chapter 79

GASOLINE DIRECT-INJECTION SYSTEMS

OBJECTIVES: After studying Chapter 79, the reader will be able to: • Prepare for the ASE certification test content area "C" (Fuel, Air Induction, and Exhaust Systems Diagnosis). • Describe the differences between port fuel-injection and gasoline direct-injection systems. • List the various modes of operation of a gasoline direct-injection system. • Explain how a gasoline direct-injection system works. • Perform a visual inspection of the gasoline direct-injection system and identify the parts.

KEY TERMS: Gasoline direct injection (GDI) 887 • Homogeneous mode 889 • Spark ignition direct injection (SIDI) 887 • Stratified mode 889

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 of the fuel 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 79–1.**

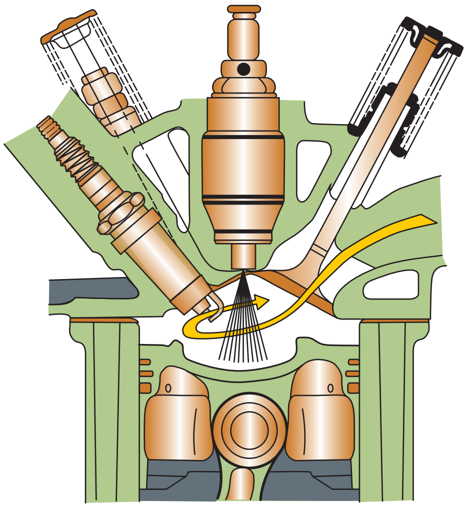

FIGURE 79–1 A gasoline direct-injection system injects fuel under high pressure directly into the combustion chamber.

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 higher 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 79–2).**
- 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).

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 FIGURE 79–3.**

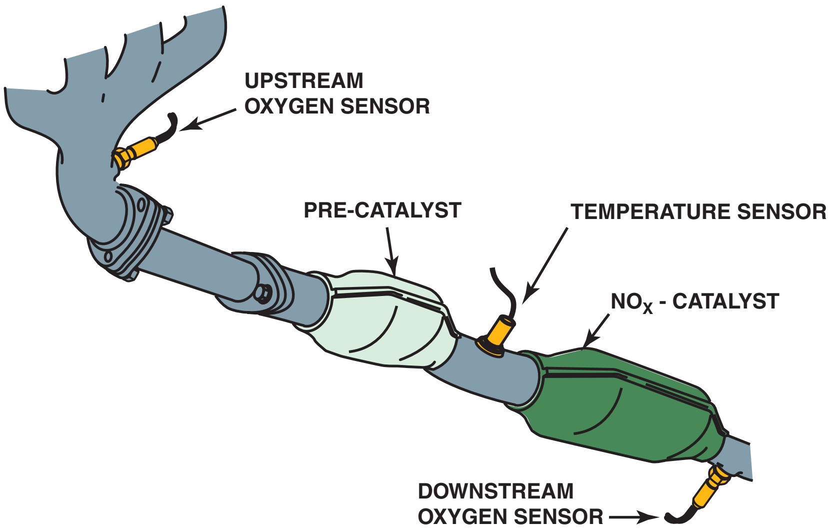

FIGURE 79–2 An engine equipped with a gasoline direct injection (GDI) sometimes requires a NO_x catalyst to meet exhaust emission standards.

