PREFACE

PROFESSIONAL TECHNICIAN SERIES Part of Pearson Automotive's Professional Technician Series, the fifth edition of *Automotive Engine Performance* represents the future of automotive textbooks. The series is a full-color, media-integrated solution for today's students and instructors. The series includes textbooks that cover all eight areas of ASE certification, plus additional titles covering common courses.

The series is also peer reviewed for technical accuracy.

UPDATES TO THE FIFTH EDITION Text was updated with the following features:

- Many new full color line drawings and photos were added to this edition to help bring the subject to life.
- Updated throughout and correlated to the latest ASE/NATEF tasks.
- New Case Studies included in this edition that includes the "three Cs" (Complaint, cause and correction).
- New OSHA hazardous chemical labeling requirements added to Chapter 2.
- Atkinson Cycle engine design added to Chapter 3.
- Scope testing of MAF sensors added to Chapter 23.
- Additional content on gasoline direct injection (GDI) added to Chapter 28.
- Fiat Chrysler Multiair System information added to Chapter 30.
- Tier 3 Emission Standards added to Chapter 31.
- Unlike other textbooks, this book is written so that the theory, construction, diagnosis, and service of a particular component or system are presented in one location. There is no need to search through the entire book for other references to the same topic.

ASE AND NATEF CORRELATED NATEF-certified programs need to demonstrate that they use course material that covers NATEF and ASE tasks. All Professional Technician textbooks have been correlated to the appropriate ASE and NATEF task lists. These correlations can be found in two locations:

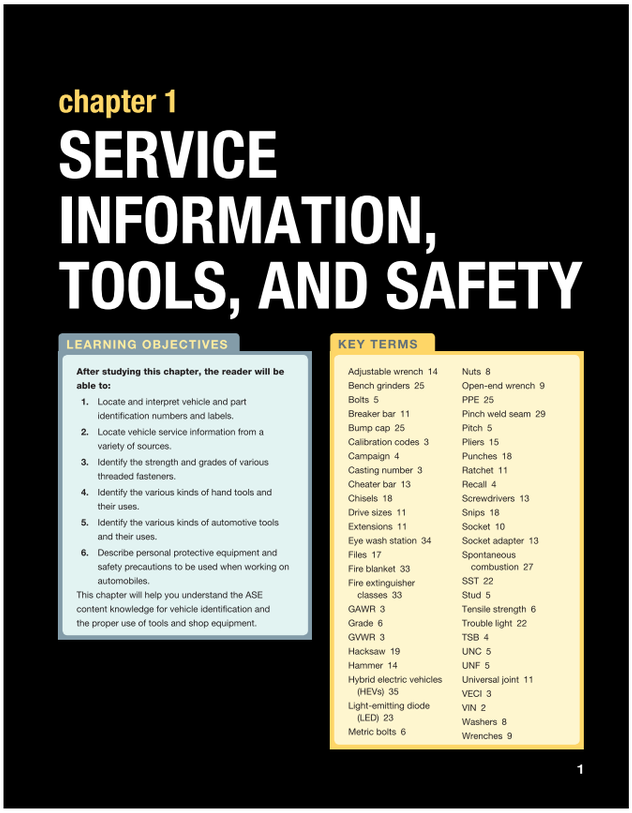
- As an appendix to each book.
- At the beginning of each chapter in the Instructor's Manual.

A COMPLETE INSTRUCTOR AND STUDENT SUPPLEMENTS PACKAGE All Professional Technician textbooks are accompanied by a full set of instructor and student supplements. Please see page vi for a detailed list of supplements.

A FOCUS ON DIAGNOSIS AND PROBLEM SOLVING The Professional Technician Series has been developed to satisfy the need for a greater emphasis on problem diagnosis. Automotive instructors and service managers agree that students and beginning technicians need more training in diagnostic procedures and skill development. To meet this need and demonstrate how real-world problems are solved, "Real World Fix" features are included throughout and highlight how real-life problems are diagnosed and repaired.

The following pages highlight the unique core features that set the Professional Technician Series book apart from other automotive textbooks.

IN-TEXT FEATURES



chapter 1

SERVICE INFORMATION, TOOLS, AND SAFETY

LEARNING OBJECTIVES

After studying this chapter, the reader will be able to:

1. Locate and interpret vehicle and part identification numbers and labels.
2. Locate vehicle service information from a variety of sources.
3. Identify the strength and grades of various threaded fasteners.
4. Identify the various kinds of hand tools and their uses.
5. Identify the various kinds of automotive tools and their uses.
6. Describe personal protective equipment and safety precautions to be used when working on automobiles.

This chapter will help you understand the ASE content knowledge for vehicle identification and the proper use of tools and shop equipment.

KEY TERMS

Adjustable wrench 14
Bench grinders 25
Bolts 5
Breaker bar 11
Bump cap 25
Calibration codes 3
Campaign 4
Casting number 3
Cheater bar 13
Chisels 18
Drive sizes 11
Extensions 11
Eye wash station 34
Files 17
Fire blanket 33
Fire extinguisher classes 33
GAWR 3
Grade 6
GVWR 3
Hacksaw 19
Hammer 14
Hybrid electric vehicles (HEVs) 35
Light-emitting diode (LED) 23
Metric bolts 6
Nuts 8
Open-end wrench 9
PPE 25
Pinch weld seam 29
Pitch 5
Pliers 15
Punches 18
Ratchet 11
Recall 4
Screwdrivers 13
Snips 18
Socket 10
Socket adapter 13
Spontaneous combustion 27
SST 22
Stud 5
Tensile strength 6
Trouble light 22
TSB 4
UNC 5
UNF 5
Universal joint 11
VECI 3
VIN 2
Washers 8
Wrenches 9

1

LEARNING OBJECTIVES AND KEY TERMS appear at the beginning of each chapter to help students and instructors focus on the most important material in each chapter. The chapter objectives are based on specific ASE and NATEF tasks.

