Construction. The Stanadyne pump, shown in *Figure 5-62* incorporates four pumping plungers. The driveshaft engages the distributor rotor in the hydraulic head. The rotor holds the four pumping plungers. The plungers are actuated simultaneously toward each other by an internal cam ring through rollers and shoes located in slots at the end of the rotor. The number of lobes normally equals the number of engine cylinders.

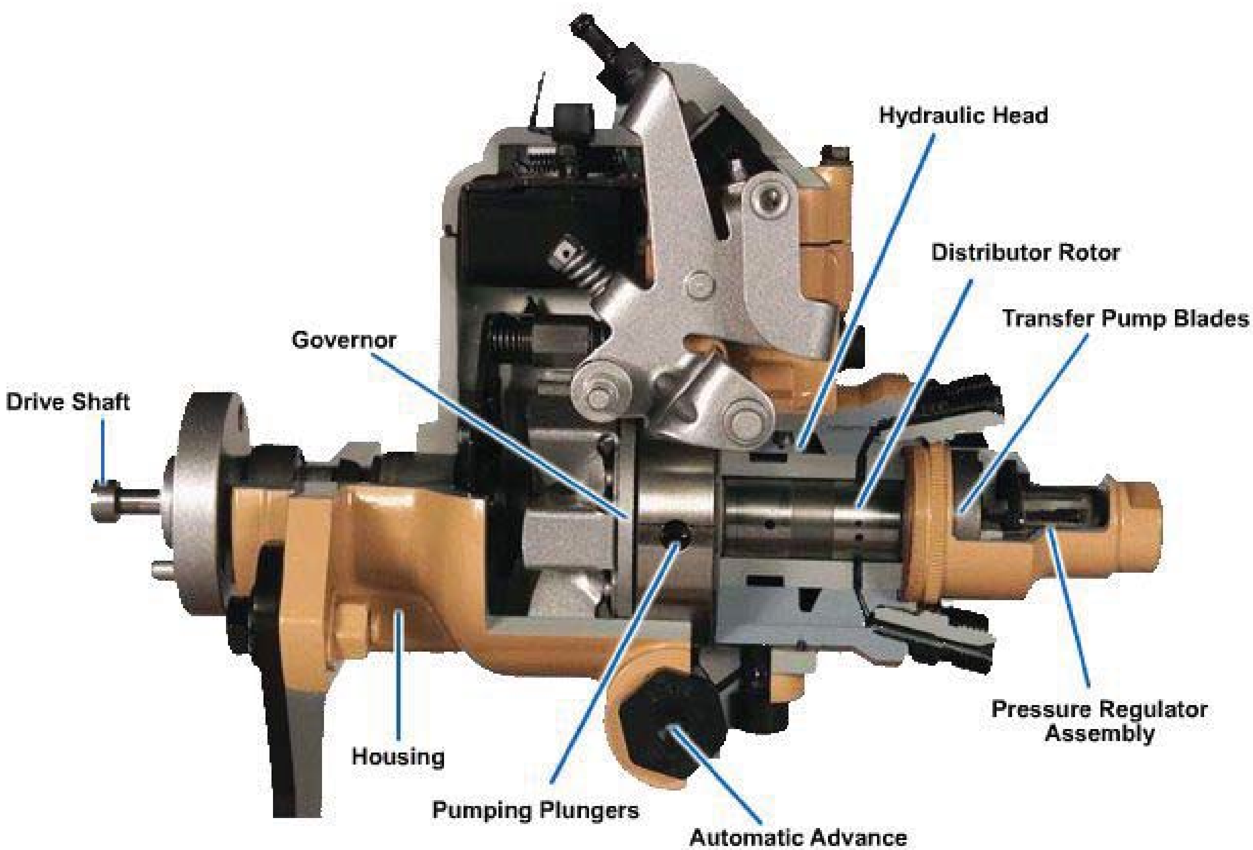

Figure 5-62 – The Stanadyne DB4 injection pump uses four opposed plungers.

The transfer pump is also a positive displacement vane type. It is enclosed in the end cap, which also houses the fuel inlet strainer and transfer pump pressure regulator. The distributor rotor incorporates two charging ports and a single axial bore. One discharge port serves all the outlet ports to the injection lines. The hydraulic head contains the bore in which the rotor revolves, the metering valve bore, the charging ports, and the head discharge fittings. The high pressure injection lines to the nozzles are fastened to these discharge fittings.

Stanadyne pumps have their own mechanical governor. The centrifugal force of the weights in their retainer is transmitted through a sleeve to the governor arm and to the metering valve. The metering valve can be closed to shut off fuel by an independently operated shut-off lever. The automatic speed advance is a hydraulic mechanism that advances or retards the beginning of fuel delivery. This can respond to speed alone or to a combination of speed and load changes.

Components. The aluminum alloy pump housing of an opposed plunger distributor injection pump contains the driveshaft, distributor rotor, transfer pump blades, pumping plungers, internal cam ring, hydraulic head, end plate, adjusting plates, transfer pump, pressure regulator assembly, governor, automatic advance, and metering valve.

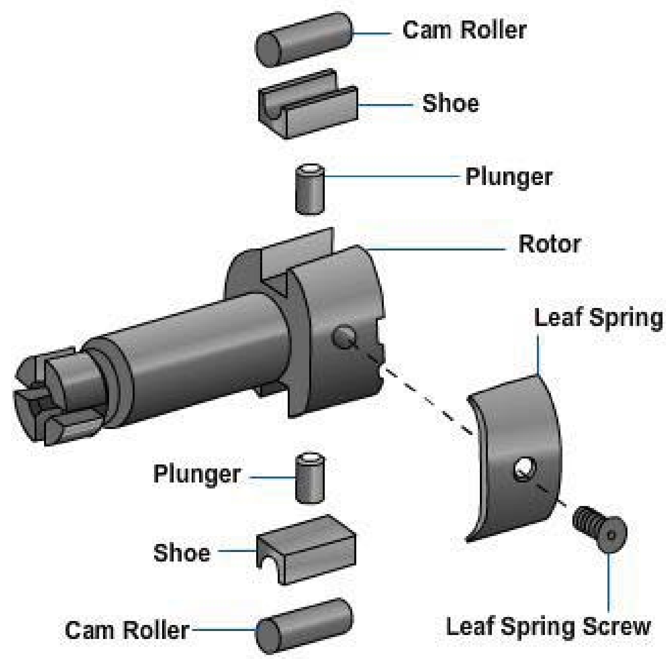

Figure 5-63 – Exploded view of a rotor assembly showing the cam rollers and shoes.

Driveshaft. The driveshaft connects to the engine drive gear and is supported by a bushing or ball bearing. It supports the governor assembly and drives the distributor rotor and transfer pump. The transfer pump consists of four linear blades. It delivers fuel to the metering valve located in the hydraulic head at low pressure. It also provides a fuel inlet to the pump and contains a pressure regulating valve that controls the transfer pump pressure throughout the speed range.

Hydraulic Head. The hydraulic head is machined with bores and passages that allow fuel to flow from the transfer pump to the metering valve, from the metering valve to the charging ports, and from the discharging ports to the discharging fittings. On the latest designs, hydraulic heads have been fitted with individual delivery valves to maintain residual line pressure and eliminate secondary injection.

Distributor Rotor. The distributor rotor is lapped fitted to the hydraulic head and the governor weight retainer assembly is fastened to its drive end. The plungers are fitted to the rotor and are pushed inward by the rollers and shoes to pump the diesel fuel. The rollers fit into the shoes and contact the cam in a way similar to a cam follower, as shown in *Figure 5-63*. Adjusting plates are mounted on the rotor and limit the outward travel of the rollers and shoes to control the fuel delivery.

Cam Ring and Metering Valve. A circular cam ring surrounds the rotor base and is located over the shoes and rollers. The number of internal cam lobes equals the number of cylinders. The cam ring forces the plungers toward each other, which causes the fuel to be pumped. It can also be rotated back and forth about the rotor to vary the start of injection.

The metering valve contained in the hydraulic head regulates the volume of fuel entering the rotor. A piston valve is used with hydraulic governors. This valve is spring-loaded and controls the fuel according to the valve's axial position. When a mechanical governor is used, the valve is a rotary type, with a slot cut in the periphery. The valve is rotated by the governor arm to regulate fuel injection.

Automatic Advance and Governor. An automatic advance device is located I the bottom of the pump. A hydraulic piston rotates the cam ring against the direction of pump rotation via the cam advance stud. The cam advance stud threads into the cam and connects it to the cam advance mechanism.

The governor weight retainer may be permanently fixed, splined, or bolted to the rotor drive end. Because the fuel metering mechanism can be affected by vibrations and shocks, the retainer often uses a cushioning device to isolate engine vibration and pulsation from the driveshaft. One end of the governor control arm rests against the thrust sleeve, and the other end connects to the governor spring and to the metering valve via a linkage hook. The control lever is connected to the shut-off lever and the fulcrum lever is connected to the governor spring.

Pump Operation and Fuel Flow. The operating principles of an opposed plunger pump can be understood more readily by following the fuel circuit during a complete pump cycle. *Figure 5-64* illustrates the fuel flow for a Stanadyne DB2 two-plunger distributor pump. The fuel flow for the DB4 four-plunger pump is the same with the exception of the charging of two additional plungers. As shown in the diagram, the transfer pump pulls fuel from the fuel tank. The fuel passes through a water separator and secondary fuel filter before reaching the transfer pump. Once through the transfer pump, some of the fuel is bypassed to the transfer pump's suction side through the pressure regulator assembly.

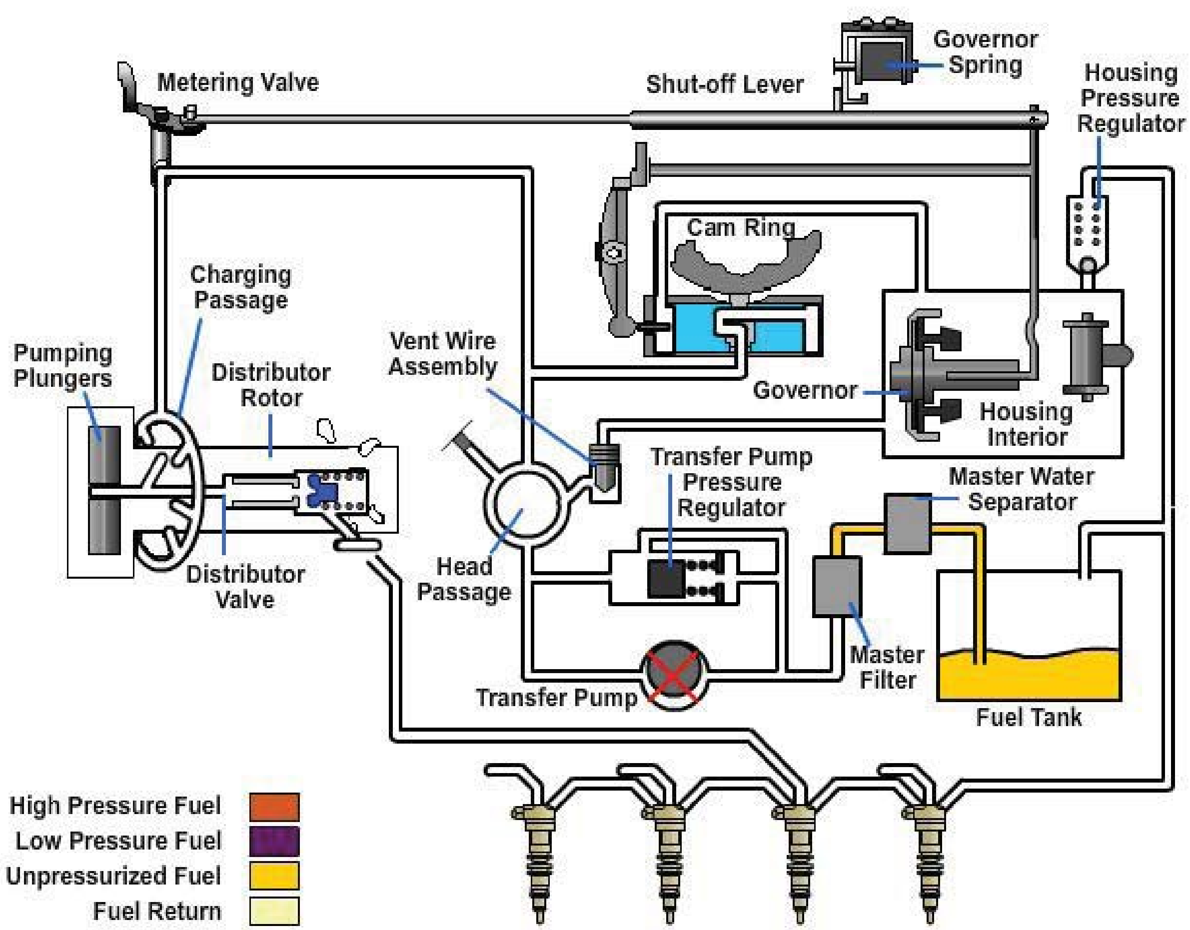

Figure 5-64 - Fuel flow during the pumping cycle in a Stanadyne DB2 distributor injection pump.

Fuel under pressure flows past the rotor retainers and into an annulus on the distributor pump rotor. Some fuel flows through a connecting passage in the head to the automatic advance mechanism. The remaining fuel moves into the charging passage. This fuel flows around the annulus, through a connecting passage, and to the metering valve.

The radial position of the metering valve regulates the fuel flow into the charging annulus, which holds the charging ports.

Pressure Regulating Valve Operation. The pressure regulating valve is located in the end plate and performs two important functions. When the injection pump is being primed, fuel is forced into the inlet connection through the mesh filter. Fuel enters the regulating sleeve located at the upper port, forcing the regulating piston downward and compressing the priming spring. When the piston has moved down far enough to uncover the lower port in the sleeve, the fuel flows directly into the hydraulic head. The pump is now primed and ready for start-up.

When the engine is running, the pump rotates and fuel is pulled into the end plate by the transfer pump. It passes through the mesh filter and is forced into the hydraulic head and end plate. When the transfer pump builds pressure, it forces the piston upward against the regulating spring (*Figure 5-65, View A*). When the correct pressure is reached, the piston uncovers the regulating port. This bypasses a small amount of fuel back to the inlet side of the transfer pump to maintain fuel pressure at the desired level, (*Figure 5-65, View B*).

Transfer pump pressure can be adjusted in one of two ways. On some pumps, the spring guide is replaced with one of a different size. This changes the fuel pressure by altering the amount the regulating spring can be compressed. Other models are equipped with an adjustment device that can be set using a special tool when the pump is running on a test bench.

Charging Cycle. As the rotor revolves, the two inlet passages align with the charging ports in the annulus. Fuel under pressure from the transfer pump and controlled by the metering valve flows into the pumping chamber, forcing the plungers apart.

The plungers move outward a distance proportional to the amount of fuel required for injection on the following stroke. If a small quantity of fuel is admitted into the pumping chamber, the plungers move out a short distance. Maximum fuel delivery is limited by a leaf spring or springs that contact the edge of the roller shoes.

During the charging phase of injection, the angled inlet passages in the rotor are in alignment with the ports in the charging annulus. The rotor discharge port is not in alignment with a head outlet, as shown in *Figure 5-66*. The rollers are also off of the cam ring lobes.

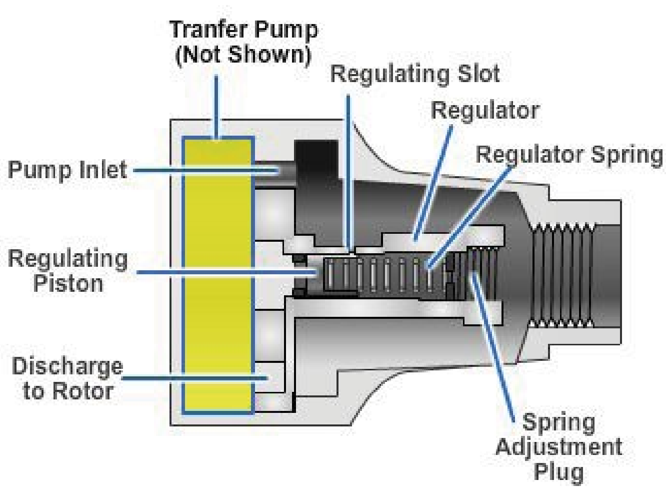

Figure 5-65 - Pressure regulating valve operation.

Discharging Cycle. As the rotor continues to revolve, as shown in *Figure 5-67*, the inlet passages move out of alignment with the charging ports. The rotor discharge port opens to one of the head outlets. The rollers then contact the cam lobes, and injection begins. Further rotation of the motor moves the rollers up the ramps, pushing the plungers inward. During this stroke, the fuel trapped between the plungers flows through the rotor's axial passage and discharge port to the injection line. Delivery to the injection line continues until the rollers move past the innermost point on the cam lobe and begin to move outward. The pressure in the axial passage is then reduced, allowing the nozzle to close and ending injection.

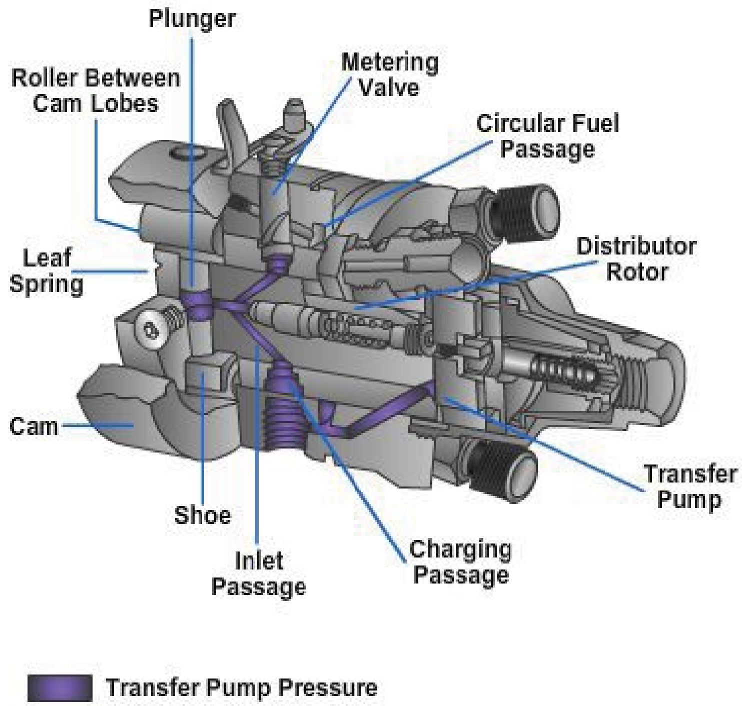

Figure 5-66 -Fuel flow during the opposed plunger pump's charging cycle.

Delivery Valve Operation. On some distributor pumps, individual delivery valves (sometimes called pressure valves) are installed in the hydraulic head outlets for each cylinder. In other pump models, such as Stanadyne's, a single delivery valve mounted in a bore in the center of the distributor rotor serves all injection lines. The delivery valve or valves keep the lines full of fuel so that a full charge of fuel can be injected at the next cycle for that cylinder.

In addition, the delivery valve rapidly decreases injection line pressure to lower than nozzle closing pressure. This allows the nozzle to snap shut quickly without nozzle dripping or dribble that could cause excessive exhaust smoke.

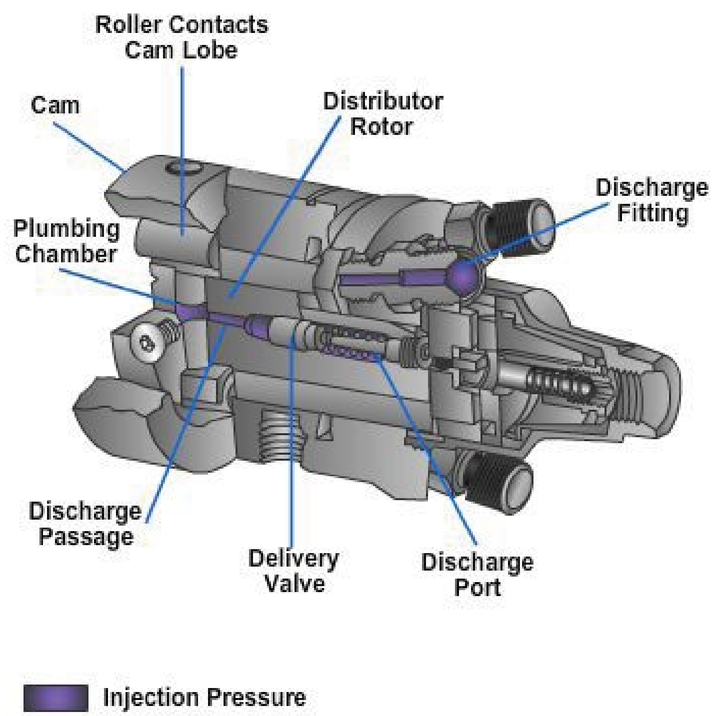

Figure 5-67 -Cutaway showing the opposed plunger pump's discharge cycle.

Lubrication Circuit. The pump is located with diesel fuel supplied by the transfer pump. A lubrication groove runs from the annular ring to the front of the rotor. From this point, the lubricating fuel flows to the main pump housing. At the top front of this housing, a return fitting allows fuel to return to the fuel tank, as shown in *Figure 5-68*. This fuel lubricates all governor components. It also bleeds any air that may have entered the fuel system.

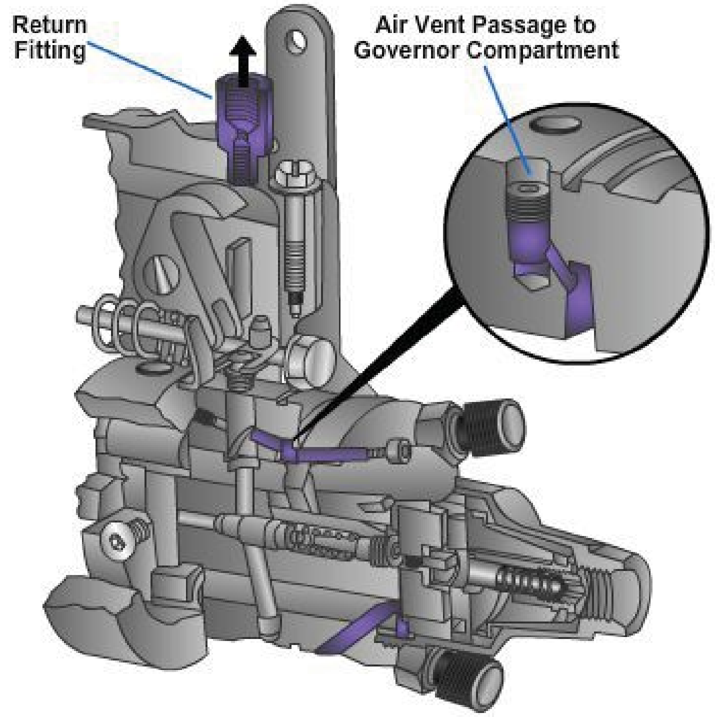

Figure 5-68 – The oil return circuit allows excess oil in the distributor pump to return to the fuel tank.

Advance Mechanism Operation. The opposed plunger distributor pump design permits the use of a direct-acting hydraulic advance mechanism powered by pressure from the fuel transfer pump. The pressure is used to rotate the cam and vary delivery timing. The advance mechanism advances or retards the start of fuel delivery in response to engine speed changes.

Fuel from the transfer pump enters the hollow hydraulic head locating screw. Fuel then flows to the advance piston, as shown in *Figure 5-69*. The piston advances the injection timing by pushing the advance cam screw to the cam ring, forcing the cam ring from retarding by holding the fuel pressure in the chamber. When fuel pressure decreases because of a reduction in engine speed, fuel from the position area drains through the orifice below the ball check valve to allow the cam ring to retard. At engine idle speed, transfer pump fuel pressure is low, and the cam ring is held in the retard position by the spring and roller force. Maximum cam ring movement is limited by the piston length and the size of the piston hole plugs. A trimmer screw is provided to adjust advance spring preload, which controls the start of the cam movement.

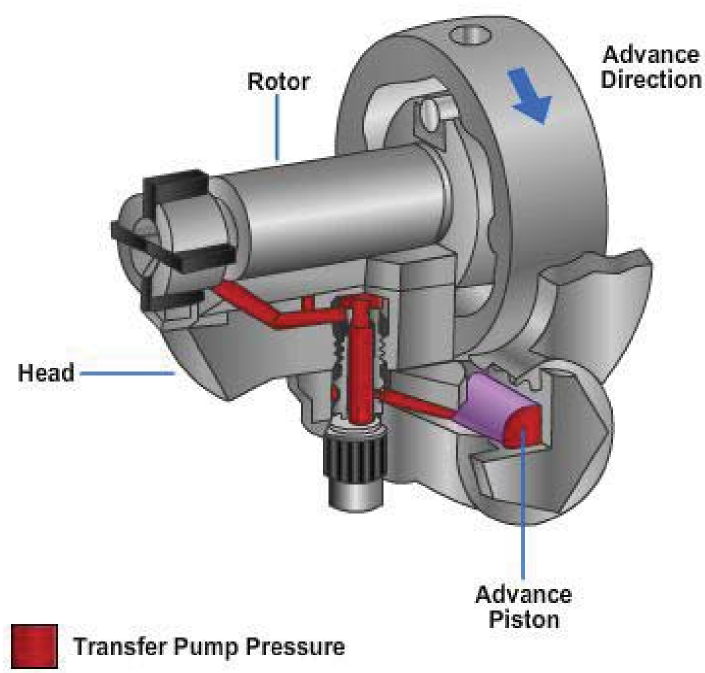

Figure 5-69 - Operation of the opposed plunger pump automatic mechanism.

Mechanical Governor Operation. The opposed plunger distributor pump can be equipped with either a mechanical or hydraulic governor. The mechanical governor is shown in *Figure 5-70*. The flyweights transmit force through the thrust sleeve, causing the governor lever to pivot. This pivoting movement rotates the metering valve, which reduces or increases the amount of fuel fed to the pumping cylinder. The flyweight force is opposed by the main governor spring and the idle spring. These forces balance each other to maintain a set engine speed. When needed, a mechanical shutoff bar rotates the metering valve to the shutoff position, regardless of the engine speed.

At idle, the flyweights offer little force against the governor lever. However, the main governor spring is slack, so the weights fly outward, causing the metering valve to rotate to the idle position. Within the idling speed range, the idle spring provides sensitive speed control.

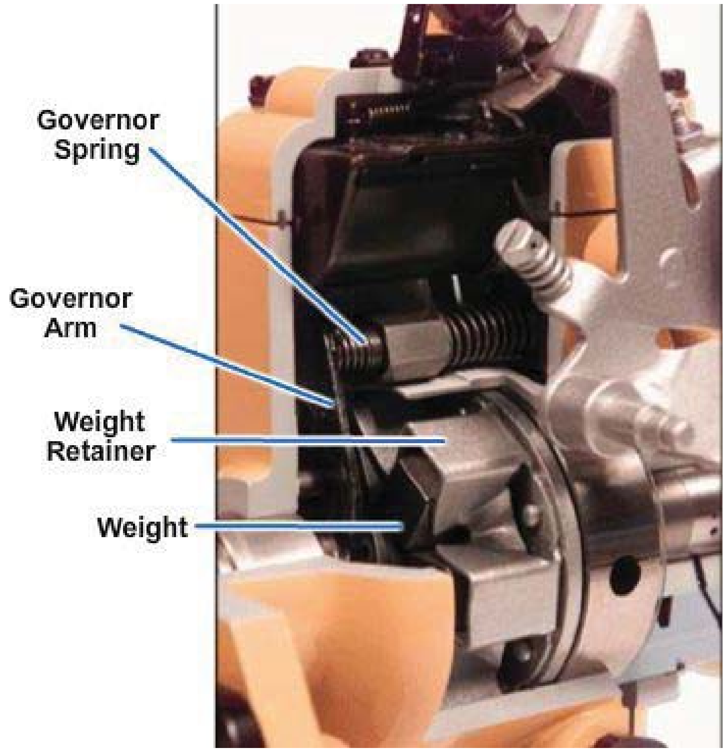

Figure 5-70 - Components of a mechanical governor.

At full load speed, the throttle applies maximum spring pressure on the lever. However, because of the load applied to the engine, it can only run fast enough to balance heavy spring load with the flyweight force. The metering valve rotates to allow the maximum amount of fuel to enter the rotor.

If the load is suddenly removed from the engine, the engine speeds up. The increased force of the flyweights overcomes the spring pressure and rotates the metering valve to the closed position. Once the valve closes completely, governor cutoff occurs, limiting maximum engine speed to safe levels. The engine then slows down until the flyweights and spring reach a balance that allows only a small amount of fuel into the rotor. This condition is known as high idle speed.

Electrical Shut-off. The governor may be equipped with an electrical shut-off device housed within the governor control cover. The device is available for 12-, 24-, and 32-volt systems. The device can either be energized-to-shut off (ETSO) or energized-to-run (ETR).

- **Energized-to-Shut-off (ETSO).** Energizing the solenoid coil overcomes the force of the shut-down coil spring, pulling the arm in and causing the tab on its lower end to contact the governor linkage hook. This moves the linkage hook against the spring tension, rotating the metering valve to its closed position, cutting off the fuel, as shown in *Figure 5-71A*.
- **Energized-Run (ETR).** De-energizing the shut-down coil allows the spring to release the shut-off arm. The lower end of the arm moves the governor linkage hook, rotating the metering valve to the closed position and cutting off the fuel, as shown in *Figure 5-71B*. Some energized-to-run systems employ a mechanical

override device for emergency use if the coil becomes inoperative due to electrical system failure. The override consists of a rod and guide assembly. When the rod is pushed into the cover to the limit of its travel, it contacts the solenoid arm assembly, locking it against the solenoid, allowing the linkage hook to operate. Pump shut-off during an electrical failure is accomplished by pulling out the override rod.

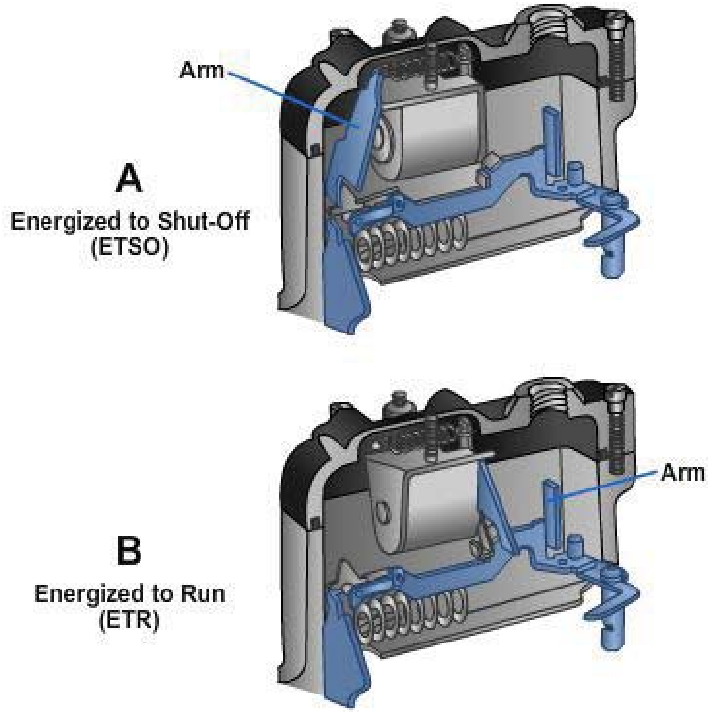

Figure 5-71 - Electrical solenoid activated fuel shut-off mechanisms. A-Energized-to shut-off. B-Energized-to-run.

Troubleshooting. A field test on an engine is an efficient way to pinpoint the cause of poor engine performance. This test will eliminate unnecessary fuel injection pump removal. Since this field test permits some analysis of engine condition as well as the fuel system, you will quickly see the extent of the difficulty and the required remedies.

Since most tests are more conveniently made under no load conditions, all possible readings are determined at high idle. If the supply pressure is lower than normal, an engine can still operate smoothly at approximately the correct high-idle speed. The governor opens the metering valve further to make up for the lower pressure; therefore, you can take successful readings at high idle.

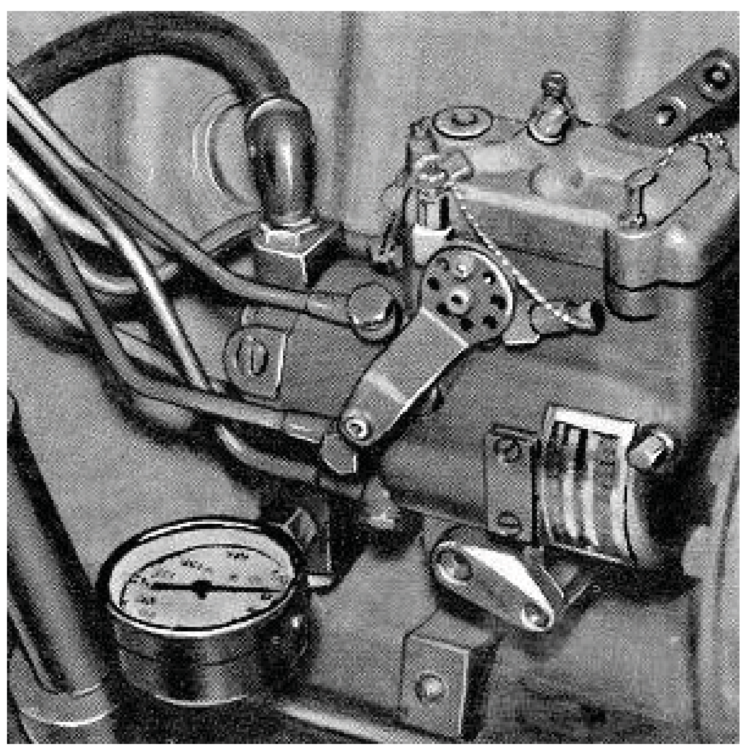

Figure 5-72 Gauge installed for checking transfer pump pressure.

First, disconnect the throttle linkage. Then, with the engine running, hold the throttle lever all the way to the rear. Adjust the high-idle stop screw until the specified high-idle speed is obtained to test the fuel pressure at high idle. Install the gauge assembly in the pressure trap of the transfer pump, as shown in *Figure 5-72*. If this reading does not fall within the prescribed range, the pump will not deliver sufficient fuel to obtain full power under load. The most common causes of low pressure are restricted fuel supply, air leaks on the suction side of the pump, worn transfer pump blades, or a malfunctioning regulator valve.

To test for excessive pressure, remove the injection fuel pump timing plate, as shown in *Figure 5-73*. Be sure you make a small hole in the timing plate gasket as you install the gauge on the pump. This hole allows pump pressure to reach the gauge as you operate the engine at both low and high idle. If the pressure is excessive, a restricted fuel return line is the probable cause. To test for restricted fuel supply on the suction side of the pump, operate the engine at high idle and read the vacuum developed. If the vacuum reading exceeds 10 inches mercury (Hg), check the fuel supply system for dirty filters, pinched or collapsed hoses, or a plugged vent.

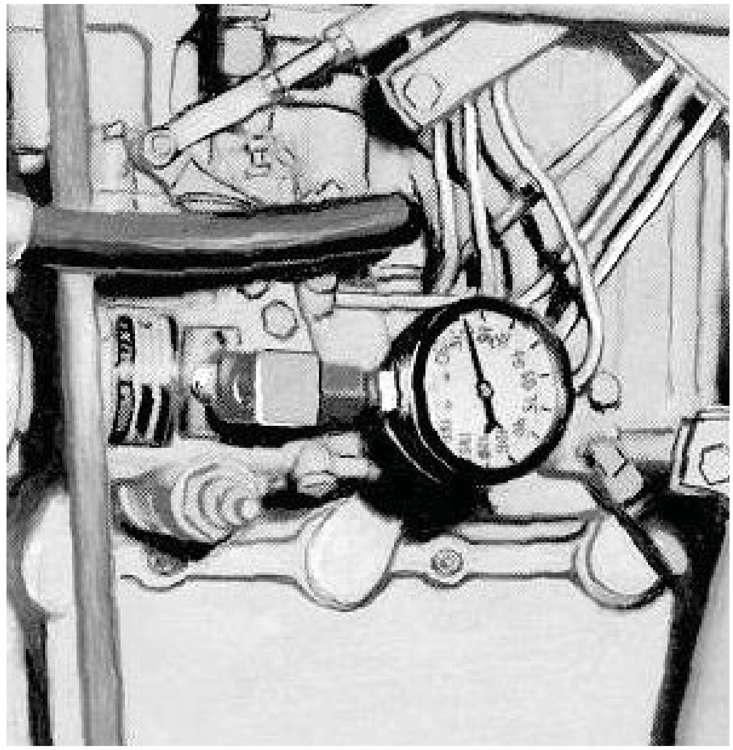

Figure 5-73 – Testing pump housing pressure.

Removal. If you find after field testing that you must remove the injection fuel pump from the engine, be sure to remove all external grease and dirt. Remember that dirt, dust, and other foreign matter are the greatest enemies of the injection fuel pump. As a precaution, keep all openings plugged during removal and disassembly.

Disassembly. The workbench, surrounding area, and tools must be clean. You should have a clean pan available in which to put parts as you disassemble the pump. You also need a pan of clean diesel fuel oil in which the parts can be washed and cleaned. After mounting the pump in a holding fixture, clamp the fixture in a vise. Now you are ready to disassemble the pump. Follow the step-by-step procedure in the manual for the model pump on which you are working.

