3. Fuel lines are constructed from ______________.
   a. Seamless steel tubing
   b. Nylon plastic
   c. Copper and/or aluminum tubing
   d. Both a and b are used
4. What prevents the fuel pump inside the fuel tank from catching the gasoline on fire?
   a. Electricity is not used to power the pump
   b. No air is around the motor brushes
   c. Gasoline is hard to ignite in a closed space
   d. All of the above
5. A good fuel pump should be able to supply how much fuel per minute?
   a. 1/4 pint
   b. 1/2 pint
   c. 1 pint
   d. 0.5 to 0.8 gallons
6. Technician A says that fuel pump modules are spring-loaded so that they can be compressed to fit into the opening. Technician B says that they are spring-loaded to allow for expansion and contraction of plastic fuel tanks. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
7. Most fuel filters are designed to remove particles larger than ______________.
   a. 10 microns
   b. 20 microns
   c. 70 microns
   d. 100 microns
8. The amperage draw of an electric fuel pump is higher than specified. All of the following are possible causes *except:*
   a. Corroded electrical connections at the pump motor
   b. Clogged fuel filter
   c. Restriction in the fuel line
   d. Defective fuel pump
9. A fuel pump is being replaced for the third time. Technician A says that the gasoline could be contaminated. Technician B says that wiring to the pump could be corroded. Which technician is correct?
   a. Technician A only
   b. Technician B only
   c. Both Technicians A and B
   d. Neither Technician A nor B
10. A fuel filter has been accidentally installed backwards. What is the most likely result?
   a. Nothing will be noticed
   b. Reduced fuel economy
   c. Lower power at higher engine speeds and loads
   d. Fuel system pulsation noises may be heard

# chapter 78 FUEL-INJECTION COMPONENTS AND OPERATION

**OBJECTIVES: After studying Chapter 78, the reader will be able to:** • Prepare for ASE Engine Performance (A8) certification test content area "C" (Fuel, Air Induction, and Exhaust Systems Diagnosis and Repair). • Describe how a port fuel-injection system works. • Describe the fuel injection modes of operation. • Discuss central port injection (CPI) systems. • Explain how a stepper motor works. • Discuss the purpose and function of the fuel-pressure regulator. • List the types of fuel-injection systems.

**KEY TERMS:** Demand delivery system (DDS) 882 • Electronic air control (EAC) 885 • Electronic returnless fuel system (ERFS) 881 • Flare 885 • Fuel rail 882 • Gang fired 878 • Idle speed control (ISC) motor 885 • Mechanical returnless fuel system (MRFS) 881 • Nonchecking 880 • Port fuel-injection 876 • Pressure control valve (PCV) 882 • Pressure vent valve (PVV) 881 • Sequential fuel injection (SFI) 878 • Throttle-body injection (TBI) 876

## ELECTRONIC FUEL-INJECTION OPERATION

Electronic fuel-injection systems use the powertrain control module (PCM) to control the operation of fuel injectors and other functions based on information sent to the PCM from the various sensors. Most electronic fuel-injection systems share the following:

1. Electric fuel pump (usually located inside the fuel tank)
2. Fuel-pump relay (usually controlled by the computer)
3. Fuel-pressure regulator (mechanically operated spring-loaded rubber diaphragm maintains proper fuel pressure)
4. Fuel-injector nozzle or nozzles

● **SEE FIGURE 78–1.** Most electronic fuel-injection systems use the computer to control these aspects of their operation:

1. **Pulsing the fuel injectors on and off.** The longer the injectors are held open, the greater the amount of fuel injected into the cylinder.
2. **Operating the fuel pump relay circuit.** The computer usually controls the operation of the electric fuel pump located inside (or near) the fuel tank. The computer uses signals from the ignition switch and RPM signals from the ignition module or system to energize the fuel-pump relay circuit.

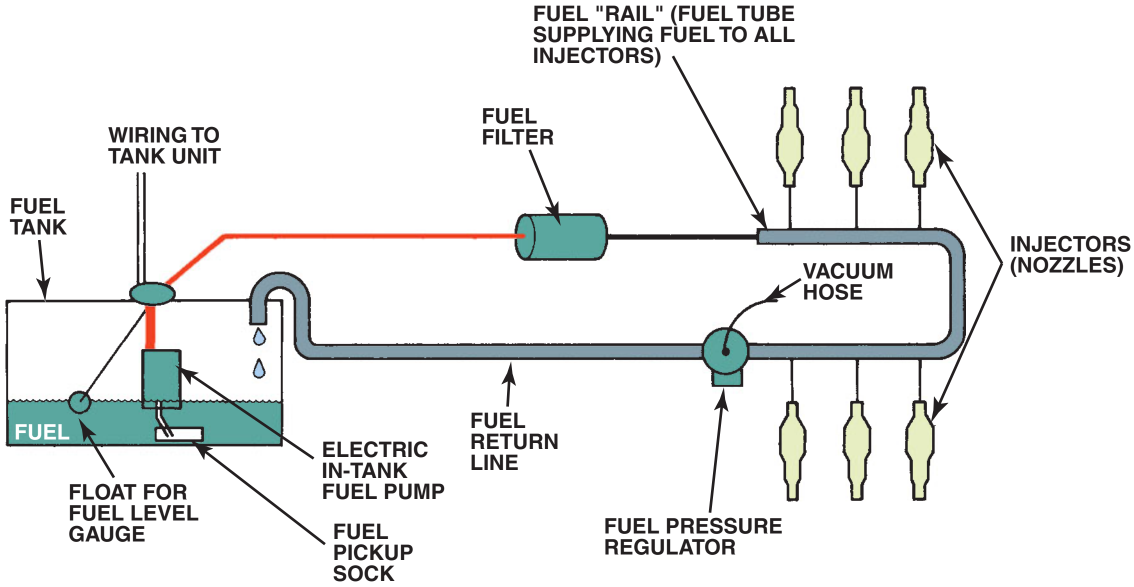


**FIGURE 78–1** Typical port fuel-injection system, indicating the location of various components. Notice that the fuel-pressure regulator is located on the fuel return side of the system. The computer does not control fuel pressure. But does control the operation of the electric fuel pump (on most systems) and the pulsing on and off of the injectors.

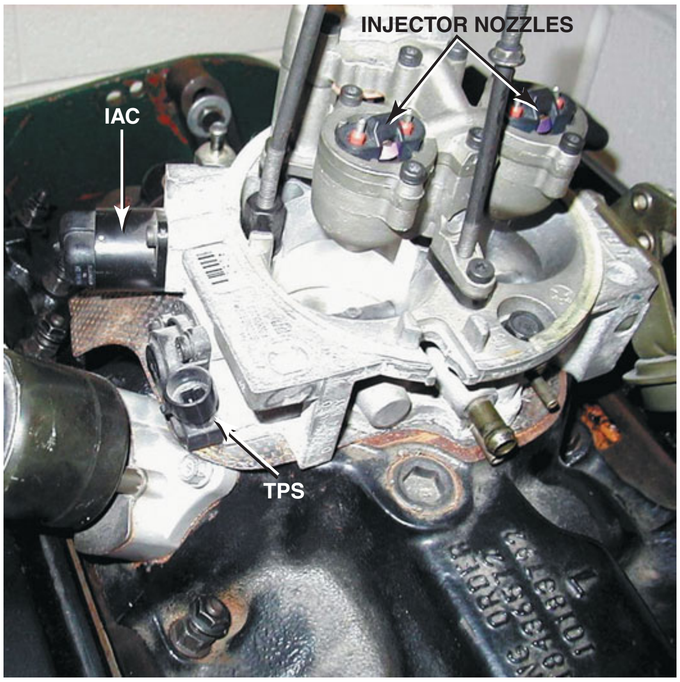


**FIGURE 78–2** A dual-nozzle TBI unit on a Chevrolet 4.3-L V-6 engine. The fuel is squirted above the throttle plate where the fuel mixes with air before entering the intake manifold.