TECH TIP

It Just Takes a Second

Whenever removing any automotive component, it is wise to screw the bolts back into the holes a couple of threads by hand. This ensures that the right bolt will be used in its original location when the component or part is put back on the vehicle.

TECH TIPS feature real-world advice and "tricks of the trade" from ASE-certified master technicians.

SAFETY TIP

Shop Cloth Disposal

Always dispose of oily shop cloths in an enclosed container to prevent a fire. ● **SEE FIGURE 1–69**. Whenever oily cloths are thrown together on the floor or workbench, a chemical reaction can occur, which can ignite the cloth even without an open flame. This process of ignition without an open flame is called **spontaneous combustion**.

SAFETY TIPS alert students to possible hazards on the job and how to avoid them.

CASE STUDY

There Is No Substitute for a Thorough Visual Inspection

An intermittent "check engine" light and a random-misfire diagnostic trouble code (DTC) P0300 was being diagnosed. A scan tool did not provide any help because all systems seemed to be functioning normally. Finally, the technician removed the engine cover and discovered a mouse nest. ● **SEE FIGURE 30-24**.

Summary:

- **Complaint—**Customer stated that the "Check Engine" light was on.
- **Cause—**A stored P0300 DTC was stored indicating a random misfire had been detected caused by an animal that had partially eaten some fuel injector wires.
- **Correction—**The mouse nest was removed and the wiring was repaired.

CASE STUDY present students with actual automotive scenarios and show how these common (and sometimes uncommon) problems were diagnosed and repaired.

FREQUENTLY ASKED QUESTION

How Many Types of Screw Heads Are Used in Automotive Applications?

There are many, including Torx, hex (also called Allen), plus many others used in custom vans and motor homes. ● **SEE FIGURE 1–9**.

FREQUENTLY ASKED QUESTIONS are based on the author's own experience and provide answers to many of the most common questions asked by students and beginning service technicians.

NOTE: Most of these "locking nuts" are grouped together and are commonly referred to as *prevailing torque nuts*. This means that the nut will hold its tightness or torque and not loosen with movement or vibration.

NOTES provide students with additional technical information to give them a greater understanding of a specific task or procedure.

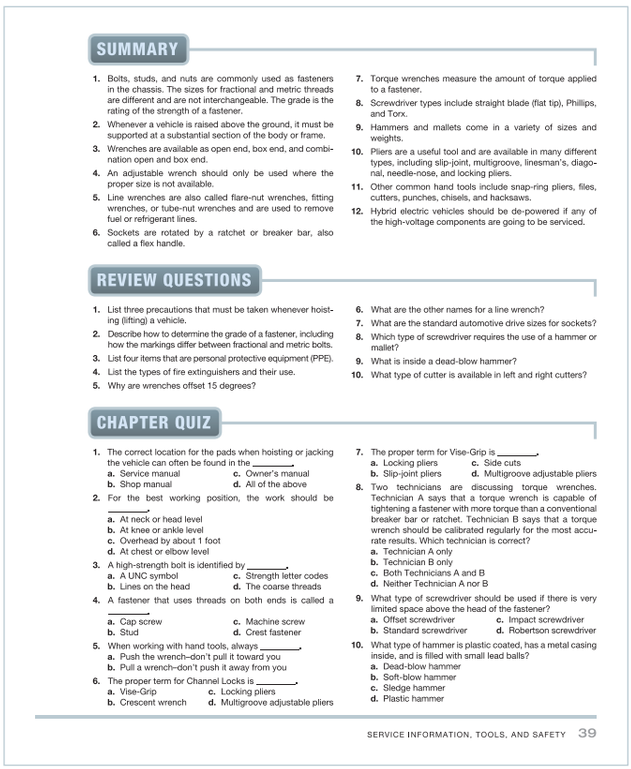
CAUTION: *Never* use hardware store (nongraded) bolts, studs, or nuts on any vehicle steering, suspension, or brake component. Always use the exact size and grade of hardware that is specified and used by the vehicle manufacturer.

CAUTIONS alert students about potential damage to the vehicle that can occur during a specific task or service procedure.

WARNING

Do not use incandescent trouble lights around gasoline or other flammable liquids. The liquids can cause the bulb to break and the hot filament can ignite the flammable liquid, which can cause personal injury or even death.

WARNINGS alert students to potential dangers to themselves during a specific task or service procedure.



SUMMARY

1. Bolts, studs, and nuts are commonly used as fasteners in the chassis. The sizes for fractional and metric threads are different and are not interchangeable. The grade is the rating of the strength of a fastener.
2. Whenever a vehicle is raised above the ground, it must be supported at a substantial section of the body or frame.
3. Wrenches are available as open end, box end, and combination open and box end.
4. An adjustable wrench should only be used where the proper size is not available.
5. Line wrenches are also called flare-nut wrenches, fitting wrenches, or tube-nut wrenches and are used to remove fuel or refrigerant lines.
6. Sockets are rotated by a ratchet or breaker bar, also called a flex handle.
7. Torque wrenches measure the amount of torque applied to a fastener.
8. Screwdriver types include straight blade (flat tip), Phillips, and Torx.
9. Hammers and mallets come in a variety of sizes and weights.
10. Pliers are a useful tool and are available in many different types, including slip-joint, multigroove, linesman's, diagonal, needle-nose, and locking pliers.
11. Other common hand tools include snap-ring pliers, files, cutters, punches, chisels, and hacksaws.
12. Hybrid electric vehicles should be de-powered if any of the high-voltage components are going to be serviced.

REVIEW QUESTIONS

1. List three precautions that must be taken whenever hoisting (lifting) a vehicle.
2. Describe how to determine the grade of a fastener, including how the markings differ between fractional and metric bolts.
3. List four items that are personal protective equipment (PPE).
4. List the types of fire extinguishers and their use.
5. Why are wrenches offset 15 degrees?
6. What are the other names for a line wrench?
7. What are the standard automotive drive sizes for sockets?
8. Which type of screwdriver requires the use of a hammer or mallet?
9. What is inside a dead-blow hammer?
10. What type of cutter is available in left and right cutters?

