29

Gasoline and Diesel Fuel Injection: Operation, Diagnosis, and Service

OBJECTIVES: After studying Chapter 29, you should be able to:

1. Prepare for the interprovincial Red Seal certification examination in Appendix VIII (Engine Performance) on the topics covered in this chapter.
2. Describe how to check an electric fuel pump for proper pressure and delivery volume.
3. Explain how to check a fuel-pressure regulator.
4. Describe how to test fuel injectors.
5. Explain how to diagnose gasoline fuel-injection problems.
6. Explain the differences between throttle-body, port and direct fuel-injection.
7. Describe the operation of a diesel mechanical fuel-injection system.
8. Describe the operation of an electronic diesel fuel-injection system.

FUEL INJECTION

Electronic gasoline fuel-injection systems from the mid 1970s to the mid 1990s and later are all very similar in design and operation because they share a common beginning with Robert Bosch GmbH, a German company. Bosch is the largest supplier of fuel-injection systems in the world. It doesn't matter if it's a Fiat, Ferrari or a Ford, a Nissan, Toyota, Chevrolet, or a Chrysler, Bosch either designed or supplied the complete system or some components in the system. In the mid-1990s, automobile manufacturers began moving away from the original Bosch design and we now see many variations. However, Bosch is still a major component supplier for many of these late systems.

BASIC GASOLINE FUEL-INJECTION OPERATION

Most fuel-injection systems are closed loop, which means that any fuel sent to the injectors and not used in the engine will be returned to the fuel tank. See Figure 29–1.

Fuel Pump

The electric fuel pump delivers fuel from the tank to the system and develops fuel pressure. See Figure 29–2. The pump is usually located inside the fuel tank, where it is cooled by the surrounding fuel. Many pumps are incorporated with the fuel gauge sender unit. Some earlier vehicles, usually imports, mounted the pump outside the tank on the frame of the underbody. In-tank pumps are replaced by removing the fuel tank or, in some cases, through an access opening in the trunk floor.

The roller-cell pump, similar to power steering, is driven by a permanent-magnet electric motor. It provides high-pressure fuel, at about 200 to 350 kPa (30 to 50 psi) for port injection and low-pressure fuel, at about 70 kPa (10 psi) for throttle-body injection. Some Fords use port style injectors in their central fuel-injection (TBI type); system pressures are about 200 kPa (30 psi) for these units.

In the event of a restricted fuel filter or line blockage, the pump is capable of producing pressures of 700 kPa (100 psi) or higher. An excess pressure valve (relief valve) is built into the pump

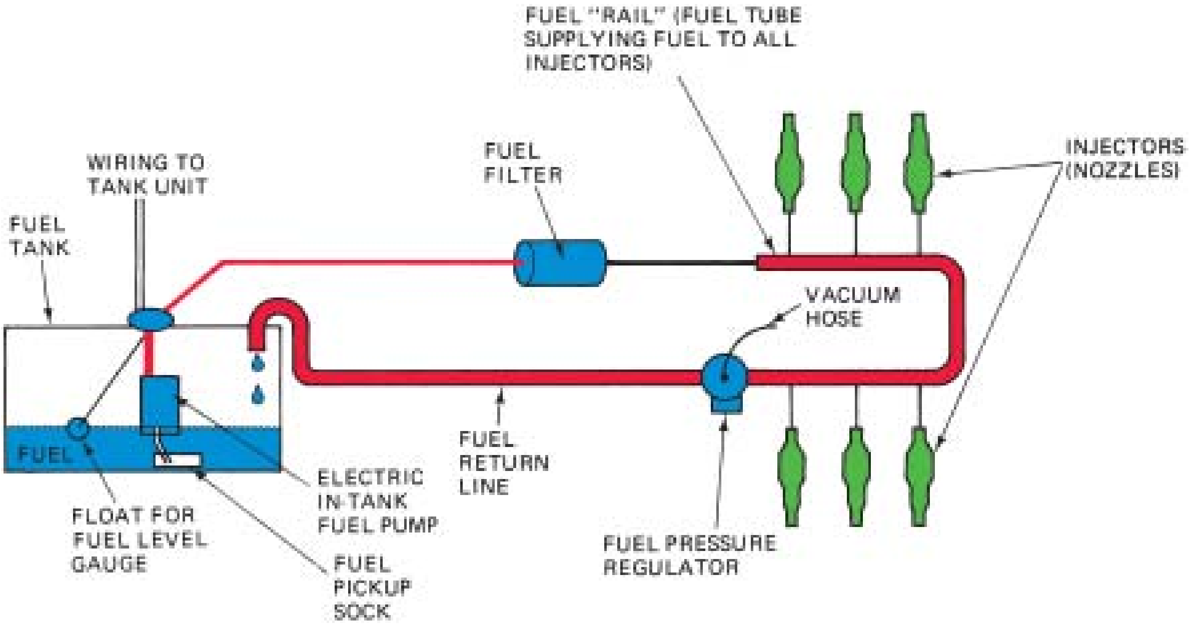


Figure 29–1 Typical port fuel-injection system, indicating the location of various components. Notice that the fuel pressure regulator is located on the fuel *return* side of the system. The computer does not control fuel pressure, but does control the operation of the electric fuel pump (on most systems) and the pulsing on and off of the injectors.

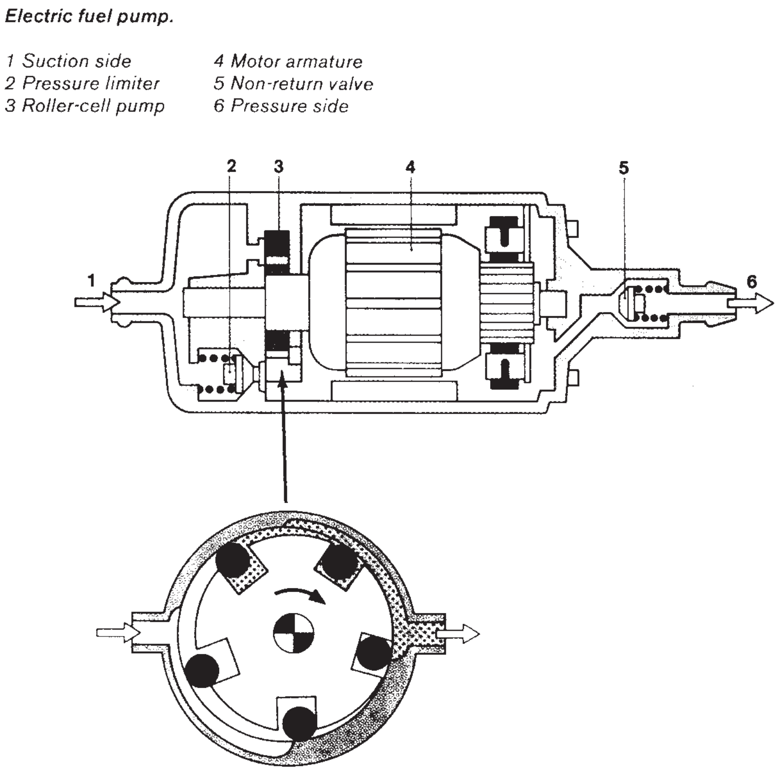


Figure 29–2 Schematic of a roller-cell fuel pump. Note #5 non-return valve, which prevents fuel pressure from bleeding back through the pump, and #2 pressure limiter (relief) valve, which acts as a safety valve if the fuel filter or line is restricted. (Courtesy Robert Bosch)

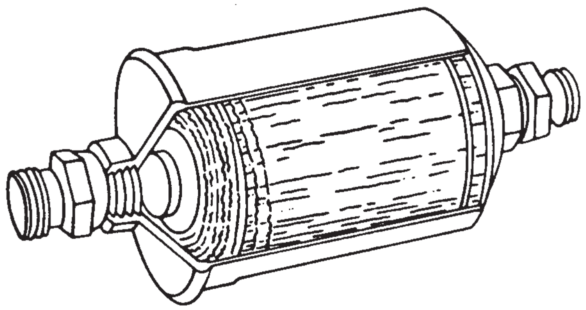


Figure 29–3 The fuel filter is located between the fuel pump and the fuel rail. Many filters are directional and have an arrow (or different sized fittings) to prevent incorrect installation. Most systems also have a filter "sock" at the fuel tank pick-up. (Courtesy Robert Bosch)

as a safety feature. A one-way check valve is also built into the pump outlet to prevent any fuel pressure in the lines or rail from bleeding back through the pump.

Fuel Filter

The fuel filter is a very important service item. See Figure 29–3. It prevents any rust or dirt in the fuel from reaching the fuel injectors where damage would occur; injector blockage, sticking or leakage are the usual result.

The filter is directional and may have an arrow or different sized fittings to prevent mounting backwards. Filters are normally replaced after a given number of kilometres or whenever major service is performed, e.g., fuel pump replacement or injector cleaning. Fuel system pressures *must* be released and the fuel tank cap removed before loosening filter lines. Pressurized fuel can spray for a long distance, causing personal injury or a fire.

Fuel Rail (Port Injection)

The fuel rail (or ring) acts as a manifold supplying fuel to each injector. See Figure 29–4. It also acts as a mounting point for the fuel-pressure regulator. Some domestic vehicles have the regulator riveted to the fuel rail; both are supplied if either needs replacing. The fuel injectors are sealed with O rings where they mount to the rail; the O rings should be replaced whenever the rail is removed from the injectors.

Domestic fuel rails usually have a fuel-pressure test fitting (Schrader valve) mounted on the rail, which makes servicing much easier. Many imported vehicles do not use Schrader valves and require special adaptors to test system pressures and fuel volume.

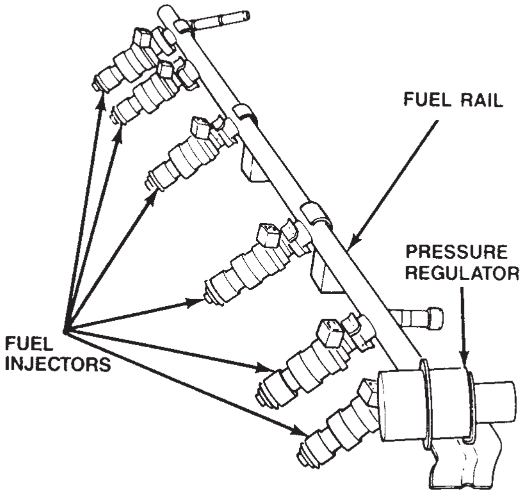


Figure 29–4 The fuel rail is a hollow manifold that supplies fuel to the injectors. Excess fuel not used in the engine flows through a pressure regulator (usually mounted on the rail) and returns to the tank. (Courtesy DaimlerChrysler Corporation)

Fuel Injectors

Electronic fuel injectors are liquid-control solenoids that open when electrically activated. See Figure 29–5. The injectors are pulsed on and off to control fuel volume. The longer the injectors are held open, the greater the amount of fuel injected into the manifold or intake port. Injectors are never operated at a 100% duty cycle. "On" time is called "pulse width"; the longer the pulse width, the greater the fuel flow; "on" time is usually in the 5 to 15 millisecond range.

Port Injection

Port injection systems used on gasoline-powered engines inject a fine mist of fuel into the *intake manifold* just above the intake valve. The pressure in the intake manifold is below atmospheric pressure on a running engine, and the manifold is therefore a vacuum. See Figure 29–6.

One major advantage of using port injection instead of the simpler throttle-body injection is that intake manifolds on port-injected engines only contain air, not a mixture of air and fuel. No pre-heating of the manifold is required to vaporize the fuel. This allows a cooler charge of intake air, which increases power. Another advantage is the equal volume of fuel provided to each cylinder. These "dry" manifolds also allow the engine design engineer the opportunity to design long, tuned intake-manifold runners that help the engine produce increased torque at lower engine speeds.

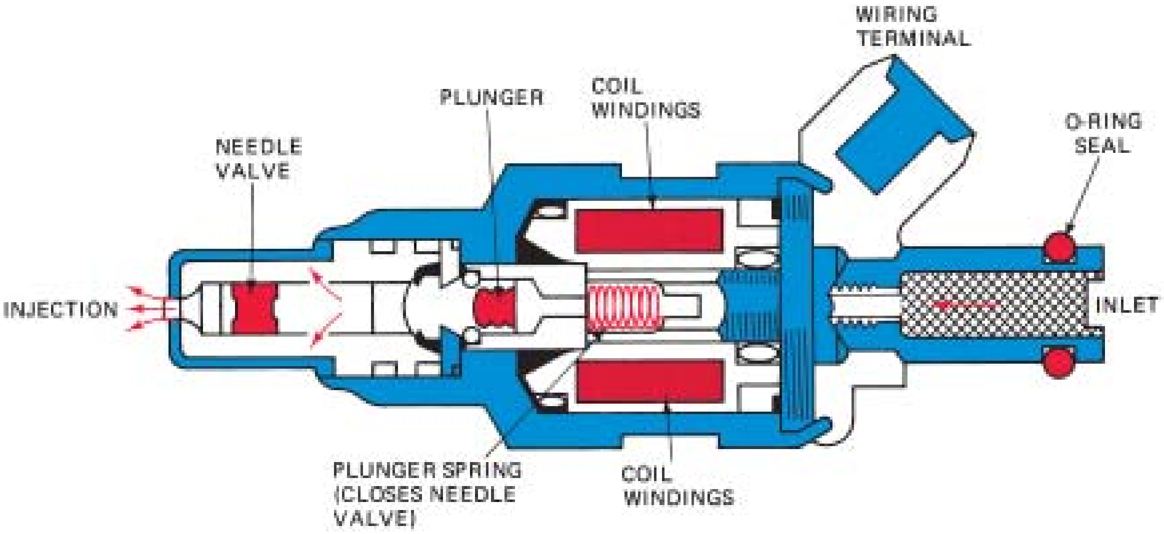
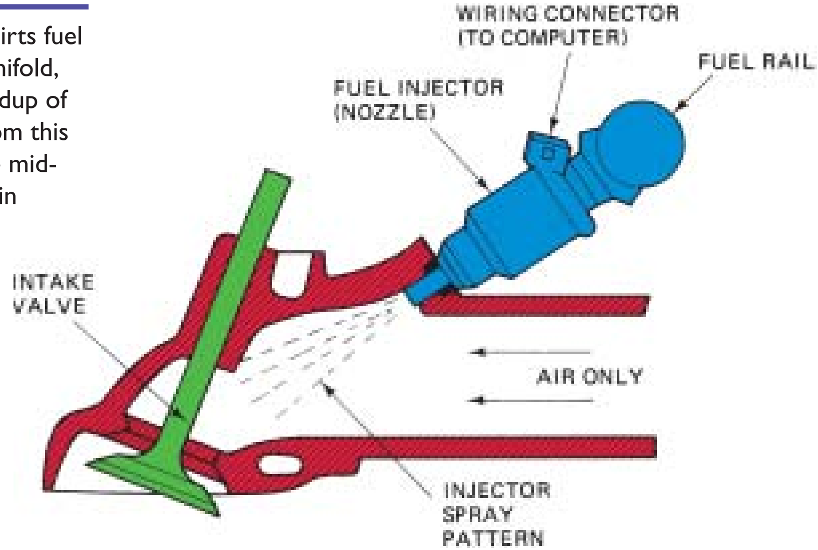


Figure 29–5 Cross-section of a typical port fuel-injection nozzle assembly. These injectors are serviced as an assembly only; no part replacement or service is possible other than cleaning or external O-ring replacement. Contamination at the needle valve area is a common problem, especially with older type injectors. Later injectors, called deposit-resistant, changed the tip design to reduce the formation of injector deposits.

Figure 29–6 A typical port-injection system squirts fuel into the low pressure (vacuum) of the intake manifold, about 75 mm (3 in.) from the intake valve. A buildup of soft carbon on the intake valve often resulted from this design. The petroleum industry responded in the mid-1990s by increasing the percentage of detergent in gasoline. The detergent also reduced injector contamination.



NOTE: Some port-injection systems used on engines with four or more valves per cylinder may use two injectors per cylinder. One injector is used all the time, and the second injector is operated by the computer when high engine speed and high-load conditions are detected by the computer. Typically, the second injector injects fuel into the high-speed intake ports of the manifold. This system permits good low-speed power and throttle response as well as superior high-speed power.

Fuel Pressure Regulator: Port Injection

Fuel injectors that inject fuel into the intake port are influenced by intake manifold vacuum. At idle, manifold vacuum is very strong and a given amount of fuel flows. As the throttle opens, manifold vacuum diminishes (pressure in the manifold rises) and less fuel will flow because of the higher pressure at the injector tip. Vacuum-modulated pressure regulators increase fuel pressure about 35 kPa (5 psi) as the throttle is opened. See Figure 29–7. This compensates for the increase in manifold pressure.

Any excess fuel not injected into the engine returns to the tank via a return line.

The pressure regulator also prevents fuel pressure from bleeding into the return line when the engine is shut off; this maintains pressurized fuel at the rail and injectors for faster starting.

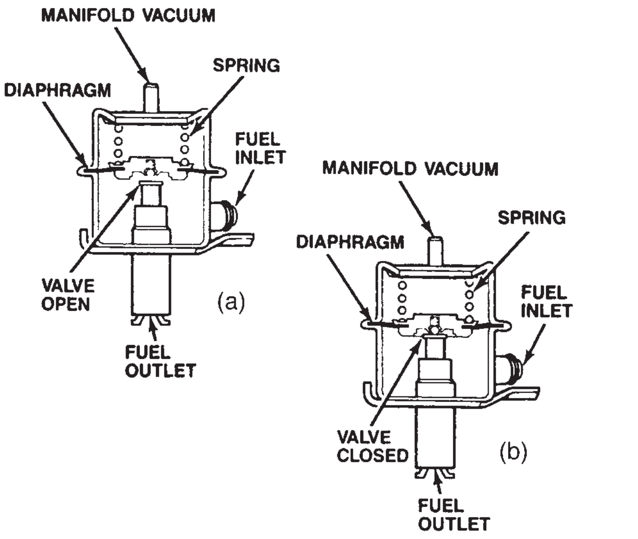


Figure 29–7 The vacuum-modulated pressure regulator controls system fuel pressure with a spring-loaded diaphragm. (a) Strong manifold vacuum (closed throttle) works against the spring and fuel pressure decreases. (b) As manifold vacuum drops (throttle opens), full spring pressure is now exerted on the diaphragm and fuel pressure rises. (Courtesy DaimlerChrysler Corporation)

Injector Firing Strategy

Fuel injectors have a number of operating strategies. They can all be fired at the same time (see Figure 29–8) with only one driver transistor. This is known as *simultaneous* injection; it is not timed. Some systems operate with two driver transistors; half of the injectors fire on one revolution, the other half fire on the second revolution; they also are not timed. *Sequential* injection, which requires a separate ground wire and transistor for each injector (ground side controlled), is timed. Injection usually occurs at the end of the exhaust stroke as the intake valve is opening.

Sequential injection has a number of advantages over simultaneous injection: 1) Emissions are reduced during low RPM and idle conditions. 2) It works with waste spark ignitions that fire the spark plug every revolution. 3) OBD II systems have the ability to cancel fuel delivery to any cylinder that is misfiring. This protects the catalytic converter.

Many imported vehicles use a resistor, which reduces the voltage at the injectors to approximately one-quarter of source voltage. This allows the use of low resistance injectors, which improves injector response. Domestic vehicles operate the injectors at source voltage and regulate injector response with the PCM.

