows the location of connectors and identifies each terminal in a connector. These diagrams are useful when trying to diagnose electrical problems.

console: Part of an alignment machine that typically consists of a color monitor, keypad, and computer, all mounted in a roll-around cabinet.

constant-ratio gearbox: Gearbox that uses the same gear reduction when steering from full left to full right.

constant velocity universal joint: Type of universal joint that normally has two cross-and-roller (Cardan) joints connected by a centering socket and center yoke. It is used in independent drive axle assemblies to allow the shafts to transfer torque through an angle smoothly. It is also called a double-Cardan joint.

contact cleaner: Chemical for cleaning deposits from contacts, switches, and other components.

continuity: A complete circuit path.

continuous fuel injection: Type of fuel injection in which injectors spray fuel whenever the engine is running.

continuously variable transmission/transaxle (CVT): Design of transmission/transaxle that uses a belt running between two variable-width pulleys to create an infinite number of driving ratios, rather than three, four, or five forward speeds.

control arm: Movable lever arm that forms part of a vehicle's suspension system. It fastens the steering knuckle to a vehicle's frame or body.

control arm bushing: Sleeve that connects the control arm to the frame and allows the control arm up-and-down movement on a shaft. The bushings are made of rubber that is tightly attached to inner and outer metal shells by a chemical and heat process.

control rack: Toothed rod inside a mechanical diesel injector pump that rotates the pump plunger to control the quantity of injected fuel. It is also called a control rod.

control sleeve: Collar through which a diesel injection pump plunger moves. It alters the amount of fuel pushed to each injector by controlling the length of the plunger's effective stroke.

control switch: Part of a cruise control system that signals the computer to maintain present vehicle speed.

control valve: Valve that controls the application of hydraulic pressure within a power piston in a power steering system.

controller area network (CAN): A high-speed computer data bus that can be used by several computers and sensors at the same time to communicate with each other.

convection: Heat transfer caused by the air surrounding objects.

conventional current theory: The theory that states that electrons flow through a circuit from positive (+) to negative (–). Electrons leave the positive terminal of the battery, flow through the circuit, and then re-enter the battery through the negative terminal.

conventional flow cooling: Type of engine cooling in which hot coolant flows from the cylinder head to the radiator.

conversion chart: A chart used to change a measurement value from one measuring system to another.

converter circuit: Portion of a hybrid power control module that can step dc voltage up or down.

converter pump: See *impeller.*

coolant heat storage system: System of components in a hybrid vehicle that house hot coolant after the engine is shut off or when the vehicle is in full electric propulsion. When the engine is started or demanded on, the stored, hot coolant is injected back into the engine to keep combustion efficiency high.

coolant strength: A measure of the concentration of antifreeze compared to the concentration of water. This ratio determines the freeze-up protection of the coolant.

coolant temperature sensor (CTS): A sensor that monitors engine coolant temperature. It is used by the engine control ECM to determine how much fuel is needed and when to enter closed loop operation.

coolant test strip: Product used to check coolant strength and pH level.

coolant voltage test: Test using a digital multimeter to measure voltage generated by antifreeze. This indicates the general age and condition of the antifreeze solution.

cooling fin: A series of thin metal strips placed between cooling passages to help dissipate heat.

cooling system: Radiator and other components that allow a coolant to circulate and maintain a constant engine operating temperature. Cooling systems are also necessary to control operating temperatures of an HV battery, motor-generator, or HV ECM circuit in hybrid/electric vehicles.

cooling system bleed screw: Screw provided to allow for removal of trapped air when refilling the cooling system.

cooling system diagnosis chart: Vehicle service manual chart showing which tests and repairs are needed for different cooling system problems, and their proper sequence.

cooling system fan: Fan that pulls air through the core of a radiator and over an engine to help remove heat. It increases the volume of air flowing through the radiator, especially at low vehicle speeds.

cooling system hydrometer: Tool used to measure the freezing point of the cooling system antifreeze solution. A coolant sample is pulled up into the clear scaled measuring reservoir and graded based on freezing point.

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cooling system pressure test: Test that uses low air pressure forced into a sealed vehicle liquid-cooling system to locate leaks.
cooperativeness: The ability to work together with others to achieve a common goal.
cooperative training program: Program that allows a student to earn school credit and a wage by working in a commercial repair shop.
core plug: See *freeze plug.*
cotter pin: A metal pin that fits through a hole in a bolt, nut, or part to secure it.
counter gear: See *countershaft gear.*
countershaft: Shaft on which cluster gears are mounted. They transmit force from input gears to output gears. It is also termed a cluster gear shaft.
countershaft gear: A series of helical gears machined out of a single piece of steel. The largest gear on the countershaft gear is always the countershaft driven gear, which is the forward most gear. In addition to the driven gear, there is usually one gear on the gear cluster for each available reduction and overdrive ratio, plus a gear for reverse. It is also called a counter gear.
cracked cylinder head: Break in an engine cylinder head that results from engine overheating or physical damage from other broken parts. Usually, the crack happens at an exhaust seat or between chambers, allowing coolant or pressure leakage.
cradle: Segmented frame on a front-wheel-drive vehicle that supports the engine and front suspension.
crane boom: Extended neck of many engine hoists to which the lifting fixture is attached.
crankcase dilution: Excessive blowby or fuel in the vehicle engine oil.
cranking balance test: Test to find problematic engine cylinders that show a low compression pressure.
crankpin: Term for a machined and polished surface to which a piston connecting rod bolts. It is offset from and spins around the main crankshaft journal.
crankshaft: The main shaft that supports the connecting rods and turns piston reciprocation into motion.
crankshaft balancing: See *engine balancing.*
crankshaft-driven oil pump: An oil pump directly engaged to and powered by the crankshaft. The inner pumping element fits over and is keyed or locked to the crankshaft snout.
crankshaft end play: The forward and rearward movement of the crankshaft in its bore.
crankshaft front seal: Seal that keeps engine oil from leaking out between the crankshaft snout and the engine front cover.
crankshaft oil seal: Seal that prevents oil from leaking out of the front and rear of an engine.
crankshaft position sensor: Electronic sensor used to detect engine speed by monitoring the rotation of the crankshaft.
crankshaft pulley: Pulley that may be part of a harmonic balancer or bolted to the front of it. It operates belts for the alternator, water pump, air conditioning compressor, and other units.
crankshaft service: Service that includes cleaning the crankshaft, measuring journal wear, checking the crankshaft for straightness and cracks, and installing the crankshaft.
crankshaft sprocket: Sprocket keyed to a crankshaft snout. It transfers power through a timing chain to the camshaft sprocket.
crankshaft turning: Machining term for grinding the rod and main journals of a crankshaft smaller in diameter to fix journal wear or damage.
crankshaft vibration damper: Flywheel device attached to the front of a crankshaft that, due to its design, lessens the torque vibrations imparted on a crankshaft.
crash test: Test simulation where vehicles are crashed into stationary walls or other vehicles to measure how the vehicles and their occupants withstand and react to the impact forces.
crash test dummy: Inanimate human figure equipped with sensors used to measure the impact forces acting upon the human body during crash tests.
creeper: A padded board with wheels underneath that allows a technician to easily roll under and work on vehicles supported by jack stands.
crimp connector: A wire-splicing device that provides a quick way of joining wires or installing a terminal on a wire by crushing a metal lug around the wire conductor.
crimping pliers: Tool used to crush the metal part of a crimp connector around the wire connector.
crisscross pattern: A pattern of lines crossing one another back and forth. This pattern is used when tightening fasteners to give an even, gradual clamping force all along the part.
cross-and-roller joint: Type of universal joint that has bearing-capped yokes at right angles to each other, forming a cross shape when each shaft end is connected. It is also referred to as a Cardan universal joint.
crossbolted block: Design with cap screws inserted through the sides of a block and main bearing caps, in addition to the standard cap screws, for added strength.
crossflow radiator: Radiator design with cooling tubes running horizontally through the core and tanks on either side.
crossover pipe: Exhaust pipe that connects right and left header pipes together to equalize back pressure for a slight increase in engine power with natural aspiration.
crude oil: Oil mined directly out of the ground. It is used to make gasoline and diesel fuel, as well as many other products. It is also referred to as petroleum.
cruise control module: Part of a cruise control system that uses input signals to control outputs to throttle actuator.
cruise control system: System that uses a computer, sensors, and a throttle actuator to maintain vehicle speed for highway driving.
crush zone: Area on a vehicle located at the front and rear of the body-frame assembly that is designed to collapse during a severe impact.
cubic centimeter (cc): A metric unit commonly used to refer to engine displacement. One liter is equal to 1000 cubic centimeters.
cubic inch displacement (CID): A unit commonly used to refer to engine displacement. One cubic inch is roughly equal to 16.387 cubic centimeters.
cup: Rubber cup within the cylinder machined into a master cylinder assembly. It, along with the return spring and piston, builds pressure for a brake system.
cup expander: The ends of a wheel cylinder spring have metal expanders that help press the outer edges of the cups against the wall of the wheel cylinder when not pressurized.
curb height: Distance measured up from the level parking surface to a specific point on the unoccupied vehicle.
curb weight: The weight of an unoccupied vehicle with fuel, oil, and coolant filled, and all standard equipment installed.
curiosity: The eagerness and desire to attain knowledge and experience.
current: The rate of electron flow in a circuit.
current-limiting dwell: Dwell timing in which the engine control module sends a large amount of current through the ignition coil windings until a strong magnetic field develops around the windings.
cushioning spring: See *facing spring.*
customary measuring system: A system of measurement mainly used in the United States; originated from sizes taken from parts of the human body. For example, the width of a human thumb was used to standardize the inch.
customary rule: A straightedge scale that has numbered lines that represent full inches. Fractions of an inch (1/2″, 1/4″, 1/8″, and 1/16″) are shown with smaller, unnumbered lines.
cut point: See *emission standard base line.*
CV-joint boot: Flexible synthetic rubber balloon seal that keeps road dirt out of, and grease on, the bearings in a constant velocity joint.
CV-joint kit: Constant velocity joint replacement kit that contains a boot fitting and straps, new joint parts, and lubricating grease.
cybernetics: Study of how electrical and mechanical mechanisms can mimic the actions of the human body.
cycle: Term for the continuing formation of one complete positive curve and one negative curve illustrated by the voltage change in ac current.
cylinder: A hole or holes that have a set depth and contain pistons.
cylinder arrangement: The position of cylinders in the engine block in relation to the crankshaft.
cylinder balance test: See *engine power balance test.*
cylinder bore: Diameter of an engine cylinder, measured across the cylinder, parallel with the top of the block.

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cylinder head: Metal section bolted on top of the engine block and forms part of the combustion chamber.
cylinder head milling: A machine shop operation where a thin layer of metal is cut or machined off the head gasket surface of a cylinder head.
cylinder honing: Machining process that provides a lightly roughened or textured surface on the smooth walls of a used cylinder. The process is also needed after cylinder boring to smooth rough cylinder walls. It is also called deglazing.
cylinder leakage test: Test that measures air leakage out of the engine combustion chamber to find mechanical problems.
cylinder number: Number that identifies the cylinders, pistons, and connecting rods of the engine. Normally, these numbers are stamped on the connecting rod or cast into the intake manifold.
cylinder out-of-round: Difference in cylinder diameter when measured front-to-rear and side-to-side in the block.
cylinder select: See *expanded display.*
cylinder sleeve: Metal, pipe-shaped insert that fits into a cylinder block to allow piston operation without cylinder block wear.
cylinder sleeving: Machining or boring an engine cylinder oversize and pressing in a cylinder liner.
cylinder taper: Difference in the diameter from the top to the bottom of a cylinder measured on the piston ring contact surface of the cylinder.

D

damper unit: A simple shock assembly that fits inside the coil spring on a strut assembly to prevent excessive jounce and rebound.
damping spring: See *torsion spring.*
data bus: Pathway for data inside a computer. It can also be used to refer to a circuit used to connect two on-board computers.
data link connector (DLC): Plug-in connector used to link the scan tool to a vehicle computer. It allows the scan tool to access vehicle computer data. It is also called a diagnostic connector or assembly line diagnostic link (ALDL).
datastream value: Voltage, degree, and other values that come to the ECM from sensors and actuators in the form of analog and digital signals.
daylight running lights: Type of headlight that turns on automatically whenever the ignition key is in the Run position.
dead axle: An axle that does not rotate, but merely forms a base onto which the hubs and wheels are attached.
dead battery: A fully discharged battery. This can be a common problem of 12-volt starting systems.
dead blow hammer: Type of hammer that has a plastic-coated, metal face filled with small metal balls called lead shot. The lead shot prevents a rebound when striking, and the coating prevents surface damage.
dead cylinder: Engine cylinder in which combustion is not occurring during the power stroke.
dead O_2 sensor: Term for an oxygen sensor that has little or no resistance or voltage output change when exhaust content changes.
dealership: A place of business that sells and services vehicles for a specific vehicle manufacturer.
decarbonizing cleaner: A very powerful chemical that can remove carbon, paint, gum, and most other deposits from parts.
decibel impact sensor: Air bag sensor that measures the amount of sound produced by a major collision.
decimal conversion chart: A chart used to quickly find equivalent values for fractions, decimals, and millimeters.
deck: A flat surface machined on the top of the block surrounding the cylinder heads.
decking: Process of surface milling cylinder head mounting surfaces until they are parallel and equidistant from the main bore. It is also referred to as squaring a block.
deck plate: Rigid metal cap bolted onto an engine block deck surface when power honing or boring to replicate the stress of an installed cylinder head. This prevents cylinder out-of-round or tapering when a cylinder head is torqued down.
deck warpage: Engine deck that is no longer flat or squared correctly. It often results from engine overheating, especially with thin-wall or aluminum blocks. A straightedge and feeler gauge on the head gasket sealing surface(s) of the block can measure the problem.
deep cycling: Allowing a battery to use 50–80% of its energy before charging.
DEFI amplifier: Device that boosts the voltage and current signal sent from an ECM to operate high-pressure direct fuel injectors.
DEFI fuel pressure regulator: Regulator controlled by the ECM that uses an electric solenoid to bypass excess fuel pressure back to the low pressure side of the system.
DEFI injector operating voltage: Usually higher than battery voltage, from 50–100 volts dc.
deglazing: See *cylinder honing.*
delivery valve: Spring-loaded valve in the outlet fittings to a diesel injection line that closes the injector nozzle quickly.
dependability: In relation to work performance, it is being a reliable employee, such as by reporting to work on time, not leaving early, or not taking too many days off.
desoldering bulb: Tool used to remove solder from an existing soldered joint. Once the solder is melted, the bulb is squeezed, placed near the molten solder, and released to suck the solder away from the joint.
deteriorated motor oil: Worn-out engine oil that contains hard, abrasive particles of carbon, steel, iron, ash, and other materials trapped inside the oil filter.
detonation: Severe combustion problem that results when unburned air-fuel mixture explodes violently in the cylinder.
Detroit locker: See *ratchet differential.*
diagnostic chart: Flowchart with diagrams and tables used in troubleshooting common vehicle system problems. Most diagnostic charts begin with a specific trouble code.
diagnostic connector: See *data link connector (DLC).*
diagnostic laptop computer: A laptop computer with automotive diagnostic software that combines the abilities of an advanced scan tool with dozens of test instruments to monitor, test, and record vehicle parameters, and to help technicians diagnose and repair vehicle problems based on online service information.
diagnostic tablet: A handheld, touch-screen computer that can retrieve and identify trouble codes, monitor vehicle performance, and perform tests remotely via an online network and a wireless sending unit that the technician plugs into the vehicle's DLC.
diagnostic trouble code (DTC): Digital signal produced and stored by a computer when an operating parameter is exceeded. It can be used to determine where a malfunction is located in a computer-controlled system.
diagonally split: Type of corner to corner brake system that has each master cylinder piston operating the brake assemblies on opposite corners of the vehicle.
dial indicator: Tool used to measure part movement or end play in thousandths of an inch or hundredths of a millimeter. Plunger movement of the tool is shown by a needle or digital display.
diaphragm spring: Steel spring disc positioned in the middle of a diaphragm pressure plate. Its segmented design aids in manual clutch operation.
diaphragm spring pressure plate: Type of pressure plate with a circular diaphragm spring cut into wedges mounted in the center of the plate. As pressure is applied to the center of the spring, the outer edges of the spring wedges push the plate to separate it from the clutch disc.
die: Tool for cutting threads on the outside of a rod or shaft.
dielectric grease: A special grease that blocks moisture and helps prevent corrosion without affecting electrical conduction.
diesel engine boost pressure: Allows a maximum turbocharger inlet air pressure of up to 20 psi (1.4 Bar).
diesel engine compression reading: Compression reading averages 275–400 psi (1900–2750 kPa), depending on the engine design and compression ratio.
diesel exhaust fluid (DEF): A mixture of urea and de-ionized water that is stored in a separate tank near the fuel tank of a diesel vehicle equipped with a selective catalytic reduction system.
diesel fuel: A thicker fraction of crude oil that contains more heat energy and can produce more cylinder pressure and vehicle movement than an equal amount of gasoline.
diesel fuel grades: Standards created to separate diesel fuels into three groups.

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diesel fuel injection: High-pressure, mechanical/hydraulic system that delivers fuel directly into a diesel engine's combustion chambers.
diesel fuel supply system: System that feeds fuel to an injection pump, normally using an engine-driven inline electric pump, which passes the gas to the fuel lines and nozzles.
diesel injection computer: Monitors injector sensor inputs and calculates the outputs for the actuators to more precisely control the mechanical, high-pressure plungers inside a diesel injection pump.
diesel injection sensor: Sensor that monitors and feeds a signal to the computer for engine temperature, speed, and other variables that affect fuel needs.
diesel injection timing: Controlled by ECM gathered sensor information, it refers to diesel fuel being injected into the combustion chambers in relation to the engine's piston position.
diesel injector heat shield: Outside layer surrounding a diesel injector that protects it from engine heat.
diesel injector needle valve: Precisely machined rod with a specially shaped tip that opens and closes the nozzle (fuel opening).
diesel knock: A rumble or a dull clattering sound from very high cylinder gas pressures produced as the detonation of diesel oil expands and pushes the engine pistons down.
diesel mechanical injection (DMI): Fuel injection system that uses a mechanical, high-pressure, multi-plunger/cam lobe fuel pump with electronic controls.
diesel particulates converter: Device that stores and then burns the ash and soot trying to leave a diesel exhaust system.
diesel prechamber: See *precombustion chamber.*
dieseling: Condition in which the engine continues to run after the ignition key is turned off. A knocking or coughing noise is heard as the fuel ignites and the crankshaft spins uncontrollably. It is also referred to as after-running or run-on.
differential: An assembly of gears used to provide power to the drive axles and allow them to rotate at different speeds as necessary.
differential assembly: Gear system that redirects the power flow and allows the drive wheels to revolve at different speeds when necessary.
differential breather tube: Safety tube that inserts into a hole in a rear axle housing to vent pressure or vacuum in or out of the housing as temperature changes occur.
differential carrier: Enclosure used to mount the differential assembly on the rear axle housing.
differential case: A cast aluminum enclosure within the differential carrier that holds the bearings, ring gear, and spider gears that power the drive axles. It is also called a differential housing.
differential clutch piston: A piston used to apply clamping force to the clutch friction discs and steel plates in a clutch pack.
differential friction disc: Discs covered with a synthetic fiber or ceramic coating to increase surface friction between steel clutch discs in a clutch set.
differential gear: See *spider gear.*
differential housing: See *differential case.*
differential ID number: Identification number located on a differential that provides information on the exact type of differential for ordering parts and looking up specifications.
differential lubricant: Oil (often SAE 80W-90 gear oil) dispersed to all parts of a differential by the movement of the ring gear. It is needed to reduce friction between the moving parts in the rear axle assembly.
differential ratio: See *rear axle ratio.*
differential solenoid valve: Valve that operates the hydraulic spool valve to adjust the amount of clamping force applied to each axle clutch set.
differential voltage signal: Voltage signal used with twisted-pair conductors that consists of two complementary digital signals with opposing polarities.
digital-analog meter: Digital multimeter that has both an alphanumeric display and a bar graph to show fluctuating electrical values.
digital audio player: A compact music player that stores large amounts of digital data on an internal memory chip.
digital electronics: A specialized field of electronics that encompasses the ways in which a computer uses logic gates and the binary numbering system to make complex decisions (outputs) based on specific facts (inputs).
digital instrument: Instrumentation that uses various lights and electronic displays to show operating conditions. An electronic control module is needed to act as an interface between the sensor and the digital readout panel.
digital multimeter: Multimeter that uses a vacuum fluorescent or liquid crystal display to give a digital readout, best suited for measuring constant values.
digital pyrometer: An electronic tool used to take very accurate temperature measurements.
digital radio: Radio that uses analog signals that are compressed and digitized (converted to on-off signals) so more programming can be broadcast in a given spectrum. The signal is similar to the signal produced by a digital compact disc.
digital scope pattern: Oscilloscope readout that has very short, repeating changes in voltage (from no voltage to a few volts dc positive).
digital signal: An electronic signal that uses on and off (or high-low) pulses.
digital thermometer: An electronic device for measuring temperature.
digital video disc (DVD) player: Electronic device that has a display screen and the ability to play high-capacity discs containing video.
dimmer switch: Foot- or hand-operated switch that operates the high and low beam headlights.
diode: A semiconductor device that allows current flow in one direction, but resists it in the other.
diode assembly: See *alternator rectifier.*
diode frame: Case into which the rectifier diodes are mounted.
diode trio: Three diodes connected to the rotor field windings through a connection in the voltage regulator. The three diodes supply current to the field windings.
direct current (dc): Electric current that flows steadily in one direction only.
direct electronic fuel injection (DEFI): Fuel injection system that, in addition to an electric fuel pump, uses a mechanical fuel pump and high-pressure injectors to spray fuel straight into an engine's combustion chambers.
direct gasoline injection systems: See *direct electronic fuel injection (DEFI).*
direct ignition coil: Coil that is bolted directly over the top of each engine spark plug. Coils fire only on the power strokes for maximum voltage and combustion efficiency.
direct ignition system: A computer-controlled ignition system that has ignition coils mounted on top of the spark plugs. This type of system has an individual high-voltage, step-up coil for each spark plug, so there is no need for spark plug wires.
direct injection system: Type of fuel injection system that sprays high-pressure fuel straight into an engine's combustion chambers.
directional tire: High-performance tire designed to rotate in a specific direction to minimize hydroplaning.
disc brake assembly: Consists of a caliper, brake pads, a disc, and related hardware (bolts, clips, springs, etc.).
disc brake pad: Steel plate to which linings are riveted or bonded. Each caliper has an inner and outer brake pad that fits inside the hydraulic brake caliper.
disc brake service: Process that includes replacing worn brake pads, rebuilding the caliper assembly, turning (machining) the brake discs, and bleeding the system.
disc lining: See *friction material.*
discharge: Process of drawing electric current from a battery.
discharge service valve: An A/C service valve that is located at the output from the compressor, in the system high side.
discharge side: See *high side.*
discharging: Current and electrons flowing out of the battery cells, or the release of stored energy. This is a conversion of chemical energy into electrical energy by the battery.
display device: Electronic screen that shows output information in a dash instrument cluster(s) of an automobile. It includes vacuum-fluorescent, liquid-crystal, and plasma displays.
display pattern: See *parade pattern.*
distillation: First conversion process in the refining of crude oil. During this process, a fractionating tower breaks crude oil down into different parts, or fractions.

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distilled water: Water that has been boiled and the vapors collected in a clean container to remove contaminants. This type of water should be added to the liquid electrolyte of lead-acid batteries to prevent impurity buildup within the battery.
distortion: Results when speaker output is not a good reproduction of the original input.
diverter valve: Valve that prevents air from entering the exhaust system during deceleration.
division: Arithmetic process used to determine how many times one number is contained in another number.
dog clutch: Type of clutch that uses fitted driving gear teeth that engage or disengage matching recesses in the driven gear. When engaged, it creates a coupling that rotates at the same speed with no slippage.
dog tracking: Term for when the rear tires do not follow the tracks of the front tires.
DOT serial number: Department of Transportation serial number stamped on a tire sidewall to identify the particular tire manufacturer, plant location, construction, and date of manufacture.
double-Cardan joint: See *constant velocity universal joint.*
dowel: A small protrusion on a bearing bore or cap that fits in a hole in a split-type bearing, positioning the bearing correctly in the bore.
downflow radiator: Radiator design with cooling tubes running vertically through the core and tanks on the top and bottom.
dragging brake: A condition where brakes remain partially applied after the brake pedal is released.
dragging clutch: Problem that occurs when a clutch disc stays engaged to the flywheel—as the clutch pedal is depressed—and drags against it. It can be caused by excessive clutch pedal free travel or a damaged/worn clutch disc.
drain line: Tube connected to the drain passage of a turbocharger that returns oil to an oil pan after passing through the turbo bearings.
drain passage: Machined passage in a turbocharger that funnels oil into the drain line after passing through the turbo bearings.
drill: Tool with a cutting tool attachment or drill bit attachment used to create holes in metal and plastic parts. Drills can be handheld or mounted and use a variety of power sources.
drill bit: Tool piece, available in many different styles and sizes, that fastens into a drill chuck to cut holes in metal and plastic parts.
drilled connecting rod: Type of connecting rod with a machined hole throughout its entire length for supplying oil to the piston pin.
drill press: A large, floor- or bench-mounted drill for drilling large holes, deep holes, or a great number of holes in several parts. A handle controls the drill bit pressure applied to a part.
driveability problem: Term for any vehicle problem that affects the performance of the drivetrain.
drive belt inspection: Process of looking for splits, tears, cuts, and wear on a vehicle drive belt.
drive chain: A chain used to transfer power from an engine crankshaft to the transaxle gearbox, or transmission. It is also called a drive link.
drive link: See *drive chain.*
drive shaft: A steel tube that transfers rotating motion from the transmission to the rear axle assembly of a vehicle. It is also called a propeller shaft.
drive shaft assembly: An assembly consisting of a drive shaft, front and rear universal joints, rear yoke, and front slip yoke. It provides a smooth delivery of power to the rear axle assembly, while allowing the rear axle to move up and down to compensate for road conditions.
drive shaft balancing weight: Small metal weight frequently welded to a drive shaft to smooth operation and reduce vibration.
drive shaft noise: Squeaking, whining, or clunking sound emitted from a drive shaft usually caused by dry, worn universal joints, a worn slip joint and support bushing, or a dry, worn center support bearing.
drive shaft runout: Variation from perfect drive shaft rotation. If runout is too large, the drive shaft will vibrate.
drive shaft vibration: Rapid small or large movement along a drive shaft that can be caused by any problem that affects drive shaft balance, runout, and angle.
drive shaft vibration damper: A large, ring-shaped weight mounted on rubber that helps keep the shaft spinning smoothly by absorbing twisting vibration.
drive trace: A graph showing emission levels over the time of the test.
drive trace report: Printout of the five drive traces (HC, CO, NO_X, CO_2, and purge) normally monitored during an emission test. If there is a problem, a technician can analyze this report to find and repair problem(s) causing the increased air pollution.
drive train: All of the collective parts (engine, transmission, drive shaft, differential, drive axles, etc.) that generate power and transmit it to the wheels.
drive-by-wire system: See *throttle-by-wire system.*
driveline: Term for the components and parts that transfer engine power from a vehicle transmission to its drive wheels.
driveline angle: The angle of a drive shaft installed between a transmission and rear axle assembly. If the angle is too sharp, the universal joints can cause speed fluctuations and vibration.
driven disc: Steel disc with tabs along the outer edge to match to the clutch drum. Discs are placed between driving discs in the clutch assembly and press against them to allow power flow through the transmission.
driver information center (DIC): Small, dash-mounted keyboard display inside the passenger compartment. It gives the driver information on vehicle and outside conditions based on data provided from vehicle sensors.
driver's-side air bag: Air bag located inside the steering wheel that protects the driver from head and chest injury during a high-speed frontal collision.
driving disc: Friction material-coated metal disc with a notched inside edge to match splines on a clutch hub. When the clutch is engaged, it presses against the driven discs to spin them and the clutch drum at the same speed.
driving hub: Metal mounting surface for the wheel. It keeps power moving from the stub axle to the wheel.
driving range: Distance a vehicle can be driven without stopping for fuel or, in the case of hybrid/electric vehicles, to be charged.
driving shell: Metal cylinder that surrounds the secondary clutch assembly and forward planetary gearset. Tabs on the shell connect these componets to the front clutch assembly to transfer power. It is also called the clutch shell.
drop-center wheel: Wheel design in which the center section is smaller in diameter (dropped) from the rim. A tire bead can fall into this recess for easier installation and removal of the tire.
droplight: A portable source of light that can be taken to a repair area under a vehicle or anywhere else in a vehicle.
dropped valve guide: A valve guide that has fallen around the head of a valve after breaking free from its press-fitting.
dropping brake pedal: A condition where the brake pedal slowly moves all the way to the floor when steady pressure is applied to it.
dropping resistor signal: Used to provide input signals to the body or instrumentation electronic control module as varying dc voltage and current signals.
drum brake assembly: A brake assembly consisting of a backing plate, a wheel cylinder, brake shoes and linings, retracting springs, hold-down springs, a brake drum, and an automatic adjusting mechanism.
drum brake service: Removing parts from the backing plate, cleaning and inspecting the parts, replacing the brake shoes, replacing or rebuilding the wheel cylinders, turning (resurfacing) the brake drums, lubricating and reassembling the brake parts, and preadjusting, bleeding, and testing the brakes.
drum brake shoe assembly: Metal shoe with an applied heat-resistant friction material that rubs against a revolving brake drum to produce braking action.
dry-charged battery: A battery that is charged, but lacks electrolyte. It is filled with electrolyte when it is placed into service.
dry park test: Simple test to check the operation of steering system components. While on a level surface or lift, one technician slightly turns the steering wheel right and left as a second technician systematically examines and feels the steering parts for looseness and wear.
dry sleeve: A thin cylinder sleeve that is not exposed to engine coolant.
dry stick (wax) lubricant: Vehicle lubricant used on door latches and strikers.