**NOTE: This is a safety feature, because 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.**

Computer-controlled fuel-injection systems are normally reliable systems if the proper service procedures are followed. Fuel-injection systems use the gasoline flowing through the injectors to lubricate and cool the injector electrical windings and pintle valves.

**NOTE: The fuel does not actually make contact with the electrical windings because the injectors have O-rings at the top and bottom of the winding spool to keep fuel out.**

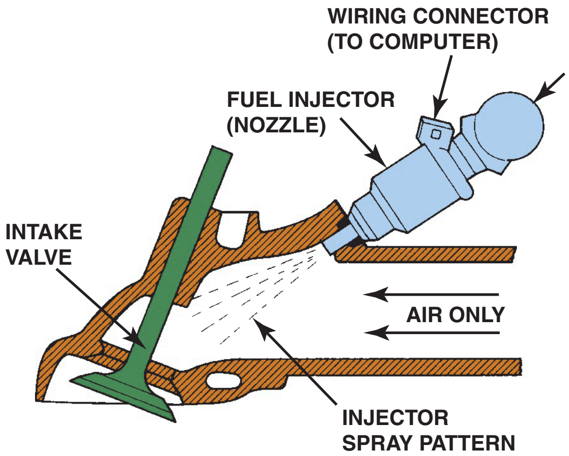


**FIGURE 78–3** A typical port fuel-injection system squirts fuel into the low pressure (vacuum) of the intake manifold, about 2 to 3 in. (70 to 100 mm) from the intake valve.

There are two types of electronic fuel-injection systems:

- **Throttle-body-injection (TBI)** type. A TBI system delivers fuel from a nozzle(s) into the air above the throttle plate. ● **SEE FIGURE 78–2.**
- **Port fuel-injection**-type. A port fuel-injection design uses a nozzle for each cylinder and the fuel is squirted into the intake manifold about 2 to 3 inches (70 to 100 mm) from the intake valve. ● **SEE FIGURE 78–3.**

## SPEED-DENSITY FUEL-INJECTION SYSTEMS

Fuel-injection computer systems require a method for measuring the amount of air the engine is breathing in, in order to match the correct fuel delivery. There are two basic methods used:

1. Speed density
2. Mass airflow

TECH TIP

**"Two Must-Do's"**

For long service life of the fuel system always do the following:

1. Avoid operating the vehicle on a near-empty tank of fuel. The water or alcohol that may be in the tank becomes more concentrated when the fuel level is low. Dirt that settles near the bottom of the fuel tank can be drawn through the fuel system and cause damage to the pump and injector nozzles.
2. Replace the fuel filter at regular service intervals.

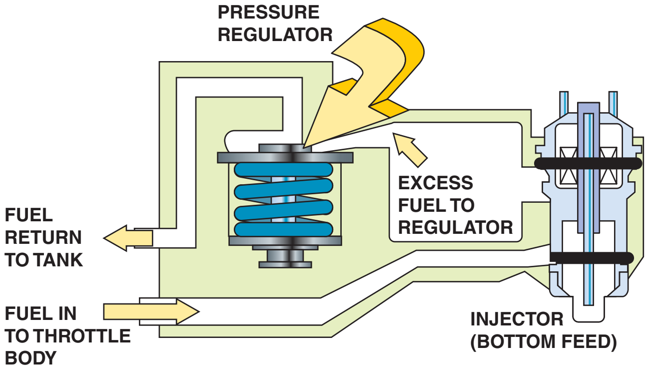


**FIGURE 78–4** The tension of the spring in the fuel-pressure regulator determines the operating pressure on a throttle-body fuel-injection unit.

The speed-density method does not require an air quantity sensor, but rather calculates the amount of fuel required by the engine. The computer uses information from sensors such as the MAP and TP to calculate the needed amount of fuel.

- **MAP sensor.** The value of the intake (inlet) manifold pressure (vacuum) is a direct indication of engine load.
- **TP sensor.** The position of the throttle plate and its rate of change are used as part of the equation to calculate the proper amount of fuel to inject.
- **Temperature sensors.** Both engine coolant temperature (ECT) and intake air temperature (IAT) are used to calculate the density of the air and the need of the engine for fuel. A cold engine (low-coolant temperature) requires a richer air–fuel mixture than a warm engine.

On speed-density systems, the computer calculates the amount of air in each cylinder by using manifold pressure and engine RPM. The amount of air in each cylinder is the major factor in determining the amount of fuel needed. Other sensors provide information to modify the fuel requirements. The formula used to determine the injector pulse width (PW) in milliseconds (ms) is:

**Injector pulse width = MAP/BARO × RPM/maximum RPM**

The formula is modified by values from other sensors, including:

- Throttle position (TP)
- Engine coolant temperature (ECT)
- Intake air temperature (IAT)
- Oxygen sensor voltage (O2S)
- Adaptive memory

A fuel injector delivers atomized fuel into the airstream where it is instantly vaporized. All throttle-body (TB) fuel-injection systems and many multipoint (port) injection systems use the speed-density method of fuel calculation.

## MASS AIRFLOW FUEL-INJECTION SYSTEMS

The formula used by fuel-injection systems that use a mass airflow (MAF) sensor to calculate the injection base pulse width is:

**Injector pulse width = airflow/RPM**

The formula is modified by other sensor values such as:

- Throttle position
- Engine coolant temperature
- Barometric pressure
- Adaptive memory

**NOTE: Many four-cylinder engines do not use a MAF sensor because, due to the time interval between intake events, some reverse airflow can occur in the intake manifold. The MAF sensor would "read" this flow of air as being additional air entering the engine, giving the PCM incorrect airflow information. Therefore, most four-cylinder engines use the speed-density method of fuel control.**

## THROTTLE-BODY INJECTION

The computer controls injector pulses in one of two ways:

- Synchronized
- Nonsynchronized

If the system uses a synchronized mode, the injector pulses once for each distributor reference pulse. In some vehicles, when dual injectors are used in a synchronized system, the injectors pulse alternately. In a nonsynchronized system, the injectors are pulsed once during a given period (which varies according to calibration) completely independent of distributor reference pulses.

The injector always opens the same distance, and the fuel pressure is maintained at a controlled value by the pressure regulator. The regulators used on throttle-body injection systems are not connected to a vacuum like many port fuel-injection systems. The strength of the spring inside the regulator determines at what pressure the valve is unseated, sending the fuel back to the tank and lowering the pressure. ● **SEE FIGURE 78–4.** The amount of fuel delivered by the injector depends on the amount of time (on-time) that the nozzle is open. This is the injector pulse width—the on-time in milliseconds that the nozzle is open.

The PCM commands a variety of pulse widths to supply the amount of fuel that an engine needs at any specific moment.

- A long pulse width delivers more fuel.
- A short pulse width delivers less fuel.

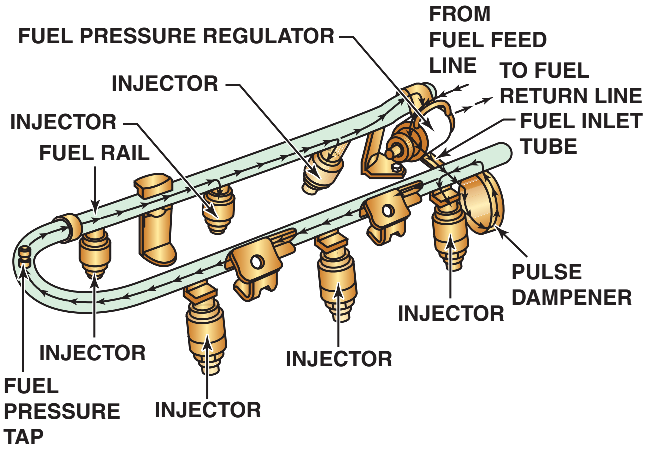


**FIGURE 78–5** The injectors receive fuel and are supported by the fuel rail.

### FREQUENTLY ASKED QUESTION

**How Do the Sensors Affect the Pulse Width?**

The base pulse width of a fuel-injection system is primarily determined by the value of the MAF or MAP sensor and engine speed (RPM). However, the PCM relies on the input from many other sensors to modify the base pulse width as needed. For example,

- **TP Sensor.** This sensor causes the PCM to command up to 500% (5 times) the base pulse width if the accelerator pedal is depressed rapidly to the floor. It can also reduce the pulse width by about 70% if the throttle is rapidly closed.
- **ECT.** The value of this sensor determines the temperature of the engine coolant, helps determine the base pulse width, and can account for up to 60% of the determining factors.
- **BARO.** The BARO sensor compensates for altitude and adds up to about 10% under high-pressure conditions and subtracts as much as 50% from the base pulse width at high altitudes.
- **IAT.** The intake air temperature is used to modify the base pulse width based on the temperature of the air entering the engine. It is usually capable of adding as much as 20% if very cold air is entering the engine or reduce the pulse width by up to 20% if very hot air is entering the engine.
- **O2S.** This is one of the main modifiers to the base pulse width and can add or subtract up to about 20% to 25% or more, depending on the oxygen sensor activity.