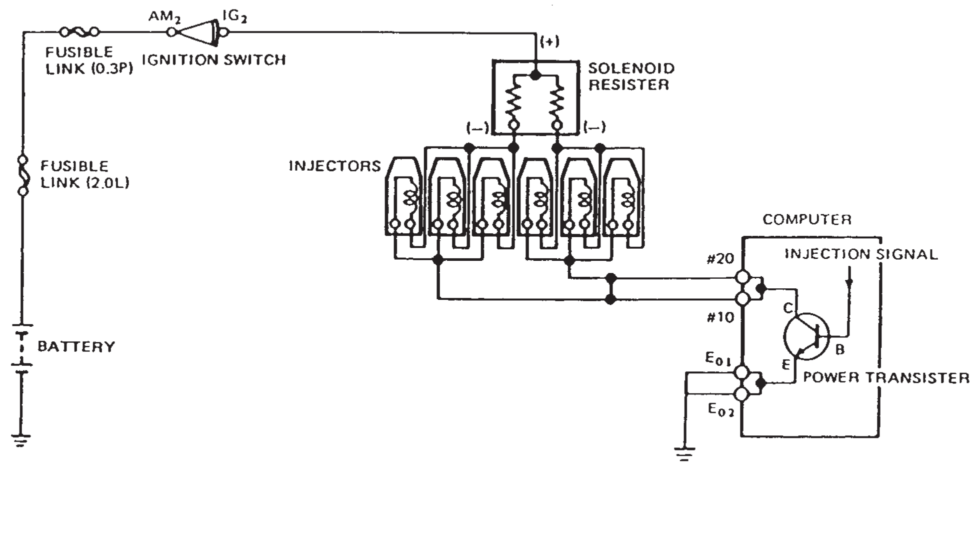
Overspeed protection is also built into most computer programs. If the engine is operated above red line or is over-revved in neutral, the computer cuts off every second injector (or similar strategy) to bring the RPM down to a safe level.

Fuel Pump Electrical Circuits

The computer usually controls the operation of the electric fuel pump, located in (or near) the fuel tank. When the ignition switch is first turned on, the computer energizes the fuel pump relay and the pump operates. See Figure 29–9. If the computer does not receive a signal that the engine is rotating, the pump will be shut off after 2 to 3 seconds. When the computer receives information that the engine is being cranked, or has started, it continues to energize the fuel pump. The signal may come from one or more of the following:

- Movement inside the vane airflow sensor from air entering the engine.
- Oil pressure is noted at the oil pressure sender.
- An ignition tach signal (RPM) is present; this is the most common.

Figure 29–8 Wiring schematic for a simultaneous injection system. (Courtesy Toyota Canada Inc.)



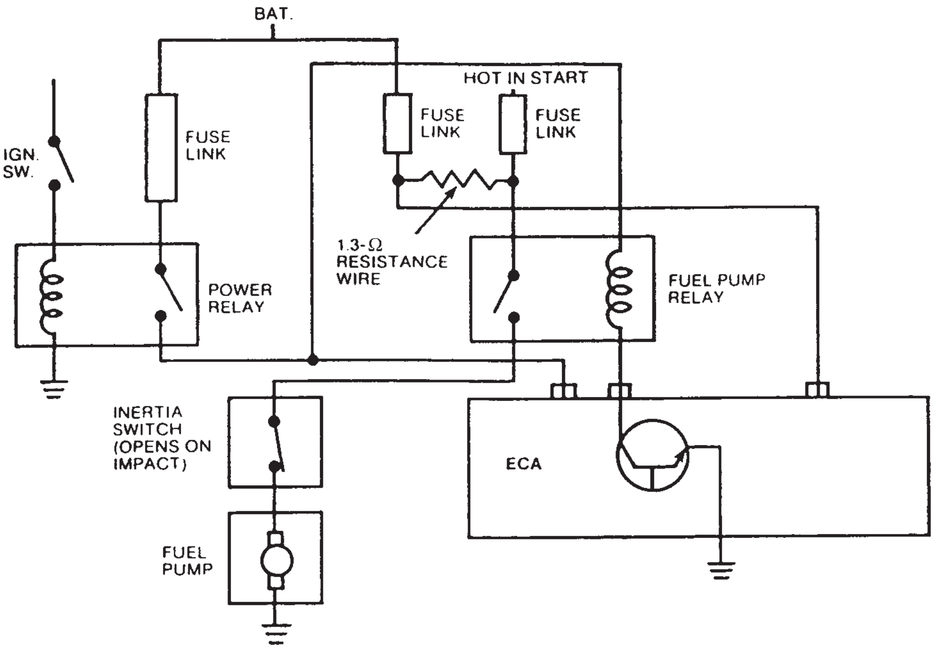


Figure 29–9 Schematic of a Ford fuel pump electrical circuit. After 2 to 3 seconds of pump operation, the computer (ECA) must receive an ignition signal (indicating the engine is rotating) or it will shut down the fuel pump relay. Note the inertia safety switch in the pump circuit. (Courtesy Ford Motor Co.)

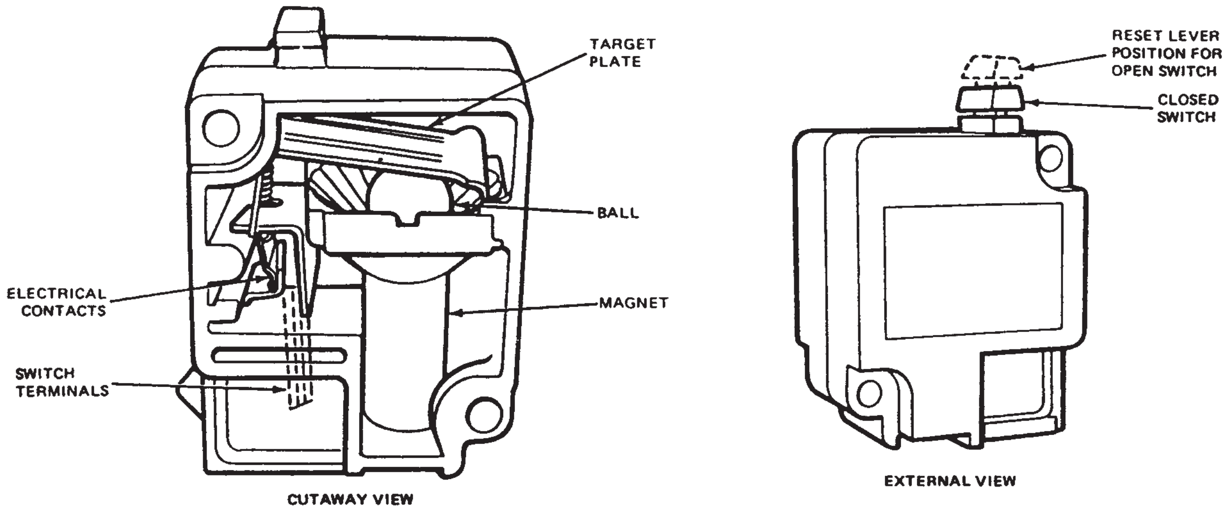


Figure 29–10 The inertia switch is used to shut off the electric fuel pump in case of an accident. Do not reset the switch before checking for fuel leaks at the tank, lines, or engine compartment. (Courtesy Ford Motor Co.)

NOTE: This is a safety feature: if the engine stalls and the tachometer (engine speed) signal is lost, the computer will shut off (de-energize) the fuel pump relay and stop the fuel pump.

Inertia Safety Switch

Ford, Jaguar and Fiat use an inertia switch in the fuel pump circuit to shut off the fuel pump in case of an accident. See Figure 29–10. A permanent magnet holds a steel ball in place; if an accident, or sharp impact, occurs, the steel ball breaks free and strikes a target plate, which opens the switch contacts, shutting off power to the pump. The switch is reset manually by depressing the reset button. Switch locations vary between vehicles; the switch may be in the trunk, on the firewall or behind a kick panel. Check the manual for location.

THROTTLE BODY INJECTION

Throttle-body injection (TBI) is also known as Central Fuel Injection (CFI) or Single-Point Injection. Throttle-body type of fuel injection uses one or two injectors (nozzles) to spray atomized fuel into the throttle body, which is similar to the base of a carburetor.

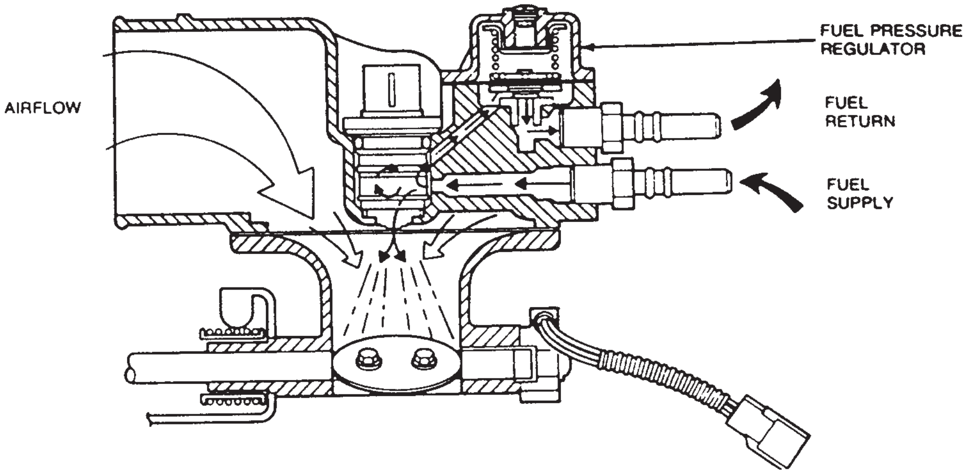


Figure 29–11 Fuel is injected above the throttle plate in this CFI system. The pressure regulator is not vacuum-modulated, as intake manifold vacuum does not have a major influence on injection rates. (Courtesy Ford Motor Co.)

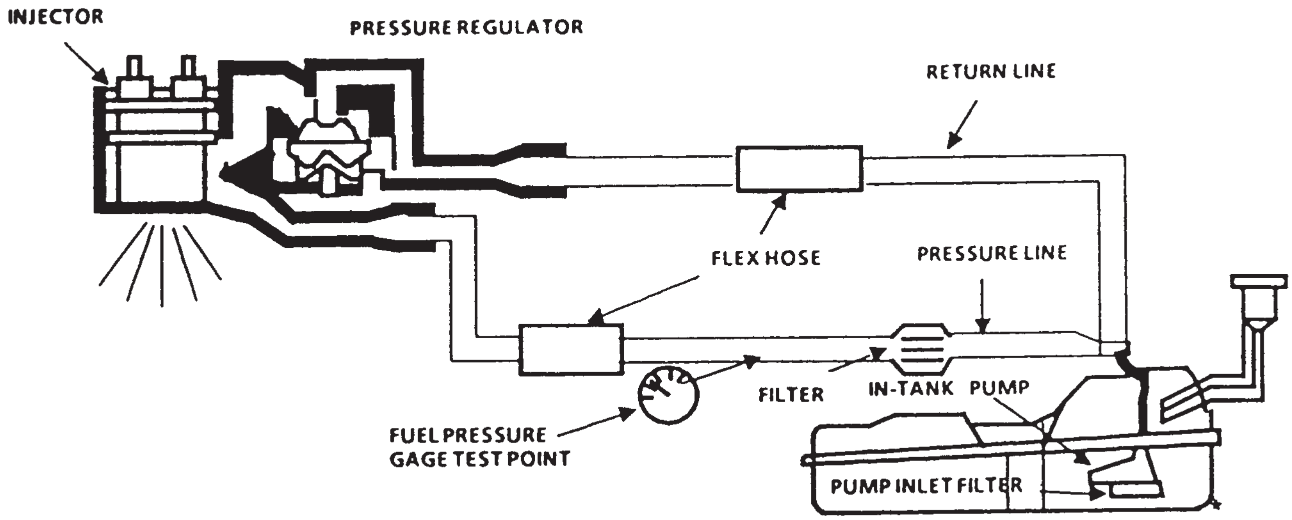


Figure 29–12 Fuel delivery and return lines on this TBI system are similar to port fuel injection. (Courtesy General Motors)

Air and fuel mix in the throttle-body unit and flow as a mixture down the intake manifold to the intake valves. See Figure 29–11. The fuel pump, filter, and lines are essentially the same as port injection. See Figure 29–12. Because fuel is injected above the throttle plate, intake manifold vacuum has no major influence on the injector. Fuel pressure regulators are not vacuum-modulated; fuel pressure is constant at 70 to 105 kPa (10 to 15 psi) depending on the model.

The ball-type tip of the TBI/CFI fuel injector is much larger than the needle tips of port injectors and it is prone to drip after the engine is shut off. See Figure 29–13. Some TBI pressure regulators (GM, Renault) have a bleed groove built into the pressure-regulator valve seat to relieve fuel pressure after the engine is turned off. Be aware of this condition when testing residual fuel pressure; there will be no pressure remaining after a few seconds.

A typical TBI system uses a throttle-position (TP) sensor and an **idle air-control (IAC)** valve. The TP is an input to the computer and the IAC is an output from the computer. The throttle-body injection unit costs less to manufacture, because it only uses one or two injectors (nozzles), whereas port-injection systems require an injector for every cylinder plus the additional computer capabilities to control all the injectors.

Throttle body injection provides better driveability and fuel economy than a mechanical (or electronically controlled) carburetor, however all of the distribution and vaporization problems associated with carburetted systems apply, as both air and fuel flow through the manifold. Unlike a port-injection system, many TBI units require that heated air be used with a heated intake manifold system to help vaporize the fuel that is injected into the incoming air inside the throttle-body unit.

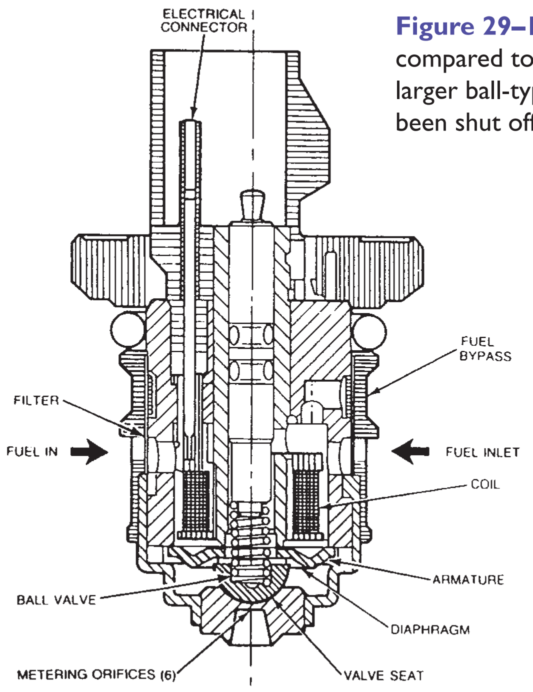


Figure 29–13 A low-pressure TBI/CFI fuel injector feeds all cylinders compared to a port fuel injector, which feeds only one cylinder. The larger ball-type injector tip is prone to leak or drip when the engine has been shut off. (Courtesy Ford Motor Co.)

BOSCH CONTINUOUS INJECTION (CIS)

Bosch continuous injection systems are also known as K-Jetronic injection: K stands for *konstant* in German. They are found on many 1970s to 1990s European vehicles (i.e., Audi, BMW, Mercedes, Volkswagen and Volvo, never on Asian or domestic automobiles).

Early CIS systems were mechanically operated; there is no computer. See Figure 29–14. Later systems, known as CIS-E, used a computer, a lambda (oxygen) sensor and a frequency valve to trim fuel mixtures. The frequency valve changes internal fuel pressures inside the fuel distributor to vary the mixture.

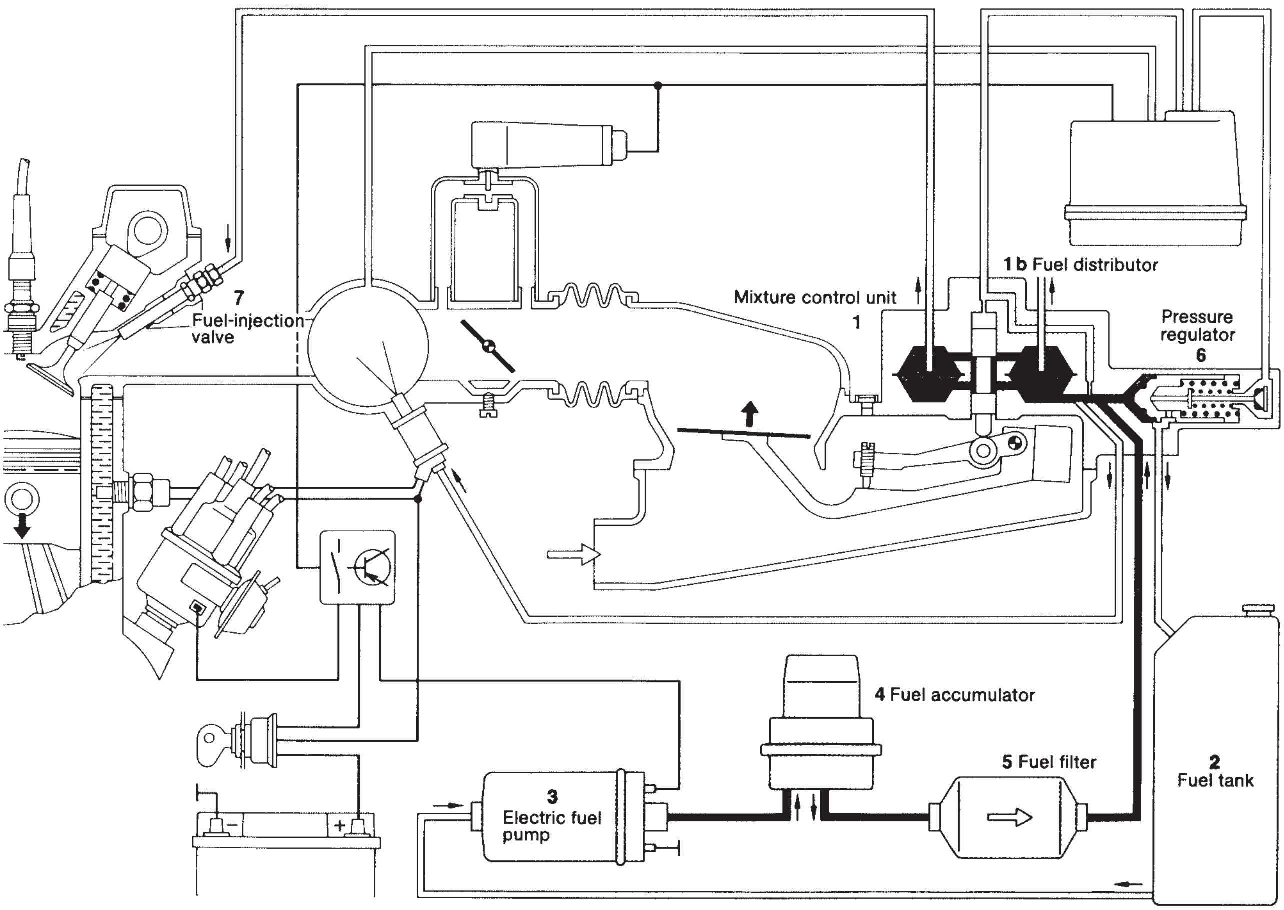


Figure 29–14 Schematic of a Bosch CIS mechanical injection system. These units are found only on European vehicles. (Courtesy Robert Bosch)

System Operation

Filtered fuel is pumped to the lower chamber of the mixture control unit where it is regulated to about 500 kPa (75 psi) by the pressure regulator. Excess fuel is returned to the tank.

Basic fuel control begins with an airflow sensor plate mounted next to the mixture control unit. Air entering the engine lifts the sensor plate; the greater the flow of air, the higher the plate is lifted. The arm on the airflow sensor plate contacts a fuel control valve called a control plunger. As the sensor plate lifts, it pushes on the control plunger, which also lifts, increasing fuel delivery. See Figure 29–15. Fuel flows from the mixture control unit to spring-loaded mechanical fuel injectors that open automatically when fuel pressure reaches 330 kPa (50 psi).