CHAPTER QUIZ

1. The correct location for the pads when hoisting or jacking the vehicle can often be found in the _____.
   a. Service manual c. Owner's manual
   b. Shop manual d. All of the above
2. For the best working position, the work should be _____.
   a. At neck or head level
   b. At knee or ankle level
   c. Overhead by about 1 foot
   d. At chest or elbow level
3. A high-strength bolt is identified by _____.
   a. A UNC symbol c. Strength letter codes
   b. Lines on the head d. The coarse threads
4. A fastener that uses threads on both ends is called a _____.
   a. Cap screw c. Machine screw
   b. Stud d. Crest fastener
5. When working with hand tools, always _____.
   a. Push the wrench–don't pull it toward you
   b. Pull a wrench–don't push it away from you
6. The proper term for Channel Locks is _____.
   a. Vise-Grip c. Locking pliers
   b. Crescent wrench d. Multigroove adjustable pliers
7. The proper term for Vise-Grip is _____.
   a. Locking pliers c. Side cuts
   b. Slip-joint pliers d. Multigroove adjustable pliers
8. Two technicians are discussing torque wrenches. Technician A says that a torque wrench is capable of tightening a fastener with more torque than a conventional breaker bar or ratchet. Technician B says that a torque wrench should be calibrated regularly for the most accurate results. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
9. What type of screwdriver should be used if there is very limited space above the head of the fastener?
   a. Offset screwdriver c. Impact screwdriver
   b. Standard screwdriver d. Robertson screwdriver
10. What type of hammer is plastic coated, has a metal casing inside, and is filled with small lead balls?
   a. Dead-blow hammer
   b. Soft-blow hammer
   c. Sledge hammer
   d. Plastic hammer

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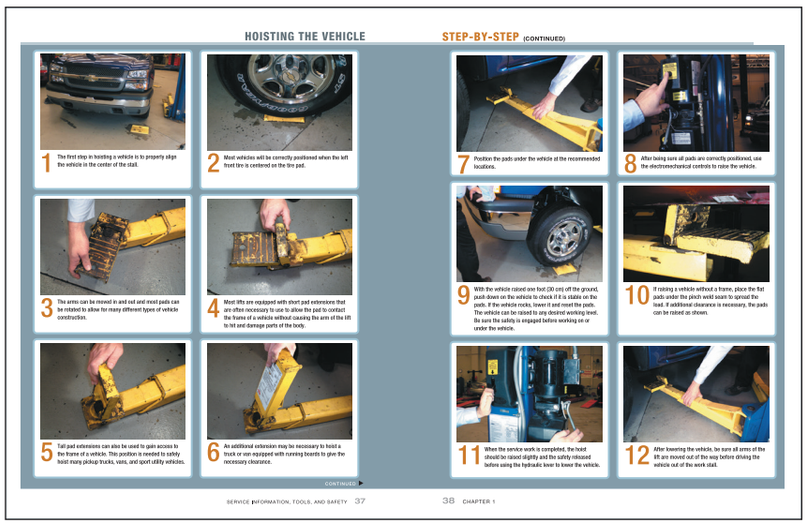
THE SUMMARY, REVIEW QUESTIONS, AND CHAPTER QUIZ at the end of each chapter help students review the material presented in the chapter and test themselves to see how much they've learned.



HOISTING THE VEHICLE

STEP-BY-STEP (CONTINUED)

1 The first step in hoisting a vehicle is to properly align the vehicle in the center of the stall.

2 Most vehicles will be correctly positioned when the left front tire is centered on the tire pad.

3 The arms can be moved in and out and most pads can be rotated to allow for many different types of vehicle construction.

4 Most lifts are equipped with short pad extensions that are offset necessary for use to allow the pad to contact the frame of a vehicle without causing the arm of the lift to hit and damage parts of the body.

5 Tall pad extensions can also be used to gain access to the frame of a vehicle. This position is needed to safely hoist many pickup trucks, vans, and sport utility vehicles.

6 An additional extension may be necessary to hoist a truck or van equipped with running boards to give the necessary clearance.

CONTINUED

7 Position the pads under the vehicle at the recommended locations.

8 After being sure all pads are correctly positioned, use the electromechanical controls to raise the vehicle.

9 With the vehicle raised one foot (30 cm) off the ground, push down on the vehicle to check if it is stable on the pads. If the vehicle rocks, lower it and reset the pads. The vehicle can be raised to any desired working level. Be sure the safety is engaged before working on or under the vehicle.

10 If raising a vehicle without a frame, place the flat pads under the pinch weld seam to spread the load. If additional clearance is necessary, the pads can be raised as shown.

11 When the service work is completed, the hoist should be raised slightly and the safety released before using the hydraulic lever to lower the vehicle.

12 After lowering the vehicle, be sure all arms of the lift are moved out of the way before driving the vehicle out of the work stall.

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38 CHAPTER 1

STEP-BY-STEP photo sequences show in detail the steps involved in performing a specific task or service procedure.