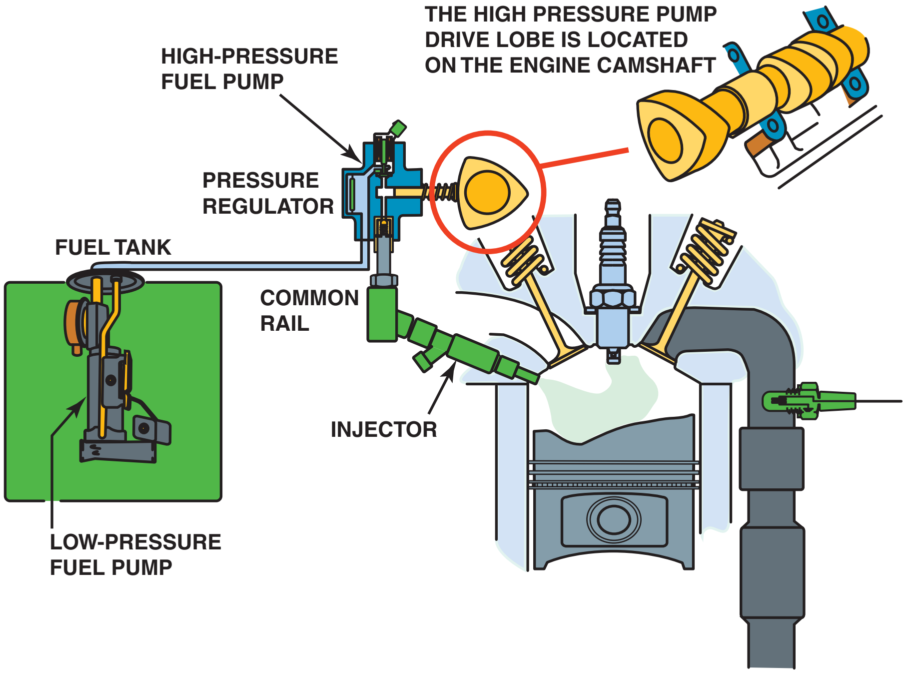

FIGURE 79–3 A typical direct-injection system uses two pumps—one low-pressure electric pump in the fuel tank and the other a high-pressure pump driven by the camshaft. The high pressure fuel system operates at a pressure as low as 500 PSI during light load conditions and as high as 2,900 PSI under heavy loads.

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 79–4.**

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.

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.

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

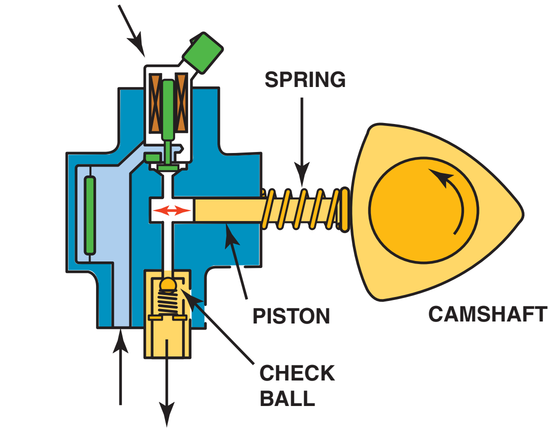

FIGURE 79–4 A typical camshaft-driven high-pressure pump used to increase fuel pressure to 2,000 PSI or higher.

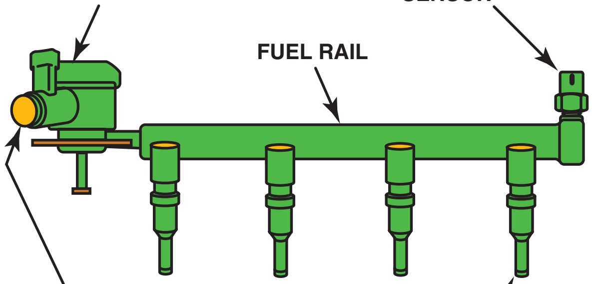

FIGURE 79–5 A gasoline direct-injection (GDI) fuel rail and pump assembly with the electric pressure control valve.