Cleaning, Inspecting, and Reassembly. Now that you have disassembled the pump and inspected all the parts carefully, replace all O rings, seals, and gaskets, and inspect all springs for wear or distortion. Clean and carefully check all bores, grooves, and seal seats for damage of any kind. Replace damaged parts as necessary.

Also, inspect each part of the injection pump for excessive wear, rust, nicks, chipping, scratches, cracks, or distortion. Replace any defective parts.

When you have finished cleaning and inspecting the pump, reassemble it. Follow the steps specified by the manufacture's maintenance and repair manual.

2.2.1 Electronic Unit Injection (EUI)

Electronic unit injectors have proven to be the most readily adaptable of all the fuel injection systems to electronic control. The spray-in pressures and fine atomization possible with unit injection systems, coupled with the system's compatibility to electronic control, has led many manufacturers to switch to unit injection. To better understand how an electronic unit injector operates, *Figure 5-74* illustrates a unit injection system.

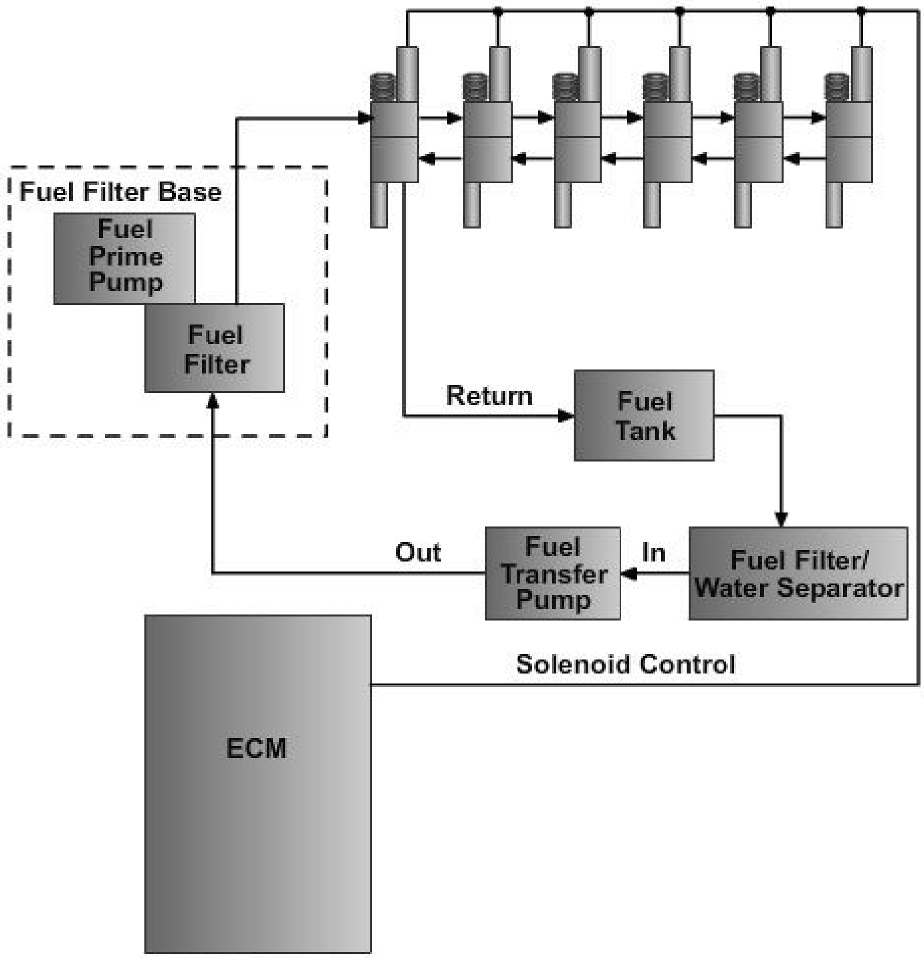

Figure 5-74 -Example fuel system layout.

The Delphi EUIs used by Caterpillar have changed little since their introduction in the late 1980s. *Figure 5-75* shows a sectional view of the Caterpillar Delphi EUI with the subcomponents labeled.

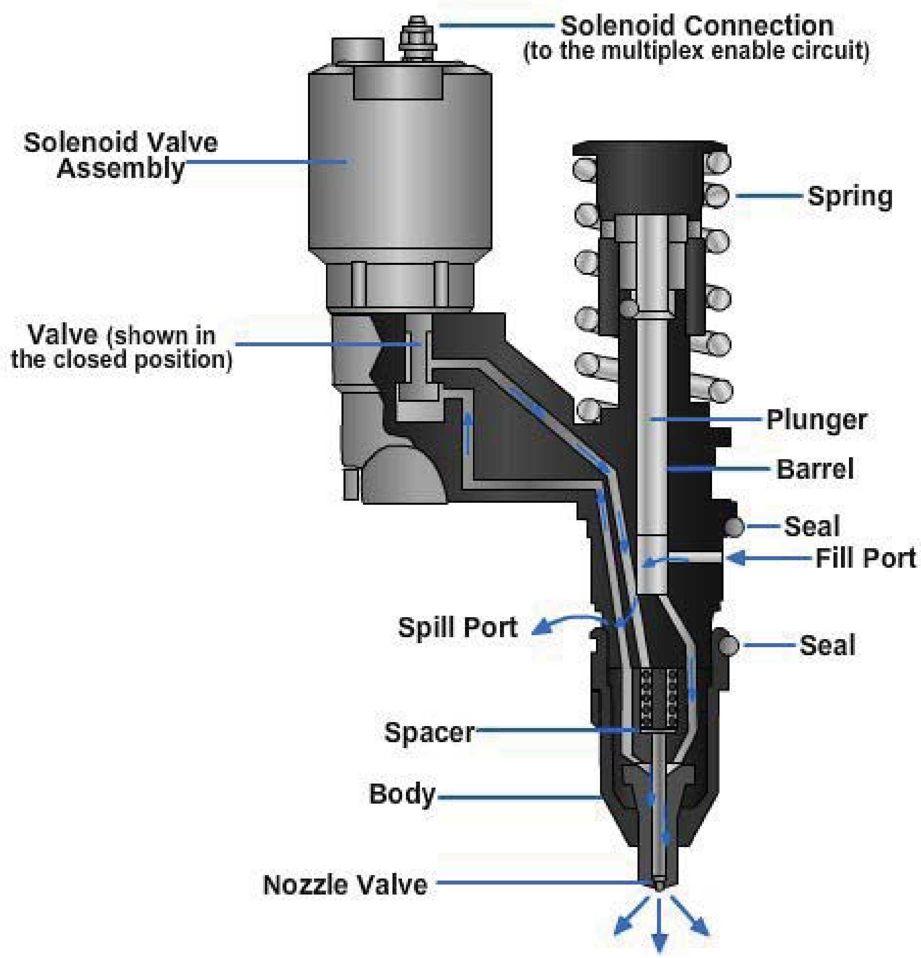

Figure 5-75 - Sectional view of a Delphi EUI and internal components.

1. Terminal. Connects to the injector drivers in the ECM.
2. Control cartridge. Solenoid consisting of a coil and armature with an integral poppet control valve. A spring loads the armature open. Energizing the solenoid closes the armature/poppet control valve.
3. EUI tappet spring. Loads the EUI tappet upward. This enables the tappet/plunger actuation train to ride the cam profile and retract the tappet after a mechanical stroke.
4. Poppet control valve. A valve integral with the solenoid armature. In *Figure 5-75* the control valve is shown closed (solenoid energized): this prevents fuel from exiting through the spill port, trapping it in the EUI circuitry, enabling effective stroke.
5. Plunger. The reciprocating member of the pump element, the plunger, is lugged to the tappet, so it reciprocates with it. In *Figure 5-75*, the plunger is shown in its upward position.
6. Barrel. The stationary member of the EUI pumping element containing the fill port, pump chamber, and duct connecting the pump chamber with the injection nozzle.
7. Upper O-ring. Seals the upper fuel charging gallery.
8. Lower O-ring. Seals the lower fuel charging gallery.

9. Nozzle spring. Defines the nozzle opening pressure value, typically around 5,000 psi. Nozzle opening pressure is initial and rebuild set by shims acting on the nozzle spring.
10. Spacer or shims. Define nozzle spring tension and therefore the specific Nozzle opening pressure value.
11. Upper nozzle assembly body. Machined with the ducting that feeds fuel to the pressure chamber of the nozzle valve.
12. Nozzle valve. The nozzle assembly is a hydraulically actuated, multi-orifii, valve closes orifice (VCO), *Figure 5-76* and *Figure 5-77*.

Figure 5-76 - External view of a multi-orifii injector nozzle.

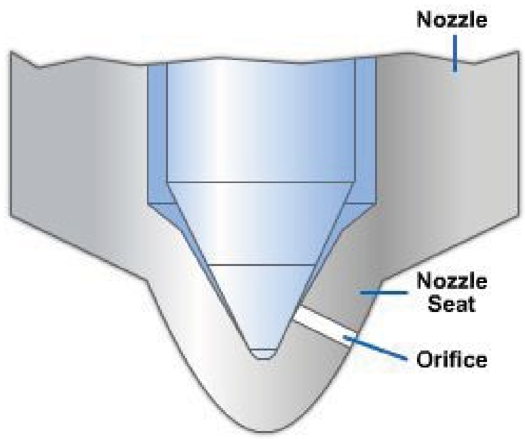

Figure 5-77 - Sectional view of a valve closes orifice (VCO) nozzle.

2.2.1.1 Electronic Unit Injector Operation

Fuel enters the injector through two filter screens. Fuel not used for injection cools and lubricates the injector before exiting through the return port and returning to the supply tank, as shown in *Figure 5-78*.

Figure 5-79 illustrates the actuator components of the unit injector. The electronic unit injection system uses mechanical action to create the pressures needed for injection. As in the mechanical unit injection system, the camshaft pivots the rocker arm through its roller follower.

This forces the injector follower down against its external return spring. This action raises the trapped fuel to a pressure sufficient to lift the injector needle valve off its seat. However, fuel metering is electronically controlled by the ECM based on input signals from various sensors.

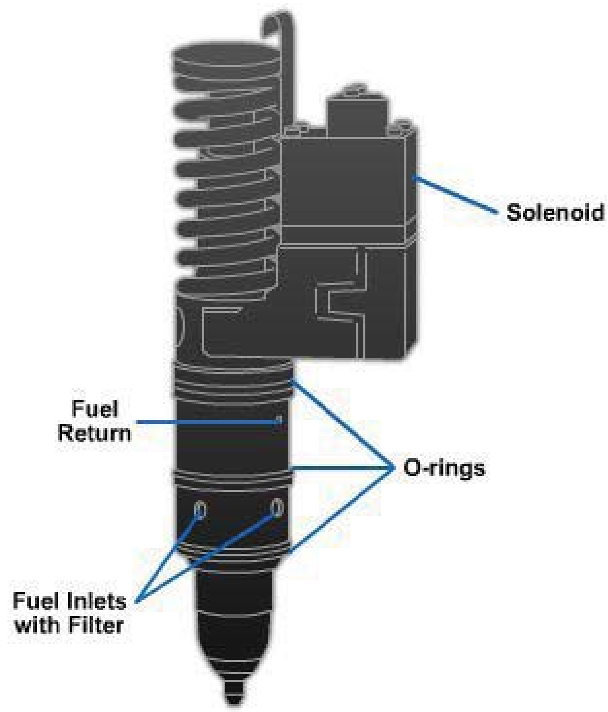

Figure 5-78 -Fuel inlet and return holes in an electronically controlled unit injector.

2.2.2 Fuel Flow

Fuel flow through the electronic unit injector is illustrated in *Figure 5-80* and *Figure 5-81*. Once fuel enters the electronic unit injector, it passes through the inlet filters and flows through a drilled passage to an electronically controlled poppet valve. At this point in the injection cycle, poppet valve is held open by spring pressure. Fuel flows through the plunger and bushing into the fuel supply chamber. With the poppet valve open, fuel simply fills the injector.

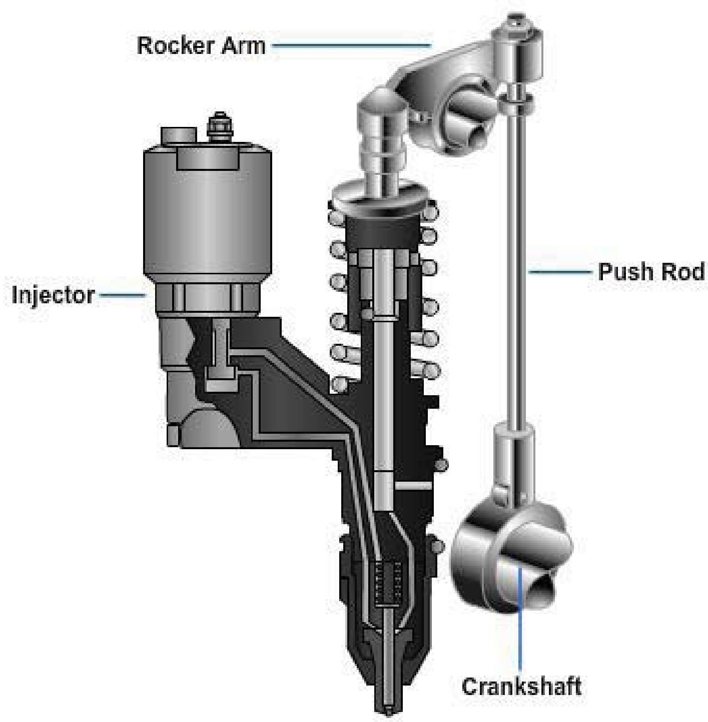

Figure 5-79 – Example of an engine electronically controlled/mechanically actuated unit injector.

When the piston is approximately 60° BTDC on its compression stroke, the camshaft begins to lift the injector rocker arm roller follower. The EUI internal plunger moves on its bushing, increasing fuel pressure. However, no increase above fuel pump pressure is possible until the ECM sends out a voltage signal to the electronic distributor unit. The electronic distributor unit (EDU) handles the high current needed to activate the injector solenoid.

When the solenoid on the EUI is energized, its armature is pulled upward, closing the poppet valve and descending the plunger. This creates a rapid rise in the pressure within the fuel supply chamber that leads to the spray-tip assembly.

A small check valve is located between the plunger base and the spray tip prevents combustion gas blowby from leaking into the injector. During normal operation, the fuel pressure below the plunger increases until it is powerful enough to lift the needle valve from its seat. The strength of the needle valve spring determines when the valve will lift off its seat. Opening pressures of 2800-3200 psi are common. When the needle valve unseats, fuel flows through the orifices in the injector tip. Forcing the fuel through these small openings increases the pressure to approximately 20,000 psi.

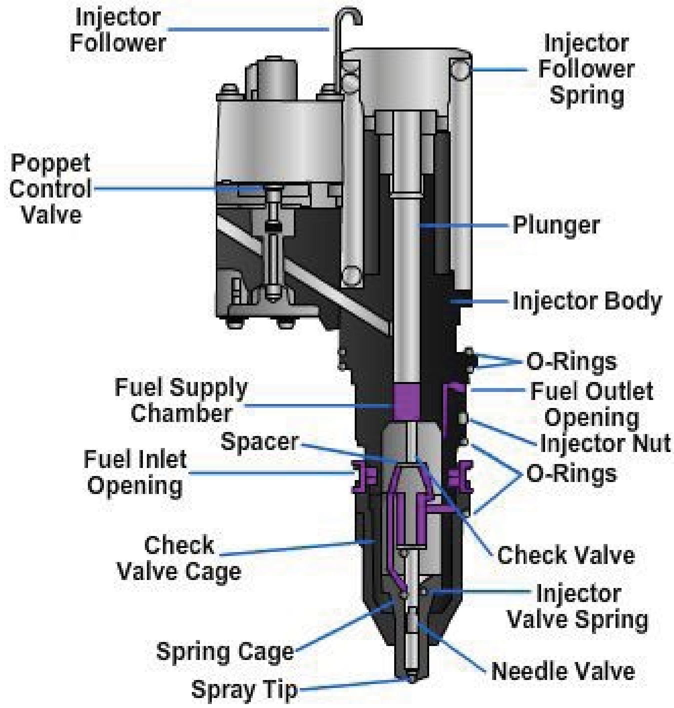

Figure 5-80 – Cutaway view of a fuel flow unit injector.

The start and duration of injection are controlled by the pulse width signal from the ECM. The longer the EUI solenoid is energized, the longer the poppet valve remains closed and the greater amount of fuel injected. Holding the poppet valve closed sets the injector plunger effective stroke. The plunger always moves down the same distance on every injection stroke, but the length of time the fuel is pressurized beneath the plunger is controlled by the solenoid.

When the ECM de-energizes the EUI solenoid, spring pressure opens the poppet valve. High-pressure fuel now flows through the small return passage in the injector body. Pressure is lost, and the force of the needle valve return spring forces the needle valve onto its seat. This results in a clean, quick end to injection. Fuel at pump pressure immediately flows into the EUI through the open poppet valve. The plunger continues to the bottom of its stroke, but it is pushing fuel through the injector tip at high pressure. When the plunger completes its downward stroke, the follower return spring pulls it up to its original position. The injector is now in position to begin the injection cycle again.

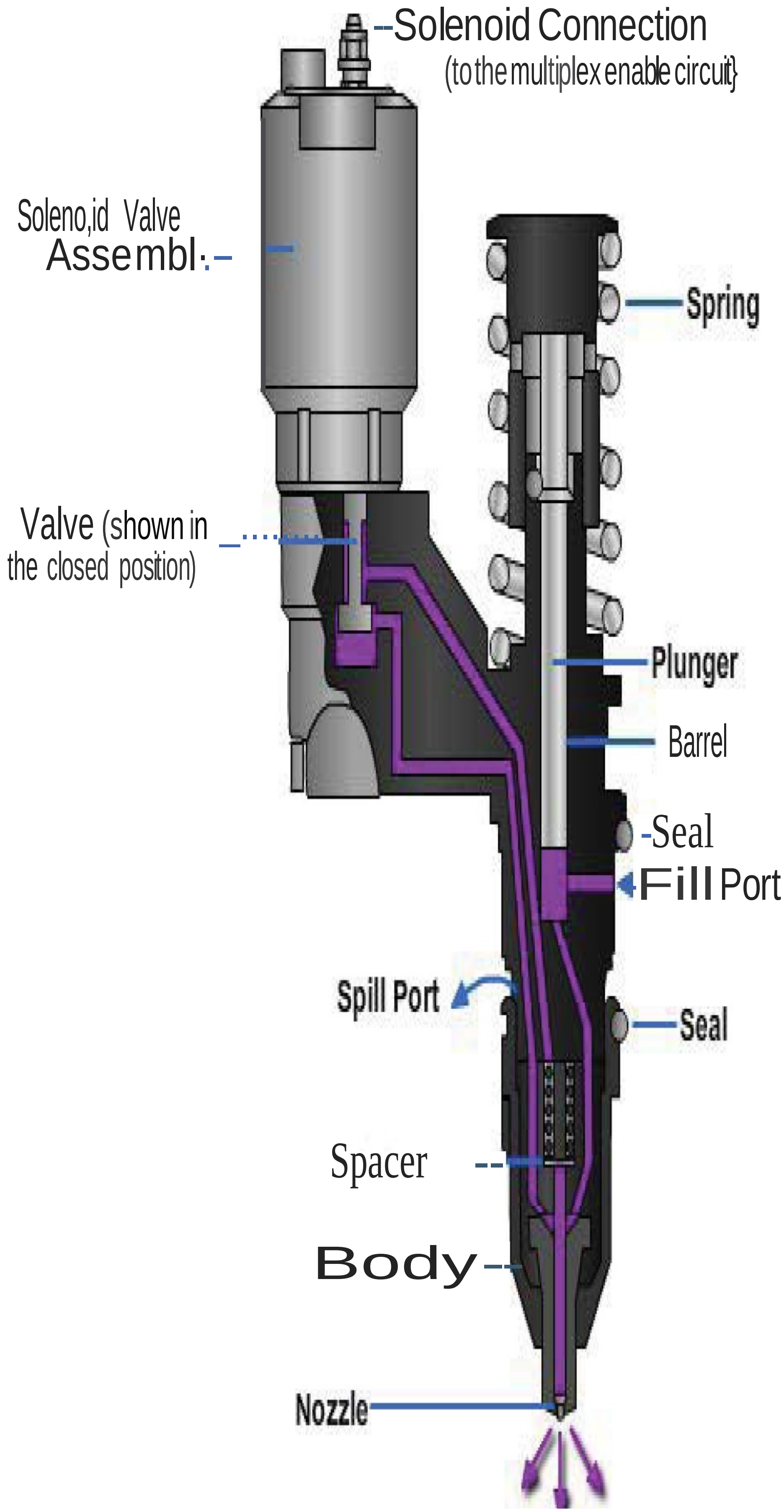

Figure 5-81 – Caterpillar EUI injection cycle.

2.2.3 yne Electronically Controlled Distribution Pump

The Stanadyne electronically controlled distributor pump shown in *Figure 5-82* regulates fuel quantity with a solenoid valve that controls the amount of low pressure fuel entering the high pressure pumping chamber. The solenoid is not pulsed. It is either fully opened or fully closed. The solenoid driver mounted on the side of the pump housing operates the solenoid on command from the ECM. The driver senses when the solenoid is fully closed to tell the ECM when injection has ended.

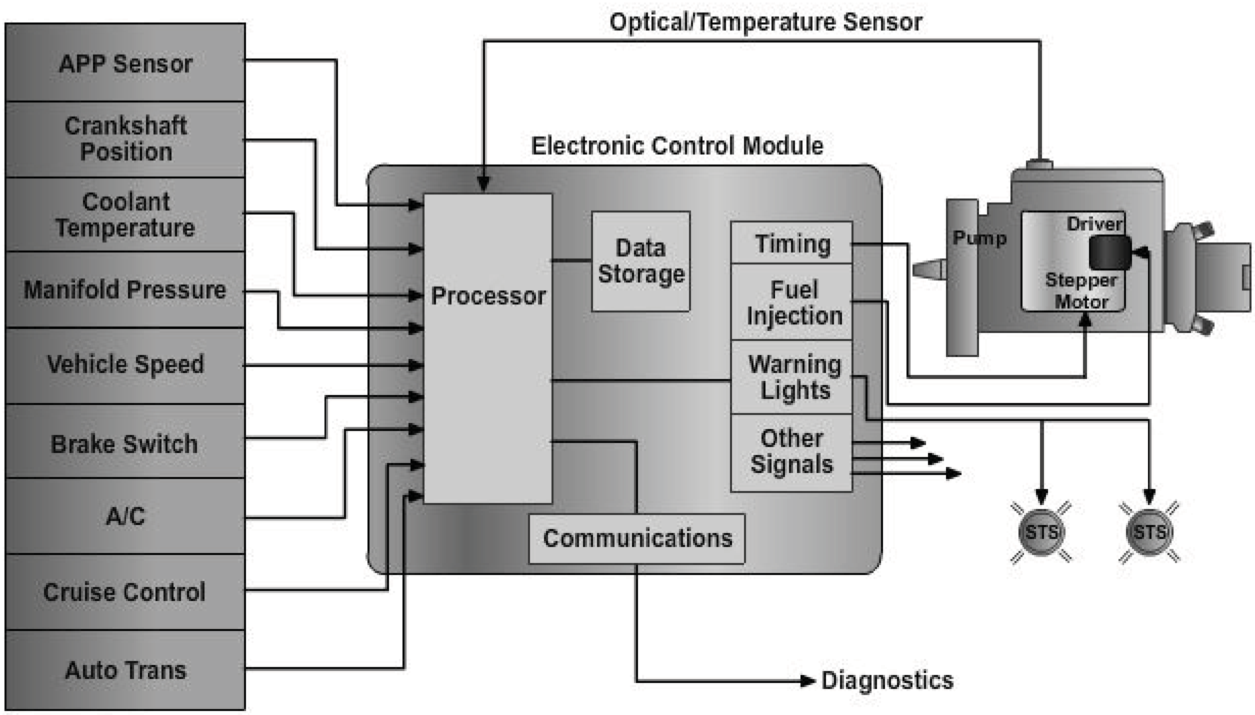

Figure 5-82 - Example of an electronically controlled distributor fuel injection pump.

An acceleration pedal position (APP) sensor supplies data on pedal position and movement to the ECM. It then operates the fuel solenoid accordingly. The pedal position sensor contains three separate potentiometers, each with its own 5v reference and district return signals. This triple redundancy helps ensure a signal is delivered to the ECM. If one or two sensors fail, the engine will run only at limited power. If all three fail, the engine will run only at idle. If an APP sensor fails, the ECM will log a trouble code into memory and turn on the *Service Throttle Soon* light. Each APP signal can be checked using a scan tool or an oscilloscope.

An optical/temperature sensor mounts on the pump itself. It consists of a thermistor-type fuel temperature sensor and two optical position pick-ups that share a housing and a 5v reference signal. The optical pick-ups read the position of tone wheels rotating with the cam ring inside the pump. One pick-up provides a high resolution signal, generating per cylinder firing stroke.

Combined with fuel temperature and crankshaft position data, this extremely fine position signal makes it possible for the ECM to trim the fuel quantity for each individual combustion stroke.

The sensor's second pick-up has eight slots, and reports pump cam position to locate the start of injection for each cylinder and to index cylinder number1. Combined with the crankshaft position signal, this information is used for pump timing, idle speed, and other powertrain control events. Additional inputs include coolant and intake air temperature, crankshaft position, barometric pressure, vehicle speed, and automatic transmission sensors.

Injection pump timing is controlled by a stepper motor mounted to the side of the distributor pump. By changing the position of the cam ring, first movement of the high pressure plunger (plunger lift) can be varied relative to crankshaft position. With mechanical governors, this is a function of hydraulic pressure in the pump housing, increasing with rpm to advance timing as speed increases. On electronically controlled pumps, the ECM operates the stepper motor. Other outputs include the injection pump driver, timing stepper motor, Service Engine Soon and Service Soon lights, and glow plug relay.

2.3.0 Cummins Fuel Systems

2.3.1 ressure-Time Fuel Injection System

For many years, Cummins manufactured engines equipped with a mechanically operated pressure-time (PT) fuel injection system that remains unique to the industry. To meet stringent emission control laws, Cummins introduced its **Pace system** on its PT-equipped engines. PACE provides electronic control of the PT system through the use of sensors, an electronically activated fuel control valve, and a PT control module. Cummins also offers an electronically controlled unit injector fuel injection system, known as *Celect-ECI*. Some Cummins engines also use inline or distributor injection system, depending on the application.

PT Fuel System Operation. *Figure 5-83* illustrates the basic components of the Cummins PT fuel system. The PT fuel injection system derives its name from two primary variables affecting the amount of injected fuel per cycle. The P refers to the pressure of the fuel at the injector inlets. This pressure is collected by the fuel pump. However, the PT fuel pump is not the same as an inline or distributor injection pump. The T refers to time available for the fuel to flow into the injector cup. The time is controlled by engine speed through the camshaft and injection train. Cummins engines are four-cycle engines, so the camshaft is driven at one-half engine speed, making additional governing of fuel flow necessary. The fuel pump varies pressure to the injectors in proportion to engine rpm.

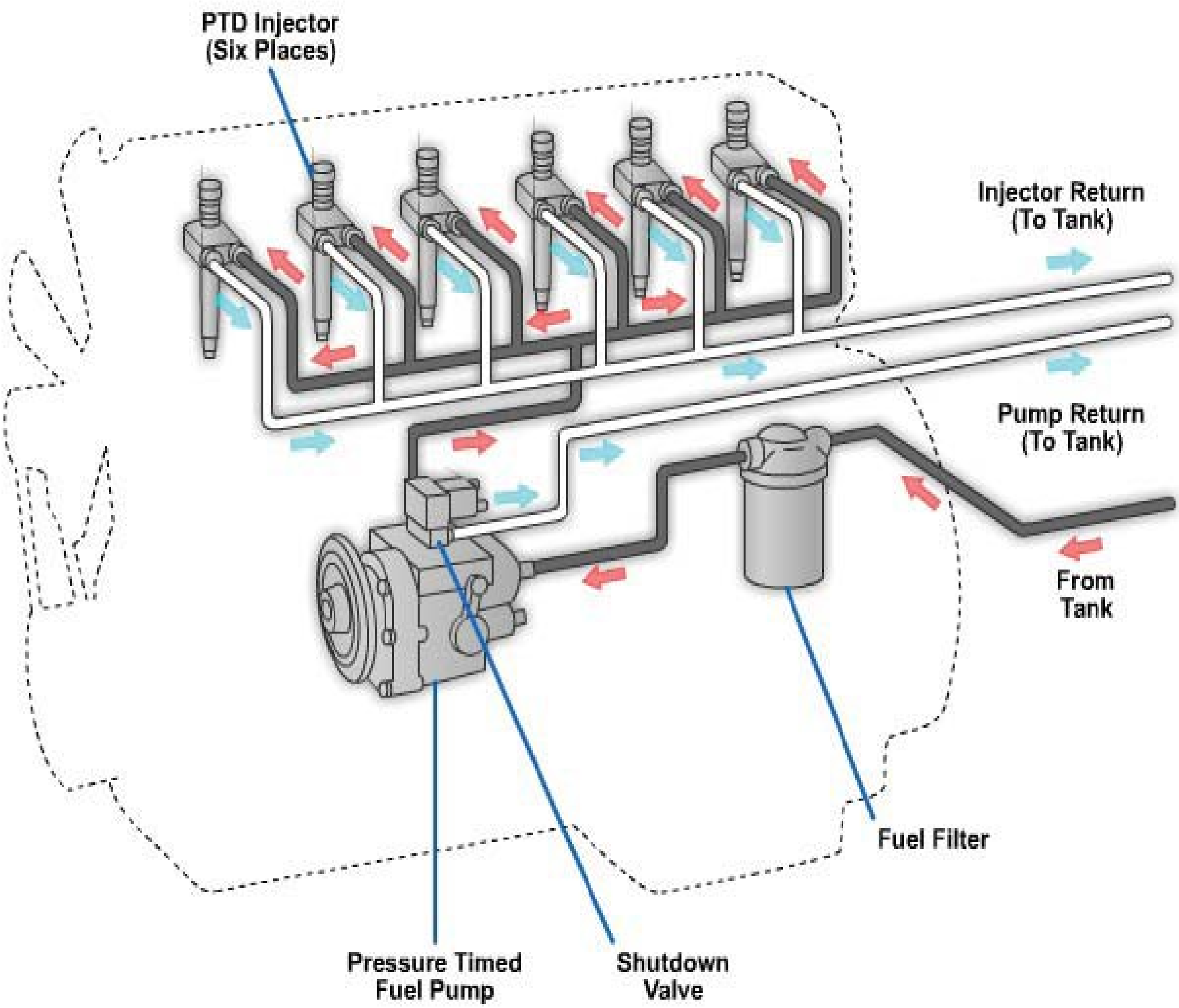

Figure 5-83 - Basic components of the Cummins Pressure-Time Fuel injection system.

The final controlling element in the fuel metering process is the size of the injector openings (orifices). The orifice size, also called flow area, is determined by calibration of a complete set of injectors.

With a given flow area, fuel metering is controlled by rail pressure and flow time. The flow time or metering time is controlled by engine speed through a camshaft-actuated plunger. The camshaft rotary motion is changed into reciprocating motion of the injector plunger. The plunger movement opens and closes the injector barrel metering orifice, as illustrated in *Figure 5-84*. The period of time the metering orifice is open is the time available for the fuel to flow into the injector cup. The greater the engine speed, the less available time to meter the fuel. *Figure 5-84, View A* illustrates the injector metering orifice closed, while *Figure 5-84, View B* illustrates the injector metering orifice opened.

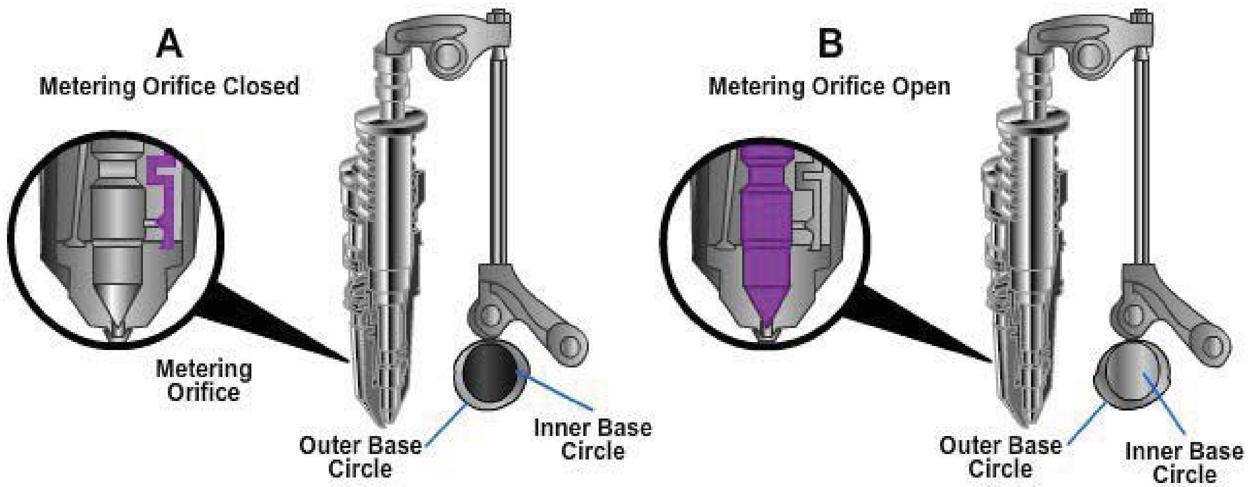

Figure 5-84 - A PT fuel system, the camshaft actuated injector.

At any given speed, only rail pressure in the PT fuel system controls the quantity of fuel metered to the injectors. One of the major advantages of the PT system is that unlike other fuel injection pumps, it is not necessary to time the PT fuel pump to the engine. The PT pump supplies fuel at a given flow rate and at a specified pressure setting to a common rail supplying all the injectors. In the PT injection system, the injectors themselves are timed to ensure that the start of injection occurs at the correct time for each cylinder.

Pressure-Time Governed Fuel Pump Functions. The pressure-time fuel pump also drives the governor. This assembly is often referred to as the pressure-time governed (PTG) fuel pump. The basic functions of the PTG fuel pump include:

- The transfer of fuel from the supply tank supply engine
- Rail pressure to the injectors
- Idle and maximum speed governing
- Operator control of power output below governed speed
- Control of exhaust smoke during acceleration
- Shutdown of the engine

The PTG fuel pump assembly is coupled to the compressor drive and driven from the engine gear train. The fuel pump main shaft drives the gear pump, governor, and tachometer shaft assemblies at engine speed, as illustrated in *Figure 5-85*. Fuel from the supply tank enters the gear pump inlet and is carried around outside the two meshing gears to the gear pump outlet. From this point, fuel flows through a wire mesh magnetic filter to the governor inlet passage. In addition to providing idle speed and maximum speed governing, the PT governor also regulates fuel pressure.

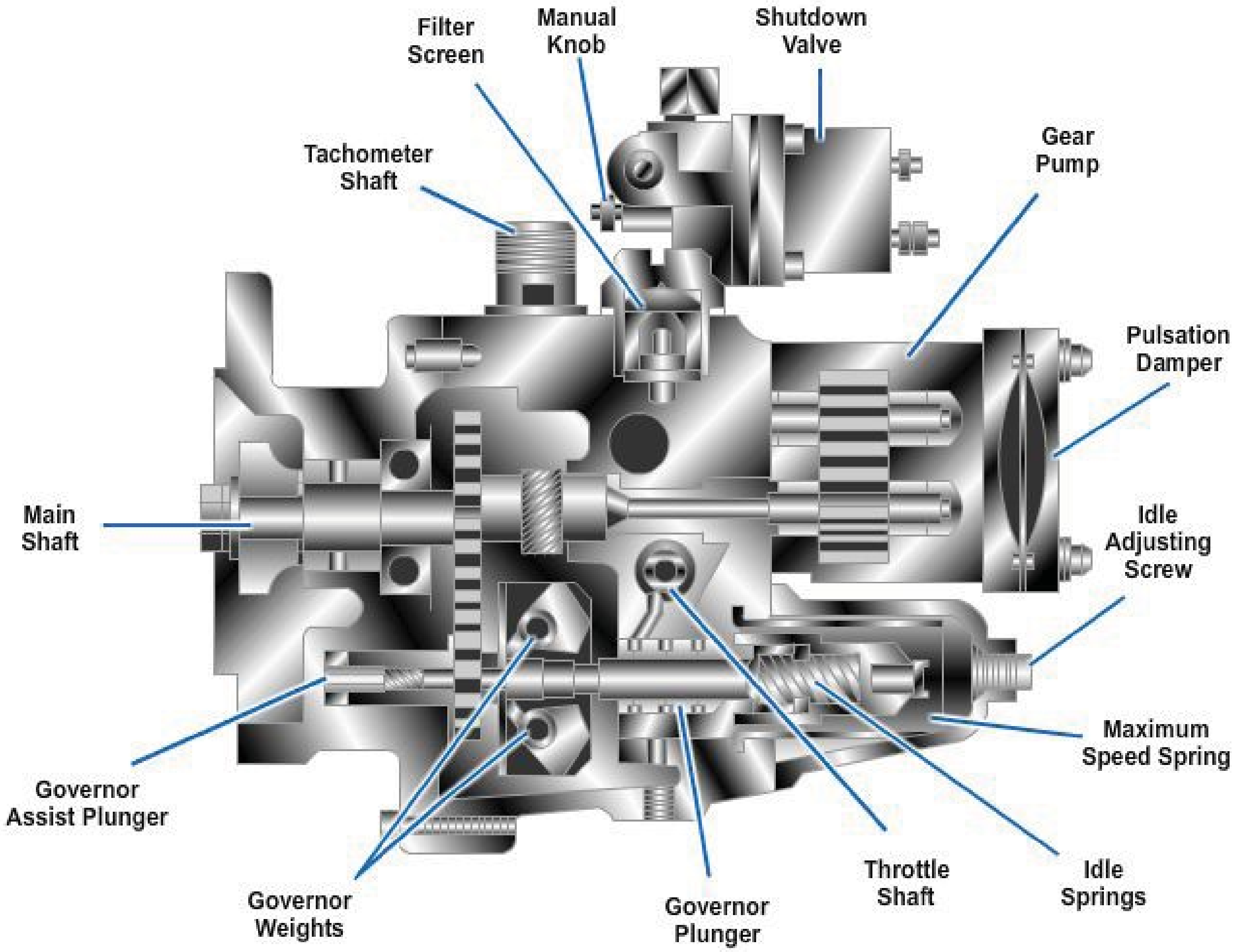

Figure 5-85 - Components of the Pressure-Time Governed Air-Fuel Control (PTG-AFC) fuel pump.