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dry sump: Engine lubrication system that uses two oil pumps and a separate oil reservoir for superior engine oiling.
dual-bed catalytic converter: A catalytic converter that has two separate catalyst units (a reduction and an oxidation converter) enclosed in a single housing.
dual-clutch transmission: Type of transmission that uses an inner and outer input shaft.
dual exhaust system: An exhaust system that uses separate pipes, mufflers, and catalytic converters for each bank of cylinders.
dual-mass harmonic balancer: Harmonic balancer with one weight mounted on the outside and inside of a crankshaft pulley for high engine speed vibration reduction.
dual master cylinder: Type of master cylinder that has two separate hydraulic pistons and two fluid reservoirs. It is also called a tandem master cylinder.
dual overhead cam (DOHC) engine: An engine equipped with two camshafts in the top of each cylinder head. One cam operates the intake valves; the other operates the exhaust valves.
dual spark plug ignition system: Ignition system that uses two spark plugs in each cylinder. One plug is located near the intake valve; the other is near the exhaust valve.
dual voltage system: Type of electrical system that uses both a 12-volt battery and high-voltage battery, each wired separately. The conventional 12-volt system powers most of the electrical/electronic circuits while the HV battery powers the double-ought (00) conductors and the HV motor-generator of modern electric drive trains.
duct: Plastic tube of various shapes that carries air over the evaporator and the heater core, as well as to the vents.
dummy shaft: A temporary shaft, such as a wooden dowel or a metal rod, used with a hammer to drive a shaft from its housing.
dump mode: A mode of ABS operation whereby the ABS releases hydraulic pressure to one or more of the brake wheel cylinders or calipers.
dump valve: See *turbo blow off valve.*
dust cap: Metal cap installed on the end of an axle or spindle to keep dirt out and grease in.
dust shield: Metal shroud or rubber boot that surrounds a shock absorber rod to keep out road dirt and debris.
duty cycle: The percentage of "on" time for a device that is pulsed on and off.
dwell meter: Tool that measures current flow as compared to degrees of engine crankshaft rotation. It is needed for use on vehicles that have a contact-point or early electronic ignition system.
dwell section: The part of an ignition scope pattern illustrating the buildup of the coil magnetic field as current flows through the primary circuit.
dye penetrant: A testing material that can be sprayed or painted onto iron and aluminum parts to locate cracks.
dynamic engine compression test: A test that measures cylinder pressures with a test gauge while an engine is idling. Exhaust system and intake air issues can be found using the test. It is also termed a running engine compression test.
dynamic imbalance: Unbalanced condition in which the centerline of a revolving object is not in the same plane as the object itself.
dynamometer: Test instrument used to measure power output and performance of an engine. It is also known as a dyno.
dyno: See *dynamometer.*

E

eccentric: An egg-shaped lobe that converts the rotary motion of one part of a mechanism to linear motion in another.
ECM-controlled starting circuit: Automatically energizes and de-energizes the 12-volt starting motor as soon as engine sensors detect fuel combustion and the resulting rapid increase in crankshaft rpms (speed sensor signal).
efficiency: The ability to produce high-quality work at a fast pace.
EFI fuel pressure regulator: Regulator that uses engine vacuum, not the ECM, to control lower fuel pressure in multiport fuel injection systems.
EFI injector operating voltage: Usually 12.5–15 volts dc for nondirect or port injection systems.
EFI tester: A tool used to locate trouble codes and electronically perform diagnostic tests on the electronic fuel injection system of a vehicle.
EGR duty cycle: A measurement of control current on and off time sent from the ECM to meter just the right amount of exhaust gases needed to reduce NO_x emissions.
EGR solenoid valve: A valve that uses an electronic solenoid to block or pass airflow to an EGR valve.
electric air injection pump: Low-pressure pump used to force air into an exhaust manifold. It is driven by a small dc motor, instead of being engine/belt driven.
electric brake caliper: Caliper that uses one or more servo motors to force the brake pads into the rotating brake disc to slow and stop the vehicle.
electric circuit: Consists of the basic components (power supply, load, and conductor) needed to utilize electrical energy.
electric cooling fan: Type of cooling fan that uses an electric motor, coolant temperature sensor, and engine ECM to provide airflow and heat transfer out of a radiator.
electric fuel pump: Fuel pump located either inside the fuel tank or in series with a fuel line; can create almost instant pressure and provides a smooth flow of fuel.
electric fuel shutoff: Solenoid that stops fuel injection when the ignition key is turned off.
electric motor: An electric device that uses the principles of magnetism to produce powerful rotating action.
electric oil pump: Electric pump that provides hydraulic pressure for clutch application to lock each drive flange to the ring gear.
electric parking brake: Parking brake system that uses a dash-mounted switch and an electric servo motor to mechanically apply the rear brake.
electric PCV valve: ECM-controlled valve that regulates engine crankcase ventilation.
electric power: The work done by an electric current; measured in watts.
electric shift solenoid: Electronically controlled solenoid in an automatic transmission that operates a spool valve located in the valve body.
electric shock: The result of current passing through the tissue of the human body, which can cause injury or death.
electric tool: A tool powered by electricity.
electric water pump: Large dc motor and impeller that forces coolant through the engine's water jackets or through an HV cooling system. It is used in place of a belt-driven water pump.
electrical device: A component that uses more than one or two volts of electricity to do work. Examples include an electric motor, relay, solenoid, or lightbulb.
electrical diagnosis: Troubleshooting process that uses a logical sequence of steps to find the source of an electrical problem. A systematic approach, beginning with verifying the problem, narrowing down the causes, performing the proper tests, and then making and verifying the repair, works better than a trial-and-error approach.
electrical ground: Shows where circuits connect or fasten to the metal frame or chassis of a vehicle.
electrical solvent: Solvent used to clean oil and grease from components before soldering. It can also be used to remove soldering flux from a component.
electrically erasable programmable read only memory (EEPROM): A type of memory module in which the programming can be changed by scan tools and other electronic equipment that burns-in the new programming.
electricity: The movement of free electrons from one atom to another.
electro-hydraulic differential: Type of electronic-controlled differential that uses electromagnets to operate hydraulic spool valves.
electrolysis: Chemical conversion process that sends an electric current through water to separate hydrogen atoms and oxygen atoms into separate gases.
electrolyte: Mixture of 35% sulfuric acid and 65% distilled water housed in each cell of a lead-acid battery. This solution creates a chemical reaction that releases electrons. It is commonly referred to as battery acid.
electromagnet: A magnet that is produced by placing a coil of wire around a steel or iron bar. When current flows through the wire, the bar becomes magnetized.
electromagnetic clutch: An electronically controlled clutch on a supercharger pulley used to engage and disengage the drive belt.

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electromagnetic interference (EMI): Electronic noise that is created when two or more wires carrying a strong voltage or signal are allowed to cross. It can also be created by radio waves.
electromagnetism: A branch of physical science that deals with the interaction of electricity and magnetism. Electricity can be used to produce magnetism, and magnetic fields can be used to produce electricity.
electromotive force (EMF): See *voltage*.
electron: A negatively charged particle that circles in a specific orbit around the nucleus of an atom.
electron flow theory: Theory that states that electricity flows from negative (–) to positive (+). Electrons leave the negative terminal of the battery, flow through the circuit, and then re-enter the positive terminal.
electronic coil module: A component in a distributorless ignition system that consists of multiple ignition coils and a coil control unit that operates the coils.
electronic component: A modern solid-state component that uses a semiconductor instead of moving parts while operating on one volt or less of electricity. Examples include diodes, transistors, sensors, and automotive computers. It is also called a solid-state component.
electronic control module (ECM): General term used for any computer that controls a vehicle system. The abbreviation ECM is also used for engine control module.
electronic device: See *electronic component*.
electronic EGR system: Emission control system that uses vehicle sensors, the ECM, and a solenoid-operated exhaust gas recirculation valve to reduce NO_x emissions.
electronic EGR valve: Valve that uses one or more electric solenoids to open and close its exhaust passages. It works without engine vacuum.
electronic four-wheel steering system: Type of four-wheel steering system that has an electric-motor-driven power rack that acts upon the rear wheels via its own recirculating-ball drive and mechanical links.
electronic height control system: A system that uses a height sensor and control module to control the operation of a small electric air compressor, which maintains the correct vehicle ride height.
electronic spark advance systems: Systems that use engine sensors and a computer, or ECM, to adjust ignition timing.
electronic speedometer: Speedometer that uses integrated circuit chips in the dash or a circuit in the ECM to react to electrical signals from the vehicle speed sensor.
electronic steering assist: A small electric motor mounted inside a rack housing that acts upon the rack to aid the driver in steering.
electronic suspension system: Suspension system that uses electronic components to control the operation of the shock absorbers or strut cartridges. Systems vary according to the type and number of input sensors they use, whether or not they are equipped with an air compressor, and the number of wheels they control.
electronic transmission control: System of electronic sensors, actuators, and a transmission module that monitor and precisely control the operation of an automatic transmission.
element: Filter material, usually made of paper, that fits inside the metal or plastic housing of an air filter. *Also*, a group of one type of atom. Hydrogen is the simplest element in the universe.
emergency brake: Provides a mechanical means (cable and levers) of applying the rear brakes. It is also called a parking brake.
emission control information sticker: Sticker normally located in an engine compartment that gives important engine data, evaporative emissions information, schematics, and other specifications for complying with EPA regulations.
emission control system: A system that is used to reduce the amount of harmful substances emitted into the atmosphere by an automobile.
emission maintenance reminder: A circuit that automatically turns on a dash light to indicate the need for emission control system service.
emission standard base line: The average allowable emission level for a specific vehicle model year displayed as a straight dashed line across an emission drive trace report. It is also referred to as a cut point.
emissions testing program: A program that uses exhaust gas readings as the engine operates at idle and at a set rpm to determine if exhaust emission levels are within acceptable state standards. It may also involve checking the vehicle for the presence of a catalytic converter and a fuel inlet restrictor. It is often called an inspection and maintenance program.
end cover: A cap that bolts on a gearbox housing to secure the end of the sector gear.
end gas: Unburned portion, after normal combustion, of an air-fuel mixture.
end seal: A seal that has to be worked down into grooves in an oil pan or front cover and block before being placed over a gasket.
energy reserve module: A module that deploys the air bag after a power failure. It must be removed or allowed to discharge for up to 30 minutes after disconnecting the battery.
engine: A device that converts energy into useful mechanical motion.
engine balancing: Machine-aided process that is needed when the weight of the pistons, connecting rods, or crankshaft is altered by installing new parts. The correct balance of weight within an engine has to be kept during reassembly to prevent major mechanical problems. It is also called crankshaft balancing.
engine bedplate: One-piece metal casting for the bottom of an engine block designed to eliminate main bearing caps. An engine block using this construction is split into an upper and lower half at the main bearings or crankshaft centerline.
engine block: The part of the engine containing the crankshaft, pistons, and cylinders. It is made of cast iron or aluminum and is the foundation for the entire engine.
engine blowby: Oil vapors and other emissions that leak past piston rings into the crankcase.
engine bottom end: Term used for the major engine parts below a cylinder head including the cylinder block, crankshaft, connecting rods, rod bearings, main bearings, piston pins, piston rings, and pistons.
engine control module (ECM): Small computerized unit that monitors and regulates the many components, parts, and systems that operate within a vehicle. The abbreviation ECM is also used for electronic control module.
engine coolant temperature sensor: Thermistor sensor that monitors the operating temperature of an engine. The sensor tip is positioned for exposure to engine coolant.
engine cooling system: System that controls the operating temperature of engine cylinder heads and cylinder block.
engine cough: A mild backfire in the engine intake manifold, quieter than an engine knock or backfire.
engine crane: Device used to remove (raise) an engine from or install (lower) an engine into a vehicle. It has a hydraulic hand jack for raising and a pressure release valve for lowering.
engine displacement: The volume of space in which the piston moves in a full stroke (TDC to BDC) multiplied by the number of cylinders in the engine. It is also termed the engine size.
engine dynamometer: A machine that tests vehicle engine power at the crankshaft (brake horsepower).
engine exhaust leak: Exhaust gas escaping out of an engine part or component. Often produces a clicking sound or metallic noise near the engine.
engine firing order: Refers to the sequence in which the spark plugs fire to cause combustion in each cylinder.
engine floating: A constant engine speed above idle.
engine front cover: A thin, stamped steel or cast aluminum cover that encloses the timing chain or gear mechanism. It blocks dirt and debris while preventing oil leakage. It is also called the timing cover.
engine front end: Term that refers to the camshaft drive mechanism, front cover, water pump, and auxiliary shafts that are attached to the front of an engine.
engine hoist: Machine that lifts an engine from a vehicle's engine bay. It can resemble a small crane with a boom and wheels for positioning, or it can be an overhead mounted machine.
engine idle speed: Operating speed (in rpms) of an engine when the vehicle is in *Park* or *Neutral*.
engine knock: Engine vibration noise caused by detonation in the combustion chamber.
engine load: A percentage measurement that represents how hard an engine is working.

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engine oil: Oil that protects an engine from friction and the resulting heat. It is also called motor oil.
engine oil debris: Bits of rubber, plastic, aluminum, titanium, steel, brass, ductile iron, etc., that can collect in a vehicle oil pan and filter.
engine oil leak: Oil leakage as a result of hardened or cracked gaskets, worn seals, loose fasteners, or damaged parts.
engine operating temperature: The temperature of the engine coolant during normal engine operating conditions.
engine overhaul: A process that includes complete disassembly of the engine; cleaning, inspection, and measurement of critical parts; replacement or service of worn or damaged parts; and reassembly of the engine. It is also called engine rebuild.
engine performance problem: Any trouble that lowers engine power, performance, fuel economy, or alters emissions.
engine power balance test: Test that involves disabling a fuel injector or spark plug in a specific engine cylinder while monitoring the corresponding rpm drop to measure cylinder power output. It is also called a cylinder balance test.
engine-powered fan: Fan that is bolted to an engine water pump hub and pulley. This type of fan has generally been replaced by electric fans.
engine rebuild: See *engine overhaul.*
engine sensor: Sensor that monitors variables within an engine and communicates with the ECM to control these factors based on operating conditions.
engine size: See *engine displacement.*
engine sludge: Black, mushy deposits found in the interior of the engine caused by oxidized petroleum products mixed with dirt and other contaminants.
engine sludging: Chocolate pudding-like oil formation resulting from extremely worn oil.
engine smoke: Smoke exiting a tailpipe when engine speed is increased or decreased. Its color can help diagnosis engine problems.
engine speed sensor: A sensor that sends information on engine speed and piston location to the ECM.
engine stand: A metal framework on small casters or wheels that is used to hold an engine for disassembly and reassembly.
engine starting system: System that cranks the engine until fuel combustion forces the pistons down and the engine can operate on its own power. In hybrids and ECM-controlled starting circuits, this system can shut off the engine when it is not needed.
engine temperature gauge: Dash-mounted gauge that indicates engine temperature.
engine throttle actuator: A small, reversible servo motor that is controlled by the ECM and opens and closes the engine throttle valve electronically.
engine throttle valve: Flap-type valve in a throttle body assembly that controls airflow and engine power output.
engine top end: Term for the parts that fasten above the engine's short block. They include the cylinder head assembly, valve train, valve cover, and intake and exhaust manifolds.
engine torque: A rating of the turning force at an engine crankshaft.
engine vacuum leak: Loss of engine vacuum pressure that can be heard as a hissing sound, which is loudest at engine idle speed.
engine vacuum test: Test that measures the strength of the vacuum created by engine cylinders during the intake stroke. It is an easy way to check for a clogged or restricted exhaust system.
engine valve train: The valves and the parts that operate them, including the camshaft, lifters, push rods, rocker arms, valves, and valve spring assemblies.
entrepreneur: Individual who starts and runs his or her own business, assuming all of the responsibilities of business ownership.
equivalent resistance: The total resistance of a series-parallel circuit found by calculating the resistance of each parallel section and then adding the series resistances to these values.
erasable programmable read only memory (EPROM): A type of microprocessor whose programming can be altered only by erasing it with special equipment and reprogramming.
ethanol: See *ethyl alcohol.*
ethical behavior: Actions conforming to accepted standards of fairness and good conduct that are based on an individual's sense of what is right and wrong.
ethyl alcohol: A colorless, toxic, and highly flammable liquid made from farm crops like grain, wheat, sugarcane, or potatoes. It is also called grain alcohol or ethanol.
evacuation routes: Designated paths that are used to show people how to exit a building quickly during a fire, gas leak, or other emergency.
evaporation: A liquid changing into a vapor (gas) state.
evaporative emissions control (EVAP) system: An emissions control system designed to prevent fuel vapor from escaping into the atmosphere.
evaporative emissions system pressure test: Additional IM 240 test that checks an EVAP system for leaks into the atmosphere. Pressure test equipment is connected to the system's vapor vent line. A computer then meters low pressure nitrogen into the system and closes it off while monitoring for a pressure drop.
evaporative emissions system purge test: Additional IM 240 test that measures the flow of fuel vapors into an engine. A flowmeter transducer is installed into the system purge line and a computer connects to the transducer for data analysis.
evaporator: A heat exchanger installed in the air conditioner blower case. Absorbs heat and humidity from the incoming air and transfers it to the circulating refrigerant.
event data recorder: A device that monitors and records vehicle operating conditions and stores them in memory.
excess crankshaft end play: Too much front-to-back movement of a crankshaft usually caused by a worn main thrust bearing.
excessive brake pedal effort: A noticeable increase in the amount of foot pressure needed to apply the brakes.
exhaust back pressure: Pressure created in an exhaust system by the flow of exhaust gases. Back pressure must be as low as possible to improve engine efficiency and prevent engine overheating.
exhaust camshaft phaser: Aids in lower emissions by closing the exhaust valves before all of the end gas has been expelled from the cylinder.
exhaust emission readings section: Part of a vehicle inspection report that gives readings for HC, CO, and NO_x, and OBD results, if applicable, from an emission test. Standard vehicle emission levels are listed along with the test results.
exhaust gas: Harmful chemical or fume produced from the combustion of hydrocarbon-based fuels (or most other fuels) within an engine.
exhaust gas analyzer: Electronic test device used to measure the amount of pollutants in exhaust emissions.
exhaust gas recirculation (EGR) system: System that injects burned exhaust gases into the engine intake manifold to lower the combustion temperature and reduce NO_x pollution.
exhaust gas sensor: See *oxygen sensor.*
exhaust leak: Pressure leak in a vehicle exhaust system that will often show up as gray or white carbon lines coming from the openings.
exhaust manifold: Connecting pipes between the cylinder head exhaust ports and the exhaust pipes.
exhaust manifold doughnut: Gasket or an O-ring that seals the connection between an exhaust manifold outlet and header pipe to prevent leakage.
exhaust manifold warpage: Condition in which the deck on an exhaust manifold is no longer flat.
exhaust note: Sound of engine exhaust gases.
exhaust pipe: Welded, rust-resistant steel tube connecting major parts of a vehicle exhaust system.
exhaust ports: Passages leading from the combustion chambers to the exhaust manifold to carry burned gases out of the cylinders.
exhaust stroke: The portion of the piston's travel that is devoted to expelling the burned fuel charge.
exhaust system: Components that quiet and carry exhaust emissions to the rear of a vehicle. These components include the muffler, exhaust pipes, catalytic converter, and exhaust manifold.
exhaust system back pressure test: Test that measures the amount of resistance to gas flow in a vehicle exhaust system.
exhaust system clamp: U-bolt for connecting parts of an exhaust system together.
exhaust system inspection: Process of checking exhaust pipes and exhaust system components for damaged, rusted, or leaking parts.
exhaust valve: Valve located over the cylinder head exhaust port that controls the flow of burned gases out of the combustion chamber.

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expanded display: Oscilloscope control that allows one cylinder waveform to be displayed above the parade pattern. It is also referred to as cylinder select.
expansion: Rapid enlargement of gases in an engine due to combustion.
expansion freeze plug: Type of freeze plug available for tight quarters. An expansion freeze plug is placed into an engine hole and a screw is tightened on the plug, allowing it to expand and lock in the hole.
expansion tube: In an A/C system, a fixed opening that meters the refrigerant flowing into the evaporator. It is also called an orifice tube.
expansion valve: A temperature-sensitive valve that controls refrigerant flow and the evaporator temperature.
exploration tests: Various tests used by oil companies to determine the probable location of crude oil underground. These tests include seismic studies, surface mapping, and test drilling.
explosion: A violent expansion of gases due to rapid combustion of volatile materials.
extension: Socket wrench lengthening accessory that is placed between a socket and its handle to allow access to difficult-to-reach fasteners.
extension housing: An aluminum or iron housing bolted to the back of a transmission case that supports the end of a transmission output shaft. A gasket fits to the front and a seal to the rear to stop oil leakage. It is also called the tail shaft housing.
extension housing bushing: Solid, plain bushing that fits inside a transmission extension housing to support the slip yoke as it spins in the transmission.
external cylinder power steering system: Power steering system with the power piston assembly as a separate part bolted to the vehicle frame and center link.
external lifter wear: Results in the bottom of a lifter becoming flat or concaved. This is due to friction between the lifter and camshaft lobe.
external oil leakage: Darkened, oil-wet areas on or around an engine.
eyewash station: Station used to wash chemicals from a technician's eyes after an accident by flushing them with water.

F

facing: See *friction material.*
facing spring: Flat, metal spring located behind the friction material on a clutch disc. It compresses inward with the friction material to smooth initial clutch engagement. It is also called a cushioning spring.
fail-safe circuit: Circuit designed into the voltage regulator that disconnects alternator output if voltage levels become too high.
failure record: ECM documentation of the number of times (keystarts or warm-ups) a particular trouble code has occurred.
falling edge: Oscilloscope reading that shows the drop in voltage of a square wave back to zero. It is also called the trailing edge.
fan: A mechanically or electrically operated device designed to create a moving stream of air, generally for cooling purposes.
fan motor: A small direct current motor with brushes that mounts on a bracket secured to the radiator and drives the electric cooling fan.
fan spacer: Part that fits between an engine-powered fan and pulley to move the fan closer to the radiator.
fan switch: A temperature-sensitive switch that controls fan motor operation. It is also called a thermo switch.
farad (F): The size, or electrical storage ability, of a capacitor. A one-farad capacitor connected to a one-volt source stores 6.28 × 1018 electrons.
fast charger: Machine that forces a high current flow into a battery for rapid recharging. The charge rate should not exceed 35 amps and battery temperature cannot exceed 125°F (52°C) or battery damage can result. It is also called a boost charger or quick charger.
fast control area network (F-CAN): A computer communications system that operates at 500 kbps (kilobits per second). It is used to control the engine, transmission, air bags, and other more critical systems.
fastener: Device used to hold, or fasten, parts together. Metal and plastic ones are found on vehicles.
fault designation: Last two digits of an alphanumeric trouble code that pinpoint exactly which component or circuit of a vehicle system might be at fault, as well as the type of problem.
faulty oil pressure switch: Malfunctioning switch that can make the indicator light glow or the gauge read low when oil pressure is normal.
feathered edge: A tire wear pattern in which one side of each tread rib is sharp and raised and the other side of each rib is rounded or recessed.
feeler gauge: A flat, thin strip of metal or small caliber wire, machined to a specific thickness, which is used to measure clearances or gaps.
fender cover: Cover placed over fenders, upper grilles, or other body sections to prevent panel or paint damage during a repair.
fiber optics: A field of electronics in which light is used to carry data through small strands of plastic or glass fiber. Also, refers to cable that has light-carrying strands of plastic or glass.
field winding: Insulated wire looped around iron pole shoes that are attached to the inside of the starter motor housing.
filament: Resistance wire inside a lightbulb that produces heat and the emission of light energy when electrical current is passed through it.
file: An abrasive tool rubbed across surfaces to smooth them. Files are classified by length, shape, and cutting surface.
filler cap: Cap that screws onto the end of a filler neck in a vehicle fuel tank assembly. It is more commonly known as a gas cap.
filler neck: Extension tube that leads from a vehicle fuel tank through the body, allowing a gas pump nozzle to be used to fill the tank with fuel.
filter bypass valve: Valve that opens to protect an engine from oil starvation if the oil filter element becomes clogged.
filter element: A paper or cotton filtering substance mounted inside a filter body that allows liquid or air to flow but traps small debris.
fire: The result of heat, fuel, and oxygen in the correct proportions to start combustion. Many automotive shop supplies and repair procedures can cause fires if not properly handled.
fire extinguisher: Container filled with chemicals that will quench a fire when sprayed on the flames.
firing line: The tall spike shown on an oscilloscope, representing the voltage needed to make the spark jump the plug gap.
firing section: Section of an oscilloscope pattern that shows voltage fluctuations as a spark plug fires.
five-gas exhaust analyzer: Exhaust gas analyzer that measures the amount of hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), carbon dioxide (CO_2), and oxygen (O_2) in a vehicle's exhaust gases.
fixed caliper: Brake caliper that is rigidly mounted to the spindle and does not move during braking.
fixed dwell: Dwell timing that should remain the same at all engine speeds.
fixed transmission solenoid: Solenoid that uses only fully "on" or "off" signals when directing a spool valve to open or close a fluid pressure passage.
flame arrester: A metal mesh sometimes located before an engine intake manifold. It prevents the flame of an engine backfire from entering the air filter.
flash erasable programmable read only memory (FEPROM): A type of ECM memory that contains vehicle operation data. It is normally reprogrammed rather than replaced.
flash-to-pass feature: Turn signal lever position that allows the driver to flash the high beam lights, indicating to other drivers ahead of the desire to pass.
flasher: Component that makes and breaks the circuit to make the vehicle lightbulbs flash on and off. Usually, one flasher is used for the turn signals and another for the emergency flasher lights.
flat: Term for a tire that has lost all or most of its air pressure due to a leak or other damage.
flat head engine: Engine in which both the intake and exhaust valves are located in the engine block. It is also called an L-head engine. This construction is no longer used in automobile engines but functions in small gas engines.
flat-rate manual: A publication that lists the flat-rate times for a variety of repairs.
flat-rate time: The average amount of time it will take a technician to do a specific repair.

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flex fan: A fan with blades that alter airflow with engine speed.
flex fuel vehicle: See *flexible-fuel vehicle (FFV).*
flexible coupling: Coupling that connects a steering shaft and steering gear input shaft to help keep road shock from being transmitted to the steering wheel.
flexible hose: Hose with an accordion shape and pleated construction that allows it to bend at different angles without collapsing and blocking flow.
flexible-fuel vehicle (FFV): Vehicle designed to operate on different types of fuel, such as E-85. Sensors monitor the contents of the fuel through measurement of combustion efficiency, and engine functions are adjusted for maximum efficiency for the type of fuel being consumed.
flight record test: Test that uses a scope connected to the vehicle during a test-drive to store a problematic sensor or actuator waveform in the scope's memory the moment it occurs.
floating caliper: A caliper that can move or "float" back and forth in relation to the rotor.
floor jack: Movable jack used to raise and lower either the front, sides, or rear of a vehicle.
fluid coupling fan clutch: Type of fan clutch operating in silicone-based oil designed to slip at higher engine speeds to save energy.
fluid leak: Vehicle fluids escaping from bad gaskets, seals, or hoses; cracks in parts; and similar problems.
fluid temperature sensor: Sensor that monitors and reacts to maintain normal vehicle shifting when temperature variations change transmission fluid viscosity.
fluorescent penetrant: Testing material that can be sprayed or painted onto iron and aluminum parts to locate cracks, but requires an ultraviolet (black) light to illuminate.
flushing: Process that drains old fluid from a vehicle system. A cleaning chemical is then sometimes run through the system before new fluid is added.
flux: Lines of magnetic force moving through a magnetic field. *Also,* material used to prevent oxidation of metal being soldered or brazed.
flux brush: Brush that is used to apply a paste-type flux to a joint.
flywheel: A large heavy wheel that forms the base for the starter ring gear, connects the crankshaft to the transmission or transaxle, and provides a mounting surface for the torque converter or clutch assembly.
flywheel battery: See *flywheel generator.*
flywheel generator: A generator that uses the kinetic energy of a high-speed ac armature (flywheel) to store huge amounts of electrical energy. It is also called a flywheel battery.
FM radio: Radio designed to receive a radio signal that varies in frequency (fluctuating speed). The FM band is from 88-108 megahertz (MHz).
footprint: Term for the shape and amount of tire tread touching a road surface.
force: A pushing or pulling action on another object measured in pounds or Newtons.
fork tool: Two-pronged tool shaped like a fork and used to force a ball joint from a steering knuckle with the help of a hammer.
forward bias: Arrangement in which a diode acts as a conductor.
forward-biased diode: Diode that acts as a conductor, allowing current to pass through the diode when voltage is connected in a certain way.
four-bolt main block: Design with four cap screws holding each main bearing cap to a cylinder block. This reduces the amount of crankshaft flex as compared to using just two bolts.
four-channel ABS: Has a separate hydraulic control circuit for each wheel that keeps any one of the four tires from skidding.
four-gas exhaust analyzer: Exhaust gas analyzer that measures the quantity of hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), and oxygen (O_2) in a vehicle's exhaust gases.
four-stroke cycle: Every two up and two down strokes of the piston results in one power-producing cycle. Two complete revolutions of the crankshaft are needed to complete one four-stroke cycle.
four-valve combustion chamber: Combustion chamber with two intake valves and two exhaust valves for each engine cylinder to increase flow in and out.
fractionating tower: Tower used in the distillation process that separates parts of crude oil as the oil vaporizes up through the tower.
frame: The steel structure that supports or is part of the vehicle's body.
frame-ground circuit: A circuit that uses the metal frame structure of the vehicle to return electricity to the power source. It is also called a one-wire circuit.
free electron: Electron that moves from atom to atom.
free-floating piston pin: Piston pin that will turn in both the rod and piston.
free travel: Distance a clutch pedal or clutch fork travels before engaging the throwout bearing to push against the pressure plate. It is necessary for proper clutch engagement.
freeze frame: Scan tool snapshot of all vehicle monitored components when a trouble code occurs or when triggered during a drive.
freeze plug: A stamped metal disc pressed or screwed in the holes where the engine core was removed from the casting. The plug allows for expansion if coolant should freeze, preventing a cracked casting. It is also called a core plug.
freeze spray: Solution used to find intermittent electrical problems by lowering the temperature of a component instantly.
Freon: See *refrigerant-12.*
frequency: The number of times that an activity, such as a vibration or the cycling of ac voltage, occurs over a set time period. Measured in Hertz, in which the time period is one second.
friction bearing: A plain bearing that has a smooth surface of soft metal, such as copper or babbitt, on which a part slides or rotates.
friction disc: See *clutch disc.*
friction material: Heat-resistant linings and surfaces applied to different part surfaces to create a strong bonding face. It is also known as disc lining or facing.
frictional horsepower (fhp): The power needed to overcome engine friction and a measure of the resistance to movement between engine parts.
front bearing cap: See *front bearing hub.*
front bearing hub: Metal sleeve that bolts to the front of a transmission case to support the input shaft and clutch release bearing. It is also known as a front bearing cap.
front cover: Cover bolted over the crankshaft snout that holds an oil seal to seal the front of the crankshaft.
front drive axle: Shaft that transfers power from the front differential or transaxle to the vehicle's front wheels. The front drive axles are straight steel shafts when used with a solid differential assembly. When used with an independently sprung differential, the axles are equipped with cross-and-roller U-joints or CV joints for flexibility.
front O_2 sensor: See *primary oxygen sensor.*
front oil seal: A seal press-fitted into the engine front cover that prevents oil leakage between a crankshaft and engine front cover.
front transmission bearing: Bearing positioned in the front of a transmission that supports and controls input shaft movement.
front universal joint: Flexible joint that fastens the slip yoke to a drive shaft.
front-wheel-drive vehicle: Configuration with the drive wheels located in the front of a vehicle, with the engine and transaxle placed directly above. All of this weight in the front of a vehicle provides superior traction.
frozen valve: See *stuck valve.*
fuel: Any substance (liquid, gas, or solid) that can easily be burned to produce heat.
fuel cell: Device filled with electrolyte and made of a plastic, gas-permeable membrane sandwiched between a positive and negative electrode plate that combines hydrogen and oxygen to produce electrical energy. It is electrolysis in reverse.
fuel delivery system: Subsystem of an electronic vehicle fuel injection system that feeds clean, liquid gas from the storage tank to the engine.
fuel efficiency: EPA numerical test rating for the distance a vehicle can travel on one gallon of fuel.
fuel filter: Screening that removes contaminants such as water, rust, and other debris in fuel and prevents them from entering the fuel system.
fuel heater: Electric heating element in a fuel line, positioned ahead of the injection pump, that warms diesel fuel to prevent it from gelling. This system accessory is needed in very cold climates.

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fuel hose: Synthetic rubber hose that carries fuel from the tank to the vehicle engine.
fuel injection system: System that sprays fuel directly into or just ahead of engine cylinders.
fuel injector: Valve controlled by electronic solenoid or spring pressure.
fuel injector boot: Soft rubber grommet or O-ring that fits between a fuel injector and its opening in an engine to prevent engine vacuum leakage.
fuel injector cleaning tool: Tool that uses shop air pressure to force a cleaning solution through fuel injectors to remove deposits.
fuel injector impedance test: Test that measures the internal resistance of injector coil windings while carrying a full amp load to determine how quickly the injector will open.
fuel injector pulsed flow test: Test that fires an injector several times with a normal pulse width to check pintle response.
fuel injector scope test: Test that measures the maximum and minimum injector voltages and time of injection in milliseconds to see if an injector is working properly.
fuel line: Double-wall steel tubing that carries fuel from the tank to the vehicle engine.
fuel line freeze: A problem (usually with diesel fuel) that results when moisture in the fuel turns to ice within the fuel line or engine.
fuel log: See *fuel rail.*
fuel metering system: Subsystem of a vehicle fuel system that gauges the correct amount of fuel to inject into the engine cylinders, depending on engine speed, temperature, load, throttle position, and other factors.
fuel pressure regulator: System that controls the amount of fuel pressure in a vehicle fuel rail.
fuel pressure relief valve: Threaded service valve in low-pressure electronic fuel injection systems that is used for manually "bleeding" any remaining gasoline pressure in the fuel rail and injectors.
fuel pressure sensor: Sensor, mounted on a fuel rail, that sends an electronic signal, proportional to the pressure inside the rail, to the ECM to control fuel pump speed and/or fuel injector pulse width.
fuel pump: Pump that draws fuel out of the fuel tank and forces it to the engine under pressure.
fuel pump capacity: Measurement of the amount of fuel the pump can deliver in a specific amount of time. It is also termed fuel pump volume.
fuel pump charging stroke: Stroke of a mechanical fuel pump during which the eccentric lobe pushes on the pump rod and plunger, compressing the pump spring and pushing the plunger into the pumping chamber, pressurizing the chamber.
fuel pump pressure stroke: Stroke of a mechanical fuel pump during which the eccentric lobe rotates away from the fuel pump, releasing the pump spring so it can pull the plunger and rod in the other direction. This snaps the outlet valve closed and pushes the inlet valve open so the pumping chamber can be refilled with fuel from the tank.
fuel pump testing: Testing that procedurally varies by vehicle but involves measuring fuel pump pressure and volume.
fuel pump volume: See *fuel pump capacity.*
fuel rail: A larger-diameter fuel line that feeds fuel to the inlet openings of the fuel injectors. Its larger size compared to the standard fuel line prevents any injector from starving for fuel under high-demand conditions. It is also called a fuel log.
fuel return system: System featuring a fuel return line that carries excess fuel back to the tank. This keeps engine heat from overheating gasoline by constantly circulating unused fuel back to the fuel tank.
fuel strainer: A semi-porous metal bag that attaches on the inlet of an in-tank fuel pump to keep debris from entering the system.
fuel supply system: Subsystem of a vehicle fuel system that draws fuel from the fuel tank and forces it into the fuel metering device (usually gasoline injectors). It consists of a fuel tank, lines, pumps, and filters.
fuel system: Vehicle system and set of components to store fuel and deliver a combustible air-fuel mixture to the engine cylinders as needed.
fuel system monitoring: A check of whether a stoichiometric, or theoretically perfect, fuel mixture is being fed to an engine.
fuel system service fitting: Part often provided on low-pressure electric fuel injection systems for releasing and measuring fuel pressure.
fuel tank: Safe storage unit for gasoline, diesel fuel, gasohol, alcohol, LPG, or other combustible material used to power a vehicle.
fuel tank baffle: Metal plate located inside a fuel tank that restricts fuel movement while the vehicle operates.
fuel tank capacity: Volume of fuel (in gallons or liters) a fuel tank can hold. Average automobile fuel tank capacity is 12–25 gallons (45–95 liters).
fuel tank pressure sensor: Sensor installed in vehicles equipped with OBD II systems to monitor the buildup of fuel tank pressure.
fuel tank strap: Thick steel band that bolts around a fuel tank to secure it to a vehicle.
fuel temperature sensor: Sensor monitoring the temperature of fuel in a vehicle fuel rail. Fuel temperature has a slight effect on a fuel density.
fuel trim malfunction trouble code: Diagnostic code set if an ECM is having difficulty maintaining engine air-fuel ratio.
fuel vapor: Various chemicals that enter the air as fuel evaporates.
full-electric vehicle: Vehicle that uses only an electric propulsion system to move. An internal combustion engine, or other source to recharge the HV battery when driving, is absent from the vehicle.
full-floating piston pin: A piston pin that is free to rotate. It is secured in place with snap rings.
full hybrid: Gas-electric hybrid vehicle that initially uses a motor-generator for acceleration and propulsion. Once the HV battery is discharged, the internal combustion engine is used to both propel the vehicle and recharge the HV battery.
full power charge mode: One of three modes for a direct electronic fuel injection system that produces a homogeneous, rich mixture (more fuel) that generates the most combustion pressure and power of the three.
full-size spare: Type of vehicle spare tire that is the same size and type as the tires currently mounted on a vehicle.
full-time hub: Type of locking hub in a four-wheel-drive vehicle that is always locked to drive the front wheels.
full-wave rectification: The process of converting alternating current to direct current, allowing both halves of each AC wave through. Both halves flow in the same direction.
fully counterweighted crankshaft: Crankshaft with weights formed opposite every rod journal. Vibration during operation is less than with a partially counterweighted crankshaft.
fully synchronized transmission: Type of manual transmission that uses a synchronizer with all forward output gears. This setup allows a driver to downshift into any lower gear (excluding reverse) while the vehicle is still in motion.
fuse: Device that interrupts current if a circuit is overloaded or a short occurs.
fuse link: A special calibrated wire installed in a circuit that will allow an overload condition for short periods. A constant overload will melt the wire and break the circuit.

