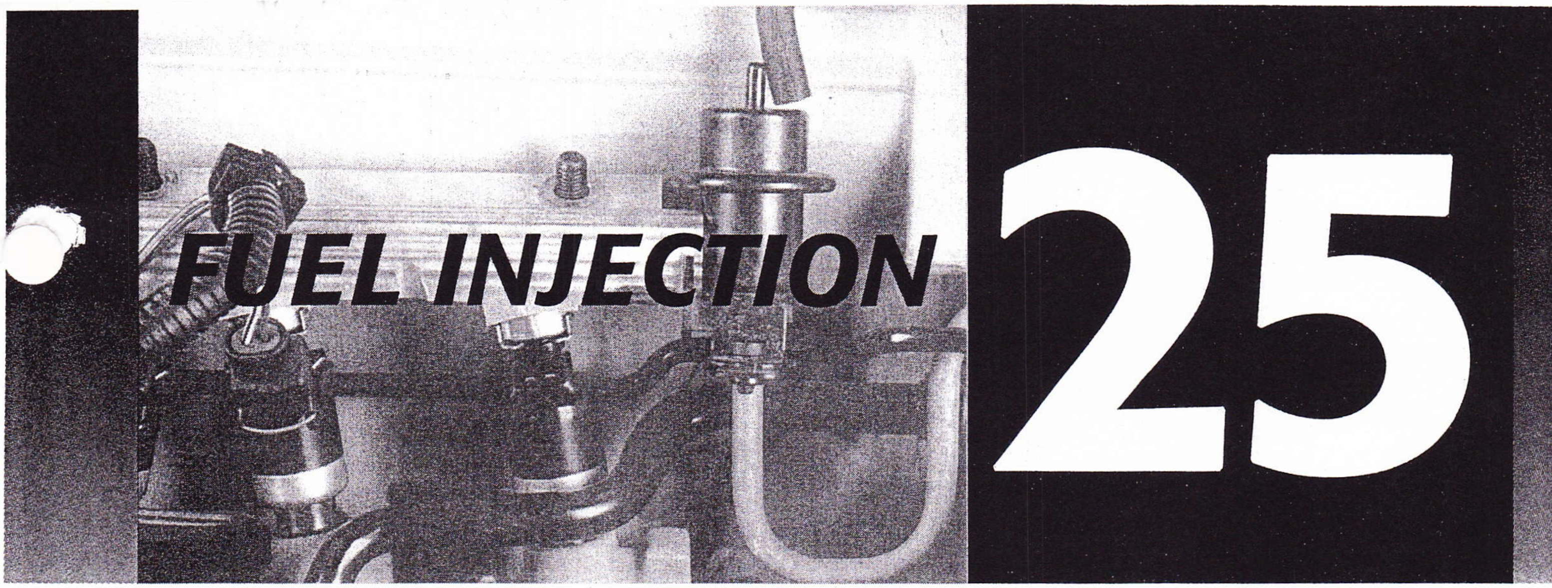
FUEL INJECTION



FUEL INJECTION 25

OBJECTIVES

◆ ***Explain the principles of operation of a fuel injection system.*** ◆ ***List the advantages of fuel injection.*** ◆ ***Explain the differences in point of injection in throttle body or port injection systems.*** ◆ ***Explain the design and function of major EFI components.*** ◆ ***Explain the design and function of CIS-E components.*** ◆ ***Service and diagnose fuel injection systems.*** ◆ ***Explain the basics of diesel fuel injection.***

Fuel injection involves spraying or injecting fuel directly into the engine's intake manifold (Figure 25–1). Fuel injection, especially when it is electronically controlled, has several major advantages over carbureted systems. These include improved driveability under all conditions, improved fuel control and economy, decreased exhaust emissions, and an increase in engine efficiency and power.

Although fuel injection technology has been around since the 1920s, it wasn't until the 1980s that manufacturers began to replace carburetors with electronic fuel injection (**EFI**) systems. Many of the early EFI systems were throttle body injection (**TBI**) systems in which the fuel was injected above the throttle plates. Engines equipped with TBI have gradually become equipped with port fuel injection (**PFI**), which has injectors located in the intake ports of the cylinders. Since the 1995 model year, all new cars are equipped with EFI systems.

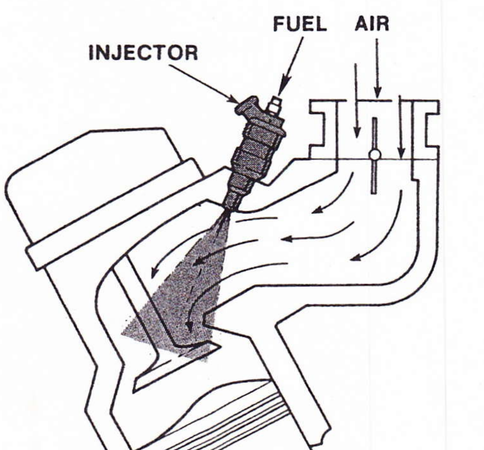


FIGURE 25–1 In a port fuel injection system, air and fuel are mixed in the intake manifold runners very close to the intake valve(s) of the combustion chamber.

Diesel engines, for quite some time, have been equipped with fuel injection systems. The two basic differences between gasoline injection and diesel injection are: diesel fuel is injected directly into the cylinders, and diesel fuel injection systems are operated mechanically rather than electronically. Although late-model diesel systems use electronic fuel controls, the fuel injection system is a mechanical system that is controlled mechanically.

GASOLINE FUEL INJECTION

Most electronic fuel injection systems only inject fuel during part of the engine's combustion cycle. The engine fuel needs are measured by intake airflow past a sensor or by intake manifold pressure (vacuum). The airflow or manifold vacuum sensor converts its reading to an electrical signal and sends it to the engine control computer. The computer processes this signal (and others) and calculates the fuel needs of the engine. The computer then sends an electrical signal to the fuel injector or injectors. This signal determines the amount of time the injector opens and sprays fuel. This interval is known as the **injector pulse width**.

Throttle body injection systems have a throttle body assembly mounted on the intake manifold in the position usually occupied by a carburetor. The throttle body assembly usually contains one or two injectors.

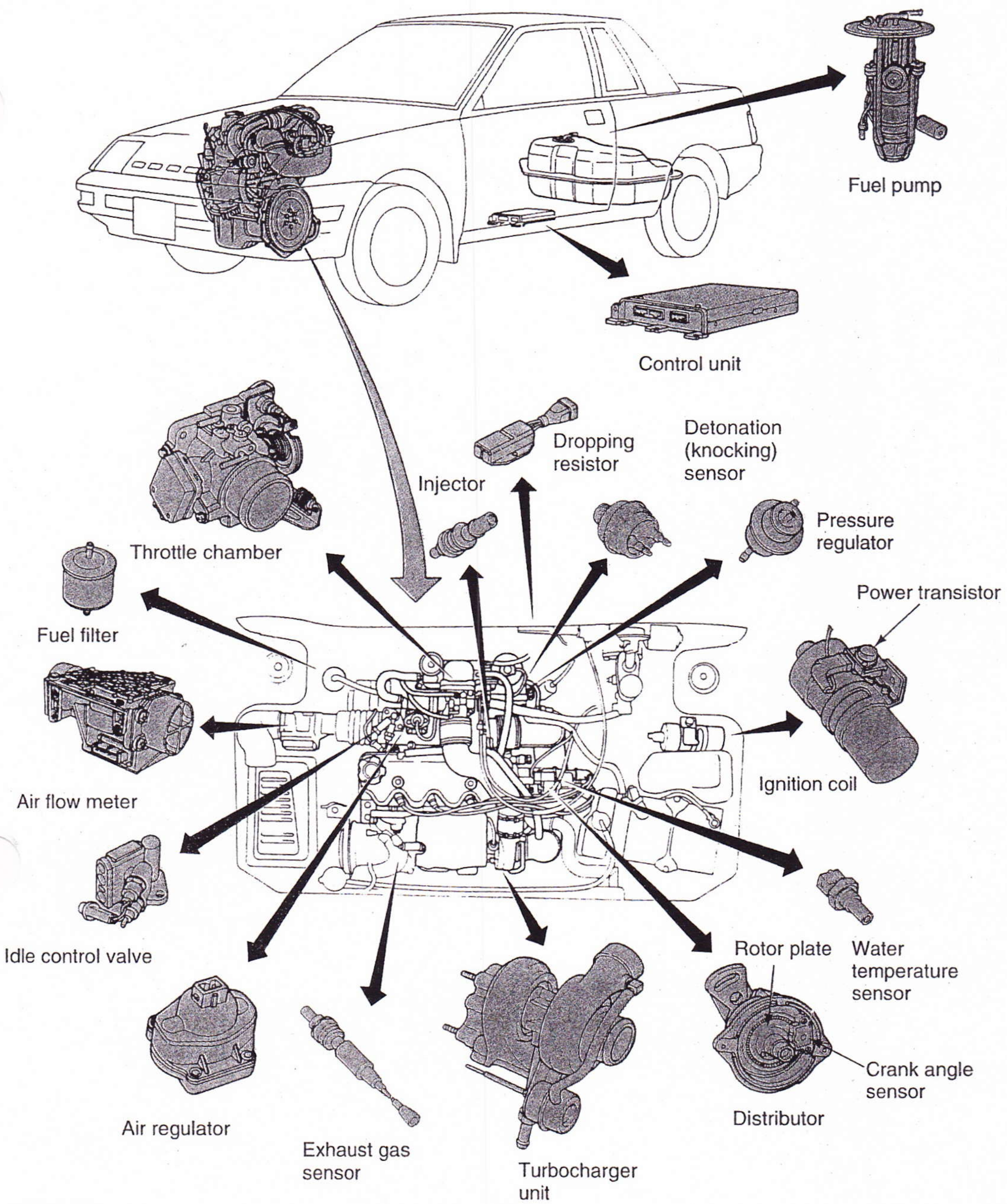


FIGURE 25–2 Main components of a typical EFI system. *Courtesy of Nissan Motors*

On port fuel injection systems, fuel injectors are mounted at the back of each intake valve. Aside from the differences in injector location and number of injectors, operation of throttle body and port systems is quite similar with regard to fuel and air metering, sensors, and computer operation.

Port-type continuous injection systems (**CIS**) have been used on many import vehicles. These systems deliver a steady stream of pressurized fuel into the intake manifold. The injectors do not pulse on and off in port and throttle body systems. In CIS, the amount of fuel delivered is controlled by the rate of airflow entering the engine. An airflow sensor controls movement of a plunger that alters fuel flow to the injectors. When introduced, CIS was a mechanically controlled system. However, oxygen sensor feedback circuits and other electronic controls have been added to the system. CIS systems that have electronic controls are commonly referred to as **CIS-E** systems.

ELECTRONIC FUEL INJECTION SYSTEM Electronic fuel injection (EFI) has proven to be the most precise, reliable, and cost effective method of delivering fuel to the combustion chambers of today's vehicles. EFI systems must provide the correct air/fuel ratio for all engine loads, speeds, and temperature conditions. To accomplish this, an EFI system uses a fuel delivery system, air induction system, input sensors, control computer, fuel injectors, and some sort of idle speed control (Figure 25–2).

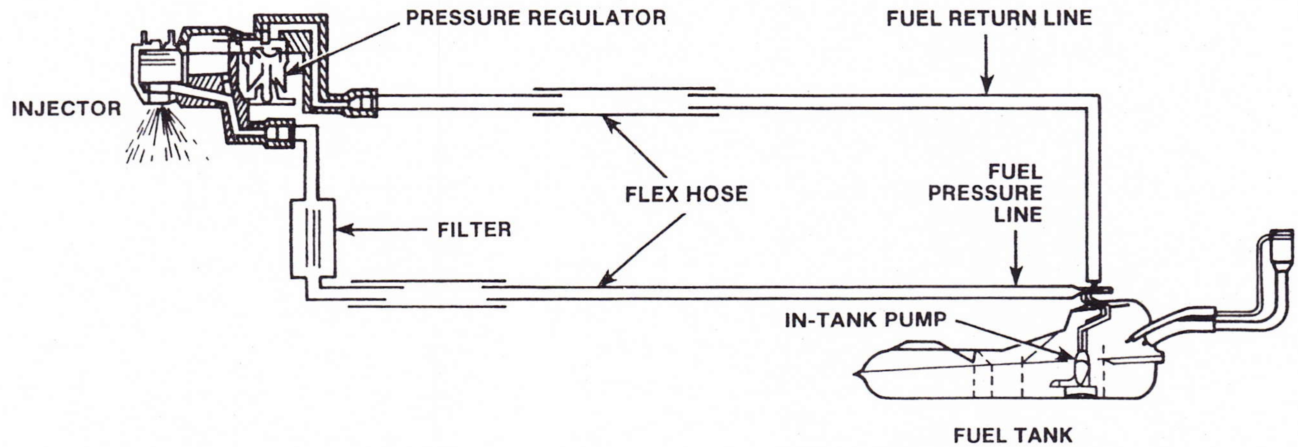


FIGURE 25–3 Components of a typical fuel circuit used in a throttle body fuel injection system.

In a typical EFI fuel delivery system (Figure 25–3), fuel is drawn from the fuel tank by an in-tank or chassis-mounted electric fuel pump. Before it reaches the injectors, the fuel passes through a filter that removes dirt and impurities. A fuel line pressure regulator maintains a constant fuel line pressure that may be as high as 50 psi in some systems. This fuel pressure generates the spraying force needed to inject the fuel. Excess fuel not required by the engine returns to the fuel tank through a fuel return line.

THROTTLE BODY VERSUS PORT INJECTION

Throttle Body Fuel Injection

For some auto manufacturers, TBI served as a stepping stone from carburetors to more advanced port fuel injection systems. TBI units were used on many engines during the 1980s and are still used on some engines. The throttle body unit is similar in size and shape to a carburetor and, like a carburetor, mounts on the intake manifold (Figure 25–4). The injector(s) spray fuel down into a throttle body chamber leading to the intake manifold. The intake manifold feeds the air/fuel mixture to all cylinders.

TBI Operation The basic TBI assembly consists of two major castings: a throttle body with a valve to control airflow and a fuel body to supply the required fuel. A fuel pressure regulator and fuel injector are integral parts of the fuel body (Figure 25–5). Also included as part of the assembly is a device to control idle speed and one to provide throttle valve positioning data.

The throttle body casting has ports that can be located above, below, or at the throttle valve depending on the manufacturer's design. These ports generate vacuum signals for the manifold absolute pres-

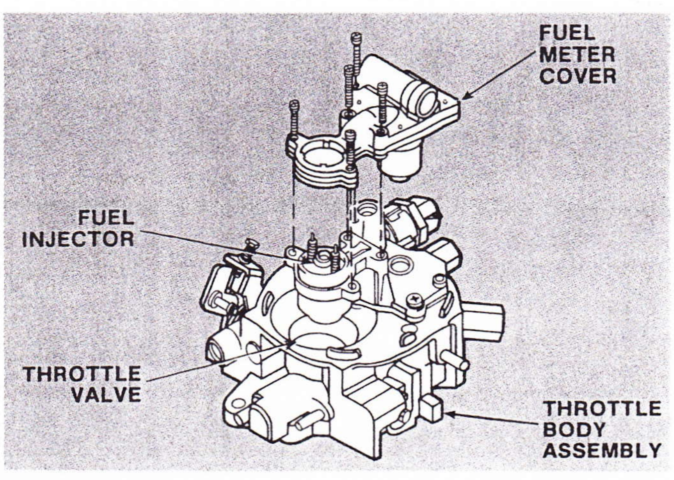


FIGURE 25–4 Parts of a throttle body injection unit.

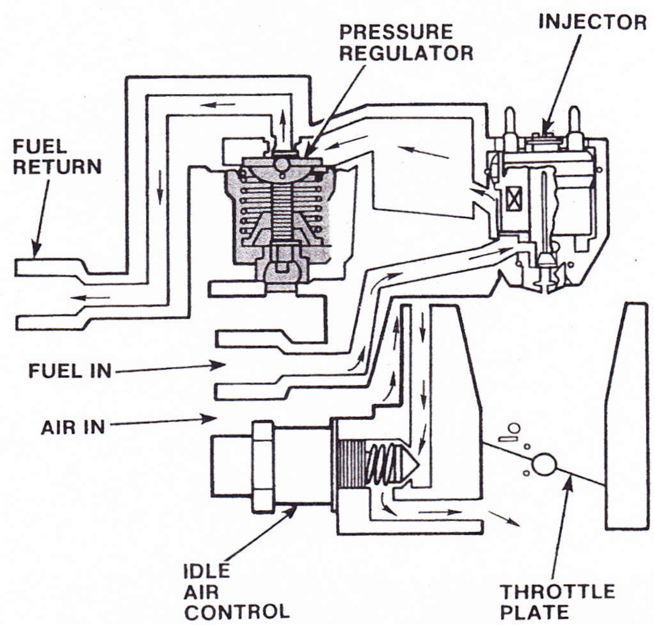


FIGURE 25–5 Fuel and airflow in a TBI injection system. The injector is a bottom fuel feed design. The idle air control allows air to bypass the throttle plate to regulate engine idle in all operating conditions.

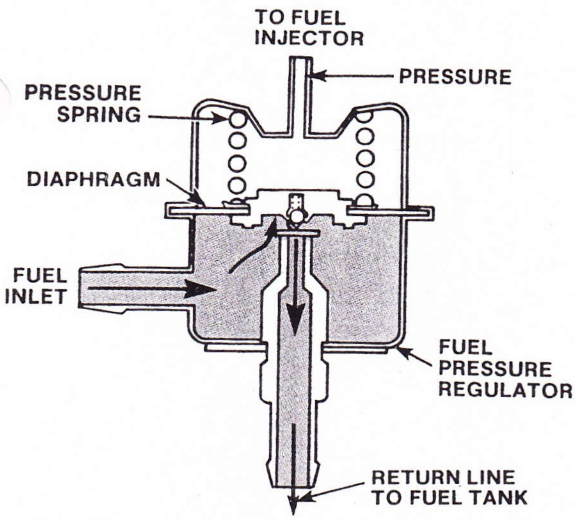


FIGURE 25–6 Operation of a diaphragm-operated fuel pressure regulator.

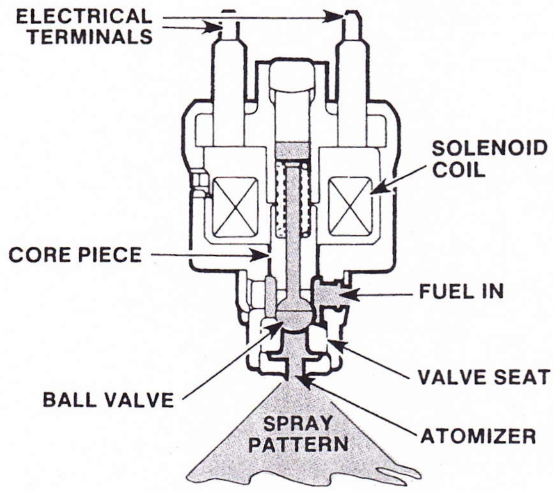


FIGURE 25–7 Solenoid-operated ball valve-type fuel injector used in a TBI system. When electronically energized, the ball valve lifts off the valve seat, allowing fuel to spray into the throttle body housing.

sure sensor and for devices in the emission control system, such as the EGR valve, the canister purge system, and so on.

The **fuel pressure regulator** used on the throttle body assembly is similar to a diaphragm-operated relief valve (Figure 25–6). Fuel pressure is on one side of the diaphragm and atmospheric pressure is on the other side. The regulator is designed to provide a constant pressure on the fuel injector throughout the range of engine loads and speeds. If regulator pressure is too high, a strong fuel odor is emitted and the engine runs too rich. On the other hand, regulator pressure that is too low results in poor engine performance or detonation can take place, due to the lean mixture.

The fuel injector is solenoid operated and pulsed on and off by the vehicle's engine control computer. (NOTE: In this chapter, the terms *control computer* and *electronic control unit* (**ECU**) are used interchangeably.) Surrounding the injector inlet is a fine screen filter where the incoming fuel is directed. When the injector's solenoid is energized, a normally closed ball valve is lifted (Figure 25–7). Fuel under pressure is then injected at the walls of the throttle body bore just above the throttle plate.

TBI Advantages Throttle body systems provide improved fuel metering when compared to carburetors. They are also less expensive and simpler to service. TBI units also have some advantages over port injection. They are less expensive to manufacture, simpler to diagnose and service, and don't have injector balance problems to the extent that port injection systems do when the injectors begin to clog.

However, throttle body units are not as efficient as port systems. The disadvantages are primarily manifold related. Like a carburetor system, fuel is still not distributed equally to all cylinders, and a cold manifold may cause fuel to condense and puddle in the manifold. Like a carburetor, throttle body injection systems must be mounted above the combustion chamber level, which eliminates the possibility of tuning the manifold design for more efficient operation.

Port Fuel Injection

PFI systems use one injector at each cylinder. They are mounted in the intake manifold near the cylinder head where they can inject a fine, atomized fuel mist as close as possible to the intake valve (Figure 25–8). Fuel lines run to each cylinder from a fuel manifold, usually referred to as a **fuel rail**. The fuel rail assembly on a PFI system of V-6 and V-8 engines usually

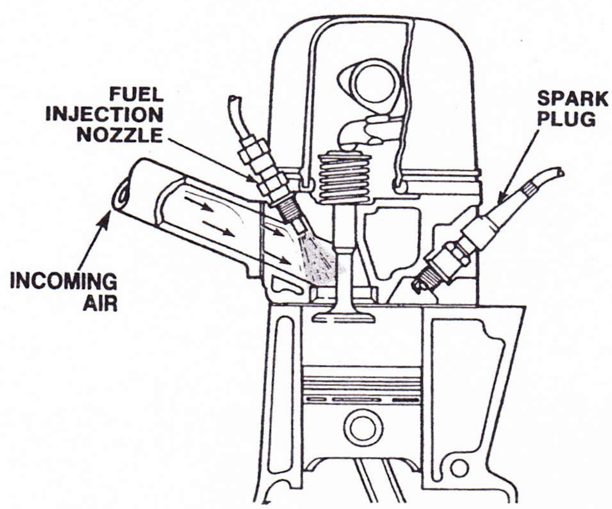


FIGURE 25–8 Port fuel injection systems use an injector at each cylinder.