Governor. The PT fuel system governor is illustrated in *Figure 5-86*. It is a simple flyweight-operated mechanical governor. The flyweights are driven at engine speed by the fuel pump mainshaft. The governor plunger is held between the flyweight feet and rotates with the flyweights. The rotating flyweights pivot on pins, allowing their feet to exert an axial force on the governor plunger. At any given engine speed, the plunger position is determined by the balance between the flyweight and spring forces. Increasing engine speed also increases the force exerted by the flyweights and forces the plunger to move to the right, as shown in *Figure 5-87*.

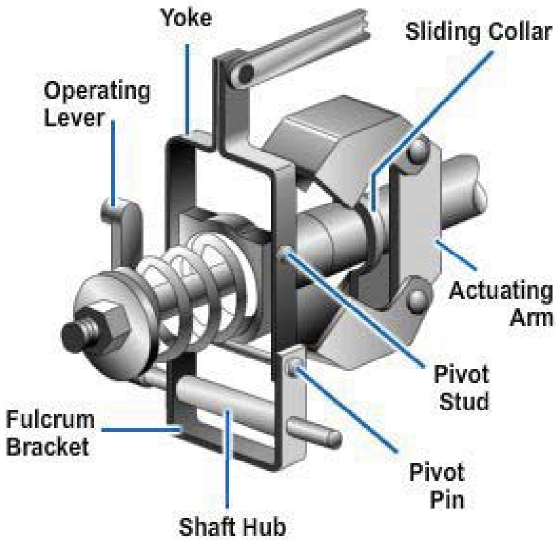

Figure 5-86 - Components of a Cummins PT fuel pump mechanical flyweight governor.

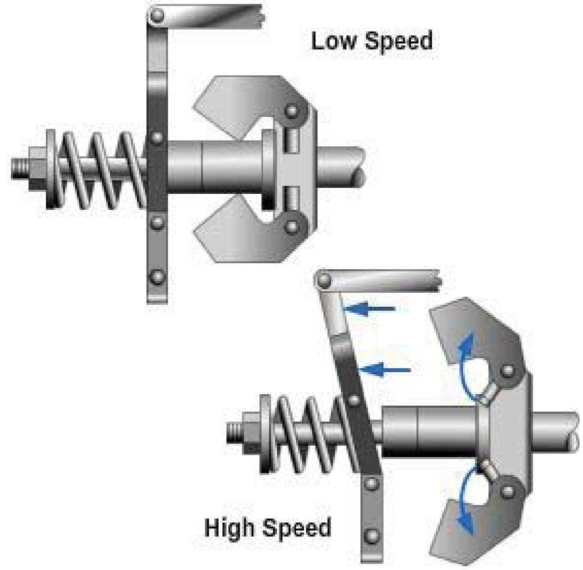

Figure 5-87 - As rotational speed increases, the centrifugal force of the governor flyweights force the governor plunger to the right.

Rail pressure control of the PT fuel system begins by regulating the fuel or supply pressure to the governor assembly. Supply pressure control is accomplished by using a bypass pressure regulator inside the governor. The pressure regulator has a button valve designed to unseat when a designated pressure is reached, as shown in *Figure 5-88*. For the regulator to open, an excess supply of fuel must be delivered to the governor. This ensures that some fuel is always being bypassed, which is necessary for the regulator to maintain control of the supply pressure.

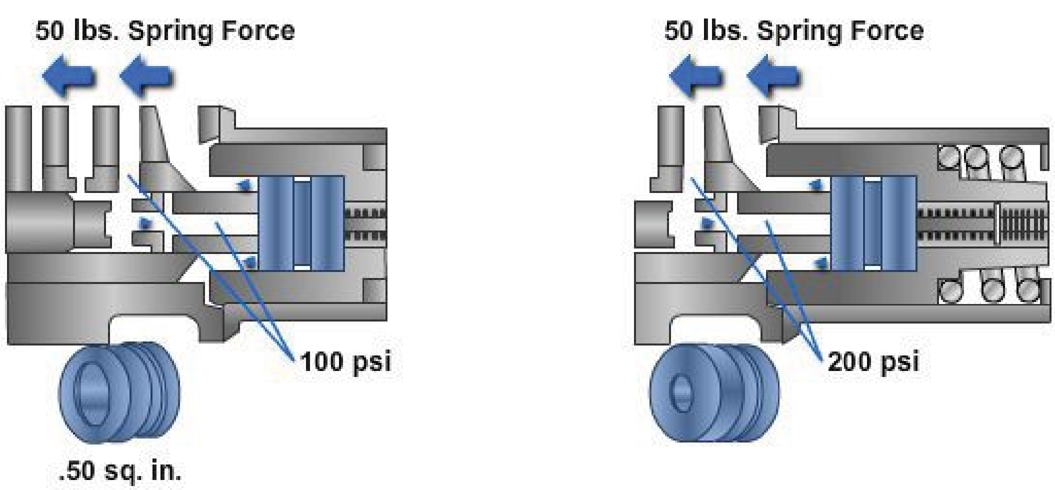

Figure 5-88 - Button valve pressure regulator.

When the fuel pressure exceeds the force holding the button valve and plunger together, fuel is bypassed to the gear pump suction side illustrated in *Figure 5-89*. The unseating pressure is determined by dividing the spring force by the button recess area. The recess area, or counterbore, is the area the fuel is pushing against. Increasing the counterbore area will reduce the pressure at which the fuel bypass opens. Decreasing the size of the recessed area will increase the pressure at which the fuel is delivered to the injector.

Throttle. The engine's power output can be controlled by the operator, within the established governor limits, through the use of a throttle. The throttle shaft is located between the governor and the fuel pump discharge. It allows the operator to control the rail pressure, and therefore, the engine power. It acts as a variable orifice, controlling the amount of fuel exiting the governor main passage. The throttle shaft's travel is limited by two stop screws located in the throttle shaft housing. A fuel-adjusting screw is located within the throttle shaft. Its setting determines the maximum flow area when the throttle shaft passage is wide open. The screw is used to adjust the rail pressure.

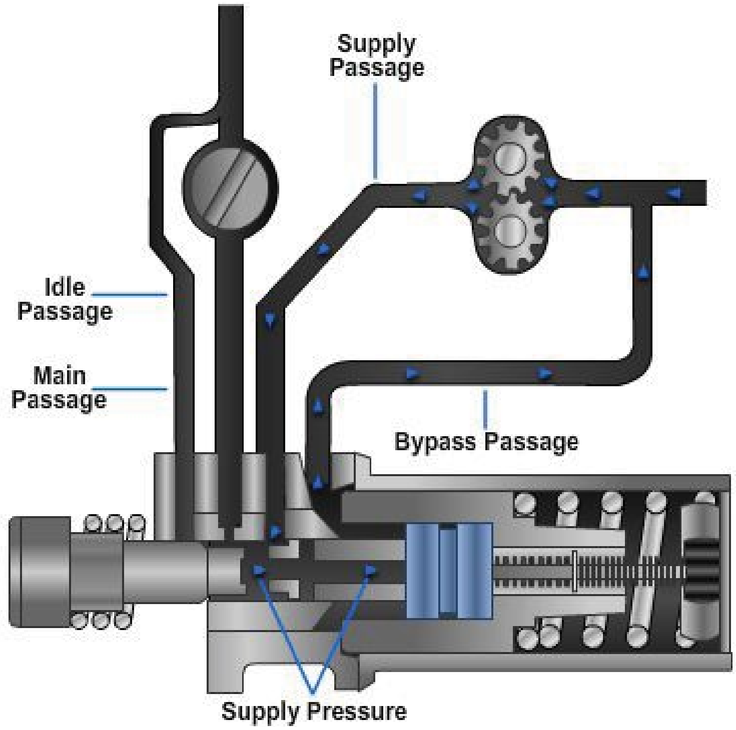

Figure 5-89 – Fuel bypass occurs when the button is unseated.

While the throttle is closed, there is a small amount of fuel flowing through the throttle shaft, This small amount of fuel is known as throttle leakage. This controlled fuel leakage is needed in the PT system to keep the injectors cooled and lubricated when the throttle is closed. If throttle leakage is set too high, the engine can experience slow deceleration and excessive injector carbon loading. If the throttle leakage is set too low, engine hesitation can result. The injector plunger may also be damaged.

When the throttle is in its closed position, the small amount of fuel flowing to the injectors is not enough to maintain idle speed. Additional fuel is provided from the governor through an idle passage around the throttle shaft.

PTG Air-Fuel Control (AFC). The PTG air-fuel control (PTG) fuel pump used on turbocharged heavy duty engines has an exhaust smoke control device built into the pump body. The AFC unit restricts fuel flow in direct proportion to intake manifold pressure during engine acceleration, under load, and lug-down conditions.

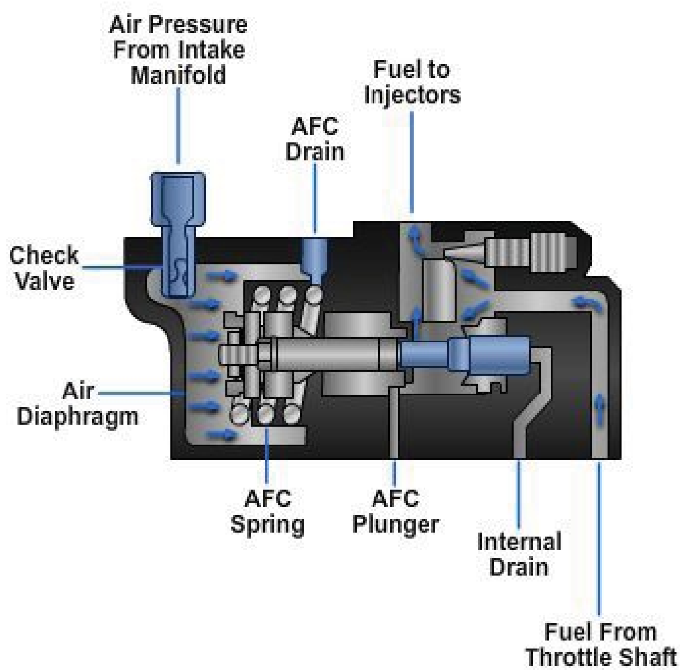

Figure 5-90 - Cutaway showing components and fuel flow through the air-fuel control (AFC) assembly.

The main components of the AFC assembly are shown if *Figure 5-90.* The AFC senses air pressure in the intake manifold. Changes in intake manifold pressure will change the piston position, which controls the plunger shoulder position over the AFC inlet passage. This determines the amount of fuel delivered to the injectors during acceleration and other engine operational states. Air pressure is applied to the diaphragm and piston through the cover inlet fitting. Increasing air pressure overcomes spring force, causing the plunger to move in the barrel. As the plunger moves, it uncovers the passage, allowing fuel to flow from the throttle shaft through the AFC. As the air pressure increases, the plunger is pushed even further, eliminating the fuel restriction and permitting maximum fuel flow through the AFC.

When there is little or no air pressure applied to the AFC diaphragm, maximum fuel pressure and flow is controlled by the No-air adjusting screw. The plunger is positioned by the return spring to block the main fuel passage around the No-air adjusting screw.

Shutdown Valve. From the AFC assembly, fuel flows to the shutdown valve. Most shutdown valves are controlled by an electrically-operated solenoid. In the shutdown mode, a spring washer seats a disc that prevents fuel flow out of the pump, as shown in *Figure 5-91, View A*. When the solenoid is energized, the electro-magnetic force overcomes the spring washer pressure. The disc unseats and flows from the pump to the injectors, as shown in *Figure 5-91, View B.* A single low pressure line from the fuel pump serves all injectors. This means the pressure and quantity of fuel metered to each injector are equal.

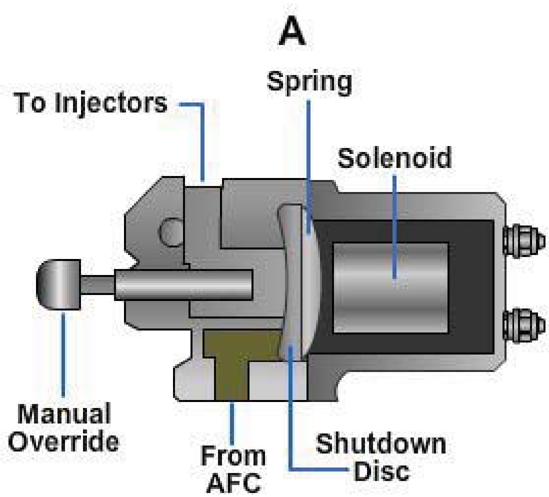

Figure 5-91- Operation of PT fuel pump shutdown valve.

Injector Operation. *Figure 5-92* illustrates the pressure-time type D Top Stop injector commonly used in Cummins PT fuel injection systems. The injector plunger is actuated by engine camshaft rotation. When the cam follower roller is on the inner base circle, the injector return spring lifts the plunger, uncovering the metering orifice. When the cam follower roller is on the outer base circle, the injector plunger's downward movement overcomes the injector return spring, closing the metering orifice and injecting fuel into the cylinder. The injector plunger is now seated in the injector cup.

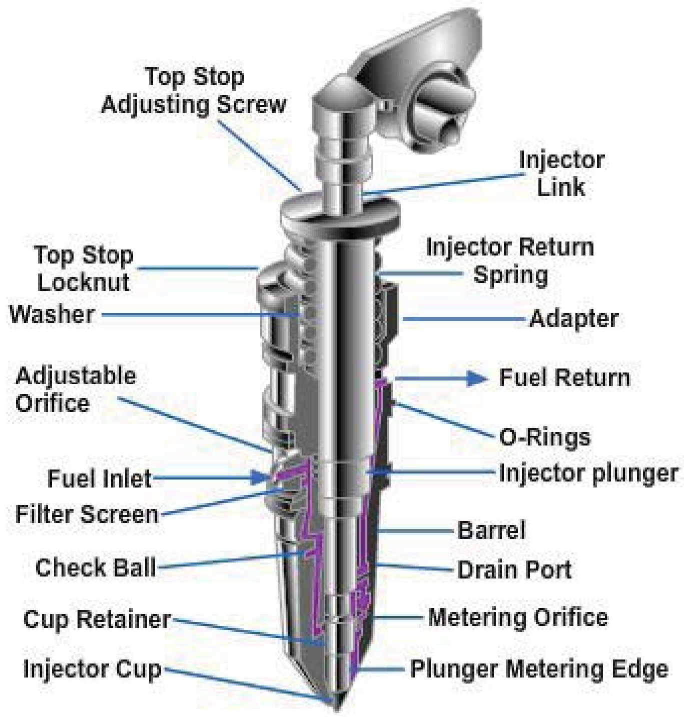

Figure 5-92 – Components of a PTD Top Stop Injector.

Fuel entering the injector flows through a wire mesh filter screen and an adjustable orifice. The size of the orifice determines the injector flow rate and the pressure at the metering orifice. From the adjustable orifice, fuel flows down an internally drilled passage in the injector adapter and barrel. The fuel seats a check ball, while continuing its flow toward the metering orifice. The check ball prevents the reversal of fuel flow during deceleration and shutdown as the plunger moves downward across the metering orifice, as demonstrated in *Figure 5-93*.

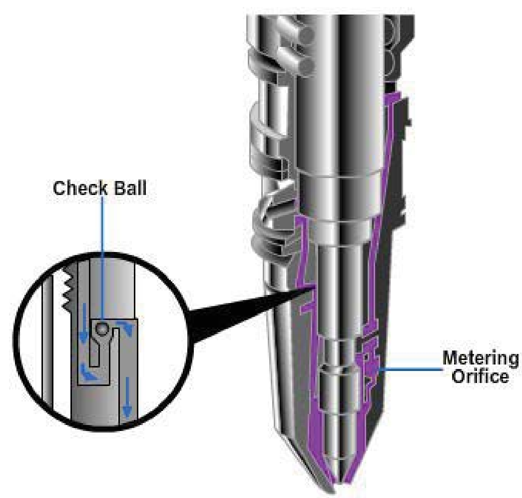

Figure 5-93 – Fuel flow into the PTD Top Stop injector.

When the metering orifice is uncovered, fuel flows into the injector cup. This occurs during the end of the engine's intake stroke and the beginning of the compression stroke. As the cam follower roller travels toward the base circle of the camshaft injector lobe, the injector return spring lifts the plunger, uncovering the metering orifice shown in *Figure 5-94, View A*. With the metering orifice open, the plunger also blocks the drain port in the injector.

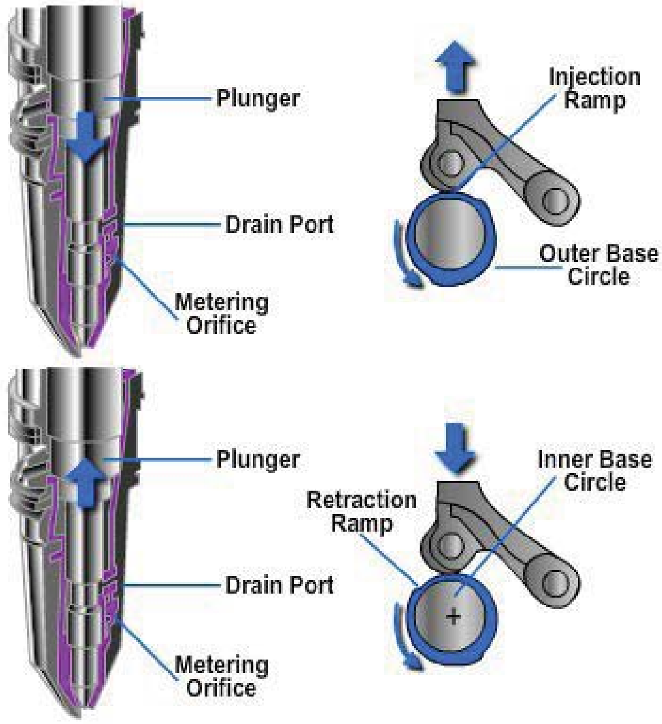

Figure 5-94 – Metering of fuel in the PTD Top Stop Injector.

With continued camshaft rotation, the cam roller travels up the injection ramp. The upward movement of the push rod pushes the injector plunger downward. As the injector plunger moves down on the compression stroke, the metering orifice closes. Shortly after the metering orifice is closed, the drain port opens. At this point, the injector cup contains the proper amount of fuel to be injected, as indicated in *Figure 5-94, View B*. The point at which injection begins varies with the level of fuel in the injector cup, as illustrated in *Figure 5-95.* With an increase in the fuel level, the injector plunger contacts the fuel earlier, advancing the start of injection.

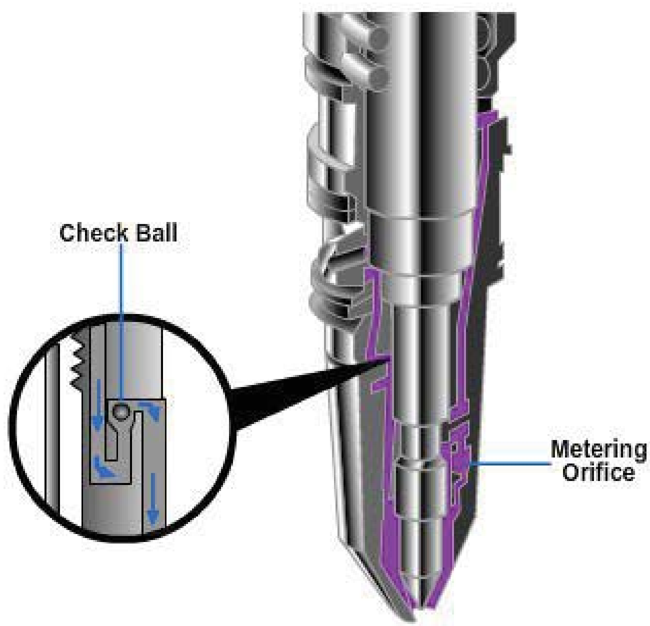

Figure 5-95 - Injector cup operation.

Fuel is injected when the pressure exerted by the injector plunger on the fuel is greater than the combustion chamber pressures. Injection ends when the plunger bottoms out in the cup, as illustrated in *Figure 5-96, View A*. At this point, the drain groove on the injector plunger aligns with drain passages in the injector barrel, permitting fuel to flow out of the drain groove and return to the tank, as demonstrated in *Figure 5-96, View B*.

2.3.1.1 1.1 Troubleshooting

Troubleshooting is an organized study of a problem and a planned method or procedure to investigate and correct the difficulty.

Most troubles are simple and easy to correct. For example, excessive fuel oil consumption is caused by leaking gaskets or connections. A complaint of a sticking injector plunger is usually corrected by repairing or replacing the faulty injector; however, something caused the plunger to stick. The cause may be improper injector adjustment or, more often, water in the fuel.

In general, the complaint of low power is hard to correct because it can have many causes. There are many variables in environmental operation and installations, and it is difficult to measure power in the field correctly. With the PT fuel system, you can often eliminate the pump as a source of trouble. Simply check to see that the manifold pressure is within specified limits. The fuel rate of the pump must not be increased to compensate for a fault in other parts of the engine; damage to the engine will result.

When you check the fuel pump on the engine, remove the pipe plug from the pump shutoff valve and connect the pressure gauge. At the governed speed (just before the governor cuts in), maximum manifold pressure should be obtained. If the manifold pressure is **NOT** within specified limits, adjust for maximum manifold pressure by adding or removing shims from under the nylon fuel adjusting plunger in the bypass valve plunger. Be careful you do not lose the small lock washer that fits between the fuel adjusting plunger and the plunger cap.

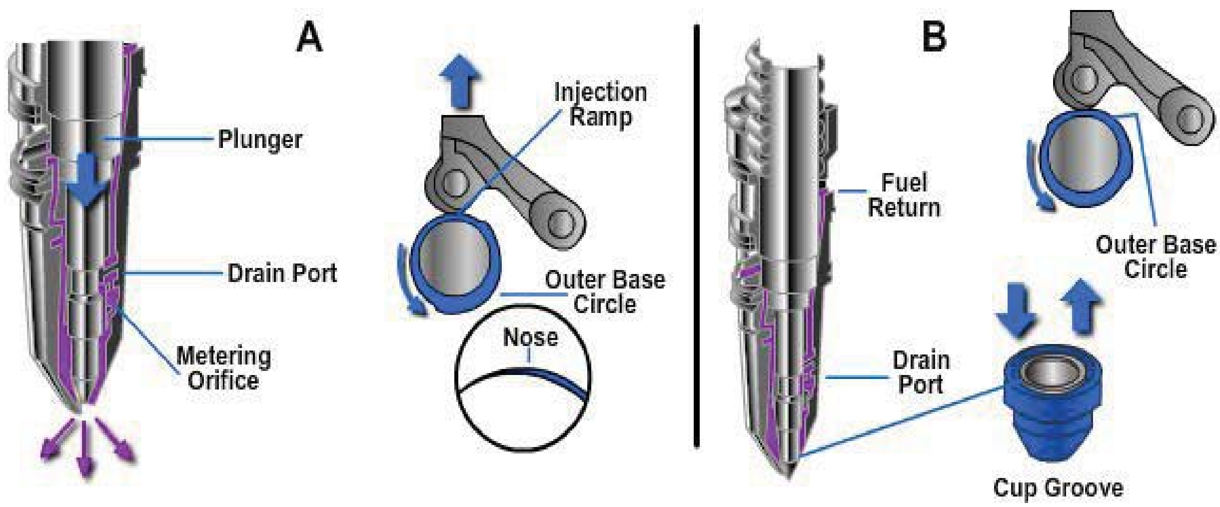

Figure 5-96 - PTD fuel injector fuel flow.

To check the suction side of the pump, connect the suction gauge to the inlet side of the gear pump. The valve in the pump, if properly adjusted, should read 8 inches on the gauge. When the inlet restriction reaches 8.5 to 9 inches, change the fuel filter element and remove any other sources of restriction. The engine will lose power when the restriction is greater than 10 to 11 inches.

Always make the above checks on a warm engine. Also, operate the engine for a minimum of 5 minutes between checks to clear the system of air.

If the pump manifold and suction pressures are within specified limits and there is still a loss of power, you should check the injectors.

Carbon in the PT injector metering orifices restricts the fuel flow to the injector cups, which results in engine power loss. Remove the carbon from the metering orifices by reverse flushing; it should be performed on a warm engine. To remove carbon, perform the following steps:

1. Loosen all injector adjusting screws one turn from the bottom or one and one-eighth turns from the set position. Lock with the jam nut after completing the required turns.
2. Start the engine and accelerate with maximum throttle from idling to high10 to 15 times.
3. Readjust the injectors to their standard setting. The engine will be difficult to start with the loose injector setting; it will smoke badly and will be sluggish. If the injector adjusting screws are loosened, the meter orifice will not be closed during injection. Extremely high injection pressure will force some of the fuel to backflow through the orifice and should remove carbon deposits. If this method is not effective, remove the injectors for cleaning.

When working on the PT fuel system of a turbocharged Cummins engine, you may find an aneroid control device. This device creates a lag in the fuel system so that its response is equivalent to that of the turbocharger, thus controlling the engine exhaust emissions (smoke level).

WARNING

The aneroid is an emissions control device. Removing it or tampering with it is in direct violation of state and federal vehicle exhaust emissions laws.

During troubleshooting of the fuel system, you should check the aneroid according to the manufacturer's specifications.

2.3.1.2 Pump Disassembly

If you determine that the fuel pump (*Figure 5-85*) must be removed from the engine, take the following precautions:

- Make sure the shop area is clean.
- Use clean tools.

Good cleaning practices are essential to good quality fuel pump repair. Take special care when the PT fuel pump, which is made of a lightweight aluminum alloy, is disassembled. Use proper tools to prevent damage to machined aluminum surfaces, which are more easily damaged than parts made of cast iron.

Before disassembling the unit, try to determine what parts need replacement.

After you place the fuel pump on the holding device, place the device in a vise and disassemble the pump. Follow the procedures given in the manufacturer's maintenance and repair manuals.

2.3.1.3 Pump Cleaning and Inspection

Now that the pump has been disassembled, you should clean and inspect all parts. Do not discard parts until they are worn beyond reasonable replacement limits. The PT fuel pump parts will continue to function long after they show some wear. Parts that are worn beyond reasonable replacement limits must not be reused. From experience you know reasonable replacement limits. Reuse all parts that will give another complete period of service without danger of failure.

NOTE

Take special care when you clean aluminum alloy parts. Some cleaning solvents will attack and corrode aluminum. Mineral spirits is a good neutralizer after using cleaning solvents.

2.3.1.4 Pump Reassembly

After you complete] y clean and inspect the pump and its parts, reassemble the pump as prescribed by the manufacturer's manual. In all assembly operations, be careful to remove burrs and use a good pressure lubricant on the mating surfaces during all pressing operations. A good pressure lubricant aids in pressing and prevents scoring and galling. Use flat steel washers. They go next to the aluminum to prevent goring by the spring steel lock washers.

2.3.1.5 Pump Testing

Mount the PT fuel pump on a test stand and in the test, the pressure from the PT pump is measured and adjusted before the pump is placed on the engine. To test this pump, let pressure develop across the special orifices in the orifice block assembly. The pressure is measured on the gauges provided. All pump tests should be made with the testing fuel oil temperature between 90°F and 100°F. Now you are ready to conduct the test.

Open the fuel shutoff valve and manifold orifice valve. Open the stand throttle and start and run the pump at 500 rpm until the manifold pressure gauge shows the recommended pressure. If the pump does not pick up the specified pressure, check for closed valves in the suction line or an air leak.

If the pump is newly rebuilt, run it at 1500 rpm for 5 minutes to flush the pump and allow the bearings to seat. Continue to run the pump at 1500 rpm and turn the rear throttle stop screw in or out to find the maximum manifold pressure at full throttle.

NOTE

With a standard governed pump, the throttle screws will be readjusted later. If the pump has a variable speed governor, the throttle shaft is locked in full-throttle position; do not readjust. On a dual or torque converter governor pump, the throttle must be locked in the shutoff position and the converter-driven governor idle-adjusting screw turned in until the spring is compressed. The converter-driven governor must be set on the engine.

The pump idle speed is set by closing the bypass and manifold orifice valves and opening the idle orifice valve. Set the pump throttle to idle and run at 500 rpm. To decrease or raise the idle pressure, add or remove shims from under the idle spring. Remember not to set the idle screw until you have adjusted the throttle screws.

Once the tests and adjustments have been completed according to the specifications recommended by the manufacturer, remove the pump from the test stand. Make sure the suction fitting is not removed or disturbed. Next, loosen the spring pack cover and drain the pump body. Cover all openings and bind fittings with tape until you are ready to install the pump.

2.3.1.6 Injector Maintenance and Testing

In the PT fuel system, fuel is metered by fuel pressure against the metering orifice of the injector. Any change in fuel pressure, metering orifice, or timing will affect the amount of fuel delivered to the combustion chamber. The following two things will interfere with the normal functions of injector orifices:

1. Dirt or carbon in the orifices or in the passages to and from the orifices; and
2. A change in the size or shape of the orifices, particularly caused by improper cleaning of the orifices after soaking dirty injectors in a cleaning solvent to remove the carbon. Be sure to dip the injectors in a neutral rinse, such as mineral spirits, and then dry them.

NOTE

Never use cleaning wires on PT fuel injector orifices.

Be sure to use a magnifying glass to inspect the injector orifices for damage. When the injector orifices are damaged, they cannot be made to function properly and must be replaced.

Check the injector for a worn plunger or injector body. Worn injectors may cause engine oil dilution from excessive plunger-to-body clearances. Dilution may also result from a cracked injector body or cup or a damaged O ring. To check the injector for leakage, assemble it. Remember to plug the off the injector inlet and drain connection holes; then mount the injector on the injector test stand.

Test the injector at a maximum of 1000 psi with the fuel flowing upward through the cup spray holes. If the counterbore at the top of the injector body falls with fuel in less than 15 seconds, the plunger clearance is excessive and may cause engine oil dilution. During this check, inspect the injector for leaks around the injector cup, body, and plugs. If the injector does not pass the test and checks, remove the damaged parts and replace them with new parts.

Any time you remove an injector plunger, use the lubricant recommended by the manufacturer when you replace the plunger in the injector body.

If the injector plunger does not seat in the injector cup, change the cup rather than trying to lap the plunger and cup together. Lapping changes the relationship between the plunger groove and metering orifice and disturbs fuel metering. Always use a new injector cup gasket when you assemble the cup to the injector body to avoid distortion of the cup. When the cup is tightened to the injector body, the gasket compresses everywhere, except under the milled slot on the end of the injector body. Then, if the gasket is reused, the uncompressed areas may cause the injector cup to cock and prevent the injector plunger from seating properly.

3.0.0 AIR INDUCTION SYSTEMS

The purpose of an air intake system is to supply the air needed for combustion of the fuel. In addition, the air intake system of a diesel engine will have to clean the intake air, silence the intake noise, furnish air for supercharging, and supply scavenged air in two-stroke engines.

The three major components of the air induction systems that increase internal combustion engine efficiency are blowers, superchargers, and turbochargers. They may be of the centrifugal or rotary type, gear driven directly from the engine, or driven by the flow of exhaust gases from the engine.

In the following sections, certain abnormal conditions of air induction system components, which sometimes interfere with satisfactory engine operation, are covered. Also, methods of determining causes of such conditions will be covered. Before performing any work on these components, make sure you follow the recommendations given in the manufacturer's service manual.

3.1.0 Superchargers

A supercharger or blower is an air pump that is mechanically driven by the engine. Its job is to force more air into the combustion chamber. More air permits a larger fuel charge to be burned in the cylinder, creating additional power from the same basic engine. Because the blower is driven by the engine, it robs the engine of power. However, this loss is more than offset by the power gained.

Many diesel engines use the process called scavenging and supercharging. In some four-cycle diesel engines, air enters the cylinder due to change in pressure created as the piston moves away from the combustion space during its intake stroke. The air is forced into the cylinder due to greater atmospheric pressure outside the engine. This process is referred to as a naturally aspirated intake.

The blower is used to increase airflow into the cylinders on all two-cycle engines and some four-cycle engines. The blower compresses air and forces it into an air box or manifold connected to the engine cylinders. This provides an increased amount of air under constant pressure to be used during engine operation.

Scavenging principles. The air produced by the blower fills the cylinder with fresh air, clearing it of combustion gases. The process is known as scavenging. The air forced into the cylinder is called scavenged air, and the entrance ports are referred to as scavenge ports.

Scavenging can take up only a small portion of the operating cycle; however, the length of time it takes is different in two-cycle and four-cycle engines. In a two-cycle engine, scavenging takes place during the end of the downstroke (expansion) and the beginning of the upstroke (compression). In a four-cycle engine, scavenging occurs as the piston is passing top dead center during the end of exhaust upstroke and the beginning of the intake downstroke. Intake and exhaust openings are both open during the scavenging process. This allows the air from the intake to pass through the cylinder and into the exhaust manifold, removing exhaust gases from the cylinder and cooling hot engine parts in the process.

Scavenging air must be directed when entering the cylinder of an engine so that waste gases are removed from the remote parts of the cylinder. The two principle methods of accomplishing this are sometimes referred to as port scavenging and valve scavenging. Port scavenging may be of the direct (cross-flow) or uniflow types, as shown in *Figure 5-97, View A* and *Figure 5-97, View B*. Valve scavenging is of the uniflow type, as shown in *Figure 5-97, View C*.These scavenging air actions also cool the internal components, such as the piston, liner, and valves, with approximately 30% of engine cooling being provided by its airflow. This leaves the cylinder full of fresh air for combustion purposes when the piston covers the liner ports.

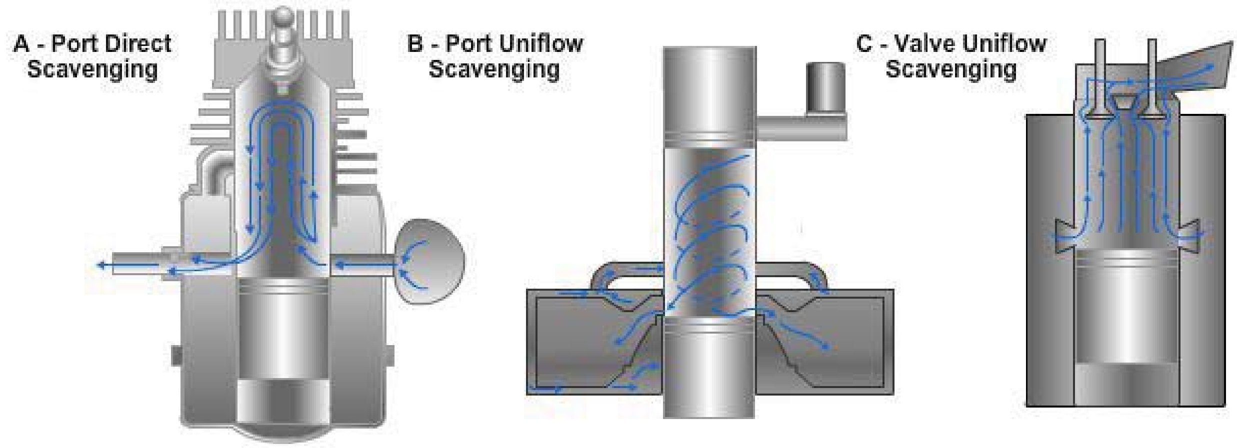

Figure 5-97 - Methods of scavenging used in diesel engines.

Supercharging principles. Increased airflow to the cylinders can also be used to increase the power output of an engine. Since engine power develops from burning fuel, increasing the power requires more fuel. The increase in fuel, in turn, requires more air in order for combustion to take place. Supercharching is a process that supplies more air to the intake system than is normally taken in under atmospheric pressure.

3.1.1 Removal

When the supercharger has to be removed from the engine, follow the procedures given in the manufacturer's service manual.