## PORT-FUEL INJECTION

The advantages of port fuel-injection design also are related to characteristics of intake manifolds:

- Fuel distribution is equal to all cylinders because each cylinder has its own injector. ● **SEE FIGURE 78–5.**
- The fuel is injected almost directly into the combustion chamber, so there is no chance for it to condense on the walls of a cold intake manifold.

### FREQUENTLY ASKED QUESTION

**How Can It Be Determined If the Injection System Is Sequential?**

Look at the color of the wires at the injectors. If a sequentially fired injector is used, then one wire color (the pulse wire) will be a different color for each injector. The other wire is usually the same color because all injectors receive voltage from some source. If a group- or batch-fired injection system is being used, then the wire colors will be the same for the injectors that are group fired. For example, a V-6 group-fired engine will have three injectors with a pink and blue wire (power and pulse) and the other three will have pink and green wires.

- Because the manifold does not have to carry fuel to properly position a TBI unit, it can be shaped and sized to tune the intake airflow to achieve specific engine performance characteristics.

An EFI injector is simply a specialized solenoid. ● **SEE FIGURE 78–6.** It has an armature winding to create a magnetic field, and a needle (pintle), a disc, or a ball valve. A spring holds the needle, disc, or ball closed against the valve seat, and when energized, the armature winding pulls open the valve when it receives a current pulse from the powertrain control module (PCM). When the solenoid is energized, it unseats the valve to inject fuel.

Electronic fuel-injection systems use a solenoid-operated injector to spray atomized fuel in timed pulses into the manifold or near the intake valve. ● **SEE FIGURE 78–7.** Injectors may be sequenced and fired in one of several ways, but their pulse width is determined and controlled by the engine computer.

Port systems have an injector for each cylinder, but they do not all fire the injectors in the same way. Domestic systems use one of three ways to trigger the injectors:

- Grouped double-fire
- Simultaneous double-fire
- Sequential

**GROUPED DOUBLE-FIRE** This system divides the injectors into two equalized groups. The groups fire alternately; each group fires once each crankshaft revolution, or twice per four-stroke cycle. The fuel injected remains near the intake valve and enters the engine when the valve opens. This method of pulsing injectors in groups is sometimes called **gang fired.**

**SIMULTANEOUS DOUBLE-FIRE** This design fires all of the injectors at the same time once every engine revolution: two pulses per four-stroke cycle. Many port fuel-injection systems on four-cylinder engines use this pattern of injector firing. It is easier for engineers to program this system and it can make relatively quick adjustments in the air–fuel ratio, but it still requires the intake charge to wait in the manifold for varying lengths of time.

**SEQUENTIAL** Sequential firing of the injectors according to engine firing order is the most accurate and desirable method of regulating port fuel injection. However, it is also the most complex and expensive to design and manufacture. In this system, the injectors are timed and pulsed individually, much like the spark plugs are sequentially operated in firing order of the engine. This system is often called **sequential fuel injection** or **SFI.** Each cylinder receives one charge every two crankshaft revolutions, just before the intake valve opens.

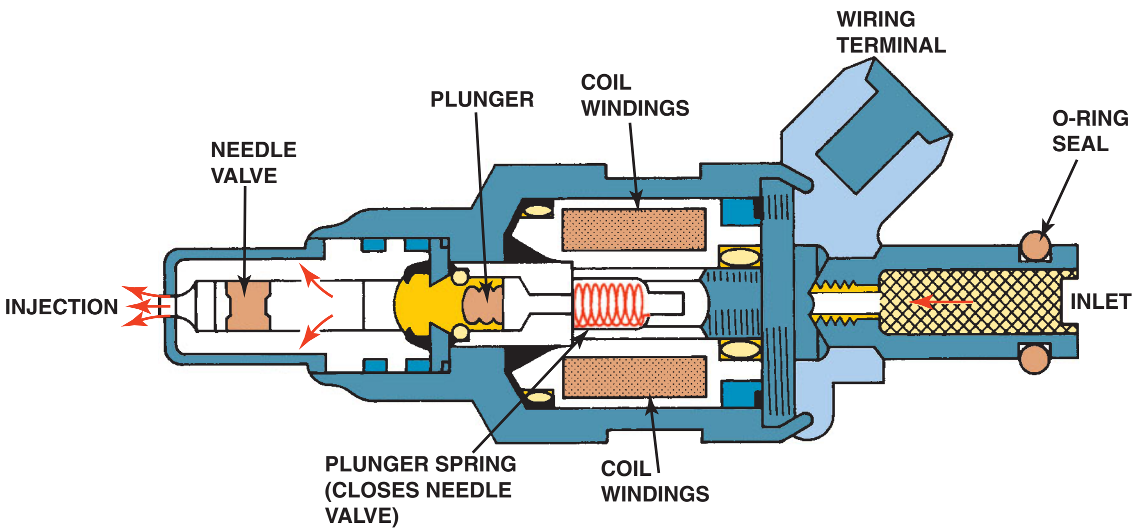


**FIGURE 78–6** Cross-section of a typical port fuel-injection nozzle assembly. These injectors are serviced as an assembly only; no part replacement or service is possible except for replacement of external O-ring seals.

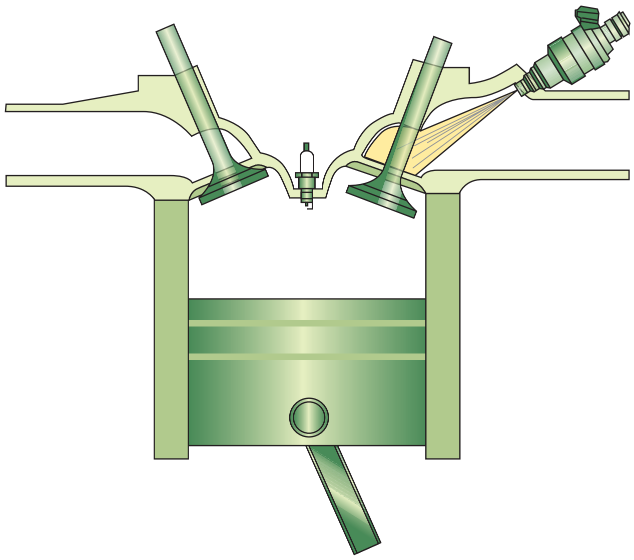

**FIGURE 78–7** Port fuel injectors spray atomized fuel into the intake manifold about 3 inches (75 mm) from the intake valve.

**FIGURE 78–8** A port fuel-injected engine that is equipped with long, tuned intake manifold runners.

This means that the mixture is never static in the intake manifold and mixture adjustments can be made almost instantaneously between the firing of one injector and the next. A camshaft position sensor (CMP) signal or a special distributor reference pulse informs the PCM when the No. 1 cylinder is on its compression stroke. If the sensor fails or the reference pulse is interrupted, some injection systems shut down, while others revert to pulsing the injectors simultaneously.