CENTRAL PORT INJECTION

The General Motors CPI system is a combination of a single electronic TBI-type injector and mechanical spring-loaded fuel injectors. See the manifold design in Chapter 9, Figure 9–42A.

The CPI fuel system is located inside a two-piece split intake manifold. Fuel arriving at the CPI unit is regulated by a built-in pressure regulator that returns unused fuel to the tank. The single maxi-injector (computer activated) injects fuel into a base, which contains six nylon tubes connected to six nylon fuel injectors (poppet nozzles). Fuel pressure at the injectors overcomes spring tension and fuel is injected into the ports. See Figure 29–16.

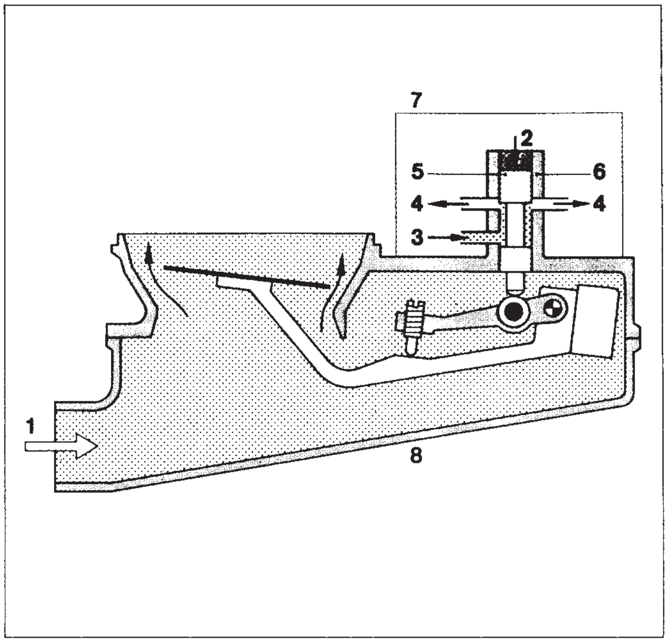


Figure 29–15 Fuel delivery in a Bosch CIS fuel distributor is metered by a control plunger, which is lifted by airflow at the sensor plate. (Courtesy Robert Bosch)

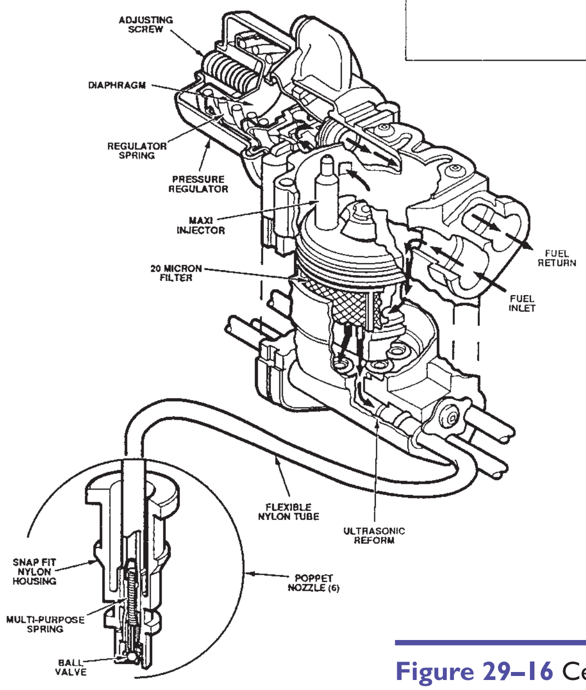


Figure 29–16 Central port injection (CPI) operation. (Courtesy General Motors)

Later designs use separate injector solenoids for each poppet valve, rather than a single maxi-injector. These systems are used primarily with V-6 and V-8 light truck engines.

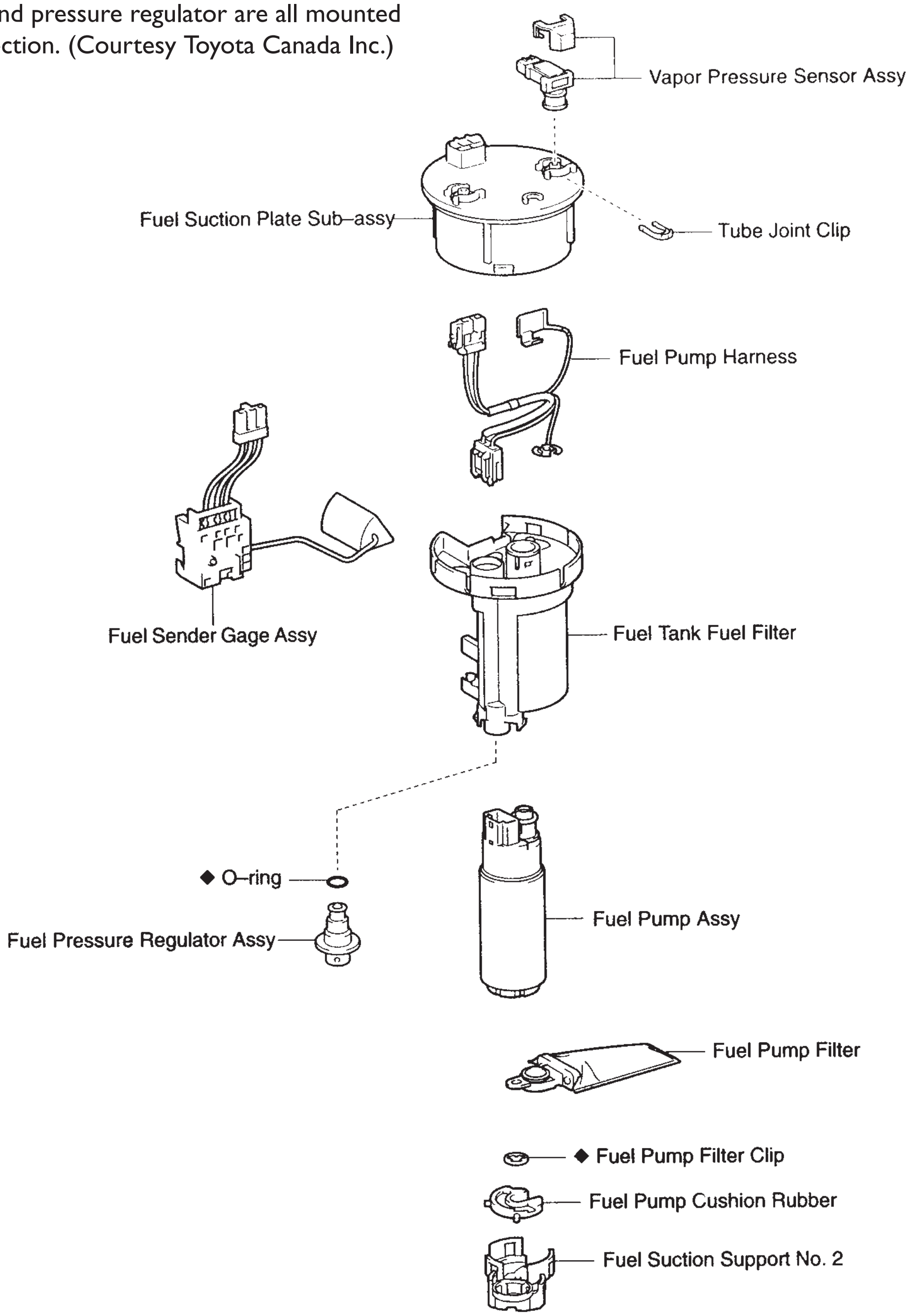
RETURNLESS FUEL INJECTION

The most common injection system found from the mid 1990s to date is returnless fuel injection. An in-tank fuel pump module contains the pump, filter, pressure regulator, and fuel gauge, all in one unit. See Figure 29–17. There is nothing outside the tank, other than a single fuel line, rail, and injectors. See Figure 29–18. The extra computing memory of the OBD II processor allows fuel volume to be tailored to demand, regardless of changes in manifold vacuum.

Removing the rear seat (or trunk mat) and service-hole cover allows access to the unit without removing the tank in most instances.

DaimlerChrysler was one of the first (mid-1990s) to use returnless injection with their V-8 and V-10 engines. Since then it has been adopted by many domestic and import manufacturers and has become the standard around the world.

Figure 29–17 The fuel pump, gauge, and pressure regulator are all mounted inside the tank with returnless fuel injection. (Courtesy Toyota Canada Inc.)



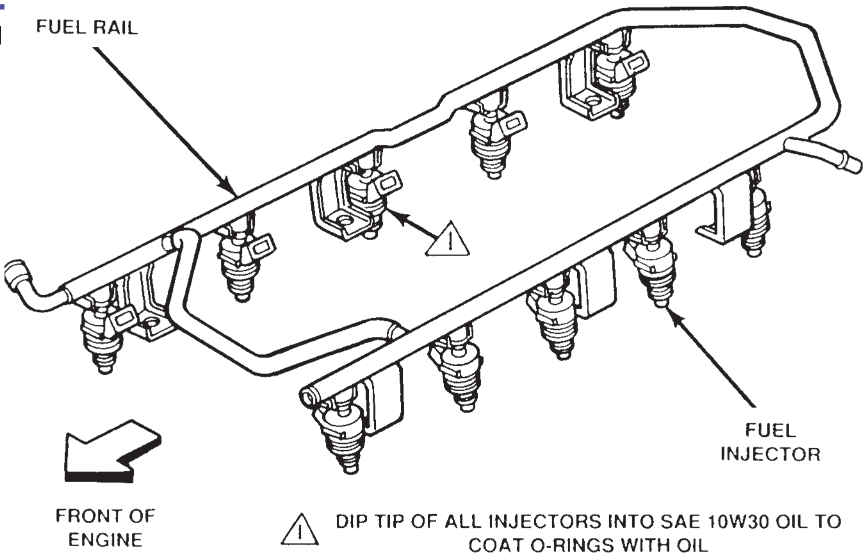


Figure 29–18 Fuel rails with returnless fuel injection contain an inlet fitting and pressure-gauge port. There is no return line. Pressure remains constant at 275 kPa (40 psi). (Courtesy DaimlerChrysler Corporation)

DIRECT FUEL INJECTION

A few Asian manufacturers—Mitsubishi, Toyota, and Isuzu—are using gasoline direct injection (GDI) with selected models. GDI sprays high-pressure fuel (8000 to 13 000 kPa, 1200 to 1950 psi) into the combustion chamber as the piston approaches the top of the compression stroke. See Figure 29–19.

The combination of high-pressure swirl injectors, with almost instant vaporization, and modified combustion chamber and port design allows the engine to run with a much leaner air/fuel mixture than conventional intake port injection. Fuel economy has shown a major improvement and engine emissions have been reduced.

Lean-burn engines traditionally lower hydrocarbon (HC) and carbon monoxide (CO) emissions; however, oxides of nitrogen (NO_x) emissions rise because of the elevated combustion temperatures created by lean mixtures. Increasing the amount of exhaust gas (EGR) fed into the incoming air and a special catalytic converter reduces NO_x to a very low level. It is expected that GDI engines will become more common as emission and fuel economy standards become more stringent.

Diagnosing Electronic Fuel-Injection Problems Using Visual Inspection

All fuel-injection systems require the proper amount of clean fuel delivered to the system at the proper pressure and the correct amount of filtered air. The following items should be carefully inspected before proceeding to more detailed tests.

- Check the air filter and replace as needed.
- Check the air induction system for obstructions.

TECH TIP

No Spark, No Squirt

Most electronic fuel-injection computer systems use the ignition primary (pickup coil or crank sensor) pulse as the trigger for when to inject (squirt) fuel from the injectors (nozzles). If this signal were not present, no fuel would be injected. Because this pulse is also necessary to trigger the module to create a spark from the coil, it can be said that "no spark" could also mean "no squirt." Therefore, if the cause of a no-start condition is observed to be a lack of fuel injection, do not start testing or replacing fuel-system components until the ignition system is checked for proper operation.

- Check the condition of all vacuum hoses. Replace any hose that is split, soft (mushy), or brittle. Be sure to use the correct type of hose designed for use on a vacuum system. Using fuel line hose instead of vacuum hose can cause the hose to be sucked closed, creating more problems. This is especially true for the PCV valve hose.
- Check the positive crankcase ventilation (PCV) valve for proper operation or replacement as needed.

NOTE: The use of an incorrect PCV valve can cause a rough idle or stalling.

- Check all fuel-injection electrical connections for corrosion or damage.
- Check for gasoline at the vacuum port of the fuel pressure regulator if the vehicle is so equipped. Gasoline in the vacuum hose at the fuel pressure

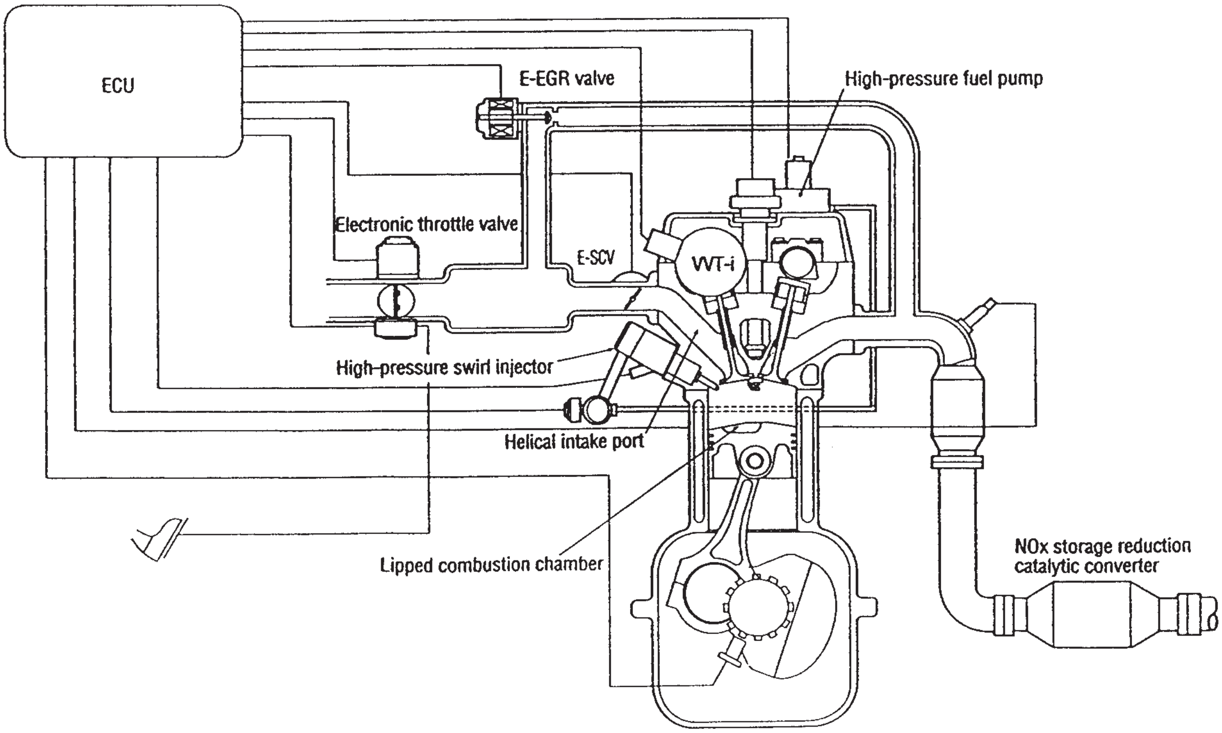


Figure 29–19 Gasoline direct injection (GDI). Note the high-pressure swirl fuel injector at the combustion chamber. (Courtesy Toyota Canada Inc.)

TECH TIP

The Ear Test

No, this is not a test of your hearing, but rather using your ear to check that the electric fuel pump is operating. The electric fuel pump inside the fuel tank is often difficult to hear running, especially in a noisy shop environment. A commonly used trick to better hear the pump is to use a funnel in the fuel filter neck.

regulator indicates that the regulator is defective and requires replacement.

Test Connectors

Many vehicles have test procedures that allow the technician to operate the electric fuel pump without starting the engine; these vary between makes, but the following is typical:

- Open the meter plate at the vane airflow sensor. See Figure 29–20.
- Jumper two test terminals at the airflow sensor.
- Jumper specified terminals at the fuel pump relay.
- Ground the fuel-pump test connector (activates the relay).
- Power the test connector (powers the fuel pump).
- Activate the fuel pump relay with a scan tool.

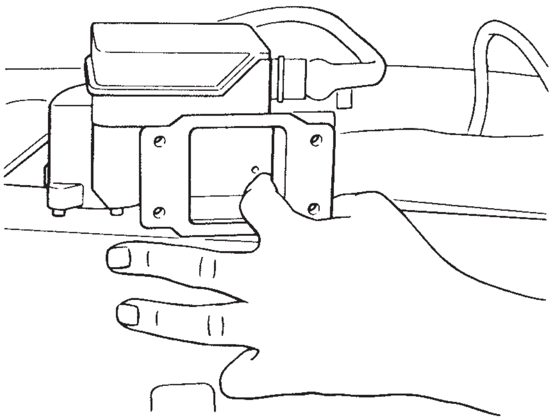


Figure 29–20 The vane airflow meter plate should open with light pressure to the fully open position and return to rest without dragging or binding. Many European and Asian vehicles (to mid-1990s) also incorporate fuel-pump safety contacts; opening the plate with a finger (engine key "on") will activate the fuel pump. Domestic vehicles with this type of meter use a tach signal, instead of contacts, for pump control. (Courtesy Robert Bosch)

Follow the manufacturer's instructions exactly; a wrong connection could ruin the computer, wiring or relay. See Figure 29–21.

Figure 29–21 Most General Motors fuel-injected vehicles are equipped with a fuel pump test connector. The operation of the fuel pump can be checked by connecting a 12 volt test light to the positive (+) terminal of the battery and the point of the test light to the test connector. Turn the ignition to on (engine off). The light should either go out or come on for 2 seconds. This is a simple test to check to see if the computer can control the fuel pump relay.

Port Fuel-Injection System Diagnosis

To determine if a port fuel-injection system, including the fuel pump, injectors, and fuel pressure regulator, are operating okay, follow these steps:

1. Attach a fuel pressure gauge to the Schrader valve on the fuel rail.

NOTE: Some fuel rails may not have a Schrader valve on the rail and therefore, special adapters may be required.

2. Turn the ignition key on or start the engine to build up the fuel pump pressure (it should be about 210 to 350 kPa [30 to 50 psi]).
3. Wait 20 minutes and observe the fuel pressure retained in the fuel rail and note the value. (The fuel pressure should not drop more than 140 kPa [20 psi] in 20 minutes.) If the drop is less than 140 kPa (20 psi) in 20 minutes, everything is okay. If the drop is *greater* than 140 kPa (20 psi) in 20 minutes, there is a possible problem with:
   - The check valve in the fuel pump
   - Leaking injectors
   - A defective (leaking) fuel pressure regulator

To determine which unit is defective, perform the following with the gauges still connected:

- Re-energize the electric fuel pump for 10 seconds.
- Clamp the fuel *supply* line, wait 10 minutes (see Caution box on the next page). If the pressure drop does not occur, replace the fuel pump. If the pressure drop still occurs, continue with the next step.
- Repeat the pressure build-up of the electric pump and clamp the fuel return line. If the pressure drop time is now okay, replace the fuel pressure regulator.
- If the pressure drop still occurs, one or more of the injectors is leaking. Remove the injectors with the fuel rail and hold over paper. Replace those injectors that drip one or more drops after 10 minutes with pressurized fuel.