3.1.2 Disassembly

If you have to disassemble the supercharger, be careful when you remove the intake and discharge connections. Be sure to cover both openings. To prevent damage to its finished surfaces, which are usually made from aluminum, wash the outside of the supercharger with mineral spirits. Use the correct service tools and follow recommended disassembly procedures in the manufacturer's maintenance and repair manuals.

3.1.3 Cleaning and Inspecting

As the supercharger parts are disassembled, you should clean and dry them thoroughly with filtered, compressed air. Discard all used gaskets, oil seals, recessed washers, roller bearings, and ball bearings. Replace these parts with new ones.

Inspect the rotors, housing, and end plates for cracks, abrasions, wear spots, and buildup of foreign material. With a fine emery cloth, smooth all worn spots found. Discard cracked, broken, or damaged parts. Remember, rotors and shafts we not separable. They must be replaced as a matched set or unit.

Inspect the drive coupling for worn pins, distorted or displaced rubber bushings, and damaged or worn internal splines. Examine the hub surface under the oil seal and replace the coupling if its surface is grooved or worn.

Check the gear fit on the rotor shafts and the gear teeth for evidence of chatter and wear. Replace the rotors and gears if they are not within the required tolerances.

Inspect all dowels, oil plungers, piston ring seals, and gasket surfaces. Replace them as necessary.

3.1.4 Reassembly

After you have inspected, cleaned, and replaced worn or damaged parts, put the supercharger back together, as prescribed in the manufacturer's maintenance and service manuals. Upon complete reassembly and after the supercharger is installed on the engine, add the proper quantity of recommended engine lubricating oil to the gear end plate through the pipe plughold.

3.2.1 Turbochargers

Turbochargers can be used on both two- and four-cycle diesel engines, as shown in *Figure 5-98*. They utilize exhaust energy, which is normally wasted, to drive a turbine-powered centrifugal air compressor that converts air velocity into air pressure to increase the flow of air into the engine cylinders. The air pressure drawn into a naturally aspirated engine cylinder is at less than atmospheric pressure. A turbocharger packs the air into the cylinder at more than atmospheric pressure. A turbocharger improves combustion, resulting in decreases exhaust emissions, smoke, and noise. Increased power output and the ability of the turbocharger to maintain nearly constant power at high altitudes are also benefits of a turbocharged engine.

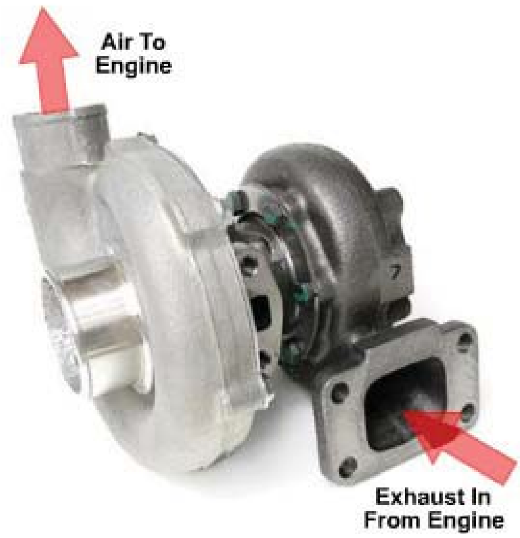

Figure 5-98 -A turbocharger.

Fuel economy is another very significant reason for using a turbocharger with a diesel engine. The extra air provided by the turbocharger allows increased horsepower output without increasing fuel consumption. Lack of air is one factor limiting the engine horsepower of naturally aspirated engines. As engine speed increases, the length of time the intake valves are open decreases, giving the air less time to fill the cylinders and lowering volumetric efficiency.

The turbocharger normally consists of three components, as shown in *Figure 5-99*:

1. A radial inward flow turbine wheel and shaft

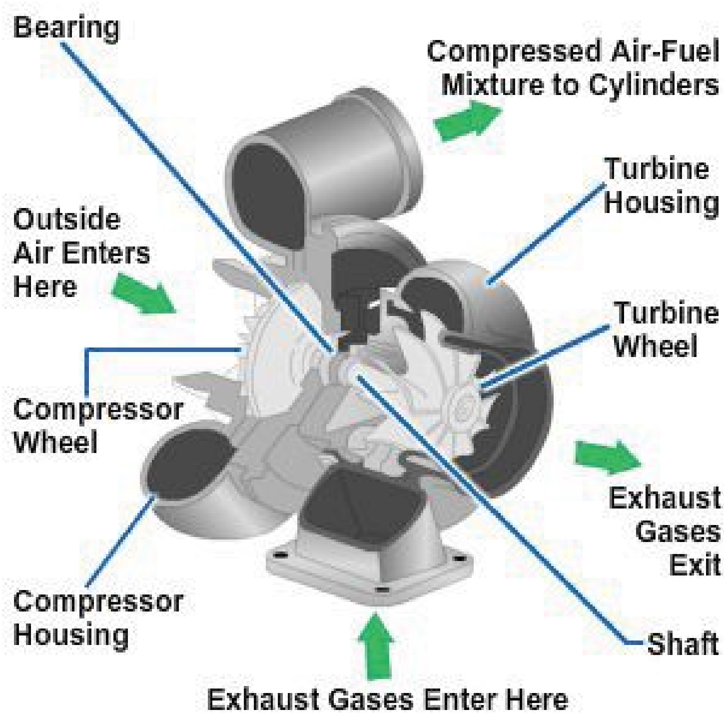

Figure 5-99 – The components of a turbocharger.

2. A centrifugal compressor wheel
3. A center housing, which supports the:
   - Rotating assembly
   - Bearing seals
   - Turbine housing
   - Compressor housing

The center housing has connections for oil inlet and oil outlet fittings.

The turbine wheel (hot wheel) is located in the turbine housing and is mounted on one end of the turbine shaft. The compressor wheel, or impeller (cold wheel), is located in the compressor housing and is mounted on the opposite end of the turbine shaft to form an integral rotating assembly, as illustrated in *Figure 5-100*.

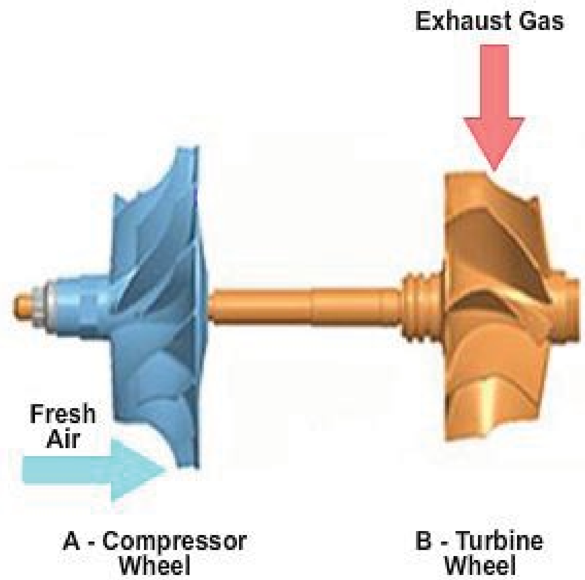

Figure 5-100 - A-Compressor wheel and B-Turbine wheel.

Other parts of the rotating assembly include the thrust bearing (or spacer), backplate, and wheel retaining nut. The rotating assembly is supported on two pressure-lubricated bearings that are retained in the center housing by snap rings. Internal oil passages are drilled in the center housing to provide lubrication to the turbine shaft bearings, thrust washer, thrust collar, and thrust space, as shown in *Figure 5-101*.

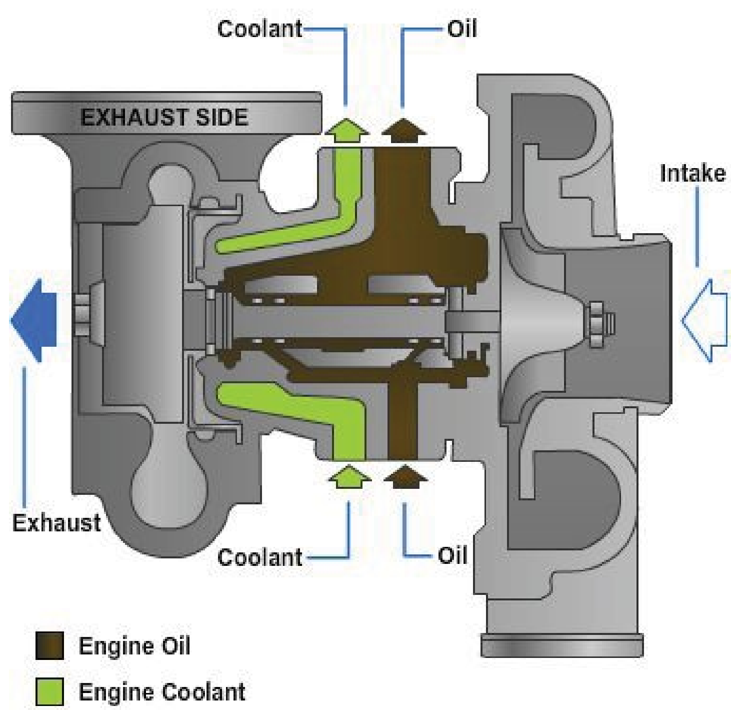

Figure 5-101 – Oil flow through a turbocharger's center section.

The turbine housing is a heat-resistant alloy casting that encloses the turbine wheel and provides a flanged exhaust gas inlet and an axially-located turbocharger exhaust gas outlet. The compressor housing, which encloses the compressor wheel, provides an ambient air inlet and a compressed air outlet. In a typical installation, the turbocharger is located to one side, usually close to the exhaust manifold. An exhaust pipe runs between the engine exhaust manifold and the turbine housing to carry the exhaust gases to the turbine wheel. Another pipe, called the crossover tube, conducts fresh compressed air to the intake manifold, as shown in *Figure 5-102*.

Figure 5-103 lists common turbocharger problems and problem causes. If a defective turbocharger is suspected, always make sure the turbocharger is really at fault. Repairs are sometimes performed on the turbocharger when the real source of the problem is a restricted air cleaner, a plugged crankcase breather, or deteriorated oil lines.

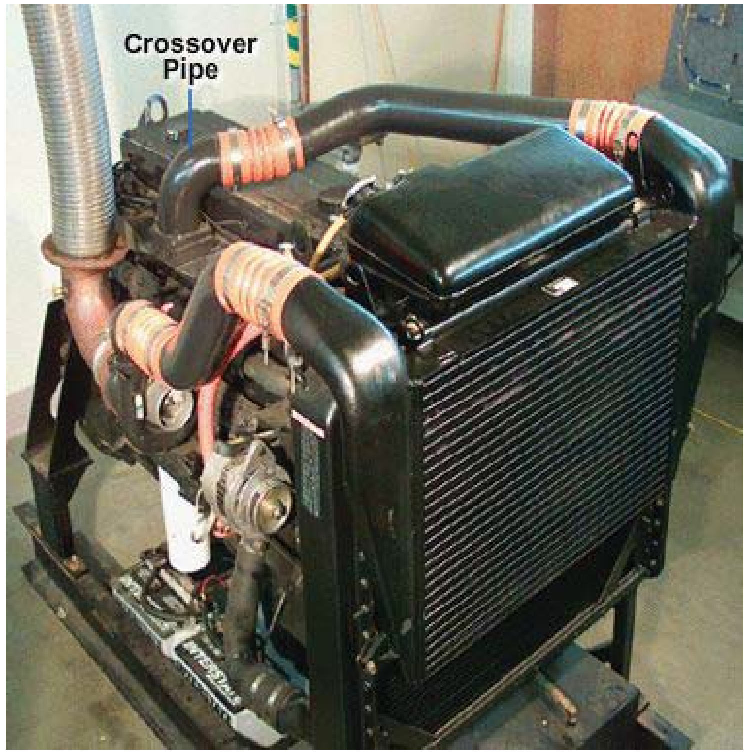

Figure 5-102 – Typical image showing the location of the crossover pipe or tube.

Common symptoms that may indicate turbocharger problems include:

- A lack of engine power
- Black smoke
- Blue smoke
- Excessive engine oil consumption
- Noisy turbocharger operation

A lack of engine power and black smoke can both result from insufficient air reaching the engine and can be caused by restrictions in the air intake or air leaks in the exhaust system or the induction system. The first step in troubleshooting any turbocharger is to start the engine and listen to the sound of the turbocharging system makes. As a mechanic becomes more familiar with this characteristic sound, he/she will be able to identify an air leak between the engine.

3.2.1 Removal, Disassembly, and Cleaning

The removal of the turbocharger from the engine is not a complicated task when you follow the procedures in the manufacturer's instructions. After removing the turbocharger from the engine, you should make sure the exterior of the turbocharger is cleaned of all loose dirt before disassembly to prevent unnecessary scoring of the rotor shaft. Disassemble it according to the manufacturer's maintenance and repair manuals.

The turbocharger parts accumulate hard-glazed carbon deposits, which are difficult to remove with ordinary solvents. This is especially true if the turbine wheel and shaft, diffuser plate, nozzle ring, and inner heat shield are affected. The cleaner must remove these stubborn deposits without attacking the metal. All parts should be cleaned as follows:

1. Place all parts in a divided wire basket so parts will not be damaged through contact with each other. Do not pile them in the basket. Avoid mutilating precision ground surfaces.
2. Immerse the parts in mineral spirits or similar solvents.

Possible Causes	Engine Lacks Oil	Black Smoke	Excessive Oil Consumption	Blue Smoke	Noise	Excessive Oil Compressor End	Excessive Oil Turbine End	Drag or Bind in Rotating Assembly	Excessive Rotating Assembly Play	Damaged Compressor Wheel	Damaged Turbine Wheel	Solutions
Dirty air cleaner	X	X		X	X	X						Clean or replace filter element.
Plugged crankcase breathers			X			X	X					Clear obstruction per manufacturer's manual.
Air cleaner element missing, leaking or loose connections to turbo					X			X		X		Replace repair or reconnect air cleaner element per manufacturer's manual.
Collapsed or restricted air pipe before turbo	X	X		X	X	X						Inspect pipe for damage or obstruction; replace or repair.
Restricted or damaged crossover pipe turbo to inlet manifold	X	X			X	X						Inspect pipe for damage or obstructions; replace or repair.
Foreign object between cleaner and turbocharger	X	X			X	X		X	X	X		Inspect air intake piping; remove foreign object.
Foreign object in exhaust system (from engine check engine)	X	X			X		X	X	X		X	Inspect exhaust piping ONLY when engine is NOT running and cold; remove foreign object.
Turbocharger flanges clamp or bolts loose	X	X	X	X	X	X	X	X	X	X	X	Inspect all connecting hardware for damage; ensure tight fits per installation instructions.
Inlet manifold cracked, gaskets loose or missing, connections loose	X	X		X	X	X						Remove and inspect inlet manifold for damage to castings and gaskets; replace if needed.
Exhaust manifold cracked, burned, gasket loose, blown or missing	X	X			X							Remove exhaust manifold ONLY when engine is cold and NOT running and inspect for damage to castings and gaskets; replace if needed.
Restricted exhaust system					X							Inspect exhaust system ONLY when engine is cold and NOT running; remove obstruction.
Oil lag at start-up								X	X			Inspect lubrication system lines, filters, and oil for obstruction; remove obstruction.
Insufficient lubrication								X	X			Inspect lubrication system lines, filters, and oil from obstruction; remove obstruction.
Lubricating oil contaminated with dirt or other material								X	X			Replace al filters and lubricating oil with new per manufacturer's manual.
Improper lubricating oil type used								X	X			Replace lubricating oil with correct grade.
Restricted oil feed line						X	X	X	X			Remove and inspect oil line; remove obstruction.
Restricted oil drain line			X				X					Remove and inspect oil line; remove obstruction.
Turbine housing damaged or restricted	X	X			X						X	Remove turbine housing; inspect for cracks or wear; replace if needed.
Turbocharger seal leakage			X	X		X	X					Inspect for proper oil feed/drain line installation. Contact manufacturer or distributor for rebuild.
Worn journal bearing	X	X	X		X	X	X	X	X	X	X	Contact manufacturer or distributor.
Excessive dirt build-up behind turbine wheel	X	X		X	X	X		X		X	X	Inspect air cleaner element and intake piping for damage or leaks; replace if needed. Clean compressor wheel and housing.
Excessive carbon build-up on compressor housing	X	X		X	X		X	X			X	Inspect crankcase ventilation system.
Too fast acceleration at initial start									X	X		Decrease acceleration at initial start-up.
Too little warm-up time									X	X		Extend warm-up period.
Fuel pump malfunction	X	X										Refer to engine manufacturer's manual and replace if needed.
Worn or damaged injectors	X	X										Inspect injectors for damage and replace if needed.
Valve timing	X	X										Refer to engine manufacturer's manual and adjust if needed.
Burned valves	X	X										Refer to engine manufacturer's manual and replace if needed.
Worn piston rings	X	X										Refer to engine manufacturer's manual and replace if needed.
Burned pistons	X	X										Refer to engine manufacturer's manual and replace if needed.
Leaking oil feed line								X	X			Remove and inspect oil line; remove obstruction.
Excessive engine pre-oil				X			X					Refer to engine manufacturer's manual and adjust if needed.
Excessive engine idle			X	X		X	X					Refer to engine manufacturer's manual and adjust if needed.
Coked or sludge center housing			X	X			X	X			X	Contact manufacturer or distributor.
Oil pump malfunction									X			Refer to engine manufacturer's manual and replace if needed.
Oil filter plugged			X	X		X	X	X	X	X	X	Refer to engine manufacturer's manual and replace if needed.
Oil bath air cleaner, air inlet screen restricted/dirty air cleaner	X	X	X	X	X							Replace air inlet screen.
Oil bath air cleaner, oil pull-over / oil viscosity too low or high	X	X	X	X	X							Replace lubricating oil with correct grade.
Boost control malfunction: westgate	X	X	X	X	X	X	X		X	X	X	Inspect for damage, leaks or obstruction; replace or repair if needed
Boost control malfunction: VNT	X	X	X	X	X	X	X		X	X	X	Contact manufacturer or distributor.
Boost control malfunction, engine management system	X	X	X	X	X	X	X		X	X	X	Refer to manufacturer's manual and adjust as needed.

Figure 5-103 - Sample Turbocharger Troubleshooting Guide.

CAUTION

Never use a caustic solution or any type solvent that may attack aluminum or nonferrous alloys.

3. Allow the parts to soak as needed to remove the carbon. A soft bristle brush may be used, if necessary, to remove heavy deposits. Never use wire or other brushes with stiff bristles.
4. With the oil orifice removed, flush out the oil passages in the main casing from the bearing end to remove dirt loosened by the soaking.
5. Remove the parts from the tank. Drain and steam clean thoroughly to remove all carbon and grease. Apply steam liberally to the oil passages in the main casing.
6. Blow off excess water and dry all parts with filtered, compressed air.
7. Carefully place parts in a clean basket to avoid damaging them before inspection and reassembly.

3.2.2 Parts Inspection

Inspect all turbocharger parts carefully before you rinse them. All parts within the manufacturer's recommended specifications can be used safely for another service period. Damage to the floating bearing may require replacement of the turbocharger main casing with a new part or an exchange main casing.

Inspect the turbine casing. If you find cracks that are too wide for welding, replace the casing.

Do not use the exhaust casing if it is warped or heavily damaged on the inside surface caused by contact with the turbine wheel or a foreign object, or if it is cracked in any way.

Usually, oil seal plates do not wear excessively during service and can be reused if they have not been scored by a seizure of the piston ring.

As you inspect the diffuser plates, look for contact scoring by the rotor assembly on the back of the diffuser plate or broken vanes. This scoring will make the plate unacceptable for reuse.

Inspect the inner heat shield. If it is distorted, replace it.

Dents found on the outer heat shield can usually be removed, allowing its reuse. However, if this shield is cut or split in the bolt circle area, replace it.

Inspect the nozzle rings closely for cracks. If the nozzle rings are cracked or if the vanes are bent, damaged, or burnt thin, replace them.

If you see signs of wear or distortion during the inspection of the piston ring seals, discard and replace them with new ring seals.

Inspect the turbocharger main casing for cracks in the oil passages, cap screw bosses, and so forth. Also, check the casing for bearing bore wear. If it exceeds the limits allowed by the manufacturer, the bearing bore may be reworked to permit oversize, outer diameter bearings.

Check the oil orifice's plug for stripped or distorted threads. Install a new plug if necessary. The rotor assembly, which consists of a turbine wheel, thrust washer, and locknut, is an accurately balanced assembly. Therefore, if any one of the above parts is replaced as a result of your inspection, the assembly must be rebalanced according to the manufacturer's specifications.

When inspecting the semifloating bearing, measure both the outside and inside diameters of the bearing. If either diameter is worn beyond limits allowed by the manufacturer, replace the bearing.

The front covers that are deeply scored from contact with the compressor wheel cannot be reused. Slight scratches or nicks only can be smoothed out with a fine emery cloth and the covers reused. Cracked covers, however, cannot be reused and must be replaced with new ones.

All cap screws, lock washers, and plain washers should be cleaned and reused unless they are damaged.

3.2.3 Reassembly and Installation

After inspection of the turbocharger component parts and replacement of damaged or worn parts, reassemble the turbocharger as prescribed by the manufacturer's maintenance and repair manuals.

Close off all openings in the turbocharger immediately after reassembly to keep out abrasive material before you mount it on the engine.

Turbochargers can be mounted on the engine in many different positions. Always locate the oil outlet at least 45 degrees below the turbocharger horizontal center line when the unit is in the operating position.

After reassembly, prime the turbocharger before engine start-up by removing the oil supply inlet fitting and adding approximately 0.5 pint of clean engine oil to the turbocharger. Operate the engine at low idle for a few minutes before operating it at higher speeds. Finally, check the system for leaks.

Turbocharged engines require proper shutdown procedures to prevent bearing damage. If the engine is shut down from high speed, the turbo will continue to rotate after engine oil pressure has dropped to zero. Always idle the engine for several minutes before shutting it down.

Turbocharger damage can also be caused by oil lag. Oil lag is a lack of lubrication that occurs when oil pressure is not sufficient to deliver oil to the turbocharger bearings. Before running the engine up to high rpm, operate at low speeds for at least 30 seconds after initial start-up to allow the oil flow to become established. Additional time should be allowed when the outside temperature is below freezing. After replacing a turbocharger, or after an engine has been unused or stored for a significant time, there can be a considerable lag after the engine is started.

4.1.1 DIESEL ENGINE INJECTION COLD STARTING DEVICES

Starting a cold diesel engine can be somewhat frustrating. The heat generated by compression tends to dissipate through the cylinder and head metal. Clearances when the engine is cold may be such that much of the compressed air escapes past the piston rings. Other problems may include the effect of cold on lubricating oil and diesel fuel viscosity. The spray pattern at the injectors coarsens and the drag of heavy metal oil between the engine's moving parts increases friction.

It is important to remember that starting has three distinct phases:

1. During the initial phase, the breakaway torque needed to start cranking can be substantial, since the engine's rotating parts have settled to the bottom of their journals and are only partially lubricated.
2. The second phase occurs during the first few revolutions of the crankshaft. In most cases, the first few crankshaft revolutions are free of heavy compressive loads. Cold oil pumped to the journals collects and wedges between the bearings and shafts. As the shaft rotates, this oil is heated by friction. As the oil thins, drag reduces significantly, and cranking speed increases dramatically. Engine compression also begins to build during this phase.
3. The third phase begins as the engine reaches firing speed. Compression levels within the cylinders are sufficient to initiate combustion. The time between the initial breakaway phase and the firing speed depends on the capacity of the starter and battery, the mechanical condition of the engine, lubricating oil viscosity, ambient air temperature, flywheel inertia, and the number of cylinders in the engine.

To ensure long engine life, if the ambient temperature dropped below 25°F, it is advisable to warm any diesel engine before initial start-up. Warming the engine will allow it to start quickly and reduce wear on starting system components. There are several methods of warming an engine in cold weather. These include coolant heaters, lube oil heaters, intake air heaters, battery heaters, and glow plugs.

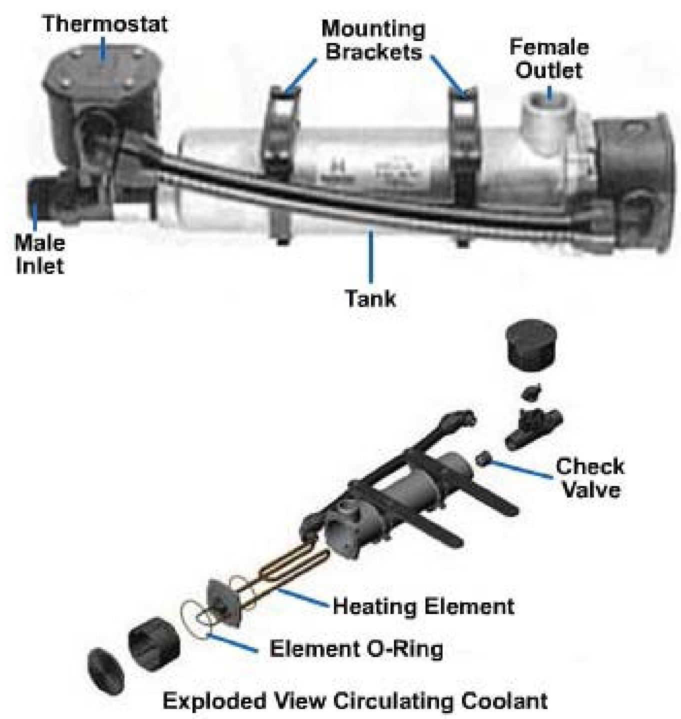

Figure 5-104 - Circulating coolant heater.

Coolant heaters. There are two types of coolant heaters – circulating heaters and immersion heaters:

- **Circulating coolant heaters,** as shown in *Figure 5-104,* are located outside the engine. Cold coolant leaves the bottom of the engine block and enters the heater tank, where it is warmed by a copper heating element. The warm coolant is then pumped into the engine blocks. Circulating heaters require 120 or 240 volts AC and operate over 3500 watts. They are available with or without thermostatic control. The main advantage of circulating coolant heaters is that they warm the engine in a very short period of time. While most circulating coolant heaters are electric, some are propane fired.
- **Immersion coolant heaters** are installed directly into the engine block in place of a freeze plug. Large engines and V-type blocks usually require the use of two immersion heaters. Immersion coolant heaters do not circulate the coolant. Heat can only move through the cylinder walls by convection, so warm-up time is

increased when compared to circulating coolant heaters. Immersion heaters operate on 120 or 240 volts AV, and are available up to 2500 watts.

Lubricating oil heaters. Most lubricating oil heaters are electric-powered immersion heaters that are installed in the oil sump through the drain plug or dipstick opening. A thermostat can also be installed as part of the heating unit. This type of heater is designed to keep the oil pan warm and allow heat to flow up into the block, warming the entire engine.

Battery warmers. Battery warmers use an electric heating pad beneath or around the battery to keep it at a temperature that allows full cranking current to be delivered to the starter motor. Battery warmers can be used alone, but should be coupled with another cold starting aid, such as a coolant or lube oil heating system.

The manifold flame heater system shown in *Figure 5-105* is another type of cold-starting system found on diesel engines. This system is composed of the housing, spark plug, flow control nozzle, and two solenoid control valves. This system is operated as follows:

1. The spark plug is energized by the flame heater ignition unit.
2. The nozzle sprays fuel under pressure into the intake manifold assembly.
3. The fuel vapor is ignited by the spark plug and bums in the intake manifold heating the air before it enters the combustion chamber.

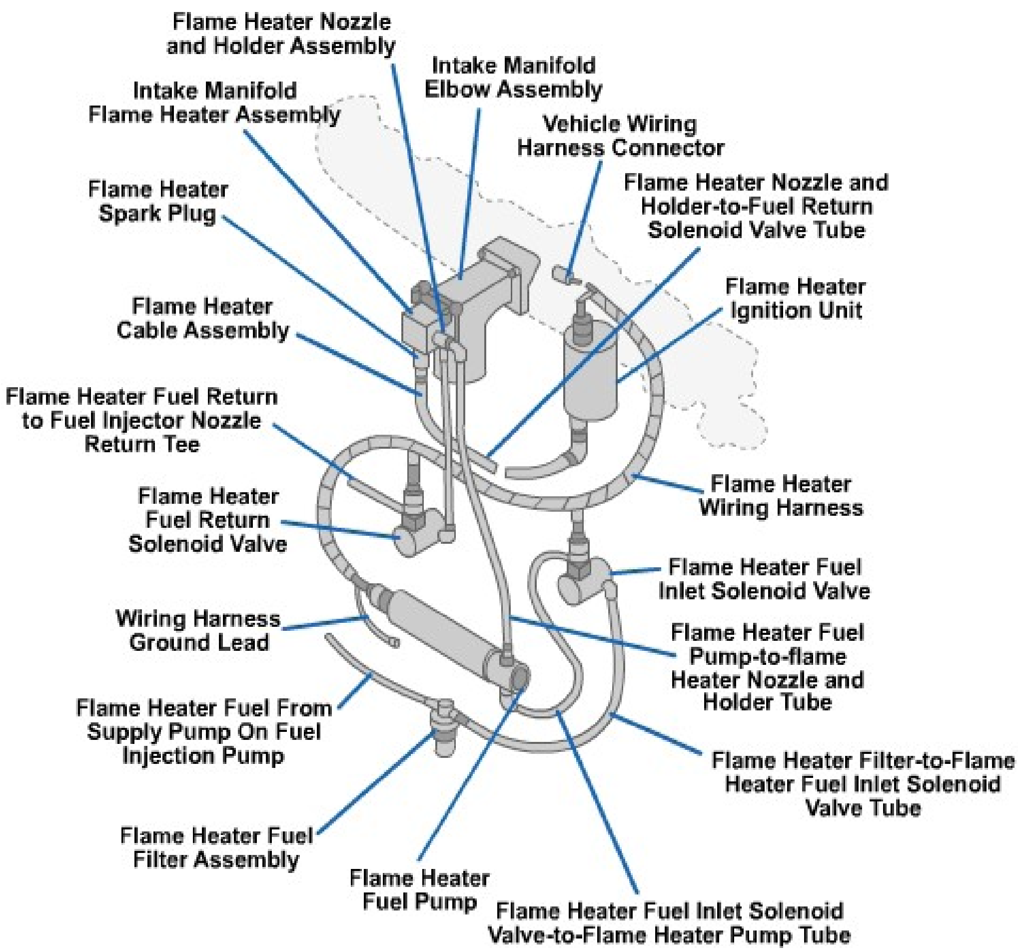

Figure 5-105 - Manifold flame heater system.

The flame fuel pump assembly is a rotary type, driven by an enclosed electric motor. The fuel pump receives fuel from the vehicle fuel tank through the supply pump of the vehicle and delivers it to the spray nozzle. The pump is energized by the on/off switch located on the instrument panel.

The intake manifold flame heater system has a filter to remove impurities from the fuel before it reaches the nozzle.

The two fuel solenoid valves are energized (open) whenever the flame heater system is activated. The valves ensure that fuel is delivered only when the system is operating. These valves stop the flow of fuel the instant that the engine or the heater is shut down.

When troubleshooting or repairing these units, consult the manufacturer's repair manual.

4.1.0 Glow Plugs

Glow plugs, as illustrated in *Figure 5-106,* are heating elements that warm the air in the precombustion chambers to help start a cold diesel engine. The glow plugs are threaded into holes in the cylinder head. The inner tip of the glow plug extends into the precombustion chamber.

A glow plug control circuit automatically disconnects the glow plugs after a few seconds of operation. The entire engine coolant temperature sensor checks the temperature of the coolant. It feeds this electrical data to a control unit. Thus, if the engine is already warm, the control will not turn on the glow plugs.

Indicator lights also operated by the control unit inform the operator whether or not the engine is ready to start. The glow plugs need only a few seconds to heat up.

When the engine is cold and the operator turns the ignition switch to run, a large current flows from the battery to the glow plugs. In a few seconds, the glow plug tips will heat to a dull red glow.

When the glow plug indicator light goes out, the operator can start the engine. The compression stroke pressure and heat, along

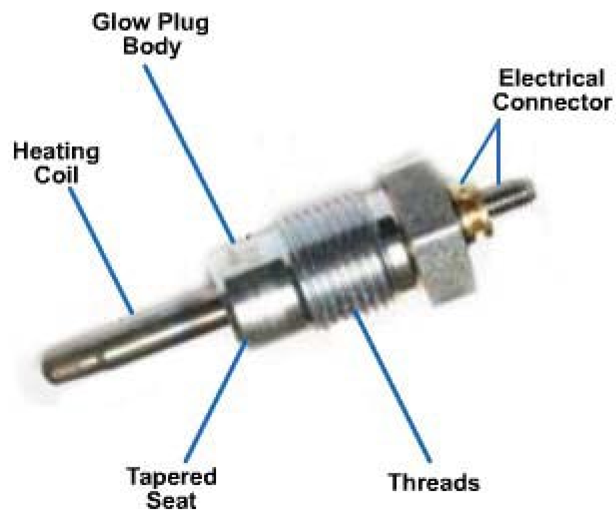

Figure 5-106 – A glow plug.

Figure 5-107 - Ether starting aid system.

with the heat from the glow plugs, help the engine to start easier.

Glow plugs are not complicated and are easy to test. Disconnect the wire going to the glow plug and use a multimeter to read the ohms resistance of the glow plug. Specifications for different glow plugs vary according to the manufacturer. Be sure and check the manufacturer's repair manual for the correct ohms resistance value.

4.2.0 Ether

WARNING

Starting fluids must never be used if the engine is equipped with either glow plugs or an electric coil air intake heater.

For many years, highly combustible ether was used as a starting aid for diesel engines. Mechanics and operators poured ether on a rag and placed it over the air intake, or removed the air filter element and inserted it into the casing. If they guessed the dosage correctly, the engine might start. But, if too much ether was used, severe detonation or an explosion sometimes occurred, resulting in broken pistons and rings and bent connecting rods. The force of these explosions inside the cylinders destroyed many engines, and also caused injury to personnel.

CAUTION

Ether is to be used in extreme emergency. If you must use ether, the engine has to be turning over before you spray it into the air intake.

Use of spray cans of ether is discouraged as they can be dangerous. The only method of safely using ether is with a closed dispensing system. Starting aid systems of this type normally consist of a cylinder of pressurized ether, a metering valve, tubing, and an atomizer installed in the intake manifold, as shown in *Figure 5-107*. The valve is tripped only once during each starting attempt to prevent build-up of ether in the intake manifold that could lead to an explosion or hydraulic lock.

Diesel engines can also be fitted with another one-shot starting device consisting of a holder and needle. A capsule containing ether is inserted into the device. The needle pierces the capsule, releasing the premeasured dose of ether into the intake manifold. Regardless of the system used, starting fluid should only be introduced into the intake manifold while the engine is cranking, and then very sparingly.

CAUTION

Diesel engines can become "dependent" upon ether as a starting aid, even to the point that an engine will not start without it.

5.1.1 EMISSION SYSTEMS

There are four types of exhaust emissions:

1. Hydrocarbons
2. Carbon monoxide
3. Oxides of nitrogen and
4. Particulates

Hydrocarbons (HC) are a form of emission resulting from the release of unburned fuel into the atmosphere. All petroleum products are made of hydrocarbons (hydrogen and carbon compounds). This includes gasoline, diesel fuel, LP-gas, and motor oil.

Hydrocarbons are produced by incomplete combustion or by fuel evaporation. For example, hydrocarbons are produced when unburned fuel escapes from the exhaust system of a poorly running engine. They can also be produced by fuel vapors escaping from the vehicle's fuel system. Some of the additives used in gasoline are extremely reactive, which allows the unburned fuel vapors to easily combine photochemically with other elements in the air to form smog.

Hydrocarbon emissions are a hazardous form of air pollution. They can contribute a variety of illnesses, including eye, throat, and lung irritation, and possibly cancer.

Carbon Monoxide (CO) is an extremely toxic emission resulting from the release of partially burned fuel. It is a result of incomplete combustion of a petroleum-based fuel.

Carbon monoxide is a colorless, odorless, and deadly gas. CO prevents human blood cells from carrying oxygen to body tissues. It can cause death if inhaled in large quantities. Symptoms of carbon monoxide poisoning include headaches, nausea, blurred vision, and fatigue.

Any factor that reduces the amount of oxygen present during combustion increases carbon monoxide emissions. For example, a rich air-fuel mixture increases CO.

Oxides of Nitrogen (NO_x) are emissions produced by extremely high temperatures during combustion. Air consists of approximately 79% nitrogen and 21% oxygen, With enough heat above approximately 2500°F, nitrogen and oxygen in the air-fuel mixture combine to form NO_x emissions. Oxides of nitrogen contribute to the dirty brown color of smog. They also produce ozone in smog, which causes an unpleasant odor and is an eye and respiratory irritant. Oxides of nitrogen are also harmful to many types of plants and rubber products.

An engine with a high compression ratio, lean air-fuel mixture, and high-temperature thermostat will produce high combustion heat, resulting in the formation of NO_x. This poses a problem, as these same factors tend to improve gas mileage and reduce HC and CO emissions. As a result, emission control systems must interact to lower each form of pollution.

Particulates are solid particles of carbon soot and fuel additives that blow out a vehicle's tailpipe. Carbon particles make up the largest percentage of these emissions. The rest of the particulates consist of other additives sometimes used to make gasoline and diesel fuel.