SUPPLEMENTS

RESOURCES IN PRINT AND ONLINE

Automotive Engine Performance

NAME OF SUPPLEMENT	PRINT	ONLINE	AUDIENCE	DESCRIPTION
Instructor Resource Manual 0134067002		✔	Instructors	NEW! The Ultimate teaching aid: Chapter summaries, key terms, chapter learning objectives, lecture resources, discuss/demonstrate classroom activities, and answers to the in text review and quiz questions.
TestGen 0134067053		✔	Instructors	Test generation software and test bank for the text.
PowerPoint Presentation 0134067045		✔	Instructors	Slides include chapter learning objectives, lecture outline of the test, and graphics from the book.
Image Bank 0134067010		✔	Instructors	All of the images and graphs from the textbook to create customized lecture slides.
NATEF Correlated Task Sheets - For Instructors 0134066960		✔	Instructors	Downloadable NATEF task sheets for easy customization and development of unique task sheets.
NATEF Correlated Task Sheets - For Students 0134067061	✔		Students	Study activity manual that correlates NATEF Automobile Standards to chapters and pages numbers in the text. Available to students at a discounted price when packaged with the text.
CourseSmart eText 0134067037		✔	Students	An alternative to purchasing the print textbook, students can subscribe to the same content online and save up to 50% off the suggested list price of the print text. Visit **www.coursesmart.com**

All online resources can be downloaded from the Instructor's Resource Center: **www.pearsonighered.com/irc**

chapter 28

GASOLINE DIRECT-INJECTION SYSTEMS

LEARNING OBJECTIVES

After studying this chapter, the reader will be able to:

1. Discuss how to troubleshoot a gasoline direct-injection system.
2. Explain how a gasoline direct-injection system works.
3. Describe the differences between port fuel-injection and gasoline direct-injection systems.
4. List the various modes of operation of a gasoline direct-injection system.

This chapter will help you prepare for Engine Repair (A8) ASE certification test content area "C" (Fuel, Air Induction, and Exhaust Systems Diagnosis and Repair).

KEY TERMS

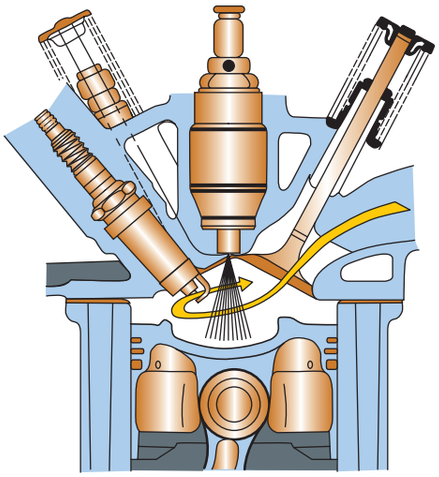

FIGURE 28–1 A gasoline direct-injection system injects fuel under high pressure directly into the combustion chamber.

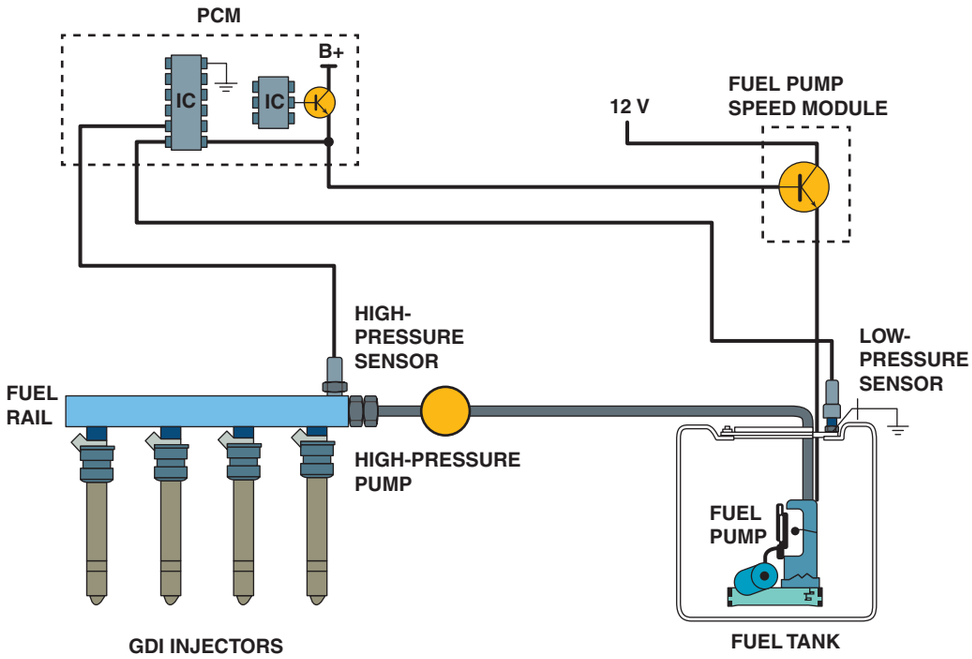

FIGURE 28–2 A GDI system uses a low-pressure pump in the gas tank similar to other types of fuel-injection systems. The PCM controls the pressure of the high-pressure pump using sensor inputs.

DIRECT FUEL INJECTION

Several vehicle manufacturers such as Audi, Mitsubishi, Mercedes, BMW, Toyota/Lexus, Mazda, Ford, and General Motors are using **gasoline direct injection (GDI)** systems, which General Motors refers to as a **spark ignition direct injection (SIDI)** system. A direct-injection system sprays high-pressure fuel, up to 2,900 PSI, into the combustion chamber as the piston approaches the top of the compression stroke. With the combination of high-pressure swirl injectors and modified combustion chamber, almost instantaneous vaporization occurs. This combined with a higher compression ratio allows a direct-injected engine to operate using a leaner-than-normal air–fuel ratio, which results in improved fuel economy with higher power output and reduced exhaust emissions. ● **SEE FIGURE 28–1**.

ADVANTAGES OF GASOLINE DIRECT INJECTION

The use of direct injection compared with port fuel injection has many advantages including:

- Improved fuel economy due to reduced pumping losses and heat loss
- Allows a higher compression ratio for higher engine efficiency
- Allows the use of lower-octane gasoline
- The volumetric efficiency is higher
- Less need for extra fuel for acceleration
- Improved cold starting and throttle response
- Allows the use of greater percentage of EGR to reduce exhaust emissions
- Up to 25% improvement in fuel economy
- 12% to 15% reduction in exhaust emissions

DISADVANTAGES OF GASOLINE DIRECT INJECTION

- Higher cost due to high-pressure pump and injectors
- More components compared with port fuel injection
- Due to the high compression, a NO_x storage catalyst is sometimes required to meet emission standards, especially in Europe. (● **SEE FIGURE 28–2.)**
- Uses up to six operating modes depending on engine load and speed, which requires more calculations to be performed by the Powertrain Control Module (PCM).