DIAGNOSTIC STORY

The Quad Four Story

A service technician was diagnosing a rough-running condition on a General Motors Quad Four engine. The paper test indicated a cylinder miss. To help determine which cylinder was possibly causing the problem, the technician disconnected the fuel-injector connectors one at a time. When the injector was disconnected from cylinder #2, the engine did not change in the way it was running. A compression test indicated that the cylinder had good compression. The technician removed the ignition cover and used conventional spark plug wires to connect the coils to the spark plugs. The technician then connected short lengths of rubber vacuum hose to each of the plugs. The technician then touched each rubber hose with a grounded test light to ground out each cylinder. Again, cylinder #2 was found to be completely dead.

Then the technician made a mistake by assuming that the fault had to be a defective fuel injector. A replacement fuel injector did not solve the problem. Further testing of the injectors revealed that injector #3 was shorted. Because both injectors #2 and #3 share the same driver inside the computer, the injector that was shorted electrically required more current than the normal good injector. Because the computer driver circuit controls and limits current flow, the defective (shorted) injector would fire (squirt), whereas the good injector did not have enough current to work.

CAUTION: The use of fuel-injector cleaner may damage the electrical windings of the fuel injector. Gasoline flows over the copper coil windings of an injector to help keep it cool. If a strong solvent is used in the fuel-injection cleaner, the varnish insulation on the coil may be damaged. As a result, the coil windings may short against each other, lowering the resistance of the injector.

TECH TIP

The Electric Fuel Pump Clue

The on-board computer controls the operation of the electric fuel pump, fuel-injection pulses, and ignition timing. With a distributorless ignition system, it is difficult at times to know what part in the system is not operating if there is no spark from any of the ignition coils. A fast-and-easy method for determining if the crankshaft sensor is operating is to observe the operation of the electric fuel pump. In most electronic fuel-injection systems, the computer will operate the electric fuel pump for only a short time (usually about 2 seconds) unless a crank pulse is received by the computer.

Most manufacturers provide a fuel pump test lead with which the technician can monitor the electrical operation of the pump. On most vehicles, if voltage is maintained to the pump during engine cranking for longer than 2 seconds, then the crankshaft sensor is working. If the pump only runs for 2 seconds then turns off during cranking of the engine, the crankshaft sensor, wiring, or computer may be defective.

NOTE: Another way of testing is to use a scan tool. If an RPM signal is processed and displayed by the computer, then the crank sensor is functioning.

DIAGNOSTIC STORY

The Rich-Running Chrysler

A four-cylinder Chrysler was running so rich that black smoke poured from the exhaust all the time. It was equipped with a TBI-type fuel-injector system, and the fuel pressure was fixed at about 260 kPa (38 psi)—the same as the maximum fuel-pump pressure. A replacement fuel-pressure regulator did not correct the higher-than-normal fuel pressure. The fuel return line was also carefully inspected for a kink or other obstruction that may have caused excessive fuel pressure. The technician discovered the root cause of the problem to be a stuck shuttle valve, a part of many Chrysler TBI systems used to close off the fuel return to the tank to keep the pressure high, permitting faster restarts when the engine is hot. The shuttle valve simply slides downward on an incline to close off the fuel regulator return passage. The technician removed the shuttle valve and cleaned it. Vehicle operation then returned to normal and both the technician and the customer were satisfied that a low cost and fast solution was found.

CAUTION: Do not clamp plastic fuel lines. Connect shut-off valves to the fuel system to shut off supply and return lines.

TESTING FUEL PUMP PRESSURE

The most common gasoline fuel injection systems operate with system pressures ranging from 70 kPa (10 psi) on low pressure TBI/CFI to 350 kPa (50 psi) on port injection. There are exceptions, so service specifications should always be checked before starting.

Typical System Pressures

Normal Operating Pressure	kPa (psi)	Maximum Pump Pressure kPa (psi)
Low-pressure TBI units	70 kPa (10 psi)	140 kPa (20 psi)
High- pressure TBI units	210 kPa (30 psi)	450 kPa (65 psi)
Port fuel-injection systems	350 kPa (50 psi)	700 kPa (100 psi)
Central port fuel injection	420 kPa (60 psi)	700 kPa (100 psi)
Bosch K-Jetronic (mechanical)	525 kPa (75 psi)	700 kPa (100 psi)
Returnless injection	280 kPa (40 psi)	550 kPa (80 psi)

Maximum fuel pressure should never be reached provided the fuel pressure regulator is operating and there is no blockage in the filter or lines; blockage before the gauge test fitting may not show a pressure rise at the gauge.

Closed loop injection returns excess fuel to the tank. The continuous flow of fuel cools the injector and helps prevent vapour from forming in the fuel system. Although vapour or foaming in a fuel system can affect engine operation, the cooling and lubricating flow of the fuel helps to ensure the durability of the injector nozzles.

Returnless injection systems cycle any excess fuel at the regulator inside the tank. The fuel is not exposed to high underhood temperatures (until it is used at the injectors) or heated by pumping it through the rail and back to the tank; the fuel remains cool.

To measure fuel-pump pressure, locate the Schrader valve, if equipped, or install a suitable adaptor. Attach a fuel pressure gauge as shown in Figure 29–22. Check the pressure while the engine idles. The fuel pressure should remain constant on all systems other than vacuum modulated port fuel injection where pressures vary with changes in manifold vacuum.

Figure 29–22 A fuel pressure gauge connected to the fuel pressure tap (Schrader valve) on a port-injected V-6 engine.

Port Fuel-Injection Pressure Regulator Diagnosis

Most port fuel-injected engines use a vacuum hose connected to the fuel pressure regulator. At idle, the pressure inside the intake manifold is low (high vacuum). Intake manifold vacuum is applied above the diaphragm inside the fuel pressure regulator. This reduces the pressure exerted on the diaphragm and results in a drop (about 35 kPa or 5 psi) in fuel pressure applied to the injectors. To test a vacuum-controlled fuel pressure regulator, follow these steps:

1. Connect a fuel pressure gauge to monitor the fuel pressure.
2. Locate the fuel pressure regulator and disconnect the vacuum hose from the regulator.

> **NOTE:** If gasoline drips out of the vacuum hose when removed from the fuel pressure regulator, the regulator is defective and will require replacement.

3. Using a hand-operated vacuum pump, apply vacuum, about 500 mm (20 in.) Hg to the regulator. The regulator should hold vacuum. If the vacuum drops, replace the fuel pressure regulator. See Figure 29–23.
4. With the engine running at idle speed, reconnect the vacuum hose to the fuel pressure regulator while watching the fuel pressure gauge. The fuel pressure should drop (about 35 kPa, 5 psi) when the hose is reattached to the regulator.

Testing Fuel-Pump Volume

Fuel pressure alone is not enough for proper engine operation. Sufficient fuel capacity (flow) must be at least 1 litre (2 pints) per minute (0.5 litre or 1 pint in 30 seconds).

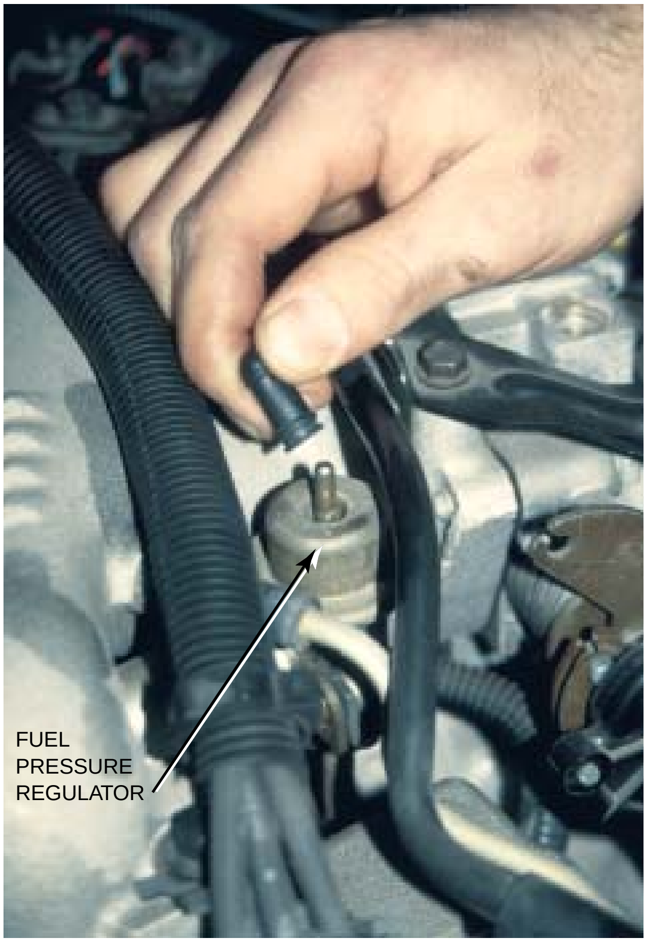


Figure 29–23 If the vacuum hose is removed from the fuel pressure regulator when the engine is running, the fuel pressure should increase. If it does not increase, then the fuel pump is not capable of supplying adequate pressure or the fuel pressure regulator is defective. If gasoline is visible in the vacuum hose, the regulator is leaking and should be replaced.

All fuel must be filtered to prevent dirt and impurities from damaging the fuel-system components and/or engine. The first filter (sock) is inside the gas tank and is usually attached to the fuel pump (if the pump is electric) and/or fuel-gauge sending unit. The main fuel filter is usually located between the fuel tank and the fuel rail or inlet to the fuel-injection system. For long engine and fuel-system life and optimum performance, the main fuel filter should be replaced every year or every 24 000 km (15 000 mi). Consult vehicle manufacturers' recommendations for exact time and kilometre (mileage) intervals.

If the fuel filter becomes partially clogged, the following are likely to occur:

1. There will be low power at higher engine speeds. The vehicle usually will not go faster than a certain speed (engine acts as if it has a built-in speed governor).

TECH TIP

Stethoscope Fuel Injection Test

A commonly used test for injector operation is to listen to the injector with a stethoscope while the engine is operating at idle speed. See Figure 29–24. All injectors should produce the same clicking sound. If any injector sounds different from the others, further testing or replacement may be necessary. All injectors should make a "clicking" sound. If any injector makes a "clunking" or "rattling" sound, it should be tested further or replaced. With the engine still running, place the end of the stethoscope probe to the return line from the fuel pressure regulator. See Figure 29–25. The sound of fuel should be heard flowing back to the fuel tank. If no sound of fuel is heard, then the fuel pump, fuel filter, or the fuel pressure regulator is at fault.

2. The engine will cut out or miss on acceleration, especially when climbing hills or during heavy-load acceleration.

A weak or defective fuel pump can also be the cause of the symptoms just listed. If an electric fuel pump for a fuel-injected engine becomes weak, the engine may also be hard to start, or it will idle rough or stall.

CAUTION: Be certain to consult the vehicle manufacturer's recommended service and testing procedures before attempting to test or replace any component of a high-pressure electronic fuel-injection system.

NOTE: Most electric fuel pumps have a life expectancy of about 160 000 km (100 000 mi) before replacement. The usual cause of failure is brush wear at the commutator. Some manufacturers are now using brushless, permanent magnet fuel pumps, which provide a major improvement in service life.

SAFETY TIP

The arcing of the electric current from the fuel pump brushes to the armature commutator will not cause a gasoline fire or explosion, as there is insufficient oxygen in the pump while it is mounted on the vehicle.

This is not true if the pump has been removed from the vehicle; any remaining fuel vapours will mix with air if the pump is electrically activated (tested) off the vehicle. The pump could explode! Always follow the manufacturers' procedures when testing pumps.

Figure 29–24 All fuel injectors should make the same sound with the engine running at idle speed. A lack of sound indicates a possible electrically open injector or a break in the wiring. A defective computer could also be the cause of a lack of clicking (pulsing) of the injectors.

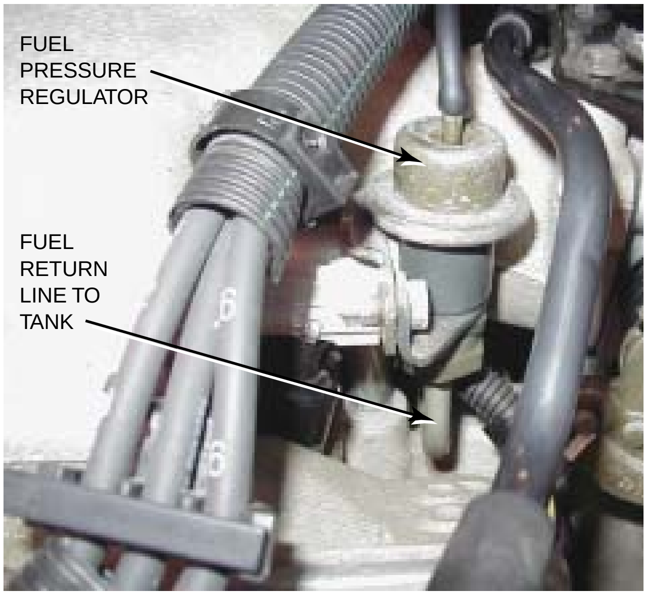
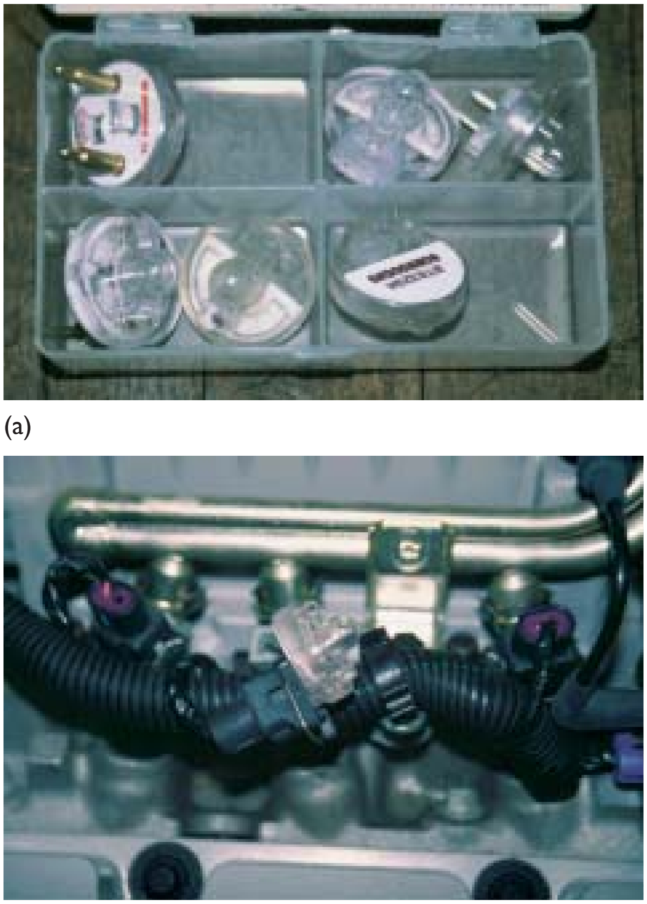


Figure 29–25 Fuel should be heard returning to the fuel tank at the fuel return line if the fuel pump and fuel pressure regulator are functioning correctly.

TECH TIP

Fuel-system pressure is controlled by a fuel pressure regulator at the fuel rail or throttle body. A restricted fuel filter or line will cause fuel pressure to increase, up to 700 kPa (100 psi) in some cases. The fuel pump slows down because of the added load and usually becomes noisier. A complaint of "whining noise in the rear" could be corrected by replacing the fuel filter. A fuel volume test (after the filter) will verify the diagnosis.



(a)

(b)

Figure 29–26 (a) Noid lights are usually purchased as an assortment so that one is available for any type or size of injector wiring connector. (b) The connector is unplugged from the injector and a noid light is plugged into the injector connector. The noid light should flash when the engine is being cranked if the power circuit and the pulsing to ground by the computer are functioning correctly.

Testing for an Injector Pulse

One of the first checks that should be performed when diagnosing a no-start condition is whether the fuel injectors are being pulsed by the computer. Checking for proper pulsing of the injector is also important in diagnosing a weak or dead cylinder.

A **noid** light is designed to electrically replace the injector in the circuit and to flash if the injector circuit is working correctly. See Figure 29–26. To use a noid light, disconnect the electrical connector at the fuel injector and plug the noid light into the injector harness connections. Crank or start the engine. The noid light should flash regularly.

> **NOTE:** The term *noid* is simply an abbreviation of the word *solenoid*. Injectors use a movable iron core and are therefore a solenoid. Therefore, a noid light is a replacement for the solenoid (injector).

Possible noid light problems and causes include the following:

1. **The light is off and does not flash.** The problem is an open in either the power side or ground side (or both) of the injector circuit.
2. **The noid light flashes dimly.** A dim noid light indicates excessive resistance or low voltage available to the injector. Both the power and ground side must be checked.
3. **The noid light is on and does not flash.** If the noid light is on, then both a power and a ground are present. Because the light does not flash (blink) when the engine is being cranked or started, then a short-to-ground fault exists either in the computer itself or in the wiring between the injector and the computer.

Checking Fuel-Injector Resistance

Each port fuel injector must deliver an equal amount of fuel or the engine will idle rough or perform poorly.

The electrical balance test involves measuring the injector coil-winding resistance. For best engine operation, all injectors should have the same electrical resistance. To measure the resistance, carefully release the locking feature of the connector and remove the connector from the injector.

Always check the service information for the exact specifications for the vehicle being checked.

> **NOTE:** Some engines require specific procedures to gain access to the injectors. Always follow the manufacturers' recommended procedures.

With an ohmmeter, measure the resistance across the injector terminals. Be sure to use the low-ohms feature of the digital ohmmeter to be able to read in tenths (0.1) of an ohm. See Figures 29–27 and 29–28. Subtract the lowest reading injector from the highest. For example,

$$\begin{aligned} \text{Highest-resistance injector} &= 17.4 \text{ ohms} \\ -\ \text{Lowest-resistance injector} &= \underline{17.2} \text{ ohms} \\ \text{Difference} &= 0.2 \text{ ohms} \end{aligned}$$

Acceptable maximum differences should be limited to 0.3 to 0.4 ohms. A greater difference in resistance indicates a possible problem. Further testing should be performed. The resistance of the

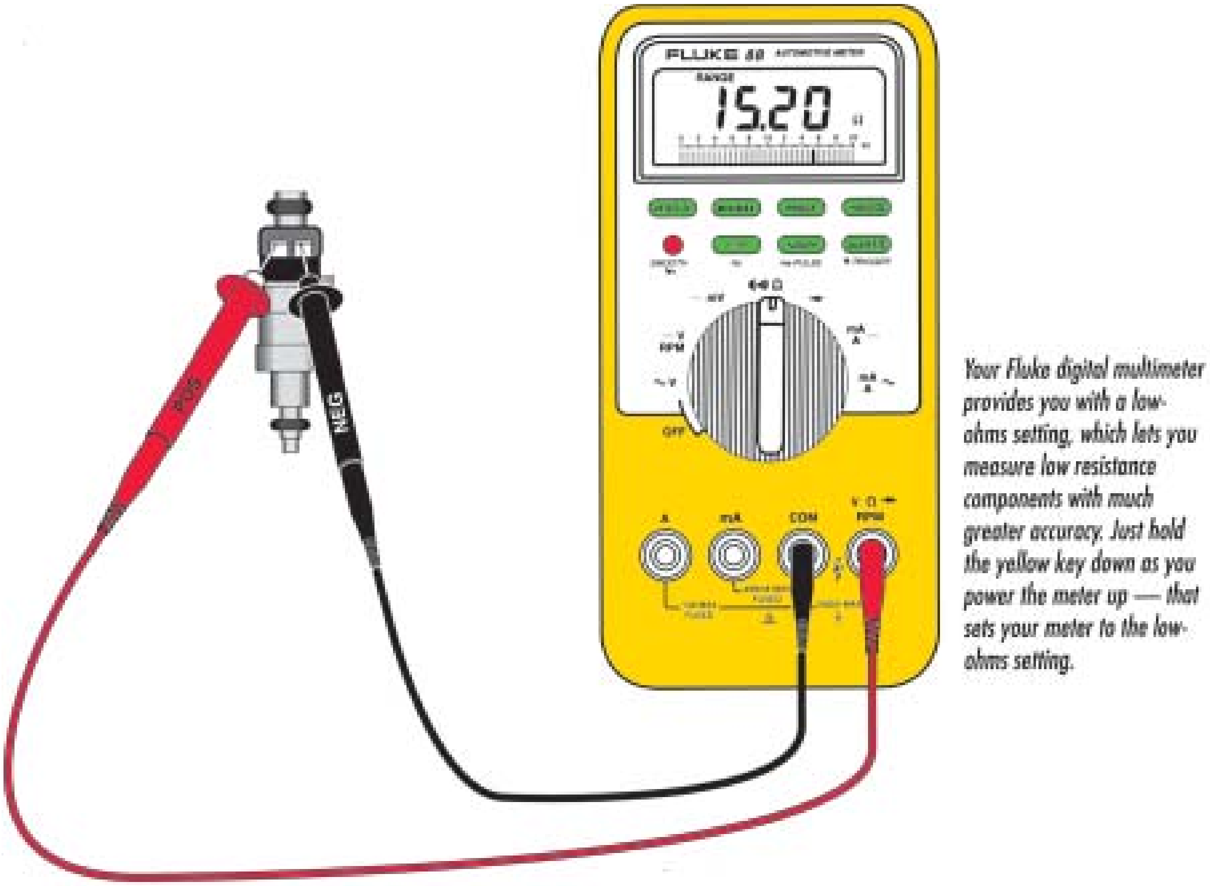


Figure 29–27 Connections and settings necessary to measure fuel-injector resistance. (Courtesy of Fluke Corporation)

Figure 29–28 To measure fuel-injector resistance, a technician constructed a short wiring harness with a double banana plug that fits into the V and COM terminals of the meter and an injector connector at the other end. This setup makes checking resistance of fuel injectors quick and easy.

injectors should be measured twice—once when the engine (and injectors) are cold and once after the engine has reached normal operating temperature. If any injector measures close to or over 1.0 ohm different from the others, it must be replaced after making certain that the terminals of the injector are electrically sound.