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 900 PSI (6,200 kPa) at idle to over 2,000 PSI (13,800 kPa) during high speed or heavy load conditions. ● **SEE FIGURE 79–5.**

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 60–70 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 79–1** 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 to 60 PSI	Lift pump—50 to 60 PSI High-pressure pump—500 to 2,900 PSI
Injection pulse width at idle	1.5 to 3.5 ms	About 0.4 ms (400 μs)
Injector resistance	12 to 16 ohms	1 to 3 ohms
Injector voltage	6 V for low-resistance injectors, 12 V for most injectors	50 to 90 V
Number of injections per event	One	1 to 3
Engine compression ratio	8:1 to 11:1	11:1 to 13:1

CHART 79–1

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 six modes of operation including:

- **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:
  - 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

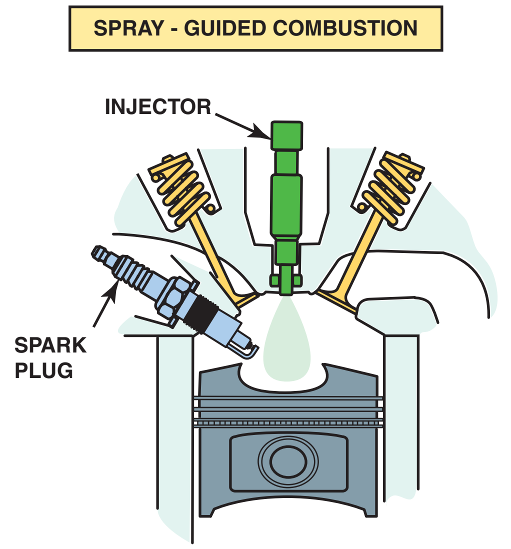

FIGURE 79–6 In this design, the fuel injector is at the top of the cylinder and sprays fuel into the cavity of the piston.

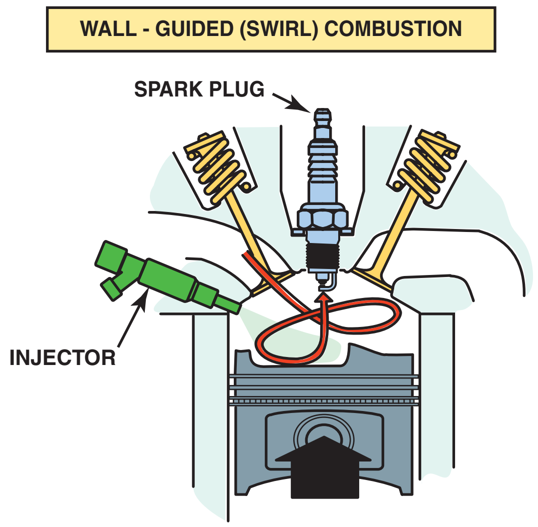

FIGURE 79–7 The side injector combines with the shape of the piston to create a swirl as the piston moves up on the compression stroke.

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 occurs 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.

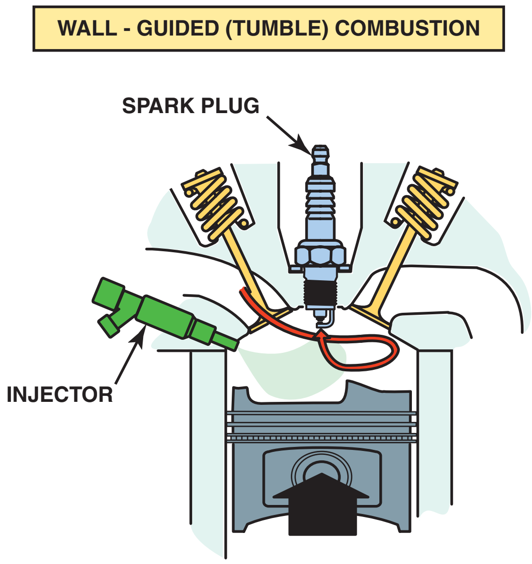

FIGURE 79–8 The piston creates a tumbling force as the piston moves upward.

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 79–6.**
- **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 79–7.**
- **Tumble combustion.** Depending on when the fuel is injected into the combustion chamber, helps determine how the air–fuel is moved or tumbled. ● **SEE FIGURE 79–8.**

LEXUS PORT- AND DIRECT-INJECTION SYSTEMS

OVERVIEW Many Lexus vehicles use gasoline direct injection (GDI) 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 79–9** 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