While a particulate emission is rarely a problem with gasoline engines, it is a serious problem with diesel engines. Diesel particulates are normally caused by an extremely rich air-fuel mixture or a mechanical problem in the injection system.

About 30% of all particulate emissions are heavy enough to settle out of the air in a relatively short period of time. The other 70%, however, can float in the air for extended periods.

Sources of Vehicle Emissions. The majority of vehicle emissions come from these three basic sources:

1. Engine crankcase blowby fumes-chemicals that form in the engine bottom end from heating of oil, as well as unburned fuel and combustion by-products that blow past the piston rings and into the crankcase

2. Fuel vapors-various chemicals that enter the air as fuel evaporates
3. Engine exhaust gases-harmful chemicals produced and blown out the tailpipe when an engine burns a hydrocarbon-based fuel (or most other fuels)

Vehicle Emission Control Systems. Several different emissions control systems are used to reduce the amount of air pollution produced by vehicles. The major ones found include:

- Positive crankcase ventilation system-recirculates engine crankcase fumes back into the combustion chamber
- Evaporate emissions control system-closed vent system that stores fuel vapors and prevents them from entering
- Exhaust gas recirculation system-injects burned exhaust gases into the engine to lower combustion temperatures and prevent the formation of NO_x
- Air injection system-forces outside air into the exhaust system to help burn unburned fuel
- Thermostatic air cleaner system-maintains a constant temperature of the air entering the engine for improved combustion and performance in cold weather
- Catalytic converter-chemically changes combustion by-products into harmless substances
- Computer control system-electronic controls used to monitor and interface with various systems to increase overall engine efficiency and reduce emissions

Positive Crankcase Ventilation. A positive crankcase ventilation system uses engine vacuum to draw blowby gases into the intake manifold for reburning in the combustion chambers. Prior to the PCV, crankcase fumes were simply vented into the atmosphere. A road draft tube vented crankcase fumes and blowby gases out the back of the engine and this contributed to air pollution.

Engine blowby is caused by pressure leakage past the piston rings on the blower strokes. A small percentage of combustion gases can flow through the ring end gaps or the piston ring grooves and into the crankcase. If not reburned in the engine, these fumes will contribute to air pollution if vented to the atmosphere. If not vented from the crankcase, the gases will build to a point where engine damage would occur.

Engine blowby gases contain unburned fuel (HC); partially burned fuel (CO); particulates; and small amounts of water, sulfur, and acid. For this reason, blowby gases must be removed from the engine crankcase. Blowby gases can cause:

- Air pollution (if released into the atmosphere)
- Corrosion of engine parts
- Engine oil dilution
- Sludge formation

A PCV system keeps the inside of the engine clean and reduces air pollution. Older engines used an open PCV system. This system was not sealed and gases could leak out when the engine was shut off. These systems have been completely replaced by the closed PCV system.

A closed PCV system uses a sealed oil filler cap, a sealed oil dipstick, ventilation hoses, and either a PCV valve or a flow restrictor. The gases are drawn into the engine and burned. The system stores the gases when the engine is not running.

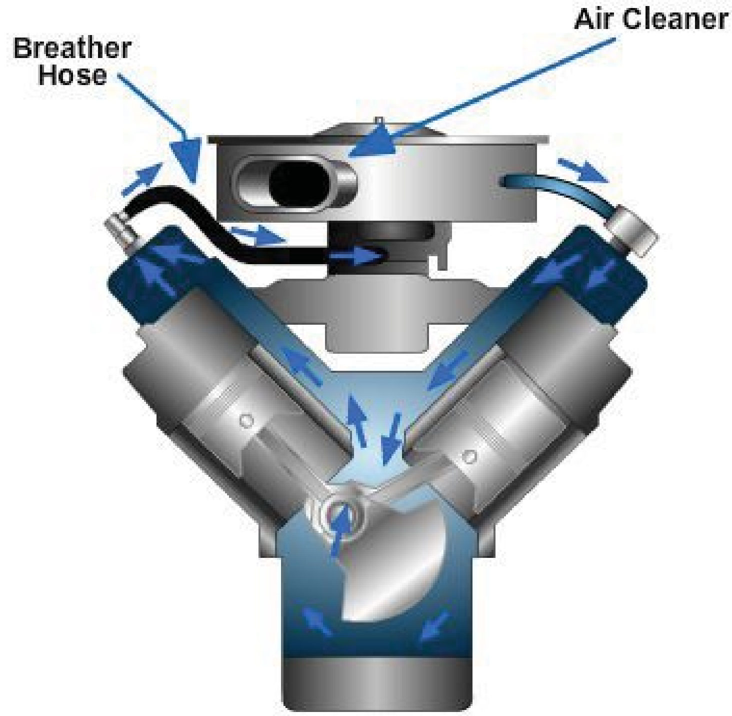

Figure 5-108 -PCV system.

PCV System Operation. Although designs vary and can use either vacuum or electronic control, the operation of all PCV systems is basically the same, as shown in *Figure 5-108*. The PCV system draws vapors out of the crankcase and routes them into the engine to be burned.

A hose usually connects the intake manifold to the PCV valve. With the engine running, vacuum acts on the engine's crankcase. Air is drawn in through the engine's air cleaner, through a vent hose into a valve cover, then drawn into the crankcase.

After the fresh air mixes with the crankcase gases, the mixture is pulled by vacuum past the PCV valve, through the hose, and into the engine intake manifold. The crankcase gases are then drawn into the combustion chambers for burning.

An electronically controlled PCV system often uses a solenoid valve in the vacuum line leading to the valve. The computer system can energize or de-energize the solenoid to block or pass vacuum. This allows the computer to help control PCV operation.

PCV Valve. A PCV valve is used to control the flow of air through the PCV system. It may be located in a rubber grommet in a valve cover, in a breather opening in the intake manifold of plenum, or on the side of the engine block. The PCV valve varies the flow of air for idle, cruise, acceleration, wide open throttle, and engine-off conditions.

Figure 5-109 shows the action of a PCV valve under various conditions. At idle, the PCV valve is pulled toward the intake manifold by high vacuum. This restricts the flow of air and prevents a lean air-fuel mixture. When cruising, the lower intake manifold vacuum allows the spring to open the PCV valve. However, enough vacuum is present to keep the PCV valve from completely closing. More air can flow through the system to clean out crankcase fumes. At wide open throttle or with the engine off (low or no intake manifold vacuum), spring pressure closes the PCV valve completely.

In case of an engine backfire (air-fuel mixture in the intake manifold), the PCV valve plunger is seated against the body of the valve. This keeps the backfire (burning) from entering and igniting the fumes in the engine crankcase.

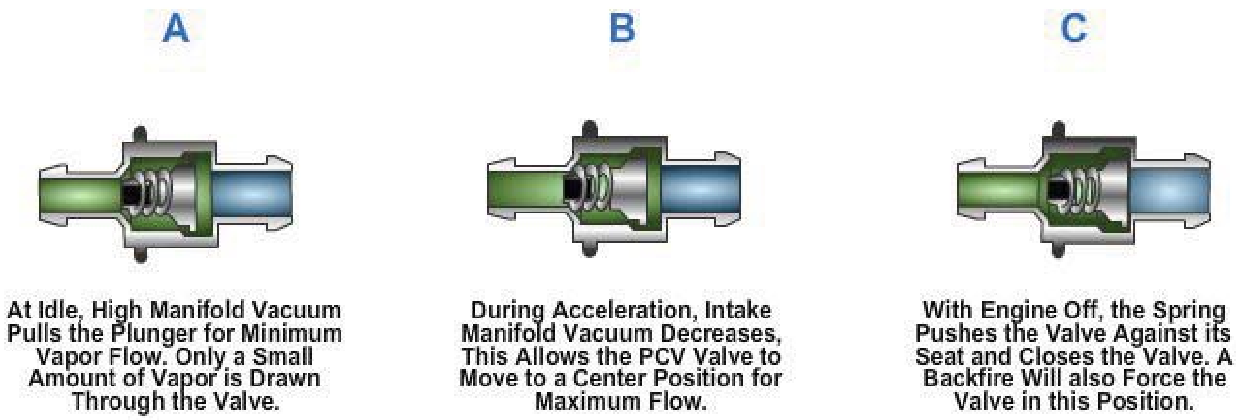

Figure 5-109 -PCV valve operation under operating conditions.

Electric PCV Valve. Most vehicles now use electronically controlled crankcase ventilation systems. In these systems, an electric PCV valve, which contains a small solenoid and air valve, is controlled by the ECM to regulate engine crankcase ventilation. When energized by the engine ECU, the valve opens to allow the blowby gases in the engine crankcase to be routed back into the engine intake manifold for combustion, as the one shown in *Figure 5-110*.

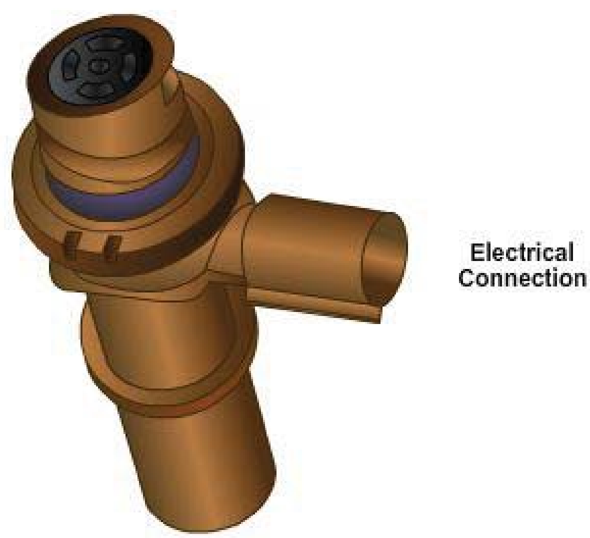

Figure 5-110 – Electric PCV valve.

Oil/Air Separator. An oil/air separator is a device that makes oil vapors condense and flow into the oil pan. It can be used instead of a PCV system to reduce emissions and prevent oil sludging. The separator simply allows oil mists and vapors to settle out into a liquid so that they do not continue to circulate through the engine.

Evaporative Emissions Control System. The evaporative emissions control (EVAP) system prevents toxic fuel system vapors from entering the atmosphere. Gasoline and many of its additives evaporate easily, especially if exposed to the atmosphere.

Pre-emission-control vehicles used vented gas tank caps. Carburetor bowls were also vented to the atmosphere, which caused a considerable amount of hydrocarbon emissions from unburned fuel. Today, vehicles use an evaporative emissions control system to prevent this source of air pollution

Evaporative Emissions System Components. The components of a typical evaporative emissions system are shown by the diagram in *Figure 5-111*.

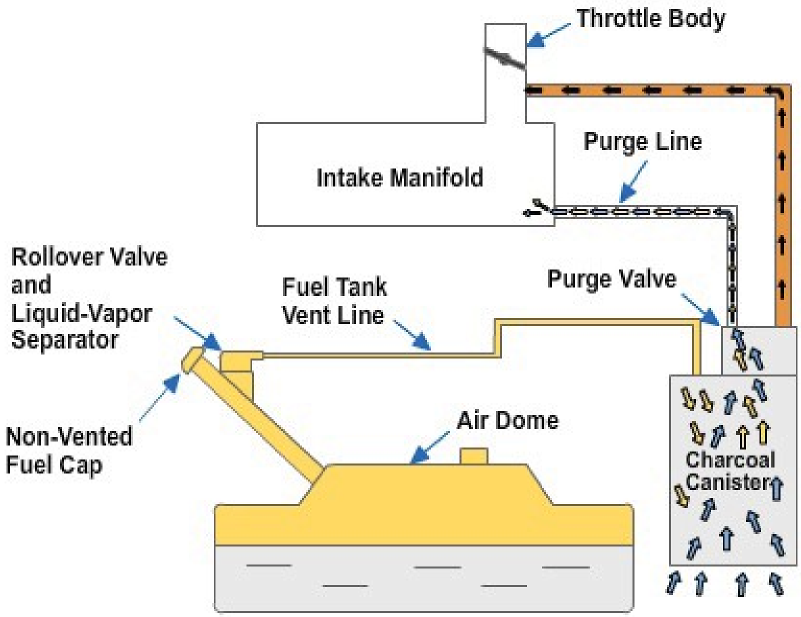

Figure 5-111 - Evaporative emissions control.

- **Non-vented fuel tank cap** prevents fuel vapors from entering the atmosphere through the tank's filler neck. It may contain pressure and vacuum valves that open in extreme cases of pressure or vacuum to prevent tank bulging or collapsing. When the fuel expands (from warming), tank pressure forces fuel vapors out of a vent line or lines at the top of the fuel tank, not out of the tank cap.
- **Fuel tank vent line** carries fuel vapors to a charcoal canister.
- **Air dome** is a hump formed in the top of the fuel tank to allow for fuel expansion and tank filling without spillage. The dome normally provides about 10% air space to allow for fuel heating and the resulting volume increase.
- **Liquid-vapor separator** is sometimes used to keep fuel from entering the evaporative emission system. It is simply a small valve located above the main fuel tank. Liquid fuel condenses on the walls of the liquid-vapor separator because of the difference in temperature between the separator and the fuel. The liquid fuel then flows back into the fuel tank.
- **Rollover valve** is used in the vent line from the fuel tank. It keeps liquid fuel from entering the vent line in case the vehicle rolls over during a vehicle mishap. The valve contains a metal ball or a plunger valve that blocks the vent line when the valve is turned over.
- **Charcoal canister** stores fuel vapors when the engine is not running. The metal or plastic canister is filled with activated charcoal granules, as shown in *Figure 5-112*. The charcoal is capable of absorbing fuel vapors. The top of the canister has fittings for the fuel tank vent line and the purge (cleaning) line. The bottom of the canister may have an inlet filter that cleans the outside air entering the canister.

- **Purge line** is used for removing the stored vapors from the charcoal canister. It connects the canister to the engine intake manifold. When the engine is running, engine vacuum draws the vapor out of the canister and through the purge line.
- **Purge valve** controls the flow of vapors from the canister to the intake manifold. This vacuum-or electrically operated valve is located on the top of the canister or in the purge line. Purge valves generally allow flow when the engine reaches operating temperature and is operating above idle speed. This helps minimize emissions when the engine is cold and prevents rough idle.

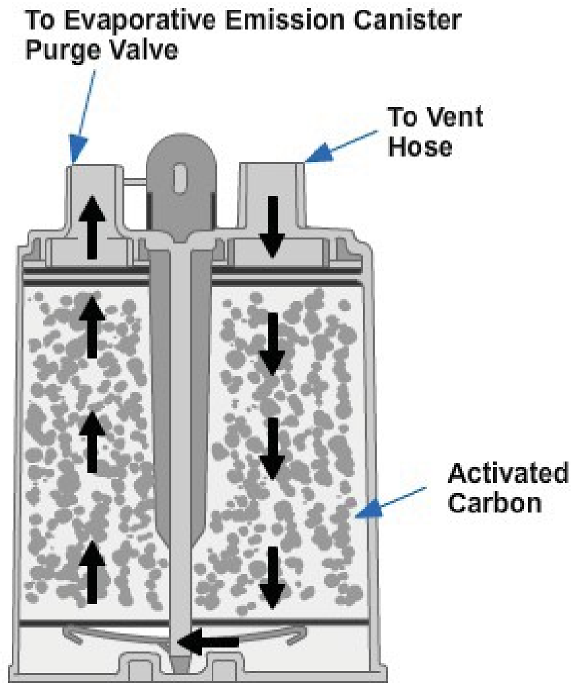

Figure 5-112 – Cutaway view of a charcoal canister.

Evaporative Emissions Control System Operation. *Figure 5-113* illustrates evaporative emissions system operation. Note that this system contains a vacuum-operated purge valve. When the engine is operating above idle speed, the intake manifold causes the purge valve to open. This allows gases to flow through the purge line and causes fresh air to be drawn through the filter in the bottom of the canister. The incoming fresh air picks up the stored fuel vapors and carries them through the purge line. The vapors enter the intake manifold and are pulled into the combustion chambers for burning. When the engine is shut off, gasoline slowly evaporates, producing unwanted vapors. These vapors flow through the fuel tank vent line and into the charcoal canister. The activated charcoal in the canister absorbs the fuel vapors and holds them until the engine is started again.

An evaporative emissions control system contains an electronically operated purge valve, or purge solenoid. The purge solenoid is normally closed and opens when energized by the ECM. The ECM energizes the solenoid only after the following conditions have been met:

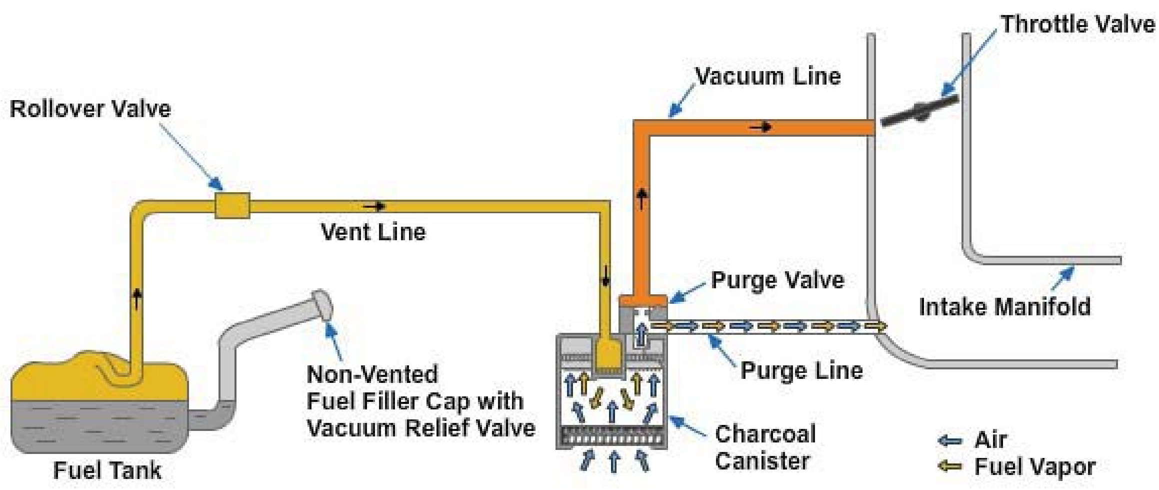

Figure 5-113 - The operation of an evaporative control system and its relayed components.

- The vehicle has been operating in closed loop for a specified period of time.
- The coolant temperature is within manufacturer's specifications.
- Vehicle speed is above approximately 15 mph.
- The engine is operating above idle speed.

Enhanced Evaporative Emissions Control System. As its name implies, an enhanced evaporative emission control system has several components and features not found in conventional EVAP systems. The enhanced system, which is found in OBD II vehicles, not only provides better control of fuel vapors, but it also monitors the condition of the fuel system. In addition to the components found in a conventional evaporative emission system, the enhanced EVAP system contains the following:

- **Fuel tank pressure sensor**-sensor that monitors internal fuel tank pressure and sends a signal to the control module
- **Canister vent solenoid**-electrically operated vacuum valve that replaces the fresh air vent used on older canisters
- **Service port** -fitting that allows the connection of service tools for testing and cleaning purposes

The canister used in enhanced EVAP systems does not have a bottom inlet filter. Instead, fresh air is fed to the canister by the vent solenoid. The purge valve, or purge solenoid, in these systems is an electrically operated valve that controls the flow of vapors from the canister to the manifold, as shown in *Figure 5-114.*

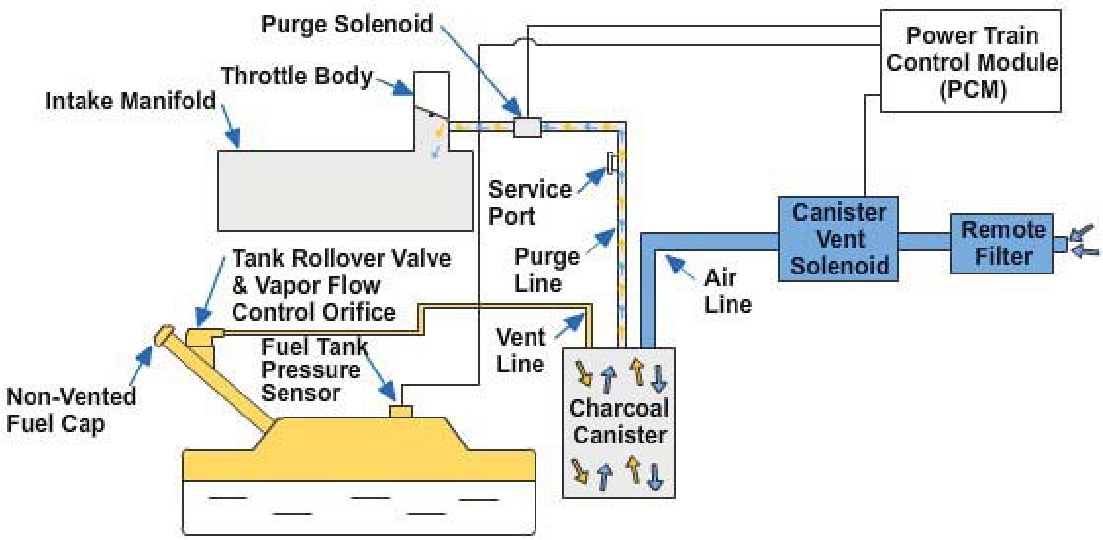

Figure 5-114 - The canister evaporative emission system.

Enhanced Evaporative Emission Control System Operation. The enhanced EVAP system often uses a normally closed, pulse-width modulated purge solenoid. The control module can send different length electrical pulses to the solenoid to precisely control vapor flow. When energized, the purge solenoid opens to allow vapor to be pulled into the engine.

The canister vent solenoid is normally open, allowing fresh air into the canister during purge mode. When the system is in the diagnostic mode, the control module closes the vent solenoid, blocking airflow into the canister. The module then opens the purge solenoid, creating a vacuum in the system. When the control module determines that there is enough vacuum in the system (based on the tank pressure sensor signal), it closes the purge solenoid, sealing the system. The module then monitors the pressure sensor signal. If the system is properly sealed, the signal should remain steady until the control module reopens the vent solenoid.

IM 240. IM 240 is an enhanced emissions test that requires the vehicle to be operated on a dynamometer at speeds up to 55 mph for 240 seconds while the exhaust emissions are measured. Two additional tests-the evaporative emission system purge test and the evaporative emission system pressure test-may be required in some locations.

5.1.0 Evaporative Control System Troubleshooting

Evaporative Emissions System Purge Test. The evaporative emissions system purge test measures the flow of fuel vapors into the engine while performing the IM 240 test. A flow meter transducer is installed into the system purge line between the charcoal canister and the engine intake manifold fitting. A personal computer connects to the flow transducer to analyze data. The computer can then detect if there is adequate purge flow to remove fumes from the canister to draw them to the engine for burning.

Evaporative Emissions Systems Pressure Test. An evaporative emissions system pressure test checks the system for leaks into the atmosphere. It is performed during the IM240 test. Pressure test equipment is connected to the evaporative emission system's vapor vent line. A computer then meters low-pressure nitrogen into the system.

When about 0.5 psi pressure is reached, the computer closes off the system and checks for a pressure drop for 2 minutes. If pressure remains above recommendations, the evaporative emission system passes the pressure test. If the pressure drops too much, repairs are needed to fix the leakage.

Evaporative Emissions Control System Service. A faulty evaporative emissions control system can cause fuel odors, fuel leakage, fuel tank collapse (vacuum buildup), excess pressure in the fuel tank, or a rough engine idle. These problems usually stem from a defective fuel tank pressure-vacuum cap, leaking charcoal canister valves, deteriorated hoses, or incorrect hose routing.

Evaporative Emissions Control System Maintenance and Repair. Maintenance on an evaporative emissions control system typically involves cleaning or replacing the filter in the charcoal canister. Service intervals for the canister filter vary. However, if the vehicle is operated on dusty roads, clean or replace the filter more often.

Also inspect the condition of the fuel tank filler cap. Make sure the cap is installed properly and the seals are in good condition. Special testers are available for checking the opening of the pressure and vacuum valves in the cap. The cap should be tested when excessive pressure or vacuum problems are noticed.

Use a hand vacuum pump to test the charcoal canister vacuum purge solenoids for diaphragm leakage. If a diaphragm will not hold a vacuum, it is ruptured and must be replaced. You can also use the vacuum gauge to check for a vacuum supply to any vacuum canister solenoid.

5.2.1 Emission Control Components Troubleshooting

Vacuum Solenoid Service. Various vacuum solenoids are used to interface emission system electronics with the devices that operate off engine vacuum. They can be used in almost all emission control systems.

When trying to find problems, you should refer to a vacuum hose diagram, which shows the routing of all vacuum hoses. Just as a wiring diagram helps tracing circuit problems, a vacuum hose diagram will give useful information on finding incorrectly routed hoses, leaking or restricted hoses, and bad vacuum components. *Figure 5-115* is a sample vacuum diagram from a service manual. Note how the emissions devices are connected. The service manual will explain the function and testing of each device.

When troubleshooting vacuum solenoids, check for hard, brittle hoses that can leak and prevent normal operation of parts. If the vacuum solenoid is electrically powered, check it for voltage. Connect a volt-meter to the solenoid terminals and start the engine. Make sure you are getting voltage to the unit when needed.

You can also connect a remote source of voltage to a vacuum solenoid to check its operation. When voltage is connected to the solenoid, it will switch vacuum on or off.

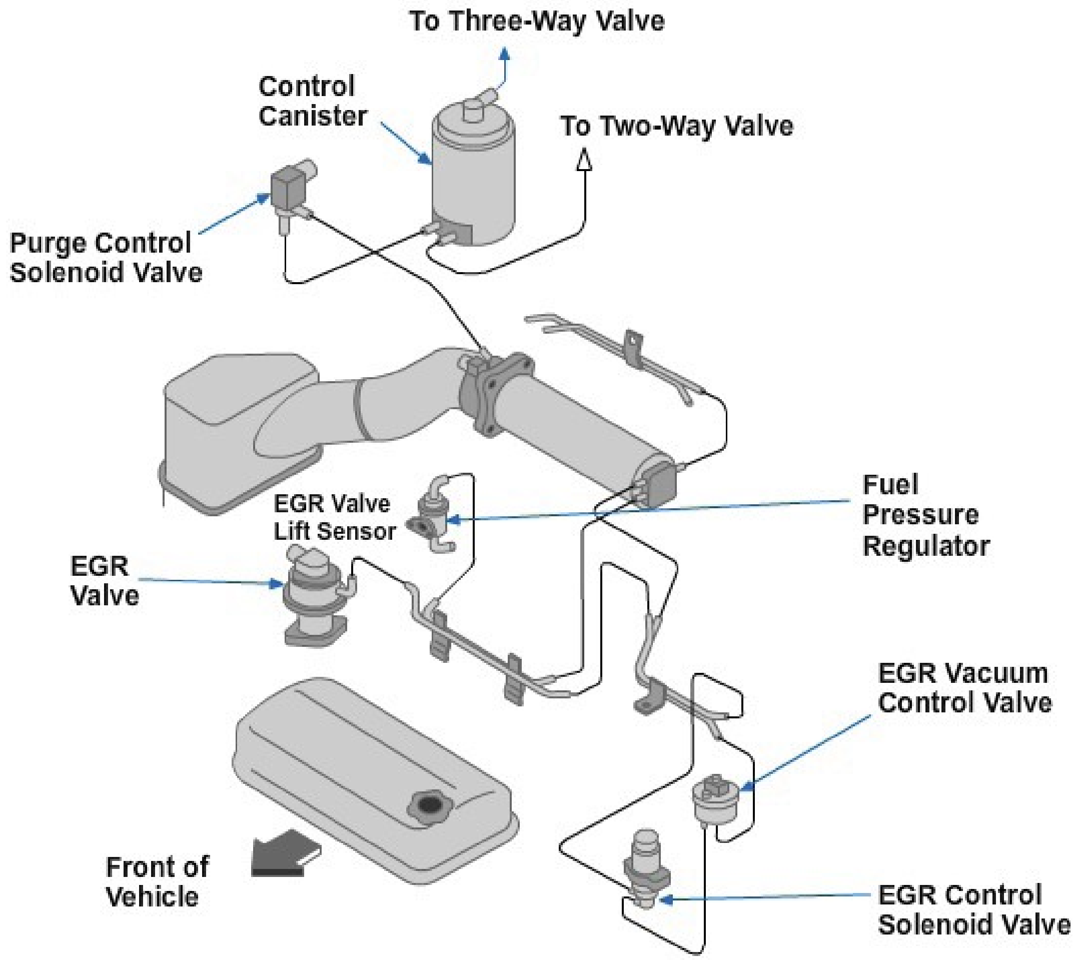

Figure 5-115 -Vacuum hose routing diagram as it appears in a service manual.

PCV System Service. An operative PCV system can increase exhaust emissions. It can also cause engine sludging and wear, rough engine idle, and other problems. A leaking PCV system can cause a vacuum leak and produce a lean air-fuel mixture, causing a rough engine idle. A restricted PCV system can enrich the fuel mixture, affecting engine idle and causing the engine to surge (idle speed goes up and down) and emit black smoke.

PCV System Maintenance. Most auto manufacturers recommend periodic maintenance of the PCV system. Inspect the condition of PCV hoses, grommets, fittings, and breather hoses. Replace any hose that shows any signs of deterioration. Clean or replace the breather filter, if needed. Also, check or replace the PCV valve. Since replacement intervals vary, always refer to the service manual.

PCV System Testing. To quickly test a PCV valve, pull the valve out of the engine and shake it. If the PCV valve does not rattle when shaken, replace the valve. With the engine idling, place your finger over the end of the valve, as shown in *Figure 5-116.* With the airflow stopped, you should feel suction on your finger and the engine idle speed should drop about 40-80 rpm.

If you cannot feel any vacuum, the PCV valve or hose might be plugged with sludge. If engine rpm drops more than 40-80 rpm and the engine begins to idle smoothly, the PCV valve could be stuck open.

Figure 5-116 - With the engine running, place your finger over the PCV valve to check for suction.

A PCV valve tester will measure the exact amount of airflow through the system. To use a tester, make sure the engine intake manifold vacuum is correct. Then, connect the tester to the engine as described in the operating instructions. Start and idle the engine. Observe the airflow rate on the tester. Replace the PCV valve if airflow is not within specified limits.

CAUTION

Do not attempt to suck through a PCV valve with your mouth. Sludge and other deposits inside the valve are harmful to the human body.

Another simple check of the PCV valve can be made by pinching the hose between the valve and the intake manifold with the engine at idle, as illustrated in *Figure 5-117*. There should be a clicking sound from the valve when the hose is pinched and unpinched. If no clicking sound is heard, check the PCV valve

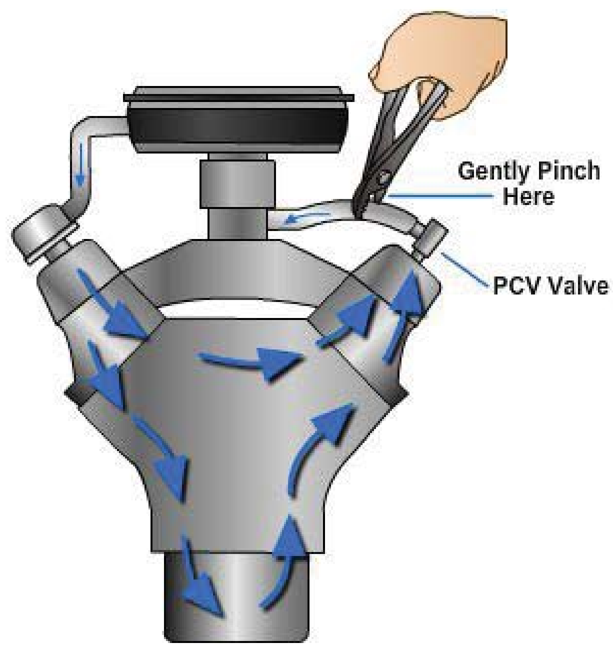

Figure 5-117 -Pinch PCV hose with pliers. Ensure to wrap something around the hose so the hose is not damaged by the pliers.

grommet for cracks or damage. If the grommet is alright, replace the PCV valve.

Some manufacturers suggest placing a piece of paper over the PCV breather opening to test the PCV system. After a few minutes of operation, the piece of paper should be pulled down against the breather opening by the crankcase vacuum. If the suction does not develop, there is a leak in the system, such as a ruptured gasket or cracked hose, or the system may be plugged.

A four- or five-gas exhaust analyzer can also be used to check the general condition of a PCV system. Measure and note the analyzer readings with the engine idling. Then, pull the PCV valve out of the engine, but not off the hose. Compare the readings after the PCV valve is removed.

A plugged system will show up on the exhaust analyzer when oxygen and carbon monoxide do not change. Crankcase dilution (excessive blowby or fuel in the oil) will usually show up as an excessive (1% or more) increase in oxygen or a 1% or more decrease in carbon monoxide. This is because the excess crankcase fumes will be pulled into and burn in the engine, affecting your readings.

Thermostatic Air Cleaner System. The thermostatic air cleaner system speeds engine warm-up and keeps the air entering the engine warm. By maintaining a more constant inlet air temperature, a carburetor can be calibrated leaner at startup to reduce emissions. A typical thermostatic air cleaner is shown in *Figure 5-118*.

Thermostatic air cleaners are not needed with fuel injection systems. An electronic fuel injection system can alter its operation with cold air entering the engine more efficiently than a carburetor system.

A thermal vacuum valve is normally located in the air cleaner to control the vacuum motor and heat control door. A vacuum supply is connected to the thermal vacuum valve from the engine. Another hose runs from the thermal valve to the vacuum motor (diaphragm).

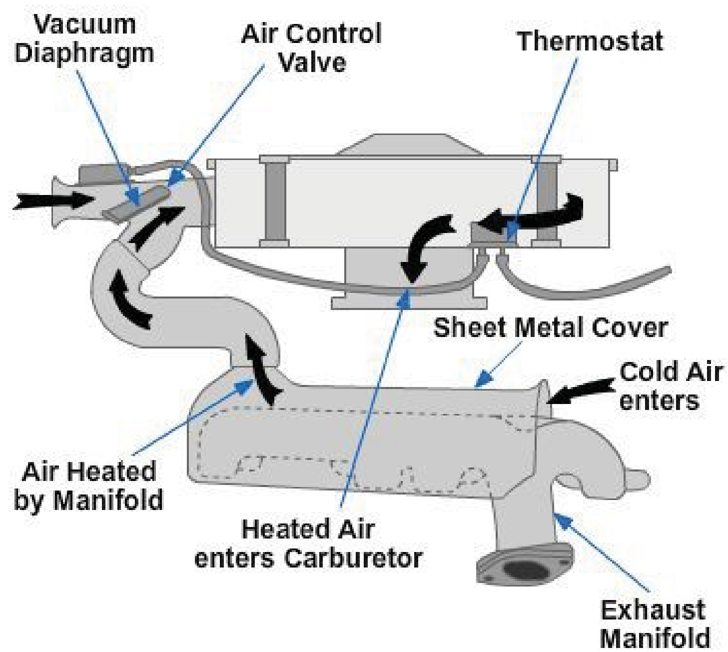

Figure 5-118 -Thermostatic air cleaner.

The vacuum motor, also called a vacuum diaphragm, operates the heat control door, or flap, in the air cleaner inlet. The vacuum motor consists of a flexible diaphragm, spring, rod, and diaphragm chamber. When the vacuum is applied to the unit, the diaphragm and rod are pulled upward, moving the heat control door.

The heat control door can be opened or closed to route either cool or heated air into the air cleaner. When the door is closed, hot air from the exhaust manifold shroud enters the engine. When the door is open, cooler outside air enters the engine.

Thermostatic Air Cleaner System Service. An inoperative thermostatic air cleaner system (heated air inlet) can cause several engine performance problems. If the air cleaner flap remains in the open position (cold air position), the engine could miss, stumble, stall, and warm up slowly. If the air cleaner flap stays in the closed position (hot air position), the engine could perform poorly when at full operating temperature.

Thermostatic Air Cleaner System Maintenance. The thermostatic air cleaner system requires very little maintenance. You should inspect the condition of the vacuum hoses and hot air tube from the exhaust manifold shroud. The hot air tube is frequently made of heat-resistant paper and metal foil. It will tear very easily. If torn or damaged, replace the hot air tube.

Testing Thermostatic Air Cleaner System. For a quick test of the thermostatic air cleaner system, watch the action of the heat control door in the air cleaner snorkel.