Measuring Resistance of Grouped Injectors

Many vehicles are equipped with a port fuel-injection system that fires two or more injectors at a time. For example, a V-6 may group all three injectors on one bank to pulse on at the same time, then the other three injectors will be pulsed on. This sequence alternates. To measure the resistance of these injectors, it is often easiest to measure each group of three that is wired in parallel. The resistance of three injectors wired in parallel

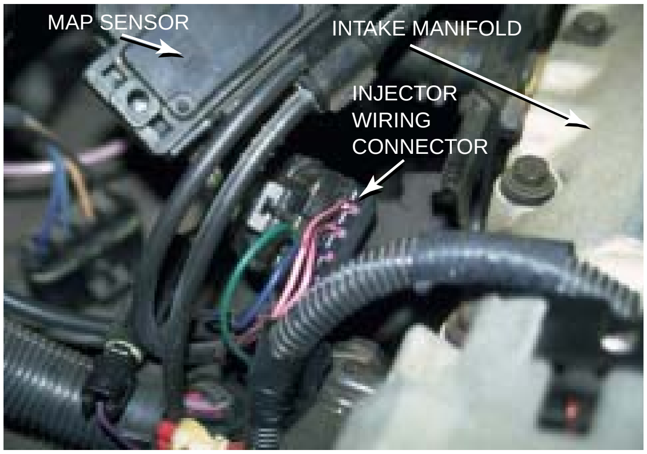


Figure 29–29 The fuel injector wiring connector on this General Motors 3.1-litre V-6 is hidden and attached to the rear of the intake manifold. Both groups of three injectors can be easily measured using an ohmmeter. Both groups of injectors should measure within 0.5 ohm of each other.

is one-third of the resistance of each individual injector. For example,

Injector resistance = 12 ohms
Three injectors in parallel = 4 ohms

A V-6 has two groups of three injectors. Therefore, both groups should measure the same resistance. If both groups measure 4 ohms, then it is likely that all six injectors are okay. However, if one group measures only 2.9 ohms and the other group measures 4 ohms, then it is likely that one or more fuel injectors are defective (shorted). This means that the technician now has reasonable cause to remove the intake manifold to get access to each injector for further testing. See Figure 29–29.

Pressure-Drop Balance Test

The pressure balance test involves using an electrical timing device to pulse the fuel injectors on for a given amount of time (usually 500 milliseconds) and observing the drop in pressure that accompanies the pulse. If the *fuel flow* through each injector is equal, the drop in pressure in the system will be equal. Most manufacturers recommend that the pressures be within about 10 kPa (1.5 psi) of each other for satisfactory engine performance. This test method not only tests the electrical functioning of the injector (for definite time and current pulse) but also tests for mechanical defects that could affect fuel flow.

Scope Testing Fuel Injectors

A scope such as a digital storage oscilloscope (DSO) can be attached to the pulse side of the injector and the waveform checked and compared to a known-good pattern. See Figures 29–30 and 29–31.

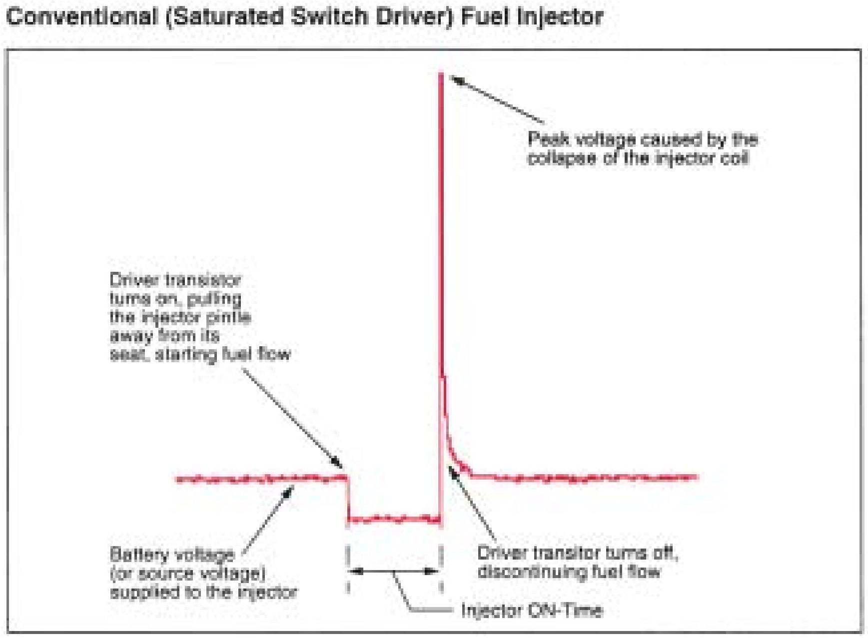


Figure 29–30 The injector on-time is called the *pulse width.* (Courtesy of Fluke Corporation)

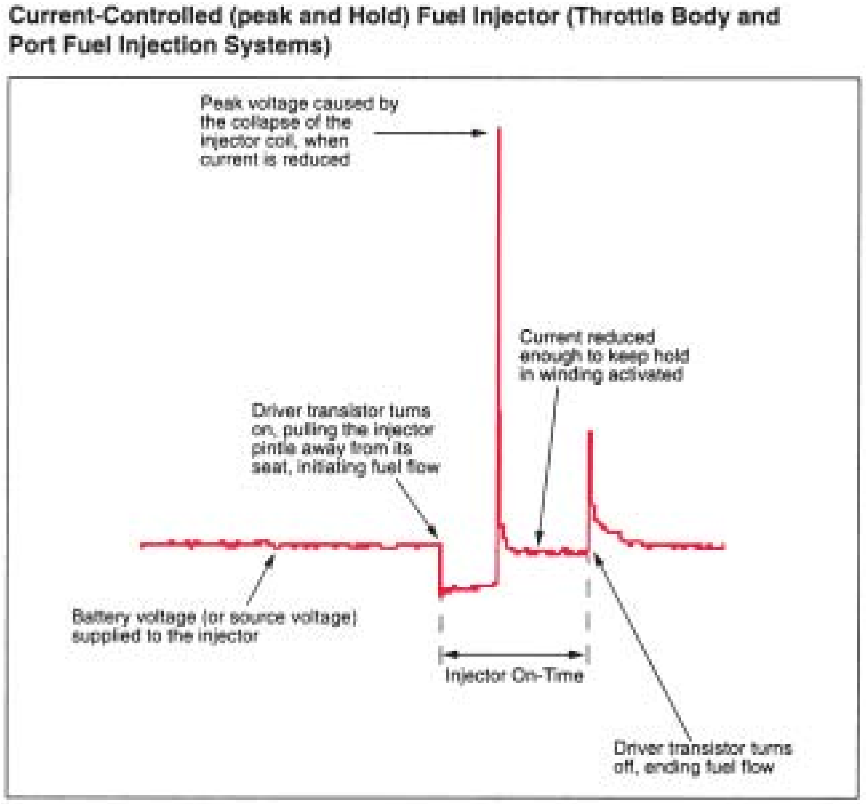


Figure 29–31 A typical peak and hold fuel-injector waveform. Most fuel injectors that measure less than 6 ohms will display a similar waveform. (Courtesy of Fluke Corporation)

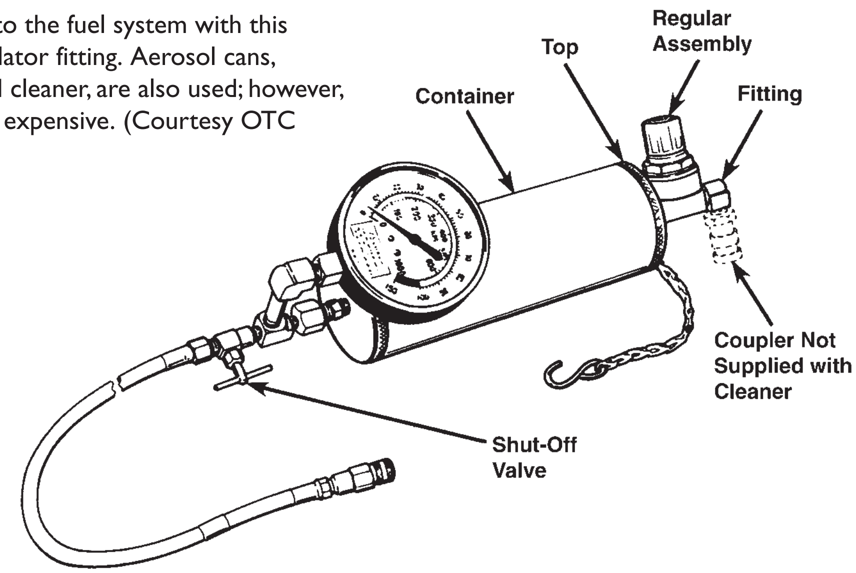


Figure 29–32 Fuel-injector cleaner is fed into the fuel system with this cleaning unit; shop air is attached to the regulator fitting. Aerosol cans, already pressurized and containing pre-mixed cleaner, are also used; however, they contain less cleaner and are often more expensive. (Courtesy OTC Division, SPX Corporation)

CLEANING FUEL INJECTORS

Most fuel injectors can be cleaned on the vehicle by feeding injector-cleaning liquid into the fuel rail, or TBI/CFI test port while the engine is running.

One common piece of equipment is shown in Figure 29–32. Liquid cleaner, which may require diluting with gasoline, is poured into the container after the top has been unscrewed. The top, containing an adjustable air pressure regulator, is reinstalled and a shop air hose is attached to the regulator. Ensure that the shut-off valve is closed and adjust the container pressure to 35 kPa (5 psi) lower than the fuel-injection-system operating pressure. TBI/CFI systems operate with low pressures; a 15 kPa (2 psi) lower setting is fine with these units.

Hang the cleaning unit under the hood and attach the supply hose to the Schrader valve (or adaptor) on the fuel rail or as directed in the operating instructions. Disconnect the wiring to the electric fuel pump on the vehicle. Block the fuel return line by clamping, if rubber, or by installing a shut-off valve if plastic or plastic-lined. See Figure 29–33.

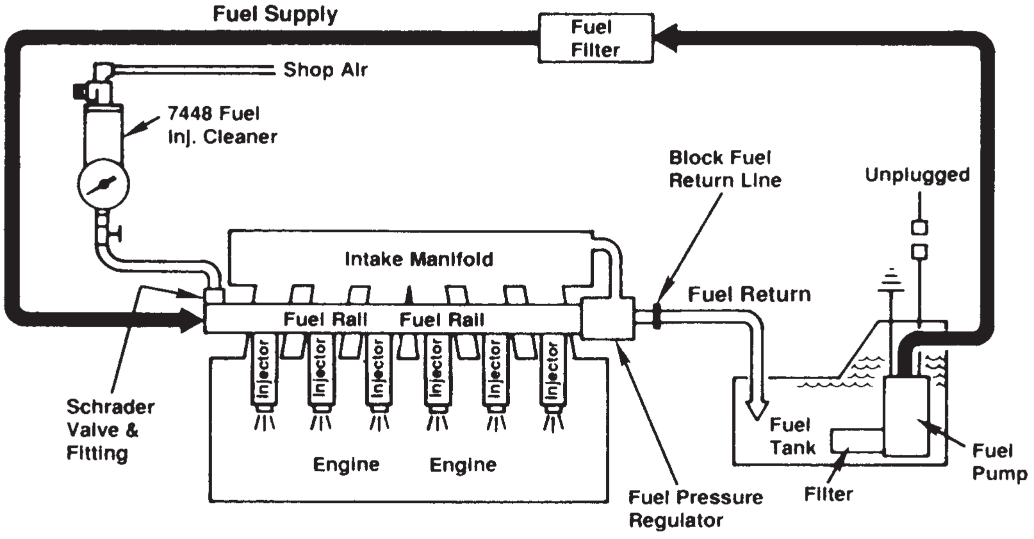


Figure 29–33 Typical hookup for on-vehicle injector cleaning. Note the blocked fuel return line and the unplugged wiring to the fuel pump. (Courtesy OTC Division, SPX Corporation)

Frequently Asked Question ???

If Three Out of Six Injectors Are Defective, Should I Also Replace the Other Three?

This is a good question. Many service technicians recommend that the three good injectors also be replaced along with the other three that tested as being defective. The reasons given by these technicians include:

- All six injectors have been operating under the same fuel, engine, and weather conditions.
- The labour required to replace all six is just about the same as replacing only the three defective injectors.
- Replacing all six at the same time helps ensure that all of the injectors are flowing the same amount of fuel so that the engine is operating most efficiently.

With these ideas in mind, the customer should be informed and offered the choice. Complete sets of injectors such as those in Figure 29–34 can be purchased at a reasonable cost.

Open the shut-off valve, start the engine and let it run until the container runs out of fluid. Some manufacturers recommend a fast idle only; others run the engine at various speeds. Remove the equipment, reconnect the pump, remove the return line shut-off, restart the engine and check the injector operation.

Cleaning the injectors on the vehicle will usually correct leaking or contamination at the injector tip; if this operation is not successful, the injectors must be removed for electronic cleaning (high frequency vibration) or replacement.

Figure 29–34 A set of six new injectors.

Remember always to keep a fire extinguisher, (suitable for gasoline) on hand whenever working with fuel injection.

IDLE AIR SPEED CONTROL

On an engine equipped with fuel injection (TBI or port injection), the idle speed is controlled by increasing or decreasing the amount of air bypassing the throttle plate. Again, an electronic stepper motor is used to maintain the correct idle speed. This control is often called the **idle air control (IAC).** See Figures 29–35 through 29–37.

When the engine stops, most IAC units will extend the conical valve until the valve bottoms in the air bypass passage. The computer notes this position and then moves the valve outward to get

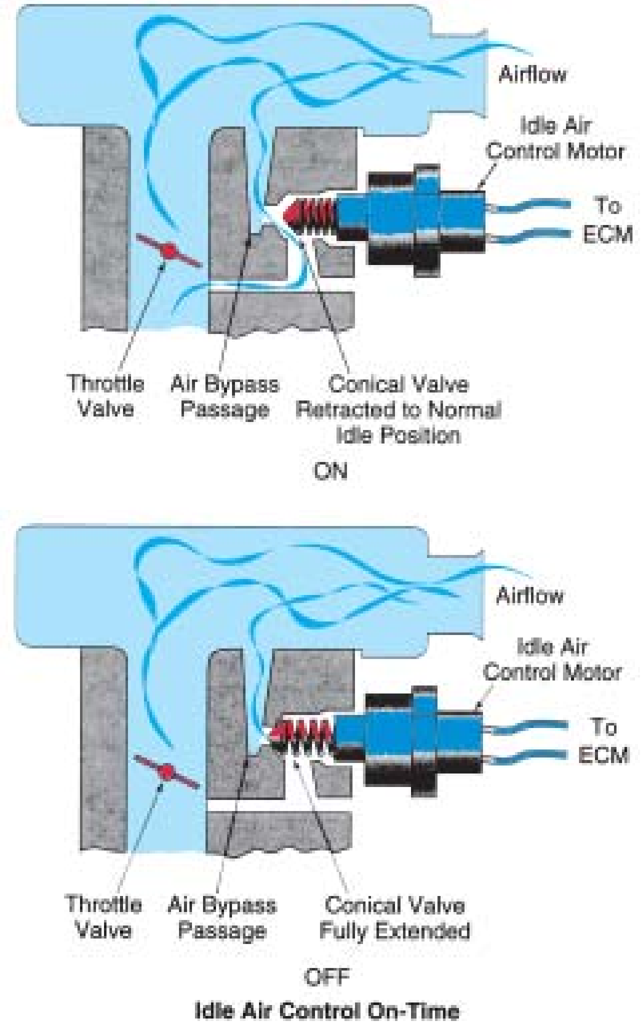


Figure 29–35 An idle air control (IAC) controls idle speed by controlling the amount of air that passes around the throttle plate. More airflow results in a higher idle speed. (Courtesy of Fluke Corporation)

Figure 29–36 A typical IAC.

Figure 29–37 Some idle air control units are purchased with the housing as shown. Carbon buildup in these passages can cause a rough or unstable idling or stalling.

ready for the next engine start. When the engine starts, the engine speed is high to provide for proper operation when the engine is cold. Then, as the engine gets warmer, the computer reduces engine idle speed gradually by reducing the number of counts or steps commanded by the IAC.

When the engine is warm and restarted, the idle speed should momentarily increase, then decrease to normal idle speed. This increase and then decrease in engine speed is often called an engine **flare.** If the engine speed does not flare, then the IAC may not be working (it may be stuck in one position).

Some air control valves (Ford, Hitachi) can be removed and disassembled for cleaning. Never use liquid cleaners on electrical components or plastic control valves as damage can occur.

THROTTLE BODIES: PORT FUEL INJECTION

Throttle Body Icing

Port fuel injection manifolds are not heated; air only passes through the runners. Under certain low temperature, high humidity conditions, moisture in the incoming air will freeze at the throttle plate area of the throttle body. Many current throttle bodies incorporate a pocket, or passage, for engine coolant to warm the body. See Figure 29–38.