G

gas cartridge: Hybrid air bag device that contains inert argon gas pressurized to 3000 psi (20,700 kPa) used to inflate air bags.
gas-charged shock absorber: Type of shock absorber that uses a low-pressure gas to help keep the oil around the shock piston from foaming.
gasket: A soft, flexible material placed between two parts to prevent leaks.
gasohol: Fuel mixture of gasoline and alcohol. Usually, gasohol uses a mix of 2–20% grain alcohol and the rest 87 octane gasoline.
gasoline: Refined, abundant, and highly flammable product of crude oil that is the most common type of automotive fuel. Additives are added to gasoline to improve its operating characteristics.
gasoline engine boost pressure: Averages a turbocharger inlet pressure of around 10–15 psi (0.7–1.0 Bar) in passenger vehicles.
gasoline engine compression reading: Should be around 125–175 psi (860 kPa to 1200 kPa) in each cylinder. Readings must be within about 10–15% of each other.
gasoline injection system: System that uses pressure from an electric or mechanical fuel pump to spray fuel into an engine's intake manifold (multiport or manifold injection) or its combustion chambers (direct injection).
gassing: Formation of acid fumes during the chemical reaction inside the battery. This involves the conversion of water in the electrolyte into hydrogen and oxygen.

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gate: Indented metal part mounted on a shift rail. It aids in locking a shift fork into the correct synchronizer during gear shifts. *Also*, an electronic circuit that produces a specific output for a given input.
gauge tester: Variable resistor test tool used to check gauge and sending unit operation.
gear: An object, either disk- or cone-shaped, into which a series of teeth are cut on its rim.
gear backlash: Term for the measured clearance between meshing gear teeth that allows for lubrication and expansion during operation. In general, the greater the amount, the more play there will be between two meshing gears.
gear-driven oil pump: Type of pump that uses the engine timing gears for power.
gear housing: Metal housing that holds the pinion gear and the rack in a rack-and-pinion steering system.
gear oil: Heavy oil that provides lubrication for the gears and bearings in rear axle assemblies and in manual transmissions and transaxles.
gear oil pump: A type of pump that uses meshing gears to provide pressure and fluid movement.
gear preload: A small amount of pressure applied to differential bearings to remove play and excess clearance with gears.
gear ratio: The relationship between the number of turns made by a driving gear to complete one full turn of the driven gear. If the driving gear makes four revolutions in order to turn the driven gear once, the gear ratio would be four to one (4:1). It can also be determined by dividing the number of teeth on the driven gear by the number of teeth on the drive gear.
gear reduction: A setup in which a small gear is used to drive a larger gear to produce an increase in torque. The speed at the output shaft will be less than the speed of the input.
gear shift lever: Hand-operated lever used in a manual transmission to select the proper gear after depressing the clutch pedal.
gearbox: A transmission (usually worm and ring gear) in a power window motor that changes the rotating motion of the motor armature into a partial rotation of a larger gear.
gearbox housing: A metal case that bolts to a vehicle frame or reinforced area of a unibody to provide an enclosure for the components of worm-type steering gearbox.
gearbox ratio: A comparison between steering wheel rotation and sector shaft rotation. Steering gearbox ratios range from 15:1 to 24:1. It is also termed steering ratio or steering gear reduction.
gel battery: Type of lead-acid battery that contains the electrolyte in a paste-like consistency instead of a liquid. This allows the battery to still function without any electrolyte leakage if the battery case breaks.
general circuit failure: Specific type of computer system failure caused by a component that has no output or has an output that is out of specifications.
global navigation satellite system (GNSS): See *global positioning system (GPS).*
global positioning system (GPS): Uses a series of Earth-orbiting satellites to communicate through a vehicle's antenna the location and time information anywhere near Earth's surface. It is also known as a global navigation satellite system (GNSS).
glow plug: A heating element used to help diesel engines start when cold.
glow plug analyzer: Test equipment used to test diesel glow plugs and the operating condition of a diesel engine. It measures the internal resistance or current to each glow plug and glow plug temperature to detect a dead cylinder.
glow plug control circuit: Circuit that monitors engine temperature and automatically disconnects glow plugs after a few seconds of operation.
glow plug resistance-balance test: Test that monitors the temperature and internal resistance of a glow plug within a cylinder as combustion occurs. A cylinder firing correctly will raise these two elements of its glow plug.
grabbing brake: Brakes that apply too quickly, even with light brake pedal application.
grabbing clutch: Problem that occurs when a clutch disc engages with a jerk or shudder no matter how slowly and carefully pressure is applied to and released from the clutch pedal. It is also referred to as a chattering clutch.
grain alcohol: See *ethyl alcohol.*
graphite: A soft form of the element carbon that adds flexibility, corrosion resistance, and helps retard scoring caused by grit when used as a lock lubricant.
grease gun: Battery- or air-powered tool used for dispensing lubricant into different vehicle components. Its design allows for quick and precise application, especially in difficult-to-reach areas.
grease job: Process of lubricating high-friction areas on the suspension, steering, and drive train systems.
grease seal: Seal that holds lubrication in the axle and the knuckle or bearing support.
grid repair agent: A substance that conducts electricity and is used to repair a broken heating grid within glass.
gross horsepower (ghp): The brake horsepower of an engine with optimum fuel and ignition settings and without allowing for power absorbed by the engine-driven accessories.
ground: The terminal of the battery connected to the vehicle's frame.
ground-circuit resistance test: Test performed by placing the voltmeter across the negative battery terminal and alternator housing.
ground prong: The round, third prong on an electrical plug. If a short develops in the electrical equipment, current passes through this connection to ground because of its low resistance.
grounded circuit: Type of short circuit in which current flows directly into a ground that was not part of the original circuit.
grounded side electrode: Part of a spark plug that causes the electricity to jump the gap and return to the battery through frame ground.

H

hacksaw: A type of saw used to cut metal objects. Blades of various lengths can be mounted in the saw's adjustable frame.
half-wave rectification: The process of converting alternating current to direct current, allowing only half of each AC wave through. In this configuration, a single diode is used in series with an AC source.
halogen lightbulb: A bulb that uses tungsten and halogen gas to produce light. It is brighter than an incandescent bulb.
hanger: Fastening device for securing an exhaust system to the underside of a vehicle.
hard failure: An always present computer system failure that sets a diagnostic code as soon as the ignition key is turned to run.
hard ring coating: Coating of a piston ring made from chrome or moly. It is used to increase ring life and reduce friction only in new or freshly machined cylinders.
hard starting: Excessive cranking time is needed to start an engine.
hard steering: Term for a steering problem that requires a driver to use excessive force and effort to turn the steering wheel/vehicle. It can be a common problem with power steering systems.
harmonic balancer: A round metal or rubber device mounted to a crankshaft to minimize torsional vibration. It is also known as a vibration damper.
harmonic vibration: A high frequency vibration caused by the crankshaft.
harness connector: Multi-terminal connector that joins several wires and consists of a two-part plastic housing that snaps together to prevent the terminals from working free.
harness routing diagram: A diagram that shows how major wiring is arranged and where it is located in the vehicle.
harsh shift: Term for a gear shift in an automatic transmission that happens too quickly, causing the vehicle to jerk.
head gasket: Gasket that creates a seal between engine block and cylinder head surfaces to prevent oil, coolant, and combustion chamber pressure leakage.
head pressure testing machine: Machine that seals all oil and coolant passages before pressurizing an engine head and submerging the head in a water tank to check for leaks.
header: Term for a high-flow, high-performance exhaust manifold sometimes made of stainless steel or lightweight steel tubing.
header pipe: Steel tubing that carries exhaust gases from the exhaust manifold to the catalytic converter.
headlamp system: System consisting of the battery, headlamp wiring, fuse panel, light switch, dimmer switch, headlamps (headlights), taillights, marker lights, and instrument lights.

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headlight aimer: Devices for pointing the car's headlamps in a specified position.
heads-up display (HUD): Display that reflects semi-transparent information onto the windshield or a plastic dash panel so the driver does not have to take his or her eye off the road. It complements the conventional displays in the instrument cluster.
heat checked: Brake discs that have small, hardened, and cracked areas caused by overheating.
heat shield: Sheet of metal or fiberglass used to shelter heat sensitive components, such as wiring, from excessive engine and exhaust heat.
heat shrink tubing: Hollow plastic tubing that shrinks when heat is applied.
heat sink: Metal mount for removing excess heat from power transistors of electronic components. *Also*, a spring-loaded, clamp-on device that is sometimes used to help prevent overheating of electronic components while soldering.
heat-cleaning oven: Machine that circulates superheated air over engine parts to remove organic materials such as oil, grease, paint, varnish, and plastic without the use of chemicals. It is also referred to as a burn-off oven.
heated oxygen sensor (HO_2S): Oxygen sensor that contains a small heater element.
heated seat: Seat that uses a heating element (or multiple heating elements), switch, relay, and related wiring to warm the seat cushions in cold weather.
heated windshield system: Windshield that has a special conductive film sandwiched inside its glass. When high voltage (typically 70 to 90 volts) is passed through this clear conductive film, the glass heats up and melts ice or snow.
heater core: A small, radiator-like unit in the blower case in which coolant circulates. It provides a large surface area for heat dissipation into the passenger compartment.
heater hose: Small-diameter hose that carries engine coolant to the heater core.
heater monitor: Checks the action of the heating element in an oxygen sensor by rapidly turning the heating element on and off while checking its response.
heating system: Uses heat from the engine cooling system to supply warm air into the passenger compartment.
height sensor: Sensor that converts the relative position of a vehicle's body and axle into an electrical signal. Some vary their electrical resistance as the distance changes; others use magnets to vary the magnetic field of the current passing through the sensor as the distance changes.
helical gear: A gear that has teeth cut at an angle, called a helix angle, to its centerline.
hemispherical combustion chamber: A dome-shaped combustion chamber with valves tilted on each side of the chamber and a spark plug located near the center. It provides increased engine aspiration while suffering less heat loss than other designs. The design is commonly nicknamed a hemi.
hertz (Hz): Unit of measure for the frequency of ac current.
hesitation: Condition in which an engine does not accelerate normally when the gas pedal is pressed, or stalls before developing power.
high back pressure: High resistance condition in a vehicle exhaust system that reduces engine power and performance.
high-efficiency air filter: A passenger compartment filter that cleans the air by trapping pollen and other particles in the air.
high fluid level: Overfill of fluid in a transmission that can cause churning and foaming within the system. This may lead to engagement and shifting problems.
high impedance fuel injector: Fuel injector that should have an internal resistance of between 10 and 12 ohms.
high-input failure: Specific type of computer system failure that results when the signal reaching the ECM has more voltage, more current, or a higher frequency than normal.
high-intensity discharge bulb (HID): Lightbulb that uses a high-voltage electric arc between electrodes to excite xenon vapor in the bulb, producing an extremely bright light.
high oil consumption: Lubrication problem caused by external or internal oil leakage, requiring oil to be added to an engine frequently.
high oil pressure: Condition when oil faces too much resistance as it tries to lubricate. It causes the oil gauge to read higher than normal and can cause the oil filter to rupture.
high pressure cutout switch: A/C system control that prevents compressor damage from abnormal operating conditions by opening the compressor coil circuit when discharge pressure is too high.
high-pressure spare: Type of compact spare tire filled to a higher-than-normal air pressure—usually around 60 psi.
high-pressure washer: Engine-powered water pump assembly using a hose and spray nozzle to shoot an adjustable stream of water at various velocities. It is used to remove dirt, oil, and hardened substances from parts.
high side: Part of an A/C system that consists of the parts between the output of the compressor and the flow-control restriction. It is also known as the discharge side.
high-time: See *on-time*.
high-voltage buffer zone: Perimeter of about 3 feet completely surrounding a hybrid electric vehicle, created before servicing the vehicle to prevent electrocution. There should be no other potential conductors of electricity in this area.
high-voltage disconnect: Device on hybrid electric vehicles located near the battery pack, commonly a switch, handle, or connection, that allows the HV battery to be physically disconnected from all vehicle circuits.
hold-down spring: Holds the brake shoes against the backing plate when the brakes are in the released position.
holding device: Device that holds an item or piece in place. It is meant to free a technician's hands to use other tools.
holding fixture: An apparatus used to securely hold heavy or clumsy parts, such as cylinder heads, transmissions, or transaxles during repairs. It is also referred to as a stand.
hole gauge: Gauge for measuring very small diameter holes in parts where an internal micrometer cannot be used.
horn system: Vehicle system that uses a switch mounted on the steering wheel and a relay to send current to the horn. The horn uses a coil-operated diaphragm to produce sound waves and an audible sound.
hose clamp: Tightening device used to secure hoses tightly to their metal fittings.
hose inspection: Process of checking for deterioration, splitting, cracking, or other signs of impending failure in a system's hoses.
hose spring: Spring frequently installed inside the lower radiator hose to prevent the hose from collapsing.
hot spark plug: A spark plug that has a long insulator tip and tends to burn off deposits for a self-cleaning action.
hot spot: Area in an engine suffering from an abnormal buildup of combustion heat.
hot tank: Tank that uses heat and very powerful cleaning agents to clean engine parts. It is used to aggressively remove mineral deposits, hard carbon deposits, oil, grease, and paint.
hot wire: Wire that carries current to the load. It is the part of the circuit between the positive terminal of the battery and the load.
hot wire short to ground: A short that produces low circuit resistance and extremely high current, usually blowing the fuse or circuit breaker.
Hotchkiss driveline: Type of driveline that uses an exposed drive shaft with two universal joints to operate a rear axle assembly. Springs are used on the "live" rear axle to limit movement and twist.
hourly rate: A pay system in which a stated amount of pay is given for each hour worked.
hub: Mounting plate for the wheels on the end of an axle, spindle, or bearing.
hub and wheel bearing assembly: Parts and components that attach a hub and wheel bearings to a vehicle axle. The hub provides a mounting place for a wheel, and along with the wheel bearings, provides a means to transfer axle rotation to the wheels.
hub locknut: Locknut fastener that screws on the end of an axle shaft to secure the hub and other parts of assembly. It is also termed an axle locknut.
hunting gearset: Term for a gearset that does not mesh the same ring and pinion gear teeth during each revolution of the ring gear.
HV: Abbreviation for high-voltage.
HV battery: High-voltage nickel metal hydride or lithium-ion battery capable of 100–300 volts of electricity. They are used alongside a conventional 12-volt lead-acid battery in many hybrid vehicles. They are also called a battery stack or battery bank.

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HV battery amp-hour rating: Rating that compares the electrical power available for one hour of continuous discharge. This is the equivalent of the cold cranking rating.

HV battery cables: Two orange conductor cables that connect direct current to the HV power control module.

HV battery continuous power rating: Measurement of the amount of voltage and current that can be safely generated before the battery is fully discharged.

HV battery control module: Computer that monitors HV battery pack temperatures, input and output levels, recharge and discharge voltages, and battery state-of-charge.

HV battery cooling system: System that uses circulated air or liquid to carry heat away from battery packs and out of the battery housing when under high amperage draw.

HV battery cover: Enclosure that holds high-voltage battery modules to protect against damage.

HV battery ECM: Electronic control module that interprets signals from HV battery temperature and voltage sensors to avoid battery overheating.

HV battery fan: Fan energized by a hybrid vehicle ECM to force fresh air through an air-to-liquid heat exchanger and over the battery pack outer surfaces for cooling.

HV battery frame: Metal holder that secures the battery packs together and attaches them to the vehicle frame.

HV battery nominal operating voltage: The maximum dc voltage available from the HV battery.

HV battery pack: Set of low-voltage battery cells wired in a series to produce a high-wattage means of storing chemical/electrical energy. Each battery pack has six or more battery cells enclosed in a housing.

HV battery peak power rating: Measurement of the amount of current that can be fed to the HV motor for a short period of time. This can determine the vehicle's acceleration speed with full-electric propulsion.

HV battery radiator: Small air-to-liquid heat exchanger mounted in the battery housing. Intake air is routed through the cool fins of an intercooler or heat exchanger before it circulates over battery packs.

HV battery state-of-charge (SOC): Voltage condition of an HV battery usually shown on a hybrid dash display. The value should be at least 80% of maximum voltage rating after a full recharge. When it drops below 20–30%, the motor-generator recharges the battery.

HV battery temperature sensor: Sensor that monitors the temperature of an HV battery to prevent battery thermal and overheating damage.

HV capacitor bank: Electrical energy storage device that does not require an electrolyte, but consists of at least two electrical conductors separated by an insulator. HV capacitor banks are light, wear-proof, and can accept or output short bursts of high-power electrical energy.

HV ECM cooling system: System that forces air or a liquid through or over an aluminum heat sink surrounding the high-power transistors for each leg of the three-phase ac motor/generator assembly.

HV flywheel generator: Generator that accelerates a large flywheel rotor around electromagnets to store large amounts of electrical energy. It is also called a kinetic energy generator.

HV motor: A motor powered by electricity that is used to propel, or assist in propelling, a gas-electric hybrid vehicle.

HV motor-generator cables: Cables electrically connecting three-phase alternating current from the power control module to the motor-generator with each cable carrying a single phase of ac.

HV motor-generator cooling system: System that uses liquid coolant to prevent the traction motor from overheating in full-electric and hybrid gas-electric vehicles.

HV PCM cooling system: System that often uses the same electric water pump and circulated liquid coolant as a motor-generator and HV battery to cool the module.

HV PCM water jacket: Area formed between inner and outer housings surrounding the high-power, control circuit boards mounted on a heat sink (inner PCM housing contacting coolant).

HV power cable: Consists of all large-diameter, high-voltage conductors wrapped in orange plastic insulation that electrically connect the HV battery, HV power control module, and motor-generator.

HV power cable leakage: Can be discovered by measuring the cable's resistance to ground. A grounded ohmmeter should read infinite resistance with good insulation. Any resistance reading shows unwanted current leakage to ground.

HV power cable resistance: Measurement of current flow restriction that should read less than 0.001 ohm (1 milliohm) per 10 feet of cable. Add approximately 0.025 ohm per electrical connection.

hybrid air bag: Air bag used in hybrid vehicles that uses two methods to inflate the air bag: a small explosive charge and a pressurized gas cartridge.

hybrid air cooling system: System that uses an electric blower fan and a system of ducts to route cool passenger compartment air around the high-voltage battery pack.

hybrid battery cell: Individually sealed rechargeable battery containing a semi-solid electrolyte around positive and negative plates. Each nickel-metal hydride (NiMH) or lithium-ion cell generates about 1.2–1.6 volts dc.

hybrid battery pack: Several battery modules wired in series that generate high-voltage dc. The power control module converts battery pack voltage to ac or changes it to a higher or lower voltage.

hybrid brake: A form of regenerative braking. This electric braking system works with the conventional hydraulic brakes to slow the vehicle, while at the same time generating electricity to recharge the vehicle's HV battery.

hybrid control module: Electronic control circuit that measures driving conditions, voltages, and current loads to efficiently operate the motor-generator, HV PCM, and battery.

hybrid drive ready light: A light in a combination meter that blinks or glows to signify when the electric drive is engaged and the vehicle is ready to be driven.

hybrid electric vehicle (HEV): Vehicle that uses two different sources of propulsion to power the vehicle drive train.

hybrid ground fault interrupter: A device that continuously monitors a hybrid electric vehicle's system for any high-voltage loss into the metal frame of the vehicle. If detected, a warning light is activated, and the module de-energizes the main power relays to disconnect the battery pack from its electric drive circuit.

hybrid liquid cooling system: System that uses an electric water pump, small diameter hoses, and a separate radiator or heat exchanger to pull heat out of an HV battery, HV power control module, and motor-generator.

hybrid master warning light: A light in a combination meter that warns if there is a problem in any part of the gas-electric hybrid drive train.

hybrid power cable: Heavy-gage wire that transfers extremely high voltages to the components of a hybrid's electric drive system. The power cables are heavily insulated to prevent these voltages from shorting to ground.

hybrid power control module: Set of high-power circuits that manage the flow of electrical energy through a hybrid vehicle's electric drive train.

hybrid power display: A display in a combination meter that informs a driver of the hybrid drive operating conditions such as energy efficiency and battery life.

hybrid transmission: Automatic transmission in a hybrid vehicle modified with an electric drive motor-generator(s) for electric drive propulsion, high-voltage battery recharging, and regenerative braking.

hydra-booster: See *hydraulic booster*.

hydraulic booster: A power brake hydraulic booster that uses power steering pump pressure to help the driver apply the brake pedal. It uses fluid pressure, instead of vacuum, to help force the piston forward. It is also termed a hydra-booster or hydro-boost.

hydraulic brake: Type of brake that uses fluid pressure to actuate braking.

hydraulic circuit diagram: Diagram that shows the fluid passages and connections to components and parts within a hydraulic circuit.

hydraulic clutch release mechanism: Type of clutch release mechanism that uses a simple hydraulic circuit to transfer clutch pedal action to the clutch fork. The circuit includes a clutch cylinder, hydraulic line, and slave cylinder.

hydraulic four-wheel steering system: Type of four-wheel steering system that uses a

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conventional power rack-and-pinion steering system up front. A rear power steering pump, which is driven by the differential, provides fluid pressure for a control valve that operates the rear steering system when a set road speed is reached.

hydraulic line: System of steel tubes and rubber hoses that contain and move high-pressure fluid within a hydraulic system.

hydraulic press: A machine that uses hydraulic pressure to produce tons of force for assembly or disassembly of pressed-together components.

hydraulic pressure modulation: Refers to the electro-hydraulic unit's ability to rapidly cycle pressure to the wheel cylinders or calipers on and off, preventing wheel lockup and skidding.

hydraulic system: Arrangement of pistons and tubing that use fluid pressure to transmit force from one part to another.

hydraulic tool: A tool powered by pressurized liquid.

hydraulic valve lifter: A valve lifter that uses hydraulic pressure from the engine's oil system to keep it in constant contact with both the camshaft and push rod/valve stem.

hydro-boost: See *hydraulic booster.*

hydrocarbon (HC): Highly flammable chemical mixture of about 12% hydrogen and 82% carbon that makes up the majority of crude oil. It is also an exhaust by-product of burned fossil fuels.

hydrogen: Highly flammable gas that could be a promising future automotive fuel due to its ideal burning characteristics, abundant availability, and harmless environmental by-products.

hydrometer: Tool used to measure the specific gravity (weight or density) of a liquid. A battery hydrometer finds the specific gravity of the electrolyte, which is an indication of the battery's state of charge.

hydrometer reading: Displayed in different ways depending on the type of hydrometer used. A fully charged battery should have a hydrometer reading of at least 1.265.

hydroplaning: A loss of control that occurs when a layer of water prevents a tire's tread from contacting the road surface.

hypoid gear: Gear used in applications where power flow must be diverted by some angle. Similar to spiral bevel gears except the driving pinion gear meshes with the ring gear below the centerline of the ring gear.

I

icon: Small pictures used on modern alignment equipment to help operate the equipment.

idle air control motor: Solenoid- or servo motor-operated air bypass valve that may be used to help control engine idle speed.

idle air control motor tester: Tool that energizes the solenoid or servo motor to check its effect on engine idle speed.

idle live reading: Typical circuit value with an engine running at curb idle speed and full operating temperature.

idler arm: Part of the parallelogram steering linkage attached to a vehicle frame opposite the pitman arm to prevent unwanted flexing of the center link.

idling: Term for an engine running while the vehicle is not in gear.

ignition coil: Device used to produce the high voltage needed to fire the spark plugs for ignition.

ignition coil open-circuit voltage: Maximum voltage potential of the ignition coil that ranges from 40,000–100,000 volts in late-model designs.

ignition control module (ICM): An "electronic switch" that turns the current flow through an ignition coil on and off based on data from the ECM and crankshaft and/or camshaft position sensors.

ignition lag: Time lapse between initial fuel injection and actual ignition (burning).

ignition load test: Test that measures spark plug firing voltages when engine speed is rapidly increased. It is also referred to as an acceleration test.

ignition lock mechanism: Device, normally located on the top, right-hand side of a steering column, that locks a vehicle ignition.

ignition supply voltage test: Test that measures the amount of voltage going to the positive terminal of the ignition coil(s).

ignition switch: Key-operated switch mounted in a steering column for connecting and disconnecting power to the ignition and electrical system. When turned to start, the ignition switch closes the starter relay to complete the circuit to the solenoid windings and on to the starter motor to crank the engine. It is also called a start switch.

ignition system: Components that produce a spark to ignite the air-fuel mixture in the engine.

ignition system supply voltage: Voltage that is fed to the ignition system by the battery, alternator, or HV PCM.

ignition timing: Relationship between the exact time a plug is fired and the position of the piston in terms of degrees of crankshaft rotation. It is also known as spark timing.

I-head engine: See *overhead valve engine.*

illuminated entry system: Turns on the interior lights when the vehicle door handle is moved or the door is opened. These systems can vary from simple to complex.

IM 240 test: Type of emissions test that is performed by state sponsored I/M programs. A vehicle is placed on a dyno and operated at real driving conditions while exhaust gas is sampled from the tailpipe.

impact driver: Tool that, when struck with a hammer, exerts a powerful turning and downward force to loosen extremely tight screws.

impact extension: Case-hardened steel extension that must be used with air and electric impact wrenches. It has a black matte finish and is thicker and much stronger than conventional chrome-plated extensions.

impact sensor: Sensor mounted in the front or side of the vehicle that tells the air bag control module that a collision has occurred.

impact socket: Case-hardened steel socket that must be used with air and electric impact wrenches. It has a black matte finish and is thicker and much stronger than conventional chrome-plated sockets.

impact wrench: Heavy-duty compressed-air wrench that provides a very fast means of installing or removing threaded fasteners. An impact wrench uses an air motor to produce a striking force to rotate a driving head. It is also called an air wrench.

impedance: Resistance to alternating current at a given frequency.

impeller: A wheel-like device that has fins cast into it. It is the driving fan that produces oil movement within a torque converter. It is also termed a converter pump.

impeller electric fuel pump: Pump that spins an impeller (fan blade) to produce centrifugal force. Fuel moving outward due to this force produces enough pressure to propel the fuel through the fuel lines.

improper range/performance failure: Specific type of computer system failure that occurs when a sensor or actuator produces values slightly lower or higher than normal.

improper wheel balance: A tire and wheel assembly with an uneven distribution of weight. If one side is heavier than the other, the tire will rotate incorrectly, causing tire and steering wheel vibration.

inboard CV joint: A constant velocity joint that can move in and out to compensate for changes in drive axle length as the wheels move in relation to the transaxle. It connects the inner stub shaft to the interconnecting shaft in a swing drive axle.

incandescent lightbulb: Bulb that generates light by sending current through a filament (usually tungsten resistance wire) inside a vacuum. This produces heat and the emission of light energy.

incorrect camber: Produces wear on one side of the tire tread.

incorrect shift point: Problem in an automatic transmission where the timing of a gear shift is delayed, rushed, or fails completely.

incorrect toe: Causes a feathered edge to form on the tire tread.

independent drive axle assembly: An axle assembly made of multiple shafts connected by a universal joint. The flexible nature of the assembly allows for smooth operation and transfer of power from the differential to the hubs and drive wheels of the vehicle.

independent shop: An automotive repair facility that is not affiliated with a vehicle manufacturer, retail store, or franchise operation.

independent suspension: A suspension system that allows each wheel to move up and down without influencing the other wheel on that axle.

indicated horsepower (ihp): Amount of power formed in an engine's combustion chambers, measured by a special pressure-sensing device.

indicator light: Light in a vehicle instrument cluster that indicates various system statuses and warns of a system problem.