The major advantage of using port injection instead of the simpler throttle-body injection is that the intake manifolds on port fuel-injected engines only contain air, not a mixture of air and fuel. This allows the engine design engineer the opportunity to design long, "tuned" intake-manifold runners that help the engine produce increased torque at low engine speeds. ● **SEE FIGURE 78–8.**

**NOTE: Some port fuel-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 responses as well as superior high-speed power.**

## FUEL-PRESSURE REGULATOR

The pressure regulator and fuel pump work together to maintain the required pressure drop at the injector tips. The fuel-pressure regulator typically consists of a spring-loaded, diaphragm-operated valve in a metal housing.

Fuel-pressure regulators on fuel-return-type fuel-injection systems are installed on the return (downstream) side of the injectors at the end of the fuel rail, or are built into or mounted upon the throttle-body housing. Downstream regulation minimizes fuel-pressure pulsations caused by pressure drop across the injectors as the nozzles open. It also ensures positive fuel pressure at the injectors at all times and holds residual pressure in the lines when the engine is off. On mechanical returnless systems, the regulator is located back at the tank with the fuel filter.

In order for excess fuel (about 80% to 90% of the fuel delivered) to return to the tank, fuel pressure must overcome spring pressure on the spring-loaded diaphragm to uncover the return line to the

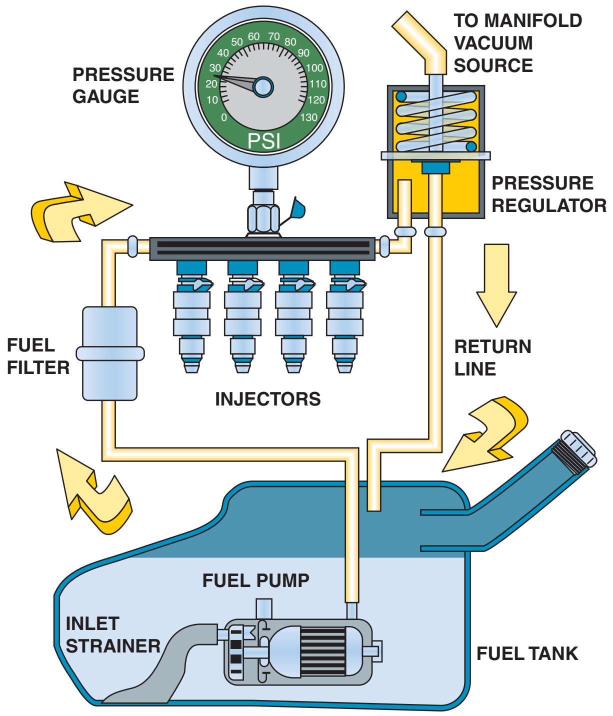


**FIGURE 78–9** A typical port fuel-injected system showing a vacuum-controlled fuel-pressure regulator.

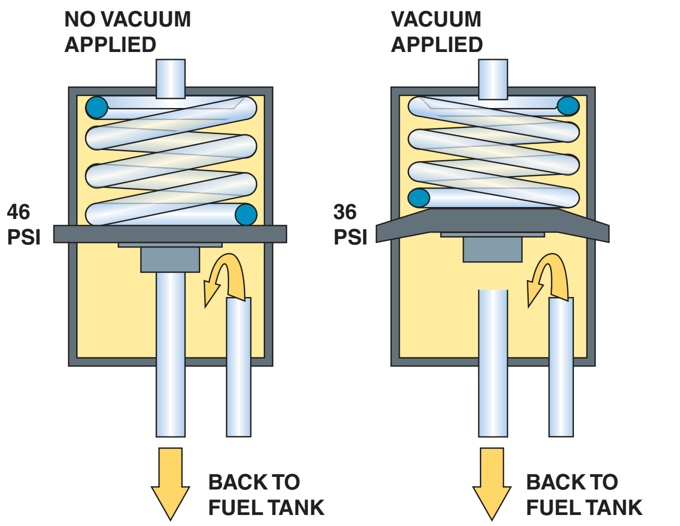


**FIGURE 78–10** A typical fuel-pressure regulator that has a spring that exerts 46 pounds of force against the fuel. If 20 inches of vacuum are applied above the spring, the vacuum reduces the force exerted by the spring on the fuel, allowing the fuel to return to the tank at a lower pressure.

tank. This happens when system pressure exceeds operating requirements. With TBI, the regulator is close to the injector tip, so the regulator senses essentially the same air pressure as the injector.

The pressure regulator used in a port fuel-injection system has an intake manifold vacuum line connection on the regulator vacuum chamber. This allows fuel pressure to be modulated by a combination of spring pressure and manifold vacuum acting on the diaphragm. ● **SEE FIGURES 78–9 AND 78–10.**

In both TBI and port fuel-injection systems, the regulator shuts off the return line when the fuel pump is not running. This maintains pressure at the injectors for easy restarting after hot soak as well as reducing vapor lock.

**NOTE: Some General Motors throttle-body units do not hold pressure and are called nonchecking.**

Port fuel-injection systems generally operate with pressures at the injector of about 30 to 55 PSI (207 to 379 kPa), while TBI systems work with injector pressures of about 10 to 20 PSI (69 to 138 kPa). The difference in system pressures results from the difference in how the systems operate. Since injectors in a TBI system inject the fuel into the airflow at the manifold inlet (above the throttle), there is more time for atomization in the manifold before the air–fuel charge reaches the intake valve. This allows TBI injectors to work at lower pressures than injectors used in a port system.

**TECH TIP**

**Don't Forget the Regulator**

Some fuel-pressure regulators contain a 10-micron filter. If this filter becomes clogged, a lack of fuel flow would result. ● **SEE FIGURE 78–11.**

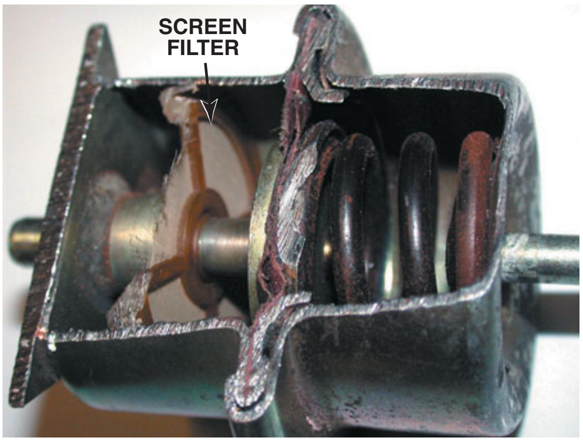


**FIGURE 78–11** A lack of fuel flow could be due to a restricted fuel-pressure regulator. Notice the fine screen filter. If this filter were to become clogged, higher than normal fuel pressure would occur.

## VACUUM-BIASED FUEL-PRESSURE REGULATOR

The primary reason why many port fuel-injected systems use a vacuum-controlled fuel-pressure regulator is to ensure that there is a constant pressure drop across the injectors. In a throttle-body fuel-injection system, the injector squirts into the atmospheric pressure regardless of the load on the engine. In a port fuel-injected engine, however, the pressure inside the intake manifold changes as the load on the engine increases.

| Engine Operating Condition | Intake Manifold Vacuum | Fuel Pressure |
|---|---|---|
| Idle or cruise | High | Lower |
| Heavy load | Low | Higher |