Electronic Throttle Control

Most electronic throttle control systems do not use a throttle cable. An electric motor on the side of the throttle body operates the throttle plate when commanded by the PCM. An accelerator position sensor at

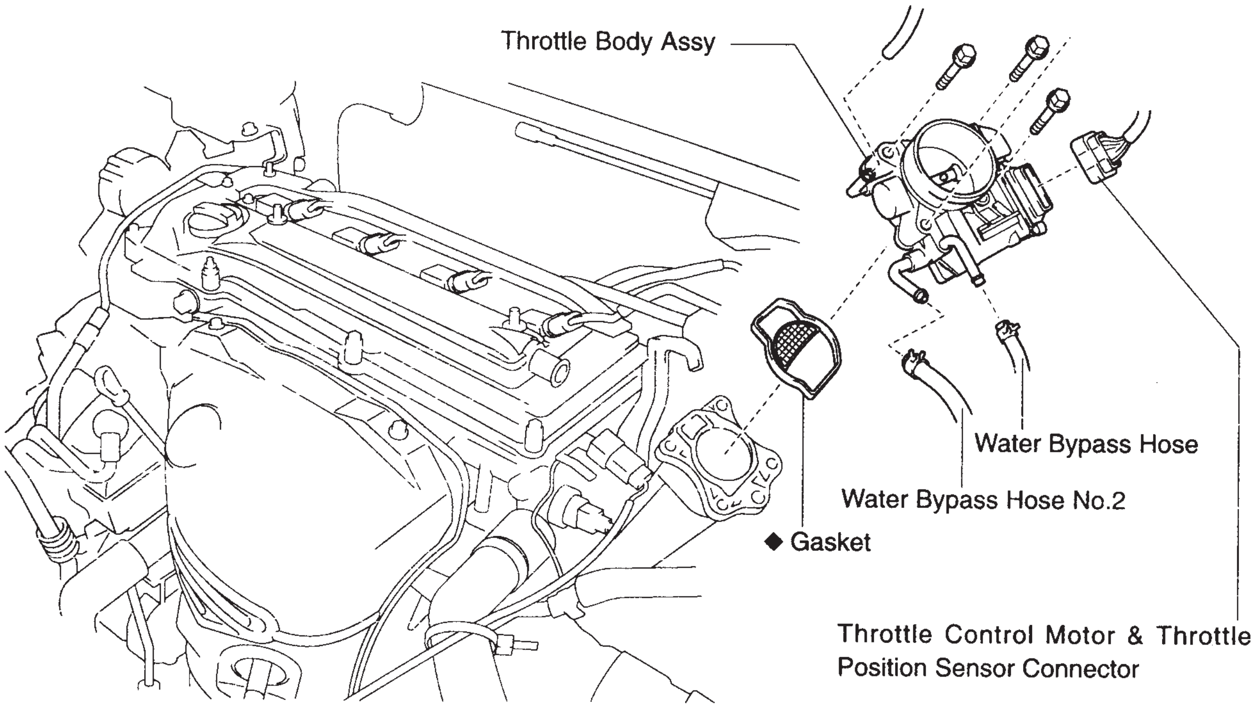


Figure 29–38 This electronic throttle body uses engine coolant to prevent throttle plate icing. Note the location of the throttle control motor and position sensor. (Courtesy Toyota Canada Inc.)

the accelerator pedal sends a signal to the PCM, which in turn, adjust the throttle motor to match the driver's input. The throttle position sensor on the throttle body sends throttle angle information to the PCM.

Electronic throttles originated with traction control systems where the computer reduces throttle opening when wheel spin is detected. Since then, it has become common with or without traction control.

Conditions of excessive RPM or engine overheating may also trigger reduced throttle opening.

Throttle Plate Contamination

The positive crankcase ventilation (PCV) system picks up ventilating air, usually between the mass airflow sensor and the throttle plate. See Figure 29–39. Crankcase fumes often backfeed into the throttle body causing a buildup of deposits at the throttle plate and bore. These deposits are normally removed during regular maintenance service or when a driveability concern is noted.

The throttle plates of a port fuel-injected engine may require cleaning, especially if the following conditions exist:

- Rough idle
- Stalling
- Surging at idle
- Hesitation during acceleration
- Higher than normal IAC counts as displayed on a scan tool.

See Figures 29–40 and 29–41.

FALSE AIR

Speed density fuel injection relies on information typically from MAP, CTS, ACT, RPM, and TPS for calculating fuel delivery. An air leak in the hose between the air cleaner and the throttle body usually will not affect driveability.

The opposite is true with mass-air systems; any air leaks could change the mass airflow sensor reading and cause hard starting and rough running. This usually occurs during open loop operation when fuel is not being trimmed by the oxygen sensor. See Figures 29–42 and 29–43.

DIESEL FUEL INJECTION

Diesel injection systems have seen many changes over the past few years, driven in part by new, more stringent emissions regulations and a call for increased economy. Earlier systems used a mechanical fuel injection pump to meter fuel delivery; however,

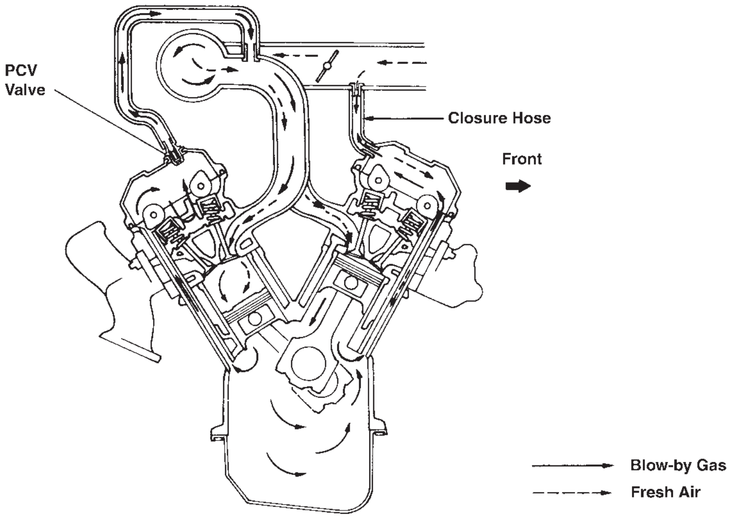


Figure 29–39 Airflow through the positive crankcase ventilation (PCV) system. Note the closure hose at the front cam cover; blow-by gases may back-flow into the air intake under certain driving conditions, i.e., full-throttle, high RPM operation. (Courtesy Toyota Canada Inc.)

(a) (b)

Figure 29–40 (a) Dirty throttle plate. This throttle plate was so dirty that the technician removed the entire throttle body to be sure it was thoroughly cleaned. (b) Most throttle plates can be cleaned on the vehicle using a brush and throttle body cleaner. Be sure the cleaner is safe for oxygen sensors.

Figure 29–41 Some vehicles, such as this Ford, have labels on the throttle body warning not to clean the throttle plates. A slippery coating is placed on the throttle plate and throttle bore that prevents deposits from sticking. Cleaning this type of housing can remove this protective coating.

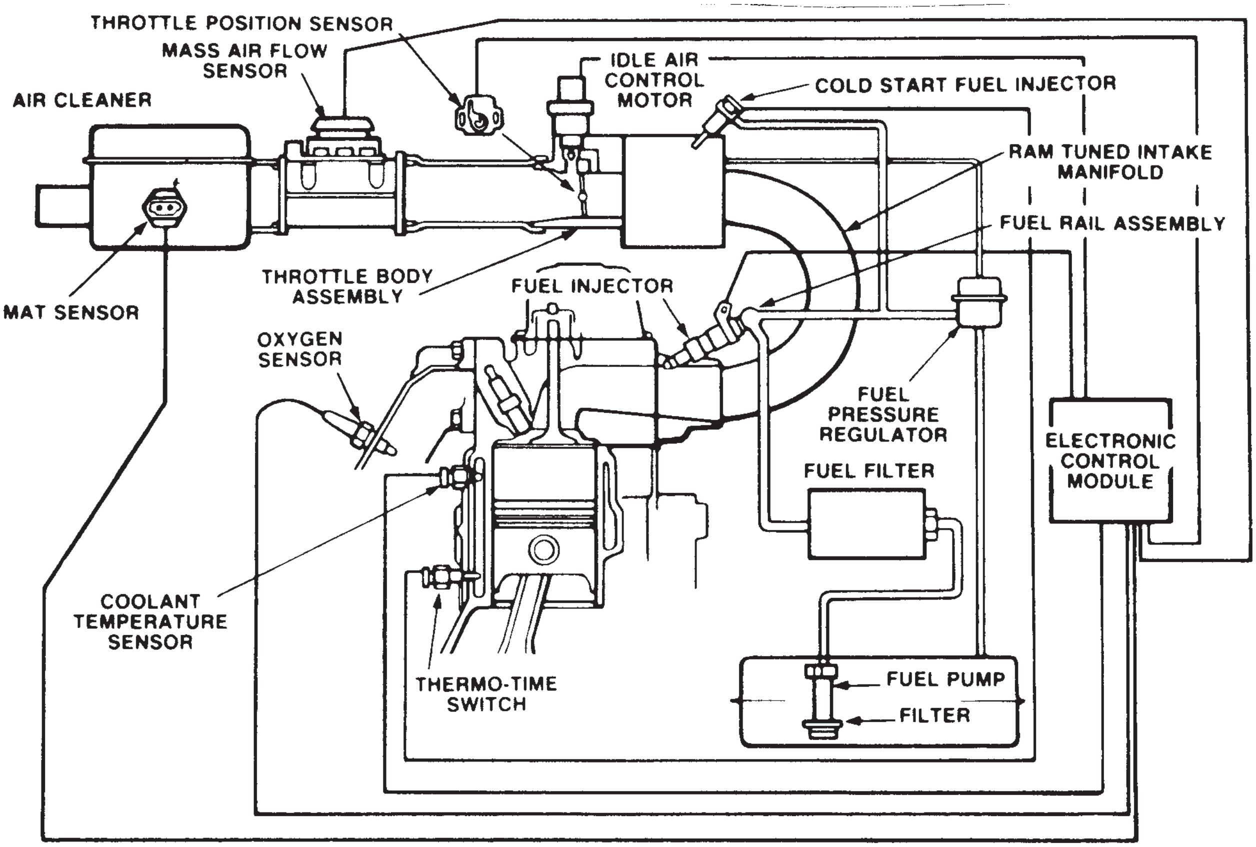


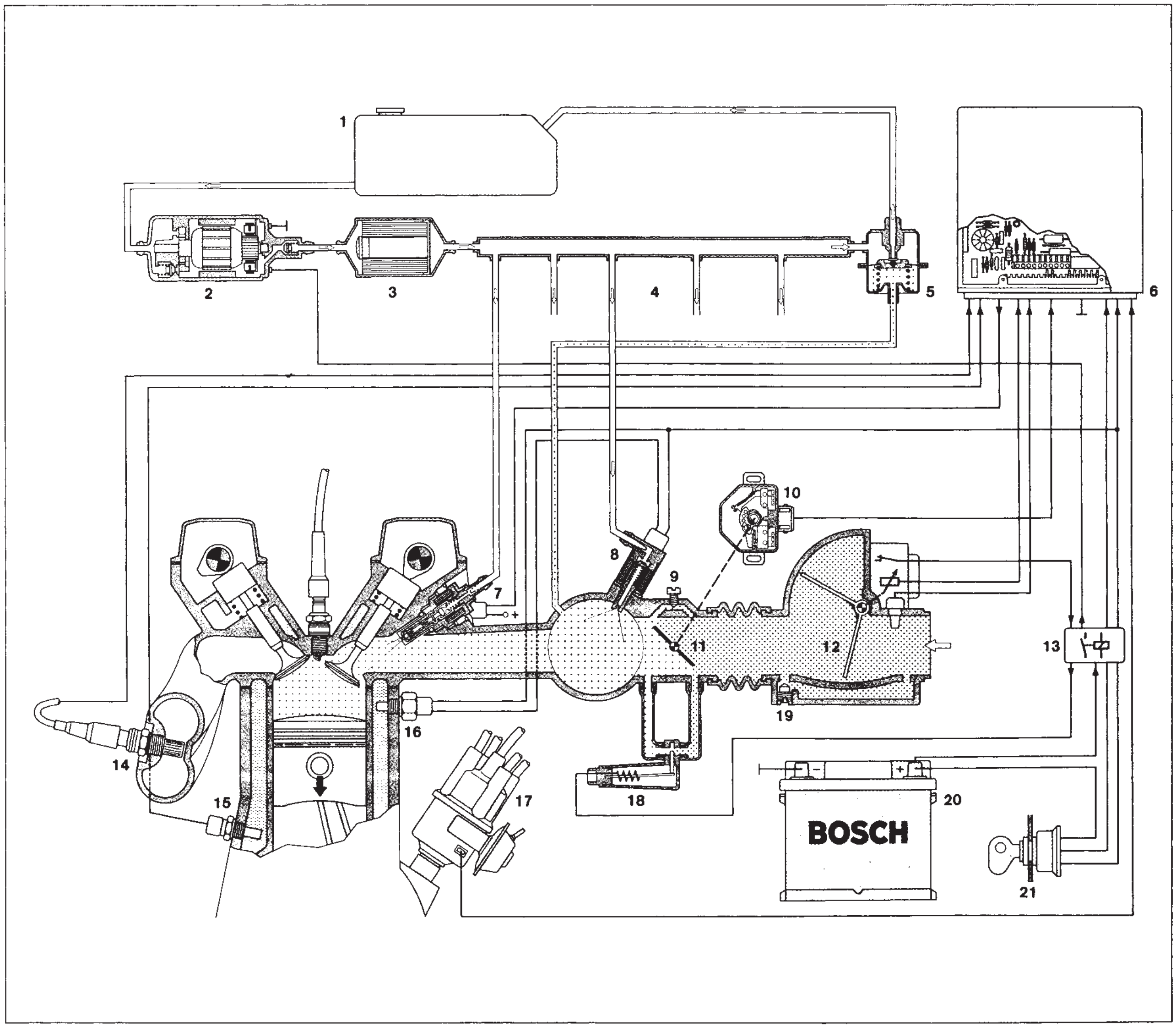
Figure 29–42 Schematic of a General Motors 2.8 litre gasoline fuel injection system with a mass airflow sensor. Many European and Asian vehicles use a cold-start fuel injector (as does this vehicle); however, cold-start injectors are not common in domestic vehicles, which typically use a major increase in injector pulse-width ("on" time) or a primer pulse (extra injector pulse) for cold engine starting. (Courtesy General Motors)

this did not allow the precise control required to meet new standards. Electronic systems were introduced in the mid to late 1990s. We will start with conventional fuel injection.

CONVENTIONAL (MECHANICAL) FUEL INJECTION

Conventional fuel injection uses, for the most part, all mechanical components. There is limited electrical use. Other than glow-plug circuits, solenoids, block heaters, and fuel heaters, fuel delivery is governed by a mechanical injection pump. See Figure 29–44. Although here are variations between makes and engine types, the following is common with most systems.

- Fuel tanks—Very similar to gasoline vehicles; multiple tanks are often used for long distance vehicles such as vans or pick-up trucks. The fuel supply line in the tank usually contains a pre-filter to limit large contaminants from entering the system.
- Lift pump—Transfers fuel from the fuel tank, through the fuel filter and on to the delivery system. This may be an electric pump or a mechanical pump driven by the engine.
- Fuel filter—Very important with a diesel engine as any small particles or abrasives that get past the filter may cause damage to the injection pump or injectors. See Figure 29–45. Hand priming pumps are often found on the fuel filter; they are used to remove trapped air from the fuel system and to force fuel to the injection pump. Many late-model systems remove air automatically.
- Water/fuel separators—Water in the fuel creates a number of driveability problems as well as system damage. Water is heavier than diesel fuel and will accumulate at the bottom of the separator, where it is drained as part of regular maintenance. Some separators have a sensor that illuminates a warning light on the instrument panel when the water reaches a given level. See Figure 29–46. Many late-model systems incorporate the fuel filter, water separator, and fuel heater in one unit.



Summary of the L-Jetronic system
1 Fuel tank, 2 Electric fuel pump, 3 Fuel filter, 4 Distributor pipe, 5 Pressure regulator, 6 Control unit, 7 Injection valve, 8 Start valve, 9 Idle-speed adjusting screw, 10 Throttle-valve switch, 11 Throttle valve, 12 Air-flow sensor, 13 Relay combination, 14 Lambda sensor (only for certain countries), 15 Engine temperature sensor, 16 Thermo-time switch, 17 Ignition distributor, 18 Auxiliary-air device, 19 Idle-mixture adjusting screw, 20 Battery, 21 Ignition-starter switch

Figure 29–43 The Bosch L-Jetronic (L stands for *luft,* which is "air" in German) gasoline fuel injection system. The vane airflow sensor measures airflow, not mass. It is not as accurate as a mass air sensor, but it is a major improvement over speed-density systems. L-Jetronic injections are used on many European, Asian and some domestic vehicles from the mid-1970s to the mid-1990s. (Courtesy Robert Bosch)

- Fuel heaters—Because diesel fuel has a tendency to wax and thicken when cold, electric heaters are often used to warm the fuel. Canadian diesel fuels are also blended to match seasonal temperatures; a very light fuel is supplied for winter use.
- Fuel injection pump—Diesel fuel must be injected into the combustion chamber area at extremely high pressure, over 17 500 kPa (2500 psi), to overcome cylinder pressures.

An injection pump increases fuel pressure, controls speed and power by metering the volume of fuel injected, and directs the fuel to the correct injector. It may also contain a governor, which limits the maximum RPM of the engine, and a fuel shut-off.

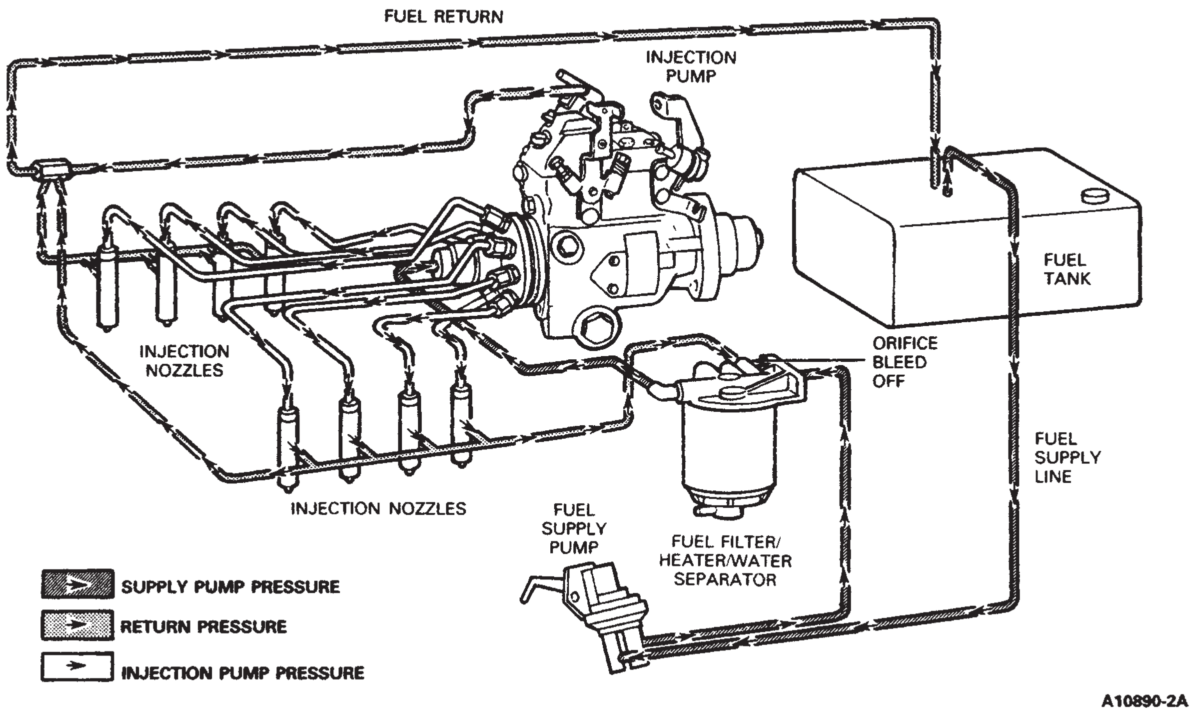


Figure 29–44 Schematic of the fuel delivery and return on a conventional (mechanical) diesel fuel injection. (Courtesy Ford Motor Co.)