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indirect injection system: Type of fuel injection system that sprays fuel into an engine intake manifold or intake ports.

indirect tire pressure monitoring: Type of tire pressure monitoring system that relies on the anti-lock brake system wheel speed sensors, instead of separate sensors, to monitor wheel rotational speeds and tire pressure.

induction: The imparting of electricity to an object by passing it through magnetic fields.

inductive pickup: A test lead for a multimeter that is placed around a current-carrying wire to make an amperage reading by measuring the magnetic field around the wire.

inductive wire tracer: Instrument (consisting of a pulse generator and an inductive probe) that can be used to find internal breaks in wires and disconnected wires or terminals. As the pulse generator produces a low-voltage alternating current in the wiring, the inductive probe is moved along the wire. The tracer makes an audible beeping sound if the wire has continuity and is carrying the pulsing signal. A break in the wire or a poor connection causes the signal to stop or change tone.

inertia: Force that tends to keep stationary objects from moving and keeps moving objects in motion.

inertia ring: Part of a harmonic balancer that, along with the rubber ring it is positioned on, sets up a damping action on a crankshaft as it tries to twist and untwist.

inertia switch: Switch that can be used to block current flow to the electric fuel pump after a severe impact or collision. After a collision, a button on the inertia switch must be pressed before the electric pump will function again.

inertia switch circuit: Circuit that controls a switch that can be used to block current flow to the electric fuel pump after a severe impact or collision.

infinite resistance: Description of a circuit path that is not complete; current is blocked through the tested circuit or component. It is displayed on a digital multimeter as an ∞ (infinity) symbol.

inflatable door impact beam: An experimental automotive protective device that employs a powerful pyrotechnic charge that is used to expand the metal beam so it balloons out to a larger diameter. The larger beam can withstand more violent collisions.

inflatable seat belt: Seat belt that uses small air bags located in the shoulder harness straps.

infrared sensor: Sensor that sends out an invisible light beam from the front of a vehicle. In a collision avoidance system, when the beam hits an object and returns to the sensor, the computer interprets the information.

injection line: High-strength stainless steel tubing that carries fuel to each injector nozzle within a diesel fuel system.

injection-pressure test: Test that uses a pressure transducer (sensor) and scope to measure instantaneous pressure in fuel injection lines or a fuel rail.

injection pump: A high-pressure, mechanical pump. It is powered by the engine and forces fuel to the diesel injector under very-high pressure.

injection pump camshaft: Engine-powered rod that spins inside an inline diesel injection pump, moving its lobes against pump roller tappets to operate the pump plungers.

injection pump roller tappet: Spring-seated roller that rides against an injection pump camshaft to transfer the camshaft motion to pump plungers.

injection pump solenoid: Electronic device that controls injection timing and injection quantity with signals from a computer.

injection pump vent: Small passage in a diesel injection pump that allows fuel to return to the fuel tank.

injection timing: The relationship between injection of fuel and the positions of the engine's pistons.

injector balance test: Test that measures pressure drop and flow from fuel injectors.

injector body: Main section of a fuel injector, which houses its various parts and fuel passages.

injector leakage: Dripping or draining of fuel from a fuel injector. This problem points to a dirty injector nozzle or worn components.

injector maximum flow test: Test that fires each fuel injector for a predetermined amount of time while measuring flow through the injector with the injector pintle and nozzle held fully open.

injector nozzle: Spring-loaded valve that sprays fuel into an engine combustion chamber.

injector pressure chamber: Chamber machined into the inner cavity in an injector body around the tip of a diesel injector needle valve. Injection pump pressure forces fuel into this chamber to push the needle valve open.

injector pulse width: Shape of an electronic signal that determines the amount of time each fuel injector is energized and kept open to spray fuel into an engine.

injector spring: Spring fitted around a diesel injector needle valve that holds this valve in the normally closed position. Spring tension helps control injector opening pressure.

injector substitution: Simple way to verify a fuel injector problem by installing a good injector for the one being tested.

inline diesel injection pump: Type of diesel injection pump featuring plungers lined up in a row, similar to pistons in an inline engine. It can be used with all hydraulic or electro-hydraulic injectors.

inline engine: An engine with its cylinders arranged in a single straight row. Each cylinder is placed in a straight line parallel to the crankshaft.

inline pump plunger: Small piston inside an inline diesel injection pump that pushes on and pressurizes diesel fuel.

inner race: Steel cup or cone that rests on a spindle or drive axle shaft to serve as an inner surface for wheel bearing rotation.

inner stub shaft: Section of front-drive axle that is splined to side differential gears. It is connected to the interconnecting shaft through a universal joint.

inner tube: Soft, thin rubber liner tube fitted separately inside an older tire to accept air pressure to inflate the tire.

input: An electrical signal of a vehicle condition that is received and used by a computer.

input gear: Machined gear on a transmission input shaft that drives the forward gear on the countershaft assembly. A spur gear may be used for synchronizer engagement.

input shaft: A splined shaft that delivers power to a mechanism, such as the transmission input shaft delivering power to the transmission gears. It is also called a turbine shaft.

inspection and maintenance program: See *emissions testing program.*

inspection facility information section: Part of a vehicle inspection report that identifies the emission inspections facility and inspectors, as well as date and time of the test.

instrument cluster: Housing and clear plastic cover that holds most of the dash gauges, speedometer, and indicator lights. Digital instrument clusters do not use analog or needle gauges; but rather computer-driven numbers or graphic displays.

instrumentation electronic control module: A control module that reacts to signals from vehicle sensors, dash switches, and other ECMs to operate the digital or digital-analog displays in the dash.

insulated circuit resistance test: Test that uses a voltmeter to check for excessive resistance in an insulated, energized circuit.

insulating glove: Type of glove specially made to work on high-voltage components and cables. OSHA-approved lineman gloves or approved gloves with an insulation rating value of at least 1000 volts should be worn for hybrid electric vehicle service.

insulator: A substance that resists or stops the flow of electrons. Examples include air, glass, plastic, rubber, and porcelain. *Also,* a rubber bushing and metal insert that fits into a hole in a leaf spring to prevent rattles and noises.

intake air temperature (IAT) sensor: A sensor that uses a thermistor to measure the temperature of the air entering the engine. It is usually located on the air cleaner or on the engine air inlet duct to adjust air-fuel mixture. Cold air is denser than warm air, requiring more fuel for the proper air-fuel ratio.

intake camshaft phaser: Primarily increases engine power and torque by closely controlling airflow past intake valves and into cylinders.

intake manifold: Series of connecting tubes or housing between the throttle plate and the openings to the intake valves.

intake manifold gasket: Gasket that seals the joint between an intake manifold and a cylinder head.

intake manifold warpage: Condition in which an intake manifold's sealing surfaces are no longer flat.

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intake port: Large passages in the cylinder head from the intake manifold runners to the combustion chambers through which air-fuel mixture enters the cylinders. *Also,* a port, or vent, in a brake master cylinder that allows fluid to enter the rear of the cylinder as the piston slides forward.

intake stroke: The portion of the piston's movement that is devoted to drawing the air-fuel mixture into the combustion chamber.

intake valve: Valve through which air and fuel is admitted to the cylinder.

integral carrier: Type of differential carrier that is constructed as one piece with the axle housing. A removable sheet metal or cast metal inspection cover is available to service the rear end components.

integral-piston power steering system: Power steering system that uses an integral power steering gearbox or hydraulic piston assembly machined into the rack housing.

integral power steering gearbox: Gearbox that contains a hydraulic piston assembly machined directly into the worm-type steering gearbox, along with a flow-direction valve.

integral valve guide: Valve guide that is machined through the cylinder head casting.

integral valve seat: Precisely machined face on a valve port opening in a cylinder head casting.

integral voltage regulator: Device that uses an electronic circuit to control alternator output by changing the amount of current flowing through the rotor's field windings. It is mounted inside or on the back of the alternator.

integrated ABS: Combines the power booster, master cylinder, and modulator units into one assembly. All these units are mounted together.

integrated circuit (IC): A single chip of semiconductor material that contains various electrical components in miniaturized form.

intercalation: Inside a rechargeable battery, the reversible embedding of protons and electrons in the porous electrode materials between the positive and negative battery plates.

interconnecting shaft: The center axle shaft in a front-wheel drive axle assembly that fits between the two universal joints and inner/outer stub shafts.

intercooler: An air-to-air or air-to-liquid heat exchanger mounted between a turbocharger/supercharger and a vehicle engine. Passing heated, charged air through an intercooler before entering an engine cools the air and increases engine power.

intercooler coolant: A mixture of 50% water and 50% antifreeze. A small reservoir is normally provided for servicing the coolant.

intercooler line: Metal or rubber line that carries coolant from an intercooler to an intercooler radiator and back to the intercooler.

intercooler pump: A small electric water pump that keeps coolant circulating through the cooling tubes and intercooler radiator.

intercooler radiator: A small heat exchanger for transferring heat from the intercooler coolant to the outside air.

interference angle: A 1/2° to 1° difference between the valve seat face angle and the angle of the valve face. This decreases the contact angle between the seat and the valve to speed up valve sealing during engine operation.

intermediate pipe: Steel tubing that carries exhaust between the catalytic converter and muffler.

intermediate section: Section of an oscilloscope pattern that shows voltage fluctuations after a spark plug stops firing but before the ignition control module allows current flow through the ignition coil. It is also referred to as the coil oscillations section.

intermittent: An event that occurs at varying intervals and/or under certain conditions.

intermittent fuel injection: Type of fuel injection in which injectors open and close regardless of intake valve positions.

intermittent problem: System malfunction that occurs infrequently, usually when certain conditions are met, such as temperature, humidity, vehicle operation, or in response to tests performed by a computer.

internal engine leak: Engine problem that can be represented by oil in a coolant reservoir tank.

internal lifter wear: When on a hydraulic lifter, wear prevents the lifter from pumping to take up valve train clearance.

internal oil leakage: Leaking oil within an engine. Burning engine oil will show up as blue smoke coming out an engine's exhaust.

International Automotive Technicians Network (iATN): An Internet website and community dedicated to automotive service technicians for assistance with vehicle diagnosis and repair problems.

interview: A meeting between a job candidate and an employer that allows the employer to more thoroughly question and examine the candidate's qualifications.

in-vehicle engine overhaul: Overhaul that can only be done when cylinder and crankshaft wear are within specifications and the oil pan and heads can be easily removed with the engine installed in the vehicle.

inverter circuit: Portion of the hybrid power control module that changes dc to ac and ac to dc.

ionization knock sensing system: A system used to detect knocking. In this system, the ECM prompts the ignition coil to send a low-voltage discharge across the spark plug gap immediately following combustion. Combustion quality affects the resistance across the plug gap by varying the degree of ionization in the gases between the plug electrodes.

isolation mode: An ABS operation mode whereby the ABS control module detects that a tire is starting to skid and energizes the modulator to isolate that hydraulic circuit from the other brake lines.

J

jack stand: An adjustable stand used to support an automobile that has been raised by a jack.

jet valve: Extra valve on an air jet combustion chamber that opens at low and idle engine speeds to inject an airstream to improve fuel mixing and combustion.

jounce: Term for the compression/bouncing movement of a coil spring.

jounce bumper: Blocks of hard rubber located directly beneath the upper spring seat to keep suspension system parts from contacting the frame or body when the car hits large bumps or holes.

jump start: Service procedure using jumper cables and another running vehicle to start a vehicle with a discharged (dead) 12-volt battery. One jumper cable is connected to the positive terminal on each battery. The other jumper cable is attached to the negative terminal of the charged battery and the frame (ground) of the dead vehicle, away from the battery. As the other vehicle runs, crank the ignition of the dead vehicle.

jumper wire: Short piece of insulated wire used to bypass electrical connections or devices to test operation. Most jumper wires have small alligator clips on each end.

junction block: An electrical block, usually located in an engine compartment. It contains fuses, circuit breakers, and relays to power high-amperage devices.

K

keep alive memory (KAM): A type of computer memory that stores changes in sensor values. It provides information to a computer's CPU so it can properly adjust signals to various output devices. It is sometimes referred to as adaptive strategy.

key: A small metal piece that fits into a groove partially cut into two parts to allow them to turn together.

keyless entry system: Device that allows a driver to unlock a vehicle's doors without using a key. The two basic types are remote and keypad-type keyless entry systems.

keyless entry tester: Device used to troubleshoot problems with the key chain sending unit and signal sensor of a vehicle's keyless entry system.

key-on/engine-off diagnostic: Diagnostics performed with the ignition key turned to the on position, but the engine not running.

key-on/engine-on diagnostic: Diagnostics performed with the engine running at full operating temperature.

keyway: A slot cut into a shaft, pulley, or hub that permits the insertion of a key.

kinetic energy generator: See *HV flywheel generator.*

kinetic energy recovery system (KERS): Fuel system design that captures kinetic energy generated during vehicle braking and stores the energy to assist in vehicle acceleration from a standstill. These types of systems use either a flywheel mechanism (mechanical) or a battery (electrical) to store the energy captured until it is needed.

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knee bolster: See *knee diverter.*

knee diverter: Thick plastic panel formed into the lower part of a dash as a restraint device to protect a driver's and the front passengers' knees from being injured on the metal frame of the dash. It is also called a knee bolster.

knock sensor (KS): Engine sensor that detects preignition, detonation, and knocking.

L

lack of engine power: Condition that causes a vehicle to accelerate slowly due to inadequate torque or horsepower. Various problems could be at fault. It is also termed a sluggish engine.

lap belt: Part of the seat belt that extends across a person's lap.

lapped: For a set of gears, it is a machine process that involves meshing and spinning the gears together with abrasive compound on their teeth. It decreases operational noise and increases service life.

lapping stick: A rod with a suction cup on the end used to spin a valve on its valve seat when checking valve-to-seat contact.

lateral acceleration: The amount of side force, measured in units of gravity (g-force), a vehicle can handle before its tires lose traction and skid in a sharp turn.

lateral acceleration sensor: Stability control system sensor that measures how much side force is generated by a turn.

lateral control rod: See *track rod.*

lateral runout: A measure of in-and-out movement, or wobble. It is measured in the direction that is lengthwise to the centerline of the rotating object.

lazy O_2 sensor: Term for an oxygen sensor that will not alter its output signal fast enough to maintain an efficient air-fuel ratio.

leading edge: See *rising edge.*

leaf spring: Spring assembly that consists of a series of curved steel strips, or spring leaves, that are stacked and held together by a large spring clip. Smaller clips are used to help hold the leaves in position.

leaf spring windup: A condition that causes rear leaf springs to flex when driving or braking forces are applied to the suspension system. This spring distortion can cause unintended vehicle body movements.

leak-down rate: The amount of time it takes the pressure inside a hydraulic lifter to bleed out.

lean air-fuel mixture: Fuel mixture that contains a large amount of air compared to fuel.

lean burn oxygen sensor: Type of oxygen sensor that measures the oxygen content in the exhaust of lean-burn engines. This type of sensor can measure ratios as lean as 23:1.

lean trouble code: Diagnostic code set if an O_2 sensor detects high amounts of oxygen in engine exhaust.

L-head engine: See *flat head engine.*

lift: Device used to raise a vehicle during service and repair procedures. It is a permanently installed fixture in many automotive repair shops.

lifting fixture: Device that attaches to the engine hoist and is then bolted or positioned on the engine's lifting points to lift the engine from the engine bay.

light-emitting diode (LED): Special diode that lights when forward-biased. It, along with a photo diode, is used to produce an engine speed signal for the ignition system.

light-monitoring system: Safety system that turns on a warning light in the instrument panel when a headlight, brake light, or other light burns out.

lighting system: A system that provides illumination inside and outside of a vehicle.

lightweight spare tire: Type of spare tire constructed with a thin tread and sidewall. It is lighter, making it easier to lift and replace than most spares, but must be driven with caution.

like charge: Same charged electrical fields that repel each other.

limited-slip differential: A differential unit designed to provide superior traction by transferring the driving torque to the wheel with the best traction. It is extremely useful in wet or icy conditions.

limp-in mode: ECM operation mode that engages in case of total failure. It allows limited vehicle operation so the vehicle can be driven to a repair shop.

line boring: A precise machining operation that cuts a series of aligned holes through an engine block for crankshaft main bearings or camshaft bearings.

line honing: Straightening or truing misaligned main bearing bores by scratching abrasive stones against their surfaces.

liner: Thin, rubber layer of a modern tubeless tire that creates a leakproof membrane. It is bonded to the inside of the plies.

liner protrusion: See *sleeve protrusion.*

linkage steering system: Steering system that transmits the rotation of the steering wheel through a worm-type steering gearbox to the steering arms, which act on rods connected to the wheel assemblies.

liquefied petroleum gas (LPG): One of the lightest fractions of crude oil that is a gas at room temperature and pressure. LPG requires a special fuel system to meter it into the engine if used in automobiles.

liquid cooling system: Circulation of a heat-absorbing medium through engine passages, with the accumulated heat dissipated by further circulation through heat exchanger (radiator).

liquid crystal display (LCD): A device that has a fluid crystal material sandwiched between two sealed glass plates. This device can polarize light (make all the light waves vibrate in a single plane) to display numbers, letters, or other images.

liquid electrical tape: A liquid coating that, when it dries, creates a plastic or rubber-like substance that protects a conductor.

liquid-vapor separator: Valve above the main fuel tank used to keep liquid fuel from entering the EVAP system.

liter (L): Metric unit commonly used to refer to engine displacement. Measuring volume, one liter is equal to roughly 61.023 cubic inches.

load: Electric current-using device.

load at misfire: Readout of the load (as a percentage) when an engine misfire happened.

load conversion chart: Table used to determine how much current draw should be applied to a battery for a load test. It is usually provided with the load testing equipment to convert battery ratings to load test amps.

load tester: Device used to check the condition of a vehicle's battery, charging system, and starting system. It measures both system current and voltage while applying a load to the system.

load voltage: Voltage at the vehicle battery with the engine running and all electrical accessories on.

local interconnect network (LIN): A data bus system that is designed to work in conjunction with CAN.

location grid: A grid used to locate components or connections quickly on a large wiring diagram. It is an alphanumeric system marked off around the outside of a wiring diagram.

locking hub: Controllable components that transfer power from the front driving axles to the front driving wheels on a four-wheel-drive vehicle.

locking pliers: Handheld tool that, due to its strong clamping and locking ability, is helpful for removing fasteners with heads that are badly rusted, rounded off, or damaged.

locking steering wheel: When the ignition key is off, a steel pin slides into mesh with a slotted disc that is splined to the steering shaft so the steering wheel cannot be turned.

lockup torque converter: A torque converter with an internal clutch that locks the turbine to the impeller when the automatic transmission is in direct drive or overdrive.

long-short arm suspension: Suspension design that uses control arms of different lengths to keep the tires from tilting with suspension action.

long-term fuel trim: Term for a permanent adjustment of injector pulse width to compensate for altered engine operating parameters.

longitudinal: Lengthwise; term used to identify an engine mounted with its centerline parallel to the centerline of the vehicle.

longitudinally split: Type of front to rear brake system in which one master cylinder piston operates the front wheel brake assemblies and the other operates the rear brake assemblies.

low back pressure: Low resistance, ideal condition in a vehicle exhaust system that increases engine power and gas mileage.

low boost pressure: Condition in a turbocharged/supercharged system caused by various issues that results in a lack of engine power.

low brake pedal: A brake pedal that travels too far toward the floor before fully engaging the brakes.

low engine compression: Condition in which an engine is operating on cylinders that are providing insufficient compression pressure.

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low fluid level: Fluid in a transmission below normal standards. A low fluid level can cause air to enter the system, leading to engagement and shifting problems as the oil pump builds pressure too slowly.
low fluid warning light switch: When mounted in the brake fluid reservoir, the switch contacts close when the brake fluid falls below a certain point.
low impedance fuel injector: Fuel injector that should have an internal resistance of about 0.5 to 3 ohms.
low-input failure: Specific type of computer system failure that produces voltage, current, or signal frequency below normal operating parameters.
low oil pressure: Condition when oil is not adequately pressurized to reach all lubrication areas. It is indicated when the oil indicator light glows, the oil gauge reads low, or the engine lifters or bearings rattle and knock from lack of lubrication.
low oil pressure safety circuit: Circuit designed to shut off the electric fuel pump if the engine is operating on low oil pressure or the oil pump fails.
low-pressure cutout switch: In an A/C system, shuts off the compressor when system pressure drops below a certain point to prevent compressor damage.
low side: Part of an A/C system that consists of the parts between the flow-control restriction and the inlet of the compressor. It is also called the suction side.
low-time: See *off-time.*
lower spring seat: A lower mount on a strut assembly formed around the shock body into which a coil spring fits.
lubrication service: Maintenance service of checking, adding, or replacing vehicle fluids. It also includes greasing vehicle components for proper usage and examining for problems.
lubrication system: Method of distributing lubricant (oil) to moving parts to minimize friction.
lubricator: Device that is part of a compressed-air system used to introduce oil into the airstream for improved air tool life.
lug bolt: Threaded bolt that screws into a hole in the axle hub or flange to hold the wheel.
lug nut: Fastener nut threaded on a lug stud and tightened to hold a wheel on an axle hub.
lug nut torque: Tightening force specification for lug nuts that attach a tire and wheel assembly to an axle hub.
lug stud: Special stud pressed through the back of an axle hub or flange that accepts the lug nut.

M

machine screw: Small screw that resembles a bolt. It is used on various machine parts needing just a light clamping force.
MacPherson strut suspension: Suspension system that uses only one control arm and a strut for each wheel assembly.
magnafluxing: Testing procedure that uses a magnet and metal powder to find cracks in cast iron parts.
magnet-and-ball sensor: Impact sensor that uses a small permanent magnet to hold a steel ball away from the electrical contacts in the sensor.
magnetic clutch: Used to engage and disengage the air conditioning system compressor.
magnetic field: Invisible lines of force between the poles of a permanent magnet and around the outside of current-carrying wire.
magnetism: Invisible lines of atomic force that attract or repel ferrous metals through space, air, or solid matter.
mag wheel: Nickname for a wheel constructed of aluminum or magnesium.
main bearing bore: Holes machined in the bottom of an engine block to hold the crankshaft.
main bearing cap: Metal caps fastened to the bottom of a cylinder block to form one-half of the main bore. They hold the crankshaft and main bearings in place.
main bearing knock: Deep, dull rapping noise from a crankshaft moving excessively inside a cylinder block. It is caused by bearing wear, and possibly journal wear.
main oil galleries: Large oil passages through the center or side of a cylinder block casting that connect to small oil galleries within an engine.
main shaft: See *manual transmission output shaft.*
main shaft gear: See *output shaft gear.*
maintenance-free battery: Type of lead-acid battery that does not have removable filler caps. Calcium in the battery plates reduces the battery gases and eliminates the need for water to be periodically added to the electrolyte.
main thrust bearing: Flanged version of a main bearing, designed to limit crankshaft end play.
main wiring diagram: A large diagram that contains symbols for all major wiring and electric/electronic components on a vehicle. It may vary depending on the manufacturer.
malfunction indicator light (MIL): Amber-colored light in an instrument cluster, commonly called a Check Engine or Service Engine Soon light, used to indicate that a problem exists in a vehicle's computer control system. It is also a generalized term used for any instrument cluster light used to indicate a problem in a system.
manifold absolute pressure (MAP) sensor: Sensor that monitors manifold pressure by producing an electric signal proportional to the pressure or vacuum inside an engine intake manifold. Manifold pressure is an excellent indicator of engine load.
manifold runner: Internal passages made in an intake manifold to carry either the air-fuel mixture or air to the cylinder head ports.
manual air bag deployment: Deploying an air bag by connecting a voltage source to the air bag module wires to "fire" the air bag.
manual bleeding: Process of using master cylinder pressure to force fluid and trapped air out of a brake system.
manual locking hub: Type of locking hub in a four-wheel-drive vehicle that requires the driver to turn a latch on the hub to lock it into four-wheel drive.
manual suspension leveling system: Switch-activated system that uses air shocks and an electric compressor to change vehicle suspension height based on load weight.
manual tilt steering column: Steering column that uses a hand lever on the column to unlock a flex joint so the wheel can be moved up or down.
manual transaxle: Combination of a manual transmission and a differential assembly. The gears are operated with shift forks, similar to those in a rear-wheel-drive manual transmission, controlled by the driver with a gearshift lever. Different combinations of gears are selected to obtain the desired gear ratios.
manual transaxle clutch: Clutch that resembles the clutch used with a manual transmission for a rear-wheel-drive vehicle. It uses a friction disc and a spring-loaded pressure plate bolted to a heavy flywheel.
manual transaxle input shaft: Shaft that receives power from the engine through the clutch and transmits it with gear meshing on the output shaft.
manual transaxle output shaft: Shaft that contains gears that mate with the input shaft. This rotating shaft, which holds output gears and synchronizers, delivers power to the transaxle differential.
manual transaxle transmission: Manual transmission assembly that connects to a vehicle transaxle. It provides several (usually four or five) forward gear ratios, a reverse gear, and sometimes an overdrive gear.
manual transmission: System with several gear ratios to allow for efficient operation under various conditions. The vehicle operator makes the gear selection decisions. Transmission gears and gear synchronizers are moved in and out of engagement by shift forks.
manual transmission case: Aluminum or cast iron housing that encloses the transmission shafts, gears, synchronizers, shift forks, linkage, and lubricating oil. In some designs, it is combined with the clutch housing.
manual transmission gear sensor: Sensor that monitors the position of reverse, neutral, and all forward gear ratios within a gearbox. It is a safety switch used if gears fail to shift properly. It is also known as a switching sensor.
manual transmission input shaft: Long shaft that extends from the rear of the engine crankshaft to the inside of the transmission case. It supports the clutch disc, holds it in proper alignment with the other clutch components, and transmits rotation of the clutch disc into the transmission. It is also called the clutch shaft.

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manual transmission output shaft: A splined, rotating shaft that delivers power to the drive shaft assembly and holds the output gears and synchronizers. It is also called the main shaft.

manual transmission pressure sensor: Sensor in an automated manual transmission that measures the pressure of the hydraulic fluid used to operate wet clutches that transfer power to different shafts and gears.

manual transmission shift solenoid: Computer-controlled solenoid that operates a metal plunger to slide or hydraulically move synchronizers into position. With wet clutches, it opens hydraulic spool valves to control oil flow.

manual transmission synchronizer: Assembly of hub, sleeve, and other components that locks the selected output gear to the output shaft to transmit power. It permits meshing of gears without grinding.

manual valve: Valve controlled by the shift mechanism and linkage that routes oil pressure to the correct transmission components based on the selected gear.

mass airflow (MAF) sensor: A digital sensor mounted on or near the engine intake manifold that produces an ac signal that changes in frequency as airflow into the engine changes.

mast: Rod mounted on a vehicle body that serves as an antenna.

master cylinder: A hydraulic piston-type pump that stores brake fluid and develops pressure for a brake system.

master cylinder filling tool: A tool used to automatically keep the master cylinder fluid reservoir full of brake fluid while bleeding or flushing.

master cylinder reservoir: Stores an extra supply of brake fluid.

master technician: Technician with extensive experience and knowledge of all specialized areas of automotive technology. He/she can diagnose, service, and repair each vehicle system.

matter: Anything that occupies space and has mass, or weight.

maximum inflation pressure: Tire marking that tells the highest air pressure that should be pumped into the tire.

maximum load rating: Tire marking that indicates the amount of weight the tire can carry at the recommended inflation pressure.

measuring system: A set of standardized units used for measurement.

mechanical efficiency: A measurement of mechanical friction; determined by the difference between brake horsepower (bhp) to indicated horsepower (ihp). Mechanical efficiency of 70–80% is normal.

mechanical four-wheel steering system: Type of four-wheel steering system that uses a special front rack-and-pinion gearbox with a transfer box. A shaft, controlled by the transfer box, extends back to a rear rack to turn the rear wheels.

mechanical fuel pump: Fuel pump mounted on an engine. Found in all direct injection engines, an eccentric lobe on the engine crankshaft powers the pump, pushing the pumping plunger into the pump to build pressure.

mechanical lifter: Solid lifter used in some older vehicles that transfers camshaft lobe action to the push rod. It must be adjusted periodically.

mechanical oil pump: Mechanical pump that provides hydraulic pressure for clutch application in an electro-hydraulic differential.

mechanical speedometer: Uses plastic transmission/transaxle drive gears, a metal speedometer cable, a cable housing, and a mechanical speedometer head to convey vehicle speed.

media blasting: System that uses compressed air to blast small, abrasive particles against a surface. It can remove paint, carbon, and other dry deposits from parts.

memory saver: Device that temporarily supplies enough power to prevent stored memory loss within the clock, stereo, and computer when a vehicle battery is disconnected.

memory seat: Type of seat that is connected to a computer and remembers the position of the seat, as dictated by the driver. The computer can usually store 2 or 3 driver settings.

memory tilt wheel: A steering wheel that uses a tilt control module, sensor, and motor to automatically retain and move the steering column to a driver's preprogrammed position with the press of a button.

metal additive: Tiny metal particles, commonly zinc or titanium, added to motor oil to reduce part wear by coating internal engine parts.

metering valve: Valve designed to equalize braking action at each wheel during light brake applications. A metering valve is used on vehicles with front-wheel disc brakes and rear-wheel drum brakes.

methanol: See *methyl alcohol*.

methyl alcohol: A colorless, poisonous, and very flammable liquid made out of wood chips, petroleum, garbage, and animal manure. It is also called wood alcohol or methanol.

metric (SI) measuring system: A system of measurement used nearly worldwide that operates with a power of 10 for all basic measurement units.

metric rule: A straightedge scale that has numbered lines representing millimeters. Each numbered line usually equals 10 mm, or 1 centimeter.

metric wire size: The cross-sectional area of a wire in square millimeters (mm^2). Unlike AWG gage numbers, metric wire sizes increase as the diameter of the wire increases.

micrometer: Tool capable of making small measurements accurate to one ten-thousandth of an inch (.0001") or one thousandth of a millimeter (0.001 mm).

micron: Unit of measure for millionths of an inch.

mid-engine drive train: Rear-wheel drive configuration with the engine located right behind the driver's seat with a transaxle mounted behind it. Equal weight is distributed to each tire for high cornering capabilities.

mil: Unit of measure for wire diameters. It equals 0.001 inch.

mild hybrid: Type of gas-electric hybrid vehicle that is propelled by an internal combustion engine only. The engine shuts down whenever the vehicle comes to a stop. An HV starter-alternator is used to restart and assist the engine during acceleration. Also called an assist hybrid.

milky transmission fluid: A white or nontransparent pink-colored transmission fluid. It is commonly caused by engine coolant mixing with transmission fluid.

Miller-cycle engine: Engine designed with a shorter compression stroke and a longer power stroke to increase efficiency. Commonly, a supercharger is needed to pressurize the intake manifold and block airflow as the intake valve remains open longer to delay compression.

mini catalytic converter: A very small converter placed close to an engine exhaust manifold. It heats up quickly to reduce emissions during engine warm-up.

misfire code: Scan tool readout that shows the engine has failed to ignite and burn its air-fuel mixture properly.

misfire data: Information stored in the computer indicating which cylinders are misfiring and how often.

misfire data value: Values collected by a scan tool indicating something is causing an engine cylinder not to fire.

misfire failure: Number of times an engine cylinder has failed to fire.

misfire history: Record of the number of times an engine cylinder has failed to fire.

misfire pass: Record that shows the number of times an engine cylinder has not misfired.

misfire rev. status: Misfire data that shows real misfires and rejected misfires (false data caused by rough road or other cause).

misfiring: Failure of one or more cylinders to fire and produce normal combustion power.

misfiring cylinder: Readout displaying the primary misfiring cylinder and the secondary misfiring cylinder by cylinder number.

mode switch: Dash-mounted switch that allows a driver to choose the desired shock action or ride stiffness and sometimes ride height in electronic suspension systems.

modified strut suspension: Type of suspension that has a coil spring mounted on top of the lower control arm, not around the strut.

molded hose: Hose manufactured in a special shape, with bends specific to an exact year and make of car in order to clear certain parts.

molecule: A group of two or more atoms joined together by a chemical bond.

monitor: Commonly a liquid crystal or plasma display screen that provides various graphic information from a mapping system, stereo, climate control, and other systems for the driver and passengers.

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motor-generator: Device that functions as both a powerful traction motor and as a high-energy alternator in a hybrid vehicle's power train.
motor-generator clutch: Clutch that engages its armature shaft to and from the engine crankshaft and the transmission shaft in a hybrid vehicle for different operations.
motor-generator coolant fitting: Fitting that allows a rubber hose to be clamped around the hose for a leakproof antifreeze connection.
motor-generator coolant hose: Hose that carries cooled coolant to, and heated coolant from, the motor-generator water jackets. Another hose creates a connection to the electric coolant pump or engine water pump.
motor-generator cooling system: System that removes excess heat from the stator housing and windings by the circulation of coolant through its outer housing.
motor-generator water jacket: Chambers machined inside the stator housing during manufacture that carry coolant to transfer heat away from the motor-generator.
motor-generator water pump: An electric coolant pump mounted between the system radiator and the stator housing that circulates coolant through the housing.
motor oil: See *engine oil.*
motor vehicle emission: Burned and unburned pollutant produced by car, truck, bus, and motorcycle engines and their fuel systems.
movable pole shoe starting motor: Starting motor that, when activated, pulls a pole shoe toward its armature with magnetic force, thus moving a drive yolk to slide the pinion gear to mesh with the ring gear.
muffler: A chambered unit attached to a pipe or hose that dampens pressure pulsations to deaden noise. On most vehicle exhaust systems, it is installed after the catalytic converter.
multi-cylinder engine: Engines that have more than one piston and cylinder. Automotive engines are classified as multi-cylinder engines.
multifunction switch: Switch capable of controlling several circuits. For example, headlights (bright and dim circuits) and turn lights simultaneously.
multimeter: Electrical test meter that can be used to test for voltage, current, or resistance. It is also referred to as a volt-ohm-ammeter or VOM.
multiple disc clutch: A clutch assembly that contains several clutch discs in its construction.
multiple discharge ignition system: Ignition system that fires the spark plugs more than once during each power stroke.
multiplexing: A method of using one communications path to carry two or more signals simultaneously.
multiplication: Arithmetic process in which the same number is added together a specific number of times.
multiport injection system: Type of indirect fuel injection system featuring a fuel injector mounted in each engine cylinder intake port.
multiviscosity oil: An engine oil that can exhibit different viscosity characteristics when heated or cooled.
mushroom valve: See *poppet valve.*
mushrooming: Condition where valve tips have been hammered larger by the action of the rocker arms.
mushy shift: Term for a gear shift in an automatic transmission that happens too slowly, causing the vehicle to feel sluggish.