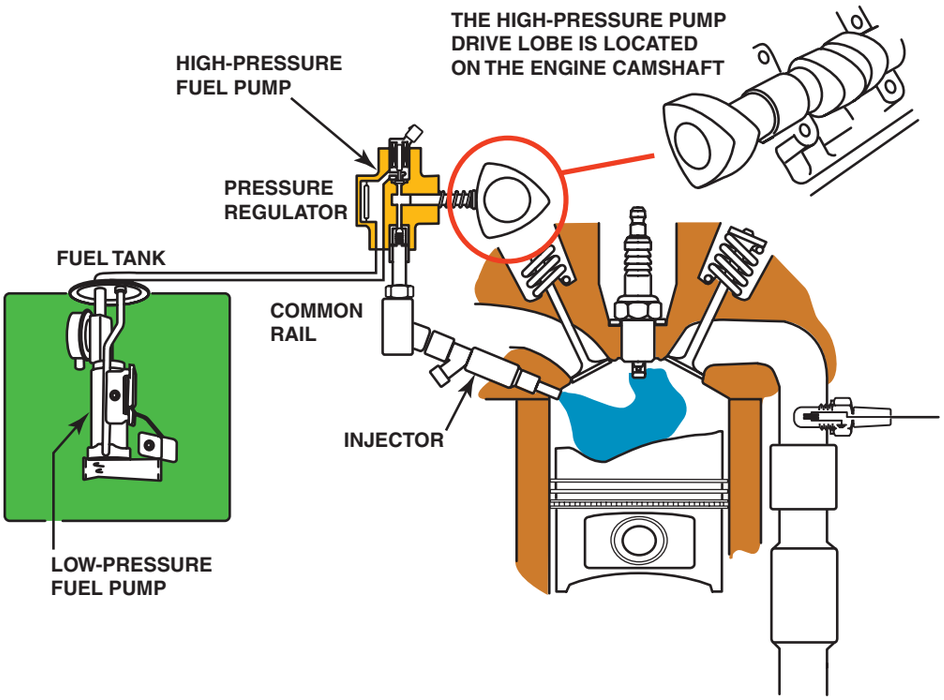

FIGURE 28–3 A typical direct-injection system uses two pumps—one low-pressure electric pump in the fuel tank and the other a high-pressure pump driven by the camshaft. The high pressure fuel system operates at a pressure as low as 500 PSI during light load conditions and as high as 2,900 PSI under heavy loads.

DIRECT-INJECTION FUEL DELIVERY SYSTEM

LOW-PRESSURE SUPPLY PUMP The fuel pump in the fuel tank supplies fuel to the high-pressure fuel pump at a pressure of approximately 60 PSI. The fuel filter is located in the fuel tank and is part of the fuel pump assembly. It is not usually serviceable as a separate component; the engine control module (ECM) controls the output of the high-pressure pump, which has a range between 500 PSI (3,440 kPa) and 2,900 PSI (15,200 kPa) during engine operation. ● **SEE FIGURES 28–2 AND 28–3**.

HIGH-PRESSURE PUMP In a General Motors system, the engine control module (ECM) controls the output of the high-pressure pump, which has a range between 500 PSI (3,440 kPa) and 2,900 PSI (15,200 kPa) during engine operation. The high-pressure fuel pump connects to the pump in the fuel tank through the low-pressure fuel line. The pump consists of a single-barrel piston pump, which is driven by the engine camshaft. The pump plunger rides on a three-lobed cam on the camshaft. The high-pressure pump is cooled and lubricated by the fuel itself. ● **SEE FIGURE 28–4**.

FUEL RAIL The fuel rail stores the fuel from the high-pressure pump and stores high-pressure fuel for use to each injector. All injectors get the same pressure fuel from the fuel rail.

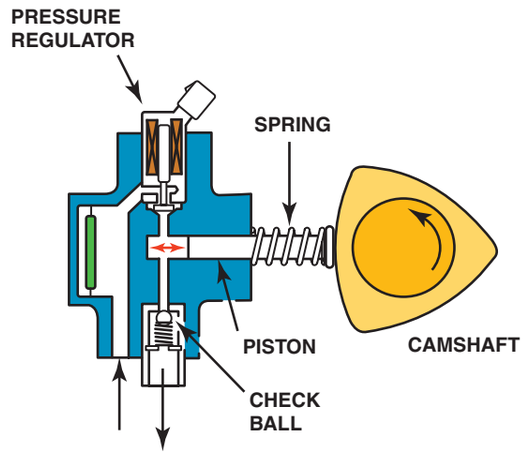

FIGURE 28–4 A typical camshaft-driven high-pressure pump used to increase fuel pressure to 2,000 PSI or higher.

FUEL PRESSURE REGULATOR An electric pressure-control valve is installed between the pump inlet and outlet valves. The fuel rail pressure sensor connects to the PCM with three wires:

- 5 volt reference
- ground
- signal

The sensor signal provides an analog signal to the PCM that varies in voltage as fuel rail pressure changes. Low pressure results in a low-voltage signal and high pressure results in a high-voltage signal.

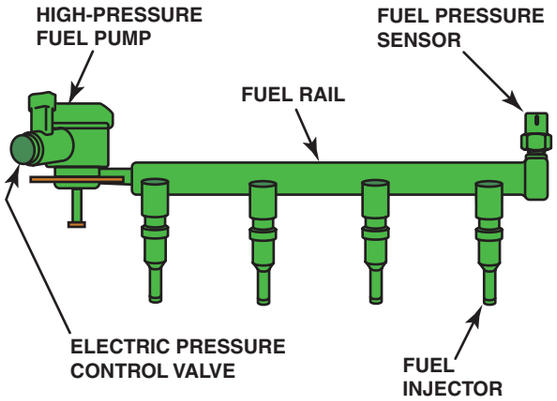

FIGURE 28–5 A gasoline direct-injection (GDI) fuel rail and pump assembly with the electric pressure control valve.