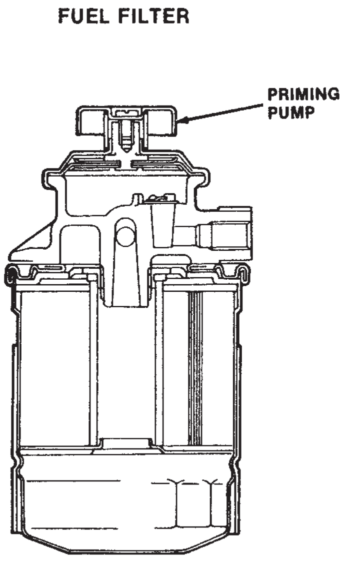


Figure 29–45 A diesel fuel filter with built-in priming pump. (Courtesy Ford Motor Co.)

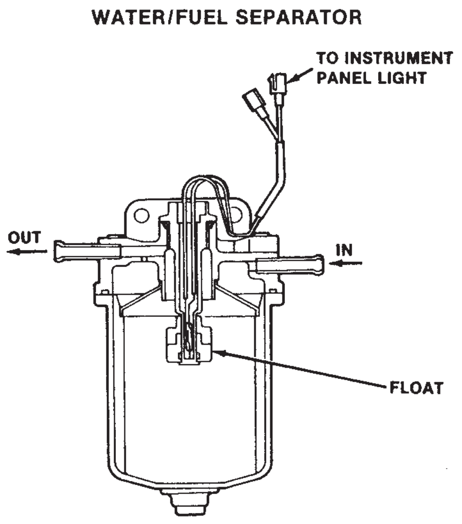


Figure 29–46 A water/fuel separator with a water level warning light. (Courtesy Ford Motor Co.)

FUEL INJECTION PUMPS

Two types of mechanical injection pumps are common with conventional systems: the in-line and the rotary.

In-line Injection Pumps (4-Cycle)

In-line pumps are usually found on large trucks and older passenger car/light truck applications. See Figure 29–47. The pump is driven at one-half the engine speed, which means the injection-pump camshaft makes one complete revolution for each two turns of the engine. When the pump cam lobe pushes up on the cam follower and plunger, the fuel above the plunger is put under very high pressure. See Figure 29–48. This high-pressure fuel opens the delivery valve spring, which allows fuel to move through steel lines to the injectors, where it is supplied to the engine. See Figure 29–49.

SAFETY TIP

Never check for fuel leaks by running your hand over the lines—a high pressure leak could penetrate your skin, enter the blood stream and cause poisoning.

It is good practice, instead, to move a piece of light coloured cardboard along the lines, checking visually for signs of liquid fuel on the cardboard. See Figure 29–50.

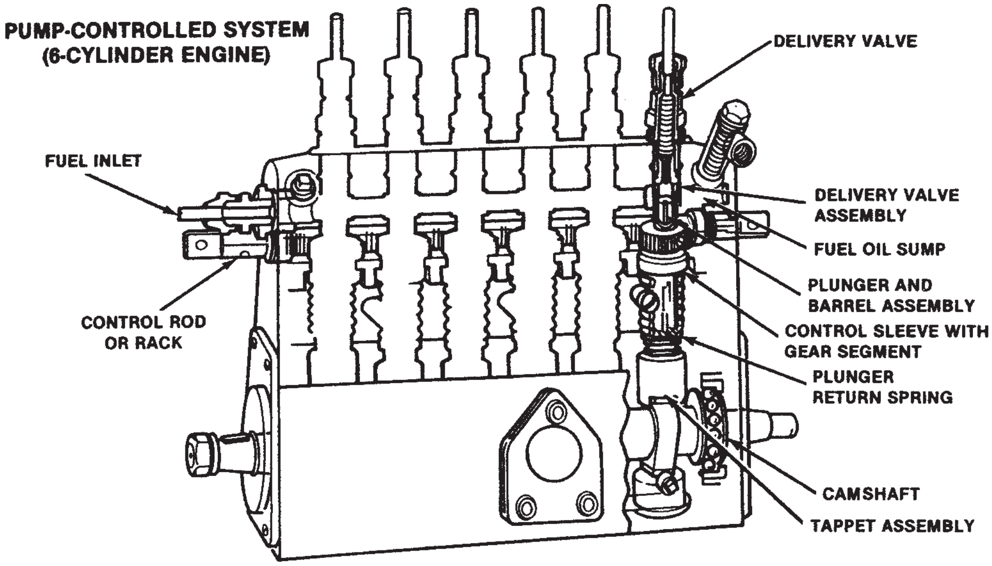


Figure 29–47 An in-line diesel injection pump. (Courtesy Ford Motor Co.)

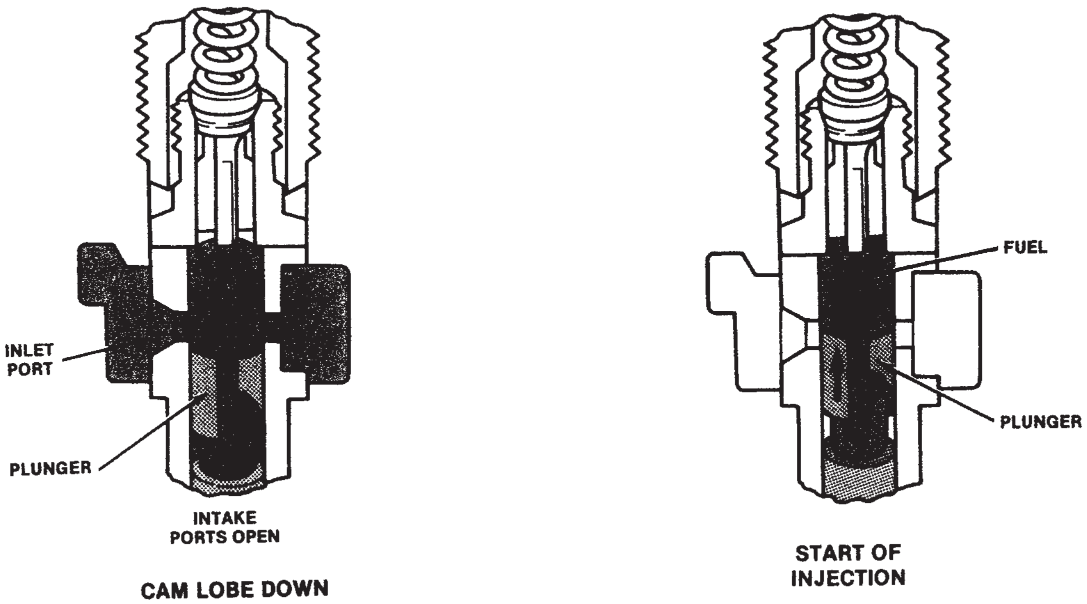


Figure 29–48 A diesel fuel injection pump: start of injection. (Courtesy Ford Motor Co.)

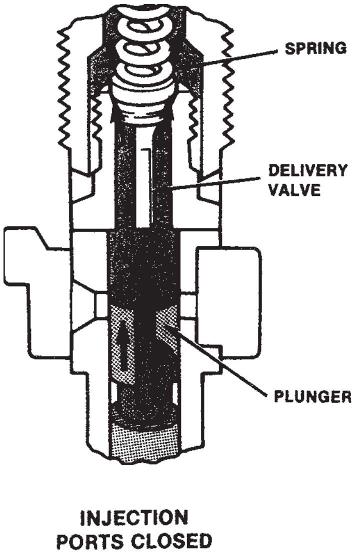


Figure 29–49 Fuel passing through the delivery valve to the injector. (Courtesy Ford Motor Co.)

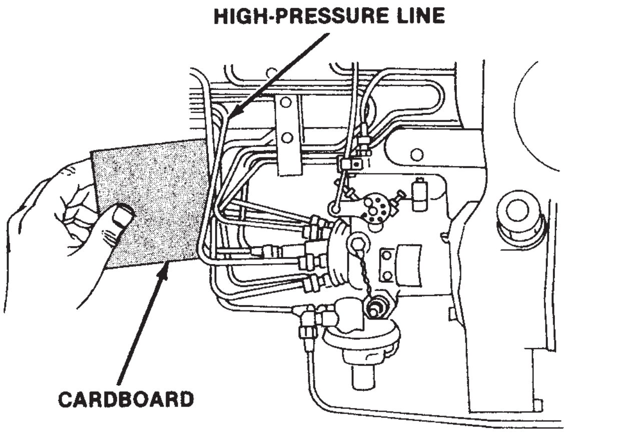
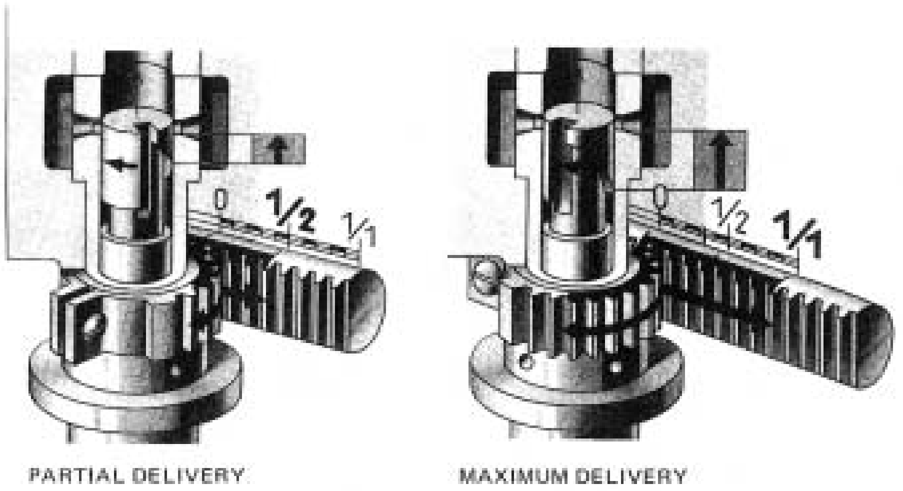


Figure 29–50 Diesel fuel leak testing. Use cardboard to test for leaks, NEVER your hand! (Courtesy Ford Motor Co.)

Figure 29–51 Movement of the control rack in an in-line injection pump changes the fuel delivery volume. (Courtesy Robert Bosch)



Fuel Control—In-line Injection Pump

Remember that diesels do not use a throttle plate; under most operating conditions the engine takes in far more air than it requires. Power and speed are controlled by the amount of fuel injected; more fuel equals higher speed and greater power.

Note the control rack in Figure 29–51, which is connected to the accelerator pedal. As the rack is moved in or out, it rotates a gear and control sleeve, which turns the plunger.

A tapered groove, called the helix, is machined into the plunger. This increases or decreases the amount of fuel as the plunger is rotated. The helix controls fuel volume by opening or restricting a passage to the spill port: a large opening means less fuel is left in the barrel for injection, a restricted opening leaves more fuel in the barrel and a greater volume of fuel is injected. See Figure 29–52.

Governors

Governors are usually incorporated into the fuel injection pump where engine speed is controlled by limiting the amount of fuel supplied to the injectors. The most common type of in-line pump governor uses flyweights, which are held in by spring pressure. See Figure 29–53. At higher RPM, centrifugal force causes the flyweights to move outward against the spring; this movement limits fuel-rack travel, which in turn restricts fuel delivery and prevents engine over-revving.

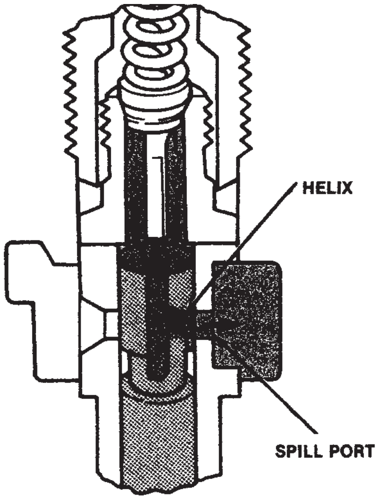


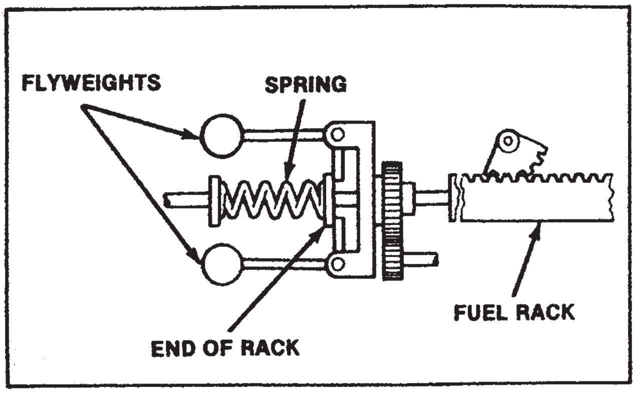
Figure 29–52 The helix controls fuel volume by varying the opening to the spill port. (Courtesy Ford Motor Co.)

SAFETY TIP

Runaway Engines

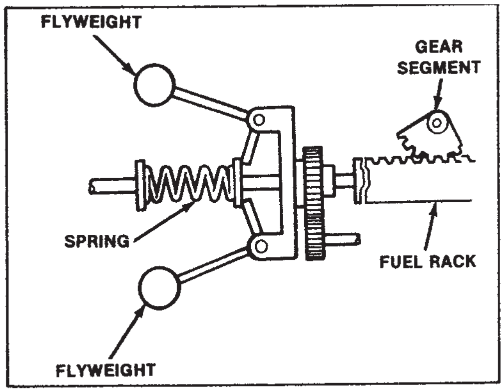
A sticking governor, in extreme cases, may continue to supply fuel to the engine. This allows the RPM to build until the engine destroys itself. In order to stop the engine, turn off the fuel line shut-off valve (if equipped) or stuff rags into the air cleaner intake to shut off the air.

Diesel engine manufacturers generally caution against running the engine with the air intake hose disconnected from the intake manifold; not only could this allow dirt and foreign material to enter the engine, serious personal injury could result if a body part is pulled into the opening.



Governor operation:

Low RPM



Governor operation:

High RPM

Figure 29–53 Governors control engine speed by limiting fuel at higher RPM. (Courtesy Ford Motor Co.)

ROTARY DIESEL FUEL INJECTION PUMPS

The common rotary pump, often called a distributor pump, uses a rotating motion rather than the reciprocating action of the in-line pump. Not only is the pressure of the incoming fuel raised, a controlled volume of fuel is sent to the proper cylinder. This type of pump normally contains a fuel metering valve, governor and a mechanical or electric fuel shut-off. See Figure 29–54.

Operation

Fuel enters the pump through a centre port, flows to a metering valve (controlled by the accelerator pedal and governor) and then, on to the pumping plungers where high pressure is developed. This pressurized fuel compresses the delivery spring, which now allows fuel movement to a rotor that distributes fuel to the correct injector. See Figure 29–55. Alignment of the rotor ports to the pump head determines which cylinder is being supplied with fuel. See Figure 29–56.

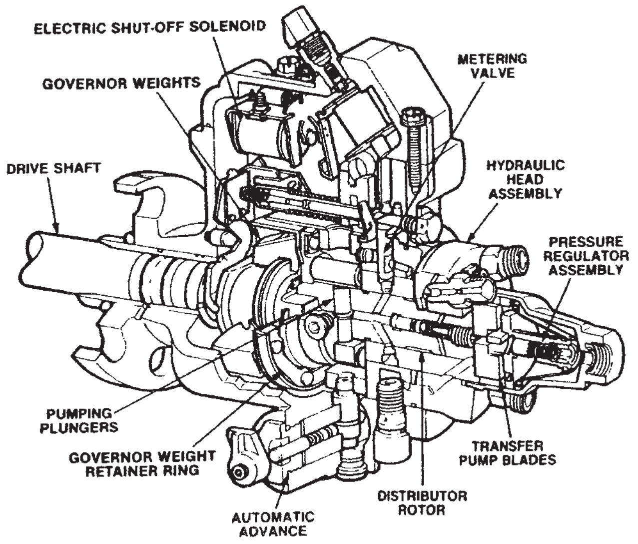


Figure 29–54 Ghost view of a rotary diesel fuel injection pump. (Courtesy General Motors)

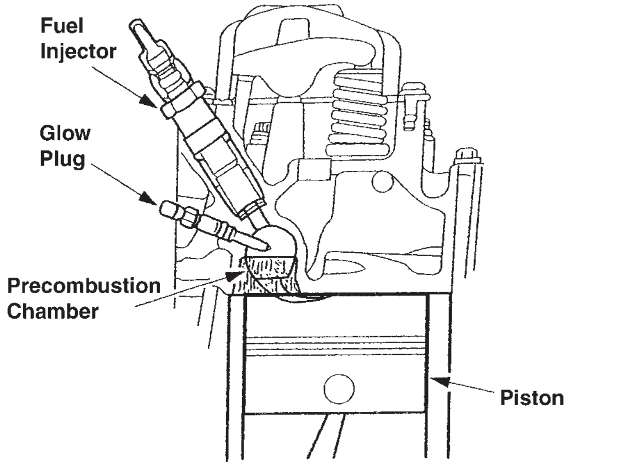
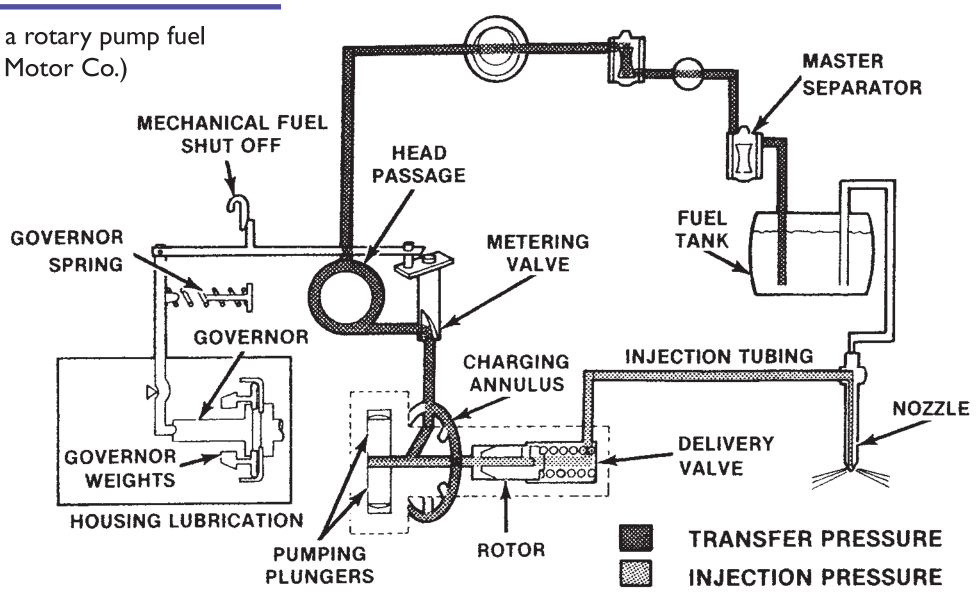


Figure 29–56 Indirect fuel injection injects fuel into a precombustion chamber. A glow plug is used to ignite the fuel during cold engine operation. (Courtesy Ford Motor Co.)

Figure 29–55 Fuel flow through a rotary pump fuel injection system. (Courtesy Ford Motor Co.)



ELECTRONIC DIESEL FUEL INJECTION

EDFI more closely matches electronic gasoline fuel injection than the previous mechanical diesel injection systems. One type, the high pressure common-rail electronically controlled diesel injection, was introduced to Canada and North America in the later 1990s; pressures in this system may exceed 160 000 kPa (23 000 psi). It is used in both passenger car and light truck applications. See Figure 29–57.