N

narrow band oxygen sensor: Category of oxygen sensor that can only measure combustion efficiency near stoichiometric (chemically correct). Its output voltage toggles to show either a rich or lean condition.
National Institute for Automotive Service Excellence (ASE): A nonprofit organization formed to promote high standards of automotive service and repair through the voluntary testing and certification of technicians.
navigation system: System using the United States' satellite global positioning system to display the geographic location of a vehicle. Advanced systems can give other useful information: traffic information, roadwork, parking lot openings, miles to destination, turnoffs, etc.
negative battery cable: Cable that is normally black and connects to ground on the engine block or frame.
negative camber: The tops of the wheels tilt inward when viewed from the front.
negative caster: Tilts the top of the steering knuckle toward the front of the vehicle.
negative charge: An atom is said to have a positive charge if it holds excess electrons.
negative post: Battery post marked in black or green and with a negative (–) symbol. It is smaller than the positive battery post.
net horsepower: Maximum horsepower at the flywheel with all engine-driven accessories in use.
neutral safety switch: Switch wired into the circuit of the 12-volt starter solenoid that prevents the engine from cranking when the transmission is in drive or reverse.
neutral safety switch adjustment: Switch tightening or replacement needed when an engine will not crank with the shift selector in the *Park* position.
neutral steering: Ideal vehicle steering condition in which all four wheels have equal traction in turns.
neutron: One of the components of the nucleus of the atom; has no charge.
night vision system: An automotive security feature that uses an infrared camera and monitor system to help the driver's view in fog, snow, rain, and other vision-impairing atmospheric conditions.
no brake pedal: A dangerous condition in which the brake pedal moves to the floor with no braking action.
no-crank problem: Engine problem in which the crankshaft fails to rotate as the ignition key or starter button is activated.
noid light: Special test light used for checking electronic fuel injector feed circuits for battery power.
noise suppressor: Capacitor that absorbs voltage fluctuations in a vehicle's electrical system to reduce noise.
no-load voltage: Voltage at the battery with the engine running and the electrical accessories off.
nonadjustable rocker arm: Valve rocker arm that offers no means of changing valve lash/clearance.
nonhunting gearset: Term for a gearset that meshes the same ring and pinion gear teeth over and over during each revolution of the ring gear.
nonindependent suspension: Type of suspension that has both the right and left wheels attached to the same solid, inflexible axle, causing movement on one side to affect the other.
nonintegrated ABS: A conventional booster and master cylinder are used with a separate electro-hydraulic modulator.
non-resistor spark plug: A spark plug that has a center electrode that is one piece of metal rod.
nonthreaded fastener: A device, such as a snap ring, used to hold, or fasten, parts together without the use of threads.
non-vented fuel tank cap: Cap that prevents fuel vapors from entering the atmosphere through the tank's filler neck.
normal combustion: Term for efficient internal combustion within an engine that is a primary factor in maximizing fuel economy, engine power, and engine service life as well as lowering emissions.
normally aspirated engine: Engine that uses atmospheric pressure, not a turbocharger or supercharger, to force air into the engine. It is also called an atmospheric engine.
no-start problem: The engine is turned over by the starter, but fails to fire and run on its own power.
NPN transistor: A transistor that has two N-type semiconductors and one P-type semiconductor bonded together.
N-type semiconductor: A semiconductor that is doped so that it has excess electrons.
nucleus: The center of an atom.
nut: A fastener with internal threads to thread onto a bolt or stud and, commonly, a six-sided outer shape.
nut lock: Thin, slotted nut that fits over a spindle adjusting nut to secure the hub parts on an axle shaft.

O

O_2 sensor: See *oxygen sensor.*
OBD II drive cycle: Predetermined routine of acceleration, deceleration, and stops that allows the ECM to reset its emissions monitoring. It is usually performed after ECM replacement or before some emissions tests.
Occupational Safety and Health Administration (OSHA): A federal agency that gives general guidelines and rules for employee safety and the safe operation of work sites.

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octane enhancer: Alcohol made up of hydrogen, carbon, and oxygen that is used as a gasoline blending component to increase octane levels and reduce engine knock. It is also called an oxygenate.

octane rating: Numerical measurement of gasoline's ability to resist knock or ping. The higher the octane rating is for a fuel, the greater its ability to resist knock or ping.

odometer chip: Miniaturized circuit that stores mileage of the vehicle.

off-car balancer: Machine that spins a wheel and tire assembly, after it is removed from a vehicle, to determine where the wheel needs balancing.

off-time: Oscilloscope reading where a square waveform stays on zero volts. It is also called low-time.

ohm (Ω): Unit of measurement for resistance to the flow of electric current in a given unit or circuit.

ohmmeter: An electrical instrument used to measure the amount of resistance in a given unit or circuit.

Ohm's law: Formula for computing unknown voltage, resistance, or current in a circuit by using two known factors to find the unknown value.

oil additive: Increases the protective properties of mineral, vegetable, or synthetic motor oil.

oil-air separator: Device that makes oil vapors condense and flow back into an oil pan.

oil burn test: Test to determine if water is present in engine oil. Hold a lit match or lighter flame against oil on a dipstick. If there is even a slight amount of moisture in the oil, the burning oil will make a "cracking and popping sound."

oil change interval: Manufacturer specified maximum number of miles (or kilometers) a vehicle can be driven between oil changes.

oil clearance: Small space between moving engine parts for the lubricating oil film. It is also called bearing clearance.

oil cooler: An air- or liquid-cooled device used to remove excess heat from the engine or transmission oil.

oil dye: Fluorescent dye sometimes added to engine oil when checking for external oil leaks.

oil filter: A filter element installed on the engine. It filters dirt and foreign debris from the oil entering an engine.

oil foaming: Problem of air bubbles forming in the engine oil, which reduces the oil's lubricating ability, caused by overfilling the engine oil.

oil gallery: Cast or drilled passageway or pipe in an engine. A gallery carries oil from one part of an engine to another.

oil level sensor: Float-variable resistance or optical-type sensor mounted in a vehicle oil pan that registers the actual quantity of oil in the engine.

oil pan: Metal or plastic pan located on the bottom of an engine or transmission. It acts as a reservoir for oil or fluid.

oil pan baffle: Sheet metal panel used to keep oil from splashing up on a spinning crankshaft and oil foaming.

oil pickup: Tube and screen that connects to the oil pump and extends to the bottom of the oil pan to pick up oil.

oil pressure gauge: A dash-mounted instrument that provides oil pressure readings in pounds per square inch or in kilopascals.

oil pressure indicator: Warning light on control panel to alert driver to low pressure situation.

oil pressure sending unit: Device that uses a variable resistor to communicate vehicle oil pressure to a computer and operate an oil pressure gauge.

oil pressure switch: Switch opened and closed by oil pressure so that it can operate the dash indicator light and shut off the fuel pump to prevent engine damage if the oil pressure is low.

oil pressure test: Test that uses a pressure gauge to measure the actual pressure in an engine.

oil pump: Device for forcing oil under pressure to the points where lubrication is needed.

oil ring: The bottom piston ring, which scrapes oil off the engine cylinder walls.

oil service rating: Identification of type of service for which an oil is suited.

oil slinger: Washer-shaped part mounted on a crankshaft sprocket to throw oil onto a timing chain during operation.

oil spurt hole: Small hole drilled in a connecting rod for improved cylinder lubrication.

oil viscosity: A measure of the oil's thickness or ability to flow. It is also referred to as oil weight.

oil weight: See *oil viscosity.*

on-board diagnostics: Term for a vehicle computer's ability to analyze the operation of its circuits and to output data identifying any problems found.

on-board diagnostics generation one (OBD I): Classification referring to any computer control system installed on vehicles built prior to 1996.

on-board diagnostics generation two (OBD II): Enhanced diagnostic system required on 1996 and newer vehicles. Protocol also called for standardization of codes, data link connectors, and terminology.

one-channel ABS: ABS channel that normally operates the rear wheel brakes together.

one-way clutch: See *overrunning clutch.*

one-wire circuit: See *frame-ground circuit.*

on-time: Oscilloscope reading where a square waveform stays at maximum voltage. It is also called high-time.

open circuit: Electrical circuit with a gap or break in continuity so that current cannot flow.

open circuit voltage: The voltage between a two-terminal device without a load connected. Each battery cell has an open circuit voltage of 2.1 volts, giving a series-wired automotive six-cell battery a 12.6 open circuit voltage.

open cooling system: Cooling system that does not use a recovery tank. The overflow tube is not connected to a coolant reservoir, and excess coolant leaks onto the ground. This system has been replaced on automobiles by closed cooling systems.

open differential: A type of differential that, at all times, provides equal amount of torque to both driving wheels. If one wheel loses traction, the opposite wheel will not have enough torque to propel the vehicle.

open diode: A diode that has a high (infinite) resistance in both directions.

open loop: In reference to an electronic fuel injection system, an ECM uses preprogrammed information instead of exhaust gas content to determine efficient air-fuel mixture.

operating parameter: An acceptable maximum or minimum electrical value saved in permanent computer memory chips.

opposed engine: An engine with cylinders lying flat or horizontal on either side of the crankshaft. It is also termed a pancake engine or boxer engine.

optional wiring: Wiring provided in a circuit that may not be in use.

orifice tube: See *expansion tube.*

O-ring valve seal: A small, round rubber seal that fits into an extra groove cut in a valve stem. It seals the gap between the valve retainer and valve stem.

oscillation: A compression-extension movement of a spring that uses up the energy that was present in the compressed spring.

oscilloscope: Diagnostic instrument that displays line patterns that relate voltages to time. It is commonly called a scope.

other sensors: Parts of a stability control system that gives the ECM information about the driver's actions and the resulting vehicle motion.

outboard CV joint: A constant velocity joint that connects the interconnecting shaft to the outer stub shaft in a swing drive axle. It transfers power from the axle shaft to the wheel hub assembly. The outboard CV joint is usually a nonsliding joint.

outer drive axle: Stub axle shaft that extends through the bearings and is splined to the wheel hub.

outer race: Steel cup or cone pressed into a hub, steering knuckle, or bearing support to serve as an outer surface for wheel bearing rotation.

outer stub shaft: In a front-wheel drive vehicle, the short shaft connecting the outer universal joint and the front wheel hub.

output: Computer-produced electrical signals that are sent from a computer after processing input data.

output shaft: Splined steel shaft that transfers rotating torque out of a transmission to the rest of the transmission driveline. It is also termed the main shaft.

output shaft gear: Gear attached to a transmission output shaft that transfers the motion from the countershaft gear it contacts to the output shaft. It is also called a main shaft gear.

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outside work area: A designated area adjacent to an auto repair shop's overhead service doors that, in good weather, can be used as an open-air repair station.
over-advanced ignition timing: Occurs when the ignition spark happens too soon before the manufacturer's specified position of the piston during the combustion stroke. This causes the engine to suffer from spark knock, or ping, caused by abnormal combustion.
overboost: Term for too much supercharger boost to an engine.
overbore limit: Maximum amount that a block should be bored oversize without resulting in cylinder walls that are too thin.
overcharging: Problem that occurs when excess current is forced through a battery.
overcooling: Cooling system problem that occurs when an engine fails to reach full operating temperature, causing poor or sluggish engine performance.
overdrive ratio: An arrangement of transmission gears that results in the driven shaft turning more revolutions than the driving shaft, lessening torque output.
overhead cam (OHC) engine: Engine with camshaft(s) located in the top of the cylinder head. Push rods are eliminated and valves can be angled for improved engine performance.
overhead cam follower: A valve lifter fitted in a bore machined in a cylinder head directly between a camshaft and valve stem. Its clearance can be manually adjusted.
overhead valve (OHV) engine: Engine in which intake and exhaust valves are in the cylinder head. It is also called an I-head engine.
overheating: Cooling system problem that occurs when an engine operating temperature is too high, warning light is on, temperature gauge shows hot, or coolant and steam blow out of the overflow.
overinflation: Term for high air pressure within a tire, which pushes the center tread against the road but lifts to outer tread edges.
overrunning clutch: Mechanism that engages and locks a pinion gear in one direction when the armature is driving the clutch. When the engine starts, the clutch releases the pinion gear, allowing the gear to spin freely. It is also referred to as a one-way clutch.
oversteer: A vehicle steering issue in which the rear tires lose traction and slide sideways but the front tires retain traction as the vehicle goes through a corner. Controlled oversteer through a corner is known as drifting.
owner's manual: Booklet provided by the vehicle manufacturer to the purchaser of a new vehicle containing basic automotive and maintenance information about the vehicle.
oxides of nitrogen (NO_x): Undesirable compounds of nitrogen and oxygen in exhaust gases. They are usually produced when combustion chamber temperatures are excessively high.
oxyacetylene torch: Type of torch used to heat, cut, weld, or braze metal parts. The oxyacetylene setup includes an oxygen tank, an acetylene tank, pressure regulators, hoses, and a handheld torch.
oxygenate: See *octane enhancer.*
oxygenated gasoline: Reformulated gasoline containing additional oxygen sold in areas where ozone reduction is necessary.
oxygen sensor (O_2S): Exhaust sensor that measures the oxygen content in an engine's exhaust gases as a means of checking combustion efficiency. It is also called an exhaust gas sensor or O_2 sensor.
oxygen sensor contamination: Substances including leaded fuel, silicone, and carbon that damage and shorten the life of a vehicle oxygen sensor.
oxygen sensor monitoring: ECM tests to the primary and secondary oxygen sensors for abnormal voltage, slow response times, and similar problems.
oxygen sensor output voltage: Voltage output should cycle up and down from about 0.2–0.8 volts (200–800 mV). A 0.2 volt or low reading would show a lean air-fuel ratio and a 0.8 volt or high reading would show a richer condition.
oxygen sensor position: In a vehicle, oxygen sensor positions are assigned a number based on its location and order in relation to the engine's banks.
oxygen sensor signal generator: Tool for sending a false 200–800 mV signal to an engine control module for testing purposes.

P

pad-wear sensor: A metal tab on the brake pad that informs the driver of worn brake pad linings. The wear sensor tab emits a loud squeal or squeak when it scrapes against the brake disc.
pancake combustion chamber: Older, less common combustion chamber design with valve heads nearly parallel with the top of the piston.
parade pattern: Oscilloscope reading that lines up waveforms side by side across the screen. It is also called a display pattern.
paraffin: Wax substance that is found in diesel fuel.
parallel circuit: An electrical circuit that has more than one path for current.
parallel communication: Means of computer network communication that involves the use of several wires to exchange multiple bits of data simultaneously.
parallel hybrid: Gas-electric hybrid vehicle that uses both the internal combustion engine and the motor-generator to apply mechanical torque to the drive train.
parallel wire: Wire that has two or more individually insulated conductors or wires molded into one flat or round body of multicolor insulation.
parallelogram steering linkage: A steering linkage using two tie-rod assemblies connected to a long center link. The link is supported on one end by an idler arm and the other end is attached to a pitman arm. The two sides of the linkage run parallel and are equal in length, characteristics that give the linkage its name.
parasitic load: Any electric circuit draw present when the engine and all electrical devices are shut off. Circuits requiring small currents while the engine is not running (clock, ECMs, etc.) are included.
park assist tester: Device used to troubleshoot the output from a laser at the rear of the vehicle in a park assist system.
parking brake: See *emergency brake.*
parking pawl: A latch that locks the transmission output shaft so that the vehicle will not roll when the gear shift lever is in the *Park* position.
part: The smallest removable item on a vehicle. A part can also be referred to as a component.
part warpage: Condition in which the sealing surfaces on a part are not flat and therefore will not seal properly.
partially counterweighted crankshaft: Crankshaft with weights formed opposite the rod journals in the center portion of the shaft only.
particulate: Solid particle of soot and other substances that results from combustion.
passenger-side air bag: Air bag that deploys from the right side of the dash.
passive restraint system: A restraint system that operates without driver or passenger activation. Air bags and automatic seat belts are passive restraint systems.
passive sensor: A sensor that changes an externally produced signal, but does not generate its own voltage.
PCV valve: Positive crankcase ventilation system flow control valve. It is mounted on the engine valve cover or intake manifold.
PCV valve tester: Tester that measures the exact amount of airflow through a positive crankcase ventilation system.
peak-and-hold fuel injector: Type of fuel injector that uses a high amount of current to open an injector and a low amount of current (less than one amp) to hold the injector open.
pendulum belt retractor: A retractor that uses the inertia of a small hinged metal weight to engage the seat belt's locking mechanism during vehicle deceleration. When the vehicle brakes or stops quickly, a small pendulum in the retractor is thrown forward, causing the belt-locking mechanism to engage.
pent-roof combustion chamber: Combustion chamber that resembles a hemispherical combustion chamber, but with flat, angled surfaces.
permanent-magnet starter: Starting motor that uses high-strength field magnets instead of field windings to rotate the armature.
petroleum: See *crude oil.*
phosphorous additive: Nonmetal additive used as a cleaning agent in motor oil to carry oil impurities to an oil filter.
photon: A particle of electromagnetic light energy.

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photonic device: Any device that can emit or detect light.
photoresistor: A semiconductor that acts as a resistor in the dark, but changes to a conductor when exposed to light.
phototransistor: An electronic device that conducts current through its emitter-collector junction when excited by light. When light is blocked, the emitter-collector junction changes to an insulator and blocks current.
photovoltaic cell: A photonic device that converts light directly into current. It consists of N-type and P-type semiconductor materials that can absorb light energy in the form of photons and an antireflective layer that helps it absorb more light energy, making it more efficient. It is also called a solar cell.
physical injury: Cuts, broken bones, strained backs, and other ailments that can result from hundreds of different accidents. Safety in the workplace prevents accidents.
pickup screen: Screen that prevents large particles from entering the pickup tube and oil pump.
pickup-sending unit: A variable resistor that extends down into a fuel tank to draw out fuel and operate the fuel gauge.
pickup tool: A tool with a magnet hinged to the end of a telescoping rod. If bolts, nuts, or other small iron parts are dropped out-of-reach, this tool can be used to attract and grab the item.
piezo diesel injection: Type of diesel fuel injection that uses a high-pressure mechanical pump and an electrically operated piezo crystal to force an injector nozzle open.
piezo diesel injector: Diesel injector that uses a crystalline ceramic material instead of an electromagnet to open the injector valve.
piezo fuel injector: Type of fuel injector that uses a crystalline ceramic material, instead of an electromagnet, that converts electrical energy directly into motion to open an injector valve.
piezoelectric crystal: Crystalline ceramic material that produces a small output signal when exposed to physical strain or pressure.
pilot: A steel shaft that is installed in a valve guide to support a grinding stone used for valve seat reconditioning.
pilot bearing: Bearing that fits into the bore at the center of the crankshaft flange, providing the front support for the transmission input shaft.
pilot bushing: Bronze bushing that fits into the bore at the center of the crankshaft flange, providing the front support for the transmission input shaft.
pilot-operated absolute valve: An A/C system control that is used with the expansion valve to control evaporator temperature.
pilot shaft: Metal support shaft inserted through the transmission input bore to hold up clutch plate pieces during disassembly or reassembly.
pin hole diameter: Distance measured across the inside of a piston pin hole.
pin number: Number used to identify the location and purpose (electrical value and internal connection) of each terminal in a computer wiring harness connector.
ping: Mild knock or metallic rattling noise (not as loud as a detonation knock) that can be heard during preignition and engine acceleration.
pinging: See *ping*.
pinion bearing preload: The force applied to a pinion bearing to eliminate excess play and clearance.
pinion gear: A small gear that is either driven by or driving a larger gear.
pinion gear depth: Distance that a pinion gear extends into its carrier to mesh with the ring gear. It can be adjusted with a shim of different thickness added to the pinion gear and bearing assembly.
pinion gear shim: Metal ring commonly used to control pinion gear depth or pinion bearing preload if solid spacers are used.
pinion pilot bearing: Roller bearing at the end of the pinion gear that provides extra support under severe demands.
pinion shaft: Shaft holding the two differential idler (pinion) gears.
pinpoint test: A specific, sometimes complex, test of an individual component. Vehicle service manuals will usually explain these tests and provide other necessary critical information.
pintle response: Amount of time for the pintle to move as the magnetic field in an injector coil builds.
pipe wrench: An adjustable wrench with toothed jaws used to grasp cylindrical objects.
piston: Component that rides up and down in a cylinder to transfer force or build pressure.
piston and servo: Devices that operate clutches and bands in an automatic transmission/transaxle; they are activated by oil pressure from the valve body.
piston boot: Rubber covering that keeps road dirt and water off the caliper piston and the wall of the cylinder.
piston boss: Reinforced area around the piston pin hole that supports the piston pin under severe loads.
piston breakage: Part of a piston is cracked or broken, most commonly the skirt.
piston clearance: Distance between the side of a piston and the cylinder wall.
piston diameter: Distance measured across the sides of a piston. Allow for slight changes in this measurement due to piston taper.
piston displacement: The volume of space in which a piston moves from BDC to TDC. Measurements for piston stroke and cylinder size are needed for calculation.
piston head: The top portion of a piston that is exposed to the heat and pressure of combustion. It is also called the piston crown.
piston head shape: Contour of a piston top chosen to work with the shape of the cylinder head combustion chamber.
piston knock: A loud metallic knocking sound produced when a piston flops back and forth inside its cylinder. It is caused by piston skirt or cylinder wear, excessive piston-to-cylinder clearance, or mechanical damage. It is also called piston slap.
piston pin: Fastening device that slides through a machined hole in a piston to hold the piston onto a connecting rod.
piston pin hole: A machined hole through a piston that accepts a piston pin.
piston pin knock: Double knocking sound from a pin hammering against the rod or piston as the piston changes direction in the cylinder. Excessive clearance between a piston pin and piston pin bore or connecting rod bushing can cause the noise.
piston pin offset: Practice that locates a piston pin hole to one side of a piston centerline, slightly toward the piston's major thrust surface, to quiet its operation.
piston ring: A split ring installed in a groove in the piston. It seals the compression chamber from the crankcase.
piston ring gap: The clearance between the ends of a piston ring when it is installed in a cylinder. It allows for installation and tension against a cylinder wall after cylinder wear.
piston ring groove: Slot machined in a piston to accept a piston ring.
piston ring radial wall thickness: Distance from the face of a piston ring to its inner wall.
piston ring side clearance: Distance between the side of a compression ring and the piston groove.
piston ring width: Distance from the top of a piston ring to the bottom of the ring.
piston seal: Seal in a brake caliper that prevents pressure leakage between the piston and cylinder.
piston skirt: The side of the piston below the last ring. It keeps the piston from tipping in its cylinder.
piston slap: See *piston knock*.
piston stroke: Distance that a piston moves from bottom dead center (BDC) to top dead center (TDC).
piston taper: Slight difference in piston top diameter from the piston bottom when cold. A taper makes a piston almost equal in size at the top and bottom when hot.
piston wear: Decrease in the piston diameter due to friction, commonly measured on the skirt right below the piston pin hole.
piston-to-cylinder clearance: Distance between the edge of a piston and the cylinder wall.
pitman arm: Arm that converts the turning movement of a gearbox sector gear to linear motion and transfers this motion to the steering linkage.
pivot ring: Ring built into a pressure plate assembly, located near the outer rim. The ring holds the diaphragm spring as it flexes during operation.
planar zirconia oxygen sensor: Type of oxygen sensor in which the zirconia element, electrodes, and heater are combined in a flat, laminated strip. This reduces contamination and vibration.
planetary gearset: Gear assembly in which a planet gear, housed inside a planet gear carrier, revolves around a central sun gear and ring gear. It is used in transfer cases, manual transmissions with overdrive units, and automatic transmissions. They

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provide gear reduction, direct drive, and overdrive.

plastic hammer: A light hammer with a soft head that is used where light blows are needed to prevent part breakage or damage.

plateau honing: Honing process that uses extra fine stones to final size cylinder dimensions and final smooth the surface finish. It also produces the desired crosshatch pattern in cylinder walls.

pleated fuel filter: Plastic or coated paper filter resembling an accordion in design. It is the most common fuel filter element found in gasoline fuel systems.

pliers: A handheld tool used to grip, cut, crimp, hold, and bend various parts. Different pliers are designed for different tasks.

plug-in hybrid electric vehicle (PHEV): Gas-electric hybrid vehicle designed with a battery pack that can be recharged in 4–8 hours by plugging into a high-voltage battery charger. This allows for 30–40 miles of electric only driving before the internal combustion engine kicks in to recharge the HV battery.

plunger return spring: Spring that keeps a downward pressure on injection pump plungers and roller tappets. This holds the tappets against the camshaft when the lobes rotate away from the rollers.

plunging joint: A type of constant velocity joint that can shift and slide in its housing to counteract shaft movements.

ply separation: Condition in which tire plies pull apart as a result of overheating due to underinflation, or other causes.

p-metric: Size designation system for tires that uses metric values and international standards.

PN junction: The common edge of the P-type and N-type semiconductors.

pneumatic: Term for tools or equipment that are filled or powered with pressurized air.

PNP transistor: A transistor that has two P-type semiconductors and one N-type semiconductor.

pocket rule: A rule, typically 6" long, that easily fits in a pocket. It is also called a pocket scale.

pole shoe: Placed around the inside of the armature housing. Field windings coil around the pole shoes. When current passes through the winding, it creates a magnetic field between the poles to spin the armature.

poor fuel economy: Condition in which an engine consumes too much fuel compared to engine load and the manufacturer's estimated MPG rating.

pop tester: Manually operated device for checking a diesel injection nozzle spray pattern, opening pressure, and leakage while it is out of the engine.

poppet valve: A valve used to open and close a circular port or hole. It is also termed a mushroom valve.

portable electric drill: A handheld drill that can have a rechargeable battery or a power cord. It can be taken directly to the repair area.

positive battery cable: Cable that is normally red and fastens to the starter solenoid.

positive camber: The tops of the wheels tilt outward when viewed from the front of the vehicle.

positive caster: Tilts the top of the steering knuckle toward the rear of the vehicle.

positive charge: An atom is said to have a positive charge if it holds excess protons.

positive crankcase ventilation (PCV) system: Emission control system that prevents the release of crankcase vapors to the atmosphere by channeling them to the intake manifold.

positive post: Battery post marked in red and with a positive (+) symbol. It is larger than the negative battery post.

potential difference: See *voltage.*

potentiometer: A variable resistor with three external connections that can be used to adjust voltage in a circuit.

power: Rate at which work is done. It is measured in foot-pounds per second or per minute. The metric unit for power is the watt (kilowatt).

power antenna: A radio antenna equipped with a small electric motor for raising and lowering.

power booster: See *stereo amplifier.*

power brake: Brake system that uses a booster and either engine vacuum, electric pump, or hydraulic pressure to assist brake pedal application.

power brush: Brush mounted in a drill and used to remove hard carbon deposits.

power cylinder: A hydraulic cylinder that holds the power piston in a power steering system. It can be a separate part attached to the system or integrated into the steering gearbox.

power distribution diagram: A diagram that shows how battery current feeds to the main components or sections of the vehicle's electrical system.

power door lock: A lock that uses switches to activate solenoids inside a vehicle door to move the latch mechanism.

power hone: A machine shop tool that sizes and finishes the cylinder walls in an engine block.

power mirror: Rear view mirror that uses a tiny electric motor to pivot the mirror. A multi-position switch activates the small motor inside the mirror.

power piston: A hydraulic, double-acting piston housed in the power cylinder of a power steering system. It moves from left to right based on oil pressure to aid in vehicle steering.

power rack-and-pinion steering: Rack-and-pinion steering system that uses hydraulic pump pressure to assist the driver in moving the rack and the front wheels.

power seat: Type of vehicle seat that uses switches, electric motors, and drive assemblies to change the seat position.

power seat module: Computer module that can be programmed to return a vehicle seat to a desired position for different drivers.

power splitter: Device that contains a planetary gearset and is used to control the transfer of power through a hybrid drive train.

power steering fluid reservoir: A separate container that holds an extra supply of power steering fluid. It can also be formed as part of a power steering pump body.

power steering hose: High-pressure, hydraulic, rubber hoses that connect the power steering pump and the integral gearbox or the power cylinder.

power steering oil cooler: A small metal line or radiator located in one of the power steering lines that is used to remove excess heat from the oil.

power steering pressure test: Set of tests that uses a pressure gauge and shutoff valve to measure the pressure and operation of power steering system components.

power steering pump: Engine belt-driven pump that produces the hydraulic pressure for vehicle steering system operation.

power steering system: System that uses hydraulic pressure to assist a driver's efforts when turning the steering wheel. It could also use an electric motor in the rack to provide power assist.

power steering wheel: A steering wheel that uses a computer and various switches, sensors, and motors to automatically tilt and telescope (extend or retract) the steering wheel.

power stroke: The downward movement of the piston, propelled by the expansion of gases, that occurs after the air-fuel charge has been ignited.

power switch: Used in a cruise control system to feed current to the computer to activate and ready the system for operation.

power tilt steering column: Steering column that uses a small electric motor, a control switch, and a gear mechanism to change steering wheel angle or height.

power tool: A tool driven by compressed air, electricity, or pressurized liquid. This type of tool is faster to use and provides greater force than manual tools.

powertrain: Group of components such as the engine, transmission, axles, joints; used to provide driving force to the wheels.

powertrain control module (PCM): Name for a computer that controls the engine, transmission, and emission system of a vehicle.

power trunk release: Consists of a solenoid mounted on the trunk latch, a fuse, a switch, and related wiring. When powered, the solenoid plunger acts on the trunk latch to pop the trunk open.

power window: A window that uses a small direct current motor to move the window glass up and down.

power window motor: Electric motor located inside each door to operate the window regulator (up-down mechanism for the glass).

prechamber cup: Cup that forms an enclosure in diesel engines around the tip of an injector and glow plug known as the precombustion chamber. The cups are force-fitted into precisely machined holes in the cylinder head deck surface.

precombustion chamber: A small chamber at the top of a diesel engine cylinder. Diesel fuel is injected into this chamber and warmed by

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a glow plug and compression. Combustion begins in the precombustion chamber and expands into the combustion chamber. It is also called a diesel prechamber.

preignition: Problem that results when an overheated surface in the combustion chamber ignites the air-fuel mixture, causing it to burn prematurely. It is also called surface ignition.

preliminary visual inspection: An initial examination of a vehicle to find obvious signs of trouble, including loose wires, leaking vacuum hoses, part damage, and other problematic items.

pressed-in valve guide: Separate sleeve made of cast iron, steel, or bronze that are force-fitted into a hole machined in the cylinder head.

pressed-in valve seat: Separate, machined valve seat forced into a recess cut in a cylinder head. It is also called a seat insert.

press-fit piston pin: Piston pin that is force-fitted into a connecting rod but is free to rotate in the piston pin hole. This design prevents the pin from sliding out to rub on the cylinder wall.

pressure blaster: An enclosed cabinet for sandblasting and for cleaning dry parts. It has protective rubber gloves that extend into the cabinet for holding and positioning parts.

pressure bleeding: Process of bleeding a brake system using a pressure bleeder tank, which contains brake fluid under pressure.

pressure cycling switch: Used in place of or in conjunction with a thermostatic switch to maintain the correct evaporator temperature.

pressure differential valve: See *brake warning light switch.*

pressure-fed oiling: Oil is forced, under pressure, through galleries and to moving parts of an engine by a pump.

pressure gauge: Gauge used to check various positive air or fluid pressures, such as fuel pump pressure or engine oil pressure. It measures in pounds per square inch (psi), kilograms per square centimeter (kg/cm^2), or kilopascals (kPa).

pressure line: Air hose that connects the compressor to the air shock absorbers.

pressure plate: In a manual transmission, a spring-loaded disc assembly that pushes and locks the clutch disc against the flywheel. In an automatic transmission, a metal plate in a clutch assembly that acts as a barrier for clutch discs to be pressed against during clutch engagement.

pressure plate cover: Metal housing that bolts to a flywheel and is used to hold together the parts of a pressure plate assembly in a manual transmission.

pressure plate face: Metal ring on one side of a pressure plate in a manual transmission that contacts the clutch disc during gear shifts.

pressure plate release lever: Lever mounted inside a coil spring style pressure plate assembly that moves the pressure plate face away from the clutch disc and flywheel in a manual transmission.

pressure regulator: A spring-loaded valve that limits the maximum hydraulic oil pressure in an automatic transmission. *Also,* a part of a shop's compressed-air system used to set a specific pressure for the system.

pressure relief valve: Spring-loaded bypass valve that operates when pressure reaches a preset point.

pressure tester: Hand-operated air pump used to pressurize the cooling system for leak detection.

pressure testing: Test that pressurizes the coolant and oil passages in a temporarily sealed engine block and submerges the block in a water tank to find cracks or flaws.

primary brake shoe: Term for the front shoe that normally has a slightly shorter lining than the secondary shoe.

primary circuit: The section of an ignition system that consists of all of the components and wires that operate on low voltage from the battery or alternator. Small, conventional wires carry primary currents.

primary oxygen sensor: Sensor, positioned before the catalytic converter and as close to the engine as possible, used to monitor the oxygen in the exhaust gases as it leaves the engine. It is also referred to as the front O_2 sensor.

primary piston: In the dual master cylinder, it is the term for the rear piston assembly.

primary scope pattern: Scope pattern that shows the low-voltage, or primary-voltage, changes in an ignition system.

primary superimposed pattern: Scope pattern that shows the low voltages in the primary system (the ignition module or the condenser, coil primary windings, and points) with all the cylinder waveforms displayed on top of each other.

primary winding: Low-voltage winding in a coil. It is made of heavy wire.

primary wire: Small insulated wire that carries low-voltage to the components, circuits, and ECUs in a vehicle. It is also called body wire.

printed circuit: An electrical circuit that is made by conductive strips printed on a board or panel.

problem symptom: Noticeable performance change to a vehicle system or part, such as abnormal noise, loss of power, rough idle, hesitation, etc.

processing: A computer's comparison of sensor inputs to data and operating ranges in its memory to determine a course of action.

professionalism: A representation of a highly motivated, skilled, and competent individual within a career path or job.

programmable read only memory (PROM): A semiconductor chip that contains instructions that are permanently encoded into the chip. Instructions contain base operating information for how a system's components should operate under various conditions.

prompt: Step-by-step instruction, programmed into a scan tool circuitry or cartridge, that tells how to input vehicle information and run diagnostics.

propellant charge: Expanding gas in an air bag that is usually produced by the burning of sodium azide pellets in the air bag ECM.

propeller shaft: See *drive shaft.*

proportional rack-and-pinion power steering: System that senses vehicle speed and steering load to ensure adequate road feel. It increases wheel effort at higher speeds for more road feel and lowers wheel effort at low speeds to help steer. It is also known as speed-sensitive power steering.

proportioning valve: Valve used to equalize braking action in systems with front disc brakes and rear drum brakes to prevent wheel lockup. It is commonly located in the brake line to the rear drum brakes.

proton: Positively charged component in the nucleus of an atom.

proximity sensor: Device (usually sonar or sound sensor) around the perimeter of a vehicle that measures the distance from the auto body to anything around the vehicle.