The PCM uses internal drivers to control the power feed and ground for the pressure control valve. When both PCM drivers are deactivated, the inlet valve is held open by spring pressure. This causes the high pressure fuel pump to default to low-pressure mode. The fuel from the high-pressure fuel pump flows through a line to the fuel rail and injectors. The actual operating pressure can vary from as low as 500 PSI (3,440 kPa) at idle to over 2,000 PSI (13,800 kPa) during high speed or heavy load conditions. ● **SEE FIGURE 28–5**.

NOTE: Unlike a port fuel-injection system, a gasoline direct injection system varies the fuel pressure to achieve greater fuel delivery using a very short pulse time, which is usually less than one millisecond. To summarize:

- **Port Fuel Injection = constant fuel pressure but variable injector pulse-width.**
- **GDI = almost constant injector pulse-width with varying fuel pressure.**

GASOLINE DIRECT-INJECTION FUEL INJECTORS

Each high-pressure fuel injector assembly is an electrically magnetic injector mounted in the cylinder head. In the GDI system, the PCM controls each fuel injector with 50 to 90 volts (usually 60 to 70 volts), depending on the system, which is created by a boost capacitor in the PCM. During the high-voltage boost phase, the capacitor is discharged through an injector, allowing for initial injector opening. The injector is then held open with 12 volts. The high-pressure fuel injector has a small slit or six precision-machined holes that generate the desired spray pattern. The injector also has an extended tip to allow for cooling from a water jacket in the cylinder head.

● **SEE CHART 28–1** for an overview of the differences between a port fuel-injection system and a gasoline direct-injection system.

PORT FUEL-INJECTION SYSTEM COMPARED WITH GDI SYSTEM

	PORT FUEL INJECTION	GASOLINE DIRECT INJECTION
Fuel pressure	35–60 PSI	Lift pump—50 to 60 PSI High-pressure pump—500 to 2,900 PSI
Injection pulse width at idle	1.5–3.5 ms	About 0.4 ms (400 µs)
Injector resistance	12–16 ohms	1–3 ohms
Injector voltage	6 V for low-resistance injectors, 12 V for most injectors	50–90 V
Number of injections per event	One	1–3
Engine compression ratio	8:1–11:1	11:1–13:1

CHART 28–1

A comparison chart showing the major differences between a port fuel-injection system and a gasoline direct-injection system.

MODES OF OPERATION

The two basic modes of operation include:

1. **Stratified mode.** In this mode of operation, the air–fuel mixture is richer around the spark plug than it is in the rest of the cylinder.
2. **Homogeneous mode.** In this mode of operation, the air–fuel mixture is the same throughout the cylinder.

There are variations of these modes that can be used to fine-tune the air–fuel mixture inside the cylinder. For example, Bosch, a supplier to many vehicle manufacturers, uses the following six modes of operation:

- **Homogeneous mode.** In this mode, the injector is pulsed one time to create an even air–fuel mixture in the cylinder. The injection occurs during the intake stroke. This mode is used during high-speed and/or high-torque conditions.
- **Homogeneous lean mode.** Similar to the homogeneous mode except that the overall air–fuel mixture is slightly lean for better fuel economy. The injection occurs during the intake stroke. This mode is used under steady, light-load conditions.
- **Stratified mode.** In this mode of operation, the injection occurs just before the spark occurs resulting in lean combustion, reducing fuel consumption.
- **Homogeneous stratified mode.** In this mode, there are two injections of fuel:

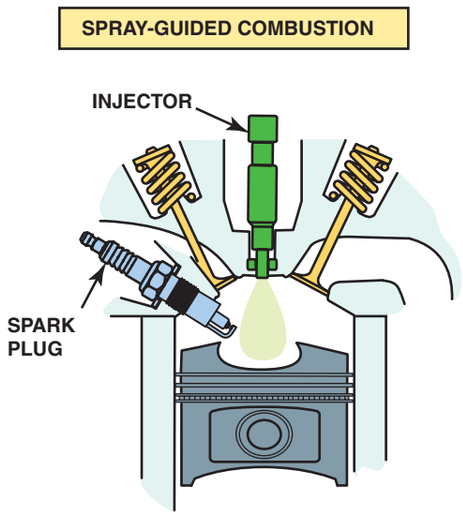

FIGURE 28–6 In this design, the fuel injector is at the top of the cylinder and sprays fuel into the cavity of the piston.

- The first injection is during the intake stroke.
- The second injection is during the compression stroke.

As a result of these double injections, the rich air–fuel mixture around the spark plug is ignited first. Then, the rich mixture ignites the leaner mixture. The advantages of this mode include lower exhaust emissions than the stratified mode and less fuel consumption than the homogeneous lean mode.

- **Homogeneous knock protection mode.** The purpose of this mode is to reduce the possibility of spark knock from occurring under heavy loads at low engine speeds. There are two injections of fuel:
  - The first injection occurs on the intake stroke.
  - The second injection occurs during the compression stroke with the overall mixture being stoichiometric.

  As a result of this mode, the PCM does not need to retard ignition timing as much to operate knock-free.
- **Stratified catalyst heating mode.** In this mode, there are two injections:
  - The first injection is on the compression stroke just before combustion.
  - The second injection is after combustion occurs to heat the exhaust. This mode is used to quickly warm the catalytic converter and to burn the sulfur from the NO_x catalyst.

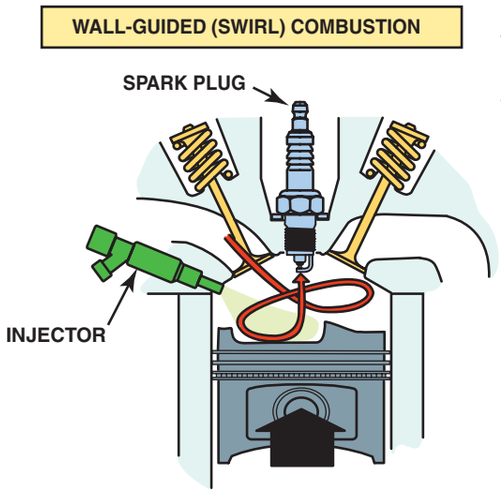

FIGURE 28–7 The side injector combines with the shape of the piston to create a swirl as the piston moves up on the compression stroke.