Start and idle the engine. When the air cleaner temperature sensor is cold, the door should be open. Place an ice cube on the sensor, if needed. Then, when the engine and sensor warm to operating temperature, the door should swing closed, as depicted in *Figure 5-119, View A.*

If the air cleaner flap does not function, test the vacuum motor and the temperature sensor. To test the vacuum motor, apply vacuum to the motor diaphragm with a hand vacuum pump. With the prescribed amount of vacuum, the motor should pull the heat control door open. If the door leaks or does not open, it should be replaced. After replacing the motor, recheck the thermostatic air cleaner system operation to make sure the air temperature sensor is working properly, as depicted in *Figure 5-119, View B.*

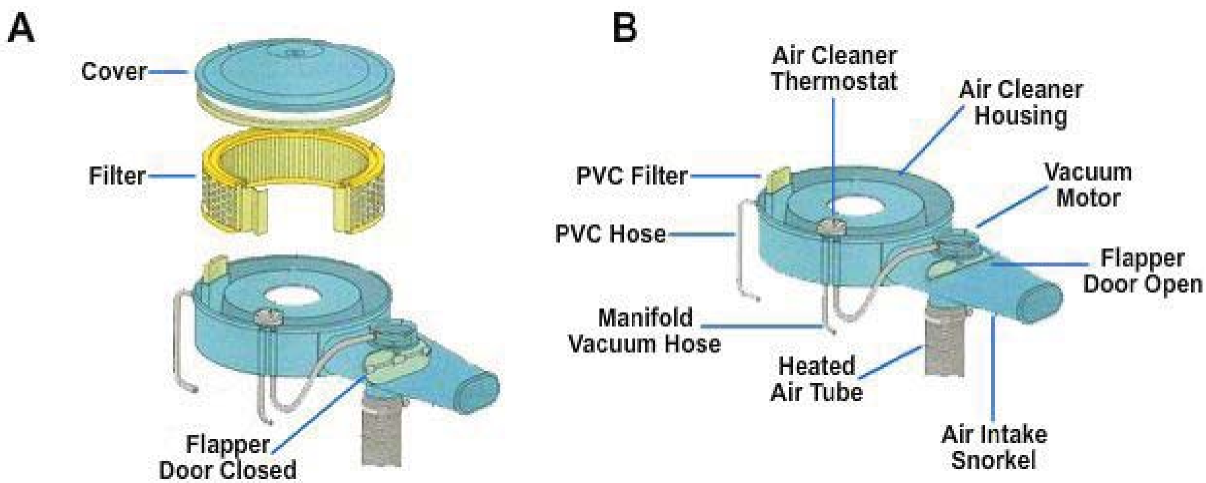

Figure 5-119 - Checking the operation of a thermostatic air cleaner.

To test the thermal vacuum valve in the air cleaner, place a thermometer next to the unit. With the valve cooled below its closing temperature, apply vacuum to the thermal vacuum valve. It should pass vacuum to the vacuum motor, and the heat control door should open.

Then, warm the thermal vacuum valve to its closing temperature. A heat gun (hair dryer) can be used to heat the unit. When warm, the valve should block the vacuum and the heat control door should close. Replace the thermal vacuum valve if the door fails to open and close properly.

Exhaust Gas Recirculation (EGR). The exhaust gas recirculation system, or EGR system, allows burned exhaust gases to enter the engine intake manifold to help reduce NO_x emissions. When exhaust gases are added to the air-fuel mixture, they decrease peak combustion temperatures (maximum temperature produced when the air-fuel mixture burns). For this reason, an exhaust gas recirculation system lowers the amount of NO_x in the engine exhaust. EGR systems can be controlled by engine vacuum or by the engine control module.

Vacuum-Controlled EGR. A vacuum-controlled EGR system uses engine vacuum to operate the EGR valve. A basic vacuum EGR system is simple. It consists of a vacuum-operated EGR valve and a vacuum line from the throttle body or carburetor. The EGR value usually bolts to the engine intake manifold or a carburetor plate. Exhaust gases are routed through the cylinder head and intake manifold to the EGR valve. *Figure 5-120, View A* shows that, with the throttle closed at idle speed, vacuum to the EGR valve is blocked and the valve remains closed to prevent rough idling. *Figure 5-120, View B* shows that when the throttle opens for more engine speed, the vacuum port to the EGR valve is exposed to vacuum. The EGR valve diaphragm is pulled up and exhaust gases enter the engine intake manifold without adversely affecting engine operation.

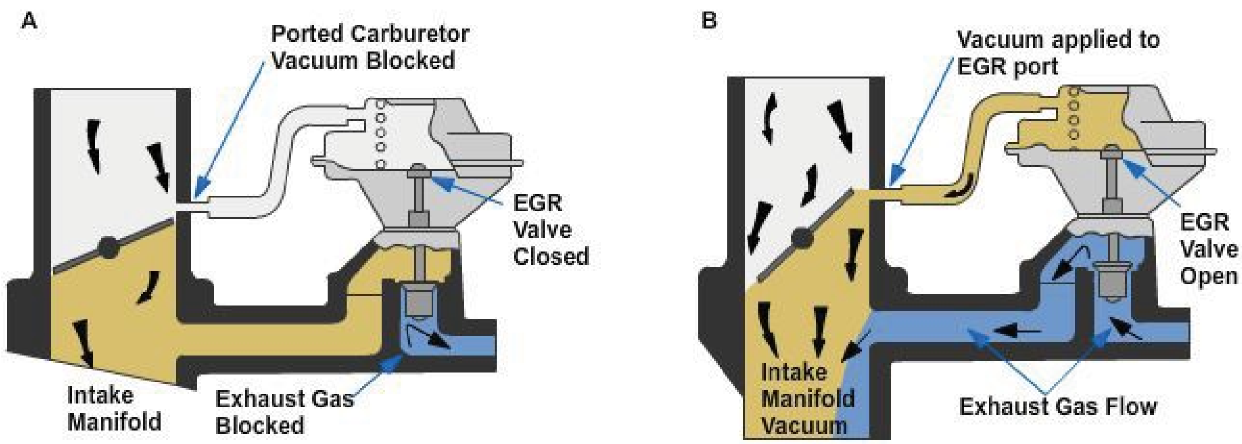

Figure 5-120 - Basic EGR valve operation.

The EGR valve consists of a vacuum diaphragm, spring, plunger, exhaust valve, and diaphragm housing. It is designed to control exhaust flow into the intake manifold, as illustrated in *Figure 5-121.*

Vacuum EGR Operation. At idle, the throttle plate in the throttle body or carburetor is closed. This blocks off engine vacuum so it cannot act on the EGR valve. The EGR spring holds the valve shut and exhaust gases do not enter the intake manifold. If the EGR valve were to open at idle, it could upset the air-flow mixture and the engine could stall.

When the throttle plate opens to increase speed, engine vacuum is applied to the EGR hose. Vacuum pulls the EGR diaphragm up. In turn, the diaphragm pulls the valve open.

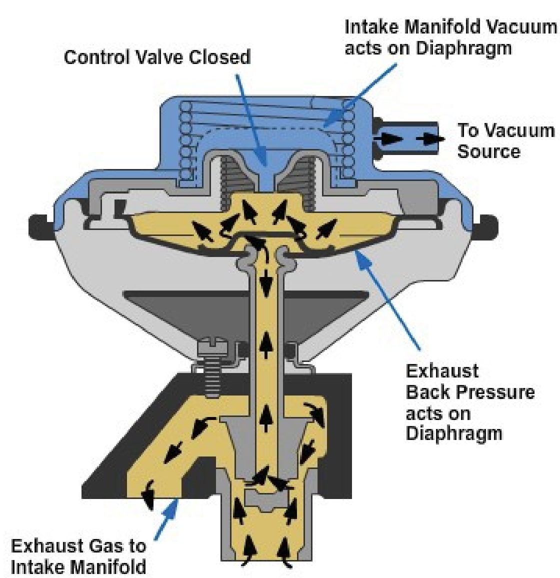

Figure 5-121 -Back pressure EGR valve.

Engine exhaust can then enter the intake manifold and combustion chambers. At higher engine speeds, there is enough air flowing into the engine that the air-fuel mixture is not upset by the open EGR valve.

Electronic-Vacuum EGR Valves. An electronic-vacuum EGR valve, as illustrated in *Figure 5-122,* uses both engine vacuum and electronic control for better exhaust gas metering. An EGR position sensor is located in the top of the valve and sends data back to the ECM. This allows the computer to determine how much the EGR valve is opened.

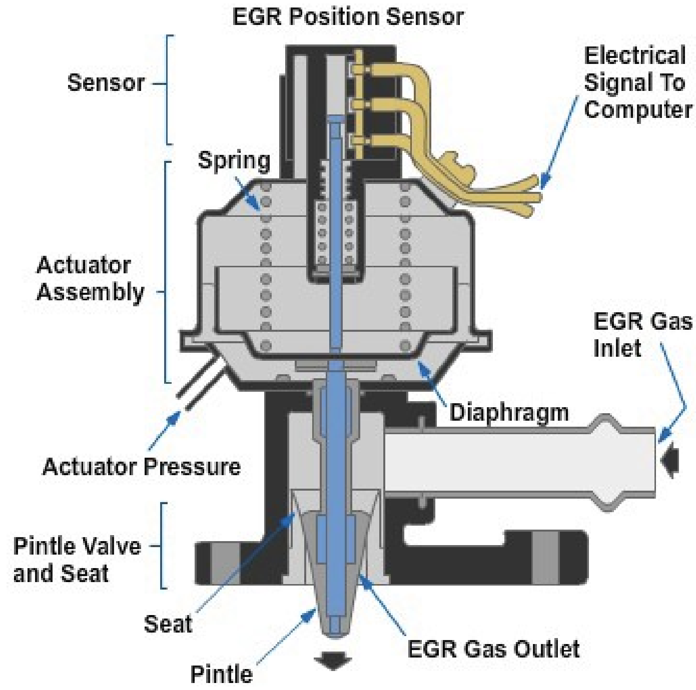

Figure 5-122 - Cutaway of an Electronic-Vacuum EGR valve.

With some systems, EGR solenoid valves are used to control more closely the EGR opening. These valves use electric solenoids to block or pass airflow to the EGR valve. They are located in one or more of the vacuum lines going to the EGR valve. The ECM can then energize the solenoids to alter when and how fast the EGR valve opens or closes to improve efficiency, as demonstrated in *Figure 5*-123. The diagram shows how the control module can be used to monitor and control a vacuum-operated EGR valve. The electric solenoids can block or allow flow in the vacuum line going to the EGR valve, providing computer control for this system. The engine coolant temperature sensor allows the control to keep the EGR valve closed when the engine is cold and NO_x emissions are not a problem.

EGR System Variations and Components. There are several EGR system variations that might be encountered, including:

- A back pressure EGR valve that uses both engine vacuum and exhaust back pressure to control valve action provides accurate control of EGR valve operation.
- An engine coolant temperature switch may be used to prevent exhaust gas recirculation when the engine is cold. A cold engine does not have extremely high combustion temperatures, so production of NO_x is minimal. By blocking vacuum to the EGR valve when the engine operating temperature is below 100°F, the drivability and performance of the cold engine are improved.
- The vacuum line to the EGR valve is sometimes connected into a wide open throttle valve (WOT valve). WOT valve opens under full acceleration to provide venturi vacuum to the EGR valve. At wide open throttle, intake manifold vacuum is very low, but venturi vacuum is high.

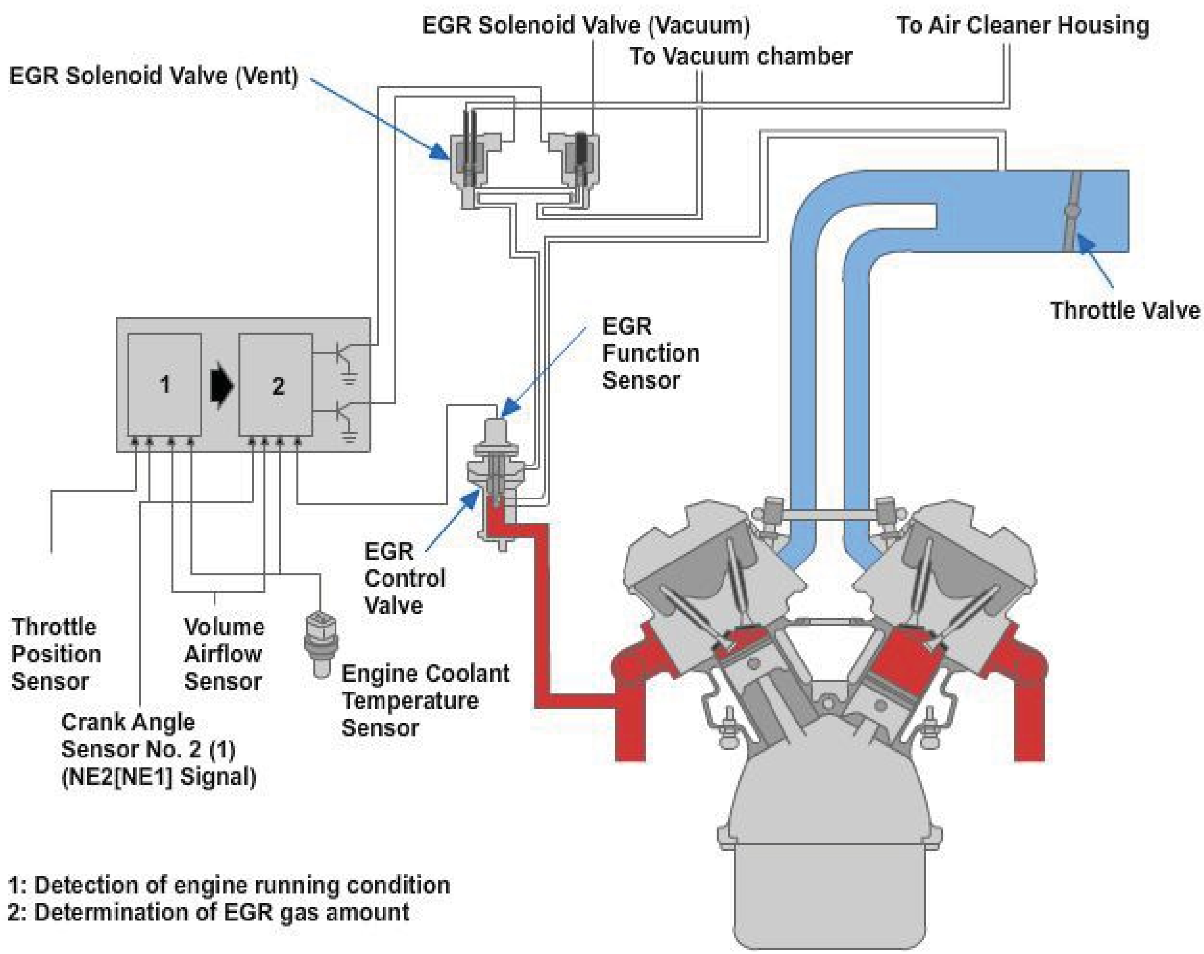

Figure 5-123 - Diagram of control module monitoring and controlling vacuum-operated EGR valve.

- Small EGR jets have been used in the bottom of a few intake manifolds to replace the EGR valve. The jets meter a small amount of exhaust into the airflow before it enters the engine cylinder head ports. The jets are small enough that they do mot upset the idler air-fuel mixture.

Electronic EGR System. An electronic EGR system uses vehicle sensors, the ECM, and a solenoid-operated exhaust gas recirculation valve to reduce NO_x emissions.

The ECM uses input data from the EGR position sensor, engine coolant temperature sensor, mass airflow sensor, throttle position sensor, crankshaft position sensor, and other sensors. The sensor signals allow the ECM to determine how much duty cycle should be sent to open and close each valve for maximum efficiency and minimum exhaust emissions.

The EGR duty cycle is a measurement of control current on and off time sent from the ECM. The ECM can precisely control the duty cycle from the ECM. The ECM can precisely control duty cycle to meter just the right amount of exhaust gases needed to reduce NO_x emissions, as represented in *Figure 5-124*.

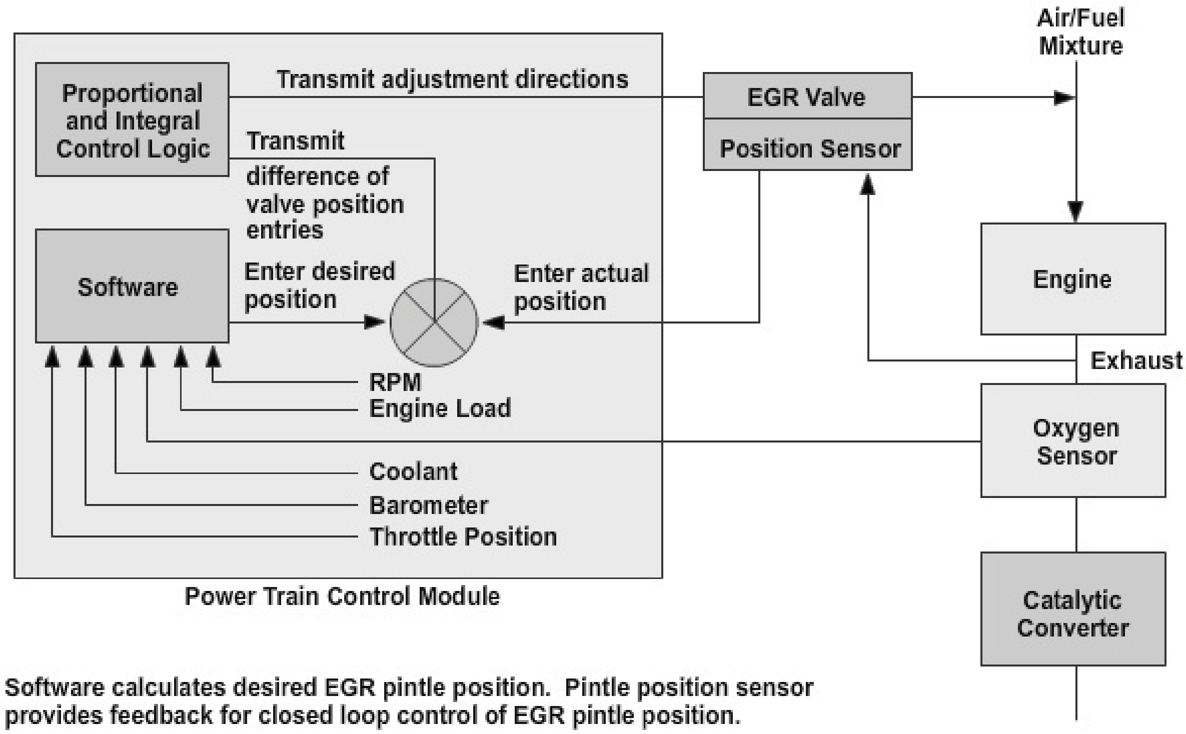

Figure 5-124 - Block diagram represents the relationship between a power train control module and the EGR system.

Electronic EGR Valves. An electronic EGR valve, sometimes termed digital EGR valve, uses one or more electric solenoids to open and close its exhaust passages. It works without engine vacuum.

A single-stage EGR valve uses only one solenoid and valve. It is a simple, dependable EGR design, as shown in *Figure 5-125, View A.* To open one of the exhaust passages in the EGR valve, the ECM energizes its solenoid. When control current is sent to the solenoid windings, it pulls up on the metal armature connected to the valve. This lifts up the valve to open an exhaust recirculation passage. Exhaust gases flow through orifices to limit engine combustion temperatures and prevent NO_x pollution. When the ECM stops current flow to the EGR solenoid, spring tension closes the valve to prevent exhaust flow into the engine.

A multi-stage EGR valve, as illustrated in *Figure 5- 125, View B,* uses more than one (usually three) solenoid valves to more closely match exhaust gas flow to engine needs.

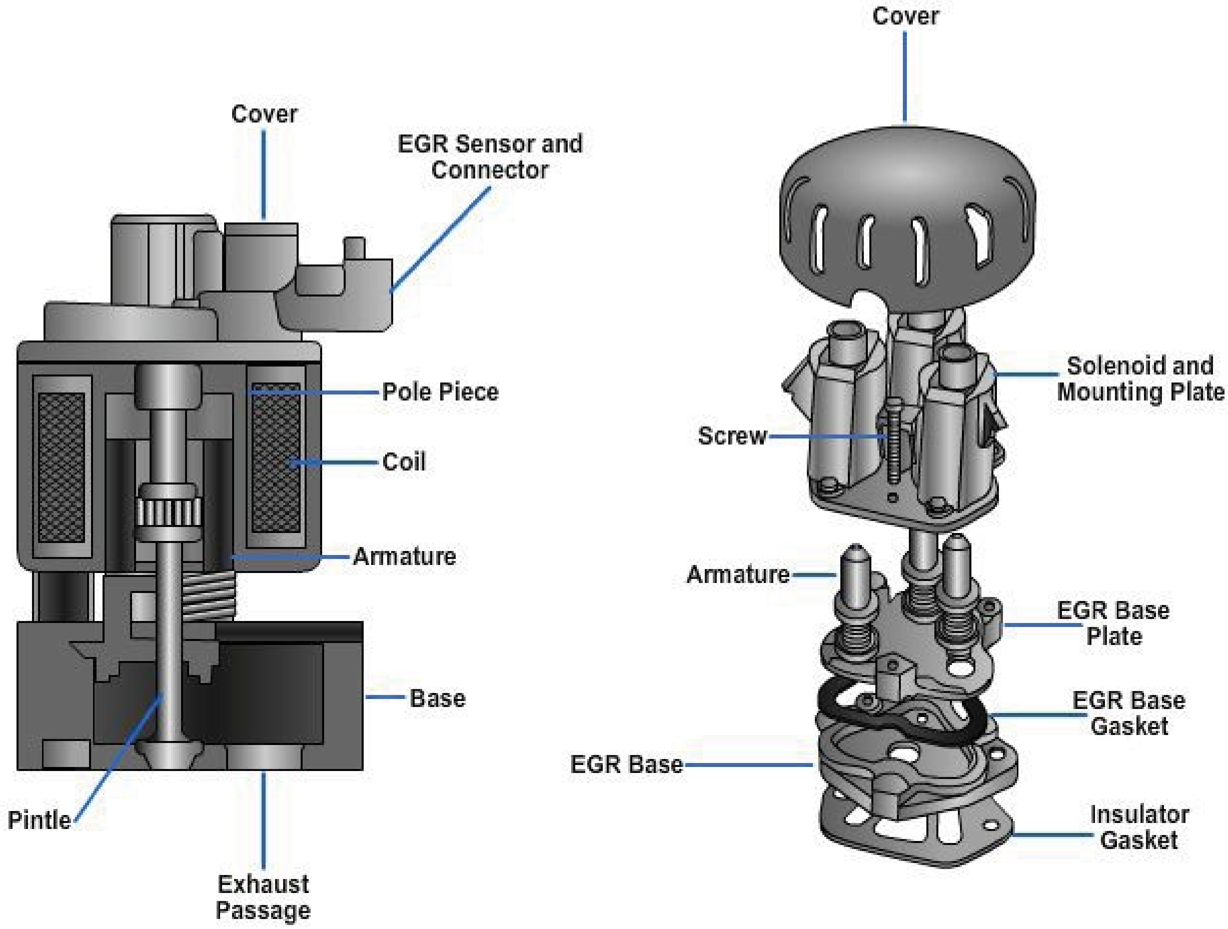

Figure 5-125 — Cutaway view showing components of an electronic or digital EGR valve and a multistage EGR valve that uses three separate solenoids and valves.

The solenoids mount on a base plate. When the valves are closed, they contact and seal against the base plate seats.

If only a small amount of exhaust recirculation gas is needed (combustion temperatures only slightly too hot), the ECM will only energize one of the EGR solenoids.

If combustion temperatures become hotter (engine conditions like speed load, or outside air temperature increase), the ECM will energize the other EGR solenoid as needed to increase exhaust gas recirculation flow. The added exhaust gases will decrease combustion temperatures to reduce NO_x.

EGR System Service. EGR system malfunctions can cause engine stalling at idle, detonation, and poor fuel economy. If the EGR valve sticks open, it will cause a lean air-fuel mixture. The engine will run rough at idle or stall. If the EGR fails to open or exhaust passage is clogged, higher combustion temperatures can cause abnormal combustion (detonation) and knocking.

EGR System Maintenance. Maintenance intervals for the EGR system vary with vehicle manufacturer. Refer to the service manual for exact mileage intervals. Some vehicles have a reminder light in the dash. The light will come on when the EGR maintenance is needed. Also, check that the vacuum hoses in the EGR system are in good condition. They can become hardened, which can cause leakage, Also check for proper wire routing and for good electrical connections on digital EGR valves.

EGR System Testing (Vacuum Type). To test a vacuum EGR system, allow the engine to warm to operating temperature. Operating the accelerator linkage by hand, increase engine speed to 2000-3000 rpm very quickly. If visible, observe the movement of the EGR valve stem. The stem should move as the engine is accelerated. If it does not move, the EGR system is not functioning.

Sometimes the EGR valve stem is not visible. You will need to test each EGR system component separately. Follow the procedures described in the service manual.

To test the EGR valve, idle the engine. With the engine idling, connect a hand vacuum pump to the EGR valve, as demonstrated in *Figure 5-126*. Plug the supply vacuum line to the EGR valve. When vacuum is applied to the EGR valve with the pump, the engine should begin to miss or stall. This lets you know that the EGR valve is opening and that exhaust gases are entering the intake manifold.

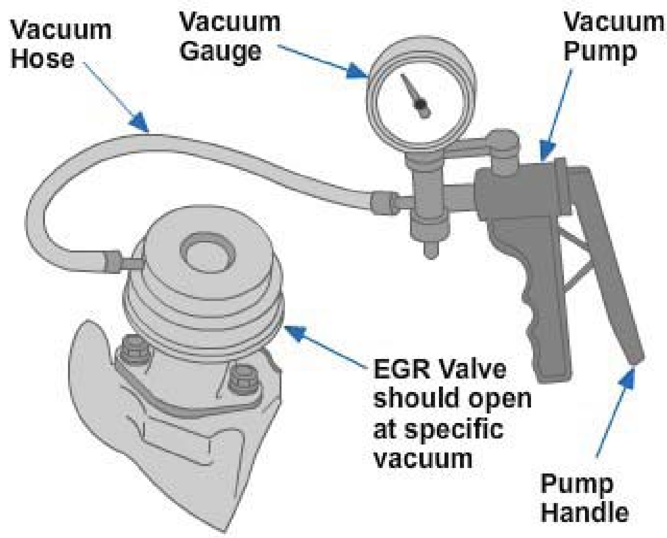

Figure 5-126 – Testing the EGR system with a hand vacuum pump.

If the EGR valve operation does not affect the engine idle, remove the valve. The valve or the exhaust manifold passage could be clogged with carbon. If needed, clean the EGR valve and exhaust passage. When the EGR valve does not open and close properly, replace the valve.

EGR System Testing (Electronic Type). Most problems with electronic or digital EGR valves will trip a trouble code. A scan tool will isolate most problems quickly and easily. EGR valves that provide electrical data to a computer control system require special testing procedures. Refer to the shop manual covering the specific system.

WARNING

Component damage could result from using an incorrect testing method.

The problem symptoms described also apply to a digital EGR. If not working normally, it can cause rough engine idle, high oxides of nitrogen, and other problems.

To pinpoint test a digital EGR valve, connect a hand-held scope to the wire going to the valve, as shown in *Figure 5-127*. Connect the scope to ground and probe through the EGR valve connector. The service manual wiring diagram will tell you which wires to probe. The scope's waveform will measure the voltage applied to the EGR from the ECM and it will also check the condition of the EGR windings. If voltage to the EGR is not indicated, check for a bad electrical connection. There could also be an ECM problem in the control circuit to the EGR valve.

Figure 5-127 - An oscilloscope can be used to check digital EGR valves and their ECM control circuits.

Air Injection System. An air injection system forces fresh air into the exhaust ports or catalytic converter to reduce HC and CO emissions. The exhaust gases leaving an engine can contain unburned and partially burned fuel. Oxygen from the air injection system causes this fuel to continue to burn in exhaust manifold or the catalytic converter, as shown in *Figure 5-128.*

The air injection pump is belt-driven and forces air at low pressure into the system. The spinning vanes, or blades, pull air in one side of the pump. The air is trapped and compressed as the vanes rotate. As rotation continues, air is forced out of a second opening in the pump, as shown in *Figure 5-129*.

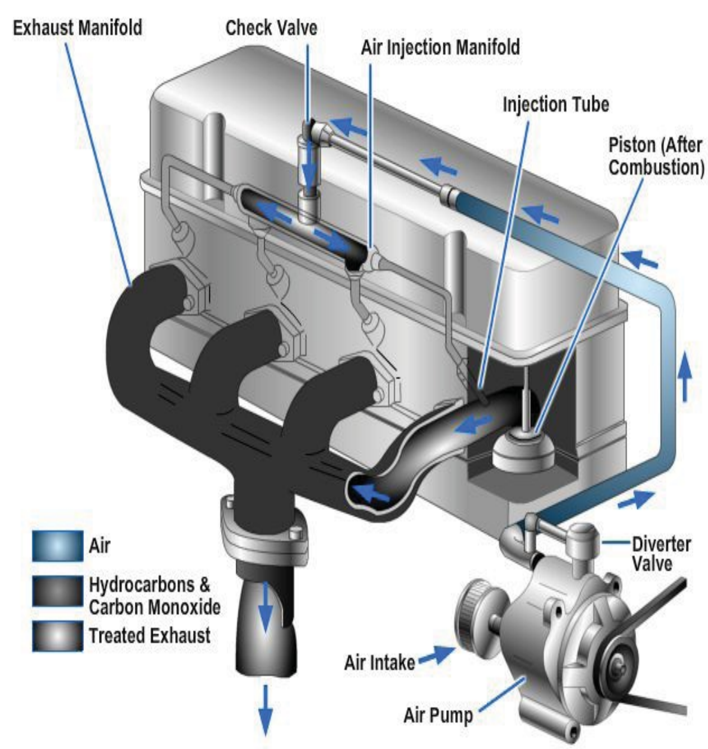

Figure 5-128 - Diagram illustrating the air injection system.

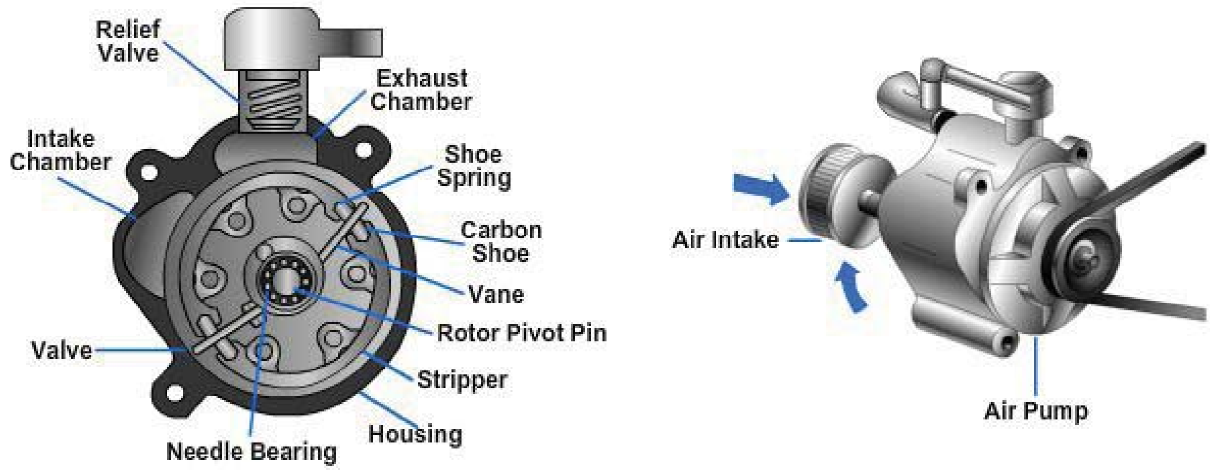

Figure 5-129 – Rear and side cutaway views of an air pump.

Electric air injection pumps are driven by a small dc motor, instead of being engine driven. This reduces emissions at start-up and with high engine temperatures because a more constant flow of air is produced by the electric motor. Air pump speed does not change with engine speed.

Air Injection System Components. *Figure 5-130* shows the major parts of an air injection system. The diverter keeps air from entering the exhaust system during deceleration. This prevents backfiring, which is an explosive burning of the air-fuel mixture outside the combustion chamber in the exhaust system. The diverter valve also limits maximum system air pressure. It releases excessive pressure through a silencer or muffler. A plastic or rubber hose connects the pump output to a diverter valve.

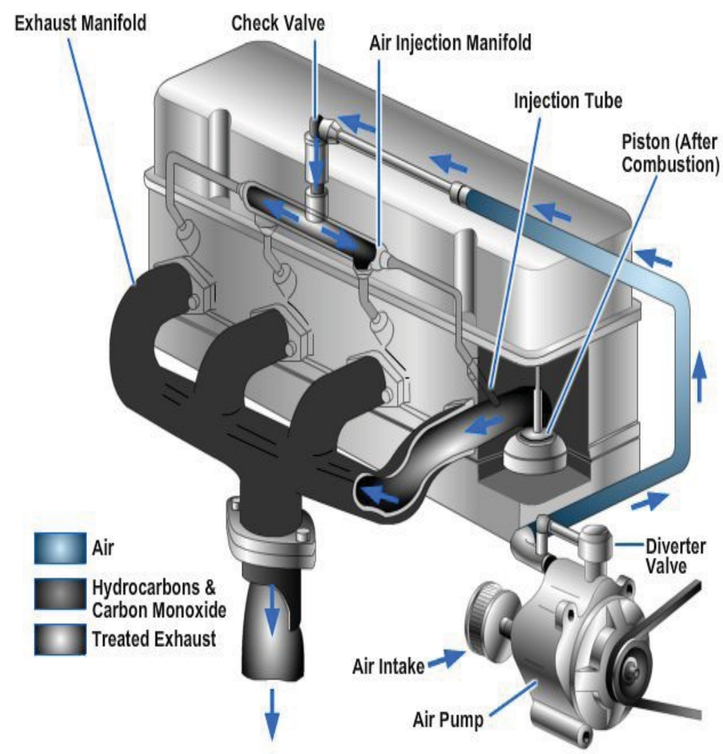

Figure 5-130 – The basic parts of air injection system.

An air distributor manifold is used in air injection systems to direct a stream of air toward each engine exhaust valve. Fittings on the air distribution manifold screw into threaded holes in the exhaust manifold or cylinder head. *Figure 5-130* shows a typical air distribution manifold.

An air check valve is usually located in the line between the diverter valve and the air distribution manifold. It keeps exhaust gases from entering the air injection system.

Air Injection System Operation. When the engine is running, the spinning vanes in the air pump force air into the diverter valve. If not decelerating, the air is forced through the diverter valve, check valve, air injection manifold, and into the engine exhaust ports.

The fresh air blows on the engine exhaust valves to keep any fuel burning as it leaves the engine.

During periods of deceleration, the diverter valve blocks airflow into the engine exhaust manifold. This prevents a possible backfire, which could damage the vehicle's exhaust system. When needed, the diverter valve's relief valve releases excess pressure.

Vehicles can also use the air injection system to force air into the catalytic converter. This is done to help the converter burn, or oxidize, the partially burned fuel more completely. A metal line runs from the air pump to the catalytic converter. Air from this line is forced into the converter.

Air Injection System Service. Air injection system problems can cause engine backfiring, other noises, and increased HC and CO emissions. Air injection is used to help burn fuel that enters the exhaust manifolds and exhaust system. Without this system, the fuel could ignite all at once with a loud bang or backfiring. Insufficient air from the air injection system could also prevent the catalytic converter from functioning properly.

Air Injection System Maintenance. Air injection system maintenance typically includes replacing the pump inlet filter (if used), adjusting pump belt tension, and inspecting the condition of the hoses and lines.

If the pump belt or any hoses show signs of deterioration, they should be replaced. Refer to the manual specifications for maintenance intervals.

Testing Air Injection Systems. A four- or five-gas exhaust analyzer provides a quick and easy method of testing an air injection system. Run the engine at idle and record the readings. Then, disable the air injection system and remove the air pump belt or use pliers to pinch the hoses to the air distributor manifold. Compare the exhaust analyzer readings before and after disabling the air injection system.

Without air injection, the exhaust analyzer's oxygen reading should drop approximately 2%-5%, while hydrocarbon and carbon monoxide readings should increase. This shows that the air injection system is forcing air into the exhaust system. If the analyzer readings do not change, the air injection system is not functioning. Test each component until the source of the problem is found.

To test the air pump, remove the output line from the pump. Use a low-pressure gauge to measure the amount of pressure developed by the pump at idle. Typically, an air pump should produce about 2-3 psi of pressure, as shown by *Figure 5-131*.

If a low-pressure gauge is not available, place your finger over the line and check for pressure.

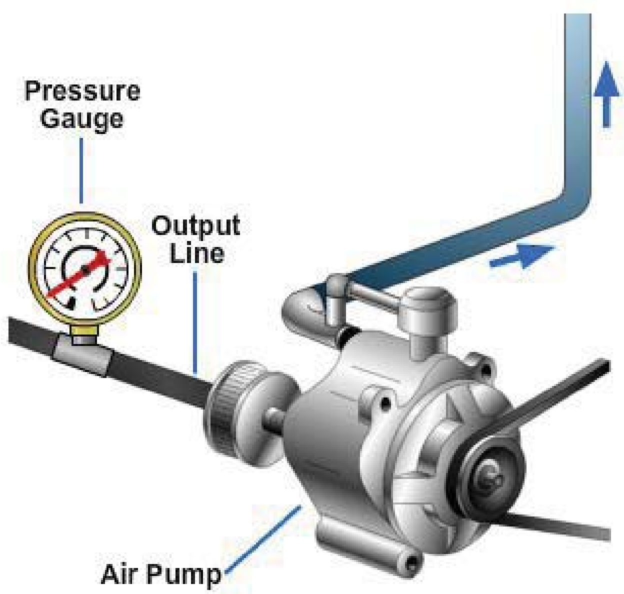

Figure 5-131 – A pressure gauge can be used to check air pump output.

Replace the pump if faulty. When testing the diverter valve or other air injection system valves, refer to the service manual. It will explain testing procedures for the specific components.