Prussian blue: A metal stain often used to spot metal parts during layout. It can be used to check the valve-to-seat contact.

pry bar: Strong steel bars that are used to adjust/move parts during various automotive repairs.

P-type semiconductor: A semiconductor that is doped so that it has excess protons.

puller: Tool used to remove gears, pulleys, seals, and other press-fit parts. Different types and designs of pullers are used for various functions.

pulling brake: A condition where the vehicle will veer to the right or left when the brakes are applied.

pull-pull cable: A manual temperature control that loops cable in its housing so that it always pulls when activated.

pulsating clutch pedal: Problem that occurs when a clutch pedal makes small up and down motions when depressed. This can be caused by vibration from a rotating clutch component, or a warped or misaligned part or clutch housing.

pulse air system: System forcing fresh air into the exhaust ports of an engine by using the pressure pulses in the exhaust system to operate check valves.

pulse width: The speed of a voltage signal change over time. High frequency signals have a short pulse width and low frequency signals have a long pulse width.

punch: Removal and starting tool designed to be struck with a hammer. It is used to remove pins, plugs, and other pressed-in parts from bores as well as provide an indentation to start a drill bit.

purge line: Line connecting the charcoal canister and engine intake manifold.

purge valve: Vacuum- or computer-operated valve that controls the flow of fuel vapor stored in the charcoal canister to the intake manifold.

push rod: Metal tube with specially formed ends that transfers motion between the lifters and rocker arms in cam-in-block engines.

push rod guide plate: Machined plate bolted to a cylinder head to hold a push rod in alignment with the rocker arm.

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push rod service: Maintenance service that involves checking for push rod tip wear and straightness.
push-pull cable: A manual temperature control that uses a stiff steel cable that slides back and forth in its housing.

Q

quick charger: See *fast charger.*
quick-disconnect coupling: Type of coupling used on air hoses in a compressed-air system. The outer sleeve of the coupling can be pulled back to attach or detach the tips of power tools or other equipment.

R

R-12: See *refrigerant-12.*
R-134a: Refrigerant used in the air conditioning systems of most vehicles manufactured after 1992. It replaced R-12 due to environmental concerns.
race: Term for engine speed (rpm) increasing drastically without a corresponding increase in vehicle speed.
rack: A flat toothed steel bar inside a rack-and-pinion steering system that is moved left or right by the pinion gear. *Also,* a part of an alignment machine that is comprised of the ramps, turning radius gauges, and one of several types of equipment for measuring alignment angles.
rack-and-pinion steering gear: A steering gear that utilizes a pinion gear on the end of the steering shaft. The pinion gear engages a long, toothed rack, which is connected to the steering arms via tie-rods.
rack-and-pinion steering system: A simple steering system that uses a pinion gear directly meshing with a steering rack bar to convert the rotation of the steering wheel to straight line movement at the wheels.
radar sensor: Sensor that transmits electromagnetic energy waves from the front of a vehicle. In a collision avoidance system, when the waves hit an object and return to the sensor, the computer interprets the information.
radial ply tire: Tire construction method that has plies running straight across from bead to bead, with stabilizer belts directly beneath the tread.
radial runout: A measure of out-of-roundness, which causes uneven rotation. It is measured at right angles to the centerline of an object.
radiation: A method of heat transfer that is commonly carried out by infrared waves (rays from the sun, for example).
radiator: An arrangement of tubes and cooling fins that serves as a heat exchanger on a vehicle.
radiator cap: Cap that seals and pressurizes the cooling system of a vehicle.
radiator cap pressure test: Test that measures the cap opening pressure and checks the condition of the sealing washer.
radiator cap pressure valve: Spring-loaded valve that seals the radiator filler neck, but will open to release pressure if the engine overheats and cooling pressure exceeds the cap rating.
radiator cap vacuum valve: Small valve that opens to allow flow back into a radiator when the coolant temperature drops after engine operation.
radiator core: Fragile center section of a radiator made up of tubes and cooling fins soldered or bonded together. Coolant heat is transferred into the air flowing through these coolant filled tubes running through the core.
radiator filler neck: Opening for adding coolant that holds a removable radiator pressure cap to prevent coolant boiling when above 212°F (100°C).
radiator hose: Flexible tube that carries coolant between the engine and radiator.
radiator petcock: Fitting on the bottom of a radiator tank for draining coolant.
radiator shroud: Plastic or metal enclosure that keeps air from circulating between the back of the radiator and the front of the fan; typically attached to the rear of the radiator and surrounds the fan.
radiator tank: Metal or plastic end that fits over the core tube ends to provide storage for coolant and fittings for hoses.
radio: Term referring to the transmission of information through electromagnetic waves with frequencies below visible light.
radio frequency: Specific alignment of electromagnetic waves that is transmitted by different radio stations to send their information.
radio noise: Undesired interference or static (popping, clicking, or crackling) obstructing the normal sound of the radio station.
radio station: Broadcasting company that sends out an electromagnetic signal from a large broadcasting tower.
radio suppression wire: See *resistance wire.*
radio system: In a vehicle, it consists basically of an antenna, radio (receiver-amplifier), power supply circuits from an ECM, and speakers.
rain-sensing wiper system: Windshield wiper system that automatically turns the windshield wipers on when water is detected on the windshield. The system uses a moisture sensor with an infrared system to detect water on the outer surface of the windshield.
random access memory (RAM): A portion of computer memory that serves as temporary storage for data. This data is lost if power to the computer is lost. It is used to store sensor information and diagnostic trouble codes.
random cylinder misfire code: Diagnostic trouble code indicating that a problem is occurring in all cylinders.
raster pattern: Oscilloscope reading in which voltage waveforms are placed one above the other on the screen. It is also called a stacked pattern.
ratchet differential: Type of automatic locking differential that uses a dog clutch to lock the axle for 100% torque applied to both driving wheels or unlock the axle to allow different wheel speeds when cornering. It is commonly called a Detroit locker.
read only memory (ROM): A type of computer memory that stores permanent data that cannot be removed from memory. It contains the general information to operate a computer.
reading tires: Inspecting tire tread wear and diagnosing the cause for any abnormal wear.
reapply mode: An ABS operation mode whereby the ABS applies hydraulic pressure to one or more of the wheel brake assemblies.
rear axle bearing: Ball or roller bearing that fits between the rear axles and the inside of the rear axle housing to reduce friction.
rear axle ratio: The relationship between the numbers of teeth on the pinion gear and ring gear. Ratio affects acceleration, pulling power, and fuel economy. It is also called the differential ratio.
rear axle seal: Seal that fits into an axle housing. The seal lips contact the axle or axle collar to prevent lubricant leakage.
rear drive axle: Shaft that transfers power from the rear differential assembly to the vehicle's rear wheels. The axles may be straight shafts, or they may be equipped with cross-and-roller U-joints or CV joints.
rear drive axle assembly: Differential, axles, and other components transferring power from driveline to rear wheels.
rear end: Term for a rear drive axle assembly.
rear main oil seal: Seal that fits around the rear of the crankshaft to prevent oil leakage.
rear O_2 sensor: See *secondary oxygen sensor.*
rear seat air bag: Air bag that fits into the rear cushion of the front seats. It inflates to protect the passengers in the rear seat from injury during a frontal collision.
rear universal joint: Flexible joint that connects a drive shaft to the rear yoke.
rear wheel bearing: Ball- or roller-type bearing that reduces friction between the axle and axle housing.
rear window defogger: System that uses a switch, a relay, an indicating light, and a window heating grid that heats up to defog or deice the vehicle's window when activated. It is also called a rear window defroster.
rear window defroster: See *rear window defogger.*
rear yoke: Driveline component that holds a rear universal joint and transfers torque to gears in the rear axle assembly and differential.
rear-wheel drive: Configuration with the engine in the front of a vehicle and the drive wheels in the rear. Due to vehicle weight being more evenly dispersed, this drive train configuration offers more precise steering than front-engine, front-wheel drive vehicles.
rebound: Term for the extension of a suspension system spring.
receiver-drier: Removes moisture from the cooling system and stores extra refrigerant.
reciprocal: Of a number, it equals 1 divided by that number.

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reciprocal method: A method that can be used to calculate resistance in all parallel circuits. In this method, the reciprocal of the total resistance equals the sum of the reciprocals of all of the branch resistances.

reciprocating electric fuel pump: Similar to a mechanical fuel pump with its back-and-forth pumping motion but uses a solenoid instead of a rocker arm to produce this motion.

reciprocating weight: The weight of engine parts, including bearings, rings, and oil, during operation.

recirculating-ball gearbox: Worm-style steering gearbox that has small steel balls that circulate between rotating gear members.

rectification: The process of converting alternating current to direct current.

rectifier diode: Diodes, commonly six, that provide full-wave rectification when converting stator current to direct current inside the alternator.

reduction starter: Starter that uses an extra set of gears to improve gear reduction that increases the rotating force applied to the engine flywheel.

reed valve: A flexible metal flap that exposes ported holes to allow the entrance and exit of gases from the crankcase in a two-stroke engine. *Also*, a thin piece of metal in an A/C compressor that bends to open and close an opening. They are normally used as check valves to produce flow through the compressor and system.

reference voltage (Vref): A known voltage (usually 1–5V) fed to passive sensors by a computer. Changes in sensor resistance can then be read by the computer as a change in current.

reference voltage test: Test that uses a multimeter to measure the ECM reference voltages being sent out to resistive sensors.

refinery: Complex where newly extracted crude oil is converted into more useful substances, such as motor oil, gasoline, and diesel fuel. It is also referred to as surface ignition.

refractometer: Handheld type of coolant strength measuring device in which a drop of coolant is placed on a scaled measuring window and then examined through an eyepiece.

refrigerant: A substance with a very low boiling point that is circulated through a refrigeration, or air conditioning, system.

refrigerent-12 (R-12): Refrigerant used in older air conditioning systems. It has been replaced by R-134a. It is also called R-12 or Freon.

refrigerant hose: Hose that carries refrigerant to each air conditioning system component and back to the compressor.

refrigerant oil: Lubricant used in the compressor of an air conditioning system.

refrigerant system: Uses a confined gas to provide cool, dehumidified (dried) airflow into the passenger compartment.

regenerative braking: Braking system in a hybrid vehicle that uses the energy from slowing the rotational force of the vehicle's drive axles to spin the motor generator, causing the motor generator to produce electrical energy to recharge the battery.

relay: A magnetically operated switch that enables low current in one circuit to control (close or open) a greater current flow in a second circuit.

relay rod: See *center link.*

relay tester: Test device for relay operation. Special relay testers can work quickly by plugging into a relay outlet and testing it automatically.

relearn procedure: Process and time period after vehicle service during which the computer system adjusts to new components and programming information.

release arm: See *clutch fork.*

release bearing: Bearing that applies force to the release levers or fingers of a pressure plate to disengage the clutch disc from the flywheel. It is also called a throw-out bearing.

release rod: Rod in a clutch linkage mechanism connected to the bellcrank to transfer bellcrank movement to the clutch fork.

relief valve: Valve that limits the maximum output pressure of a pump.

reminder system: Vehicle warning system that makes an audible signal (buzz, chime, or audible warning) if seat belts are not fastened when the engine is started, keys are left in the ignition with the engine off, or headlamps are left on with the engine off and a door open.

remote ground: A method of grounding a circuit in that an extra wire is connected from the circuit to ground.

removable carrier: Separate housing for the differential assembly that can be unbolted and removed from the rest of the rear axle housing after the drive axles are removed.

repair area: Any section within an auto repair shop where repair operations are performed.

repair information section: Part of a vehicle inspection report which provides a vehicle owner with instructions for having the vehicle repaired if it fails an emission test.

reserve capacity rating: Time needed to lower 12-volt battery terminal voltage below 10.2 volts at a discharge rate of 25 amps. The rating assumes that the test starts with a fully charged battery at 80°F (27°C).

residual pressure valve: Maintain residual fluid pressure of approximately 10 psi (69 kPa) to help keep contaminants out of a hydraulic brake system.

resistance: The measure of opposition to electrical flow in a circuit.

resistance key: Theft deterrent ignition key with a small electrical resistor mounted on the side. The metal teeth and resistance of the key must match the value programmed into the control module for the vehicle to start normally.

resistance wire: Wire that contains internal resistance (carbon-impregnated strands of rayon braid) to prevent radio noise. The wire has about 10,000 ohms of resistance per foot. It is also known as radio suppression wire.

resistor: A device placed in a circuit to lower voltage and current flow.

resistor spark plug: Spark plug that has an internal resistor built into the center electrode. The resistor has a resistance of about 10,000 ohms. This resistance is designed to reduce induced static in radios and to increase spark plug life by reducing tip erosion.

respirator: A device worn when working with harmful airborne materials that filters dangerous particles from the air a technician breathes.

résumé: A mandatory job search document that summarizes a job applicant's work history, education, qualifications, and skills required for an employment position.

resume switch: Switch in a vehicle cruise control system that allows a driver to reset the same cruising speed when desired.

retainer: The individualized bracket and fasteners that hold a battery in its tray.

retainer plate type axle: Type of axle that uses an axle retainer plate bolted to the axle housing to hold the axle in place. This design is often used with a removable rear axle carrier.

retaining collar: Plastic strap or metal spring clamp in a constant velocity joint assembly. The retainer tightens on the boot end to secure it on the axle shaft and to the universal joint housing. It is also called a strap.

retarded ignition timing: Occurs when the ignition spark happens after the manufacturer's specified position of the piston during the compression stroke. This causes the engine to have poor fuel economy and lack power, especially during acceleration.

retracting spring: Spring that pulls the brake shoes away from the brake drums when the brake pedal is released. This, in turn, pushes the wheel cylinder pistons inward.

retread: Name for used tire that has undergone a process involving heat and pressure to apply a new tread to the tire body. It is rarely done on a passenger vehicle tire.

returnless fuel injection system: Type of fuel system that does not have fuel return lines to the tank. The design helps reduce evaporative emissions by minimizing fuel vaporization.

reverse bias: Arrangement in which a diode acts as an insulator.

reverse bias voltage: A rating of the maximum voltage a diode can block without being damaged.

reverse idler gear assembly: Separate machined gear assembly on a shaft located close to the countershaft. It changes gear rotation so the vehicle moves in reverse.

reverse idler shaft: A short shaft that supports the reverse idler gear assembly.

reverse-biased diode: Diode that acts like an insulator, not allowing current to pass through the diode when voltage is connected in a certain way.

reverse-flow cooling: Type of engine cooling in which cool coolant enters the cylinder head and hot coolant exits the block to return to the radiator.

rheostat: A variable resistor with two electrical connections (terminals). One terminal is wired to one end of the resistance unit.

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The other terminal is connected to a sliding contact. Turning the control knob moves the contact and alters the resistance value.

rich air-fuel mixture: Fuel mixture that contains a large amount of fuel compared to air.

rich trouble code: Diagnostic code set if an O_2 sensor detects too much fuel is being injected into the cylinder for engine speed and load.

right-to-know law: Mandates that essential information and stipulations for safely working with hazardous materials be available to those handling them.

rim: Outer lip of a wheel that contacts the tire bead.

ring and pinion backlash: Clearance between the meshing teeth of the ring and pinion gears, needed for lubrication and heat expansion during operation.

ring and pinion contact pattern: Markings on a ring and pinion gear after spinning them together with an applied test substance. The pattern can be used to double-check or correct the gear adjustment.

ring back clearance: Distance determined from the difference between a piston ring radial wall thickness and ring groove depth.

ring configuration: Computer network configuration in which each computer is wired in series, or in a loop.

ring expander: A special tool for spreading and installing piston rings. *Also*, a ring placed behind a one-piece oil ring that increases ring tension against the cylinder wall.

ring expander-spacer: Ring installed between the two steel oil rings in a two-piece oil ring to hold the rings apart and push them outward against the cylinder wall.

ring filing: Process using a special, thin grinding wheel to remove metal from the ends of a piston ring.

ring gear: Large gear in differential that is driven by the pinion gear and, in turn, drives the spider gears.

ring gear runout: Measured amount of side-to-side movement when a ring gear is rotated.

ring groove depth: Distance measured from the tip of a ring land to the back of the ring groove. When installing a new ring, depth should be checked to make sure the new ring will fit below the surface of the piston.

ring groove width: Distance measured from the top to the bottom of the ring groove.

ring land: Area between and above piston ring grooves. It separates and supports a piston ring as it slides on the cylinder.

ring seating: Initial piston ring wear that allows the ring to perfectly match the surface of a cylinder.

ring side clearance: Distance determined from the difference between a piston ring width and ring groove width.

rising edge: Oscilloscope reading where the square wave goes from zero to high voltage. It is also called the leading edge.

road crown: The normal slope toward the outer edge of the road surface.

road crown pull: Steering wheel pull caused by hump in center of road.

road damage: See *tire impact damage.*

road feel: The feeling imparted to the steering wheel by the wheels of the vehicle in motion. This feeling is important in sensing and predetermining steering response.

rocker arm: Pivoted lever that transmits motion through its oscillation used in many parts of an internal combustion engine.

rocker assembly service: Maintenance service involving the cleaning, inspection, and measurement of rocker arms, rocker arm shafts, and related components.

roll-around cart: Wheeled cart with two deep trays that can be easily maneuvered around a shop. It is helpful when moving heavy tools or for eliminating multiple trips to a toolbox.

roller lifter: A hydraulic or mechanical valve lifter that has a roller bearing, which rides on the cam lobe to reduce friction.

roller vane electric fuel pump: A positive-displacement pump normally located in a main fuel line that uses small rollers and an offset-mounted rotor disc to produce fuel pressure.

rolling resistance: Measurement of the amount of friction produced as a tire rolls over a road surface. A high resistance can lead to aggressive and abnormal tire and tread wear.

rollover valve: Valve in the fuel tank or delivery lines that prevents the escape of raw fuel in the event of a vehicle rollover.

root cause of failure: The actual cause of a problem or failure.

rosin-core solder: A type of solder designed for electrical repairs that contains flux (lead-free cleaning agent) inside the solder.

rotary brush: A stiff brush attachment used with an air tool for cleaning parts.

rotary control valve: Valve operated by a torsion shaft connected to the pinion gear in a power rack-and-pinion steering system to route oil to the power cylinder.

rotary engine: An internal combustion engine that uses one or more spinning triangular rotors instead of pistons to accomplish the intake, compression, power, and exhaust cycles. It is also referred to as a Wankel engine.

rotary file: Grooved metal attachment used in a drill or grinder for removing metal burrs and nicks.

rotary fuel pump: Term for a fuel pump that uses a circular, or spinning, motion to produce pressure. Examples include the impeller type, the roller vane type, and the sliding vane type.

rotary oil pump: Type of oil pump that uses a set of star-shaped rotors in a housing to pressurize the motor oil.

rotary valve: A spinning disc-shaped valve that exposes ported holes to allow the entrance and exit of gases from the crankcase in a two-stroke engine. *Also*, a power rack-and-pinion steering control valve composed of a spool valve inside a valve body.

rotor: See *brake disc.*

rough idle: Condition in which an engine seems to vibrate on its mounts at very low rpms.

rpm at misfire: Readout showing engine rpm when the computer detected a cylinder misfire.

rubber boot: Fits over the master cylinder housing and the brake pedal push rod to prevent dust, dirt, and moisture from entering the back of the master cylinder.

rubber bumper: Jounce and rebound bumper that stops metal-to-metal contact during extreme suspension compression and extension.

rubber dust boot: Clamp-secured flexible rubber housing that fits over the inner ball sockets of a rack-and-pinion tie-rod assembly to keep out dirt and water, as well as to hold in lubricating grease.

rubber isolator: Rubber part of an upper strut damper unit that prevents suspension noise from transmitting into the body structure of a vehicle.

rubber mallet: Type of hammer with a head made of solid rubber. It will rebound, or bounce, when used to strike another solid object.

run-flat tire: Tire designed with a stiff sidewall to allow it to run while deflated.

running engine compression test: See *dynamic engine compression test.*

run-on: See *dieseling.*

rust penetrant: A chemical that is sprayed on rusted parts (often rusted fasteners) that dissolves rust or corrosion.

Rzeppa CV joint: A type of constant velocity joint that uses a star-shaped ball-and-cage assembly to provide joint motion. It is used in front-wheel-drive swing axle assemblies.

S

safety data sheets: Documents that list the detailed chemical composition, handling procedures, and precautionary information for products that can present a health or safety hazard on the job site. Manufacturers of such products must provide this information with their products.

safety rim: A wheel designed with two safety ridges to prevent the tire from dropping into the center of the wheel in the event of a blowout.

safety system: Systems that provide protection for vehicle passengers, including seat belts, air bags, and security systems.

safety washer: Flat washer that keeps the outer wheel bearing from rubbing on and turning the spindle adjusting nut on a hub and wheel bearing assembly.

safing sensor: A backup sensor to ensure no accidental air bag deployment by confirming that a vehicle is involved in a collision. It is also called an arming sensor.

satellite radio: Type of radio system that operates off a radio transmitter orbiting in outer space at an altitude of about 22,000 miles (35,000 km) above Earth's surface. The satellite broadcasts use an FCC-allocated broadcast frequency in the S-band (2.3 GHz).

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saturated ignition coil: Term for an ignition coil with a fully formed magnetic field.
scan tool: Electronic tool, usually handheld, that is used to read and interpret diagnostic codes and engine sensor information.
scan tool datastream value: Electrical values measured and displayed in real time with a vehicle running and/or being driven.
scavenge pump: Secondary oil pump in a dry sump lubrication system that pulls oil out of an oil pan and feeds it back into a separate oil reservoir.
schematics: Straightforward graphic representations of an electrical, vacuum, or pressure circuit.
Schrader valve: Type of pneumatic valve that has a valve core consisting of a spring-assisted poppet valve threaded into its valve stem.
scope: See *oscilloscope*.
scope screen: Oscilloscope screen that can give instructions, display voltages as a trace, or give other values as digital displays.
scope sweep rate: Frequency or time division shown on a scope screen during each test.
scope test: Test that analyzes a voltage waveform.
scope time: Displayed on a scope screen along the horizontal axis in degrees, milliseconds, or duty cycle.
scope voltage: Displayed on a scope screen along the vertical axis, or scale.
scratch awl: A tool that resembles a screwdriver, but has a sharp, pointed tip. It is used for marking sheet metal and other parts.
screwdriver: Handheld tool used to remove or install screws. The shape of the tip of a screwdriver determines on what screw it should be used.
screw extractor: Tool used to remove broken screws or other broken fasteners that have broken flush with or below a part surface.
scuff pad: Pad mounted in a drill or similar tool that can cut through and lift off gasket material and silicone, yet is too soft to easily damage metal surfaces.
seal: A formed device made of plastic, rope, neoprene, or Viton. It is used to prevent oil leakage around a moving part, such as a shaft.
sealed-beam headlamp: Headlamp that has its filament(s) enclosed in a vacuum-sealed glass housing.
sealer: Sticky substance applied to parts or a gasket before installation to improve the sealing ability of the gasket, take the place of the gasket, hold the gasket in place during reassembly, or improve the sealing ability of dynamic seals and hose connections.
sealing ring: Piston-type ring placed around the turbo shaft at each end of the turbo housing to prevent oil leakage.
seat belt: Strong nylon straps that hold people in their seat during a collision.
seat belt anchor: Provides a means of bolting the seat belt to the car's body and frame structure.
seat belt buckle: Part of the seat belt that engages and disengages the belt around the occupant's body.
seat belt reminder system: System that activates a dash light and generates an audible tone to warn the vehicle's occupants to buckle their seat belts.
seat cover: Cover placed over a seat to protect it from dirt, oil, and grease during a repair.
seat cushion sensor: Sensor that detects the weight of a person sitting in the passenger seat.
seat narrowing: Process of grinding a valve seat in or out so it correctly contacts a valve face.
seat stone: A grinding stone mounted on a threaded drive attachment used to cut a fresh surface on the face of a valve seat.
seat width: The area of the valve seat that is actually in contact with the valve face.
secondary brake shoe: Term for the rear brake shoe that has the largest lining surface area.
secondary circuit: In an ignition system, all components operating on coil (high) voltage. It carries high voltage from coil to spark plugs.
secondary nonresistance wire: A wire that has a metal conductor with no extra resistance. This type of wire is used only in high-performance applications, such as off-road racing, because it causes static in nearby radios.
secondary operating voltage: Ignition system voltage that ranges from 4,000–100,000 volts, depending on the system design.
secondary oxygen sensor: Sensor, positioned after a primary oxygen sensor in an exhaust system, that primarily monitors a catalytic converter for proper operation. It is also called a rear O_2 sensor.
secondary piston: In a dual brake master cylinder system, it is the term for the front piston.
secondary resistance wire: A wire that has a constrained amount of resistance designed directly into the metal conductor. It is designed to help prevent radio interference or static from the high voltage pulses going to the spark plugs. It is also called carbon-core wire.
secondary scope pattern: Scope pattern that shows the high voltages needed to fire the spark plugs.
secondary superimposed pattern: Scope pattern that shows the high voltages produced by the ignition coils with all the cylinder waveforms displayed on top of each other.
secondary winding: The high-voltage winding in an ignition coil. It is made of several thousand turns of very fine wire.
secondary wire: Wire with extra thick insulation that carries high-voltage electricity from the ignition coil to the spark plug.
secondary wire insulation test: Test used to check for secondary wire leakage or arcing through its insulation to ground or another wire.
secondary wire resistance test: Test that checks the condition of a spark plug or coil wire conductor. This test is used to check for a bad wire when an oscilloscope is not available.
sector shaft: Output shaft/gear in a steering gearbox that transfers motion to the steering linkage.
security system: System of motion sensors and switches that communicate with signals to an electronic control module. If the vehicle is tampered with, theft deterring features are activated.
select-fit: Term for engine parts chosen and installed in a certain position to improve the fit or clearance between parts.
selective catalytic reduction (SCR): An emission control system used on diesel engines that injects diesel exhaust fluid into the vehicle's exhaust stream ahead of a catalytic converter. The converter breaks down toxic NO_X emissions into harmless water and nitrogen.
self-energizing action: Movement when brake shoes are forced against the rotating drum and are pulled away from their pivot point by friction. This draws the shoes tighter against the drum.
self-leveling shock absorber: A shock absorber designed with a hydraulic lock action that holds the shock rod at the same length for normal vehicle curb height under various conditions.
self-sealing tire: A tire with a sealing compound applied to its liner to stop air leakage in case of puncture.
self-stripping connector: Type of connector useful for connecting to an existing wire in a harness because it cuts through a wire's insulation and locks onto the conductor.
semi-automatic transmission: Type of transmission that often uses paddle shift buttons on the steering wheel instead of a console shift lever. Electric actuators switch gear locations semi-automatically based on signals sent to a computer control system from the paddle shifters.
semi-centrifugal pressure plate: Type of pressure plate that reduces slippage at high engine speeds. It uses weighted release levers applying centrifugal force to increase clamping pressure on a clutch disc. Weaker coil springs also allow clutch engagement at low engine speeds.
semiconductor: A substance, such as silicon, that acts as a conductor or insulator, depending on its operating condition and application.
semifloating axle: A type of axle used in most rear-wheel drive vehicles. The outer end of the axle turns the wheels and supports the weight of the vehicle. The splined inner end floats in the differential gear.
semi-independent suspension: A suspension system that uses a flexible axle to allow each wheel to move up and down with minimal influence to the other wheel on that axle.
sending unit: Variable resistor used in dash gauges to control current flow to gauges.
sensor link: A linkage rod that connects the height sensor to the suspension in an electronic height control system.
sensor rotor: A toothed ring that rotates with the wheel hub. As each tooth passes the sensor, it induces an ac signal based on wheel and tire speed. It is also called a trigger wheel.
sensor socket: Specialty socket with a shape and cutout designed to fit over specific vehicle sensors.

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sensor system: Group of devices measuring pressure, temperature, engine speed, and exhaust cleanliness for an engine control module (ECM).
separator: Permeable membrane that fits between battery plates to prevent shorting. It must be resistant to acid and oxidation.
sequential turbocharger system: System designed to reduce turbo lag that uses two electronically controlled turbochargers that operate as needed. It is also called a twin turbocharger system.
serial communication: Means of computer network communication that uses only one wire to exchange digital data. In this setup, data is transferred one bit at a time.
series circuit: An electrical circuit with only one path for current flow.
series hybrid: A gas-electric hybrid vehicle that has a separate generator and traction motor. It does not use a motor-generator. In a series hybrid configuration, the traction motor is the only method used to apply torque to the vehicle's drive train.
series-parallel circuit: A circuit consisting of at least one series circuit and one parallel circuit. It is also known as a combination circuit.
series/parallel hybrid: Gas-electric hybrid vehicle that combines the advantages of the parallel hybrid with those of the series hybrid. The internal combustion engine can power the vehicle, disconnect to let the electric motor propel, or energize a generator to recharge the battery.
service dispatcher: Individual in charge of tracking shop repairs and organizing/assigning technicians to perform each auto repair.
service information: Printed or electronic instructional material that details how to diagnose and repair a vehicle. It may consist of step-by-step procedures, specifications, diagrams, exploded part illustrations, troubleshooting charts, descriptions of common problems for specific vehicle makes and models, and other useful information. It is also referred to as a shop manual.
service manager: Management position responsible for the complete service and repair operation of a large repair facility. The efforts of the shop supervisor, parts specialist, service writer, service dispatcher, and other shop personnel are coordinated by the manager.
service station: An automotive repair location where much of the work is quick service repairs that only take an hour or two.
service writer: Individual who completes repair orders, describing vehicle problem(s), for each vehicle entering a shop.
servo: Piston device that operates a band in an automatic transmission. *Also*, a small dc motor that can turn or move parts.
servo action: With most drum brake designs, shoe energization is supplemented by servo action. Servo action results when the primary (front) shoe helps apply the secondary (rear) shoe.
servo motor: A small dc motor actuator that can produce a rapid spinning motor when energized by a relay or main computer.
servo piston: Plunger part of a servo that moves within a machined cylinder in a transmission case.
servo seal: Seal that fits around a servo piston and cylinder to prevent oil leakage.
set screw: Headless screw most often used to lock a part onto a shaft.
setback: A condition in which one front wheel is set farther back from the front of the vehicle than the other front wheel.
shackle: A bracket for connecting a leaf spring to a vehicle frame that allows length changes in the spring during suspension movement.
sharp valve margin: Condition in which a valve clearance is too small.
sheet metal screw: Screw with tapering threads that are very widely spaced. This type of screw, also called a tapping screw, is used on plastic and sheet metal parts.
shielded twisted-pair conductor: A twisted-pair conductor encased in a metal shield for greater electromagnetic interference reduction.
shielded twisted-pair wire: Wire that consists of multiple insulated conductors wrapped around each other and has a sheath of metal around the conductors to avoid radio interference.
shielded wire: Wire with a flexible metal tube around the conductor to block interference.
shift fork: Pronged device in a manual transmission that straddles and moves the synchronizers and gears back and forth on their shafts for gear engagement.
shift linkage: Mechanical rods, cables, or hydraulic circuits in a manual transmission that connect a shift lever to the shift forks.
shift schedule: A programmed table of perimeters stored in a transmission control module that is used to calculate shift points in an electronically controlled automatic transmission.
shift valve: Valve that uses controlled oil pressure from specific valves to determine the correct gear needed for different engine loads. It is also called a balanced valve.
shock absorber: A piston operating in an oil- or gas-filled cylinder that dampens and controls spring oscillation in suspension systems.
shock absorber bounce test: Simple test to determine shock absorber strength. One corner of a vehicle body is pushed down and then released. The number of times the vehicle body rebounds before stopping is counted—more than three can indicate a problem.
shock absorber compression: The downward movement of the piston and upward flow of oil within the shock cylinder that occurs when the vehicle's tire is forced upward upon hitting a bump.
shock absorber extension: The upward movement of the piston and downward flow of oil within the shock cylinder that occurs as the control arm returns down after a compression.
shock actuator: Solenoid-operated valve that controls fluid flow inside shock absorbers in an electronic shock absorber system.
shop equipment: General term for large tools, such as floor jacks, parts cleaning tanks, steam cleaners, and battery chargers that are used in an automotive shop.
shop stall: A small, designated work area where a vehicle can be parked for repairs.
shop supervisor: Management position that directs technicians and ensures that shop work is correctly performed and in a timely manner.
short circuit: An accidental grounding of an electrical circuit or electrical device, causing a tremendous amount of current through the circuit or device.
shorted diode: A diode that has a low (almost zero) resistance in both directions.
short-term fuel trim: Term for a temporary adjustment of injector pulse width to correct fuel mixture.
shoulder belt: Part of the seat belt that extends across a person's shoulder and chest.
shroud: A plastic or metal enclosure around a fan to guide and facilitate airflow.
side curtain air bag: Air bag designed to drop down like a "curtain" over the side window glass.
side terminal: Female-threaded electrical connection located on the side of a battery. It connects with a special bolt on the battery cable end.
side-impact air bag: Small air bag in the door panels or the outside edge of each front seat that deploys when the vehicle is hit from the side. They generally do not deploy during a frontal impact.
side-impact beam: High-strength steel or carbon fiber beam mounted in the vehicle doors to help prevent intrusion into the passenger compartment.
sidewall: The portion of a tire between the bead and tread.
sight glass: Located in the top of the receiver-drier to show the amount of refrigerant in the system.
signal amplitude: Level of voltage present in a wave. High-amplitude signals have more voltage than low-amplitude signals.
silicone lubricant: A lubricant that comes in a spray can and is used on rubber door weather stripping and windows.
sine wave: The curve that represents alternating current in a basic circuit.
single cylinder misfire code: Diagnostic trouble code that indicates there is a problem in one engine cylinder.
single exhaust system: An exhaust system that has only one pipe leading from the exhaust manifold to the catalytic converter, muffler, and out to the tailpipe.
single overhead cam (SOHC) engine: An engine equipped with one camshaft, that controls both the intake and exhaust valves, in the top of each cylinder head.
single-stage EGR valve: Type of electronic EGR valve that uses only one solenoid and valve to open its exhaust passages.
single-viscosity oil: Rated and designed for a limited range of operating temperatures.
single-wire conductor: Type of conductor with one insulated wire that carries data signals between computers.