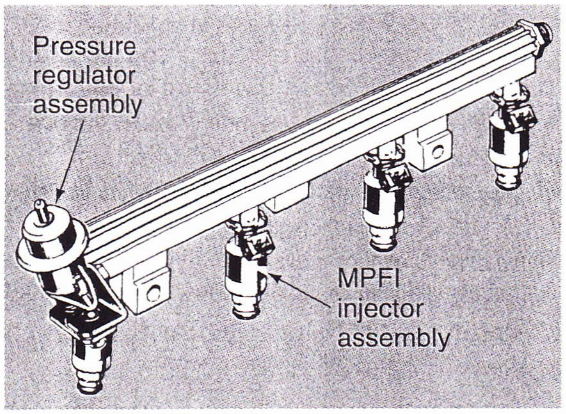


FIGURE 25–9 Fuel rail with fuel pressure regulator and fuel injectors for a four-cylinder port fuel injected engine. *Courtesy of Oldsmobile Division, General Motors Corporation*

consists of a left- and right-hand rail assembly. The two rails can be connected either by crossover and return fuel tubes or by a mechanical bracket arrangement. A typical fuel rail arrangement is shown in Figure 25–9. Fuel tubes crisscross between the two rails. Since each cylinder has its own injector, fuel distribution is exactly equal. With little or no fuel to wet the manifold walls, there is no need for manifold heat or any early fuel evaporation system. Fuel does not collect in puddles at the base of the manifold. This means the intake manifold passages can be tuned or designed for better low-speed power availability (Figure 25–10). The port-type systems provide a more accurate and efficient delivery of fuel. Some engines are now equipped with variable induction intake manifolds that have separate runners for low and high speeds. This technology is only possible with port injection.

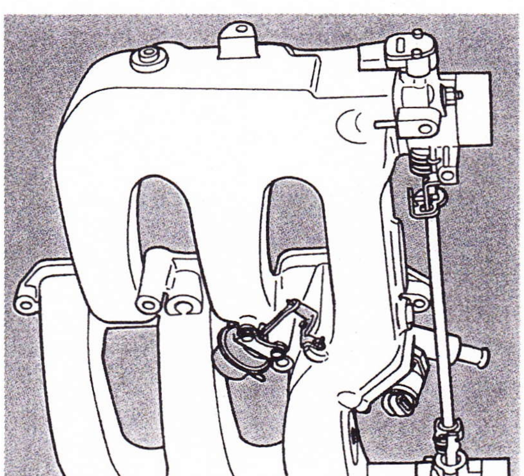


FIGURE 25–10 Typical tuned intake manifold for a port injection engine. *Courtesy of Chrysler Corporation*

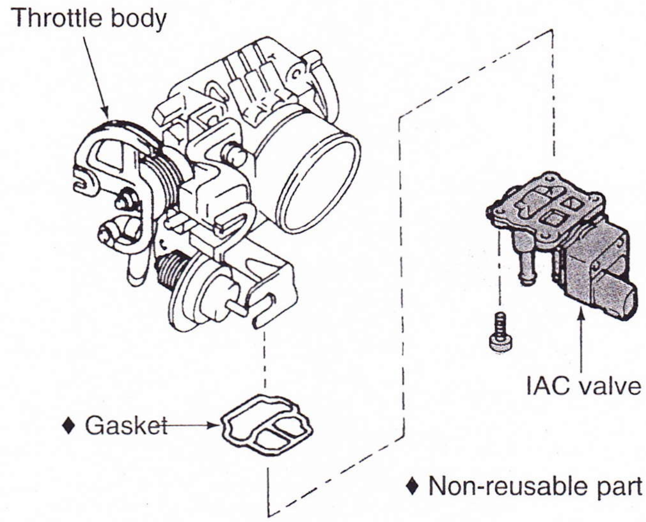


FIGURE 25–11 Throttle body assembly of a port fuel injection system. *Courtesy of Toyota Motors*

The throttle body in a port fuel injection system controls the amount of air that enters the engine as well as the amount of vacuum in the manifold. It also houses and controls the idle air control (**IAC**) motor and the throttle position sensor (TPS). The TPS enables the ECU to know where the throttle is positioned at all times.

The throttle body (Figure 25–11) is a single, cast-aluminum housing with a single throttle blade attached to the throttle shaft. The TPS and the IAC valve/motor are also attached to the housing. The throttle shaft is controlled by the accelerator pedal. The throttle shaft extends the full length of the housing. The throttle bore controls the amount of incoming air that enters the air induction system. A small amount of coolant is also routed through a passage in the throttle body to prevent icing during cold weather.

Port systems require an additional control system that throttle body injection units do not require. While throttle body injectors are mounted above the throttle plates and are not affected by fluctuations in manifold vacuum, port system injectors have their tips located in the manifold where constant changes in vacuum would affect the amount of fuel injected (at a given pulse width). To compensate for these fluctuations, port injection systems are equipped with fuel pressure regulators that sense manifold vacuum and continually adjust the fuel pressure to maintain a constant pressure drop across the injector tips at all times.

Pressure Regulator The pressure regulator in port injection systems is similar to the regulator used in TBI systems. A diaphragm and valve assembly is positioned on the center of the regulator, and a diaphragm spring seats the valve on the fuel outlet (Figure 25–12).

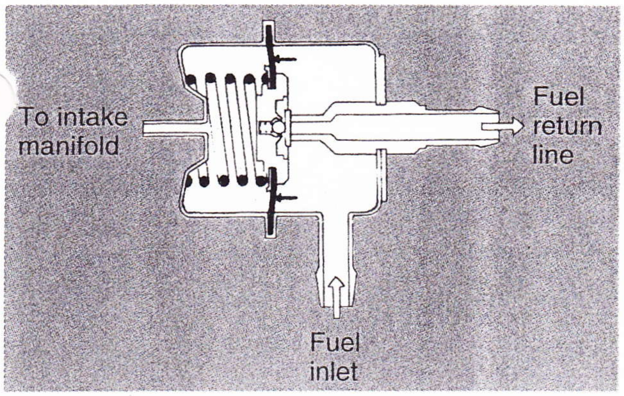


FIGURE 25–12 Fuel pressure regulator for port injection engines. *Courtesy of Chrysler Corporation*

When fuel pressure reaches the setting of the regulator, the diaphragm moves against the spring tension, and the valve opens. This action allows fuel to flow through the return line to the fuel tank. The fuel pressure drops slightly when the pressure regulator valve opens, and the spring closes the regulator valve. In many systems, the regulator maintains fuel pressure at 39 psi (269 kPa).

A vacuum hose is connected from the intake manifold to the vacuum inlet on the pressure regulator. This hose supplies vacuum to the area where the diaphragm spring is located. This vacuum works with the fuel pressure to move the diaphragm and open the valve. When the engine is running at idle speed, high manifold vacuum is supplied to the regulator. Under this condition, the specified fuel pressure opens the regulator valve. When the engine is running under heavy load and/or wide-open throttle, a very low vacuum is supplied to the regulator. During these times, the vacuum does not help open the regulator valve and a higher fuel pressure is required to open the valve.

The change in fuel pressure allows the fuel to be sprayed into the manifold with the same effect, regardless of the pressure present in the manifold. When there is a high vacuum in the manifold, a very low pressure exists and the pressure difference between the fuel spray and the vacuum is the same as when there is a higher pressure in the manifold (low vacuum) and a higher fuel pressure.

Port Firing Control While all port injection systems operate using an injector at each cylinder, they do not fire the injectors in the same manner. This one statement best defines the difference between typical multiport injection systems (**MPI**) and sequential fuel injection systems (**SFI**).

SFI systems control each injector individually so it is opened just before the intake valve opens. This means the mixture is never static in the intake manifold and adjustments to the mixture can be made almost instantaneously between the firing of one injector and the next. Sequential firing is the most accurate and desirable method of regulating port injection.

In MPI systems, the injectors are grouped together in pairs or groups, and these pairs or groups of injectors are turned on at the same time. When the injectors are split into two equal groups, the groups are fired alternately, with one group firing each engine revolution (Figure 25–13).

Since only two injectors can be fired relatively close to the time when the intake valve is about to open, the fuel charge for the remaining cylinders must stand in the intake manifold for varying periods of time. These periods of time are very short; therefore, the standing of fuel in the intake manifold is not that great a disadvantage of MPI systems. At idle speeds, this wait is about 150 milliseconds; at higher speeds, the time is much less. The primary advantage of SFI is the ability to make instantaneous changes to the mixture.

In SFI systems, each injector is connected individually into the computer, and the computer completes the ground for each injector, one at a time. In MPI systems, the injectors are grouped and all injectors within the group share the same common ground wire.

Some injection systems fire all of the injectors at the same time for every engine revolution. This type of system offers easy programming and relatively fast adjustments to the air/fuel mixture. The injectors are connected in parallel so the ECU sends out just one signal for all injectors. They all open and close at the same time. It simplifies the electronics without compromising injection efficiency. The amount of fuel required for each four-stroke cycle is divided in half and delivered in two injections, one for every 360 degrees of crankshaft rotation. The fact that the intake charge must still wait in the manifold for varying periods of time is the system's major drawback.

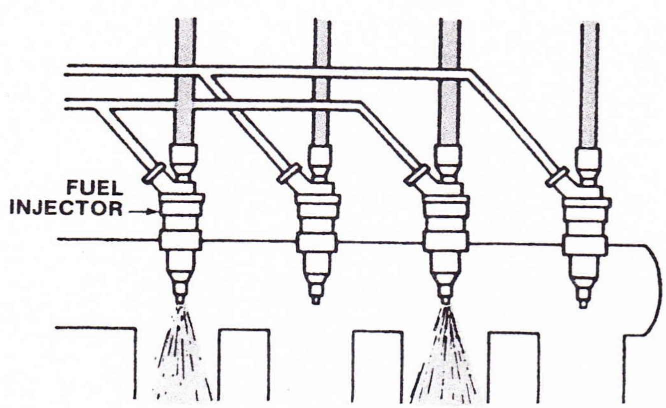


FIGURE 25–13 Grouped single-fire port injection.

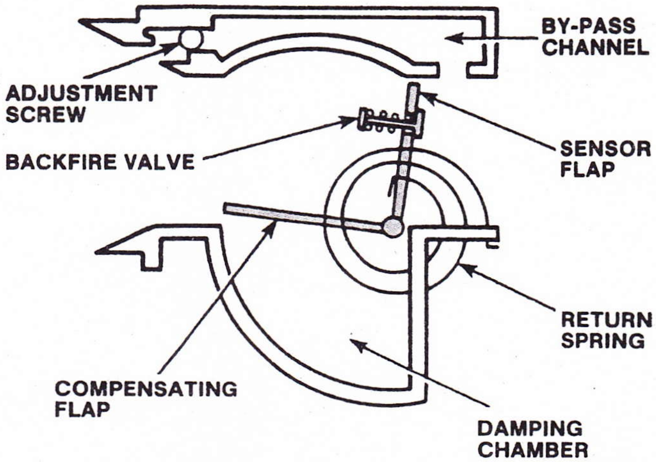


FIGURE 25–14 Typical airflow sensor.

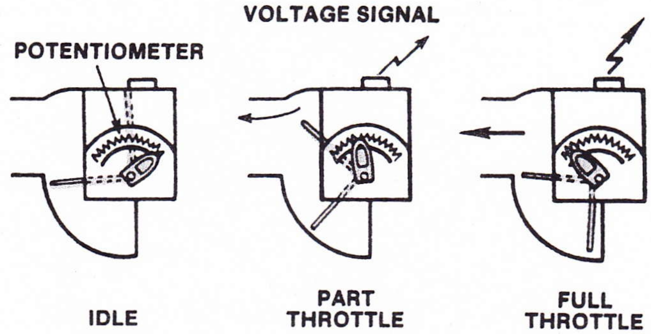


FIGURE 25–15 In a typical airflow sensor, the strength of the voltage signal produced by the potentiometer varies in response to the amount the sensor flap moves.

SYSTEM SENSORS

The ability of the fuel injection system to control the air/fuel ratio depends on its ability to properly time the injector pulses with the compression stroke of each cylinder and its ability to vary the injector "on" time, according to changing engine demands. Both tasks require the use of electronic sensors that monitor the operating conditions of the engine.

Airflow Sensors

To control the proportion of fuel to air in the air/fuel charge, the fuel system must be able to measure the amount of air entering the engine. Several sensors have been developed to do just that.

VOLUME AIRFLOW SENSOR The airflow sensor shown in Figure 25–14 measures airflow, or air volume. The sensor consists of a spring-loaded flap, potentiometer, damping chamber, backfire protection valve, and idle bypass channel. As air is drawn into the engine, the flap is deflected against the spring. A potentiometer, attached to the flap shaft, monitors the flap movement and produces a corresponding voltage signal (Figure 25–15). The strength of the signal increases as the flap opens. The signal voltage is relayed to the electronic control module.

DAMPING CHAMBER The curved shape of the airflow sensor is the damping chamber. The damping flap in this chamber is on the same shaft as the airflow sensing flap and is also about the same area. As a result, the damping flap smooths out any possible pulsations caused by opening and closing of the intake valves. Airflow measurement can be a steady signal, closely related to airflow as controlled by the movement of the flap.

BACKFIRE PROTECTION The airflow sensor flap provides for backfire protection with a spring-loaded valve. If the intake manifold pressure suddenly rises because of a backfire, this valve releases the pressure and prevents damage to the system.

IDLE BY-PASS The airflow sensor assembly includes an extra air passage for idle, bypassing the airflow sensor plate. This is seen near the top of Figure 25–14. When the throttle is closed at idle, the opening and closing of intake valves can cause pulsations in the intake manifold. Without the idle by-pass, such pulsations could cause the flap to shudder, resulting in an uneven air/fuel mixture. The idle by-pass smooths the flow of the idle intake air, ensuring regular signals to the electronic control.

Another design of airflow sensor, called a Karman Vortex sensor, works on a different operating principle. Air entering the airflow sensor assembly passes through vanes arranged around the inside of a tube. As the air flows through the vanes, it begins to swirl. The outer part of the swirling air exerts high pressure against the outside of the housing. There is a low-pressure area in the center. The low-pressure area moves in a circular motion as the air swirls through the intake tube. Two pressure-sensing tubes near the end of the tube sense the low-pressure area as it moves around. An electronic sensor counts how many times the low-pressure area is sensed.

The faster the airflow, the more times the low-pressure area is sensed. This is translated into a signal that indicates to the combustion control computer how much air is flowing into the intake manifold.

Air Temperature Sensor

Cold air is denser (weighs more) than warm air. Cold, dense air can burn more fuel than the same volume of warm air because it contains more oxygen. This is why airflow sensors that only measure air volume must have their readings adjusted to account for differences in air temperature.

Most systems do this by using an air temperature sensor mounted in the throttle body of the induction system. The air sensor measures air temperature and sends an electronic signal to the control computer. The computer uses this input along with the air volume input in determining the amount of oxygen entering the engine.

In some early EFI systems, the incoming air is heated to a set temperature. In these systems an air temperature sensor is used to ensure that this predetermined operating temperature is maintained.

Mass Airflow Sensors

A **mass airflow sensor** (MAF), (Figure 25–16) does the job of a volume airflow sensor and an air temperature sensor. It measures air mass. The mass of a given amount of air is calculated by multiplying its volume by its density. As explained previously, the denser the air, the more oxygen it contains. Monitoring the oxygen in a given volume of air is important, since oxygen is a prime catalyst in the combustion process. From a measurement of mass, the electronic control unit adjusts the fuel delivery for the oxygen content in a given volume of air. The accuracy of air/fuel ratios is greatly enhanced when matching fuel to air mass instead of fuel to air volume.

The mass airflow sensor converts air flowing past a heated sensing element into an electronic signal. The strength of this signal is determined by the energy needed to keep the element at a constant temperature above the incoming ambient air temperature. As the volume and density (mass) of airflow across the heated element changes, the temperature of the element is affected and the current flow to the element is adjusted to maintain the desired temperature of the heating element. The varying current flow parallels the particular characteristics of the incoming air (hot, dry, cold, humid, high/low pressure). The electronic control unit monitors the changes in current to determine air mass and to calculate precise fuel requirements.

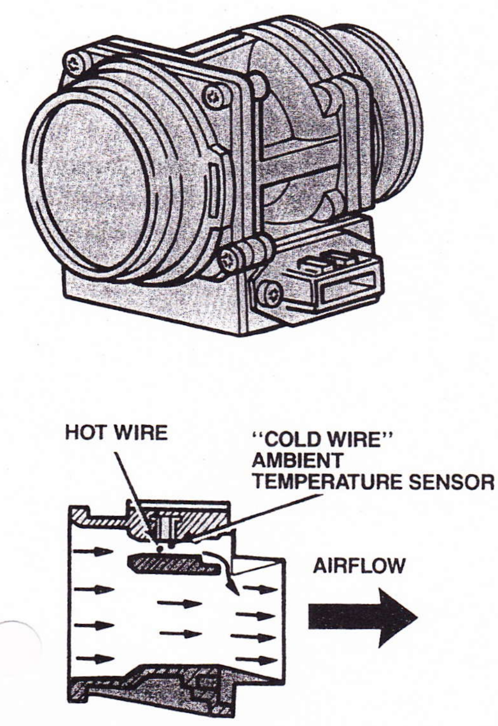


FIGURE 25–16 Components of a mass airflow sensor. *Courtesy of Ford Motor Company*

There are two basic types of mass airflow sensor: hot wire and hot film. In the first type, a very thin wire (about 0.2 mm thick) is used as the heated element. The element temperature is set at 100° to 200°C above incoming air temperature. Each time the ignition switch is turned to the off position, the wire is heated to approximately 1,000°C for 1 second to burn off any accumulated dust and contaminants.

The second type uses a nickel foil sensor, which is kept 75°C above ambient air temperatures. It does not require a burn-off period. Thus, it is potentially longer lasting than the hot wire type.

Manifold Absolute Pressure Sensor

Some EFI systems do not use airflow or air mass to determine the base pulse of the injector(s). Instead, the base pulse is calculated on manifold absolute pressure (MAP).

The MAP sensor measures changes in the intake manifold pressure that result from changes in engine load and speed. The pressure measured by the MAP sensor is the difference between barometric pressure (outside air) and manifold pressure (vacuum). At closed throttle, the engine produces a low MAP value. A wide-open throttle produces a high value. This high value is produced when the pressure inside the manifold is the same as pressure outside the manifold, and 100 percent of the outside air is being measured. This MAP output is the opposite of what is measured on a vacuum gauge. The use of this sensor also allows the control computer to adjust automatically for different altitudes.

The control computer sends a voltage reference signal to the MAP sensor. As the MAP changes, the electrical resistance of the sensor also changes. The control computer can determine the manifold pressure by monitoring the sensor output voltage. A high pressure, low vacuum (high voltage) requires more fuel. A low pressure, high vacuum (low voltage) requires less fuel. Like an airflow sensor, a MAP sensor relies on an air temperature sensor to adjust its base pulse signal to match incoming air density.

In EFI systems with a MAP sensor, the computer program is designed to calculate the amount of air entering the engine from the MAP and engine rpm input signals. This type of EFI system is referred to as a **speed density** system because the computer calculates the air intake flow from the engine speed input and the density of the intake manifold vacuum input. Many EFI systems with MAF sensors do not have MAP sensors. However, there are a few engines with both of these sensors. In these cases, the MAP is used mainly as a backup if the MAF fails. When the EFI system has a MAF, the computer calculates the intake air flow from the MAF and rpm inputs.

Other EFI System Sensors

In addition to airflow, air mass, or manifold absolute pressure readings, the control computer relies on input from a number of other system sensors. This input further adjusts the injector pulse width to match engine operating conditions. Operating conditions are communicated to the control computer by the following types of sensors.

COOLANT TEMPERATURE The coolant temperature sensor signals the electronic control unit when the engine needs cold enrichment, as it does during warm-up. This adds to the base pulse, but decreases to zero as the engine warms up.

THROTTLE POSITION The switches on the throttle shaft signal the electronic control unit for idle enrichment when the throttle is closed. These same throttle switches signal the electronic control unit when the throttle is near the wide-open position to provide full load enrichment.

ENGINE SPEED The ignition system sends a tachometer signal reference pulse corresponding to engine speed to the electronic control unit. This signal advises the electronic control unit to adjust the pulse width of the injectors for engine speed. This also times the start of the injection according to the intake stroke cycle.

CRANKING ENRICHMENT The starter circuit sends a signal for fuel enrichment during cranking operations even when the engine is warm. This is independent of any cold-start fuel enrichment demands.

ALTITUDE COMPENSATION As the car operates at higher altitudes, the thinner air needs less fuel. Altitude compensation in a fuel injection system is accomplished by installing a sensor to monitor barometric pressure. Signals from the barometric pressure sensor are sent to the ECU to reduce the injector pulse width (or reduce the amount of fuel injected).

COASTING SHUTOFF Coasting shutoff can be found on a number of control systems. It can improve fuel economy as well as reduce emissions of hydrocarbons and carbon monoxide. Fuel shutoff is controlled in different ways depending on the type of transmission (manual or automatic). The ECU makes a coasting shutoff decision based on a closed throttle as indicated by the throttle position or idle switch or on engine speed as indicated by the signal from the ignition coil. When the ECU detects that power is not needed to maintain vehicle speed, the injectors are turned off until the need for power exists again.

ADDITIONAL INPUT INFORMATION SENSORS Additional sensors are also used to provide the following information on engine conditions. NOTE: This list does not attempt to cover all of the sensors that are used by all manufacturers. It contains the most common.

- Detonation
- Crankshaft position
- Camshaft position
- Timing of ignition spark
- Air conditioner operation
- Gearshift lever position
- Battery voltage
- Amount of oxygen in exhaust bases
- Emission control device operation

Figure 25–17 shows the typical inputs and outputs of an onboard computer (ECU) responsible for controlling the EFI system.

ELECTRONIC CONTROL COMPUTER

The heart of the fuel injection system is the control computer or electronic control unit (ECU). The ECU is a small computer that is usually mounted within the passenger compartment to keep it away from the heat and vibration of the engine. The ECU includes solid state devices, including integrated circuits and a microprocessor.

The ECU receives signals from all the system sensors, processes them, and transmits programmed electrical pulses to the fuel injectors. Both incoming and outgoing signals are sent through a wiring harness and a multiple-pin connector.