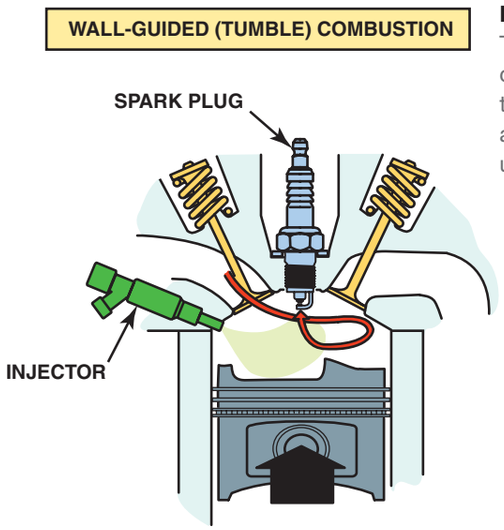

FIGURE 28–8 The piston creates a tumbling force as it moves upward.

PISTON TOP DESIGNS

Gasoline direct-injection (GDI) systems use a variety of shapes of piston and injector locations depending on make and model of engine. Three of the most commonly used designs include:

- **Spray-guided combustion.** In this design, the injector is placed in the center of the combustion chamber and injects fuel into the dished-out portion of the piston. The shape of the piston helps guide and direct the mist of fuel in the combustion chamber. ● **SEE FIGURE 28–6**.
- **Swirl combustion.** This design uses the shape of the piston and the position of the injector at the side of the combustion chamber to create turbulence and swirl of the air–fuel mixture. ● **SEE FIGURE 28–7**.
- **Tumble combustion.** Depending on when the fuel is injected into the combustion chamber helps determine how the air–fuel mixture is moved or tumbled. ● **SEE FIGURE 28–8**.

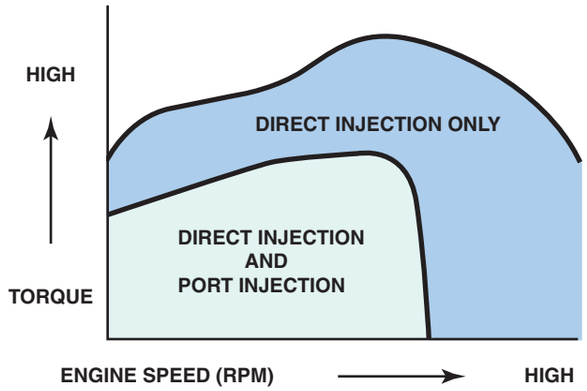

FIGURE 28–9 Notice that there are conditions when the port fuel-injector, located in the intake manifold, and the gasoline direct injector, located in the cylinder, both operate to provide the proper air–fuel mixture.

LEXUS PORT- AND DIRECT-INJECTION SYSTEMS

OVERVIEW Many Lexus vehicles use gasoline direct injection and in some engines they also use a conventional port fuel-injection system. The Lexus D-4S system combines direct-injection injectors located in the combustion chamber with port fuel-injectors in the intake manifold near the intake valve. The two injection systems work together to supply the fuel needed by the engine. ● **SEE FIGURE 28–9** for how the two systems are used throughout the various stages of engine operation.

COLD-START WARM-UP To help reduce exhaust emissions after a cold start, the fuel system uses a stratified change mode. This results in a richer air–fuel mixture near the spark plug and allows for the spark to be retarded to increase the temperature of the exhaust. As a result of the increased exhaust temperature, the catalytic converter rapidly reaches operating temperature, which reduces exhaust emissions.

ENGINE START SYSTEM

An engine equipped with gasoline direct injection could use the system to start the engine. This is most useful during idle stop mode when the engine is stopped while the vehicle is at a traffic light to save fuel. The steps used in the Mazda start-stop system, called the *smart idle stop system (SISS)*, allow the engine to be started without a starter motor and include the following steps:

STEP 1 The engine is stopped. The normal stopping position of an engine when it stops is 70 degrees before top dead center, plus or minus 20 degrees. This is because the engine stops with one cylinder on the compression stroke and the PCM can determine the cylinder position, using the crankshaft and camshaft position sensors.

STEP 2 When a command is made to start the engine by the PCM, fuel is injected into the cylinder that is on the compression stroke and ignited by the spark plug.

STEP 3 The piston on the compression stroke is forced downward forcing the crankshaft to rotate counterclockwise or in the opposite direction to normal operation.

STEP 4 The rotation of the crankshaft then forces the companion cylinder toward the top of the cylinder.

STEP 5 Fuel is injected and the spark plug is fired, forcing the piston down, causing the crankshaft to rotate in the normal (clockwise) direction. Normal combustion events continue allowing the engine to keep running.

GASOLINE DIRECT-INJECTION SERVICE

NOISE ISSUES Gasoline direct-injection systems operate at high pressure and the injectors can often be heard with the engine running and the hood open. This noise can be a customer concern because the clicking sound is similar to noisy valves. If a noise issue is the customer concern, check the following:

- Check a similar vehicle to determine if the sound is louder or more noticeable than normal.
- Check that nothing under the hood is touching the fuel rail. If another line or hose is in contact with the fuel rail, the sound of the injectors clicking can be transmitted throughout the engine, making the sound more noticeable.
- Check for any technical service bulletins (TSBs) that may include new clips or sound insulators to help reduce the noise.