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skidpad: Flat, circular driving course used for different vehicle handling tests.
skirt length: Distance from the bottom of a piston skirt to the centerline of a piston pin hole.
slave cylinder: Operating piston assembly inside a cylinder for hydraulic clutch linkage. It is actuated by the hydraulic pressure developed in the master cylinder.
sledgehammer: Type of heavy hammer with an extra large head that produces powerful blows.
sleeve protrusion: Distance that a cylinder sleeve sticks above the block deck. Sleeve protrusion helps seal combustion pressure at the head gasket. It is also called liner protrusion.
sleeving: Process of installing new metal inserts that fit and line the inside of an engine cylinder to protect the block from piston wear.
sliding caliper: The sliding caliper disc brake is a one-piston caliper that is mounted in slots machined in the caliper adapter. The caliper is free to slide sideways in the slots or grooves as the linings wear.
sliding vane electric fuel pump: A positive-displacement pump normally located in a main fuel line. It uses small square vanes and an offset-mounted rotor disc to produce fuel pressure.
slip joint: See *slip yoke*.
slip yoke: Driveline component that connects a drive shaft to a transmission output shaft and allows back-and-forth drive shaft movement in response to road conditions. It is also called a slip joint.
slow charger: Machine that feeds a small amount of current into the battery to recharge at a slow pace—about 12 hours at 10 amps. It is considered ideal over fast charging because the atomic charges are better forced back onto the battery plates and electrolyte. It is also called a trickle charger.
slow-cranking condition: Engine problem in which the crankshaft rotates slower than normal upon ignition and struggles to start the engine.
sluggish engine: See *lack of engine power*.
smart key system: Feature of some late-model vehicles allowing a driver to lock or unlock doors, open the trunk, or start the vehicle based on the proximity of the key fob to the vehicle.
smart restraint system: Restraint system that uses conventional impact sensor inputs, as well as data from the seat sensors, side door impact sensors, yaw sensors, wheel speed sensors, seat belt sensors, and even collision-predicting sensors.
smog: Generalized term used to describe air pollution caused by chemical fumes and smoke.
snap ring: A semi-flexible metal ring fastener with a opening that allows it to be popped into place. It holds parts within a component, allowing for rotational movement without lateral movement.
snapshot: A scan tool method of recording engine operating conditions at the exact moment that a malfunction occurs.
socket: A small cylinder-shaped, box-end tool in various standard/metric sizes. A socket attaches to a socket handle for removing or installing bolts and nuts.
socket handle: Handle that fits into the square opening in the top of a socket, extension, or universal joint to provide leverage when tightening or loosening fasteners.
soft failure: Computer system failure, also called intermittent failure, that only occurs under certain conditions. It stores in the memory for 30–50 keystarts or warm-ups.
soft ring coating: Porous metal coating on a piston ring. It is used to help the ring wear in quickly and form a good seal in slightly worn engine cylinders.
solar cell: A large solar panel that converts sunlight into electricity.
solar vehicle: A vehicle that uses solar panels to generate electricity for propulsion. Solar panels convert sunlight directly into electric current. The current powers an electric motor, which powers the vehicle.
solar ventilation ECM: A small ECM that monitors and controls the operation of the solar ventilation system.
solar ventilation switch: Allows the solar ventilation system to be manually turned on and off.
solar ventilation system: Uses energy from sunlight to operate the blower of a vehicle's A/C system.
solder: An alloy (mixture of metals) that has a relatively low melting point compared to other metals. It comes in roll form for easy application to a joint.
soldering: Involves using heat and molten solder to join electric components or wires.
soldering gun: A trigger-operated tool equipped with a transformer that sends high current through a high-resistance tip to generate heat for melting solder on hot electrical wires. It is more powerful and produces a stronger bond than a soldering iron.
soldering iron: A tool consisting of a heating element, heated tip, and handle. The heated tip melts electrical wires so solder can be used to join them. Its tip is also generally smaller and more suited for delicate work than the tip on a soldering gun.
soldering pick: Tool used to scrape corrosion from components before solder is applied. It can also be used to help hold or pin down small components while soldering.
soldering sponge: Water-soaked sponge used to clean the tip of the soldering gun or iron and various holding devices.
soldering torch: Tool that burns butane gas to generate heat for soldering wires and electric components together.
solenoid: An electrically operated magnetic device used to operate some unit. An iron core is placed inside a coil. When electricity is applied to the coil, the iron core centers itself in the coil and, as a result, it will exert some force on anything it is connected to.
solenoid diesel injector: Similar to a solenoid fuel injector but the body of the injector must be machined from thicker metal with larger internal passages to carry even more fuel pressure than direct gasoline injection.
solenoid disc: Disc that is pulled into the coil windings of the starter solenoid when the ignition key is turned on, completing the battery-to-starter circuit by touching both of the high-current terminals.
solenoid fuel injector: Type of electronic fuel injector that uses a small set of coil winding to produce an electromagnet inside the injector housing. When current energizes this electromagnet, it pulls the fuel valve open.
solenoid valve: A solenoid-operated air valve in an electronic height control system that can release air pressure from the system.
solenoid winding: Metal wire loop in the solenoid that conducts a small amount of battery current when the ignition is turned on.
solid wire: Inflexible wire with a single conductor inside its plastic insulation.
solvent gun: A type of blowgun with an attached solvent reservoir. It is used to spray solvent on large parts during cleaning.
sound system: System that includes many audio devices, such as an AM-FM stereo, compact disc player, satellite radio, or mp3 interface.
space saver spare: See *compact spare tire*.
spare tire: An extra wheel and tire assembly stored in or on a vehicle that can be installed if the vehicle has a flat tire.
spark ignition engine: An engine that uses an electric arc at the spark plug to ignite the air-fuel mixture. Gasoline engines are examples.
spark intensity test: Test that measures the brightness and length of the electric arc (spark) produced by the ignition system. It provides a quick and easy way of checking the general condition of the ignition system. It is also called a spark test.
spark knock: Engine combustion problem caused by the spark plug firing too soon in relation to the position of the piston.
spark line: Oscilloscope line showing voltage needed to maintain an arc across the spark plug gap.
spark plug: Part of an ignition system that converts high voltage into an electric spark or arc in the engine combustion chamber to burn the engine's fuel.
spark plug cleaner: Air-powered device that blasts the plug tip with abrasive to clean spark plugs.
spark plug gap: The spacing between the side electrode and the center electrode of a spark plug.
spark plug heat range: A rating of the operating temperature of the spark plug tip.
spark plug reach: The distance between the end of the spark plug threads and the seat or sealing surface on the plug. This determines how far the plug extends through the cylinder head.
spark plug wire: Wire that carries coil voltage from a side terminal of the distributor cap to a spark plug.
spark test: See *spark intensity test*.
spark tester: Device used to check ignition system output voltage. It looks like a spark plug with a very wide air gap and a ground wire.

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spark timing: See *ignition timing.*
speaker: Audio device that uses a permanent magnet and a coil of wire mounted on a flexible diaphragm to convert electricity into motion and sound.
specialized technician: An expert technician in a specific area or system of automotive repair.
specialty shop: An automotive service facility that concentrates in one type of repair work, such as an exhaust or transmission shop.
speed-sensitive power steering: See *proportional rack-and-pinion power steering.*
spider: Welded center section of a drop-center wheel that bolts to a vehicle wheel hub.
spider gear: Idler and axle bevel gears in a differential that drive the rear axles of a vehicle. They are also referred to as differential gears.
spillback ball: Large "ping-pong-type" ball in the filler neck of a fuel tank assembly to prevent fuel from leaking out of the vehicle during fill-ups.
spindle: Shaft extending outward from the steering knuckle or the suspension system that holds the hub and wheel bearings.
spindle adjusting nut: Nut threaded on end of a spindle for adjusting the wheel bearing.
spin-on oil filter: A sealed unit having the element permanently enclosed in the filter body. This is the most common style automotive oil filter.
spiral bevel gear: A variation of a bevel gear in which the gear teeth are curved.
splash lubrication: Term for a style of lubrication where oil is distributed to needed areas by spraying or splashing.
splash oiling: Oil distributed to needed areas by spraying or splashing.
spongy brake pedal: Brake pedal that feels like it is connected to a spring or a rubber band.
spool control valve: Valve in a power steering gearbox or gear housing that routes oil to the power cylinder.
spool valve: Valve used to redirect fluid flow to different locations in a hydraulic circuit.
spray pattern: Term for fuel shape and consistency as it is discharged from the nozzle of a fuel injector. It should be a narrow, cone-shaped mist of fluid for best combustion.
spray-on gasket solvent: Solvent applied to soften a gasket so that it can be scraped off more easily.
spring bind: Condition caused when a valve spring's coils hit each other from over-compression, stopping additional compression and valve opening action.
spring closed length: The length of a valve spring when installed on the engine with the valve closed.
spring fatigue: A weakening of the strength/resistance of a spring that occurs after prolonged service or damage.
spring free length: Total length of a spring in its uncoiled position. For example, the length of a valve spring when removed from the engine.
spring open length: The length of a valve spring when installed on the engine with the valve fully open.
spring rate: The stiffness or tension of a spring, or the amount of weight needed to compress or bend a spring.
spring tension: The stiffness of a valve spring.
sprocket: Contoured gear or wheel that meshes with a chain or belt.
sprung weight: The weight of all the parts of the vehicle that is supported by the springs and suspension system.
spun rod bearing: A bearing that has been hammered out flat and damaged with the outer part of the bearing still rotating inside of the connecting rod bore.
spur gear: A gear that has its teeth cut parallel to a gear shaft centerline.
squish area: The area between the piston head at TDC and the cylinder head. This area makes up the combustion chamber.
stability control system: Electronically links the steering, suspension, braking, and traction control systems together to prevent a loss of vehicle control and skidding when cornering at high speed.
stabilizer bar: See *sway bar.*
stacked pattern: See *raster pattern.*
stake: Term for denting or bending certain types of fasteners whose edges can be bent downward into a slot to secure it on a shaft.
staking: Making a small dent in cylinder head metal next to a valve seat to hold it in place after replacement.
stall speed: Highest speed of impeller rotation in a torque converter without rotation of the turbine.
stall test: Method used to shop-test for transmission slippage or a malfunctioning torque converter in an automatic transmission.
stalling: Condition in which the engine suddenly stops running, or dies.
standard bearing: Bearing designed with the original dimensions specified by an engine manufacturer for a brand new and unmachined crankshaft.
star configuration: Computer network configuration in which one main processing computer and several less complex computers work as a network.
star wheel: Screw-type brake shoe adjusting mechanism.
start switch: See *ignition switch.*
starter armature: System that supports starting motor windings and strengthens their magnetic fields to produce the high torque and high speeds necessary to crank the engine.
starter current draw test: Test that measures that amount of current used by a vehicle starting system.
starter ground circuit test: Test for problems in the circuit between a starting motor and a negative battery terminal.
starter relay: Device that when closed, accepts a small current flow from the ignition switch or ECM to handle a slightly larger current flow to the starter solenoid.
starter shim: Thin metal strip used to adjust clearance between a starter motor pinion gear and the flywheel ring gear.
starter solenoid: High-current relay that establishes an electrical connection between the battery and the starting motor.
starter-actuated solenoid: Solenoid that completes the battery-to-starter circuit and also operates the pinion gear. It has a plunger that moves a shift lever to engage the pinion gear.
starting headlight test: Quick test that involves turning the headlights on while attempting to start a vehicle. Depending on what the headlights and starter do as the engine is cranked, the test can give a general idea of the starter system problem.
starting motor: High-torque electric motor used to turn the gears at the engine flywheel. It converts electrical energy from the battery into mechanical energy to crank the engine.
starting motor rebuild: Process of repairing a damaged or worn-out starter motor. This involves disassembly, cleaning, inspection, replacement of worn or damaged parts, polishing the commutator, lubrication, and reassembly/reinstallation.
starting system: Electric motor and other components used to rotate the engine until it starts.
states of matter: Vapor, liquid, and solid.
static imbalance: Condition in which a tire's weight mass is not evenly distributed around the axis of rotation. This condition is characterized by up-and-down vibration as the tire's weight mass tries to bring the tire back into balance.
stator: A small hub in a torque converter that improves oil flow. *Also,* a stationary set of wire windings that surrounds a rotor in a motor-generator or an armature in an alternator.
stator shaft: See *stator support.*
stator support: Stationary splined tube in a torque converter that supports the input shaft. It is also called a stator shaft.
steam cleaner: Machine that heats water into steam for removing heavy deposits of dirt, grease, and oil from the outside of large automotive part assemblies without chemicals.
steel rule: Measuring tool used to make straight-line measurements accurate to about 1/64" (0.5 mm). It is also referred to as a scale.
steel shell: Part of a spark plug that supports the other parts of the plug and has threads for screwing the plug into the engine cylinder head.
steering angle sensor: Part of a stability control system that measures how sharply the steering wheel is rotated to the right or left.
steering axis inclination: The angle, away from the vertical, formed by the inward tilt of the ball joints, king pin, or MacPherson strut tube.
steering column: Hollow tube that supports a steering wheel and a steering shaft.
steering column assembly: Assembly consisting of a vehicle steering wheel, steering shaft, column (outer housing), ignition key mechanism, and, sometimes, a flexible coupling and a universal joint.
steering damper: Oil-filled shock absorber positioned between a vehicle frame and center link in some parallelogram steering linkage arrangements.

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steering feel: The feedback of road imperfections vibrating through a steering wheel.
steering gear reduction: See *gearbox ratio.*
steering gearbox: Mechanism that connects with the steering shaft to multiply turning torque and change turning motion into a straight-line motion to the left or right for moving the steering knuckles.
steering knuckle: Steering part that holds the wheel bearings, axle stub shaft, and hub.
steering linkage: Components connecting the steering gearbox to the steering knuckles and wheels.
steering pinion gear: Gear rotated by a steering wheel and steering shaft with teeth that mesh with the teeth on the rack in a rack-and-pinion steering system.
steering ratio: See *gearbox ratio.*
steering sensor: A sensor that provides wheel orientation and speed data to the computer in an electronic shock absorber system.
steering shaft: A two-piece shaft that transfers turning motion from the steering wheel to the gearbox.
steering system: The components that let the driver change the direction of a vehicle.
steering system inspection: Process of checking for excessive wear and movement in the operating parts of a vehicle steering system.
steering wheel: Wheel turned by a driver to rotate a steering shaft that passes through the steering column and vehicle firewall.
steering wheel play: The amount of movement in a steering wheel before it starts to move steering rack or linkage. Steering problems can arise if this is not within specifications.
steering wheel pull: A noticeable wheel tug, either right or left, that is felt through a steering wheel strain in one direction.
steering wheel touch control: Switches mounted on a steering wheel to manipulate some vehicle systems with minimal distraction.
stereo amplifier: An electronic component for radio speakers. It increases the current output of the radio and/or compact disc player for driving the speakers more efficiently. It is also called a power booster.
stethoscope: A listening device that amplifies the sound generated by internal parts. It consists of a probe connected to earpieces.
sticktion: Term describing the initial resistance to force between rubber seals or bushings and metal parts. It can cause noises between parts and affect vehicle ride smoothness.
stiff clutch pedal: Problem that occurs when part of a clutch release assembly is not moving in sync. The pedal feels tight, requiring more force to be applied to it to release the clutch.
stoichiometric fuel mixture: Chemically correct air-fuel mixture (14.7 parts air to 1 part fuel) that given constant engine conditions, burns as efficiently as possible during combustion.
stoichiometric mode: One of three modes for a direct electronic fuel injection system that produces a theoretically homogenous (equally mixed and dispersed) mixture of fuel and air.
stone dressing tool: Diamond-tipped cutting tool used to smooth and true the face of a seat stone.
stool creeper: A stool with wheels that allows a technician to sit while working on vehicle parts that are near the ground.
stoplight switch: A spring-loaded electrical switch that operates the rear brake lights of the vehicle when the brakes are actuated.
storage: Collection of programming, data, operating parameters, trouble codes, and other information that a computer accumulates and remembers on its memory chips.
stranded wire: Flexible wire that has numerous individual wires twisted together inside the insulation.
strap: See *retaining collar.*
strategy-based diagnostics: See *systematic approach.*
stratified charge combustion chamber: A combustion chamber design in which a rich air-fuel mixture is first ignited in a small chamber connected to the main chamber. These flames instantaneously ignite a lean air-fuel mixture waiting in the main chamber.
stratified charge mode: One of three modes for a direct electronic fuel injection system that uses a small charge of fuel injected into the combustion chambers during the end of the compression stroke.
stress testing: The use of heat, cold, or moisture to simulate extreme operating conditions encountered by vehicle components, parts, and systems.
structural oil pan: Oil pan designed to add strength to an engine bottom end and cylinder block with ribs and bosses to help support the crankshaft and main bearings.
strut assembly: Suspension component that consists of a shock absorber, a coil spring (most types), and an upper damper unit. It replaces the upper control arm.
strut bearing: A ball bearing that allows the shock-and-spring assembly to rotate for steering action; only used on the front of the vehicle.
strut rod: Rod that fastens to a control arm and vehicle frame to keep the arm properly oriented.
strut rod nut: A hex nut that screws on top of a shock absorber rod to hold it in an upper strut retainer.
strut shock absorber: A piston operating in an oil-filled (or oil and gas) cylinder to prevent coil spring oscillations.
strut spring compressor: Screw-type tool used to compress strut springs during removal and installation.
stub axle: Two short outer axles connected to a long central axle shaft through the CV joints. The stub axles connect to the transaxle and the wheels.
stuck valve: Condition in which a valve stem rusts or corrodes and locks in the valve guide. It is also called a frozen valve.
stud puller: Tool used to remove studs and bolts broken off above the surface of a part. It is also called a stud wrench.
stumbling: Condition in which an engine repeatedly loses power and causes the vehicle to jerk upon acceleration or highway cruising.
subtraction: Arithmetic process of taking away a certain number or quantity from another.
suction service valve: An A/C service valve that is located at the inlet to the compressor, in the system low side.
suction side: See *low side.*
suction throttling valve: An A/C system control that is used with the expansion valve to control evaporator temperature.
sump: The lowest area in an oil pan where oil collects.
supercharger: A belt-driven compressor that pumps air into an engine's intake manifold. Superchargers are dependent on engine speed and are most efficient at high engine speeds.
supercharger assembly: The components of a supercharger. The supercharger assembly consists of a housing, rotors, two timing gears, an extension housing, and a drive pulley.
supercharger belt: Belt attached to a supercharger drive pulley that drives the rotors inside the supercharger.
supercharger bypass valve: Valve that allows boost pressure from a supercharger to flow back into the intake air during low engine loads. During high demand, the valve closes so all boost pressure flows into the engine.
supercharger cooling system: System that uses liquid coolant passed through an intercooler positioned on the supercharger to keep the blower intercooler temperature cooler than the engine's operating temperature.
supercharger drive pulley: Pulley that draws power from an engine crankshaft through a large serpentine belt or supercharger belt to drive a supercharger.
supercharger extension housing: Bolted to the front of the supercharger housing, it encloses a shaft that connects one of the supercharger timing gears to the drive pulley.
supercharger housing: Large aluminum enclosure for the rotors, rotor bearings, and drive gears of a supercharger.
supercharger rotor: Meshing, twisted blades or fans that spin to produce pressure inside a supercharger housing.
supercharger timing gear: Gears that keep the two rotors timed and spinning at the same speed. One is driven by the drive pulley; the other is driven by the first timing gear.
superheat switch: An A/C system control that senses low system pressure and high compressor temperature, and sends current to the thermal limiter.
surface ignition: See *preignition.*
surging: Condition in which engine power fluctuates up and down.
suspension control module: Computer that controls the electronic suspension system. It uses sensor inputs to issue output commands to electrical devices that control air pressure or hydraulic fluid flow to suspension parts.
suspension leveling system: Suspension system designed to keep vehicle level and at proper height, even when carrying a heavy load.

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suspension system: Components that let vehicle wheels move up and down without body movement.
suspension system spring: Spring that compresses and extends as a vehicle travels over road hazards to absorb vibrations and smooth the ride.
sway bar: A transversely-mounted spring steel bar that is installed to control body lean during cornering. The ends of the sway bar are attached to the lower control arm on each side of the vehicle, and the center is attached to the frame. It is also called a stabilizer bar.
sway bar link: Metal bar that connects a sway bar to a suspension control arm.
swing axle: Flexible axle with a U-joint mounted on each end to allow for up-and-down suspension movement. They are used on vehicles with the differential mounted solidly on the frame.
swirl combustion chamber: The shape of the intake and exhaust ports and the combustion chamber roof create a swirling effect to help mix the air-fuel mixture.
switch: An electrical device used to connect or disconnect the power supply in a circuit.
switch diagnostic test: A test that involves activating various switches while using a scan tool to determine if the switch is working normally.
switching sensor: See *manual transmission gear sensor.*
synchronizer: Assembly of hub, sleeve, and other components that brings certain transmission gears to the same rotational speed as the output shaft before sliding in mesh with them to lock them to the output shaft.
synthetic oil: Oil manufactured by further processing and blending crude mineral oils together with about 25% more synthesized (modified) mineral oils.
system: A set of fitted parts and assemblies designed to complete a specific function.
system wiring diagram: A diagram that contains only the components and wires for a particular circuit, such as the ignition system circuit.
systematic approach: Problem-solving approach that involves using a knowledge of automotive system theory and a logical process of elimination to find the source of a vehicle problem. It is also called strategy-based diagnostics.

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tach: Abbreviated name for a tachometer.
tach-dwell meter: A tachometer and a dwell meter combined into one instrument. The tachometer is for measuring engine speed (rpm). The dwell meter measures current flow as compared to degrees of engine crankshaft rotation.
tachometer: Device used to measure engine speed in rpm.
tail shaft housing: See *extension housing.*
tailpipe: Steel tubing that carries exhaust from a muffler to a point at the rear or side of a vehicle, where it can be dispersed.
tandem master cylinder: See *dual master cylinder.*
tap: Tool for cutting threads inside a hole.
tape measure: A flexible roll of measuring tape that extends to several feet or meters in length and is used for long measurements. It is also called a tape rule.
tappet: See *valve lifter.*
tapping screw: See *sheet metal screw.*
taxable horsepower (thp): A general rating of engine size focused on cylinder size measurements used to find the tax placed on a vehicle.
teardown: The general method of disassembly of an engine. Specific teardown procedures will vary by engine.
technical bulletin: See *technical service bulletin.*
technical service bulletin (TSB): A service bulletin published by auto manufacturers and equipment suppliers that helps a technician stay current with recent technical changes, repair problems, and other service-related information. It is also called a technical bulletin.
technology: The application of math, science, physics, engineering, and other subjects to a manufacturing or production process.
telescoping gauge: Tool used in conjunction with a micrometer to measure internal part bores or openings.
temperature warning light: Dashboard light that illuminates to inform the driver when the engine is overheating.
tensile strength: The amount of pull a fastener can withstand before it breaks.
terminal: A connecting point in an electrical circuit.
test indicator: See *battery charge indicator.*
test light: Piece of test equipment that shows the presence of current by lighting a small light.
thermal efficiency: A comparison of the amount of fuel burned to the amount of horsepower output.
thermal limiter: An A/C system control that receives current from the superheat switch when it senses low system pressure and high compressor temperature to prevent damage.
thermal runaway: Occurs when a transistor is driven too hard (too much output current is controlled by the transistor). The output of the transistor will fluctuate as the transistor's thermal capacity is exceeded.
thermistor: Type of resistor that undergoes internal resistance changes as temperature fluctuates.
thermo switch: See *fan switch.*
thermometer: A tool/gauge for measuring temperature.
thermostat: A temperature sensitive device used in cooling systems to control coolant flow in relation to temperature.
thermostat housing: A pot metal, aluminum, or plastic enclosure that holds a thermostat in place on an engine.
thermostat rating: Information stamped on a thermostat to indicate the operating (opening) temperature of the thermostat.
thermostatic cycling switch: Turns the compressor on and off to maintain the correct evaporator temperature (approximately 32°F or 0°C).
thermostatic fan clutch: Type of fan clutch that contains a temperature-sensitive, bimetallic spring to control fan action.
thread chaser: Tool used to clean and remove burrs and other damage from threads.
thread repair insert: Item screwed along the inside walls of a damaged threaded hole. The insert replaces the damaged threads and allows the use of the original size fastener.
three-angle valve job: Type of valve seat narrowing that uses three different stone angles when grinding.
three-phase ac power: Power system used in an HV motor-generator when it must propel the vehicle. It consists of three single-phase alternating voltage waves flowing through three conductors (HV power cables) at different intervals in time.
three-valve combustion chamber: Combustion chamber with two intake valves and one exhaust valve. It nearly matches the performance of a four-valve chamber, but with lower costs and increased reliability.
three-way catalytic converter: A catalytic converter capable of reducing amounts of HC, CO, and NO_X from exhaust gases.
throttle actuator: Part of a cruise control system that physically moves the engine throttle lever to control engine power and resulting vehicle speed.
throttle body injection system (TBI): The first electronic fuel injection system used on passenger cars with injector nozzles mounted in a throttle body assembly located on top of the engine.
throttle position sensor (TPS): A variable resistor connected to the throttle plate shaft that produces different current levels for different throttle positions.
throttle safety release: Electric clutch release mechanism that returns an engine to idle even if the engine throttle actuator fails or loses power.
throttle valve: A valve controlled by linkage from the engine throttle plates or by a vacuum modulator operated from engine manifold vacuum. It controls fluid pressure to the shift valve according to the distance the throttle is moved.
throttle-by-wire system: System of components that move engine throttle valves electronically instead of using conventional mechanical linkage from an accelerator pedal. It is also called a drive-by-wire system.
throw-out bearing: See *release bearing.*
throw-out lever: See *clutch fork.*
thrust spring: Spring that preloads the rack-and-pinion gear teeth inside a gear housing to prevent excessive gear backlash.
thrust washer: A bronze or hardened steel washer placed between two moving parts to prevent longitudinal movement.
tie-rod: Inner and outer steel rods that fasten and transfer turning force from a rack or center link to steering knuckles in a steering system.
tie-rod assembly: Term for the combined components of a tie-rod.

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tilt steering column: Steering column equipped with a universal joint at the top that allows the top half of the column and the steering wheel to be positioned at different angles. It is also called a tilt steering wheel.
tilt steering wheel: See *tilt steering column.*
timed injection system: Type of fuel injection that sprays fuel into the engine during intake or compression strokes, in relation to piston and valve action.
timing advance: A method of ignition timing that fires the spark plugs on the engine's compression strokes relatively sooner than the specified manufacturer's timing.
timing belt: A flexible cogged (square) toothed belt used to rotate the camshaft(s).
timing belt drive mechanism: Mechanism, that consists basically of a crankshaft sprocket, camshaft sprocket, timing belt, and belt tensioner, used to drive a camshaft on overhead camshaft engines.
timing belt sprocket: A crank sprocket is keyed to a crankshaft snout. A camshaft sprocket bolts to the front of a camshaft. Cast iron or aluminum belt sprockets have timing marks that align with engine points to correctly open valves.
timing belt tension: Degree of tightness of an engine timing belt. If too loose, the belt could vibrate in service and fly off its sprockets. If too tight, the timing belt could break.
timing chain: Sprocket-and-chain combination that transfers rotation from the crankshaft to the camshaft. It may also mesh with other sprockets to power other devices.
timing cover: See *engine front cover.*
timing gear: Calibration-marked meshing gears on a crankshaft and camshaft that rotate the camshaft at half crankshaft speed.
timing gear backlash: The amount of clearance between timing gear teeth, which is often used as an indication of wear.
timing gear runout: Unwanted gear wobble, or side movement, during rotation. A dial indicator is used to measure the value.
timing mark: Calibrating mark on timing gears or other timing devices. They are used to set engine timing.
timing retard: A method of ignition timing that fires the spark plugs on the engine's compression strokes relatively later than the specified manufacturer's timing.
tinning: A process used to clean and prepare the surface of the soldering gun tip and the electric components. It consists of placing a thin coat of solder on the tip or parts.
tire: A treaded, rubber-covered carcass made of steel and fiber cords. It provides vehicle traction on a road surface and a cushion between the wheels and a road.
tire changer: See *tire changing machine.*
tire changing machine: Machine that uses manual and pneumatic mechanical components to force a rubber tire on or off a metal wheel/rim. It is also called a tire changer.
tire impact damage: Punctures, cuts, tears, and other physical tire injuries. It is also referred to as road damage.
tire inspection: Process of looking for excessive wear, improper inflation, or physical damage on a vehicle's tires.
tire load index number: Numerical representation (in pounds or kilograms) of the weight a tire can carry without failure.
tire maintenance: Service that includes periodic inspection, checking of inflation pressure, and rotation of vehicle tires to prevent problems.
tire marking: Writing on a tire sidewall that gives information about tire size, tire model, load-carrying ability, inflation pressure, number of plies, speed rating, manufacturer, etc.
tire pressure gauge: Air pressure gauge used to measure tire inflation pressure.
tire pressure monitor calibration tool: A handheld device that communicates wirelessly with each vehicle tire pressure sensor to accurately regulate the TPMS for proper operation.
tire pressure monitoring system (TPMS): System that monitors tire pressure with sensors and alerts the driver if one or more of the vehicle's tires is under- or overinflated.
tire rotation: Moving tires from side to side or from front to back to help equalize tire wear, making the tires last longer.
tire runout: Tire movement or wobble that is caused by a faulty tire (ply separation or manufacturing defect).
tire size: Tire marking given on its sidewall as a letter-number sequence.
tire speed rating: Tire marking indicating the maximum allowable sustained road speed a tire can safely withstand without failure.
tire temperature resistance: Tire marking indicating a tire's ability to resist heat buildup. It is given as an A, B, or C rating, with an A rating resisting temperature buildup the best.
tire traction: Tire marking for a tire's ability to grip a road surface. It is given as an A, B, or C rating, with an A rating providing the most traction and a C rating the least.
tire vibration: Tire problem commonly caused by an out-of-balance condition, ply separation, excessive tire runout, a bent wheel, tire stiffness variation, or tire cupping.
tire wear pattern: Areas of tire tread that are worn off, which can provide information on causes of the wear.
titania oxygen sensor: Type of oxygen sensor that uses a thick film of titania to detect the amount of oxygen present in exhaust gases. The sensor varies its internal resistance to signal the ECM.
toe: Determined by the difference in distance between the front and rear of the left- and right-hand wheels.
toe adjustment sleeve: Threaded sleeve provided for changing the length of a tie-rod assembly during wheel alignment.
toe-in: When the wheels are closer at the front than at the rear. Toe-in causes the wheels to point inward at the front.
toe-out: When the wheels are farther apart at the front than at the rear. Toe-out causes the front of the wheels to point away from each other.
toe-out on turn: The amount the front wheels toe-out when turning corners. It is also called a turning radius.
tool holder: Trays, racks, pouches, or other organizers of small tools and parts.
toolbox: Metal cabinet, chest, or carrying box that stores and protects a technician's tools when not in use.
toolroom: A shop area where large pieces of repair equipment, shop tools, and repair supplies are stored.
top dead center (TDC): The point of travel where the piston is at its highest point in the cylinder.
torque: Any turning or twisting force.
torque converter: Fluid-filled hydraulic coupling that acts as a clutch on an automatic transmission/transaxle and transmits and multiplies engine torque.
torque multiplication: Increasing engine torque through the use of a torque converter or gears.
torque specification: Tightening value provided by the vehicle manufacturer for certain fasteners. A general torque chart is also available when average bolt tightening values can be used.
torque steer: Undesired turning effect due to the difference in drive angles in an unequal-length drive axle system causing one wheel to receive more torque during heavy acceleration.
torque tube driveline: Type of driveline with a solid steel drive shaft enclosed in a large hollow tube that forms a rigid part of the rear axle housing. This keeps the transmission, drive shaft, and differential in alignment without flexing over rough surfaces. Late-model vehicles have replaced this style with the Hotchkiss driveline.
torque wrench: A calibrated wrench designed to measure the amount of turning force applied to a threaded fastener.
torque-to-yield: A bolt tightening method in which a bolt is first tightened to a specific torque and then turned a certain number of degrees. This stretches the bolt to its yield point.
torque-to-yield bolt: Type of bolt that is first tightened to a specified torque. Then, using a torque angle gauge, the bolt is turned a specified number of degrees beyond the torque point. This type of bolt must be replaced when reassembling the engine.
torque-to-yield specification: Set of manufacturer's instructions for tightening certain fasteners. The fastener is first tightened to a specified torque. Then, using a torque angle gauge, the fastener is turned a specified number of degrees beyond the torque point.
torquing: The process of properly tightening a fastener with specifications.
Torsen differential: A type of locking differential that uses complex worm gearsets, with worm gears driving worm wheels.
torsion bar: Spring steel rod that functions as a spring and absorbs shocks by twisting. One end of the bar is attached to the frame and the other end is attached to the control arm.