Catalytic Converter. A catalytic converter oxidizes (burns) the remaining HC and CO emissions that pass into the exhaust system. Extreme heat (temperatures of approximately 1400°F) ignite these emissions and change them into harmless carbon dioxide and water.

A catalyst is any substance that speeds a chemical reaction without itself being changed. A catalytic converter contains a catalyst agent, usually the elements platinum, palladium, rhodium, or a mixture of these materials. Platinum and palladium treat the HC and CO emissions. Rhodium acts on the NO_x emissions. Some newer converters also use cerium to extract and release additional oxygen into the exhaust stream.

The converter's catalyst agent is coated on either a ceramic honeycomb-shaped block or small ceramic beads. The catalyst is encased in a stainless steel housing that is designed to resist heat. The catalyst operating temperature is attained when the catalyst agents are hot enough (above 300°F) to start treating emissions.

Types of Catalytic Converters. A catalytic converter using a ceramic honeycomb catalyst is often termed a monolithic converter, as shown in *Figure 5-132*. Monolithic catalytic converters use a honeycomb-shaped block of ceramic material covered with catalytic elements to treat exhaust gases. The catalyst is enclosed in a stainless housing. When small ceramic beads are used, it is called a pellet catalytic converter, as illustrated in *Figure 5-133*.

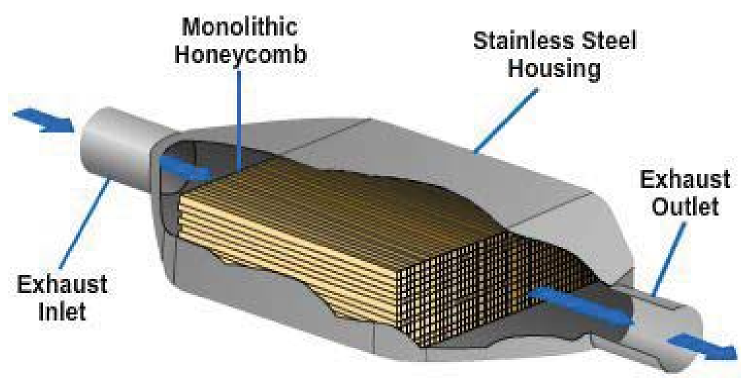

Figure 5-132 - Monolithic catalytic.

A mini catalytic converter is a very small converter placed close to the engine exhaust manifold. It heats up very quickly to reduce emissions during engine warm-up. A mini catalytic converter is used in conjunction with a larger, main converter, as illustrated in *Figure 5-134*.

A two-way catalytic converter, sometimes called an oxidation converter, can only reduce two types of exhaust emissions (HC and CO). A two-way converter is normally coated with platinum.

A three-way catalytic converter, also termed a reduction-type converter, is capable of reducing all three types of exhaust emissions (HC, C, and NO_x). A three-way converter is usually coated with rhodium and platinum.

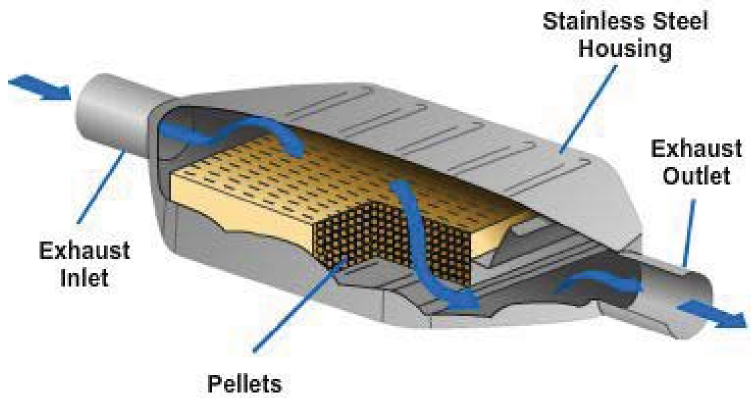

Figure 5-133 – Pellet type catalytic.

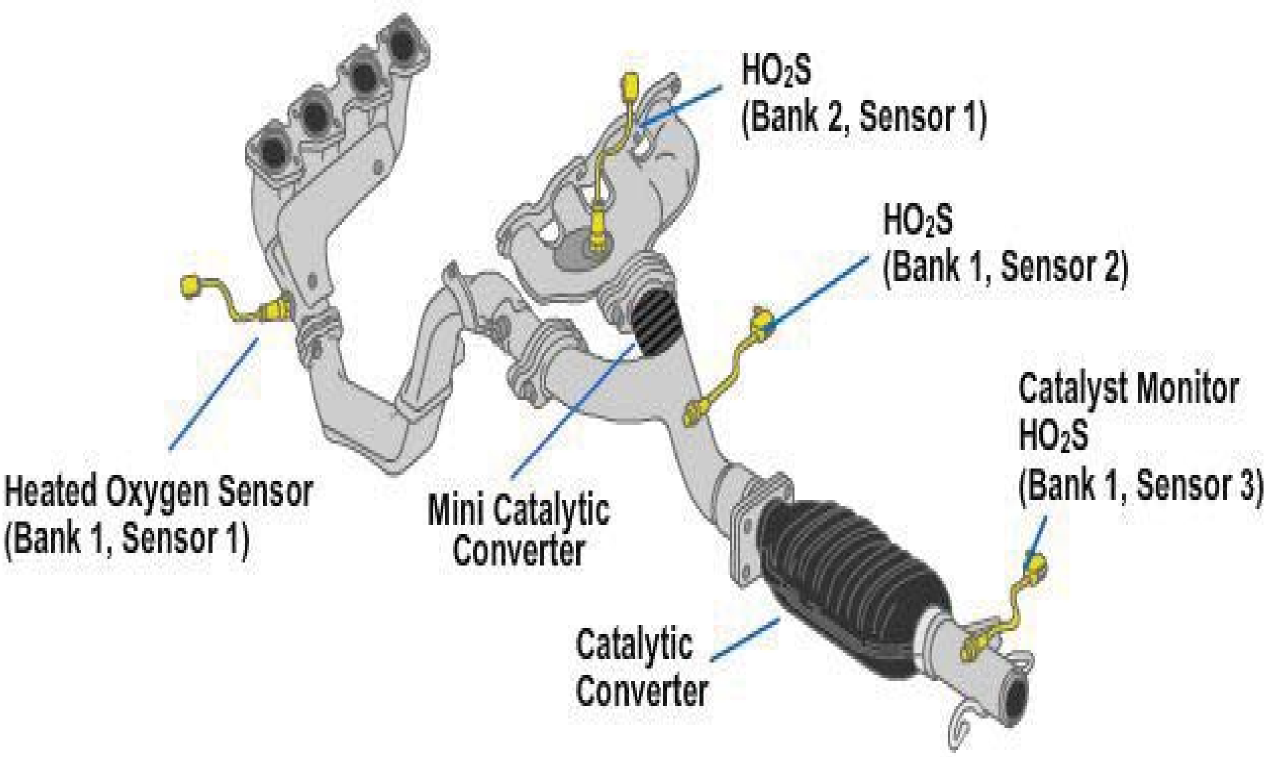

Figure 5-134 - This engine is equipped with a mini catalytic converter and a main converter.

A dual-bed catalytic converter contains two separate catalyst units enclosed in a single housing. A dual-bed converter normally has both a three-way (reduction) catalyst and a two-way (oxidation) catalyst. A mixing chamber is provided between the two. Air is forced into the mixing chamber to help burn the HC and CO emissions, as illustrated in *Figure 5-135*.

Dual-Bed Catalytic Converter Operation. When the engine is cold (below approximately 128°F), the air injection system routes the air into the exhaust manifold. Exhaust heat and the injected air are used to burn exhaust emissions. When the engine warms, the system forces air into the catalytic converter, as illustrated in *Figure 5-136.*

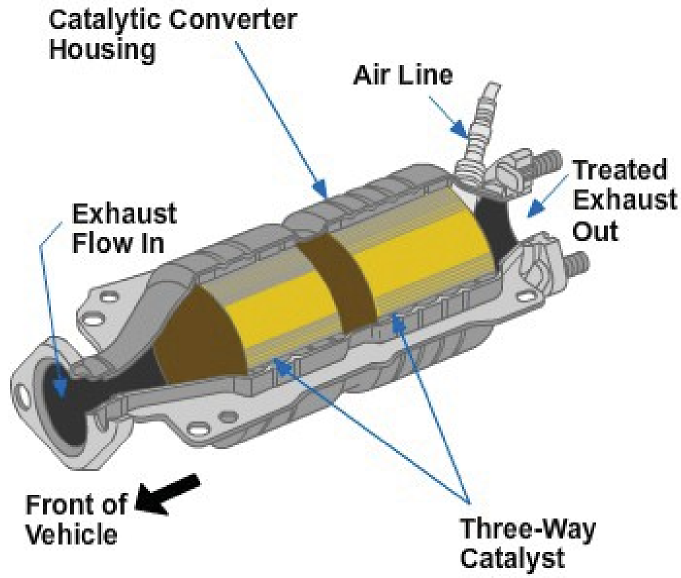

Figure 5-135 – Cutaway of a dual-bed catalytic converter.

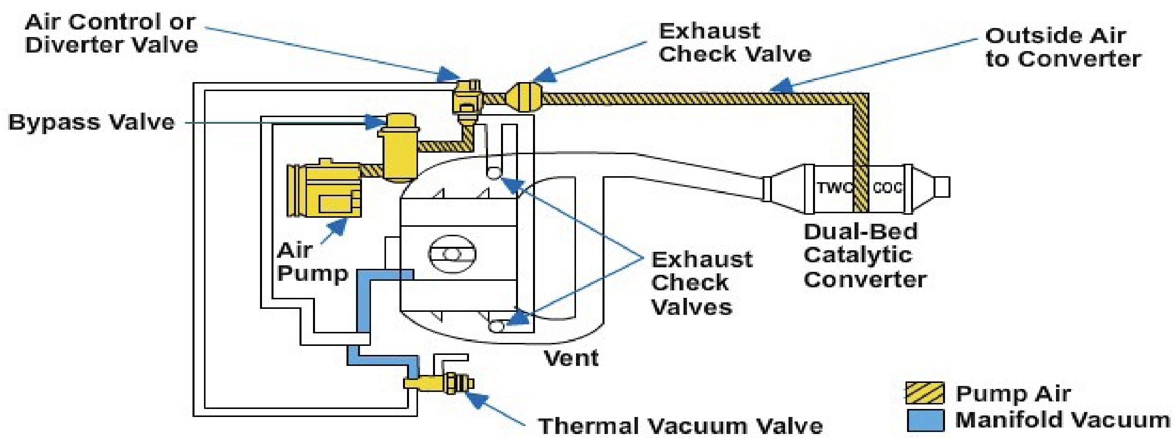

Figure 5-136 - Diagram shows how an air pump forces oxygen into a dual-bed catalytic converter.

First, the exhaust gases pass through the front three-way catalyst that removes HC, CO, and NO_x. Then, the exhaust gas flows into the area between the two catalysts. The oxygen in the air flowing into the chamber causes the gases to continue to burn. The exhaust flows into the rear two-way catalyst, which removes even more HC and CO.

Some catalysts are coated with a material that absorbs and temporarily stores NO_x emissions. When a saturation level is reached, the on-board computer temporarily enriches the fuel mixture. This causes the converter's internal honeycomb block to glow red hot, breaking up the stored NO_x emissions into harmless by-products.

Catalytic Converter Service. Catalytic converter problems are commonly caused by contamination, overheating, and extended service. A clogged catalytic converter, resulting from deposits or overheating, can increase exhaust system back pressure.

High back pressure decreases engine performance because gases cannot flow freely through the converter.

A clogged catalytic converter is a fairly common problem. The increased back pressure will reduce engine power considerably. You may notice a rotten egg odor at the tailpipe. A clogged converter can also overheat, possibly causing a fire.

An exhaust back pressure test will check for a clogged catalytic converter and other system parts. Remove the front oxygen sensor and install a pressure gauge into the threaded hole, as shown in *Figure 5-137*.

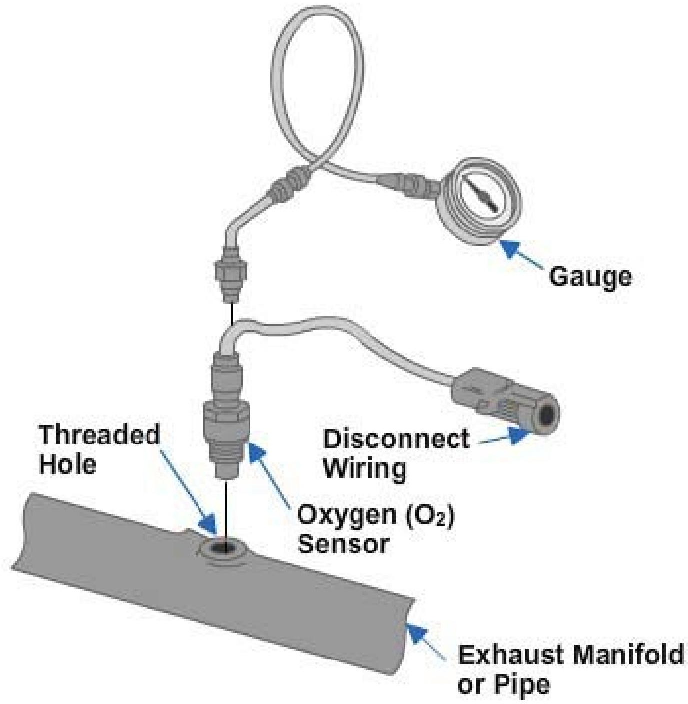

Figure 5-137 -Testing the exhaust system's back pressure.

Start the engine and read the pressure gauge at idle and at higher speeds. If the pressure gauge reads too high, the converter, muffler, or an exhaust pipe is restricted. To isolate the exhaust restriction, disconnect parts one at a time. When the back pressure drops, the source of the restriction is found.

After extended service, the catalyst in the converter can become coated with deposits. Those deposits can keep the catalyst from acting on the hydrocarbon, carbon monoxide, and oxides of nitrogen. The inner baffles and shell can also deteriorate. With a pellet-type catalytic converter, this can allow BB-size particles to blow out the tailpipe.

Pellet catalytic converters normally have a plug that allows replacement of the catalyst agent. The old pellets can be removed and new ones installed. If the converter housing is damaged or corroded, replace the converter. Monolithic (honeycomb) catalytic converters must be replaced when the catalyst becomes damaged or contaminated.

Testing Catalytic Converter Efficiency. An exhaust gas analyzer can be used to check the general condition of the catalytic converter. Follow the specified directions provided with the analyzer. Warm and idle the engine. With some systems, it may be required to disable the air injection or pulse air system before performing the test. Measure the oxygen and carbon monoxide at the tailpipe.

If oxygen readings are above approximately 5%, you know there is enough oxygen for the catalyst to burn emissions. However, if the carbon monoxide readings are still above about 0.5% (other systems operating properly), then the catalytic converter is not oxidizing the emissions from the engine and the converter or catalyst requires replacement.

The scan tool can be used to diagnose catalytic converter problems on OBD II vehicles. The catalytic converter's condition is monitored by measuring its oxygen sensors-a pre-converter sensor and a post-converter sensor. Under normal conditions, the pre-converter oxygen sensor switches frequently and the post-converter sensor seldom switches. The pre-converter sensor switches more frequently because it "smells emissions," while the post-converter sensor "sniffs" cleaner gases.

Catalytic Replacement. To install new pellets in a catalytic converter, follow service manual instructions. It is required to use a special vibrating tool to shake the old pellets out of hole in the converter. Then, new pellets are installed and the service plug is replaced in the converter housing. This procedure is not used frequently since it is faster and easier to simply replace the catalytic converter.

⚠ WARNING ⚠

Remember that the operating temperature of a catalytic converter can be over 1400°F. This is enough heat to cause serious burns. Do not touch a catalytic converter until it is determined it has cooled.

Catalytic Converter Replacement. On many vehicles, the converter can be unbolted from the exhaust system. Remove the clamps that secure the converter to the exhaust pipes. Then, use a muffler cutter or a chisel to cut or loosen the old converter from the exhaust pipes. Hammer blows to the converter should then free it from the vehicle.

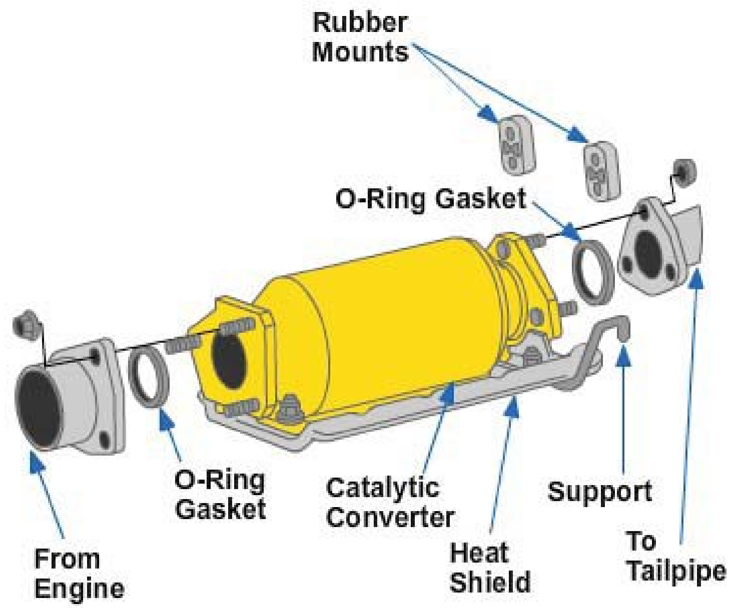

Figure 5-138 – Exploded view of a catalytic converter installation.

Sometimes the catalytic converter is an integral part of the header pipe. With this design, the converter and pipe may have to be replaced together. When installing the new converter, use new gaskets and reinstall all heat shields, as demonstrated in *Figure 5-138*.

After replacing a catalytic converter, turn in the old converter to be recycled. The platinum and other precious metals are valuable.

Computerized Emission Control Systems. A computerized emission control system uses various engine sensors, a three-way catalytic converter, an ECM, electronic fuel injection, and other computer-controlled components to reduce pollution levels from the vehicle.

The ECM analyzes data from the many vehicle systems to monitor closely and control any function that can affect emissions.

Oxygen Sensors. The oxygen sensor monitors the exhaust gases for oxygen content. The amount of oxygen in the exhaust gases is a good indicator of the engine's operational state. The oxygen sensor's voltage output varies with any changes in the exhaust's oxygen content. For example, an increase in oxygen, which would indicate a lean mixture, will make the sensor output voltage decrease. A decrease in oxygen, which occurs during the rich mixture conditions, causes the sensor's output voltage to increase, as diagramed in *Figure 5-139*.

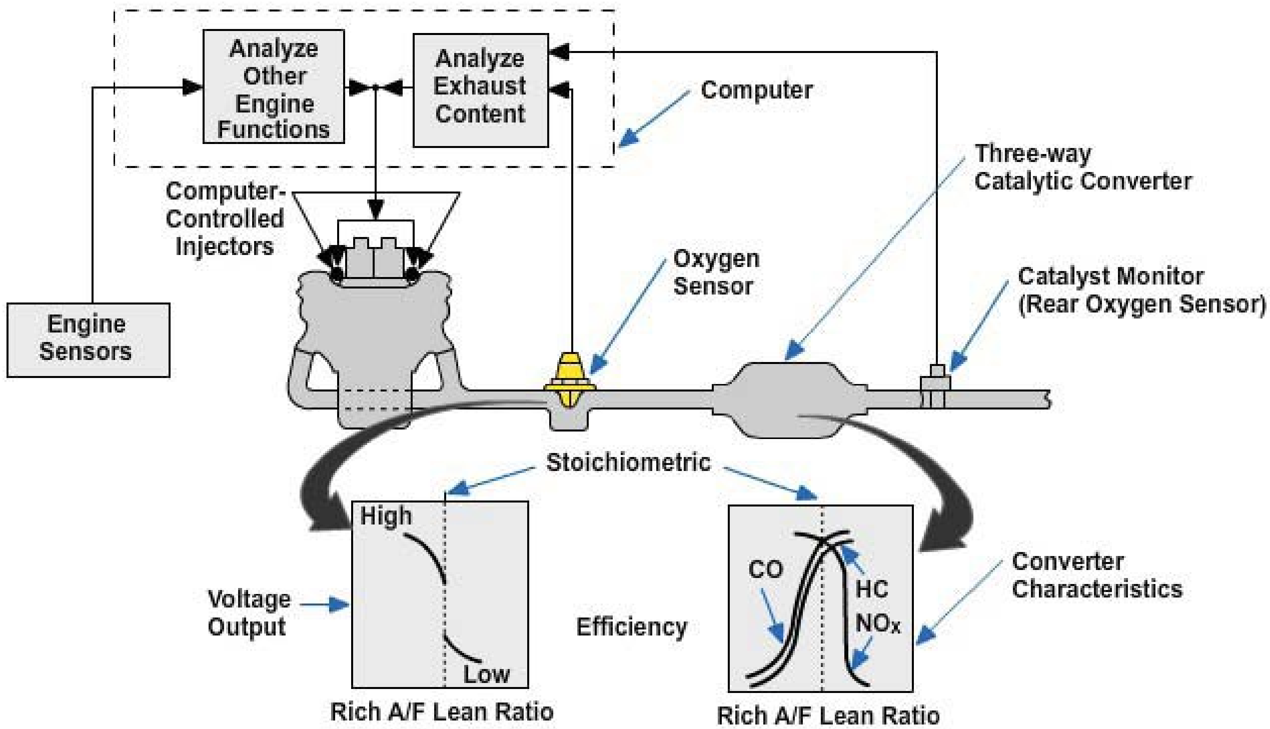

Figure 5-139 - Diagram oxygen sensor monitoring system.

In this way, the oxygen sensor supplies data to the computer. The computer can alter the opening and closing of the injectors to maintain a correct air-fuel ratio for maximum efficiency.

Primary and Secondary Oxygen Sensors. Newer vehicles are equipped with multiple oxygen sensors. The number of sensors used depends on the engine application.

A primary oxygen sensor, also termed front O_2 sensor, is used to monitor the oxygen in the exhaust gases as they leave the engine. The signal from the primary sensor indicates whether the engine's air-fuel mixture is lean or rich. All primary sensors are located before, or in front of, the catalytic converters, usually as close to the engine as possible.

A secondary oxygen sensor, or rear O_2 sensor, is mounted downstream in the exhaust system. Depending on its location downstream, the rear oxygen sensor can either be used to check the exhaust gases for oxygen content before the catalytic converter or monitor the converter for proper operation. Any O_2 sensor mounted after a converter is referred to as a catalytic monitor.

Oxygen Sensor Position. Oxygen sensor position in the vehicle is assigned a number by its location and order in relation to the engine's banks. The sensor closest to the number one cylinder is denoted as Oxygen sensor, Bank 1, Sensor 1. If the engine is equipped with only one oxygen sensor, which is the case with OBD I vehicles, it is referred to as Oxygen sensor, Bank 1, no matter where it is located in the exhaust system. If the engine is a V-type, sensors located in the other bank are considered to be located on Bank 2. Sensors further down the exhaust stream from the engine are consecutively numbered as Sensor 2, Sensor 3, and so on, as shown in *Figure 5-140*. In almost all cases, the sensor with the highest number, such as Sensor 3, is the catalyst monitor.

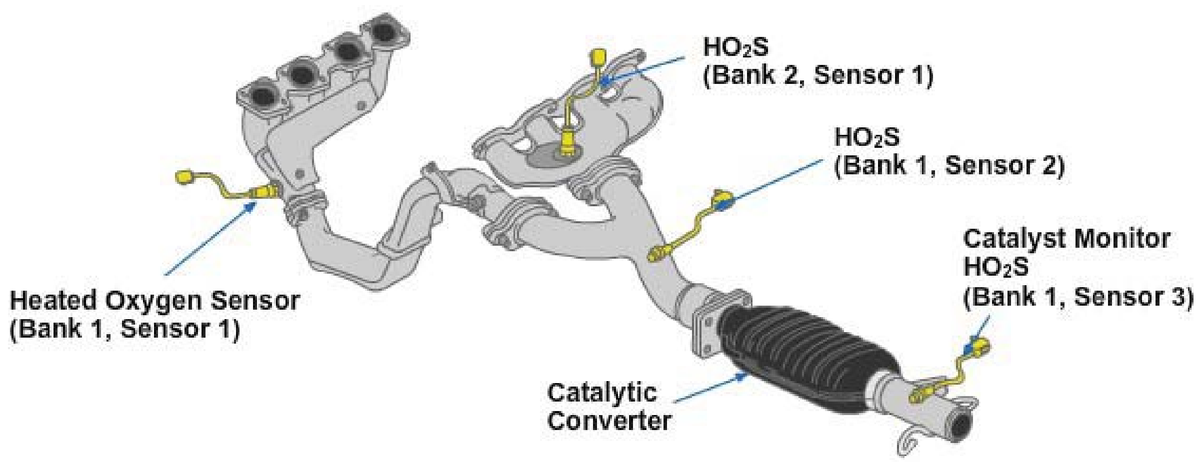

Figure 5-140 - Oxygen sensor location and identification.

Heated Oxygen Sensors. A heated oxygen sensor (HO_2S) uses an electric element to quickly warm the sensor to operating temperature. The heating element also stabilizes the temperature and operation of the sensor. The heating element allows the computer system to use the input signals sooner.

Zirconia Oxygen Sensor. Most heated O_2 sensors are also called zirconia oxygen sensors because of their active materials. Zirconia and platinum are commonly used to produce the voltage output that represents oxygen in the exhaust gases. The platinum coating on the sensor surface causes any unburned fuel to ignite, which helps the sensor to maintain a high operating temperature. At any operating temperature of about 600°F, the oxygen sensor's element becomes a semiconductor and generates a small voltage. *Figure 5-141* is an example of a heated zirconia oxygen sensor.

The zirconia oxygen sensor has an inner cavity that is exposed to the atmosphere. Since the earth's atmosphere consists of approximately 21% oxygen, this percentage serves as a reference for the amount of oxygen in the exhaust gases. The outer surface of the oxygen sensor is exposed to the exhaust gases. The outer surface serves as the positive connection of the sensor circuit. The inner cavity of the sensor serves as the negative connection, or ground.

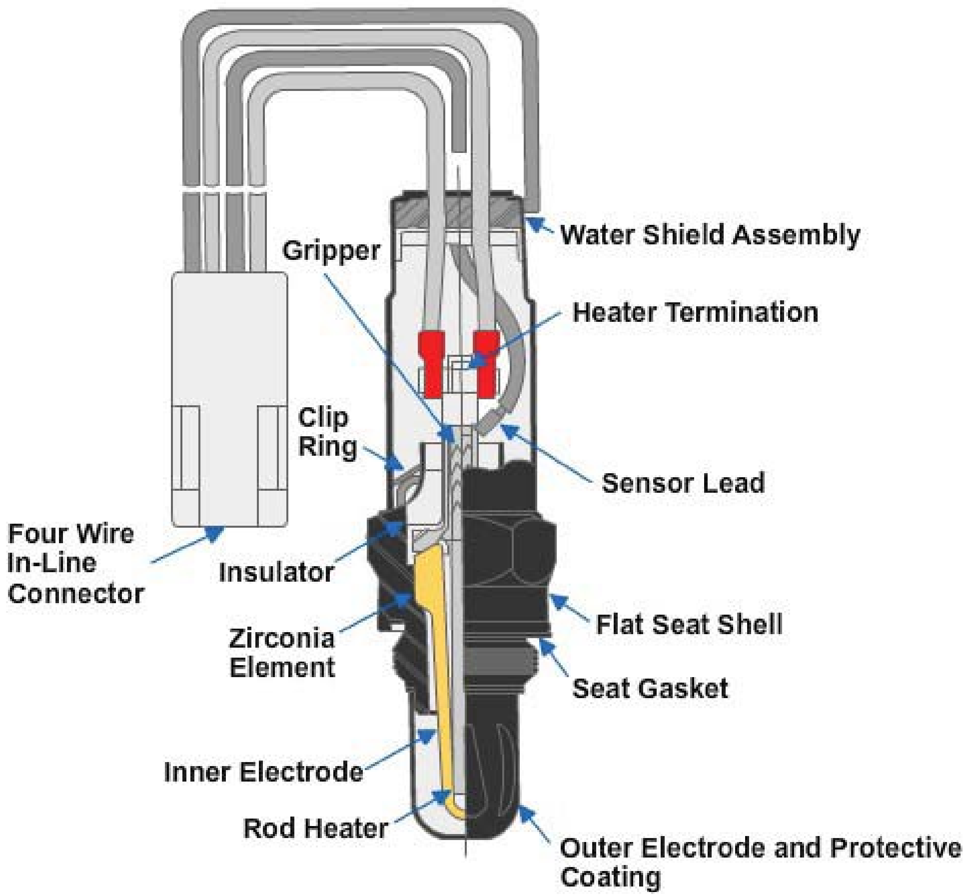

Figure 5-141 – Cutaway view showing the internal parts of a heated zirconia oxygen sensor.

The difference between the oxygen content in the inner cavity and the oxygen content of the exhaust gases flowing over the sensor's outer surface causes the sensor to generate a voltage. The ECM compares the voltage produced by the sensor to a reference voltage of approximately 450 millivolts (0.45 volts).

For example, if the engine's air-fuel mixture is too rich, there will be almost no oxygen in the exhaust gases. This creates a large difference in oxygen content between the sensor's surfaces and causes the sensor to generate a voltage of about 600 millivolts (0.6 volts). This would inform the ECM to lean the mixture to reduce emissions.

With a lean air-fuel mixture going to the engine, there will be a smaller difference in oxygen content between the sensor's inner and outer surfaces. The sensor will generate a weaker voltage signal of about 300 millivolts (0.3 volts). The ECM will then enrich the fuel mixture and try to maintain a stoichiometric (chemically correct) air-fuel mixture.

Planar Oxygen Sensors. Vehicles are equipped with plannar zirconia oxygen sensors. These sensors work the same way as conventional zirconia sensors, but the zirconia element, electrodes, and heater are combined in a flat, laminated strip, as illustrated in *Figure 5-142.* The design of this type of sensor makes it more resistant to contamination and vibration than conventional zirconia sensors. Planar sensors also light-off, or reach operating temperature, in about 10 seconds, allowing the computer control system to enter closed loop twice as fast as systems with conventional heated oxygen sensors. This significantly reduces cold-start hydrocarbon emissions.

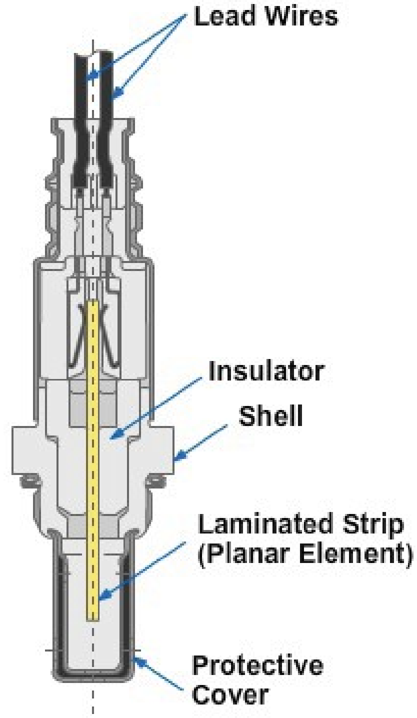

Figure 5-142 – Cutaway of a planar oxygen.

Titania Oxygen Sensors. A few vehicles are equipped with titania oxygen sensors. The main difference between titania sensors and zirconia sensors is the way they produce their output signals. Zirconia sensors generate their own voltage signals. Titania oxygen sensors, on the other hand, vary their internal resistance to modify a reference voltage.

Titania sensors offer several advantages over zirconia sensors. They provide an oxygen content signal almost immediately after cold startup, eliminating the need for a heating element. Titania sensors are smaller than zirconia sensors and are manufactured as sealed units, making them less susceptible to outside contamination.

During operation, a constant reference voltage is sent from the ECM to the titania sensor's positive terminal. As the oxygen content of the exhaust changes, the resistance of the sensor also changes (*Figure 5-143*). The amount of resistance formed in the sensor determines the sensor's voltage drop to a

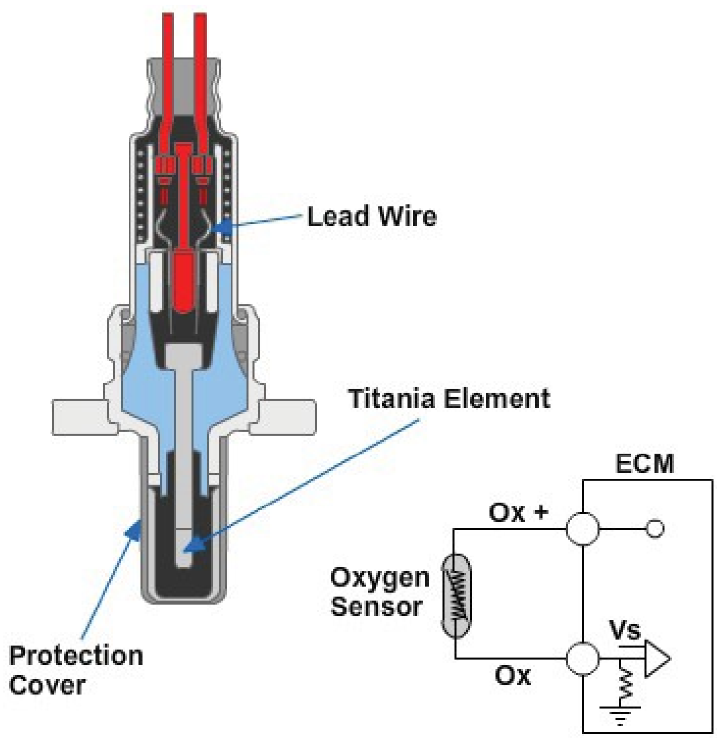

Figure 5-143 - A-Cutaway view of a titania oxygen sensor and basic circuit.

predetermined value; the ECM knows that the air-fuel mixture is too rich. If the sensor's voltage drop is below the predetermined value, the ECM knows the mixture is too lean. In either case, the control module can adjust fuel injection pulse width accordingly. *Figure 5-143, View B* is a diagram of a basic circuit from the titania oxygen sensor to the ECM.

Wide-Band Oxygen Sensors. There are vehicles equipped with wide-band oxygen sensors. As the air-fuel ratio changes, the wide-band oxygen sensor generates an internal voltage. The sensor then converts this voltage into a current. When the air-fuel ratio is lean, the current moves in the positive direction. When the air-fuel is rich, the current moves in the negative direction.

Unlike conventional oxygen sensors, which simply toggle their output voltage abruptly to indicate a lean or rich condition, the output of the wide-band sensor changes gradually and is directly proportional to the oxygen content of the exhaust gases. This makes it possible for the ECU to determine the exact air-fuel ratio at points other than stoichiometer, leading to more accurate control of the air-fuel ratio.

Oxygen Sensor Service. After prolonged service, oxygen sensors become coated or fouled with exhaust by-products. As this happens, fuel economy and emissions may be adversely affected. If gas mileage is 10% to 15% lower than normal, suspect a lazy oxygen sensor. A lazy O_2 sensor will not alter its output signal fast enough to maintain an efficient air-fuel ratio. The sensor will be slow to change its voltage or resistance with changes in exhaust content. *Figure 5-144* provides a quick reference for emission control system diagnosis.

A bad oxygen sensor will affect engine performance and emissions. If it does not work properly, fuel metering will be too lean or too rich. A bad rear oxygen sensor (catalyst monitor) may not detect an inoperative catalytic converter. A dead O_2 sensor has little or no resistance or voltage output change. Even when the exhaust content changes, the sensor's signal remains almost constant.

Testing Oxygen Sensors. Most O_2 sensor problems will trip a trouble code with OBD I and OBD II systems. However, there are times when an oxygen sensor will be close to but not out of its operating parameter and will not trip a trouble code. Even if the scan tool shows a problem with the O_2 sensor, pinpoint tests will also be needed to verify the source of the trouble.

If the scan tool readout shows that the O_2 sensor output voltage is abnormal, you might want to measure the sensor's output voltage with a multimeter. An oscilloscope can also be used to check the signal leaving the O_2 sensor. When testing a titania oxygen sensor, it may also be necessary to check the reference voltage supplied by the ECM, as well as the sensor's resistance or voltage drop. Refer to the service manual for details.

By comparing actual voltage (zirconia-type sensor) or resistance levels (titania-type sensor) to scan tool readout values and manufacturer's specifications, it can be determined whether the sensor, wiring, or ECM is at fault.

If using a dual trace scope (scope has two test leads and can display two separate wave forms at once), you can compare the signals from the front and rear oxygen sensors on OBD II vehicles. If the voltage levels from the sensors are too similar, you may have a faulty catalytic converter.

If having trouble isolating an oxygen sensor-related problem, refer to the factory service manual. It will give specific information to help find the source of the problem Testing methods for wide-band oxygen sensors are similar to those for conventional oxygen sensors. Again, refer to the manufacturer's service manual for specific instructions, as testing methods may vary.

Oxygen Sensor Replacement. If the oxygen sensor is defective, first disconnect the negative battery cable. Then, separate the sensor from the wiring harness by unplugging the connector. Never pull on the wires themselves, as damage may result. Spray the sensor threads with a generous coat of penetrating oil. Use a special sensor socket to remove the sensor from the exhaust system, Use care to avoid thread damage. Inspect the sensor for signs of contamination.