CARBON ISSUES Carbon is often an issue in engines equipped with gasoline direct-injection systems. Carbon can affect engine operation by accumulating in two places:

- **On the injector itself.** Because the injector tip is in the combustion chamber, fuel residue can accumulate on the injector, reducing its ability to provide the proper spray pattern and amount of fuel. Some injector designs are more likely to be affected by carbon than others. For example, if the injector uses small holes, these tend to become clogged more than an injector that uses a single slit opening where the fuel being sprayed out tends to blast away any carbon. ● **SEE FIGURE 28–10**.
- **The backside of the intake valve.** This is a common place for fuel residue and carbon to accumulate on engines equipped with gasoline direct injection. The accumulation of carbon on the intake valve can become so severe that the engine will start and idle, but lack power to accelerate the vehicle. The carbon deposits restrict the airflow into the cylinder enough to decrease engine power.

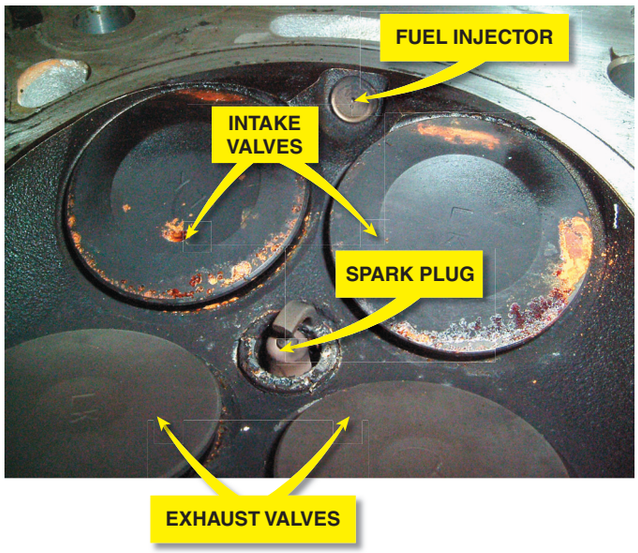

FIGURE 28–10 There may become a driveability issue because the gasoline direct-injection injector is exposed to combustion carbon and fuel residue.

NOTE: Lexus engines that use both port and gasoline direct-injection injectors do not show intake valve deposits. It is thought that the fuel being sprayed onto the intake valve from the port injector helps keep the intake valve clean.

CARBON CLEANING. Most experts recommend the use of Techron®, a fuel system dispersant, to help keep carbon from accumulating. The use of a dispersant every six months or every 6,000 miles has proven to help prevent injector and intake valve deposits.

If the lack of power is discovered and there are no stored diagnostic trouble codes, a conventional carbon cleaning procedure will likely restore power if the intake valves are coated.

SUMMARY

1. A gasoline direct-injection system uses a fuel injector that delivers a short squirt of fuel directly into the combustion chamber rather than in the intake manifold, near the intake valve on a port fuel-injection system.
2. The advantages of using gasoline direct injection instead of port fuel injection include:
   - Improved fuel economy
   - Reduced exhaust emissions
   - Greater engine power
3. Some of the disadvantages of gasoline direct-injection systems compared with a port fuel-injection system include:
   - Higher cost
   - The need for NO_x storage catalyst in some applications
   - More components
4. The operating pressure can vary from as low as 500 PSI during some low-demand conditions to as high as 2,900 PSI.

5. The fuel injectors are open for a very short period of time and are pulsed using a 50 to 90 volt pulse from a capacitor circuit.
6. GDI systems can operate in many modes, which are separated into the two basic modes:
   - Stratified mode
   - Homogeneous mode
7. GDI can be used to start an engine without the use of a starter motor for idle-stop functions.
8. GDI does create a louder clicking noise from the fuel injectors than port fuel-injection injectors.
9. Carbon deposits on the injector and the backside of the intake valve are a common problem with engines equipped with gasoline direct-injection systems.

REVIEW QUESTIONS

1. What are two advantages of gasoline direct injection compared with port fuel injection?
2. What are two disadvantages of gasoline direct injection compared with port fuel injection?
3. How is the fuel delivery system different from a port fuel-injection system?
4. What are the basic modes of operation of a GDI system?

CHAPTER QUIZ

1. Where is the fuel injected in an engine equipped with gasoline direct injection?
   a. Into the intake manifold near the intake valve
   b. Directly into the combustion chamber
   c. Above the intake port
   d. In the exhaust port
2. The fuel pump inside the fuel tank on a vehicle equipped with gasoline direct injection produces about what fuel pressure?
   a. 5 to 10 PSI **c.** 20 to 40 PSI
   b. 10 to 20 PSI **d.** 50 to 60 PSI
3. The high-pressure fuel pumps used in gasoline direct-injection (GDI) systems are powered by _____.
   a. Electricity (DC motor)
   b. Electricity (AC motor)
   c. The camshaft
   d. The crankshaft
4. The high-pressure fuel pump pressure is regulated by using _____.
   a. An electric pressure-control valve
   b. A vacuum-biased regulator
   c. A mechanical regulator at the inlet to the fuel rail
   d. A non-vacuum biased regulator
5. The fuel injectors operate under a fuel pressure of about _____.
   a. 35 to 45 PSI **c.** 500 to 2,900 PSI
   b. 90 to 150 PSI **d.** 2,000 to 5,000 PSI
6. The fuel injectors used on a gasoline direct-injection system are pulsed on using what voltage?
   a. 12 to 14 volt **c.** 100 to 110 volt
   b. 50 to 90 volt **d.** 200 to 220 volt
7. Which mode of operation results in a richer air–fuel mixture near the spark plug?
   a. Stoichiometric **c.** Stratified
   b. Homogeneous **d.** Knock protection
8. Some engines that use a gasoline direct-injection system also have port injection.
   a. True **b.** False
9. A gasoline direct-injection system can be used to start an engine without the need for a starter.
   a. True **b.** False
10. A lack of power from an engine equipped with gasoline direct injection could be due to _____.
   a. Noisy injectors
   b. Carbon on the injectors
   c. Carbon on the intake valves
   d. Both b and c