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torsion bar suspension: A suspension system that contains torsion bar springs instead of coil springs and can be height adjusted with adjustment bolts.
torsion spring: Small coil spring positioned near the inside of a clutch disc that helps absorb shock and vibration that occurs when the disc first engages with the flywheel. It is also called a damping spring.
total misfire: Readout averaging the number of engine cylinder misfires recorded during the last 200 crankshaft revolutions.
trace: Pattern of circuit voltages.
track rod: Metal rod connected on one end to a rear axle and on the other end to the vehicle frame to prevent axle side-to-side movement when cornering. It is also called a lateral control rod.
track width: Distance between the centerlines of two wheels (right and left) on the same axle.
tracking: Refers to the position or direction of the two front wheels in relation to the two rear wheels.
traction control system (TCS): Electronically controls the brakes, differential, engine, and transaxle to help reduce tire spin upon acceleration on slippery pavement.
trailing edge: See *falling edge.*
tram gauge: Wheel alignment tool that is used to compare the distance between the front and rear of a vehicle's tires for checking toe adjustment.
transaxle: A combination of transmission and differential in one case, used on front-wheel drive vehicles.
transaxle case: An aluminum housing that encloses and supports the parts of the transaxle.
transaxle differential: Gear assembly that transfers power to the front axles and wheels while allowing one wheel to turn at a different speed than the other.
transduce: To change from one form to another.
transducer switch: A type of switch in which its internal resistance changes with a change in a condition.
transfer case: Transmission-driven gearbox that provides driving force to both front and rear drive shafts on a four-wheel drive vehicle.
transformer: An electrical device that uses two sets of coils to transform voltage and current to higher or lower levels.
transistor: A semiconductor device that can be used as a switch or an amplifier.
transmission case: Aluminum or cast iron housing surrounding and supporting a transmission.
transmission control module (TCM): Name for a computer that controls the functions of an electronic-controlled transmission.
transmission control sensor: Electronic sensor that monitors a variable component of a transmission and sends signals to a transmission control module.
transmission fluid varnish: Term for a brown, glue-like substance that coats internal parts of a transmission. It is formed from broken-down transmission fluid and can cause major transmission problems.
transmission gear: Term for the gearsets and gear assemblies within a transmission that transfer power through the transmission. These gears include input, output, countershaft, reverse, and planetary gearsets.
transmission jack: Adjustable jack used to support a transmission or transaxle during removal and installation.
transmission oil cooler: Separate tank formed inside radiator tanks that dissipates heat from automatic transmission or transaxle fluid.
transmission oil pump: Pump located near the front of a transmission assembly that produces the necessary pressure and lubrication to operate an automatic transmission.
transmission pan: Steel or cast aluminum tub bolted to the bottom of a transmission case that acts as a collection unit and reservoir for transmission oil.
transmission rear seal: Seal that rides on a slip yoke and prevents fluid leakage from the rear of the transmission.
transmission shaft runout: Vibration or side-to-side movement of a worn or bent transmission shaft during operation. Irregular gear tooth wear can be a cause.
transmission solenoids: Actuators in the valve bodies of an electrically controlled automatic transmission. With current from a control module, it can act on a control valve to change hydraulic pressure for various operating conditions.
transponder key: Theft deterrent ignition key containing an electronic chip. Each time the key is turned in the ignition, it generates a coded signal that must be recognized by the transponder module in order for the vehicle to start.
transverse: Crosswise; term used to identify an engine rotated 90° from the traditional longitudinal mounting.
travel: Term for required movement/action of suspension system springs.
tread: Outer surface of tire that contacts the road.
tread wear rating: Measure of a tire's resistance to wear. Tread wear ratings range from 100 to 500. A tire with a rating of 200 should last about twice as long as a tire rated at 100.
trickle charger: See *slow charger.*
trigger wheel: See *sensor rotor.*
tripod CV joint: A type of constant velocity joint used on the inner part of a CV axle. It is triangular shaped and has three sets of needle bearings and balls on a spider assembly.
trouble code chart: Diagnostic aid that lists the problem encountered for each code.
trouble code conversion: Process of a scan tool automatically converting a number code into abbreviated words that explain a potential problem.
troubleshooting chart: Diagnostic flowchart that provides step-by-step procedures to test automotive systems.
tubeless tire: Tire that does not have a separate inner tube.
tumbler: Lock mechanism on an ignition switch.
tuner: Device that is used to adjust to different radio frequencies (stations).
turbine: The driven fan assembly in a torque converter.
turbine housing: Outer enclosure that routes exhaust gases around a turbine wheel in a turbocharger.
turbine shaft: See *input shaft.*
turbine wheel: Exhaust-driven fan that turns the turbo shaft and compressor wheel of a turbocharger.
turbo: See *turbocharger.*
turbo blow off valve: Air pressure release valve to limit maximum boost pressure as the engine throttle valves are closed rapidly for deceleration. It is also called a dump valve.
turbo lag: Short delay before a turbocharger develops sufficient boost.
turbo shaft: Steel shaft, passing through the center of the bearing housing, that connects the turbine and compressor wheels.
turbo shaft end play: Lengthwise movement between a turbo shaft and its connections. It should be .001″ (0.03 mm) to .003″ (0.08 mm).
turbo shaft radial runout: Variation in the radius of a turbo shaft. It should be .003″ (0.08 mm) to .006″ (0.15 mm).
turbocharger: A turbine device that utilizes exhaust pressure to increase the air pressure going into the engine cylinders. It can also be called a turbo.
turbocharger boost pressure: Maximum allowable intake manifold pressure a turbo system should build under a full engine load.
turbocharger cooling system: System that forces coolant through the turbo bearing housing to keep the turbo from overheating under prolonged high boost.
turn signal system: Vehicle system consisting of a fuse, turn signal switch, flasher unit, turn signal bulbs, indicator bulbs, and related wiring. When activated, the right or left side turn lamps flash, along with turn indicator lights in the instrument panel or on the fenders.
turning: The removal of a thin layer of metal from a rotor or drum to restore the surface finish. It is also referred to as cutting or machining.
turning plate: A tool used to eliminate stresses in the suspension and linkage when turning the wheels during alignment checks and adjustment.
turning radius: See *toe-out on turn.*
turning radius gauge: Wheel alignment tool that measures how many degrees the front wheels are turned right or left.
turns ratio: A ratio of the number of windings or wraps of wire in each transformer coil in a transformer.
twin turbocharger system: See *sequential turbocharger system.*
twisted-pair conductor: Type of conductor with two insulated wires that are wound, or twisted, into a spiral to carry data signals between computers.
twisted-pair wire: Two insulated wires that are wound, or twisted, around each other.

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two-bolt main block: Design with two cap screws holding each main bearing cap to a cylinder block.
two-channel ABS: An ABS channel that has two separate hydraulic circuits controlled by the electro-hydraulic modulator.
two-gas exhaust analyzer: Exhaust analyzer that can only measure the amount of hydrocarbons (HC) and carbon monoxide (CO) in a vehicle's exhaust gases.
two-stroke-cycle engine: An internal combustion engine that requires one revolution of the crankshaft and two piston strokes (one upward and one downward) to complete the intake, compression, power, and exhaust events.
two-way catalytic converter: A catalytic converter capable of reducing amounts of HC and CO from exhaust gases.
type A misfire: Engine misfire that is severe enough to cause catalytic converter damage. This type of misfire will trip a trouble code and illuminate the MIL.
type B misfire: Engine misfire that causes an increase in emissions but not catalytic converter damage.

U

U-joint: See *universal joint*.
umbrella valve seal: Rubber or plastic seal placed on a valve stem before the spring and retainer to seal the gap between stem and valve guide.
underinflation: Term for low air pressure within a tire, which can lead to problems including flexing sidewalls and a center tread section that does not wear.
undersize battery: A battery with a lower watt or amp rating than the battery it is replacing. It can cause starting motor performance and battery service life issues.
undersize bearing: Bearing designed to be used on a crankshaft journal that has been machined to a smaller diameter.
understeer: A vehicle steering issue in which the front tires lose traction while the rear tires retain traction as a vehicle goes through a corner. It appears as if the driver is not adequately turning the steering wheel.
unibody construction: A vehicle design in which the frame and body is one unit.
universal joint: A flexible joint that permits changes in driving angles between a driving and driven shaft. It is nicknamed a U-joint.
universal joint tool: Special tool or set of tools available for pressing universal joints apart and together. It can take the place of a vise during assembly or disassembly.
unlike charge: Opposite charged electrical fields that attract each other.
unsprung weight: The weight of all of the vehicle's parts not supported by the springs, such as wheels and tires.
upper spring seat: Metal plate with a flange to hold the upper end of a coil spring and a center hub that contacts the strut bearing.
upper strut retainer: Metal disc that secures the upper end of a strut assembly to a vehicle frame or unibody.

V

vacuum: Pressure lower than atmospheric pressure that is formed in an enclosed area.
vacuum bleeder tool: A tool that uses shop air pressure and the Venturi effect to produce suction in a brake fluid container and a small plastic hose connected to a brake system's bleeder screw.
vacuum bleeding: Method of brake bleeding that requires the use of a vacuum device to pull brake fluid through the hydraulic system.
vacuum booster: Uses engine vacuum or vacuum created by an auxiliary pump to help apply the brake pedal.
vacuum gauge: Gauge commonly used to measure negative pressure or vacuum (suction). It reads in inches of mercury (in/Hg) or metric kilograms per square centimeter (kg/cm^2).
vacuum hose diagram: Vehicle specific diagram showing the routing of all vacuum hoses.
vacuum leak: A leak (often with an accompanied hissing noise) commonly caused by deteriorated, broken, or loose vacuum hoses.
vacuum modulator valve: Valve that senses engine load based on engine manifold vacuum pressure. It mechanically changes throttle pressure to determine shift points.
vacuum motor: Large diaphragm that converts vacuum into motion.
vacuum pump: Engine-operated pump used to produce a vacuum for vehicle accessories. It is also a hand-operated pump used to test vacuum-operated devices.
vacuum suspended brake booster: Has vacuum on both sides of the piston or diaphragm when the brake pedal is released. Pushing down on the brake pedal releases the vacuum on one side of the booster. The difference in pressure pushes the piston or diaphragm for braking action.
vacuum switch: Routes engine vacuum to the correct vacuum motor. The vacuum motors then move the air doors.
vacuum test: Test that uses a vacuum gauge to measure intake manifold vacuum and indicate engine condition.
vacuum-pressure gauge: Gauge that can read and measure both negative and positive pressures.
valve adjustment: See *valve train clearance adjustment*.
valve body: Housing bolted to the bottom of a transmission containing most of the valves used in operation of an automatic transmission.
valve core: A threaded, spring-loaded valve that screws into a tire's valve stem and allows air to be added or expelled from a tire.
valve cover: A metal or plastic cover over the top of a cylinder head to prevent oil leakage.
valve face angle: The angle formed between a valve face and valve head.
valve float: A tendency for valves to remain partly open, especially at high speeds. It usually results from a weak or broken valve spring.
valve grinding: Grinding done to create a fresh, smooth surface on a worn or damaged valve face and stem tip.
valve grinding machine: Machine used to resurface valve faces and valve stem tips.
valve guide: A hole machined into the head to support the valves as they ride up and down. It may be machined oversized to accept a removable guide.
valve guide wear: Deterioration of a valve guide, which allows the valve stem to move sideways in the guide during operation.
valve keeper: Device that snaps into a groove in a valve stem. It is used to retain valve and spring assembly in the head.
valve lapping compound: An abrasive paste material used to check the valve-to-seat contact.
valve lash adjustment: See *valve train clearance adjustment*.
valve lifter: Component that is moved by the camshaft lobe and in turn moves the push rod or the rocker arm. It is also called a tappet.
valve overlap: Period in degrees of camshaft rotation in which both the intake and exhaust valves are partially open.
valve retainer: A specially-shaped washer that fits over the top of a valve spring to secure it on the valve stem.
valve retrusion: The head of a valve sinking into a cylinder head caused by extensive valve seat and face wear.
valve rotator: Device that turns an engine valve to prevent carbon buildup and hot spots.
valve seal: A seal that is placed over the valve stem to prevent oil leakage between the stem and the guide.
valve seat: Machined or installed metal surface on the intake and exhaust ports, against which a valve rests and seals.
valve seat angle: The angle formed by the face or contact surface of a seat.
valve seat machine: A specialized milling machine designed for valve guide and valve seat service.
valve seat reconditioning: Machining process using a grinding stone or carbide cutter to resurface cylinder head valve seats.
valve spring assembly: Assembly, consisting of a valve spring, a retainer, and two valve keepers, used to close a valve.
valve spring free height: The length of a valve spring in an uncompressed condition.
valve spring installed height: The length (or height) of a valve spring when installed on an engine with the valve closed.
valve spring seat: A cup-shaped washer installed between a cylinder head and bottom of a valve spring. It holds the bottom of the valve spring squarely on the head and valve stem.
valve spring shield: Thin metal shield that surrounds the top and upper sides of the valve spring and helps keep excess oil off the valve stem.
valve spring shim: Precise-thickness flat washer that fits under valve springs to reduce their installed height and maintain the correct spring tension.

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valve spring squareness: Measure of a valve spring's centerline to its seating surface.
valve spring tension: The stiffness of a valve spring.
valve stem: The thin portion of an engine valve that is inside the head. The stem rides in the valve guide. *Also,* a rubber shaft pressed into a hole in the wheel of a tubeless tire to allow inflation and deflation. The stem is threaded near the top of its body to accept the valve core.
valve stem cap: A hardened steel cup that installs over a valve stem in a valve train. It is free to rotate on the tip to reduce friction and wear between the stem and rocker arm. *Also,* a metal or plastic cap that installs over a tire valve stem. It keeps the valve clean and prevents accidental tire deflation.
valve timing: Intervals at which valves open and close, determined by camshaft configuration.
valve train clearance adjustment: Process of changing valve clearance to vehicle/engine specifications to ensure proper opening and closing of engine valves for efficient combustion and exhaust emission. It is also called a valve lash adjustment or valve adjustment.
valve train noise: A light tapping or clicking sound produced by valves that are too loose in a valve train.
valves in receiver (VIR): Both the expansion valve and the POA valve are enclosed in the receiver-drier.
vane oil pump: Type of oil pump that uses sliding wipers within a housing to build oil pressure.
vapor lock: Condition caused by bubbles in fuel due to overheating. It can cause stalling, hard starting, or failure to start.
vaporization: See *vaporize.*
vaporize: Changing an element from a liquid to a gas (vapor).
variable camshaft timing: Allows engine oil pressure to operate hydraulic camshaft phaser sprockets and other hydraulic actuators in a valve train. Valve timing can vary based on engine rpm and load.
variable displacement engine: An engine that can deactivate cylinders to conserve fuel and reduce emissions.
variable dwell: Dwell timing in which the engine control module alters ignition coil dwell timing with changes in engine speed.
variable induction system: An intake system manufactured with a set of long and short intake runners. Based on engine speed, valves open one set of runners for either more torque (low speed, long runners) or more power (fast speed, short runners) from an engine.
variable transmission solenoid: Solenoid that uses different ECM current frequencies to control how far a spool valve opens or closes a fluid pressure passage.
variable valve timing engine (VVTE): Engine that can alter valve opening and closing independent of crankshaft rotation.
variable valve timing system: System that can alter valve opening and closing independent of crankshaft rotation. At low speeds, the valves function with a standard duration, but hold open longer to increase volumetric efficiency as engine speed increases.
variable vane turbocharger: Turbocharger that uses a set of hinged blades mounted inside the turbine housing to control exhaust gas flow over the turbine wheel or fan.
variable volume oil pump: Type of oil pump capable of building high oil pressure at idle and reducing pump volume per revolution at high engine speeds for better engine efficiency.
variable-ratio gearbox: Gearbox that changes the internal gear ratio as vehicle front wheels are turned from the center position, requiring fewer turns to move the wheel from full right to full left than a constant ratio gearbox.
vehicle collision: Normally results from driver error that causes the car or truck to hit other objects (vehicles, trees, retaining walls, etc.). It is also referred to as an accident.
vehicle cradle: A strong metal structure mounted at the lower front and sometimes the lower rear of the unibody structure.
vehicle degaussing: The process of removing any large magnetic field built up around the vehicle body structure. It is also called vehicle demagnetizing.
vehicle demagnetizing: See *vehicle degaussing.*
vehicle fluid: Fluids within an engine such as engine oil, coolant, brake fluid, transmission fluid, and other liquids that help keep a vehicle operating properly.
vehicle height: Distance from the ground to the highest point on a vehicle roofline.
vehicle identification number (VIN): Individual series of letters and numbers assigned to a vehicle by the manufacturer at the factory.
vehicle information section: Part of a vehicle inspection report that identifies the type of motor vehicle tested. It lists the license plate number, VIN, year, make, model, engine type, fuel type (gas or diesel), test number, and the type of emission test needed (OBD or non-OBD).
vehicle inspection report: Subsequent report given to a driver that summarizes why the vehicle either passed or failed its state-mandated emission test.
vehicle length: Distance from the outermost point on a vehicle front bumper to the outermost point on its rear bumper.
vehicle maintenance: Any operation that will keep a vehicle in good operating condition.
vehicle sensor: Device that detects a physical operating change of a vehicle and converts it into an electrical signal for computer use. It can also be called a transducer.
vehicle speed sensor (VSS): Sensor placed in the transmission/transaxle or the rear axle assembly. It is used by the engine's ECM to monitor vehicle speed.
vehicle tracking system: A vehicle security system, commonly monitored by a hired company, that uses a hidden miniature transmitter and receiver and the global positioning satellite system to track the location of a vehicle if lost or stolen.
vehicle weight distribution: Measurement of how weight is balanced on the front and rear tires of a vehicle.
vehicle wheelbase: Distance from the centerline of the front wheels to the centerline of the rear wheels.
vehicle width: Distance between the two widest points from the right to left sides of a vehicle body measured perpendicular to the vehicle's centerline.
vent: Louvered opening that allows air to blow into the passenger compartment.
ventilation fan: A small, low-power-consumption fan used to circulate outside air through the interior.
ventilation system: Carries fresh outside air into the vehicle's passenger compartment. One or more electric fans or blower motors force outside air through the dash ducts and vents.
vernier caliper: A sliding measuring device, sometimes with a dial gauge attached, that can make quick and accurate inside, outside, and depth measurements.
vibration damper: See *harmonic balancer.*
video camera display: In-car monitor showing the view from a small camera installed in the rear body or bumper of the vehicle. The camera captures what is behind the vehicle when the vehicle is in reverse.
viscosity: Thickness or internal friction of a fluid.
viscosity compensating valve: Diesel injection pump valve that allows for different fuel weights or thicknesses and temperatures.
viscosity number: SAE standardized numbering system used to rate oil thickness. A higher number means a thicker oil.
vise: Workbench-mounted tool with adjustable jaws that is used to hold parts during cutting, drilling, hammering, and pressing operations.
vise cap: Soft metal covers installed over vise jaws before mounting delicate parts. The covers provide extra grip while also protecting the part from damage.
volt: Unit of measurement of electrical pressure; the force that will move a current of one ampere through a resistance of one ohm.
voltage: The electrical force, or pressure, that pushes free electrons and causes current. It is also referred to as electromotive force (EMF) or potential difference.
voltage drop measurement: A measurement taken with a voltmeter that determines the internal resistance of a wire or component without having to disconnect the circuit.
voltage drop test: Type of test that can locate a part or component with higher than specified resistance without disconnecting wires or parts.
voltage regulator: Electronic semiconductor device that manages the voltage and current output of an alternator.
voltmeter: Instrument used to measure voltage (electrical pressure) in a given circuit.
voltmeter indicator: Instrument cluster display that measures voltage output of the alternator.

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volumetric efficiency: A comparison between the actual and ideal efficiency of an internal combustion engine. The comparison is based on the actual volume of fuel mixture drawn in and what would be drawn in if the cylinder were completely filled on each stroke.

V-type engine: Engine arranged with two banks of cylinders that lie at an angle from vertical on each side of the crankshaft.

W

washer: Thin, flat "O"-shaped ring used under bolt heads and nuts to prevent the bolt or nut from digging into a part.

waste gate: A valve that vents excess exhaust gas to limit the amount of boost delivered by a turbocharger.

waste gate diaphragm: Flexible membrane that reacts to different amounts of boost pressure within a turbocharger.

waste gate diaphragm spring: Coil spring that holds a waste gate valve of a turbocharger in the normally closed position to build boost pressure.

waste gate housing: Airtight, metal container that encloses a waste gate diaphragm chamber with a pressure hose fitting to measure boost pressure.

waste gate pressure line: Hose that connects the waste gate of a turbocharger with a source of intake manifold pressure.

waste gate valve: Poppet, flap, or butterfly valve in a turbocharger that can open to bypass exhaust gases away from the turbine wheel to control boost pressure.

wasted-spark ignition system: System in which each coil is wired so that it fires two spark plugs at the same time; one plug on its cylinder's power stroke and the other plug on its cylinder's exhaust stroke (waste-spark).

water contamination: Water droplets mixing with diesel fuel to clog filters and corrode components that is a common issue with diesel engines.

water detector: Diesel injection system accessory that warns the driver of water in the diesel fuel.

water jacket: The area around the engine cylinders that is left hollow so that coolant may be admitted.

water pump: The coolant pump; any pump used to circulate coolant through an engine.

water pump bearing: Plain or ball bearings that allow the pump shaft to spin freely in housing.

water pump gasket: Gasket that fits between the engine and pump housing to prevent coolant leakage.

water pump housing: Iron or aluminum casting that forms the main body of pump.

water pump hub: Provides mounting place for the belt pulley and fan.

water pump impeller: Steel or plastic disk with fan-like blades. The impeller spins and produces pressure and flow.

water pump seal: Seal that prevents coolant leakage between pump shaft and pump housing.

water pump shaft: Steel shaft that transfers turning force from the hub to the impeller.

water separators: Feature of many late-model diesel injection systems that prevents damage from water contamination.

watt: Unit of measurement of electrical power. It is obtained by multiplying volts by amperes.

wave: An increase or decrease (fluctuation) in voltage and current. The polarity of the voltage changes from positive to negative.

waveform: The shape of a given voltage over a period of time. It can be graphed with an oscilloscope or a scan tool with a scope function.

wear bar: Solid bar of rubber across a tire tread that appears when a tire has worn significantly and needs replacement.

wear sleeve: Lubricated bushing installed between a drive axle and greased driving hub seal to limit excess friction on a front-wheel drive vehicle.

wedge combustion chamber: Combustion chamber that is shaped like a triangle or wedge when viewed from the side. The valves are placed at an angle to the top of the piston.

welder: A trained person who uses high electric current to create a high-power electric arc (voltage jumping from the electrode to the workpiece) to melt and fuse metal parts together.

wet clutch: Slip-resistant clutch submersed in transmission fluid that replaces a fluid coupling or torque converter in a transmission. Some hybrid vehicles use one or two wet clutches to control power flow to and from the motor-generator.

wet compression test: Compression test in which a small amount of oil is placed in the cylinder to determine which engine parts are causing the low compression pressure.

wet pavement test: A test that verifies the operation of the ABS electronics, as well as all mechanical parts associated with normal braking.

wet sleeve: A thick metal sleeve inserted into an engine cylinder that is constantly in contact with engine coolant.

wet-charged battery: Battery that is filled with electrolyte and fully charged at the factory.

wheel: Steel, aluminum, or magnesium frame bolted to the wheel hub that is designed to support the tire while withstanding loads from acceleration, braking, and cornering.

wheel alignment: Adjusting the suspension geometry so that all four tires roll in a straight line with full tread contact on the road surface.

wheel balancing machine: Machine that spins a tire, either on or off a vehicle, to identify locations where weights must be placed to balance the tire.

wheel bearing: Ball or roller bearing assemblies that reduce friction and support the wheels and axles as they rotate.

wheel bearing noise: A growling, hum, or rumble noise produced by a dry, worn, or damaged wheel bearing.

wheel brake assembly: Device that uses system pressure to produce friction for slowing or stopping wheel rotation.

wheel cap: A small metal or plastic cover in the center of a wheel, commonly used on aluminum wheels to hide the spindle nut and cap.

wheel cover: A metal or plastic cover that fits over the center section of a steel wheel.

wheel cylinder: Acts as the power piston, moving the friction linings into contact with the rotating drums or discs.

wheel cylinder assembly: Components that use master cylinder pressure to force the brake shoes out against the brake drums.

wheel cylinder boot: Covering that snaps into grooves on the outside of the housing to keep road dirt and water out of the cylinder.

wheel cylinder cup: Flexible rubber seal that fits in a wheel cylinder and against the piston to keep fluid from leaking past the piston.

wheel cylinder housing: An enclosure with a precision honed cylinder in it for the pistons, the cups, and the spring of a wheel cylinder assembly.

wheel cylinder piston: When the brake pedal is depressed, hydraulic pressure forces the wheel cylinder pistons apart and outward in the cylinder. The piston movement is transferred to the brake shoes.

wheel cylinder rebuild: Involves honing the wheel cylinder and replacing the rubber cups and boots.

wheel cylinder spring: Spring that helps hold the rubber cups against the pistons when the wheel cylinder assembly is not pressurized.

wheel hop: An up-and-down wheel movement caused by imbalanced or defective tire(s). The tire may skip over the road surface, causing a loss in traction and control.

wheel puller: Tool that is tightened with bolts into holes on a steering wheel to pull and remove the wheel from the steering column.

wheel runout: Wheel movement or wobble that is caused by impact damage or incorrect welding of the spider and rim.

wheel shimmy: A side-to-side wheel movement caused by imbalanced or defective tire(s). It can sometimes be caused by loose steering or suspension parts.

wheel speed sensor: Magnetic sensor used in an anti-lock brake system to measure wheel speed.

wheel weight: A small lead weight used to balance a tire and wheel assembly. It can be clipped or taped onto the wheel.

white diesel smoke: Smoke caused by unburned fuel, a cold engine, or coolant leaking into engine combustion chambers.

white engine smoke: Smoke caused by coolant leaking into engine cylinders, or, less seriously, the result of water condensation in an exhaust system.

wide band oxygen sensor: Category of oxygen sensor that can change its output gradually and in direct proportion to the oxygen content of the exhaust gases.

wide open throttle (WOT) switch: Shuts off the compressor during rapid acceleration to save power.

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wiggle test: Physically moving wires and connectors while the engine is off or running to locate broken wires or other causes of intermittent problems.
windings: Loop of wire on a motor armature that generates a magnetic field.
window regulator: Up-down electronic mechanism for vehicle window glass.
windshield washer: Consists of a solvent reservoir, pump, rubber hoses, connections, and washer nozzles. The electric pump forces solution onto the windshield.
windshield wiper system: Vehicle system made up of a switch, wiper motor assembly, wiper linkage, wiper arms, wiper blades, and usually a windshield washer system.
wiper linkage: Set of arms that transfers motion from the wiper motor transmission to the wiper arms.
wire: A central metal conductor surrounded by plastic insulation. The type of metal conductor and insulation varies by the application.
wire code identification system: An alphanumeric method of identification that explains the color, location, and gage size of wires on a wiring diagram.
wire color code: A system for identifying and tracing specific wires throughout a vehicle based on solid colors and/or other features (stripes, bands, hash marks, etc.).
wire gage: A measurement for wire determined by the diameter or cross-sectional area of its metal conductor. It does not include the thickness or diameter of the insulation.
wire protection devices: Devices that protect wires from damage. These devices include electrical tape, plastic tubing, retainers, clips, boots, and straps.
wire stripping pliers: Pliers designed to quickly peel the insulation off metal wires.
wire wheel: Tabletop or drill-mounted circular tool constructed of individual wire metal bristles. It is used to remove carbon deposits, usually off of valves.
wireless sending unit: A device that plugs into a vehicle's diagnostic connector with the purpose of sending and receiving radio signals to and from a diagnostic tablet.
wiring harness: A group of primary wire encased in a paper or plastic sleeve. It is used to ease installation and to prevent wire damage.
wiring inspection: Process of looking for improper routing, cracked or brittle insulation, or other obvious problem signs with the wires within a vehicle.
wiring schematics: Drawings that show how the wires connect to each component in an electric or electronic circuit. Symbols represent components, and lines represent wires. They are also called wiring diagrams.
wiring splice: The place where two or more wires are connected.
wood alcohol: See *methyl alcohol*.
work: A force applied to a body, causing it to move. It is measured in foot-pounds, watts, or joules.
work order: Form used by a technician to describe vehicle problems and to record diagnosis and repairs. It is also often used as a customer invoice or to prepare a repair estimate.
worm shaft: Shaft connected to a worm gear in a worm-type steering gearbox.
worm-and-roller steering gearbox: Gearbox that contains a roller that is mounted on the sector shaft and meshes with the worm gear. The free-turning roller reduces internal friction.
worm-drive hose clamp: Type of hose clamp that uses a worm gear that engages slots in the clamp strap to allow tightening around the hose.
worn idler arm: Damaged or overly worn idler arm in a linkage steering system that causes the front wheels, especially the right wheel, to turn without any steering wheel movement.
worn universal joint: A deteriorated and dry universal joint that is a common problem for vehicles with a drive shaft. A driveline clunk, vibration, or deep-pitched thud noise upon release of the accelerator can warn of this problem.
wrench: Handheld tool used to grip and turn nuts and bolts for installation or removal.
wrench size: Specific standard (inch) or metric (millimeter) measurement taken across the jaws of a wrench. The size of a wrench is stamped on its side.
W-type engine: Engine arranged similar to a V-type engine in that it has two banks of cylinders, but the cylinder bores in each bank are staggered.

Y

yardstick: A straightedge measuring tool used for linear measurements up to one yard (three feet) or one meter. Inches are marked on one side of the rule and metric marks are shown on the other side. It is also called a meter stick.
yaw sensor: Part of a stability control system that measures the direction of the thrust generated by vehicle movement.

Z

zener diode: A silicon diode that serves as a rectifier. It allows current to flow in one direction only until the applied voltage reaches a certain level, then the diode allows current to flow in the opposite direction.
zero resistance: Description of a perfect electrical path between two test points. There is continuity and a resistance of zero in the tested circuit or component.
zero valve lash: Term for no clearance in a valve train. Hydraulic lifters are able to automatically adjust valve clearance in engines with zero valve lash.
zirconia oxygen sensor: Type of oxygen sensor that uses zirconia and platinum to produce a voltage output that represents oxygen content in exhaust gases.
zone clearing defogger: Used on rear windows to heat and clear one area of the glass (usually the center) before another.

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