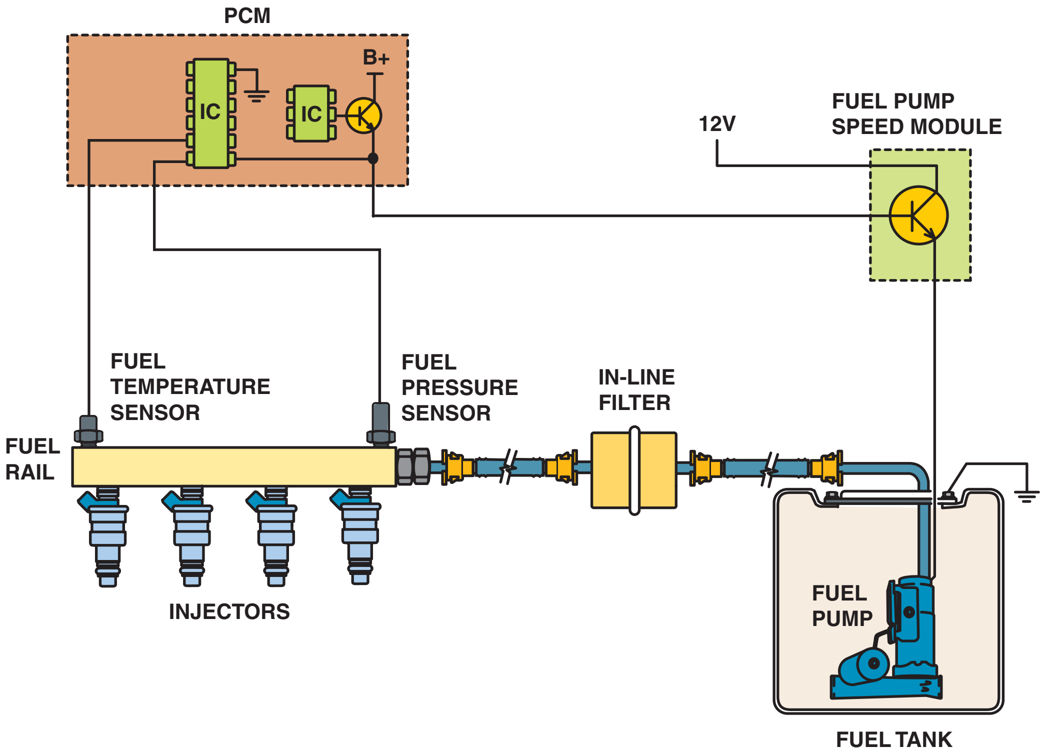


**FIGURE 78–12** The fuel-pressure sensor and fuel-temperature sensor are often constructed together in one assembly to help give the PCM the needed data to control the fuel-pump speed.

The computer can best calculate injector pulse width based on all sensors if the pressure drop across the injector is the same under all operating conditions. A vacuum-controlled fuel-pressure regulator allows the equal pressure drop by reducing the force exerted by the regulator spring at high vacuum (low-load condition), yet allowing the full force of the regulator spring to be exerted when the vacuum is low (high-engine-load condition).

## ELECTRONIC RETURNLESS FUEL SYSTEM

This system is unique because it does not use a mechanical valve to regulate rail pressure. Fuel pressure at the rail is sensed by a pressure transducer, which sends a low-level signal to a controller. The controller contains logic to calculate a signal to the pump power driver. The power driver contains a high-current transistor that controls the pump speed using pulse width modulation (PWM). This system is called the **electronic returnless fuel system (ERFS).** ● **SEE FIGURE 78–12.** This transducer can be differentially referenced to manifold pressure for closed-loop feedback, correcting and maintaining the output of the pump to a desired rail setting. This system is capable of continuously varying rail pressure as a result of engine vacuum, engine fuel demand, and fuel temperature (as sensed by an external temperature transducer, if necessary). A **pressure vent valve (PVV)** is employed at the tank to relieve overpressure due to thermal expansion of fuel. In addition, a supply-side bleed, by means of an in-tank reservoir using a supply-side jet pump, is necessary for proper pump operation.

## MECHANICAL RETURNLESS FUEL SYSTEM

The first production returnless systems employed the **mechanical returnless fuel system (MRFS)** approach. This system has a bypass regulator to control rail pressure that is located in close proximity to the fuel tank. Fuel is sent by the in-tank pump to a chassis-mounted inline filter with excess fuel returning to the tank through a short return line. ● **SEE FIGURE 78–13.** The inline filter may be mounted directly to the tank, thereby eliminating the shortened return line. Supply pressure is regulated on the downstream side of the inline filter to accommodate changing restrictions throughout the filter's service life. This system is limited to constant rail pressure (*CRP) system calibrations, whereas with ERFS, the pressure transducer can be referenced to atmospheric pressure for CRP systems or differentially referenced to intake manifold pressure for constant differential injector pressure (**CIP) systems.

**NOTE: *CRP is referenced to atmospheric pressure, has lower operating pressure, and is desirable for calibrations using speed/air density sensing. **CIP is referenced to manifold pressure, varies rail pressure, and is desirable in engines that use mass airflow sensing.**

## DEMAND DELIVERY SYSTEM (DDS)

Given the experience with both ERFS and MRFS, a need was recognized to develop new returnless technologies that could combine the speed control and constant injector pressure attributes of ERFS

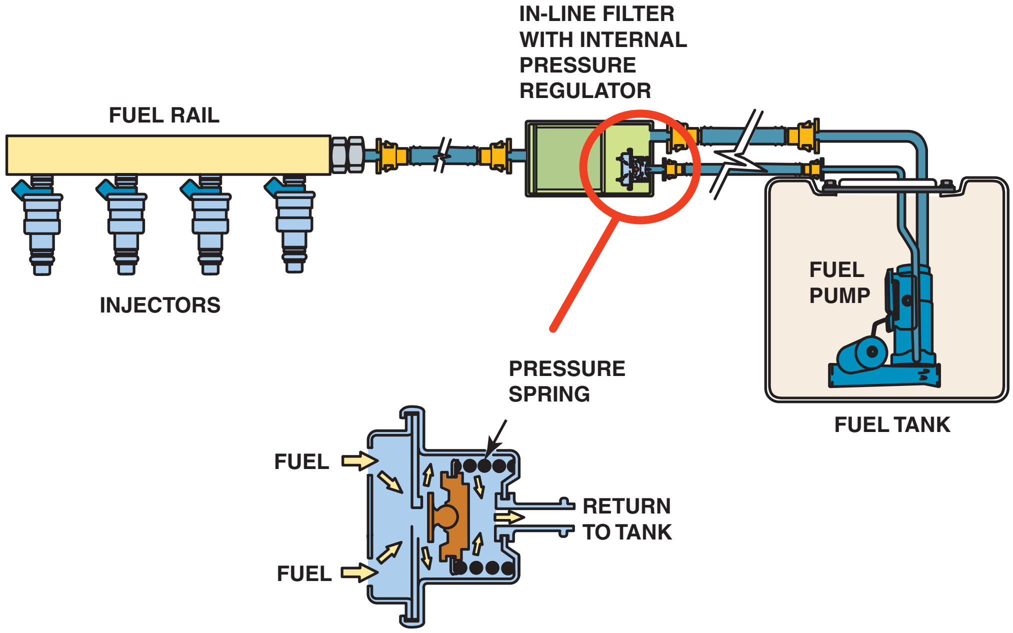


**FIGURE 78–13** A mechanical returnless fuel system. The bypass regulator in the fuel filter controls fuel line pressure.