Electronic feedback in the ECU means the unit is self-regulating and is controlling the injectors on the basis of operating performance or parameters rather than on preprogrammed instructions. An ECU with a feedback loop, for example, reads signals from the oxygen sensor, varies the pulse width of the injectors, and again reads the signals from the oxygen sensor. This is repeated until the injectors are pulsed for just the amount of time needed to get the proper amount

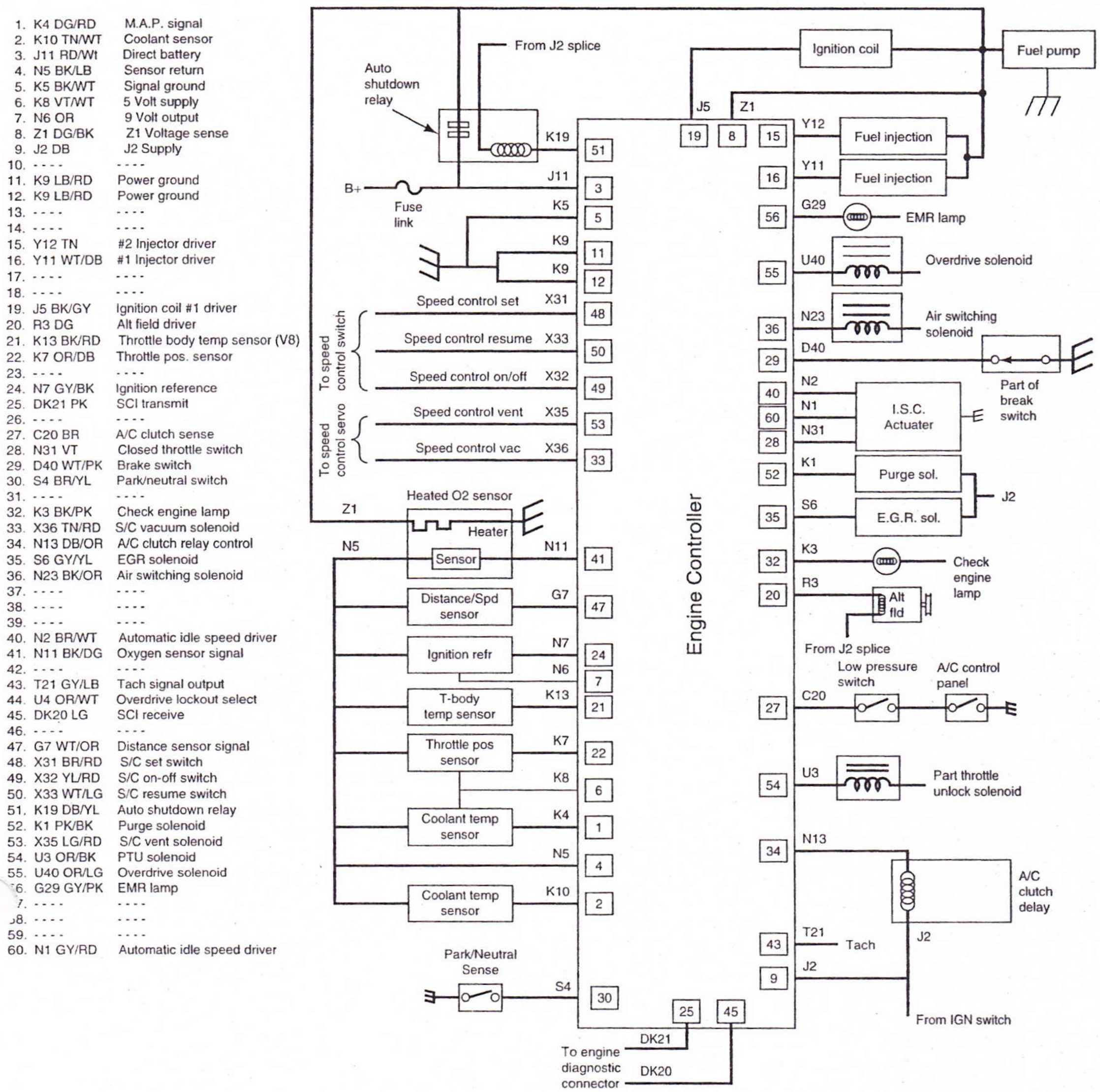


FIGURE 25–17 Input sensors from all engine systems supply the control computer (ECU) with the data needed to calculate the correct injector pulse for driving conditions and driver demands. *Courtesy of Chrysler Corporation*

of oxygen into the exhaust stream. While this interaction is occurring, the system is operating in closed loop. When conditions, such as starting or wide-open throttle, demand that the signals from the oxygen sensor be ignored, the system operates in open loop. During open loop, injector pulse length is controlled by set parameters contained in the ECU memory banks.

FUEL INJECTOR

The fuel injector is an electromechanical device that meters and atomizes fuel so it can be sprayed into the intake manifold. Fuel injectors resemble spark plugs in size and shape. As mentioned earlier, they mount into the intake manifold runners (port systems) or throttle body housing (TBI systems). O-rings are used to seal the injector at the intake manifold, throttle body, and fuel rail mounting positions. These O-rings provide thermal insulation to prevent the formation of vapor bubbles and promote good hot start characteristics. They also dampen potentially damaging vibration.

When the injector is electrically energized, a solenoid-operated valve opens, and a fine mist of fuel sprays from the injector tip. Two different valve designs are commonly used.

The first consists of a valve body and a nozzle or needle valve that has a special ground **pintle** (Figure 25–18). A movable armature is attached to the nozzle valve, which is pressed against the nozzle body sealing seat by a helical spring. The solenoid winding is located at the back of the valve body.

When the solenoid winding is energized, it creates a magnetic field that draws the armature back and pulls the nozzle valve from its seat. When the solenoid

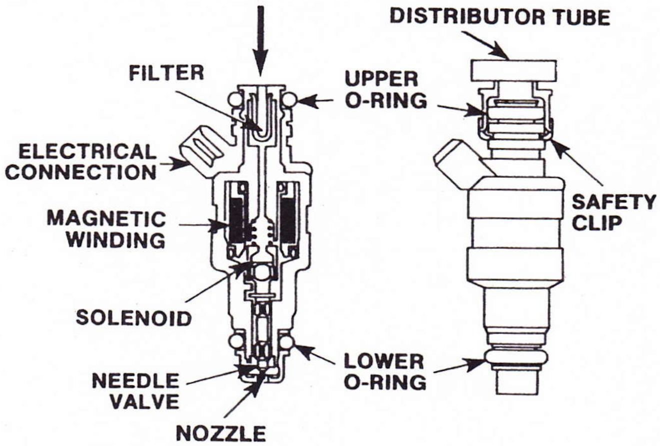


FIGURE 25–18 This fuel injector design is equipped with a nozzle or needle valve having a special ground pintle for precise fuel delivery control.

is de-energized, the magnetic field collapses and the helical spring forces the nozzle valve back on its seat.

The second popular valve design uses a ball valve and valve seat. In this case, the magnetic field created by the solenoid coil pulls a plunger upward lifting the ball valve from its seat. Once again, a spring is used to return the valve to its seated or closed position.

Fuel injectors can be either top fuel feeding or bottom fuel feeding (Figure 25–19). Top feed injectors are primarily used in port injection systems that operate using high fuel system pressures. Bottom feed injectors are used in throttle body systems. Bottom feed injectors are able to use fuel pressures as low as 10 psi.

There have been some problems with deposits on injector tips. Since small quantities of gum are present in gasoline, injector deposits usually occur when this gum bakes onto the injector tips after a hot engine is shut off. Most oil companies have added a detergent to their gasoline to help prevent injector tip deposits. Car manufacturers and auto parts stores sell detergents to place in the fuel tank to clean injector tips.

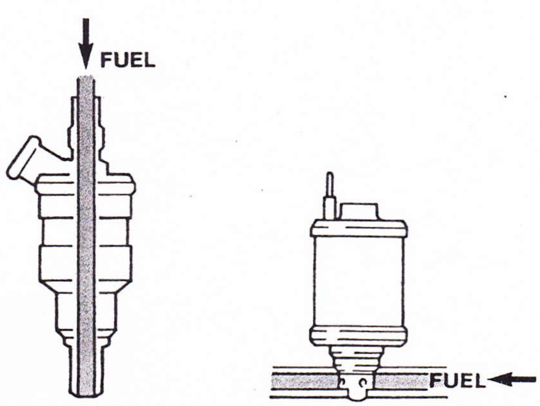


FIGURE 25–19 Examples of bottom and top feed injectors.

WARNING!

Some auto manufacturers do not want you to add any type of injector cleaner to the gasoline. It seems that the chemicals in the cleaner destroy the coating on the coil windings in the injector. ■

Some manufacturers and auto parts suppliers have designed deposit-resistant injectors. These injectors have several different pintle tip and orifice designs to help prevent deposits. On one type of deposit-resistant injector, the pintle seat opens outward away from the injector body and more clearance is provided between the pintle and the body. Another type of deposit-resistant injector has four orifices in a metering plate rather than a single orifice.

SHOP TALK

Some deposit-resistant injectors may be recognized by the color of the injector body. For example, regular injectors supplied by Ford Motor Company are painted black, whereas their deposit-resistant injectors have tan or yellow bodies. ■

COLD START INJECTOR A good number of engines equipped with port injection have an additional injector, the cold start injector. Unlike the individual injectors at the intake ports, the cold start injector is not operated directly by the ECU. Rather, it is operated by a **thermo-time switch**, which senses coolant temperature (Figure 25–20).

When the engine is cranked, voltage is supplied from the starter solenoid to one terminal on the cold start injector. If the coolant temperature is below a certain amount, the thermo-time switch completes the ground for the cold start injector. Doing this energizes the injector while the engine is cranking. The fuel from the cold start injector sprays into the intake manifold and is delivered to the cylinders. Since the injectors at each intake port will also be providing fuel, the fuel from the cold start injector allows for a richer mixture.

A bimetal switch in the thermo-time switch is heated as current flows through the injector coil. The bimetal switch action opens the circuit through the thermo-time switch after the engine has reached a certain temperature.

ELECTRICAL CONNECTOR Each fuel injector is equipped with a two-wire connector. The connector is often equipped with a spring clip that must be

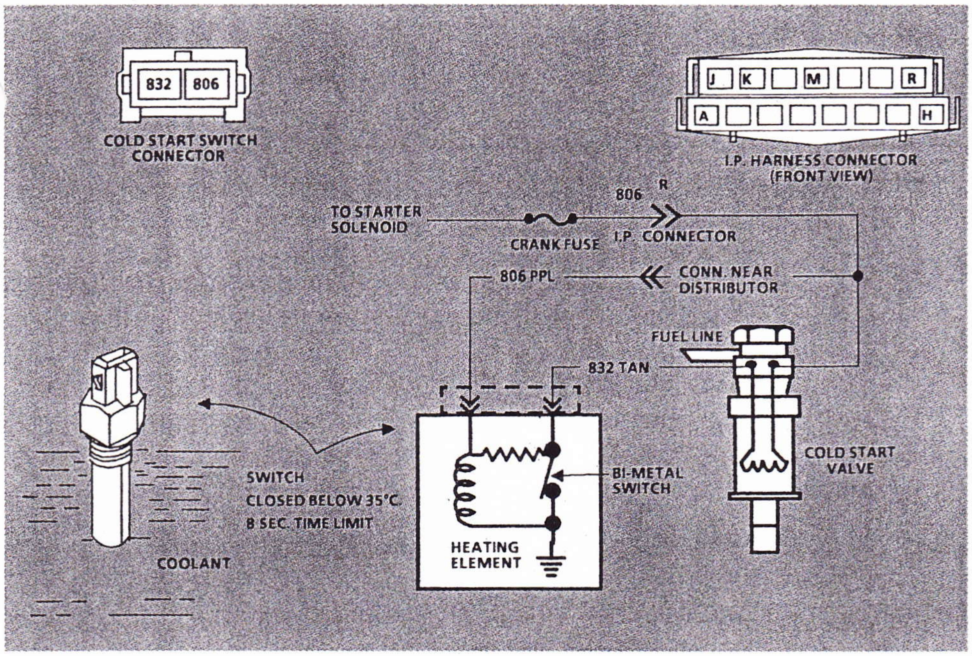


FIGURE 25–20 Cold start injector and thermo-time switch. *Courtesy of Chevrolet Motor Division, General Motors Corporation*

unlocked before the connector can be removed from the injector.

One wire of the connector supplies voltage to the injector. This voltage supply wire may connect directly to the fuse panel. It may connect to the ECU, which, in turn, connects to the fuse panel. In some systems, a resistor at the fuse panel or ECU is used to reduce the 12-volt battery supply voltage to 3 volts or less. Most other injectors are fed battery voltage (12-volts).

The second wire of the connector is a ground wire. This ground wire is routed to the ECU. The ECU energizes the injector by grounding its electrical circuit. The pulse width of the injector equals the length of time the injector circuit is grounded. Typical pulse widths range from 1 millisecond to 10 milliseconds at full load. Port fuel injection systems having four, six, or eight injectors use a special wiring harness to simplify and organize injector wiring.

IDLE SPEED CONTROL

In throttle body and port EFI systems, engine idle speed is controlled by bypassing a certain amount of airflow past the throttle valve in the throttle body housing. Two types of air by-pass systems are used, auxiliary air valves and idle air control (IAC) valves. IAC valve systems are more common.

IAC Valves

The IAC system consists of an electrically controlled stepper motor or actuator that positions the IAC valve in the air by-pass channel around the throttle valve. The IAC valve is part of the throttle body casting (Figure 25–21). The control computer (ECU) calculates the amount of air needed for smooth idling based on input data such as coolant temperature, engine load, engine speed, and battery voltage. It then signals the actuator to extend or retract the idle air control valve in the air by-pass channel.

If the engine speed is lower than desired, the ECU activates the motor to retract the IAC valve. This opens the channel and diverts more air around the throttle valve. If engine speed is higher than desired, the valve is extended and the by-pass channel is made smaller. Air supply to the engine is reduced and engine speed falls.

During cold starts idle speed can be as high as 2,100 rpm to quickly raise the temperature of the

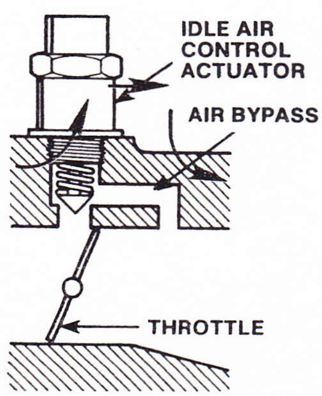


FIGURE 25–21 Components of an IAC system.

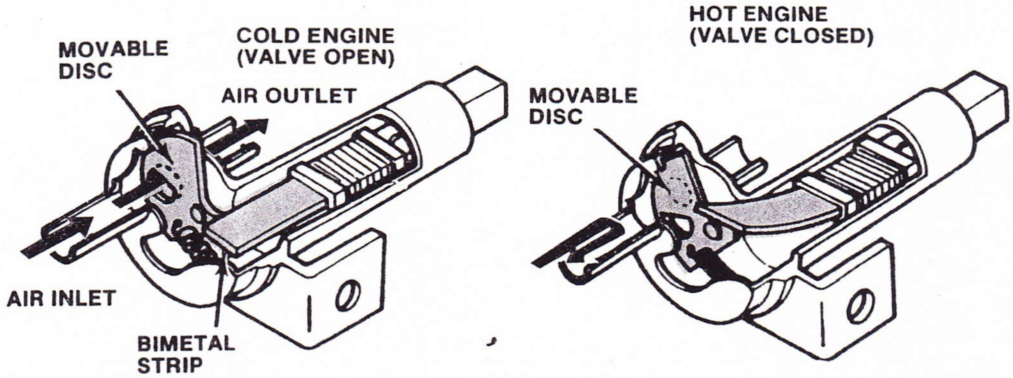


FIGURE 25–22 Operation of an auxiliary air valve. *Courtesy of Robert Bosch Corporation*

catalytic converter for proper control of exhaust emissions. Idle speed that is attained after a cold start is controlled by the ECU. The ECU maintains idle speed for approximately 40 to 50 seconds even if the driver attempts to alter it by kicking the accelerator. After this preprogrammed time interval, depressing the accelerator pedal rotates the throttle position sensor (TPS) and signals the ECU to reduce idle speed.

Auxiliary Air Valve

The major difference between an IAC valve and an auxiliary air valve is that the auxiliary air valve is not controlled by the ECU. But like the IAC system, the auxiliary air valve provides additional air during cold engine starts and warm-up.

The auxiliary air valve consists of an air by-pass channel or hose around the throttle valve, a movable plate or disc, and a heat-sensitive bimetal strip. Figure 25–22 shows how an auxiliary air valve on a port injection system operates. When the plate opens the channel, extra air bypasses the throttle. Opening is controlled by the bimetal strip. As the bimetal heats up, it bends to rotate the movable plate, gradually blocking the opening. When the device is closed, there is no auxiliary airflow.

The bimetal strip is warmed by an electric heating element powered from the run circuit of the ignition switch. This bimetal element is not a switch, but a strip that moves the movable plate directly. The auxiliary air device is independent of the cold start injector. It is not controlled by the ECU but is continuously powered when the ignition key is set to the run position.

When the engine is cold, the passage opens for extra air when the engine starts. When the engine is running and still cold, the passage is open but the heater begins operating to close it gradually. If the engine is warm at start up, the passage is closed and normal air is delivered for idle.

CONTINUOUS INJECTION SYSTEMS

Continuous injection systems (Figure 25–23) are used almost exclusively on import vehicles. The basic technology for CIS was introduced in the early 1970s and has been continuously updated and refined. During the past twenty years, continuous injection systems have gained an excellent reputation for efficiency and reliability.

The major difference between CIS and electronically controlled throttle body and port injection systems is the way in which the amount of fuel injected is controlled. In a CIS-equipped engine, the amount of fuel delivered to the cylinders is not varied by pulsing the injectors on and off. Instead CIS injectors spray fuel continuously. What does vary is the amount of fuel contained in the spray. CIS systems do this by maintaining a constant relative fuel system pressure and metering the amount of fuel to the injectors.

Basic Operation

Metering is done through a **mixture control unit**. This unit consists of an airflow sensor and a special **fuel distributor** with fuel lines running to all injectors. A control plunger in the fuel distributor is mechanically linked to the airflow sensor plate by means of a lever. As the airflow sensor measures the volume of engine intake air, its plate moves. The lever transfers this motion to the control plunger in the fuel distributor. The plunger moves up or down changing the size of the fuel metering openings in the fuel lines. This increases or decreases the volume of fuel flowing to the injectors.

Air Delivery System Air enters the system through the air filter and is measured by the airflow sensor. The amount of airflow is controlled by the throttle. The sensor plate is located in an air venturi or funnel-shaped passage in the mixture control unit. Because of the shape of this venturi or funnel, the airflow sen-

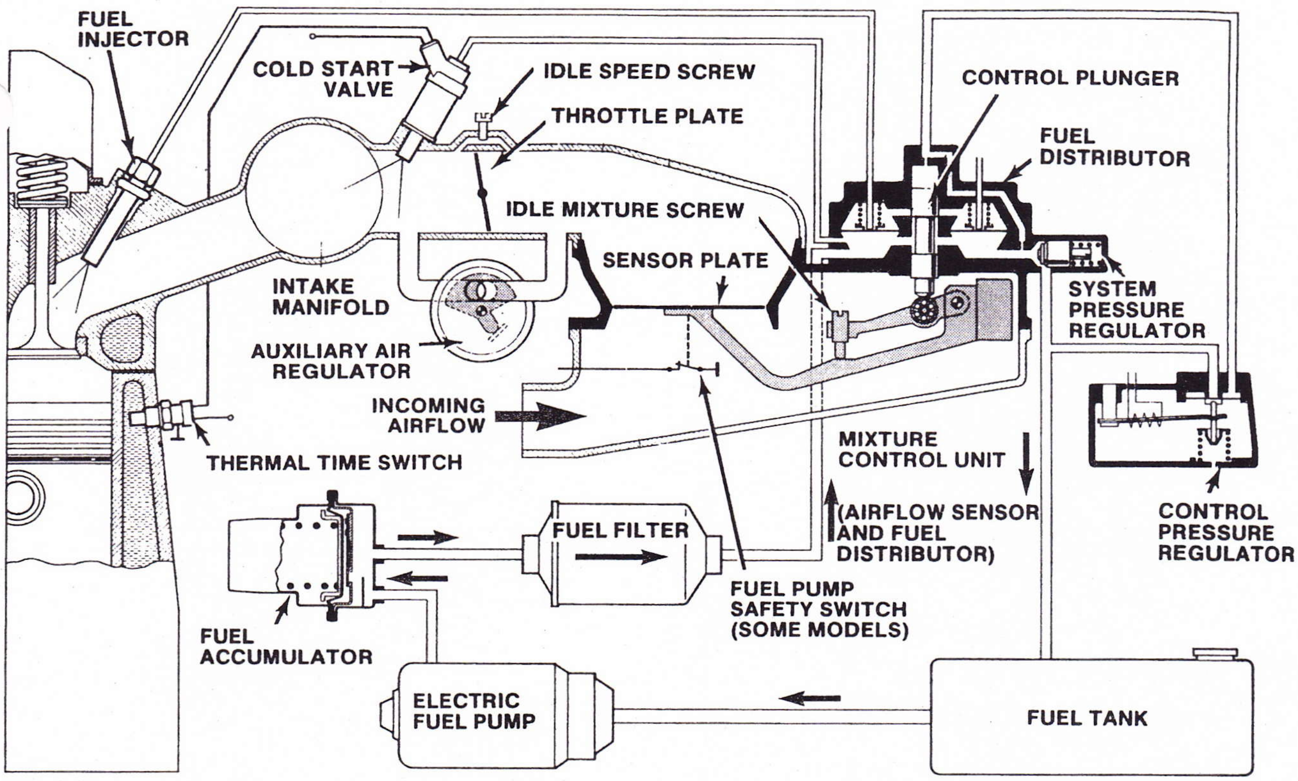


FIGURE 25–23 Components of a continuous injection system (CIS) that meters fuel mechanically. *Courtesy of Robert Bosch Corporation*

-or moves more when more air flows into the engine. Any air that enters the intake without passing the sensor plate interferes with the proper air/fuel mixture, causing the engine to run lean. The same holds true for all other types of injection systems. Proper operation of all systems depends on having no vacuum leaks.

Fuel Delivery System The main components of the CIS fuel delivery system are the fuel tank, electronic fuel pump, prefeed pump (some systems only), fuel accumulator, fuel filter, fuel distributor, and fuel injectors.

As shown in Figure 25–23, fuel is drawn from the tank by an electric fuel pump. It passes through the fuel accumulator and filter before reaching the fuel distributor in the metering control unit. Some models use a **prefeed pump** to supply the main pump. This prefeed pump helps prevent vapor lock in hot driving conditions.

The **fuel accumulator** is needed to prevent a sudden rapid rise in fuel pressure inside the fuel distributor when the vehicle is being started. Besides stabilizing the pressure, the accumulator also maintains a -st pressure within the fuel system when the engine is off. This helps eliminate vapor lock in the fuel lines.