Common-Rail Diesel Fuel Injection

Major components include:

- Fuel tanks
- Fuel lines
- Fuel injector control module
- Water separator
- Fuel filter
- Pump assembly
- Fuel rails
- Injectors

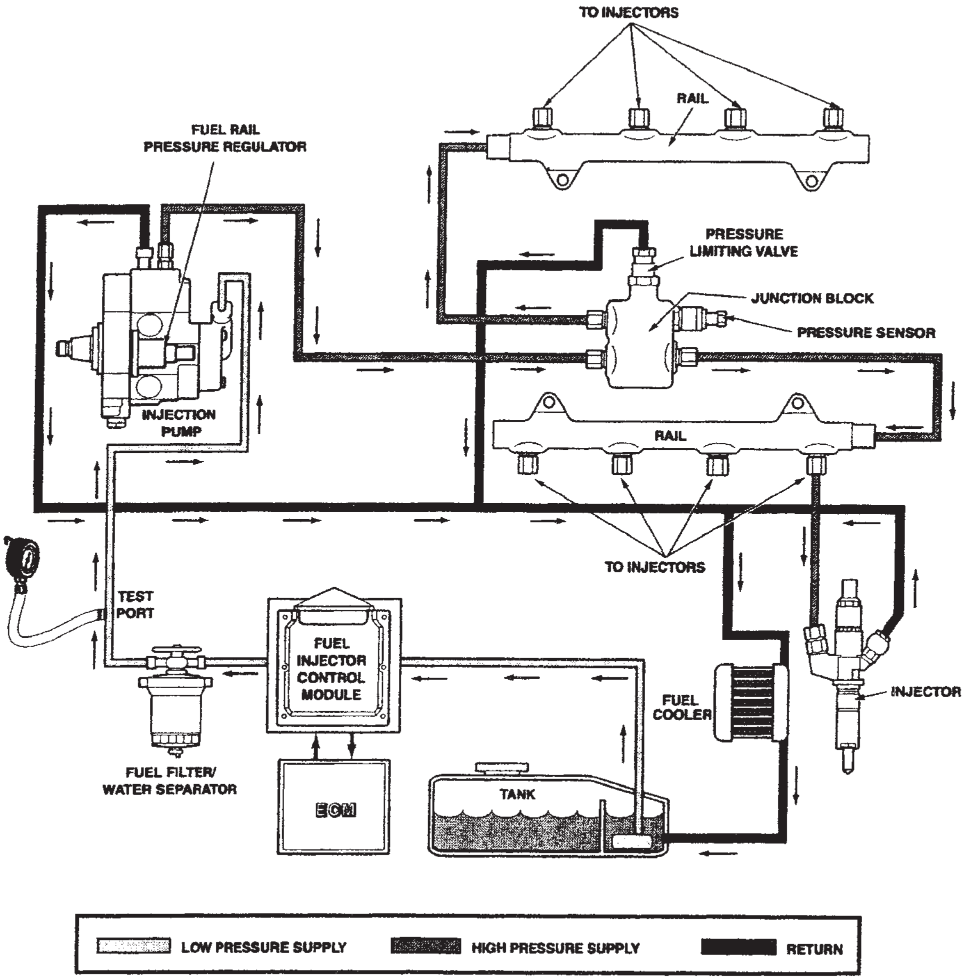


Figure 29–57 Schematic of an electronic diesel fuel injection system. (Courtesy General Motors)

Fuel Injector Control Module

Fuel delivery begins at the pick-up and pre-filter in the tank; it then flows to the base of the fuel injector control module (FICM). The module, which requires 93 volts and up to 20 amperes of current to drive the injectors, is cooled by the fuel flowing through the base. The FICM is operated by engine control module (ECM) commands.

Water Sensor-Separator/Primary Filter

Fuel continues to the WSS/PF where it is filtered; any water in the fuel is separated and collected in the lower housing. This unit may also contain an integrated hand pump used for priming and a fuel heater, which is activated in colder temperatures.

Fuel Filters

Fuel filter replacement is a common and essential service required with diesels as the typical paper element filter becomes restricted.

Injection Pump

The engine-driven fuel injection pump generates the high pressures required for system operation. It includes an ECM-controlled pressure regulator valve, which varies pump pressure with load: low pressure at idle, higher pressures with increasing engine load.

Function Block

Fuel moves from the high pressure pump to the function block, which contains both an excess-pressure limiting valve (acts as a fail-safe relief valve) and a pressure sensor, which sends fuel pressure readings to the ECM.

Common Rails

Pressurized fuel arrives at the rails which act as accumulators and reduce fuel pulsing.

Electrical Injectors

The injectors are electrical solenoids that function similarly to electronic gasoline injectors. See Figure

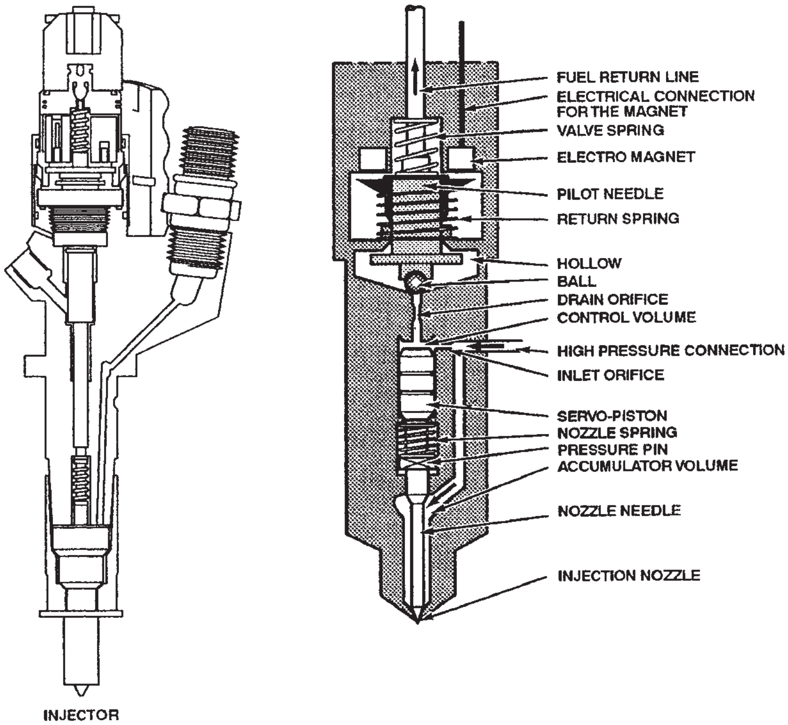


Figure 29–58 A diesel electrical fuel injector. Note the fuel return line. (Courtesy General Motors)

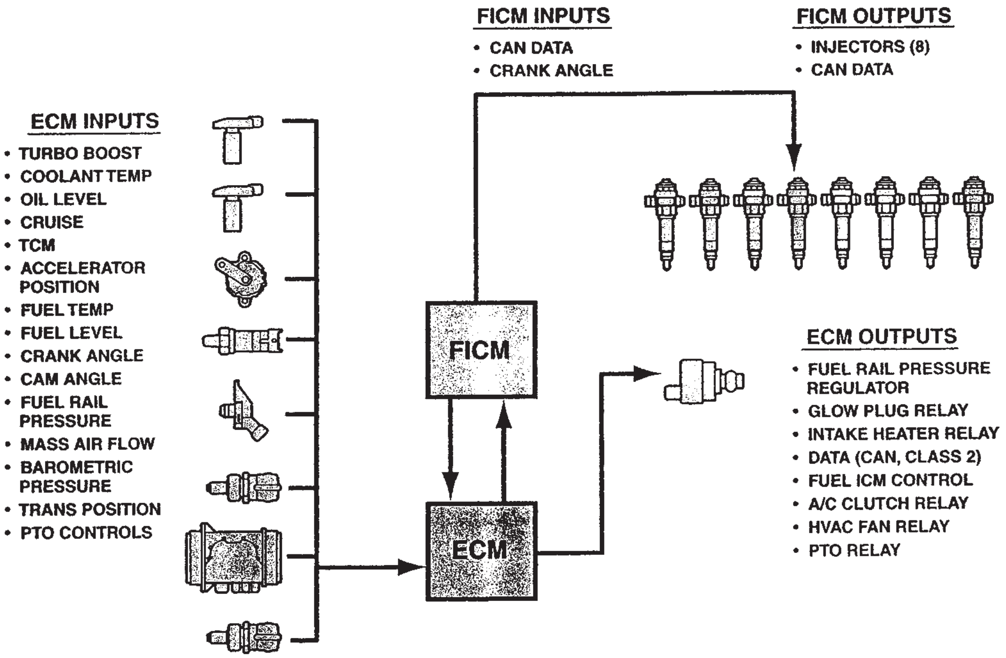


Figure 29–59. Diesel engine electronic management. Note the input sensors and the output actuators. (Courtesy General Motors)

29–58. When activated, the injector coil lifts the needle valve and fuel flows; injector fuel delivery varies with the on-time (duration) of injector opening.

DIESEL ENGINE MANAGEMENT—ECM CONTROL

The injectors are energized by an electronic control module (ECM) to begin injection. No power to the injector, no injection. The quantity of fuel delivered is determined by the on-time that the injector is held open; increasing the length of time the injector is opened increases the volume of fuel.

Major information inputs to the ECM (see Figure 29–59) would include data from the following sensors:

- Mass air flow (MAF)—Measures the intake air volume
- Intake air temperature (IAT) usually located in the MAF sensor

- Accelerator pedal position (APP)—Signals the driver's demand for speed and acceleration
- Barometric (BARO)—Senses barometric pressure for fine tuning fuel control
- Crankshaft (CKP) and camshaft (CMP) position sensors—Used to identify engine RPM and piston location

ENGINE COOLANT TEMPERATURE

Other input sensors can include fuel pressure, turbocharger (if used) boost, and fuel temperature; these vary with make and model. The ECM uses this information to control the fuel injectors and other various relays. A fuel-injector control module, managed by the ECM, may be used to supply large amounts of current to drive the injectors.

HYDRAULIC ELECTRONIC UNIT INJECTION

The HEUI system, used in some light truck applications, is unique in that it uses oil to develop the very high pressures required to inject diesel fuel. See Figure 29–60.

An engine driven high-pressure oil pump (not the lubrication pump) delivers oil to the upper end of the fuel injector. The oil, under high pressure, is blocked by a poppet valve located inside the injector. When injection is required, an electrical solenoid, controlled by the Powertrain Control Module (PCM), opens the poppet valve and oil enters the injector. This oil acts on the large upper end of a plunger, which through multiplication of force, injects fuel at pressures of 18 500 kPa (2700 psi) or higher.

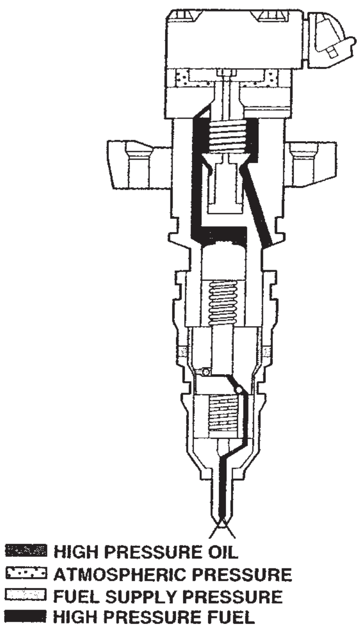


Figure 29–60 A high-pressure solenoid controlled fuel injector. (Courtesy Ford Motor Co.)

DIESEL ENGINE SERVICE

Diesel engines require normal service and maintenance for different reasons than gasoline engines: they have no ignition system, no carburetor to clean, and early diesels have limited emission controls. The following is a list of typical services that are required:

- Oil and filter change—Because of the high compression and combustion pressures, combustion residue (particulates) is blown past the piston rings and into the oil. Some diesels use two oil filters to remove contaminants.
- Fuel filter replacement—It is essential that water and foreign material are removed from the fuel, as they can damage the injection pump and injectors. Ford is now supplying a long-life fuel filter on selected models; it is incorporated into the fuel delivery module and requires no replacement or service for the life of the vehicle.
- Water drainage—Very common service; a warning light on the instrument panel may also be used to indicate excessive water in the fuel.
- Air filter replacement—Diesels take in far more air than they normally require because of no throttle plate; filters are larger than comparable displacement gasoline engines. An air filter restriction indicator may be found on the intake air hose on some models.
- Glow plug replacement—Testing of glow plugs and electrical circuits will be required for cold-start concerns.
- Compression testing—For weak piston rings and valve sealing; see Chapter 5 "Engine Condition Diagnosis" for details.
- Injection pumps and injectors—When a malfunction is noted with the pump or injectors, they are usually removed and sent to a diesel injection specialist for repair or exchange.
- The on-board computer (PCM) used with late model electronic injection, is required to monitor both engine operation and emission controls; using a scanner to access data stored in the PCM memory is also part of normal diesel service with these models.

PHOTO SEQUENCE 20 Testing a Gasoline Fuel Injector Using a Digital Storage Oscillocope

P20–1 This is the first screen you see when turning on a Fluke 98 scopemeter.

P20–2 Select "air/fuel" from the main menu.

P20–3 Select "fuel injector" from the air/fuel menu.

P20–4 The scopemeter will prompt you to connect the test lead into the input A terminal.

P20–5 Use a T-pin to backprobe the injector connector. These T-pins are usually available at discount stores and specialty shops in the craft area.

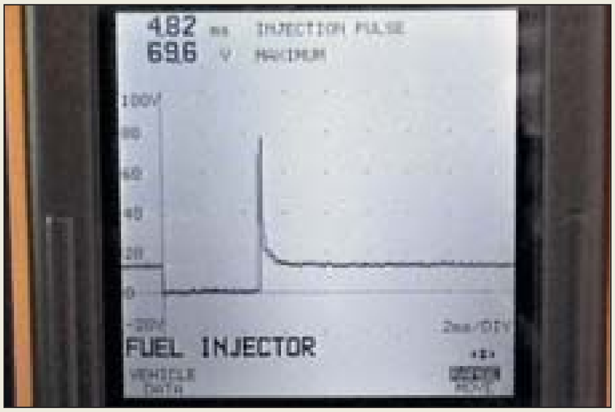
P20–6 Carefully insert the point of the T-pin into the back of the connector and lightly push on the T-pin until it contacts the metal terminal inside the connector.

Testing a Gasoline Fuel Injector Using a Digital Storage Oscillocope—continued

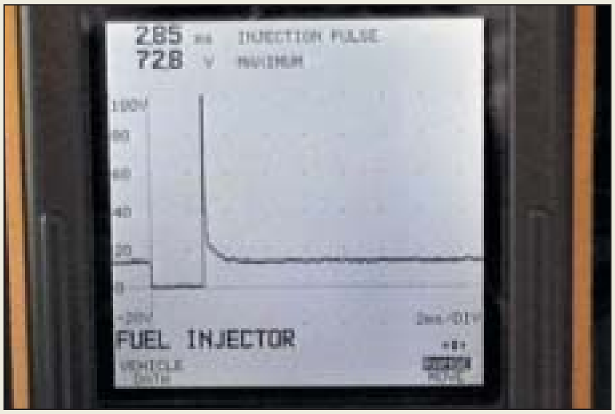
P20–7 Attach the test probe from the scopemeter to the T-pin.

P20–8 Attach the ground test lead to a good, clean engine ground.

P20–9 Start the engine.



P20–10 Observe the waveform. If the waveform does not look similar to this, insert the T-pin into the other terminal of the connector. To achieve this pattern, the scopemeter should be connected to the terminal that is being pulsed on and off by the computer. The pulse width is longer than normal in this photo because the engine is cold and the computer is pulsing the injector on for a longer time to provide the engine with additional fuel.



P20–11 Note the shortened pulse width compared to the previous photo. The engine is now at normal operating temperature and the injector pulse width should be 1.5 to 3.5 milliseconds. Also look for consistent inductive voltage spikes for all injectors, indicating that the injector coil is not shorted.

P20–12 Turn the engine off and disconnect the scopemeter.

SUMMARY

1. A typical throttle-body fuel injector uses a computer-controlled injector solenoid to spray fuel into the throttle-body unit above the throttle plates.
2. A typical port fuel-injection system uses an individual fuel injector for each cylinder and squirts fuel directly into the intake manifold about 75 mm (3 in.) from the intake valve.
3. Most electric fuel pumps can be tested for pressure, volume, and current flow.
4. A typical port fuel-injection system fuel pressure should not drop more than 140 kPa (20 psi) in 20 minutes.
5. A noid light can be used to check for the presence of an injector pulse.
6. Injectors can be tested for resistance and should be within 0.3 to 0.4 ohms of each other.
7. Different designs of injectors have different scope waveform depending on how the computer pulses the injector on and off.
8. An idle air-control unit controls idle speed and can be tested for proper operation using a scan tool or scope.
9. Conventional diesel fuel injection controls fuel delivery at the injection pump.
10. Scan tools are used to diagnose electronic diesel injection systems.

REVIEW QUESTIONS

1. List the ways fuel injectors can be tested.
2. Describe how to test an electric fuel pump.
3. List the steps necessary to test a fuel pressure regulator.
4. Explain why some vehicle manufacturers warn about using fuel-injector cleaner.
5. Describe why it may be necessary to clean the throttle plate of a port-injected engine.
6. Describe the operation of a conventional diesel injection system.
7. Explain the operation of an electronic diesel injection system.

RED SEAL CERTIFICATION-TYPE QUESTIONS

1. How much fuel pressure should most late-model port-injected engines be able to supply?
   - **a.** 70 kPa (10 psi)
   - **b.** 210 kPa (30 psi)
   - **c.** 350 kPa (50 psi)
   - **d.** 525 kPa (75 psi)
2. Fuel injectors can be tested using
   - **a.** A cylinder balance test
   - **b.** An ammeter
   - **c.** Visual inspection
   - **d.** An ohmmeter
3. Throttle body fuel-injection systems deliver fuel _____.
   - **a.** Directly into the cylinder
   - **b.** In the intake manifold, near the intake valve
   - **c.** Above the throttle plate of the throttle-body unit
   - **d.** Below the throttle plate of the throttle-body unit
4. Port fuel-injection systems deliver fuel _____.
   - **a.** Directly into the cylinder
   - **b.** In the intake manifold, near the intake valve
   - **c.** Above the throttle plate of the throttle-body unit
   - **d.** Below the throttle plate of the throttle-body unit
5. The vacuum hose was removed from a vacuum-modulated fuel pressure regulator and gasoline dripped from the hose. This could indicate a
   - **a.** Leaking fuel injector
   - **b.** Restricted return line
   - **c.** Vacuum leak at the regulator hose
   - **d.** Leaking pressure regulator diaphragm
6. Fuel pressure drops rapidly when the engine is turned off. This is normal on some TBI injection systems where the pressure regulator is equipped with _____.
   - **a.** A vacuum line
   - **b.** High-pressure fuel injectors
   - **c.** A bleed orifice
   - **d.** A fuel pressure sensor
7. In a typical port-injection system, the fuel pressure is regulated _____.
   - **a.** By a regulator located on the fuel return side of the fuel rail
   - **b.** By a regulator located on the pressure side of the fuel rail
   - **c.** By the computer by pulsing the regulator on and off
   - **d.** With the one-way check valve in the fuel pump
8. The airflow sensor plate on a K-Jetronic fuel injection system contacts the control plunger. As the plunger moves up, the mixture
   - **a.** Becomes richer
   - **b.** Shuts off because of high RPM
   - **c.** Does not change
   - **d.** Becomes leaner
9. Returnless fuel injection cycles excess fuel at the pressure regulator in/on the _____.
   - **a.** Fuel rail
   - **b.** TBI throttle body
   - **c.** Fuel tank
   - **d.** Fuel rail return line
10. Runaway diesel engines (with conventional injection) may be stopped by turning off the fuel line shut-off valve or by
    - **a.** Tapping lightly on the injection pump
    - **b.** Clamping the low-pressure supply line
    - **c.** Opening the water separator drain
    - **d.** Stuffing rags into the air intake