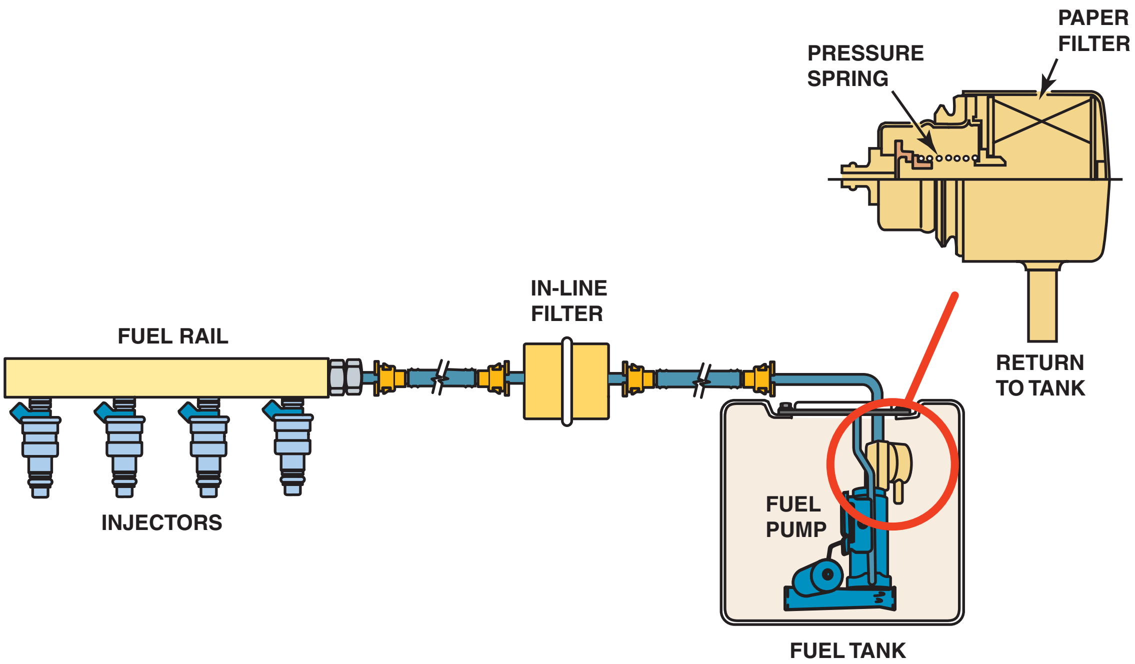


**FIGURE 78–14** A demand delivery system uses a fuel pressure regulator attached to the fuel pump assembly.

together with the cost savings, simplicity, and reliability of MRFS. This new technology also needed to address pulsation dampening/hammering and fuel transient response. Therefore, the **demand delivery system (DDS)** technology was developed.

A different form of demand pressure regulator has been applied to the fuel rail. It mounts at the head or port entry and regulates the pressure downstream at the injectors by admitting the precise quantity of fuel into the rail as consumed by the engine. Having demand regulation at the rail improves pressure response to flow transients and provides rail pulsation dampening. A fuel pump and a low-cost, high-performance bypass regulator are used within the appropriate fuel sender. ● **SEE FIGURE 78–14.** They supply a pressure somewhat higher than the required rail set pressure to accommodate dynamic line and filter pressure losses. Electronic pump speed control is accomplished using a smart regulator as an integral flow sensor. A **pressure control valve (PCV)** may also be used and can readily reconfigure an existing design fuel sender into a returnless sender.

? FREQUENTLY ASKED QUESTION

**Why Are Some Fuel Rails Rectangular Shaped?**

A port fuel-injection system uses a pipe or tubes to deliver fuel from the fuel line to the intended fuel injectors. This pipe or tube is called the **fuel rail.** Some vehicle manufacturers construct the fuel rail in a rectangular cross-section. ● **SEE FIGURE 78–15.** The sides of the fuel rail are able to move in and out slightly, thereby acting as a fuel pulsator evening out the pressure pulses created by the opening and closing of the injectors to reduce underhood noise. A round cross-section fuel rail is not able to deform and, as a result, some manufacturers have had to use a separate dampener.

**FIGURE 78–15** A rectangular-shaped fuel rail is used to help dampen fuel system pulsations and noise caused by the injectors opening and closing.

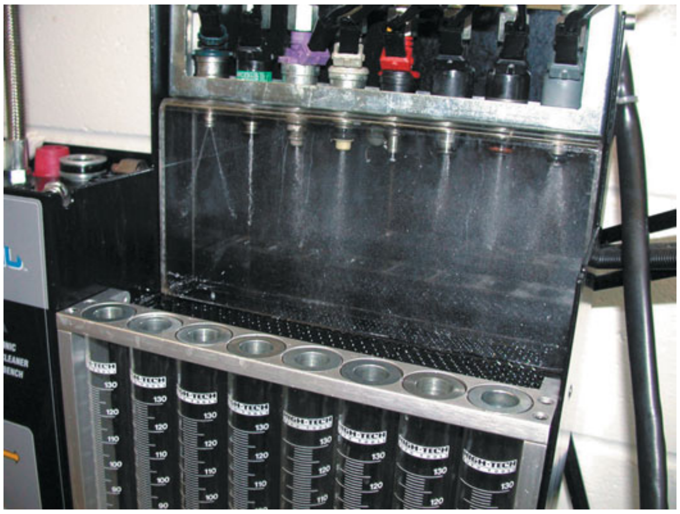

**FIGURE 78–17** Each of the eight injectors shown are producing a correct spray pattern for the applications. While all throttle-body injectors spray a conical pattern, most port fuel injections do not.

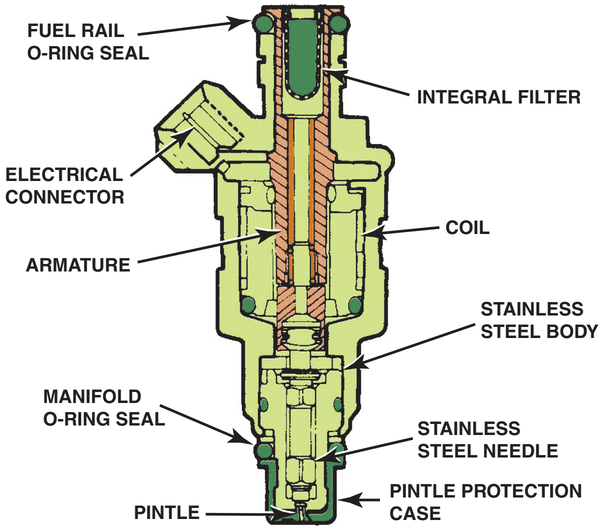


**FIGURE 78–16** A multiport fuel injector. Notice that the fuel flows straight through and does not come in contact with the coil windings.

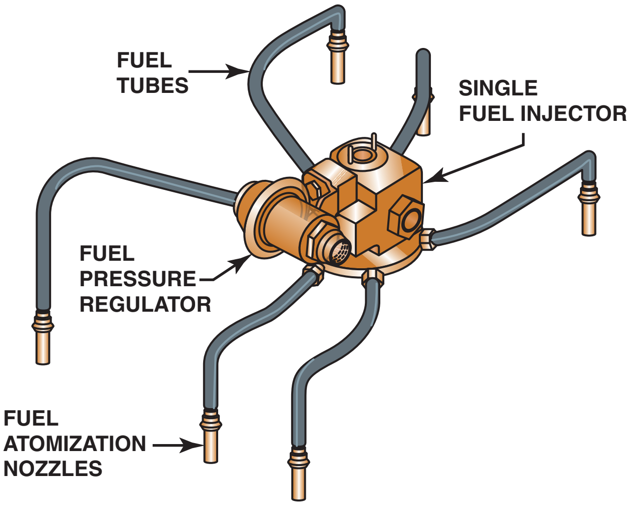


**FIGURE 78–18** A central port fuel-injection system.

## FUEL INJECTORS

EFI systems use a 12 volt solenoid-operated injectors. ● **SEE FIGURE 78–16.** This electromagnetic device contains an armature and a spring-loaded needle valve or ball valve assembly. When the computer energizes the solenoid, voltage is applied to the solenoid coil until the current reaches a specified level. This permits a quick pull-in of the armature during turn-on. The armature is pulled off of its seat against spring force, allowing fuel to flow through the inlet filter screen to the spray nozzle, where it is sprayed in a pattern that varies with application. ● **SEE FIGURE 78–17.** The injector opens the same amount each time it is energized, so the amount of fuel injected depends on the length of time the injector remains open. By angling the director hole plates, the injector sprays fuel more directly at the intake valves, which further atomizes and vaporizes the fuel before it enters the combustion chamber. PFI injectors typically are a top-feed design in which fuel enters the top of the injector and passes through its entire length to keep it cool before being injected.

Ford introduced two basic designs of deposit-resistant injectors on some engines. The design, manufactured by Bosch, uses a four-hole director/metering plate similar to that used by the Rochester Multec injectors. The design manufactured by Nippondenso uses an internal upstream orifice in the adjusting tube. It also has a redesigned pintle/seat containing a wider tip opening that tolerates deposit buildup without affecting injector performance.