The fuel distributor consists of a fuel control unit, pressure regulating valves for each cylinder, and a system pressure regulator. The fuel control unit consists of a slotted metering cylinder. This cylinder contains the fuel control plunger. Part of the control plunger protrudes past the fuel distributor and rests on the airflow sensor lever.

Fuel flows through the slots in the fuel metering cylinder. There is one metering slot for each engine cylinder. Control plunger movement within the metering cylinder determines the amount of fuel released to the fuel injectors. Each cylinder has its own pressure regulating valve. These valves maintain a constant pressure differential of approximately 1.5 psi on either side of the fuel metering slot. This pressure differential remains the same, regardless of the size of the slot opening. Without pressure regulating valves, the amount of fuel injected would not remain proportional to the size of the metering slot opening.

The fuel distributor also contains a pressure relief valve that regulates system pressure. Like the fuel pressure regulators used on EFI systems, this regulator maintains a constant system pressure by allowing excess fuel to return to the fuel tank via a return line.

Control Pressure Regulator A control pressure regulator (**warm-up regulator**) is also used to provide correct fuel pressure on top of the fuel control plunger. This helps regulate the engine air/fuel needs. A dampening restriction over the fuel control plunger also eliminates any fluctuations that may occur in the airflow sensor lever.

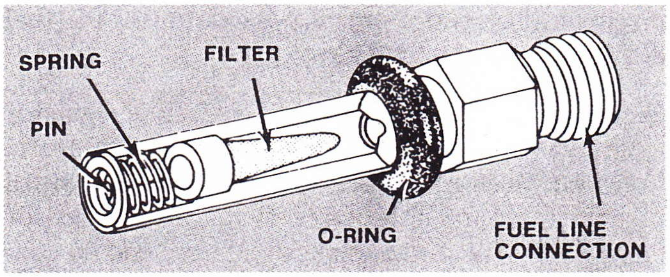


FIGURE 25–24 Typical CIS injector. *Courtesy of Robert Bosch Corporation*

FUEL INJECTORS CIS fuel injectors (Figure 25–24) open at a set fuel pressure. Once the engine is started, each injector continuously sprays finely atomized fuel into the intake port of the cylinder.

A vibrator pin or needle inside each injector helps break up and atomize the fuel. This vibrating action also helps keep the injectors from clogging. Clogging is much more common on TBI and PFI systems than on CIS-equipped engines.

When the engine is stopped, the pin and spring assembly seal off the injector to retain fuel pressure in the lines. This helps ensure quick starting.

COLD START INJECTORS AND AUXILIARY AIR VALVES CIS systems are normally equipped with a cold start injector and auxiliary air valve system to control cold starting and engine idling. These systems operate similarly to the EFI systems discussed earlier in the chapter.

CUSTOMER CARE

Recommend the periodic inspection and replacement of fuel tubing and hoses to your customers. These items should be replaced at least every three years. Otherwise, particles from deteriorating rubber hoses may plug up injectors, fuel lines, and filters. While replacing a fuel filter is not a major repair, replacing damaged injectors is expensive. ■

Oxygen Control Feedback System

Continuous injection systems can be fitted with an oxygen sensor (sometimes called **lambda sensor**) for feedback control. The sensor is mounted in the exhaust manifold so it heats up rapidly when the engine is started.

Signals from the oxygen sensor are sent to the oxygen control unit. The ECU modifies the fuel flow in the mixture control unit so the engine operates on the proper ratio. The changing exhaust gas affects the oxygen sensor and it sends a signal in a closed loop through the mixture control unit to the engine (Figure 25–25).

The oxygen control valve (sometimes called a timing or **frequency valve**) operates on signals from the oxygen control unit. It opens and closes to allow more or less fuel to return to the tank through the fuel return. This is called dwell time. By reducing the pressure in the lower part of the differential pressure valve,

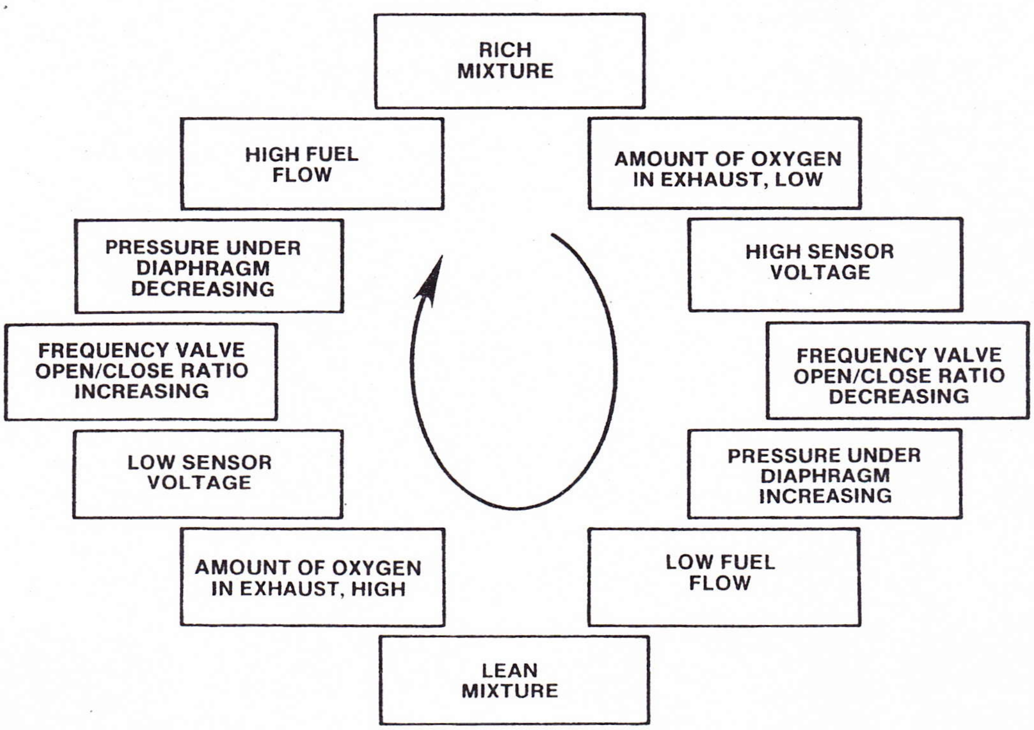


FIGURE 25–25 Closed loop operation refers to the way various components respond to each other to maintain optimum air/fuel proportioning.

fuel flow to the injector can be increased, enriching the mixture. Shortening the time that the oxygen control valve is open increases the pressure beneath the differential pressure valve diaphragm. This lessens the amount of fuel injected, leaning the mixture.

Based on a series of signals from the sensor from oxygen-rich to oxygen-lean, the control valve continually cycles from being open about 40 percent of the time to being open about 60 percent of the time averaging about 50 percent.

The oxygen control unit switches to open loop during conditions when the oxygen sensor is cold or when the engine is cold. This open loop operation holds the oxygen control valve open for a fixed amount of time. When testing the operation of the oxygen control unit and its control valve, it is possible to hear the change in sound caused by the change in open time. A better way to monitor the activity of the unit is to connect a dwellmeter across it and watch the change in cycles.

Adjusting the carbon monoxide (CO) output level is accomplished by turning a mixture screw. If the mixture adjustment is covered with a temperproof plug, this plug must be drilled and removed from the mixture control unit. The oxygen (lambda) sensor wire can be disconnected and the exhaust sample taken at the pipe provided on the exhaust manifold. As an alternate procedure, the mixture is adjusted in closed loop, with oxygen sensor connected, using a dwellmeter. Additional details are provided on the underhood decal.

CIS-E Components

As mentioned earlier, CISs can also be equipped with certain electronic controls. They combine the benefits of a basic mechanically controlled fuel injection system with simple electronic controls for enrichment, cutoff, and closed loop feedback. Economy is improved through the use of minimum enrichment during warm-up and fuel cutoff during coast.

CIS-E uses an electrohydraulic actuator in the fuel distributor, which is controlled by an ECU. The ECU receives signals from the coolant temperature sensor, throttle switch, airflow sensor plate, and the oxygen or lambda sensor.

CIS-E differs from a basic CIS in three ways. First, the airflow sensor mechanism includes a potentiometer, which signals the position and movement of the plate for acceleration enrichment. Secondly, the system pressure regulator maintains a constant pressure. It also relieves electric fuel pump pressure and maintains pressure in the system for easy restarts by controlling return fuel flow from the fuel distributor. Finally, the electrohydraulic actuator is an electromagnetic differential pressure regulator on the fuel distributor. It operates a plate valve.

System Operation The system pressure regulator maintains a constant system of primary pressure. Constant system pressure is applied to the control plunger to counter the force of the airflow sensor mechanism. There is no control pressure and no control pressure regulator.

The electrohydraulic actuator provides enrichment reducing the pressure below the diaphragm of each differential pressure valve. This has the effect of increasing the pressure at each metering slit. In turn, this increases the amount of fuel delivered. For fuel cutoff during coasting or for rpm limitation, the electrohydraulic action is reversed. A decrease in the pressure at the metering slits cuts off delivery of fuel.

SERVICING FUEL INJECTION SYSTEMS

Troubleshooting fuel injection systems requires systematic step-by-step test procedures. With so many interrelated components and sensors controlling fuel injection performance, a hit-or-miss approach to diagnosing problems can quickly become frustrating, time-consuming and costly.

Most fuel injection systems are integrated into engine control systems. The self-test modes of these systems are designed to help in engine diagnosis. Unfortunately, when a problem upsets the smooth operation of the engine, many service technicians automatically assume the computer (ECU) is at fault. But in the vast majority of cases, complaints about driveability, performance, fuel mileage, roughness, or hard starting or no-starting are due to something other than the computer itself (although many problems are caused by sensor malfunctions that can be traced using the self-test mode).

Before condemning sensors as bad, remember that weak or poorly operating engine components can often affect sensor readings and result in poor performance. For example, a sloppy timing chain, bad rings, or valves reduce vacuum and cylinder pressure, resulting in a lower exhaust temperature. This can affect the operation of a perfectly good oxygen or lambda sensor, which must heat up to approximately 600°F before functioning in its closed loop mode.

A problem like an intake manifold leak can cause a sensor, the MAP sensor in this case, to adjust engine operation to less than ideal conditions.

One of the basic rules of electronic fuel injection servicing is that EFI cannot be adjusted to match the engine, you have to make the engine match EFI. In other words, make sure the rest of the engine is sound before condemning the fuel injection and engine control components.

Preliminary Checks

The best way to approach a problem on a vehicle with electronic fuel injection is to treat it as though it had no electronic controls at all. As the previous examples illustrate, any engine is susceptible to problems that are unrelated to the fuel system itself. Unless all engine support systems are operating correctly, the control system does not operate as designed.

Before proceeding with specific fuel injection checks and electronic control testing, be certain of the following.

- The battery is in good condition, fully charged, with clean terminals and connections.
- The charging and starting systems are operating properly.
- All fuses and fusible links are intact.
- All wiring harnesses are properly routed with connections free of corrosion and tightly attached.
- All vacuum lines are in sound condition, properly routed, and tightly attached.
- The PCV system is working properly and maintaining a sealed crankcase.
- All emission control systems are in place, hooked up, and operating properly.
- The level and condition of the coolant/antifreeze is good, and the thermostat is opening at the proper temperature.
- The secondary spark delivery components are in good shape with no signs of crossfiring, carbon tracking, corrosion, or wear.
- The base timing and idle speed are set to specifications.
- The engine is in good mechanical condition.
- The gasoline in the tank is of good quality and has not been substantially cut with alcohol or contaminated with water.

EFI SYSTEM COMPONENT CHECKS

In any electronic throttle body or port injection system three things must occur for the system to operate.

1. An adequate air supply must be supplied for the air/fuel mixture.
2. A pressurized fuel supply must be delivered to properly operating injectors.
3. The injectors must receive a trigger signal from the control computer.

If all of these preliminary checks do not reveal a problem, proceed to test the electronic control system and fuel injection components.

Some older control systems require involved test procedures and special test equipment, but most newer designs have a self-test program designed to help diagnose the problem. These self-tests perform a number of checks on components within the system. Input sensors, output devices, wiring harnesses, and even the electronic control computer itself may be among the items tested.

The results of the testing are converted into trouble codes (Figure 25–26) that the technician may read using special test equipment, a testlight, a malfunction indicator lamp (**MIL**), or an analog voltmeter. The meaning of trouble codes vary from manufacturer to manufacturer, year to year, and model to model; so it is important to have the appropriate service manuals.

Always remember that trouble codes only indicate the particular circuit in which a problem has been detected. They do not pinpoint individual components. So if a code indicates a defective lambda or oxygen sensor, the problem could be the sensor itself, the wiring to it, or its connector. Trouble codes are not a signal to replace components. They signal that a more thorough diagnosis is needed in that area.

The following sections outline general troubleshooting procedures for the most popular EFI and CIS designs in use today.

Air System Checks

In an injection system (particularly designs that rely on airflow meters or mass airflow sensors), all the air entering the engine must be accounted for by the air measuring device. If it is not, the air/fuel ratio becomes overly lean. For this reason, cracks or tears in the plumbing between the airflow sensor and throttle body are potential air leak sources that can affect the air/fuel ratio.

During a visual inspection of the air control system, pay close attention to these areas, looking for cracked or deteriorated ductwork. Also make sure all induction hose clamps are tight and properly sealed. Look for possible air leaks in the crankcase, for example, dipstick tube and oil filter cap. Any extra air entering the intake manifold through the PCV system is not measured either and can upset the delicately balanced air/fuel mixture at idle.

Airflow Sensor When looking for the cause of a performance complaint that relates to poor fuel economy, erratic performance/hesitation or hard starting, make the following checks to determine if the airflow

Code	Circuit Affected or Possible Cause
12	No distributor reference pulses to the ECU. This code is not stored in memory and flashes only while the fault is present. Normal code with ignition on, engine not running.
13	Oxygen sensor circuit. The engine must run up to 4 minutes at part-throttle under road load before this code sets.
14	Shorted coolant sensor circuit. The engine must run 2 minutes before this code sets.
15	Open coolant sensor circuit. The engine must run 5 minutes before this code sets.
21	Throttle position sensor (TPS) circuit voltage high (open circuit or misadjusted TPS). The engine must run 10 seconds at specified curb idle speed before this code sets.
22	Throttle position sensor (TPS) circuit voltage low (grounded circuit or misadjusted TPS). Engine must run 20 seconds at specified curb idle speed to set code.
23	M/C solenoid circuit open or grounded.
24	Vehicle speed sensor (VSS) circuit. The vehicle must operate up to 2 minutes at road speed before this code sets.
32	Barometric pressure sensor (BARO) circuit low.
34	Vacuum sensor or manifold absolute pressure (MAP) circuit. The engine must run up to 2 minutes at specified curb idle before this code sets.
35	Idle speed control (ISC) switch circuit shorted. (Up to 70% TPS for over 5 seconds.)
41	No distributor reference pulses to the ECU at specified engine vacuum. This code stores in memory.
42	Electronic spark timing (EST) bypass circuit or EST circuit grounded or open.
43	Electronic spark control (ESC) retard signal for too long a time; causes retard in EST signal.
44	Lean exhaust indication. The engine must run 2 minutes in closed loop and at part-throttle before this code sets.
45	Rich exhaust indication. The engine must run 2 minutes in closed loop and at part throttle before this code sets.
51	Faulty or improperly installed calibration unit (PROM). It takes up to 30 seconds before this code will set.
53	Exhaust gas recirculation (EGR) valve vacuum sensor has seen improper EGR vacuum.
54	Shorted M/C solenoid circuit or faulty ECU.

FIGURE 25–26 Common ECU trouble codes.

sensor (all types except CIS) is at fault. Start by removing the air intake duct from the airflow sensor to gain access to the sensor flap. Check for binding, sticking, or scraping by rotating the sensor flap (evenly and carefully) through its operating range. It should move freely, make no noise, and feel smooth.

On some systems, the movement of the sensor flap turns on the fuel pump. If the system is so equipped, turn on the ignition. Do not start the engine. Move the flap toward the open position. The electric fuel pump should come on as the flap is opened. If it does not, turn off the ignition, remove the sensor harness, and check for specific resistance values with an ohmmeter at each of the sensor's terminals.

On other models it is possible to check the resistance values of the potentiometer by moving the air flap, but in either case a service manual is needed to identify the various terminals and to look up resistance specifications.

On systems that use a mass airflow meter or manifold pressure sensor to measure airflow, other than checking for good electrical connections, there are usually no actual physical checks. However, a hand-held scan tool can be plugged into the diagnostic connector on some models to check for proper voltage values.

SHOP TALK

To quickly diagnose an intermittent failure of GM's hot film mass airflow meter (MAF), start the engine, let it idle, and lightly tap on the sensor with a plastic mallet or screwdriver handle. If the engine stalls, runs worse, or the idle quality improves while tapping on the sensor, the MAF meter is probably defective and should be replaced. Similarly, if the engine does not start or idles poorly, unplug the MAF. If the engine starts or runs better with the sensor unplugged, the sensor is defective and should be replaced. ■

Throttle Body Remove the air duct from the throttle assembly and check for carbon buildup inside the throttle bore and on the throttle plate. Soak a cloth with carburetor solvent and wipe the bore and throttle plate to remove light to moderate amounts of carbon residue. Also, clean the backside of the throttle plate. Then, remove the idle air control valve from the throttle body (if so equipped) and clean any carbon deposits from the pintle tip and the IAC air passage.

Fuel System Checks

If the air control system is in working order, move on to the fuel delivery system. It is important to always remember that fuel injection systems operate at high fuel pressure levels. This pressure must be relieved before any fuel line connections can be broken. Spraying gasoline (under a pressure of 35 psi or more) on a hot engine creates a real hazard when dealing with a liquid that has a flash point of –45°F.

Follow the specific procedures given in the service manual when relieving the pressure in the fuel lines. If the procedures are not available, a safe alternative procedure is to apply 20 to 25 inches of vacuum to the externally mounted fuel pressure regulator (with a hand vacuum pump connected to the manifold control line of the regulator), which bleeds fuel pressure back into the tank (Figure 25–27). If the vehicle does not have an externally mounted regulator, or a service valve or injector to energize, use a towel to catch excess fuel, while slowly breaking a fuel line connection. This method should only be used when all other possibilities have been tried.

CAUTION:

Dispose of the fuel-soaked rag in a fireproof container. ■

Fuel Delivery When dealing with an alleged fuel complaint that is preventing the vehicle from starting, the first step (after spark, compression, etc., have been verified) is to determine if fuel is reaching the cylinders (assuming there is gasoline in the tank). Checking for fuel delivery is a simple operation on throttle body systems. Remove the air cleaner, crank the engine, and watch the injector for signs of a spray pattern. If a better view of the injector's operation is required, an ordinary strobe light does a great job of highlighting the spray pattern.

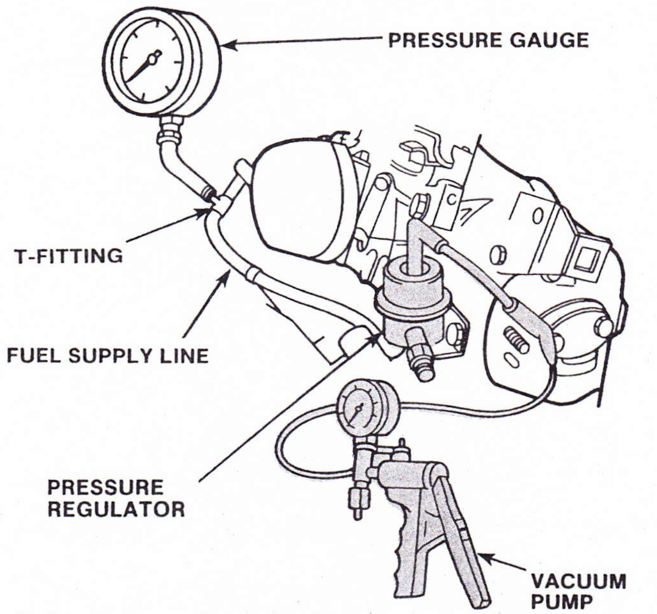


FIGURE 25–27 With an externally mounted fuel pressure regulator, it's possible to bleed off system pressure into the fuel tank using a hand vacuum pump.

It is impossible to visually inspect the spray pattern and volume of port system injectors. However, an accurate indication of their performance can be obtained by performing simple fuel pressure and fuel volume delivery tests. See the service manual for details.

Low fuel pressure can cause a no-start or poor-run problem. It can be caused by a clogged fuel filter, a faulty pressure regulator, or a restricted fuel line anywhere from the fuel tank to the fuel filter connection.

If a fuel volume test shows low fuel volume, it can indicate a bad fuel pump or blocked or restricted fuel line. When performing the test, visually inspect the fuel for signs of dirt or moisture. These indicate the fuel filter needs replacement.

High fuel pressure readings will result in a rich-running engine. A restricted fuel return line to the tank or a bad fuel regulator may be the problem. To isolate the cause of high pressure, relieve system pressure and connect a tap hose to the fuel return line. Direct the hose into a container and energize the fuel pump. If fuel pressure is now within specifications, the fuel return line is blocked. If pressure is still high, the pressure regulator is faulty.

If the first fuel pressure reading is within specs, but the pressure slowly bleeds down, there may be a leak in the fuel pressure regulator, fuel pump check valve, or the injectors themselves. Remember, hard starting is a common symptom of system leaks.

Injector Checks

A fuel injector is nothing more than a solenoid-actuated fuel valve. Its operation is quite basic in that as long as it is held open and the fuel pressure remains steady, it delivers fuel until it is told to stop.

Because all fuel injectors operate in a similar manner, fuel injector problems tend to exhibit the same failure characteristics. The main difference is that in a TBI design, generally all cylinders suffer if the injectors malfunction, whereas in port systems the loss of one injector is not as crucial.

An injector that does not open causes hard starts on port-type systems and an obvious no-start on single-point TBI designs. An injector that is struck partially open causes loss of fuel pressure (most noticeably after the engine is stopped and restarted within a short time period) and flooding due to raw fuel dribbling into the engine. In addition to a rich-running engine, a leaking injector also causes the engine to diesel or run on when the ignition is turned off.

Checking Voltage Signals When an injector is suspected as the cause of a problem, the first step is to determine if the injector is receiving a signal (from the control computer) to fire. Fortunately, determining if the injector is receiving a voltage signal is easy and requires simple test equipment. Unfortunately, the location of the injector's electrical connector can make this simple voltage check somewhat difficult. For example, on some recent Chevrolet 2.8 liter V-6 engines, the cover must be removed from the cast aluminum plenum chamber that is mounted over the top of the engine before the injector can be accessed (Figure 25–28).