## CENTRAL PORT INJECTION

A cross between port fuel injection and throttle-body injection, CPI was introduced in the early 1990s by General Motors. The CPI assembly consists of a single fuel injector, a pressure regulator, and six poppet nozzle assemblies with nozzle tubes. ● **SEE FIGURE 78–18.** The central sequential fuel injection (CSFI) system has six injectors in place of just one used on the CPI unit.

When the injector is energized, its armature lifts off of the six fuel tube seats and pressurized fuel flows through the nozzle tubes to each poppet nozzle. The increased pressure causes each poppet nozzle ball to also lift from its seat, allowing fuel to flow from the nozzle. This

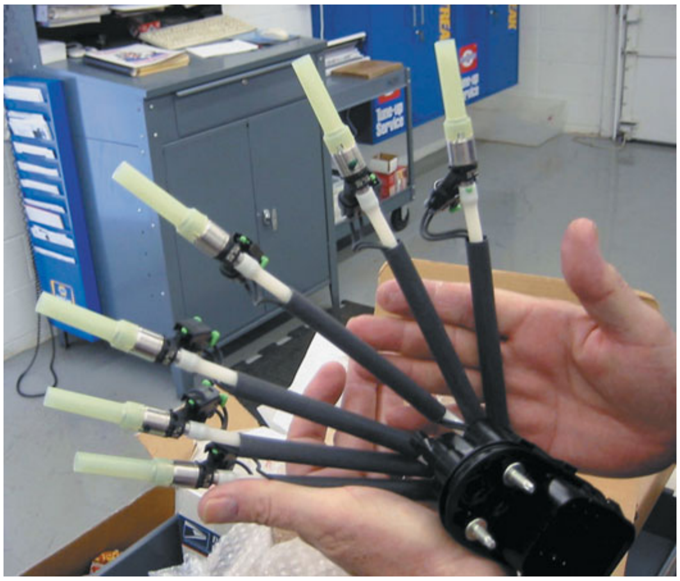

**FIGURE 78–19** A factory replacement unit for a CSFI unit that has individual injectors at the ends that go into the intake manifold instead of poppet valves.

**FREQUENTLY ASKED QUESTION**

**How Can the Proper injector Size Be Determined?**

Most people want to increase the output of fuel to increase engine performance. Injector sizing can sometimes be a challenge, especially if the size of injector is not known. In most cases, manufacturers publish the rating of injectors, in pounds of fuel per hour (lb/hr). The rate is figured with the injector held open at 3 bars (43.5 PSI). An important consideration is that larger flow injectors have a higher minimum flow rating. Here is a formula to calculate injector sizing when changing the mechanical characteristics of an engine.

**Flow rate = hp × BSFC/# of cylinders × maximum duty cycle (% of on-time of the injectors)**

- **hp** is the projected horsepower. Be realistic!
- **BSFC** is brake-specific fuel consumption in pounds per horsepower-hour. Calculated values are used for this, 0.4 to 0.8 lb. In most cases, start on the low side for naturally aspirated engines and the high side for engines with forced induction.
- **# of cylinders** is actually the number of injectors being used.
- **Maximum duty cycle** is considered at 0.8 (80%). Above this, the injector may overheat, lose consistency, or not work at all.

For example:

**5.7 liter V-8 = 240 hp × 0.65/8 cylinders × 8**
**= 24.37 lb/hr injectors required**

hybrid injection system combines the single injector of a TBI system with the equalized fuel distribution of a PFI system. It eliminates the individual fuel rail while allowing more efficient manifold tuning than is otherwise possible with a TBI system. Newer versions use six individual solenoids to fire one for each cylinder. ● **SEE FIGURE 78–19.**

**FREQUENTLY ASKED QUESTION**

**What Is Battery Voltage Correction?**

Battery voltage correction is a program built into the PCM that causes the injector pulse width to increase if there is a drop in electrical system voltage. Lower battery voltage would cause the fuel injectors to open slower than normal and the fuel pump to run slower. Both of these conditions can cause the engine to run leaner than normal if the battery voltage is low. Because a lean air–fuel mixture can cause the engine to overheat, the PCM compensates for the lower voltage by adding a percentage to the injector pulse width. This richer condition will help prevent serious engine damage. The idle speed is also increased to turn the alternator faster if low battery voltage is detected.

## FUEL-INJECTION MODES OF OPERATION

All fuel-injection systems are designed to supply the correct amount of fuel under a wide range of engine operating conditions. These modes of operation include:

| | |
|---|---|
| Starting (cranking) | Acceleration enrichment |
| Clear flood | Deceleration enleanment |
| Idle (run) | Fuel shutoff |

**STARTING MODE** When the ignition is turned to the start position, the engine cranks and the PCM energizes the fuel pump relay. The PCM also pulses the injectors on, basing the pulse width on engine speed and engine coolant temperature. The colder the engine is, the greater the pulse width. Cranking mode air–fuel ratio varies from about 1.5:1 at −40°F (−40°C) to 14.7:1 at 200°F (93°C).

**CLEAR FLOOD MODE** If the engine becomes flooded with too much fuel, the driver can depress the accelerator pedal to greater than 80% to enter the clear flood mode. When the PCM detects that the engine speed is low (usually below 600 RPM) and the throttle-position (TP) sensor voltage is high (WOT), the injector pulse width is greatly reduced or even shut off entirely, depending on the vehicle.

**OPEN-LOOP MODE** Open-loop operation occurs during warm-up before the oxygen sensor can supply accurate information to the PCM. The PCM determines injector pulse width based on values from the MAF, MAP, TP, ECT, and IAT sensors.

**CLOSED-LOOP MODE** Closed-loop operation is used to modify the base injector pulse width as determined by feedback from the oxygen sensor to achieve proper fuel control.

**ACCELERATION ENRICHMENT MODE** During acceleration, the throttle-position (TP) voltage increases, indicating that a richer air–fuel mixture is required. The PCM then supplies a longer injector pulse width and may even supply extra pulses to supply the needed fuel for acceleration.

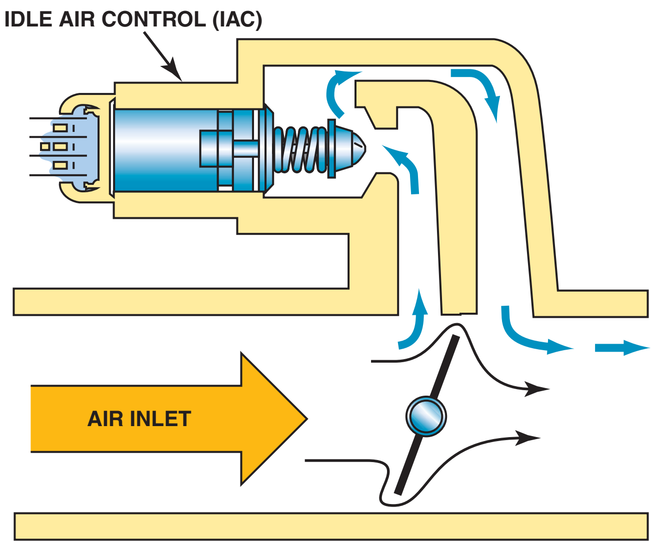


**FIGURE 78–20** The small arrows indicate the air bypassing the throttle plate in the closed throttle position. This air is called minimum air. The air flowing through the IAC (blue arrows) is the airflow that determines the idle speed.

**DECELERATION ENLEANMENT MODE** When the engine decelerates, a leaner air–fuel mixture is required to help reduce emissions and to prevent deceleration backfire. If the deceleration is rapid, the injector may be shut off entirely for a short time and then pulsed on enough to keep the engine running.

**FUEL SHUTOFF MODE** Besides shutting off fuel entirely during periods of rapid deceleration, PCM also shuts off the injector when the ignition is turned off to prevent the engine from continuing to run.