Once the injector's electrical connector has been removed, check for voltage at the injector using an ordinary test light or a convenient **noid** light that plugs into the connector (Figure 25–29). After making the test connections, crank the engine. A series of rapidly flickering lights indicates the computer is doing its job and supplying voltage or a ground to open the injector.

When performing this test, keep off the accelerator pedal. On some models, fully depressing the accelerator pedal activates the clear flood mode, in which the voltage signal to the injectors is automatically cut off. Technicians unaware of this waste time tracing a phantom problem.

If sufficient voltage is present after checking each injector, check the electrical integrity of the injectors themselves. Use an ohmmeter to check each injector winding for shorts, opens, or excessive resistance. Compare resistance readings to the specifications found in the service manual.

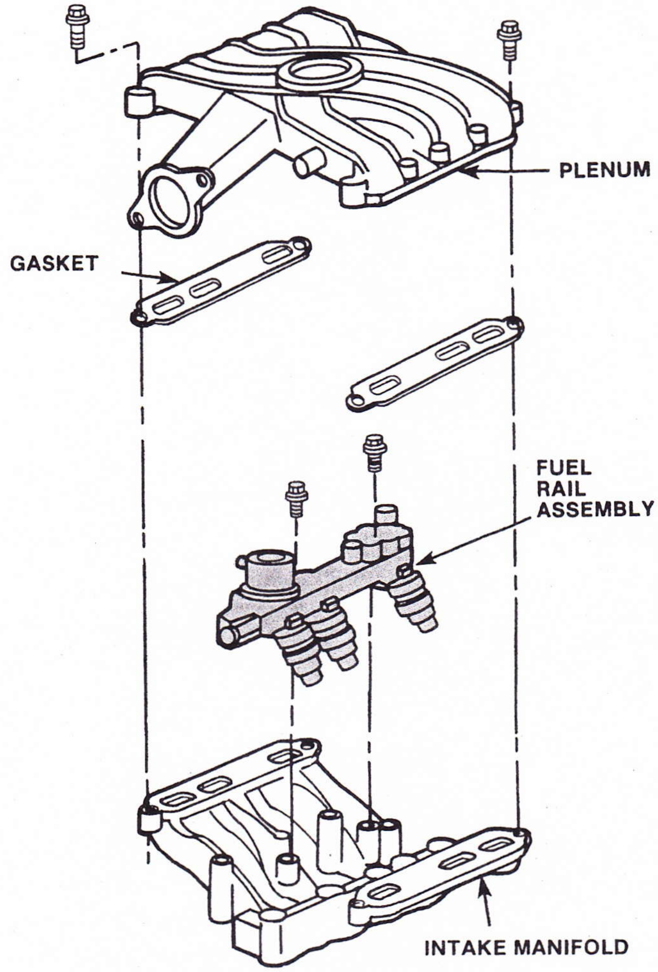


FIGURE 25–28 To access the injectors on a Chevy 2.8L V-6, the air plenum must be removed.

Injector Balance Test If the injectors are electrically sound, perform an injector pressure balance test. This test will help isolate a clogged or dirty injector.

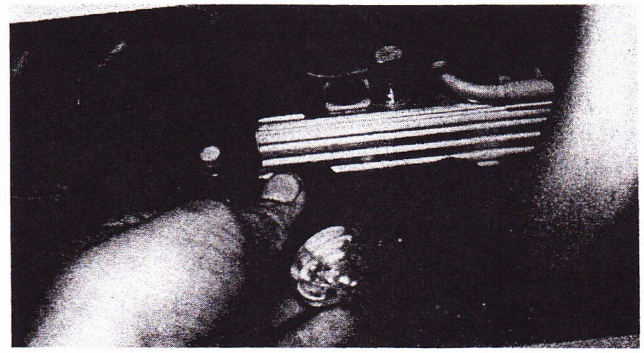


FIGURE 25–29 Checking for voltage at the injector using a noid light.

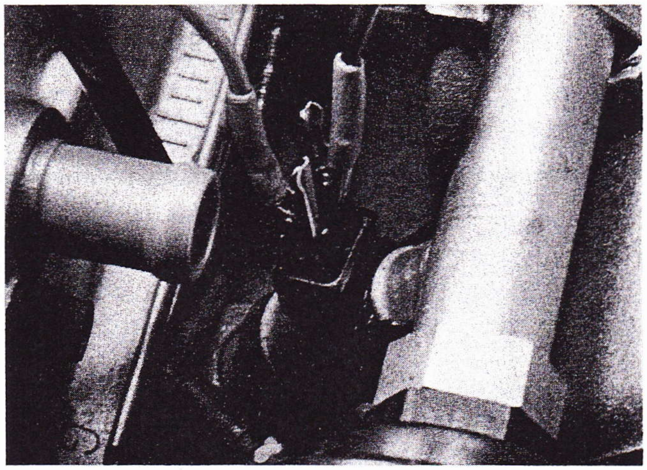


FIGURE 25–30 Performing an injector pressure balance test.

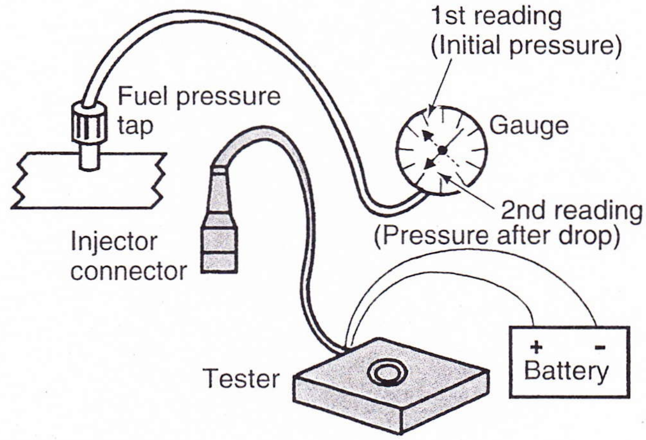


FIGURE 25–31 Injector power balance tester. *Courtesy of Oldsmobile Division, General Motors Corporation*

Photo Sequence 14 shows a typical procedure for testing injector balance. An electronic injector pulse tester is used for this test. Each injector is energized while observing a fuel pressure gauge to monitor the drop in fuel pressure. The tester is designed to safely pulse each injector for a controlled length of time. The tester is connected to one injector at a time (Figure 25–30). To prevent oil dilution, the electrical connectors to the other injectors are removed. The ignition is turned on until a maximum reading is on the pressure gauge. That reading is recorded and the ignition turned off. With the tester, activate the injector and record the pressure reading, after the needle has stopped pulsing. This same test is performed on each injector.

The difference between the maximum and minimum reading is the pressure drop. Ideally, each injector should drop the same amount when opened. A variation of 1.5 to 2 psi (10 kPa) or more is cause for concern. If there is not pressure drop or a low pressure drop, suspect a plugged injector. A higher than average pressure drop indicates a rich condition. If there are inconsistent readings, the nonconforming injectors either have to be cleaned or replaced.

Injector Power Balance Test The injector power balance test is a good method of checking injectors on vehicles with no-start problems (Figure 25–31). When the vehicle runs, several other tests are possible. The injector power balance test is an easy method of determining if an injector is causing a miss.

To perform this test, first hook up a tachometer and fuel pressure gauge to the engine. Once all gauges are in place, start the engine and allow it to reach operating temperature. As soon as the idle stabilizes, unplug each injector one at a time. Note the rpm drop and pressure gauge reading. To ensure accurate test results on many electronic systems, it may be necessary to disconnect some type of idle air control device to prevent the computer from trying to compensate for the unplugged injector.

After recording the rpm and fuel pressure drop, reconnect the injector, wait until the idle stabilizes, and move on to the next one. Note the rpm and pressure drop each time. If an injector does not have much effect on the way the engine runs, chances are it is either clogged or electrically defective. It is a good idea to back up the power balance test with an injector resistance check, pressure balance test, or noid light check.

Alternative Checks

An ohmmeter can be used to test the electrical soundness of an injector. Connect the ohmmeter across the injector terminals (Figure 25–32) after the wires to the injector have been disconnected. If the meter reading is infinite, the injector winding is open. If the meter shows more resistance than the specifications call for, there is high resistance in the winding. A reading that is lower than the specifications indicates that the winding is shorted. If the injector is even a little bit out of specifications, it must be replaced.

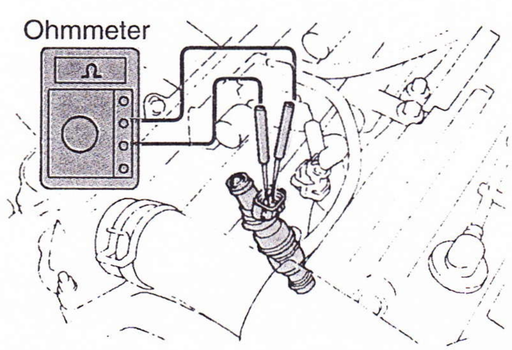
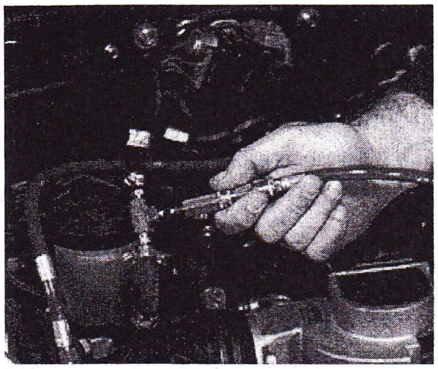


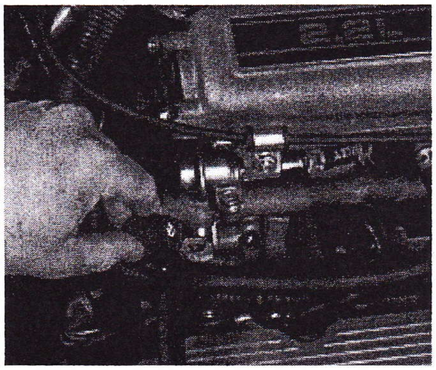
FIGURE 25–32 An ohmmeter can be connected across the injector terminals to test the injector's winding. *Courtesy of Toyota Motor Corporation*

PHOTO SEQUENCE 14

TYPICAL PROCEDURE FOR TESTING INJECTOR BALANCE

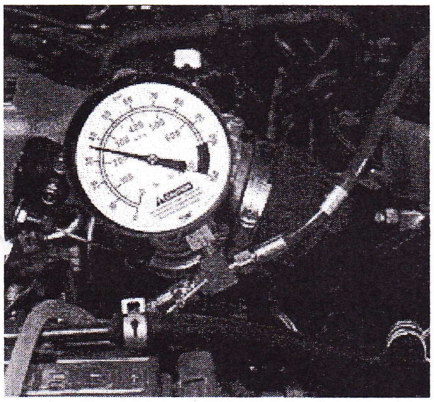


P14–1 Connect the fuel pressure gauge to the Schrader valve on the fuel rail.

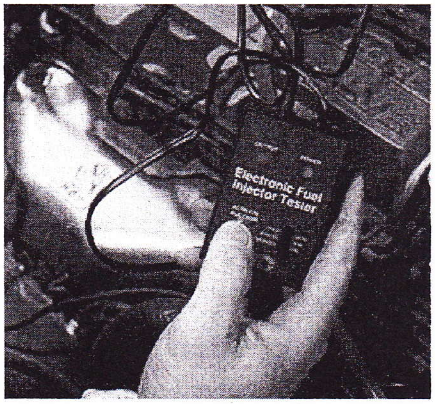


P14–2 Disconnect the number 1 injector, and connect the injector tester lead to the injector terminals.

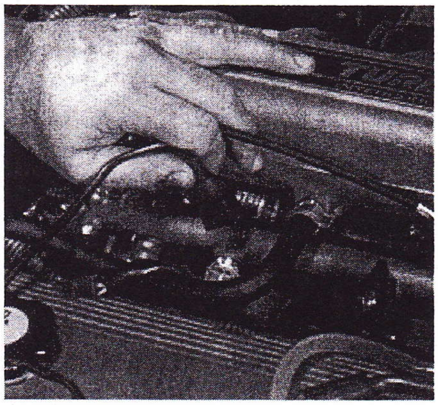
P14–3 Connect the injector tester power supply leads to the battery terminals with the proper polarity.



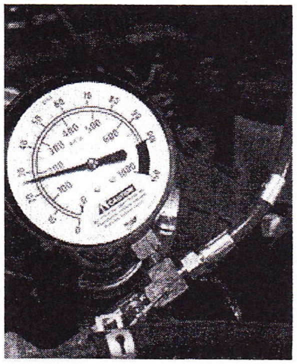
P14–4 Cycle the ignition switch several times until the specified pressure appears on the pressure gauge.



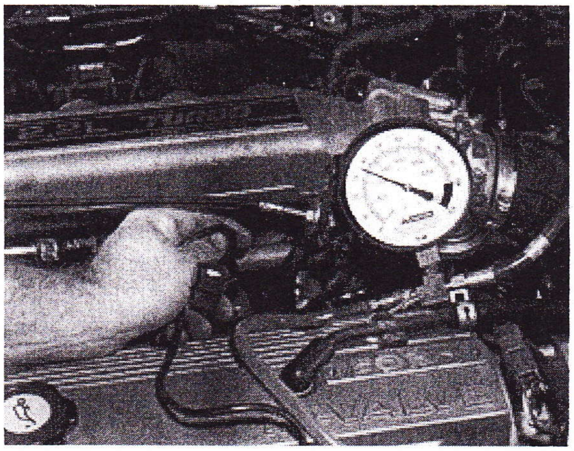
P14–5 Push the injector tester switch and record the pressure on the pressure gauge.



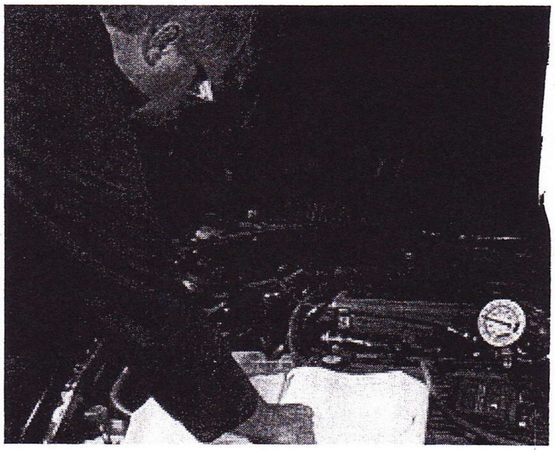
P14–6 Move the injector tester lead to the number 2 injector and cycle the ignition switch several times to restore the fuel pressure.



P14–7 Touch the injector tester switch and observe the fuel pressure.



P14–8 Move the injector tester lead to the number 3 injector and cycle the ignition switch several times to restore the fuel pressure.



P14–9 Touch the injector tester switch and observe the fuel pressure. Follow the same procedure to test number 4 injector. Compare the pressure readings to the vehicle's specifications.

If the injector's electrical leads are difficult to access, an injector power balance test is hard to perform. As an alternative, start the engine and use a technician's stethoscope to listen for correct injector operation. A good injector makes a rhythmic clicking sound as the solenoid is energized and de-energized several times each second. If a clunk-clunk instead of a steady click-click is heard, chances are the problem injector has been found. Cleaning or replacement is in order. If a stethoscope is not handy, use a thin steel rod, wooden dowel, or fingers to feel for a steady on/off pulsing of the injector solenoid.

Another way to isolate an offending cylinder when injector access is limited is to perform the more traditional cylinder power balance test and disable the spark plugs instead of the injectors. (Remember to bypass the idle air control.) Following the same warm-up and idle stabilizing procedures, watch the rpm drop and note any change in idle quality as each plug is shorted. If a lazy or dead cylinder is located, concentrate efforts on the portion of the fuel or ignition system pertaining to that cylinder (assuming, of course, no mechanical problems are present).

WARNING!

Any time cylinders are shorted during a power balance test, make the readings as quickly as possible. Prolonged operation of a shorted cylinder causes excessive amounts of unburned fuel to accumulate inside the catalytic converter and increase the risk of premature converter failure. ■

Oscilloscope Checks

An oscilloscope can be used to monitor the injector's pulse width and duty cycle when an injector-related problem is suspected. As covered earlier in the chapter, the pulse width is the time in milliseconds the injector is energized. The duty cycle is the percentage of on-time to total cycle time.

To check the injector's firing voltage on the scope, a typical hookup involves connecting the scope's positive lead to the injector supply wire and the scope's negative lead to an engine ground. Even though these connections are considered typical, it is still a good idea to read the instruction manual provided with the test equipment before making connections.

With the scope set on the low voltage scale and the pattern adjusted to fill the screen, a square-shaped voltage signal should be present with the engine running or cranking (Figure 25–33). If the voltage pattern reads higher than normal, excessive resistance in the injector circuit is indicated. Conversely, a low-

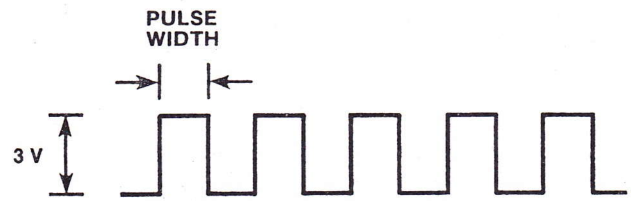


FIGURE 25–33 The trace pattern of the injector voltage pulse should be a square sine wave pattern.

voltage trace indicates low-circuit resistance. If the pattern forms a continuous straight line, it means the injector is not functioning due to an open circuit somewhere in the injector's electrical circuit.

USING SERVICE MANUALS

Consult the service manual for pulse width and duty cycle specifications for the particular vehicle being worked on. The service manual also contains fault code diagnosis for a wide range of fuel injection system tests. ■

INJECTOR CLEANING

Since a single injector can cost up to several hundred dollars, arbitrarily replacing injectors when they are not functioning properly, especially on multiport systems, can be an expensive proposition. If injectors are electrically defective, replacement is the only alternative. However, if the vehicle is exhibiting rough idle, stalling, slow or uneven acceleration, the injectors may just be dirty and require a good cleaning.

Before covering the typical cleaning systems available and discussing how they are used, several cleaning precautions are in order. First, never soak an injector in cleaning solvent. Not only is this an ineffective way to clean injectors, but it most likely destroys the injector in the process. Also, never use a wire brush, pipe cleaner, toothpick, or other cleaning utensil to unblock a plugged injector. The metering holes in injectors are drilled to precise tolerances. Scraping or reaming the opening results in a clean injector that is no longer an accurate fuel-metering device.

CUSTOMER CARE

After servicing a clogged injector, remove the fuel filter, open it up with a pipe cutter, slice the element with a razor blade, and examine the interior. If you find excessive rust particles or other contaminants, show the filter to the customer. Then recom-

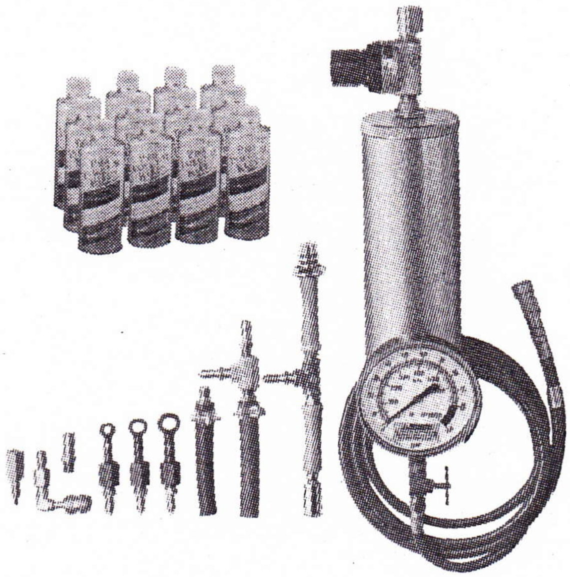


FIGURE 25–34 Injector cleaner that operates with compressed air. *Courtesy of OTC Division of SPX Corporation*

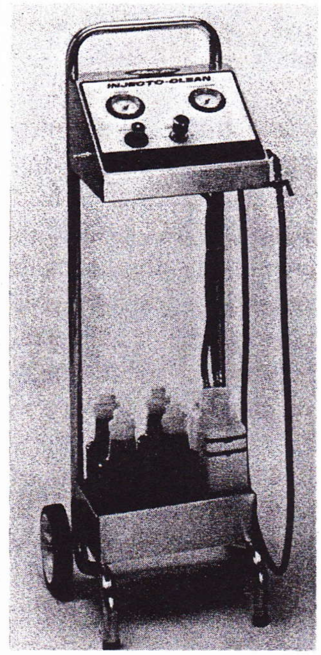


FIGURE 25–35 State-of-the-art fuel injector cleaning system.

mend that the vehicle fuel tank be removed and cleaned and the fuel line blown out. If the customer declines the recommendation, make a big note on the repair order and customer receipt that his fuel filter replacement should be done more often than specified in the owner's manual. Showing the customer the evidence of contamination also justifies the repairs already made. ■

Always use an approved on-the-car cleaning system (Figure 25–34) or injector cleaning bench to effectively clean clogged injectors. On-the-car cleaners are by far the most popular and practical method.

The basic premise of all injection cleaning systems is similar in that some type of cleaning chemical is run through the injector in an attempt to dissolve deposits that have formed on the injector's tip. The methods of applying the cleaner can range from single shot, premixed, pressurized spray cans to self-mix, self-pressurized chemical tanks resembling bug sprayers. The pre-mixed, pressurized spray can systems are fairly simple and straightforward to use since the technician does not need to mix, measure, or otherwise handle the cleaning agent.

Other systems require the technician to assume the role of chemist and mix up a desired batch of cleaning solution for each application. The chemical solution then is placed in a holding container and pressurized by hand pump or shop air to a specified operating pressure.

The more advanced units feature electrically operated pumps neatly packaged in roll-around cabinets that are quite similar in design to an A/C charging station (Figure 25–35).

SHOP TALK

If the fuel delivery system is equipped with a cold start injector, make sure it gets cleaned along with the primary injectors. This step is especially critical if the owner complains of cold starting problems.

To effectively clean the cold start injector, hook up the cleaning system and remove the cold start injector from the engine. Open the control valve on the solvent containers and use an electronic triggering device to manually pulse the injector. Direct the spray into a suitable container. Pulse the injector until the spray pattern looks healthy.

On models where the cold start injector is not readily accessible, check the fuel flow through the injector before and after the cleaning procedure. Pulse as necessary until the maximum flow through the injector is obtained. ■

INJECTOR REPLACEMENT

Consult the vehicle's service manual for instructions on removing and installing injectors. Before installing the new one, always check to make sure the sealing O-ring is in place (Figure 25–36). Also, prior to installation, lightly lubricate the sealing ring with engine oil or automatic transmission fluid (avoid using silicone grease, which tends to clog the injectors) to prevent seal distortion or damage.

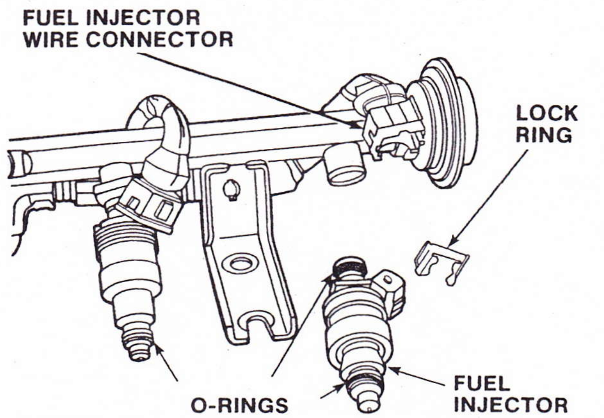


FIGURE 25–36 Before replacing an injector, inspect the sealing O-ring.

PROCEDURES
Cleaning Injectors

1. Attach the cleaner's service hose to the fuel rail following the same procedure used when hooking up a fuel pressure gauge.
2. Disable the fuel pump as per the car manufacturer's instructions (for example, pull fuel pump fuse, disconnect lead at pump, etc.). Clamp off the fuel pump return line at the flex connection to prevent the cleaner from seeping into the fuel tank. For an extra margin of safety, clamp off the inlet line also.
3. Before starting the engine, open the cleaner's control valve one-half turn or so to prime the injectors and then start the engine.
4. If available, set and adjust the cleaner's pressure gauge to approximately 5 psi below the operating pressure of the injection system and let the engine run at 1,000 rpm for 10 to 15 minutes or until the cleaning mix has run out. If the engine stalls during cleaning, simply restart it.
5. Run the engine until the recommended amount of fluid is exhausted and the engine stalls. Shut off the ignition, remove the cleaning setup, and reconnect the fuel pump.
6. After removing the clamping devices from around the fuel lines, start the car. Let it idle for 5 minutes or so to remove any leftover cleaner from the fuel lines.
7. On the more severely clogged cases, the idle improvement should be noticeable almost immediately. With more subtle performance improvements, an injector balance test verifies the cleaning results. Once the injectors are clean, recommend the use of an in-tank cleaning additive or a detergent-laced fuel.

Photo Sequence 15 outlines a typical procedure for removing and installing an injector. Always refer to the service manual for the exact procedure for the engine being serviced.

IDLE ADJUSTMENT

In a fuel injection system, idle speed is regulated by controlling the amount of air allowed to bypass the airflow sensor or throttle plates. When presented with a car that tends to stall, especially when coming to a stop, or one that idles too fast, look for obvious problems like binding linkage and vacuum leaks first. If no problems are found, go through the minimum idle checking/setting procedure described on the underhood decal. The instructions listed on the decal spell out the necessary conditions that must be met prior to attempting an idle adjustment. These adjustment procedures can range from a simple twist of a throttle stop screw (Figure 25–37) to more involved procedures requiring circumvention of idle air control devices, removal of casting plugs, or recalibration of the throttle position sensor. Specific idle adjustment procedures can also be found in the service manual.

On engines that have a provision for adjusting idle speed and mixture, the idle speed should be adjusted before adjusting the air/fuel mixture. The mixture is adjusted by turning the mixture adjustment screw clockwise to decrease the by-pass air, which enriches the mixture. This also increases the CO in the exhaust. Backing out the mixture screw increases the by-pass air, leaning the mixture and reducing CO. Because some electronic fuel injection engines run so lean, the CO meter might not react to the mixture

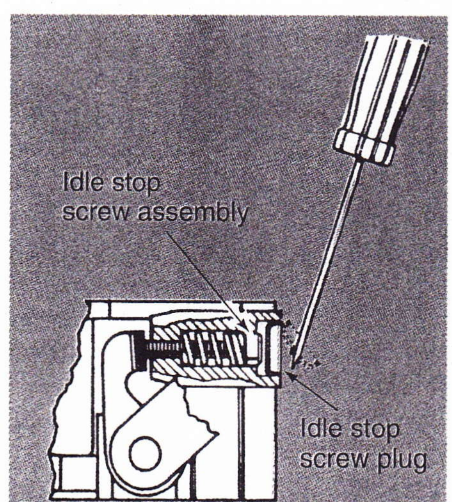
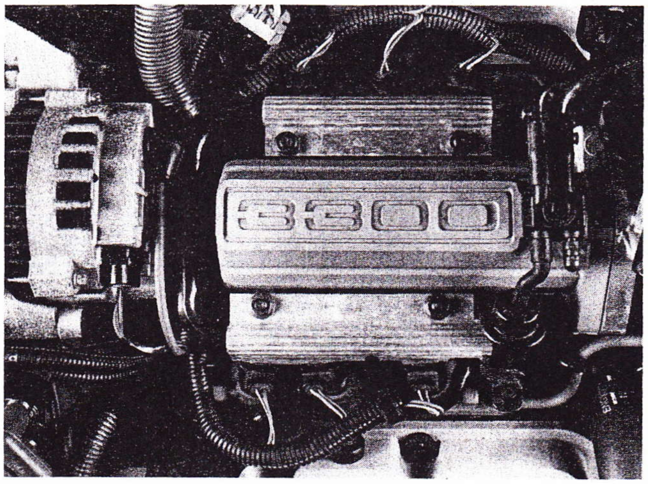


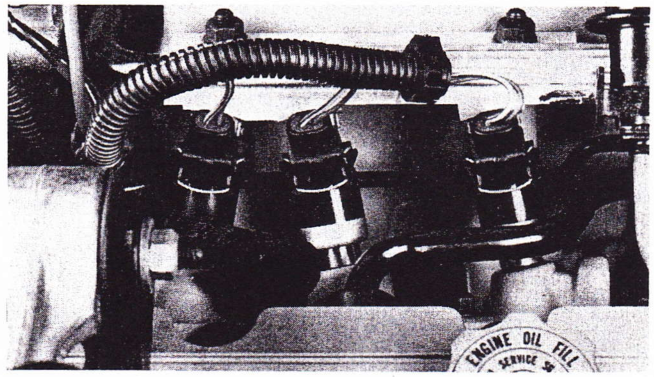
FIGURE 25–37 Adjusting the idle stop screw for minimizing air adjustment. *Courtesy of Chevrolet Motor Division, General Motors Corporation*

PHOTO SEQUENCE 15

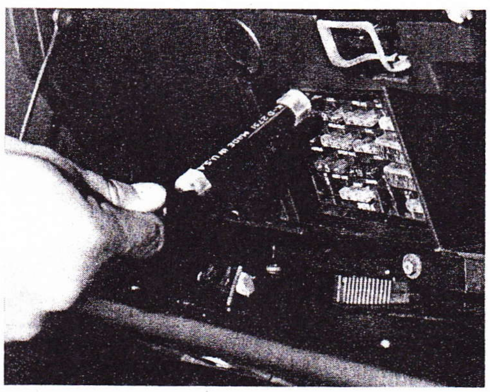
REMOVING AND REPLACING A FUEL INJECTOR ON A PFI SYSTEM



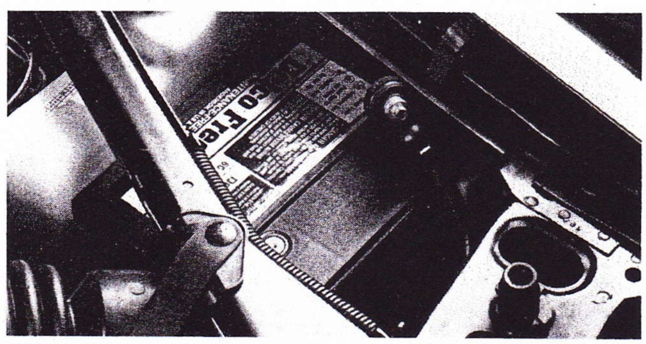
P15–1 Often an individual injector needs to be replaced. Random disassembly of components and improper procedures can result in damage to one of various systems located near the injectors.



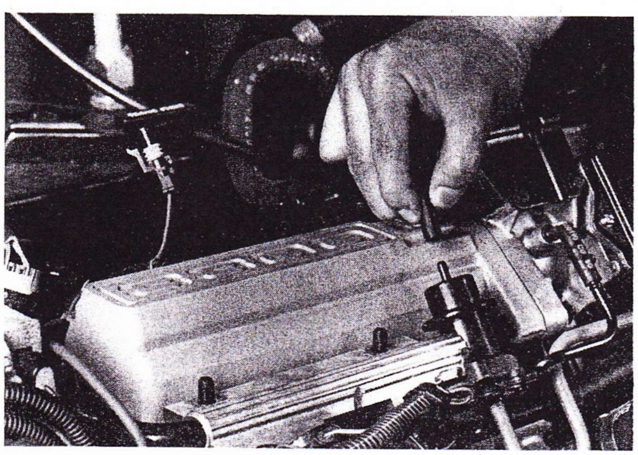
P15–2 The injectors are normally attached to a fuel rail and inserted into the intake manifold or cylinder head. They must be positively sealed because high pressure fuel leaks can cause a serious safety hazard.



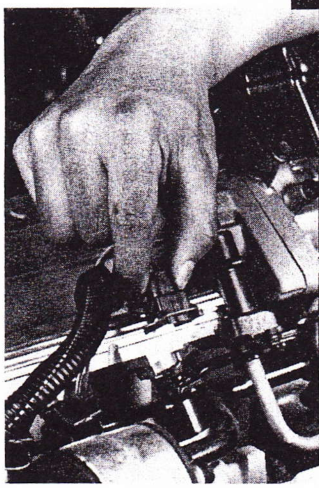
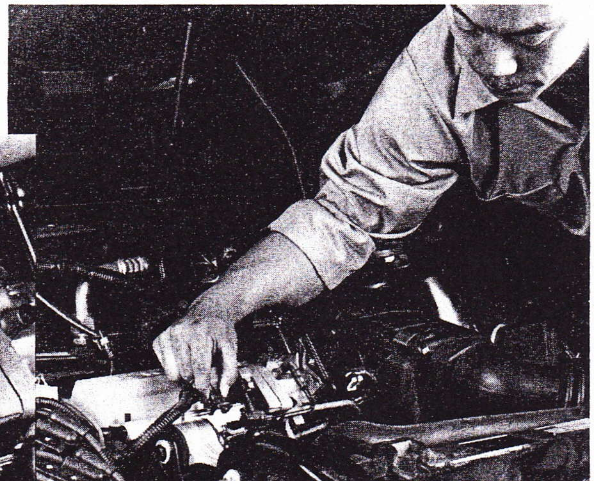
P15–3 Prior to loosening any fitting in the fuel system, the fuel pump fuse should be removed.



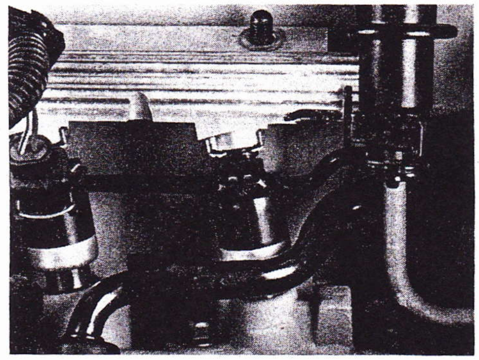
P15–4 As an extra precaution, many technicians disconnect the negative cable of the battery.



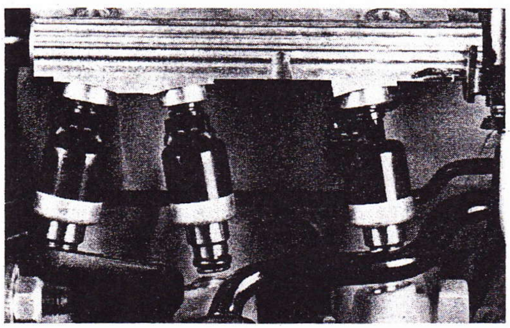
P15–5 To remove the fuel injector, the fuel rail must be able to move away from the engine. The rail holding brackets should be unbolted and the vacuum line to the pressure regulator disconnected.

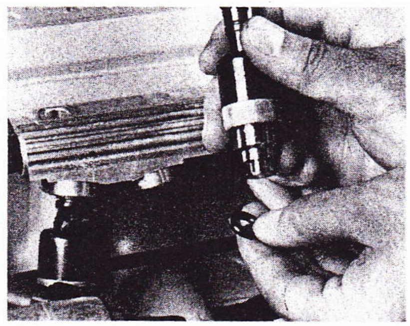
P15–6 Disconnect the wiring harness to the injectors by depressing the center of the attaching wire clip.



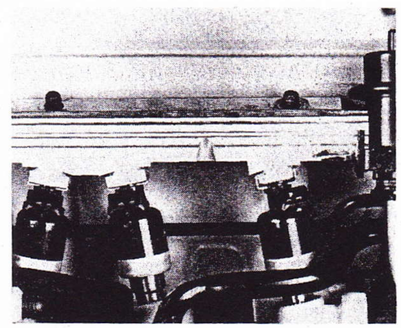
P15–7 The injectors are held to the fuel rail by a clip that fits over the top of the injector. An O-ring at the top and at the bottom of the injector seals the injector.



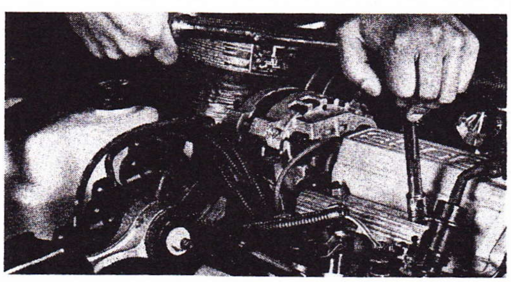
P15–8 Pull up on the fuel rail assembly. The bottom of the injectors will pull out of the manifold while the tops are secured to the rail by clips.



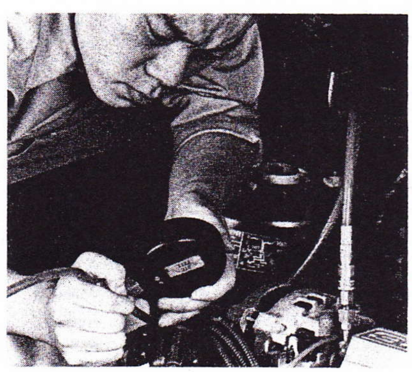
P15–9 Remove the clip from the top of the injector and remove the injector unit. Install new O-rings onto the new injector. Be careful not to damage the seals while installing them and make sure they are in their proper locations.



P15–10 Install the injector into the fuel rail and set the rail assembly into place.



P15–11 Tighten the fuel rail hold-down bolts according to the manufacturer's recommendations.



P15–12 Reconnect all parts that were disconnected. Install the fuel pump fuse and reconnect the battery. Turn the ignition switch to the run position and check the entire system for leaks. After a visual inspection has been completed, conduct a fuel pressure test on the system.

adjustment screw unless special enrichment procedures are followed. Instructions are usually given in the service manual for the particular application.

CIS CHECKS AND TESTS

Servicing mechanically controlled continuous injection systems requires the same logical approach and preliminary checks used in troubleshooting throttle body and port EFI systems. CISs are normally very reliable and should not be blamed for a problem until the preliminary ignition and engine system checks given earlier have been completed.

The following diagnostic and service tips apply to most CIS vehicles in use today.

- Often difficult cold starting is caused by a faulty cold start valve or thermal time switch.
- System pressure, idle mixture or speed, and a faulty air regulator are the common causes for rough-running engines.
- Improper pressures or pressure leaks can cause a number of problems, such as rough idling, stalling, surging or missing, or hard start problems.
- Surging or missing can also be caused by unequal fuel distribution to the injectors.
- An airflow sensor plate that is off-center in its bore can allow air to leak by, causing severe hot start problems.
- The two basic adjustments made to the CIS are idle speed and the air/fuel mixture. To set the idle speed on a typical CIS setup, turn the screw next to the throttle plate linkage, which varies the size of a by-pass drilling. Counterclockwise equals faster (Figure 25–38).
- Mixture is adjusted by turning a screw, which bears on the air sensor lever. A rubber plug is located between the fuel distributor and the air sensor cone, and must be removed for access to the screw. Use a long, 3-mm Allen wrench to adjust. Clockwise richens the blend.
- In a CIS-E engine the control computer uses input signals to decide mixtures for different conditions. It controls idle speed with the idle-speed stabilizer, holding a higher speed for a colder engine and gradually slowing it down as the engine warms. Idle specifications are given in percent of dwell to rpm. Turning the idle screw, as on most domestic cars, does not change the idle speed. The idle stabilizer changes to correct it.
- Idle mixture adjustment on CIS-E is done through a hole in the fuel distributor/air flap housing using a long, 3-mm Allen wrench. The key is to set both regulator current and exhaust CO in specifications.

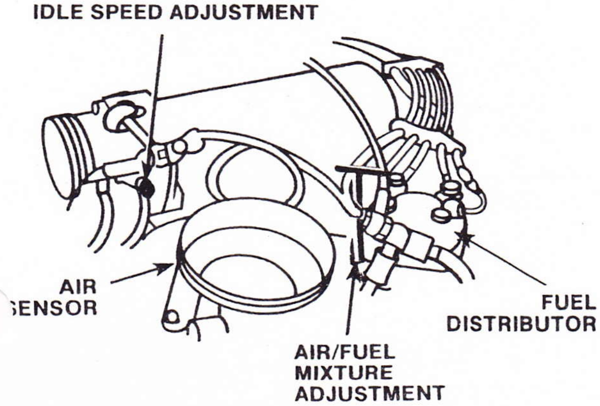


FIGURE 25–38 Location of the idle speed and air/fuel mixture screws in a CIS arrangement.

HIGH-PRESSURE DIESEL FUEL INJECTION

All diesel engines use a high-pressure fuel injection system that differs from gasoline fuel injection systems in several key areas.

- A diesel engine uses higher fuel injection pressures than a gasoline engine.
- Ignition in a diesel engine takes place as the fuel is injected into the cylinder. The heat of the highly compressed air ignites the fuel charge. A diesel engine does not have an electrical ignition system like that found on gasoline engines.
- The output power of a diesel engine is directly proportional to the fuel charge injected into the combustion chamber.
- In diesel engines, the amount of fuel to be injected is limited by a governor. This device limits the air/fuel ratio for a diesel engine up to a maximum of 10 to 1 by weight. The air/fuel ratio of a typical gasoline engine is approximately 14.7 to 1 by weight.

Combustion Cycle

Combustion in a diesel engine occurs in four sequential stages or periods: the delay period, the uncontrolled-burning period, the controlled-burning period, and the after-burning period (Figure 25–39). When the fuel is first injected into the combustion chamber, there is an initial delay as the fuel changes from a liquid state to a vapor or gas state. This liquid-to-vapor conversion is necessary so the fuel burns. The delay period is followed by a period of uncontrolled burning of the fuel already injected into the chamber. This period is followed by a controlled-burning period as the injector continues to feed fuel into the combustion chamber. If and when the fuel injection stops, all the

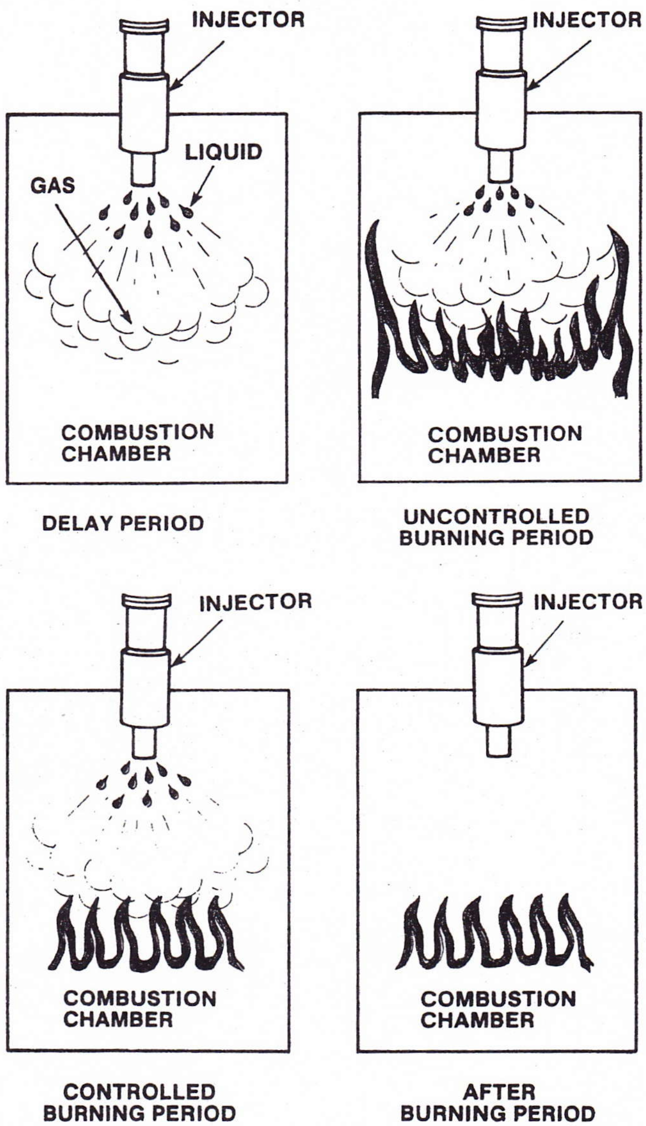


FIGURE 25–39 Four stages of diesel engine combustion.

remaining fuel in the chamber continues to burn until it is consumed. This stage is known as the after-burning period. In the diesel engine, these periods of combustion simultaneously occur in different parts of the combustion chamber during injection.

The combustion of diesel fuel is not identical under all conditions. Combustion is affected by the following.

- Injector timing
- Length of time (or pulse width) of injection
- Position of injector nozzle
- Injection pressure
- Vaporization of fuel
- Distribution of fuel in the combustion chamber

The moment fuel is injected into the cylinder it is ignited. Therefore, the fuel injection pump utilized by the diesel engine system must inject the fuel at the precise instant when the piston is nearing the TDC position of its compression stroke.

DIESEL FUEL SYSTEM COMPONENTS

The diesel fuel injection system contains the following components (Figure 25–40).