## IDLE CONTROL

Port fuel-injection systems generally use an auxiliary air bypass to control idle speed. ● **SEE FIGURE 78–20.** This air bypass or regulator provides needed additional airflow, and thus more fuel. The engine needs more power when cold to maintain its normal idle speed to overcome the increased friction from cold lubricating oil. It does this by opening an intake air passage to let more air into the engine just as depressing the accelerator pedal would open the throttle valve, allowing more air into the engine. The system is calibrated to maintain engine idle speed at a specified value regardless of engine temperature.

Most PFI systems use an idle air control (IAC) motor to regulate idle bypass air. The IAC is computer-controlled, and is either a solenoid-operated valve or a stepper motor that regulates the airflow around the throttle. The idle air control valve is also called an **electronic air control (EAC)** valve.

When the engine stops, most IAC units will retract outward to get 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.

### ? FREQUENTLY ASKED QUESTION

**Why Does the Idle Air Control Valve Use Milliamperes?**

Some Chrysler vehicles, such as the Dodge minivan, use linear solenoid idle air control valves (LSIAC). The PCM uses regulated current flow through the solenoid to control idle speed and the scan tool display is in milliamperes (mA).

Closed position = 180 to 200 mA
Idle = 300 to 450 mA
Light cruise = 500 to 700 mA
Fully open = 900 to 950 mA

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).

## STEPPER MOTOR OPERATION

A digital output is used to control stepper motors. Stepper motors are direct-current motors that move in fixed steps or increments from de-energized (no voltage) to fully energized (full voltage). A stepper motor often has as many as 120 steps of motion.

A common use for stepper motors is as an idle air control (IAC) valve, which controls engine idle speeds and prevents stalls due to changes in engine load. When used as an IAC, the stepper motor is usually a reversible DC motor that moves in increments, or steps. The motor moves a shaft back and forth to operate a conical valve. When the conical valve is moved back, more air bypasses the throttle plates and enters the engine, increasing idle speed. As the conical valve moves inward, the idle speed decreases.

When using a stepper motor that is controlled by the PCM, it is very easy for the PCM to keep track of the position of the stepper motor. By counting the number of steps that have been sent to the stepper motor, the PCM can determine the relative position of the stepper motor. While the PCM does not actually receive a feedback signal from the stepper motor, it does know how many steps forward or backward the motor should have moved.

A typical stepper motor uses a permanent magnet and two electromagnets. Each of the two electromagnetic windings is controlled by the computer. The computer pulses the windings and changes the polarity of the windings to cause the armature of the stepper motor to rotate 90 degrees at a time. Each 90-degree pulse is recorded by the computer as a “count” or “step”; therefore, the name given to this type of motor. ● **SEE FIGURE 78–21.**

Idle airflow in a TBI system travels through a passage around the throttle and is controlled by a stepper motor. In some applications, an externally mounted permanent magnet motor called the **idle speed control (ISC) motor** mechanically advances the throttle linkage to advance the throttle opening.

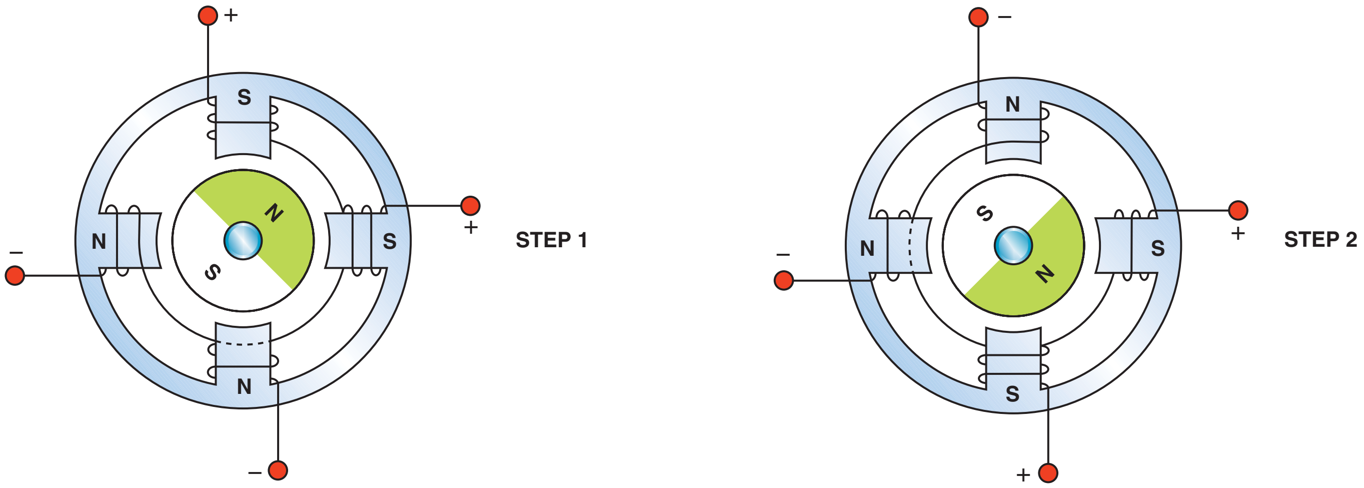


**FIGURE 78–21** Most stepper motors use four wires, which are pulsed by the computer to rotate the armature in steps.

## REVIEW QUESTIONS

1. What are the two basic types of fuel-injection systems?
2. What is the purpose of the vacuum-controlled (biased) fuel-pressure regulator?
3. How many sensors are used to determine the base pulse width on a speed-density system?
4. How many sensors are used to determine the base pulse width on a mass airflow system?
5. What are the three types of returnless fuel injection systems?

## CHAPTER QUIZ

1. Technician A says that the fuel pump relay is usually controlled by the PCM. Technician B says that a TBI injector squirts fuel above the throttle plate. Which technician is correct?
   **a.** Technician A only
   **b.** Technician B only
   **c.** Both Technicians A and B
   **d.** Neither Technician A nor B
2. Why are some fuel rails rectangular in shape?
   **a.** Increases fuel pressure
   **b.** Helps keep air out of the injectors
   **c.** Reduces noise
   **d.** Increases the speed of the fuel through the fuel rail
3. Which fuel-injection system uses the MAP sensor as the primary sensor to determine the base pulse width?
   **a.** Speed density
   **b.** Mass airflow
   **c.** Demand delivery
   **d.** Mechanical returnless
4. Why is a vacuum line attached to a fuel-pressure regulator on many port-fuel-injected engines?
   **a.** To draw fuel back into the intake manifold through the vacuum hose
   **b.** To create an equal pressure drop across the injectors
   **c.** To raise the fuel pressure at idle
   **d.** To lower the fuel pressure under heavy engine load conditions to help improve fuel economy
5. Which sensor has the greatest influence on injector pulse width besides the MAF sensor?
   **a.** IAT
   **b.** BARO
   **c.** ECT
   **d.** TP
6. Technician A says that the port fuel-injection injectors operate using 5 volts from the computer. Technician B says that sequential fuel injectors all use a different wire color on the injectors. Which technician is correct?
   **a.** Technician A only
   **b.** Technician B only
   **c.** Both Technicians A and B
   **d.** Neither Technician A nor B
7. Which type of port fuel-injection system uses a fuel temperature and/or fuel-pressure sensor?
   **a.** All port-fuel-injected engines
   **b.** TBI units only
   **c.** Electronic returnless systems
   **d.** Demand delivery systems
8. Dampeners are used on some fuel rails to ______________.
   **a.** Increase the fuel pressure in the rail
   **b.** Reduce (decrease) the fuel pressure in the rail
   **c.** Reduce noise
   **d.** Trap dirt and keep it away from the injectors
9. Where is the fuel-pressure regulator located on a vacuum-biased port fuel-injection system?
   **a.** In the tank
   **b.** At the inlet of the fuel rail
   **c.** At the outlet of the fuel rail
   **d.** Near or on the fuel filter
10. What type of device is used in a typical idle air control?
   **a.** DC motor
   **b.** Stepper motor
   **c.** Pulsator-type actuator
   **d.** Solenoid