- Fuel tank and pick-up unit
- Fuel lines
- Fuel pump system
- Fuel filter
- Water-in-fuel sensor (some systems)
- Water-in-fuel separator (some systems)
- Fuel heater (some systems)
- Injection nozzles

Pump Assembly

A diesel engine fuel pump assembly or system combines most of the functions of gasoline fuel injection, plus the timing functions of a spark ignition system. The assembly must precisely meter fuel at high pressures. Several different types of pump systems are used.

DISTRIBUTOR PUMPS Some distributor pump designs are a single unit, made up of a supply pump, governor, and injection pump. The supply pump draws the fuel from the fuel tank and delivers it to the distributor pump housing. The injection pump then increases the fuel pressure to the levels needed for the combustion. The **governor** controls the speed of the engine.

Other designs contain a transfer pump, governor, and injection pump within the distributor pump housing. This design also uses an external supply pump to deliver fuel to the transfer pump. The transfer pump increases fuel pressure and passes the fuel on to the injection pump where it is further pressurized for injection into the cylinders.

IN-LINE PUMPS This type of pump uses a separate injection pump for each cylinder.

Injection Pump Timing The injection pump is synchronized or timed to the engine's crankshaft through drive gears. The pump is designed to create or build up high fuel pressure (15,000 psi to as high as 30,000 psi). This allows the diesel fuel to be injected into the cylinder as a fine mist or spray. As a mist, the fuel rapidly evaporates when it is introduced to the high-pressure, high-temperature air charge in the cylinder and allows for ignition of the fuel. In order for the engine to operate smoothly, the following fuel injection conditions must exist.

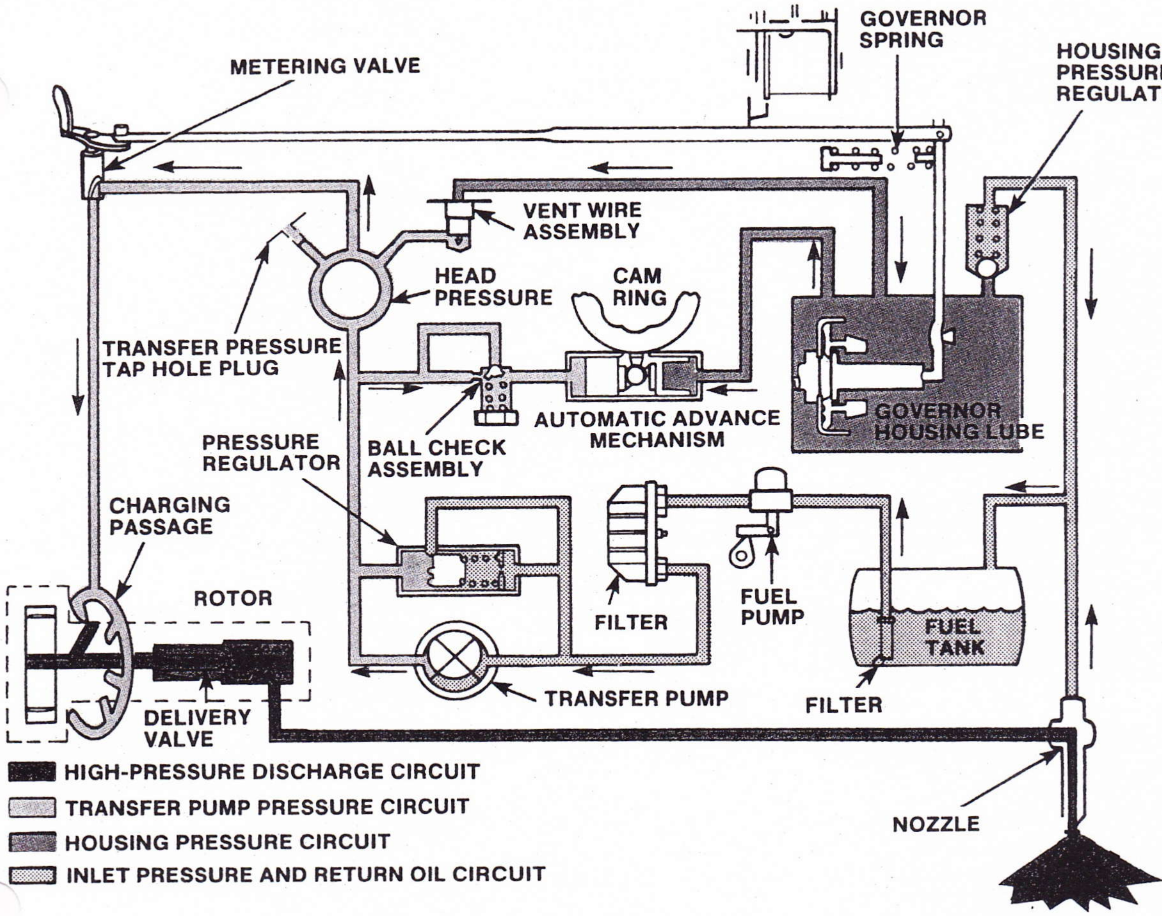


FIGURE 25–40 Diesel fuel system schematic.

- Pressure must be available at the precise instant of fuel injection into the chamber.
- Injection rate must be equal for all cylinders so there are equal power pulses from each cylinder.
- Pressure must shut off at the precise instant to control the total amount of fuel to be injected.

Distributor Injection Pumps A distributor injection pump is driven by the engine's crankshaft by timing gears. These gears drive the pump's rotor, which is fitted into a close-tolerance bore. There are two types of distributor pumps. One type uses two plungers that operate in a cross-drilled bore in the distributor rotor. The other type uses a single plunger. The two-plunger design allows the plungers to move outward and opposite each other when the pump chamber is filled with fuel. The plungers are forced together by internal cam lobes. This reduces the size of the chamber and forces fuel through the injectors. Typical cam plunger movement in a distributor injection pump is shown in Figure 25–41.

As the rotor turns, the holes in the rotor and the pump's head align with each other and allow fuel to flow between the rotor and the head. When the holes are misaligned, fuel flow stops. The holes in both components are referred to as ports. Two types of ports are utilized: charging ports and discharging ports. When the charging ports are aligned, the pump chamber fills with fuel. When the discharging ports are aligned, fuel injection takes place.

A vane transfer pump draws and pushes fuel through passages in the pump's head to a fuel metering valve. The size of the opening in the metering valve is controlled by the accelerator pedal acting through a governor. A small opening in the valve is maintained at idle speed. Depressing the accelerator causes the valve opening to increase. When maximum engine speed is attained or an overspeed condition exists, the governor takes over and automatically begins to close the valve.

Fuel from the metering valve is routed to the charging ports on the distributor injection pump. As the fuel enters the pump, it forces the plungers outward or away from each other. At idle speed the metering valve is almost closed. Very little fuel is routed to the pump chamber. This forces the plungers slightly outward, partially charging the chamber. Depressing the accelerator pump causes more fuel to enter the chamber and forces the plungers farther apart. As the rotor turns, the charging ports on the

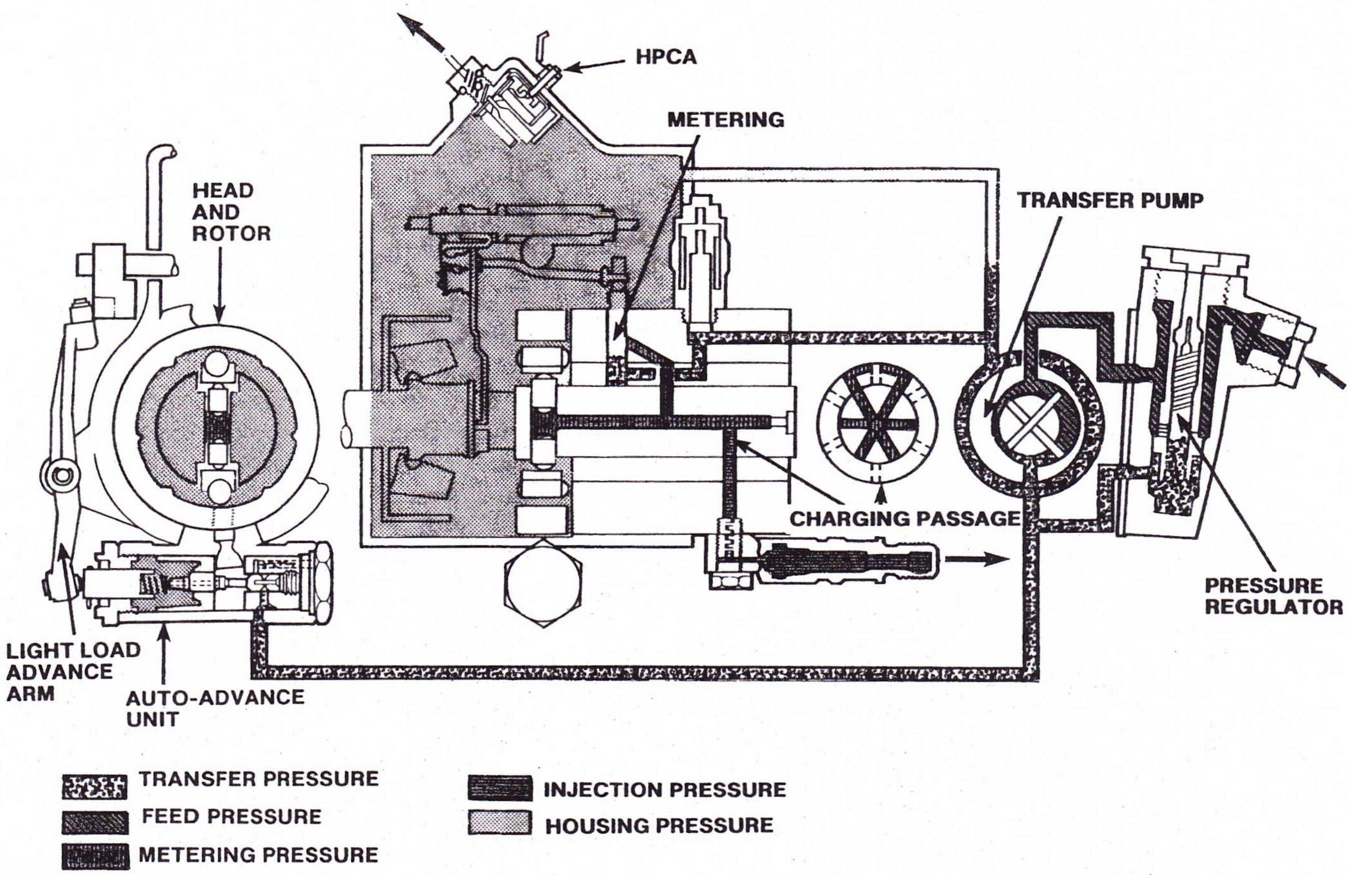


FIGURE 25–41 Cam plunger movement in a distributor injection pump.

rotor and the hydraulic head misalign, effectively closing the ports. Continued rotation of the rotor then aligns the discharge ports of both components. At this time, the plungers are forced or pushed inward by the rollers contacting the cam lobes. As the plungers move together, the fuel is forced out of the pump chamber into the fuel lines to the injectors. Fuel is prevented from dripping into the combustion chamber after the injection cycle by a delivery valve.

The quality of fuel delivered by the distributor injection pump is directly proportional to the amount of fuel entering the pump chamber through the metering valve. Fuel injection timing is controlled by an internal time-advance mechanism. Timing is altered by rotating an internal cam ring in the rotor and head assembly. A pin in the auto-advance unit is connected to the internal cam and is located between a spring and piston. Fuel pressure from the transfer pump pushes the piston toward the spring and moves the pin. Movement of the pin moves the cam in an advance direction. As the engine speed increases, transfer pump fuel pressure increases, and the timing advances accordingly.

Unused injection fuel from the transfer pump is vented back to the fuel tank through the governor housing. It is also used to lubricate and cool the internal components of the distributor injection pump.

In-Line Injection Pump The multicylinder in-line injection pump (Figure 25–42) has a plunger and barrel assembly for each engine cylinder. The assemblies are grouped together in one housing that resembles cylinders in the block of an in-line engine. A high-pressure fuel line connects each pump assembly to one injector. The pump delivers or pumps an equal amount of fuel on each stroke.

The in-line injection pump used on automotive diesel engines is lubricated with engine oil. The pump does not have a seal around the cam drive end bearing, so the oil returns to the engine through the bearing.

Injection Nozzles

The fuel injection nozzle is designed to vaporize and direct the metered fuel into the combustion chamber. The injection pump forces the required fuel into the injection nozzle at the precise time it is needed. The design of the combustion chamber usually dictates the type of nozzle used, the droplet size, and the spray pattern required for optimum combustion in the given time frame and space. A typical injection nozzle is shown in Figure 25–43.

The typical injection nozzle has small openings, so the pressure can build up under some operating conditions. A spring-loaded needle valve in the injector nozzle keeps the opening of the nozzle closed

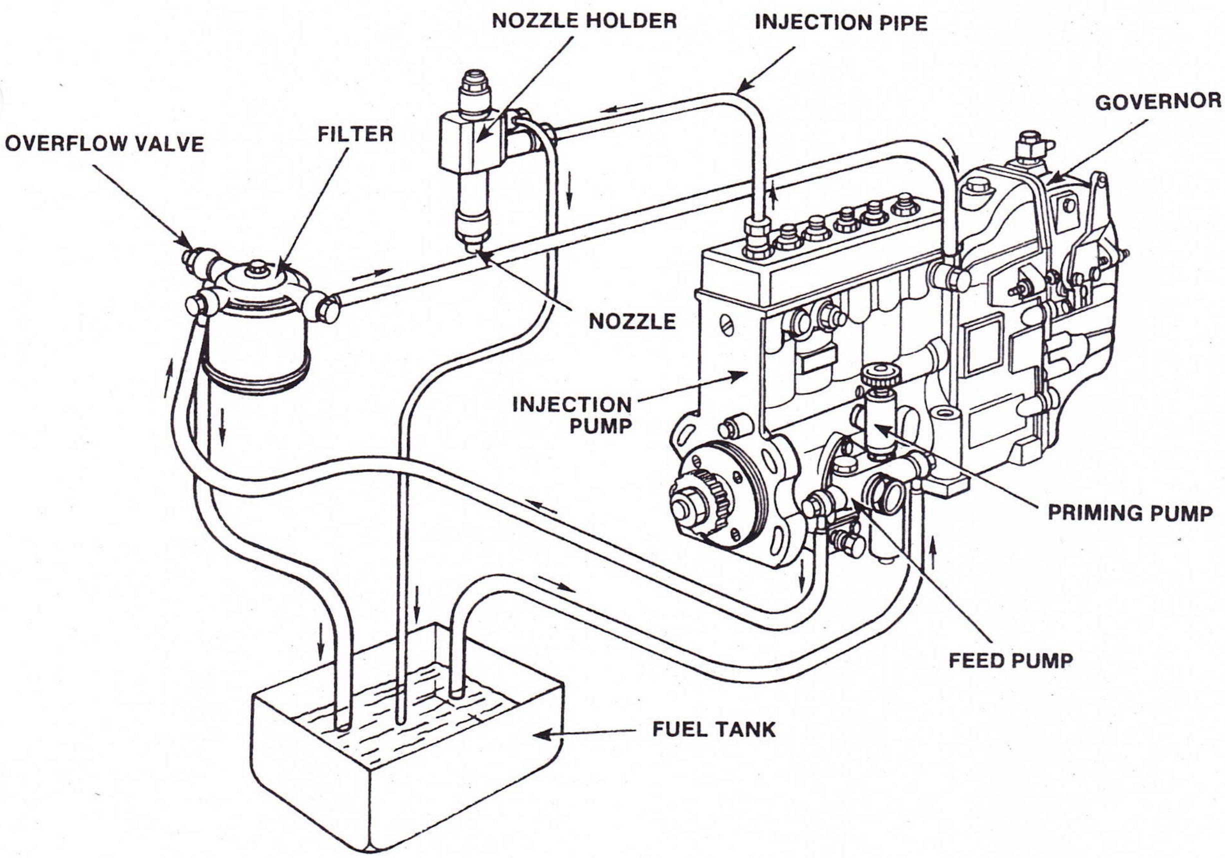


FIGURE 25–42 Typical in-line injection pump.

until the pressure reaches the operating level. The fuel pressure opens the nozzle valve and the spring closes it. Fuel from the injection pump enters and pressurizes the fuel lines and the pressure chamber. When the force on the lift area is greater than the set spring force on the spindle, the needle valve lifts off its seat and rests with its upper shoulder against the face of the holder body. Fuel in a mist or spray-type pattern is then forced out into the combustion chamber. The pattern is determined by the type of tip used on the injector nozzle.

Only the tip of the injection nozzle protrudes into the combustion chamber. Two types of injector tips are used on diesel engines: the hole type and the pintle type. Open combustion chambers use the hole type (Figure 25–44), but it is also used on a few

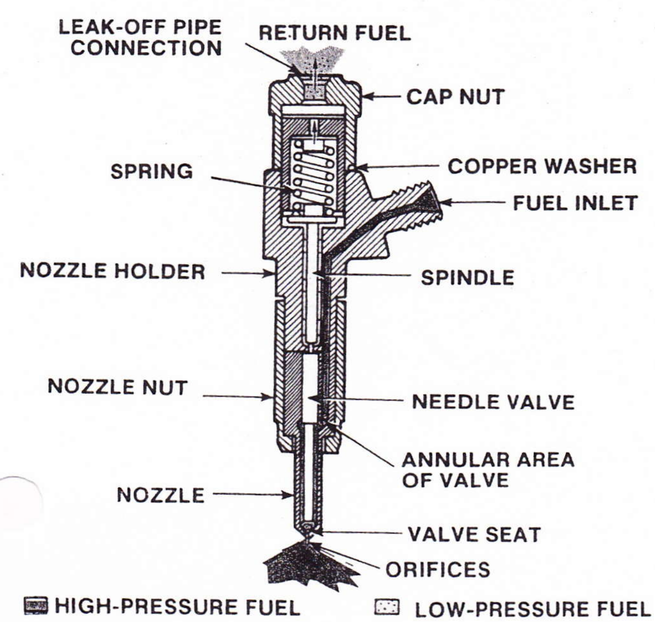


FIGURE 25–43 Parts of a diesel injection nozzle.

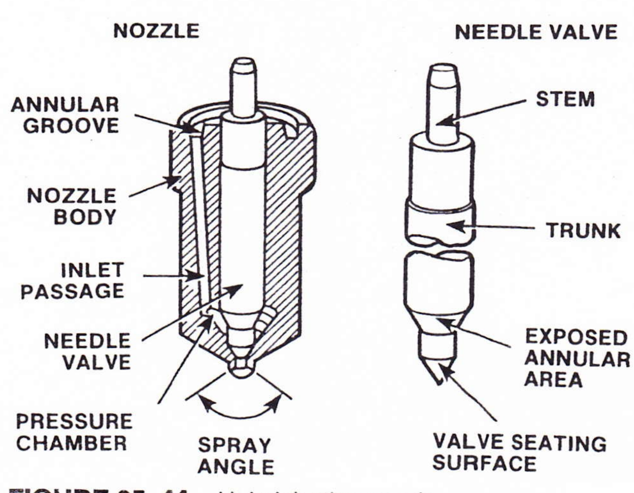


FIGURE 25–44 Hole injection nozzle.

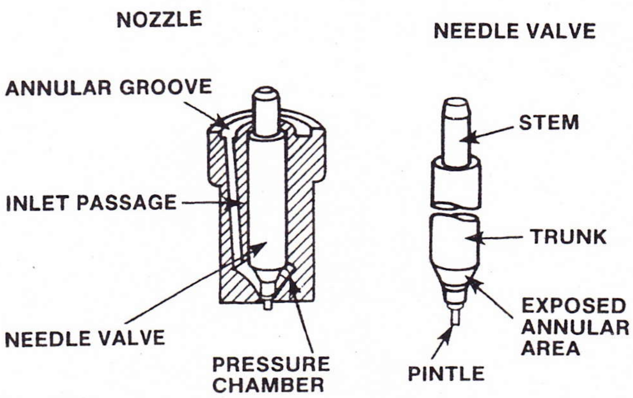


FIGURE 25–45 Pintle injection nozzle.

engines with divided combustion chambers. The pintle type tip (Figure 25–45) is used only on engines with a divided combustion chamber.

Governors

Gasoline engines are self-governing because the air entering the engine is controlled by the use of a carburetor throttle valve or by the throttle body in a fuel injected system. The driver can change engine speed by manipulating the throttle pedal.

Because of this method, in most cases, the gasoline engine has no need for a governor. If such an engine is equipped with a governor mechanism, it is for the sole purpose of limiting the maximum road speed of the vehicle and the engine rpm to prevent engine abuse or avoid poor fuel economy.

The diesel engine, on the other hand, operates with an excessive amount of unthrottled air throughout its operating speed range. The fuel injection system is separately controlled from the airflow system. When a diesel engine is started, the air is unthrottled and remains so as the driver opens the fuel control mechanism or throttle linkage to allow the injection system to inject more fuel into the cylinders. Without some form of fuel control, the diesel engine can accelerate very rapidly and self-destruct, especially if the throttle were to be placed in the full-fuel position and left there with no mechanism to regulate the fuel input.

Therefore, a governor is required on diesel engines to regulate the fuel input and prevent engine stalling at the low-speed end and from overspeeding at the high-speed end. The governor controls the speed of the engine.

At minimum speed or idle, the governor controls pump injections, so the engine gets just enough fuel to keep it running. At maximum rpm, the governor controls pump injection to limit fuel flow to keep the engine from overspeeding. At intermediate speeds, the pump responds to movements of the accelerator pedal so the driver can control car speed directly. During coasting, the governor can cut off fuel delivery for economy. See Figure 25–46 for the operation of a typical governor.

Starting Devices

Since diesel fuel does not vaporize or ignite as readily as gasoline, starting devices are required on diesel engines. These include glow plugs, fuel heaters, and engine block heaters.

Glow plugs (Figure 25–47), located in the combustion chamber, preheat the air and fuel during cranking (or prior to cranking depending on the system design). In colder climates, engine block heaters are used to heat the engine's coolant, which in turn keeps the cylinder block and head at a temperature suitable for starting purposes. A fuel heater preheats the fuel electrically before it reaches the filter. The heater, usually thermostatically controlled, is a resistance type designed to heat the fuel before it enters the filter. This reduces the possibility of wax plugging the filter, which usually occurs when the fuel temperature is 20°F or lower.

A glow plug is a low-voltage heating element that is inserted into the precombustion chamber on the intake manifold. The plug is usually controlled by the ignition switch. However, other design applications might have a separate on-off switch within the passenger compartment. The glow plug is energized only until the air in the combustion chamber is adequately heated and can support ignition at startup. The energized or heating period for a glow plug is directly dependent upon how fast the plug can heat up and what the ambient temperature of the combustion chamber is. Most glow plugs work off the car's 12-volt system.

A control module is the heart of the glow plug system (Figure 25–48). The module senses the engine's coolant temperature and de-energizes the glow plugs when the coolant is sufficiently heated after start-up. Other design variations might use a cycling type of relay to pulse the glow plugs on and off. This type of system usually has a manual on-off switch to control the cycling relay.

Fuel Pick-up

The fuel pick-up is similar to the conventional gasoline pick-up, containing a fuel-level sending unit and a strainer. However, different features are added to accommodate the characteristics of diesel fuel and the diesel fuel system.

One type of pick-up unit uses a fuel pick-up filter (sock) and check valve assembly (Figure 25–49). The sock strains large particles, limits entry of water, and draws fuel from the bottom up to the pick-up tube,

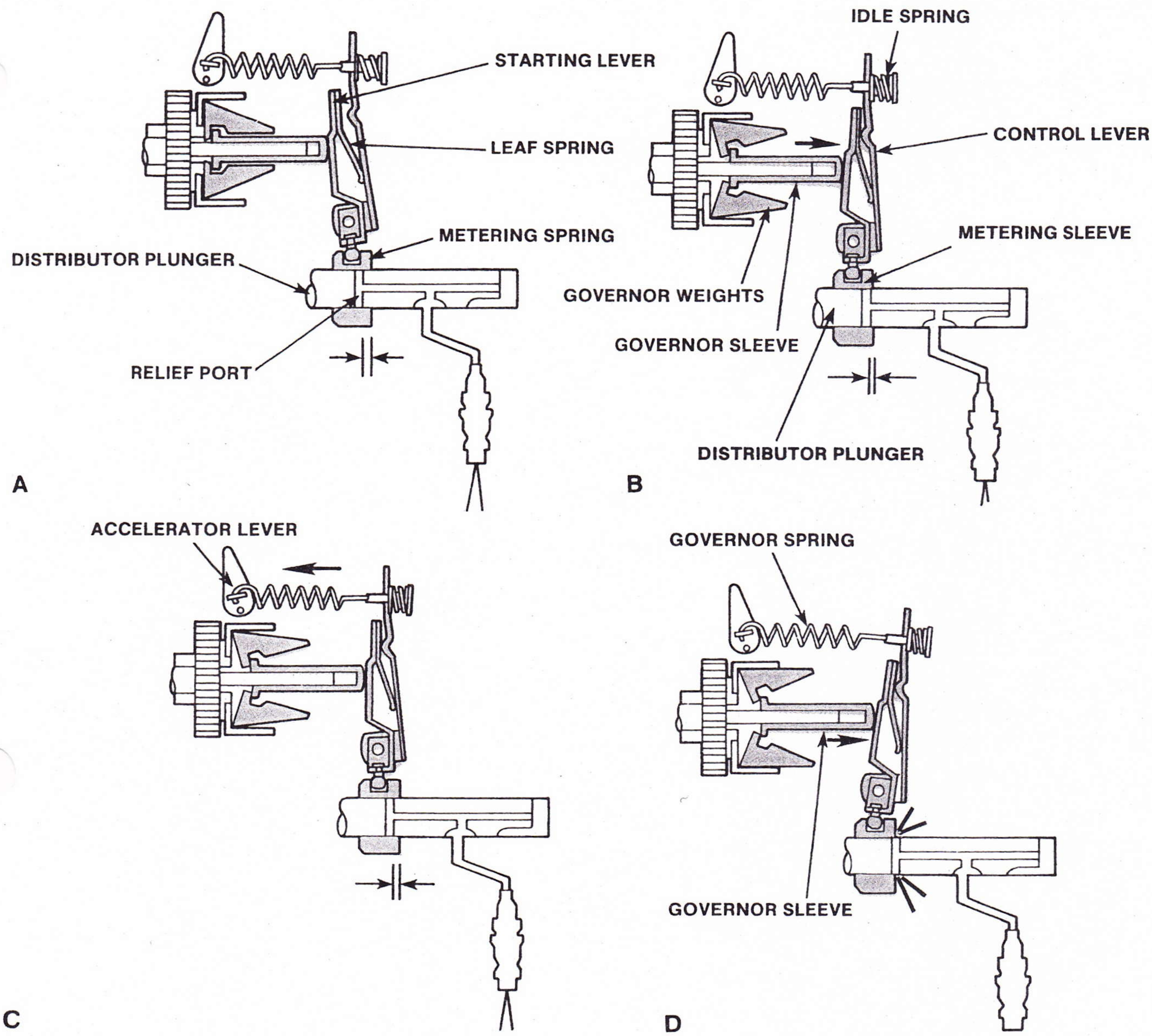


FIGURE 25–46 Governor operation in a diesel fuel injection system: (A) During starting, the metering sleeve is pushed farthest from bottom dead center, resulting in a longer injection period. (B) As engine speed increases, the weights push the governor sleeve to the right, which moves the metering sleeve to the left and shortens the injection period. (C) Depressing the accelerator moves the metering sleeve to the right, which causes more fuel to be injected. (D) Maximum engine speed is governed by limiting fuel delivery as during idle.

acting as a wick. A check valve is added to the sock. It is designed to open when the sock is restricted by wax or ice, allowing the engine to run. This type of pick-up unit is usually equipped with a water-in-fuel sensor since the sock holds back only a certain amount of water before it passes and this system may not have a water-in-fuel separator.

Another type of pick-up unit places the fuel intake in contact with the bottom of the tank supported by several small nibs. Fuel going past the nibs accelerates, creating a pressure drop. This pressure drop attracts water. Water in the diesel fuel is drawn to the intake, accelerated, and forced through the nylon screen with the fuel. Using this type of pick-up unit necessitates a water-in-fuel separator to filter and eliminate the water. This pick-up unit also has low placement of the return line and a by-pass valve in the event the intake is clogged with wax or ice. With either pick-up unit, the tank must be at least one-quarter full for the by-pass valve to pick up fuel.

Fuel Filters

To protect the fuel injection system of a diesel engine, good filtration is essential. The clearances between

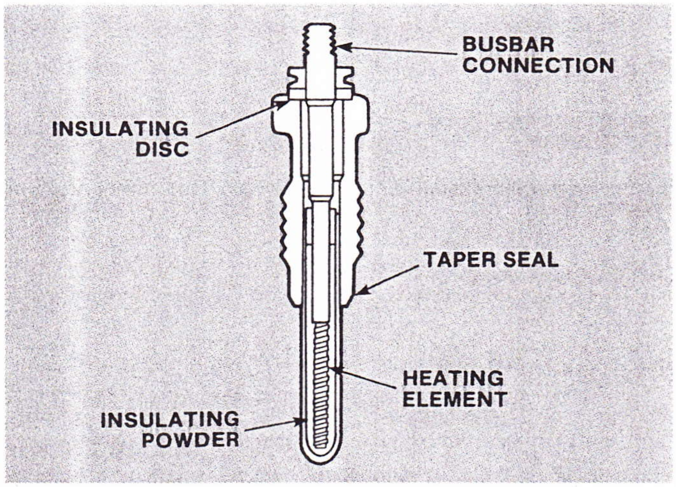


FIGURE 25–47 Cutaway view of a glow plug.

injector parts require close control of solids in the fuel. To avoid erosion and wear, solids must not pass between closely mated injector parts. The primary filter, on the suction side of the transfer pump, protects the system from large solid contaminants. Most of the water in the fuel is also removed by this filter. The secondary filter is located between the transfer pump and the fuel injectors. Since the filter is located on the discharge side of the pump, the pressure drop across the secondary filter can be much higher than on a filter located on the suction side of the pump. This allows the secondary filter to be made in a compact size using a fine filtering media that controls the size of particles allowed to pass into the fuel injectors. It also stops any water that might have passed through the primary filter.

Water Separator

A common diesel fuel problem is water in the fuel. Some vehicles are equipped with a water separator (Figure 25–50) in the fuel system. A fuel water separator works much like a filter, except that the element is replaced by a baffle. When contaminated fuel enters the separator, the heavier water settles at the bottom, while the light fuel rises to the top. A drain plug or

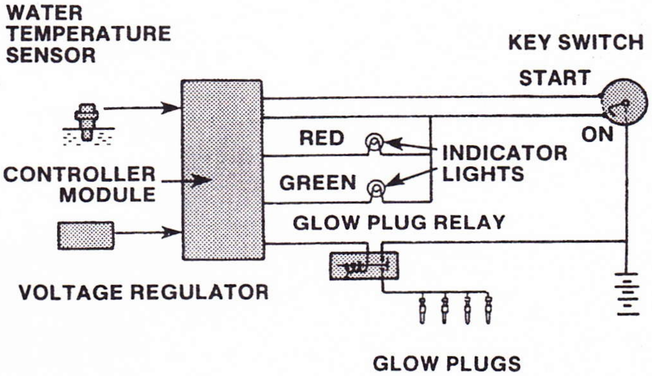


FIGURE 25–48 Electrical schematic of a glow plug system.

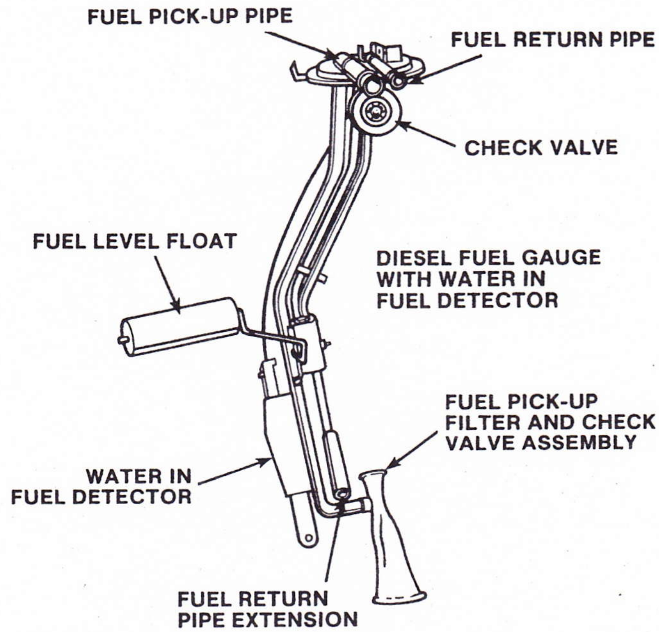


FIGURE 25–49 Combination fuel pick-up/fuel level indicator/water sensor.

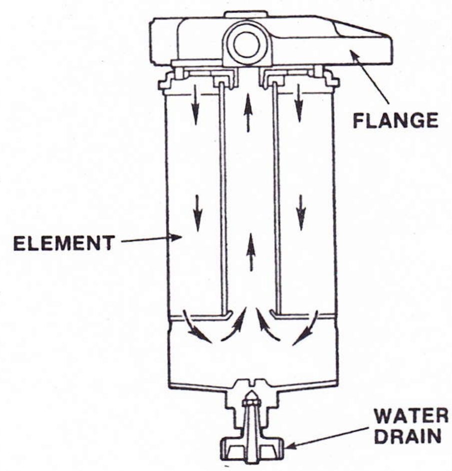


FIGURE 25–50 Diesel fuel filter/water separator.

petcock in the bottom of the separator allows the accumulated water to be drained periodically.

Fuel Lines

The fuel lines that carry the highly pressurized diesel fuel between the injection pump and fuel injectors are manufactured from special, thick-walled steel tubing. The fuel lines are of equal length to ensure that each cylinder receives an identical or equal fuel charge.

DIESEL FUEL INJECTION ELECTRONIC CONTROL

Like gasoline fuel injection systems, diesel injection systems also use computer controls to monitor and activate various input (sensor) and output devices (Figure 25–51).

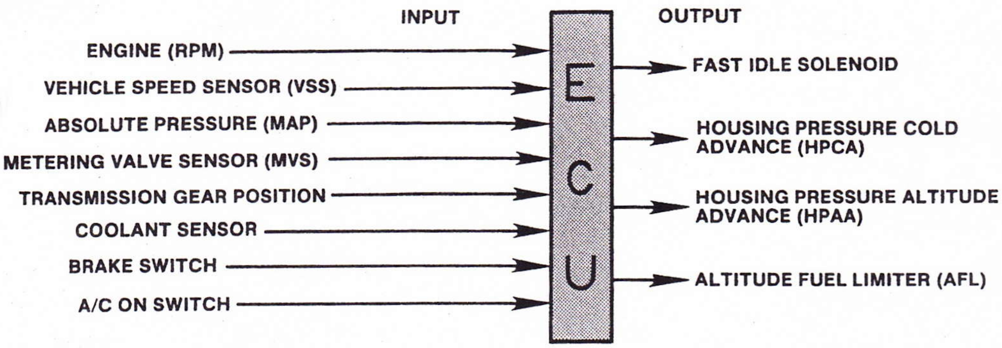


FIGURE 25–51 An electronic control system regulates the diesel fuel injection system.

Input data includes engine rpm, vehicle speed, manifold absolute pressure (MAP), metering valve position, transmission gear position, coolant temperature, and brake and air-conditioning operation.

The electronic control module or unit processes this data and signals various output devices to control engine performance and operation. These output devices include the following.

FAST-IDLE SOLENOID The fast-idle solenoid operates at temperatures below 100° and above 248°F. As the plunger of the solenoid moves, it increases spring pressure on the governor, thereby slightly increasing engine speed.

HOUSING PRESSURE COLD AND ALTITUDE ADVANCE These solenoid-operated mechanisms advance the fuel injection pump on a cold engine and at higher altitudes. This helps reduce engine noise and emissions.

ALTITUDE FUEL LIMITER This solenoid limits the travel of the metering valve at wide open throttle at altitudes above 4,000 feet.

METERING VALVE SENSOR The variable resistor sensor sends a variable voltage signal to the ECU indicating metering valve position.

CASE STUDY

A customer brings in a late-model GM automobile, with a 2.0L port fuel injected engine, and complains of poor performance and fuel economy. It is also mentioned that the service-engine-soon light had been on for some time.

Diagnosis of the problem begins with a visual inspection of the engine, including all hoses and wiring connectors. No problems are found.

Next, a scan tool is connected to the ECU and code 45 is retrieved from the computer's memory. The technician uses a code interpretation list to find a rich exhaust signal is coming from the oxygen sensor.

At first, the technician suspects a faulty oxygen sensor. By referring to the service manual, she finds that this code is set when the oxygen sensor signal to the control computer (ECU) is greater than 0.75 volt for 50 seconds and the system is in closed loop. Keep in mind that a faulty sensor is open, shorted, or has high resistance. An open sensor circuit or sensor would cause the engine to operate in open loop, not in closed loop. A short would cause high amperage, which would do physical damage to the wires and/or ECU. But, the visual inspection did not locate any damage. Excessive resistance in the circuit would cause voltages to be lower. The problem here is higher voltages. Therefore, it is unlikely that the problem is caused by a faulty sensor or sensor wiring harness. To locate the cause of the problem more testing is needed.

Following the appropriate troubleshooting tree, testing continues with the scan tool and reveals that the problem could be caused by an open in the ignition wiring, a saturated charcoal canister, a faulty MAP sensor or fuel pressure regulator, or by the improper use of RTV sealer. Detailed inspection and testing of these reveals the cause of the problem: a ruptured vacuum diaphragm in the fuel injection system's pressure regulator that allowed the excessive fuel pressure and a rich mixture.

The regulator is replaced, and the codes are cleared. The problem is corrected. To verify the repair, the technician runs the engine and observes the scan tool to make sure the engine went into closed loop and that no codes were set by the computer.

KEY TERMS

CIS
CIS-E
ECU
EFI
Frequency valve
Fuel accumulator
Fuel distributor
Fuel pressure regulator
Fuel rail
Glow plug
Governor
IAC
Injector pulse width
Lambda sensor
Mass airflow sensor
MIL
Mixture control unit
MPI
Noid
PFI
Pintle
Prefeed pump
SFI
Speed density
TBI
Thermo-time switch
Warm-up regulator

SUMMARY

- There are two types of electronic fuel injection systems: throttle body and port injection. In the throttle body injection system, fuel is delivered to a central point. In the port injection system, there is one injector at each cylinder.
- Port injection systems use one of four firing systems: grounded single fire, grouped double fire, simultaneous double fire, or sequential fire.
- The electronic fuel injection system includes a fuel delivery system, system sensors, electronic control unit, and fuel injectors.
- The volume airflow sensor and mass airflow sensor determine the amount of air entering the engine. The MAP sensor measures changes in the intake manifold pressure that results from changes in engine load and speed.
- The heart of the fuel injection system is the electronic control unit. The ECU receives signals from all the system sensors, processes them, and transmits programmed electrical pulses to the fuel injectors.
- Two types of fuel injectors are currently in use: top feed and bottom feed. Top-feed injectors are used in port injection systems. Bottom-feed injectors are used in throttle body injection systems.
- Two methods are used to control idle speed on engines equipped with fuel injection: an auxiliary air valve and an idle speed solenoid.
- While some electronic control elements are being added to the basic system, continuous injection systems (CIS) meter fuel delivery mechanically not electronically.
- CIS injectors spray fuel constantly. They do not pulse on and off. The proper air/fuel mixture is attained by varying the amount of fuel delivered to the injectors.
- Continuous injection systems can be fitted with an oxygen sensor, or lambda sensor, for feedback control. Signals from the oxygen sensor are sent to the oxygen control unit. The oxygen control valve operates on signals from the oxygen control unit.
- Troubleshooting electronic fuel injection systems requires systematic step-by-step test procedures. Using a hit-or-miss approach can be frustrating, time-consuming, and costly.
- If any EFI system three things must occur. First, an adequate air supply must be supplied for the air/fuel mixture. Second, a pressurized fuel supply must be delivered to properly operating injectors. Finally, the injectors must receive a trigger signal from the control computer.
- When checking out the EFI, the air system should be checked first. Then, check the fuel system. The injectors are checked last. Servicing CIS requires the same logical approach and preliminary checks used in troubleshooting EFI systems.
- Diesel fuel injection systems operate under very high fuel and air pressures. The output power of a diesel engine is directly proportional to the fuel charge injected into the combustion chamber. A governor is used to limit the amount of fuel that can be injected. This limits engine speed and power output to levels that do not damage engine components.
- The injection pump is the heart of the diesel fuel injection system. The pump is driven off the engine's crankshaft to control injection timing. The pump is capable of generating the 15,000 to 30,000 psi fuel pressures needed and metering precise amounts of fuel to each injector.

TECH MANUAL

The following procedures are included in Chapter 25 of the *Tech Manual* that accompanies this book:

1. Perform a fuel injector balance test.
2. Clean fuel injectors.

REVIEW QUESTIONS

1. Explain the major differences between throttle body fuel injection and port fuel injection systems.
2. What is meant by sequential firing of fuel injectors?
3. Describe the purpose of the idle speed solenoid and auxiliary air valve.
4. Describe the purpose of a manifold absolute pressure (MAP) sensor.
5. Describe the basic differences between gasoline fuel injection and diesel fuel injection systems.
6. Which of the following is *not* an advantage that fuel injection offers over carburetion?
   - **a.** leaner air/fuel ratios
   - **b.** better fuel economy
   - **c.** no choke requirements
   - **d.** lower engine torque
7. The length of time that an injector is energized is called ____.
   - **a.** intermittent system
   - **b.** pulsed system
   - **c.** injector pulse width
   - **d.** open loop mode
8. Explain the causes and results of high fuel pressure in a TBI, MFI, or SFI system.
9. While discussing EFI systems, Technician A says the ECU provides the proper air/fuel ratio by controlling the fuel pressure. Technician B says the ECU provides the proper air/fuel ratio by controlling injector pulse width. Who is correct?
   - **a.** Technician A
   - **b.** Technician B
   - **c.** Both A and B
   - **d.** Neither A nor B
10. Technician A performs an injector pressure balance test by activating each injector with an electronic pulse tester. Technician B performs the same test by momentarily applying 12 volts to the injector terminals to activate the injector. Whose method is correct?
    - **a.** Technician A
    - **b.** Technician B
    - **c.** Both A and B
    - **d.** Neither A nor B
11. Bottom-feed injectors are used in ____.
    - **a.** throttle body injection systems
    - **b.** port injection systems
    - **c.** both a and b
    - **d.** neither a nor b
12. While discussing cold start injector systems, Technician A says the cold start injector is operated by a thermo-time switch. Technician B says the cold-start injector is operated by the ECU. Who is correct?
    - **a.** Technician A
    - **b.** Technician B
    - **c.** Both A and B
    - **d.** Neither A nor B
13. Fuel tubing and hoses should be replaced at least every ____.
    - **a.** year
    - **b.** two years
    - **c.** three years
    - **d.** five years
14. While discussing the causes of higher-than-specified idle speeds, Technician A says an intake manifold vacuum leak may cause a high idle speed. Technician B says if the TPS voltage signal is higher than specified, the idle speed may be higher than normal. Who is correct?
    - **a.** Technician A
    - **b.** Technician B
    - **c.** Both A and B
    - **d.** Neither A nor B
15. An injector balance test produces a pressure drop variation of 2 psi. Technician A says this is acceptable and, therefore, no cause for concern. Technician B says it is a cause for concern. Who is correct?
    - **a.** Technician A
    - **b.** Technician B
    - **c.** Both A and B
    - **d.** Neither A nor B
16. As an alternative to an injector power balance test, Technician A uses a stethoscope to listen for correct operation. Technician B uses a thin steel rod for the same purpose. Who is correct?
    - **a.** Technician A
    - **b.** Technician B
    - **c.** Both A and B
    - **d.** Neither A nor B
17. Which of the following should be done as a preliminary step before attempting an idle adjustment of a fuel injection system?
    - **a.** blocking the drive wheels
    - **b.** connecting a tachometer
    - **c.** checking and adjusting base ignition timing
    - **d.** all of the above
18. An airflow sensor plate that is off-center in its bore can allow air to leak by, causing ____ problems.
    - **a.** idling
    - **b.** cold start
    - **c.** hot start
    - **d.** preignition
19. The governor on a diesel fuel injection system is responsible for ____.
    - **a.** injection timing
    - **b.** injection timing advance
    - **c.** fuel metering
    - **d.** both a and b
20. To relieve fuel pressure on an EFI car, Technician A connects a pressure gauge to the fuel rail. Technician B disables the fuel pump and runs the car until it dies. Who is correct?
    - **a.** Technician A
    - **b.** Technician B
    - **c.** Both A and B
    - **d.** Neither A nor B