Obtain and install the correct replacement oxygen sensor. Start the sensor by hand and then tighten the sensor with a wrench socket. Do not overtighten and damage the sensor during installation. Reconnect the wire connector and check system operation.

Emission Control System Diagnosis		
Condition	**Possible Causes**	**Correction**
Excessive hydrocarbon reading	1. Poor cylinder compression 2. Leaking head gasket 3. Ignition misfire 4. Poor ignition timing 5. Defective input sensor 6. Defective output sensor 7. Defective ECU 8. Open EGR valve 9. Sticking or leaking injector 10. Improper fuel pressure 11. Leaking fuel pressure regulator 12. Oxygen sensor contaminated or responding to artificial lean or rich condition 13. Improperly installed fuel filler cap	Test components. Service or replace as necessary.
Excessive carbon monoxide reading	1. Plugged air filter 2. Engine carbon loaded 3. Defective sensor 4. Defective ECM 5. Sticking or leaking injector 6. Higher than normal pressure regulator 7. Leaking fuel pressure regulator 8. Oxygen sensor contaminated or responding to artificial lean or rich condition	Test Components. Service or replace as necessary.
Excessive hydrocarbon and carbon monoxide readings	1. Plugged PVC valve or hose 2. Fuel-contaminated oil 3. Heat riser stuck open 4. Air pump disconnected or defective 5. Evaporative emissions canister saturated 6. Evaporative emissions purge valve stuck open 7. Defective throttle position sensor	Test Components. Service or replace as necessary.
Excessive oxides of nitrogen	1. Vacuum leak 2. Leaking head gasket 3. Engine carbon loading 4. EGR valve not opening 5. Low fuel 6. pressure 7. Low coolant level 8. Defective cooling fan or fan circuit 9. Oxygen sensor grounded or responding to an artificial rich condition 10. Fuel contaminated with excess water	Test Components. Service or replace as necessary.
Excessively low carbon dioxide reading	1. Exhaust system leak 2. Defective input sensor 3. Defective ECU 4. Sticking or leaking injector 5. Higher-than-normal fuel pressure 6. Leaking fuel in	Test Components. Service or replace as necessary.
Low oxygen reading	1. Plugged air filter 2. Engine carbon loaded 3. Defective input sensor 4. Defective ECU 5. Sticking or leaking injector 6. Higher-than-normal fuel pressure 7. Leaking fuel pressure regulator 8. Oxygen sensor contaminated or responding to artificial lean condition 9. Defective evaporative emission system valve.	Test Components. Service or replace as necessary.
High oxygen reading	1. Vacuum leak 2. Low fuel pressure 3. Defective input sensor 4. Exhaust system leak	Test Components. Service or replace as necessary.

Figure 5-144 - Emission control system diagnosis quick reference.

Diesel Particulate Filters (DPFs). Diesel particulate filters have been around for a number of years usually in special applications, such as a garbage packer, required to operate inside for long periods of time. On this type of application, they were usually known as particulate traps. A DPF will be found on every highway diesel engine meeting 2007 emissions and beyond. A DPF is an aftertreatment device designed to eliminate soot produced by the engine cylinder combustion process.

There are three general types of DPFs in use:

1. **Catalyzed.** This is the most common type of DPF. It is built into the aftertreatment canisters that also contain multistage catalytic converters and what used to be known as the muffler. Catalyzed DPFs will be found on most highway trucks and are capable of both passive and active regeneration cycles.
    a. A **passive (diesel) particulate filter**, as illustrated in *Figure 5-145,* is a standard, ceramic honeycomb structure with alternate plugged channels. A catalyst is typically upstream of the filter but may be integrated into it. In certain cases, a washcoat layer of catalytic material may be placed on the filter in addition to the catalyst.

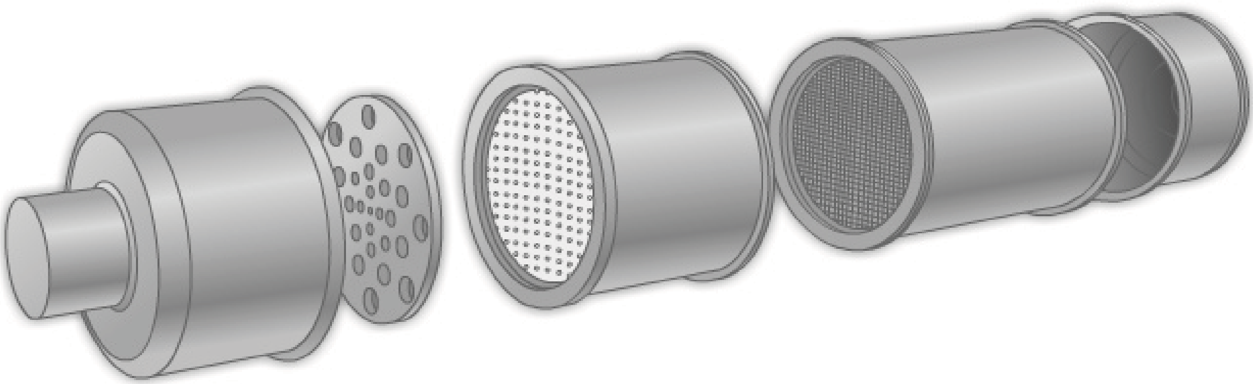

Figure 5-145 - Passive (diesel) particulate.

Passive particulate filter systems rely exclusively on chemistry to regenerate. As carbon moves through the exhaust, it is trapped by the particulate filter. That filter begins to build up with carbon and other residual exhaust species, which have also become trapped. This will continue until conditions become favorable for the elements to combust internally off the filter surface. The heat for this regeneration comes from the thermal energy that occurs naturally with exhaust temperatures of typical diesel engines.

    b. **Active particulate filters** are generally used in instances where passive particulate filters will not work because there are not sufficient natural activation energy levels to achieve regeneration.

Active particulate filters rely on outside energy sources. In an active particulate filter, the particulate matter is trapped as it works its way through the exhaust. The control system then activates the regeneration process by auxiliary means, which raises the temperature enough to activate the chemical reaction. Active regeneration is technically possible in several ways.

2. **Noncatalyzed.** This type of DPF is required in diesel-powered vocational vehicles that are operated under low engine loads for long periods. Typical applications are cement trucks, fire trucks, and garbage packers. Non catalyzed DPFs may only be capable of active regeneration cycles that require the vehicle to be stopped.

3. **Low temperature particulate filters**. These are usually aftermarket devices fitted to pre-2007 highway diesels. Many have been fitted to school buses. While being capable of significantly reducing PM, they usually do not achieve this to EPA 2007 standards.

DPF Operating Principles. The idea behind a DPF is that engine-emitted soot first collects on the walls of the device. Engine manufacturers design DPFs to function primarily in self-regeneration mode. This means that when soot collection reaches a threshold level, it is burned off in what is known as a regeneration cycle. In most cases, the regeneration cycle will occur when exhaust temperatures are sufficiently high during normal operation. When this regeneration takes place unassisted by additional fuel or air injection to the exhaust gas, it is known as self-regeneration.

Self-regeneration is also known as passive regeneration. The terminology varies by engine OEM.

Operating temperatures of the combined oxidation converter and PDF can exceed 1112°F, so most of these devices have plenty of heat shielding. Depending on the engine and its power rating, both single and duel canister versions are used. Typically, single and dual canisters are specified by horsepower rating as follows:

- Single canister: up to 600 BHP
- Dual canister: over 600 BHP

Active Regeneration. When the operating environment is not conducive to a self-regeneration cycle, regeneration can also occur when assisted by injection of some fuel ignited by a spark plug or induced high exhaust temperatures. This mode of regeneration is known as active regeneration. Fuel for an active regeneration cycle is usually sourced from the fuel subsystem and delivered at the specified charging pressure. Most diesel engine OEMs are using similar DPF but they are managed in different ways.

Frequency of Cycles. Regeneration cycles are designed to occur at set intervals. These set intervals may be as often as once every hour, or as frequently as once every 8 hours of operation, depending on the engine, its power ratings, and how the engine is being operated. Operators should be informed about the expected intervals of the regeneration cycles of the equipment they operate. During both passive and active regeneration, there will be an increase in exhaust gas temperatures.

Ash Residues. Regeneration leaves some ash residues. These ashes primarily originate from the additive package in the engine lube that is burned in the cylinder during normal combustion. Ash residues have to be removed manually. Federal law requires that this cleaning process occurs no more frequently than once a year or every 150,000 miles (whichever comes first).

Temperature Monitoring. Temperature monitoring is by dual and single thermocouples (pyrometers). A thermocouple has a hot end and a sensing end. Two dissimilar wires, one being pure iron and the other constantin wire that is 55 percent copper and 45 percent nickel, are arranged to form a circuit. They are wound together at the hot end, as illustrated in *Figure 5-146*. When the hot end is exposed to heat, a small voltage is created. This small voltage is read by a millivoltmeter at the sensing end and displayed in temperature values. Thermocouple devices must be replaced as a complete unit when diagnosed as failed. The DPF is a complex assembly within which the regeneration cycles and temperatures have to be precisely managed.

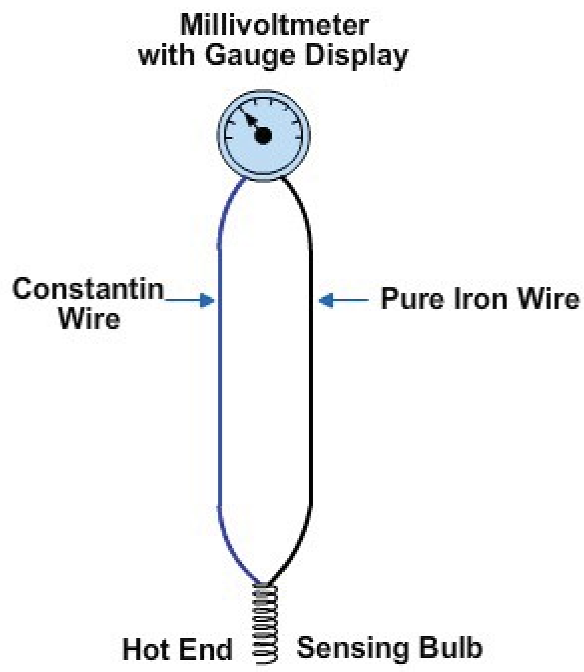

Figure 5-146 – A pyrometer.

High Exhaust Pyrometer Readings.

1. Install a master pyrometer (do not rely solely on the vehicle pyrometer).
2. Chassis dynamometer test using a full instrumentation readout.

A pyrometer is an operator's instrument as much as it is the mechanic's. A complaint of high pyrometer readings without other symptoms may be an indication that the operator requires some additional training. The operator should consider a pyrometer reading approaching its maximum as a signal to downshift gear ratios.

Some possible causes and solutions are:

- Air inlet restriction: test inlet restriction value to specification using a manometer.
- Flow restricted, boost air heat exchanger: check air flow through the heat exchanger located at the front of the chassis. Check the operation of a tip turbine if equipped.
- High engine load, low flow operation: engines using air-to-air boost air cooling require air flow through the heat exchanger. A dump truck with air-to-air boost cooling operating in a pit in extreme heat may produce high pyrometer readings, even when operated skillfully.
- Fuel injection timing: check to specification.
- Overfueling: look for other indications of an overfueling condition and check fuel settings to specification.

DPF Cleaning Station. Most of the engine OEMs state that their DPFs will require routine in-shop cleaning using special equipment. Although some early systems could be cleaned while on chassis, all current systems require out-of-chassis cleaning stations. This high-flow-back pressurizes the system for a period of around 20 minutes.

The total time the PDF cleaning procedure usually takes less than 2 hours. *Figure 5-147* shows a DPF cleaning system.

CAUTION

An appropriate respirator should be worn when servicing DPF components. Submicron ash particulate is known to cause respiratory problems.

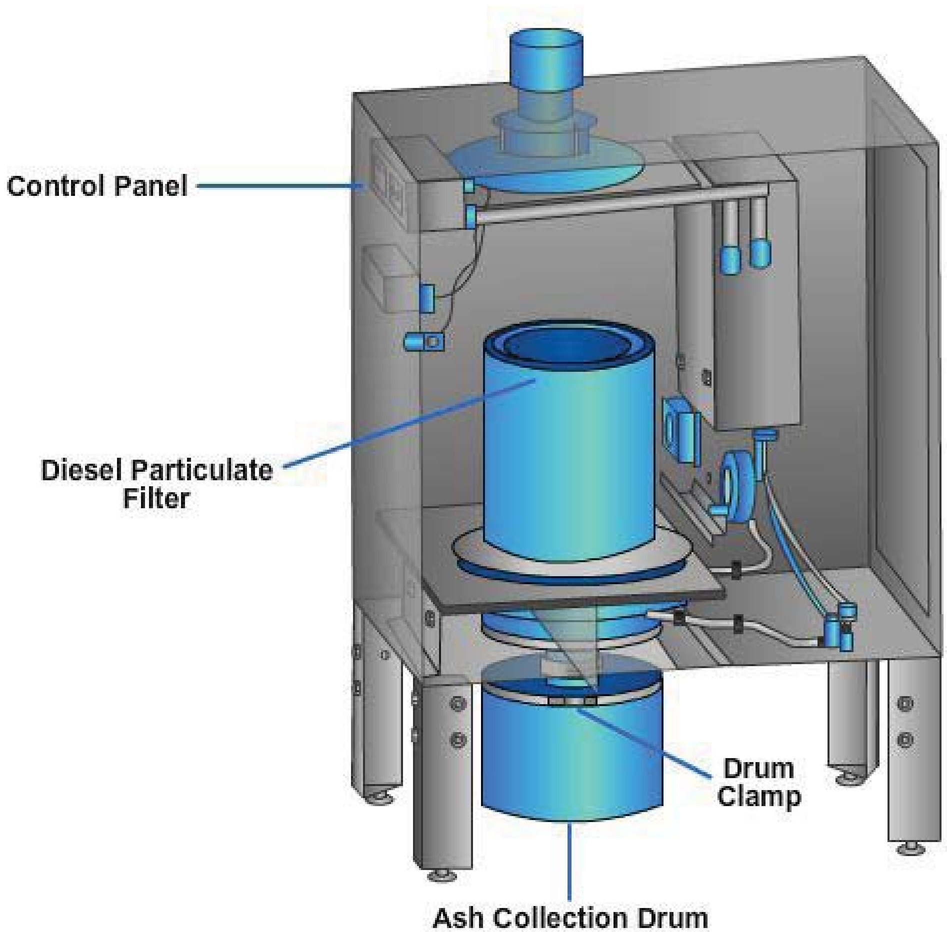

Figure 5-147 - Diesel particulate filter cleaning system.

Selective Catalytic Reduction (SCR). Like DPF, Selective Catalytic Reduction is also an exhaust gas aftertreatment process. While the DPF addresses particulate HC, an SCR system attempts to "reduce" oxides of nitrogen back to nitrogen and oxygen. Although the SCR has been used in Europe for a decade, the EPA did not approve SCR use until 2007. The reason for the reluctance on the part of the EPA in approving SCR systems is that to function, this type of system depends on using a "consumable," specifically urea. The urea that is in aqueous form has been routinely refilled, just like fuel. This means that the EPA approval required some conditions.

Aqueous Urea. SCRs use consumable urea to achieve what rhodium does in gasoline-fueled engines. Urea is composed of crystallized nitrogen compounds sourced from natural gas. The urea, in a solution with water, is known as aqueous urea. It is also referred to as diesel exhaust fluid, or DEF. It is a nontoxic solution of 67.5 % deionized water and 32.5% automotive grade urea. It is stable, odorless, colorless, and meets accepted international standards for purity and composition. The aqueous urea is injected into the exhaust gas stream by a computer-controlled injection system. After injection, the urea reduces to ammonia, which itself reacts with NO_x compounds, reducing them back to oxygen and nitrogen.

Selective Catalytic Reduction Management. SCR is managed by the engine ECM. The urea is contained in aqueous/water form in a replenishable vessel. It is injected upstream from the converter/DPF/muffler assembly sometimes assisted by on-chassis compressed air. The urea injection has to be precisely metered by the ECM. Too much urea can result in ammonia discharge through the exhaust system, while too little results in NO_x emissions. *Figure 5-148* shows a schematic of SCR components and operation.

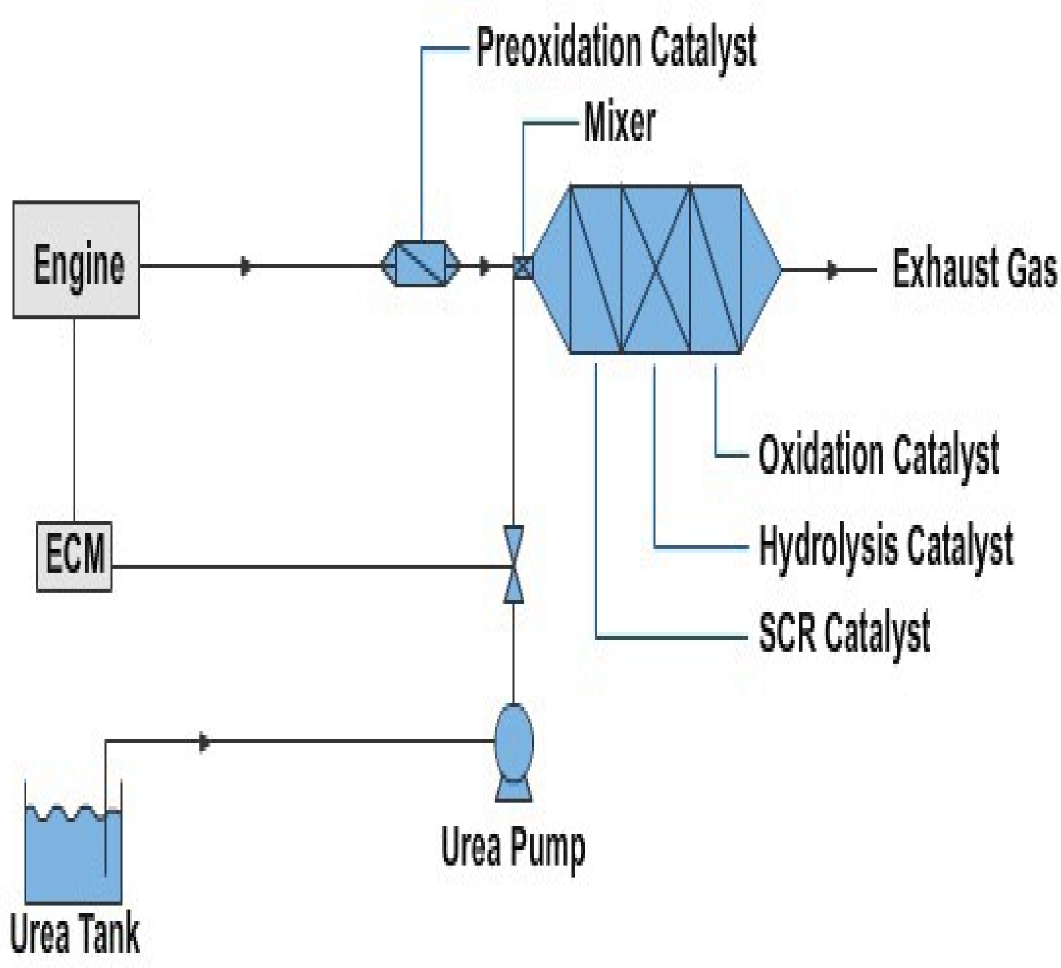

Figure 5-148 - Schematic of a selective catalytic reduction components and operation.

Urea is carried onboard the truck in tanks with capacities ranging from 20 to 50 gallons. An aqueous urea solution freezes at 12°F, so it must be freeze-protected in winter operation. The urea is consumed at a rate that varies between approximately 1.5 percent and 10 percent of the fuel used, the variability depending on how the engine is being operated, that is, how much NO_x has to be reduced.

Closed Crankcase Ventilation (CCV). Highway diesel engines meeting 2007 emissions standards are required to have closed crankcase ventilation systems, as shown in *Figure 5-149.* CCV is the diesel engine equivalent of automotive positive crankcase ventilation (PCV) systems. The objective of a CCV system is to prevent venting to atmosphere of crankcase gases. Crankcase gases consist of:

- Blowby gas from engine cylinders
- Blow-off gases from lubricant

Figure 5-149 – Cutaway of a Closed Crankcase Ventilation System.

CCV Operation. Diesel CCV systems can be directly compared with PCV circuits used on automobiles. The system is plumbed upstream from the turbocharger impeller housing so that some pull is exerted on the crankcase. The CCV piping is routed through a filter assembly and may be located on top of the rocker housing cover. OEM recommendations for CCV service intervals should be observed.

CCO Injectors. Elimination or reduction of nozzle sac volume in hydraulic injection injectors reduces the cylinder boil/dribble of sac fuel at the completion of injection. This nozzle design principle is used in all injectors.

Charge Air Cooling. Effective cooling of intake air lowers combustion temperatures, making it less likely that the nitrogen in the air mixture oxidized to form NO_x. Air-to-air charge air coolers cool air more effectively than those that relied on engine coolant. Note that anything that compromises the charge air cooler's ability to cool will result in higher NO_x emissions. This is why codes are logged when charged air heat exchangers become plugged.

Variable Geometry Turbochargers VGT). Variable geometry turbochargers that perform effectively over a much wider load and rpm range can make a significant difference to both HC and NO_x emissions, especially when ECM controlled, by providing the ability to manage boost on the basis of the fueling and emissions algorithms. VGTs are used rather than constant geometry turbochargers in almost every 2007-compliant highway diesel engine. When a constant geometry turbocharger is used today, it is usually as one of the pair used in series turbocharged engines.

Low Headland Volume Pistons. Low headland volume pistons raise the upper compression ring close to the leading edge of the piston crown. This keeps the headland gas volume close to minimum. Headland gas volume tends to be unclean and can increase HC emissions. The requirement for low headland volume pistons by engine designers has resulted in some radical design changes in diesel engine pistons within a short period of time. Most diesel engine manufacturers today favor trunk-type pistons, such as the Mahle Monotherm®, which features low headland volumes, as shown in *Figure 5-150*. Although forged steel trunk pistons have been around for quite some time, primarily in drag racing, they have evolved to being used in diesel engine technology. The advantages of forged steel trunk pistons are reduction of headland volume, thermal expansion, long life, and lightweight.

Opacity Meters. Opacity meters measure visible smoke emissions. They are simple to use and require that the unit's sensor head probe be fitted to the outlet of the exhaust pipe. Two different types are used:

1. Partial flow
2. Full flow

In the partial flow type, during the test procedure, a portion of the exhaust gas flow is diverted to a sensing chamber, in which the opacity of the smoke can be read by the opacity measurement directly at the stack outlet.

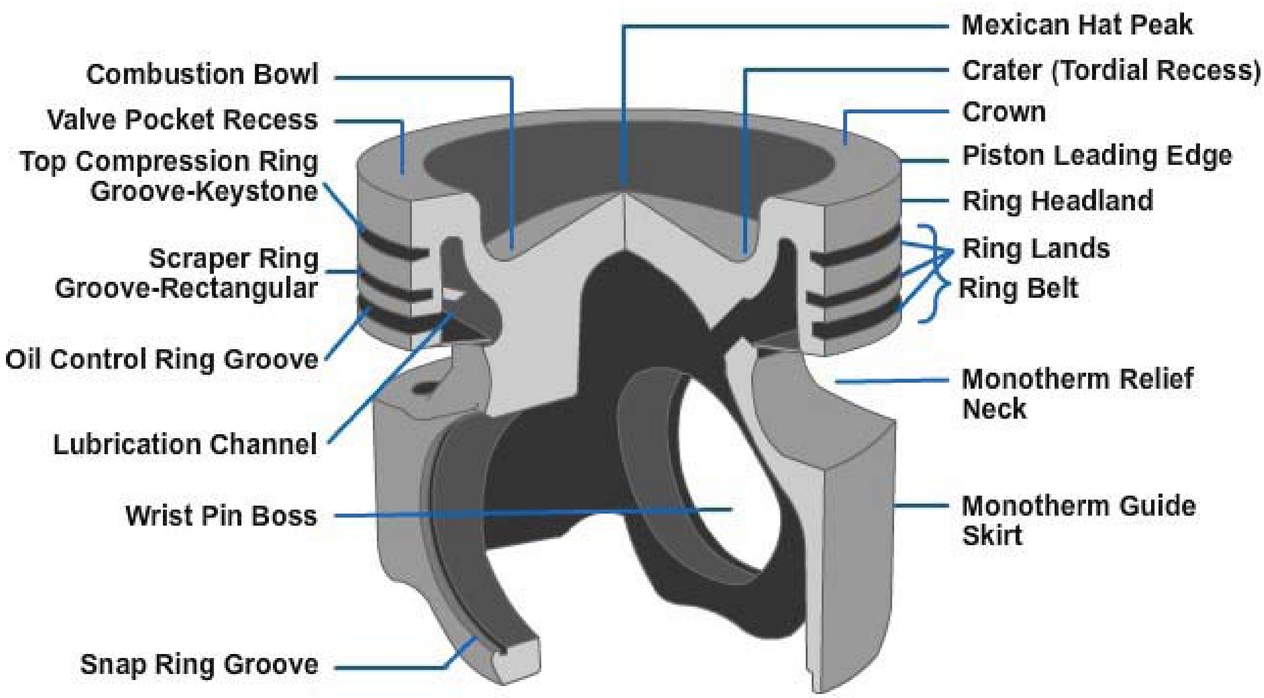

Figure 5-150 - Cutaway view of a forged steel trunk Mahle Monotherm® piston.

Light Extinction. Partial and full flow opacity meters are classified as light extinction test instruments. A beam of light from a light-emitting diode (LED) is directed at a photo diode sensor through the exhaust gas. The amount of light blocked from the photo diode sensor (by smoke) is determined by the density of the engine exhaust. The higher the density, the less light can pass through the smoke to be read by the sensor. Smoke density is expressed as percentage reading by the opacity meter. In most cases, the opacity meter is equipped with an extension handle for the sensor head, so the device can be placed at the exhaust stack outlet by the mechanic working at the ground.

Opacity meter readings are displayed in percentages. The actual readings vary according to engine horsepower and the diameter of the exhaust pipe(s). Most should produce accurate results regardless of weather conditions, and many will record the data electronically. Data recorded by the opacity meter can be hard-copy printed or transferred to PC- or Web-based systems for analysis. Any opacity meter can be used to evaluate smoke density in diesel smoke. Those used for official testing and to enforce compliance must be approved and have PC-managed and logged test sequences.

Weather Conditions. Weather conditions can have some impact on smoke density, and changes in air density influence the operation of any internal combustion engine. For this reason, SAE J1667 imposes restrictions on the environmental conditions during the administration of an "official" snap acceleration test.

Environmental Conditions. The following environmental conditions are required when performing a J1667 test:

- Temperature in the test area must be between 35°F and 86°F.
- Testing must not take place outdoors when there is visible precipitation, such as rain, snow, or fog.
- Testing must not take place when the temperature is at or below the dew point, such as during fog or high-humidity conditions.
- Vehicles using downward-direction exhaust systems should be tested over ground surface conditions that are not dusty so that dirt particulates are not combined with the exhaust gas being measured.

Snap Test. Each J1667 throttle snap consists of a three-phase cycle that must be precisely executed by the person doing the test:

1. Accelerator is snapped to high idle and held for 1 to 4 seconds or until prompted by the opacity meter to release.
2. Engine rpm must be allowed to drop to the specified idle speed.
3. Engine must run at the specified low idle for a minimum of 5 seconds and a maximum of 45 seconds before initiating the next snap, as prompted by the opacity meter.

SAE J1667 Test Cycle. The SAE J1667 test cycle consists of four phases and, again, these must be precisely executed:

1. Preliminary Snaps. Three full snaps are required to clear the exhaust system of loose particles and to precondition the vehicle.
2. Official snaps. Three official snaps should be undertaken, as prompted by test instrument software.
3. Validation. The difference between the highest and lowest maximum opacity readings of the three official test snaps should be within five opacity percentage points. If the difference is less than 5 percent, the meter software will compute the average. If the difference is greater than 5 percent, additional official snaps must be undertaken up to a maximum of nine.
4. Drift factor. Validation is required that the drift (rpm at full pedal travel) between three official test cycles does not exceed 2 percent opacity. A variation greater than ±2 percent will result in an invalid test. This is not a tough spec to meet: 2 percent of 2,000 rpm translates to 40 rpm.

Stack Dimensions. Exhaust pipe diameter has an effect on the opacity reading of exhaust gas. Before undertaking a snap test, the diameter of the exhaust stack has to be known. For instance, an engine that tests at 30% opacity when tested with a 3-inch exhaust stack will only measure 20% opacity when tested with a 5-inch tailpipe. This is why you have to input the stack diameter into the opacity meter.

Although there are exceptions because horsepower rating usually determines the stack diameter, it is recommended that the horsepower rating be inputted into the opacity test instrument before the exhaust pipe diameter. Horsepower rating is often specified on the engine ID plate or in the electronic service tool (EST) accessible read-only data.

Any truck diesel engine that fails an opacity snap test has a severe smoking problem, one that could not pass unnoticed under any circumstances. The way we see smoke depends on the state of the emission. All matter has three states: vapor or gaseous, liquid, and solid. It is possible to emit matter in all three states from a diesel engine tailpipe.

Black Smoke. The term black smoke is used to describe anything from grayish tinge, in exhaust smoke, to heavily sooted emission. It is the result of the incomplete combustion of fuel and therefore has many causes.

- **Insufficient Combustion Air.** The causes for insufficient combustion air are air starvation caused by any defect in the air intake system from the air filter, turbocharger, or boost air/heat exchanger through to intake valve problems; clogged cylinder sleeve ports (two-stroke cycle engines); restricting emergency stop gate; and so forth. Check for a problem that can be read electronically first in electronically managed engines. Test the intake air inlet restriction using a water manometer. The specifications should be checked to the OEM values, but typical maximum values will be close to:
  - 15" H_2O vacuum-naturally aspirated engines
  - 25" H_2O vacuum-boosted engines
- **Exhaust System Restriction.** Exhaust system restriction causes are turbocharger failure, collapsed exhaust system piping, internal failure of engine silencer or catalytic converter, or a clogged particulate trap.
- **Excess Fuel/Irregular Fuel Distribution.** Excess fuel/irregular fuel distribution is caused by injection timing, defective pump-to-injector piping, injector nozzle failure, variable timing control device, failure, unbalanced fuel rack settings, lugging engine (operation at high loads at speeds below peak torque rpm), incorrect governor settings, inoperative or tampered with manifold boost management system, or defective barometric capsule(altitude compensator).
- **Improper Fuel Grade.** When fuel is stored for prolonged periods, the more volatile fractions evaporate, altering the fuel's chemical characteristics. Additionally, fuel suppliers seasonally adjust fuel to accommodate temperature extremes. Use of used engine lube/fuel mixers often produces smoking. Heavier residual oils may not vaporize, and if they do, there is insufficient time to properly combust them. This practice may cause high acidity in the exhaust gas (high sulfur), which may rust out exhaust systems unusually quickly. Ensure that the engine lube/fuel mixer permits the engine to meet the emission standards for the year the engine was manufactured.

Blue Smoke. Blue smoke is usually caused by lube oil getting involved in the combustion process.

Some possible causes are turbocharger seal failure, roots blower seal failure, pullover of lube oil from oil bath air cleaner sump, worn valve guides, ring failure, glazed cylinder liners, high oil sump level, excessive big end bearing oil throe-off, low-grade fuel, fuel contaminated with automatic transmission fluid (ATF), or engine lube placed in fuel tanks as an additive.

White Smoke. White smoke is caused by condensing liquid in the exhaust gas steam. Temperature usually plays a role when white smoke is observed, both ambient temperature and the engine-operating temperature. Remember that water is a natural product of the combustion of any hydrocarbon fuel and in mid-winter conditions, it is normal for some of this to condense in the exhaust gas. However, when the white smoke is a problem, the following are some of the possible causes:

- **Cylinder Misfire.** Check for a problem that can be read electronically first on electronically managed engines; perform an electronic cylinder cutout test using a PC or ProLink if that option is in the software diagnostics. With nonelectronic engines, short out the injectors in sequence using a rocker claw/lever for MUI and PT injectors, and by cracking (loosening) the line nut high-pressure pipes in pump line nozzle systems.
- **Low Cylinder Compression Pressure.** Overall low and unbalanced cylinder compression can create problems of excessive blowby, low power, and vibration. Cylinder pressure may be checked using a compression tester. In diesel engines, the compression test should be performed when the engine is close to operating temperature by first removing all of the injectors, fitting the compression test gauge to the injector bore in one of the cylinders, and then cranking through five rotations. The batteries should be fully charged during the test. Test each cylinder sequentially and match the test results to specifications. The results should be within the engine OEM cylinder compression parameters and normally within 10% of each other. Compression testing will locate which cylinder or cylinders are at fault, but not the cause of the problem. A cylinder leakage or air test kit sometimes stands a better chance of identifying the cause of a problem. The cylinder leak test consists of a pressure regulator and couplings that fit to the injector bores. Once again, the engine should be close to its operating temperature at the beginning of the test. The test is performed with the piston in the cylinder to be tested at TDC and regulated air pressure is delivered to the cylinder. The test may indicate valve seal leaks, head gasket leaks, leaks to the water jacket, leaking piston rings, and defective pistons. The cylinder leakage test regulator delivers air at a controlled volume and pressure, then measures the percentage of leakage.
- **Low CN Fuel.** Low CN fuel may produce white smoke. Test the fuel-specific gravity by using a fuel hydrometer and compare to the fuel supplier's specifications. Consult the fuel supplier as to the correct additive and proportions to correct a CN deficiency in a storage tank.
- **Air Pumped Through the High Pressure Injection Pump Circuit.** Check the fuel subsystem because this is usually the source of the air, depending on the type of system. This condition is normally accompanied by a rough engine operation.
- **Coolant Leakage to Cylinders.** Confirm that the emission truly is coolant. Engine coolant has an acrid, bittersweet odor that is very noticeable. Locate the source. Some possibilities are injector cup failure, head gasket (fire ring) failure, cracked cylinder head, cracked wet liner flange, or cavitation perforation of wet

liner. Coolant leakage may be difficult to locate; if the failure is not immediately evident, drop the oil pan, pressurize the cooling system, and observe. If necessary, place clean cardboard under the engine with the cooling system pressurized and leave for awhile to attempt to identify the source; this may save an unnecessary engine disassembly. It is often easier to identify an internal coolant leak with the engine intact rather than disassembled, so explore all the options with the engine assembled first.

- **Low Combustion Temperatures.** Low combustion temperatures may be the result of extreme low temperature conditions or a fault in the cooling system management system, such as a defective thermostat, fan drive mechanism, or shutters.

Summary

This chapter has provided information for the construction mechanic in the overhauling and troubleshooting fuel systems for automotive, construction, and support equipment.

In the chapter, you were introduced to gasoline fuel injection systems, which primarily spoke of the throttle body. You then covered small engine carburetors, which are primarily used with support equipment and gasoline power tools.

You covered the various diesel fuel injection systems, covering such components as injectors, fuel pumps, and governors, along with the air induction systems that included superchargers and turbochargers. Additionally, the principles of the diesel engine cold starting devices, such as glow plugs and ether, were covered.

Lastly, you learned the components, purpose, and troubleshooting of the emission system.

Review Questions (Select the Correct Response)

1. Gasoline injection system has several advantages over a carburetor-type fuel system except for___________.

   A. Increased engine power
   B. Better fuel distribution
   C. Higher emissions
   D. Improved atomization

2. The fuel injector for an EFI system is simply what?

   A. a coil- or solenoid-operated fuel valve
   B. a regulated fuel injector
   C. a coil- or diode-operated fuel tap
   D. a fuel valve only

3. Generation two oxygen sensors are installed where?

   A. Only one before the catalytic converter
   B. One before or one after the catalytic converter
   C. One at the fuel injector and one before the catalytic converter
   D. One before the catalytic converter and one after

4. **(True or False)** The oxygen sensor functions immediately when the vehicle is started.

   A. True
   B. False

5. Which sensor is important for determining computer output?

   A. manifold absolute pressure sensor
   B. Throttle position sensor
   C. Engine coolant temperature sensor
   D. Airflow sensor

6. Which sensor sends an electronic signal proportional to the pressure inside the rail to the ECU?

   A. Fuel pressure sensor
   B. Fuel temperature sensor
   C. Fuel injection sensor
   D. Intake air temperature sensor

7. The throttle body injection has___________.

   A. One or two injectors delivering diesel fuel from one central point in the intake manifold
   B. One or two injectors delivering gasoline from multiple points in the intake manifold
   C. One or two injectors delivering gasoline from one central point in the intake manifold
   D. One injector delivering gasoline to two central points in the intake manifold

8. **(True or False)** On the throttle body injection system, the fuel injector is a cam-operated fuel valve.

   A. True
   B. False

9. What is the most common type of service performed on gasoline fuel injection systems?

   A. Preventive
   B. Interim
   C. Injector
   D. Depot

10. Any pressure less than atmospheric pressure is generally referred as what?

    A. combustion
    B. flow
    C. vaporization
    D. vacuum

11. The narrowed portion of the carburetor is known as what?

    A. venturi
    B. bernoulli
    C. throttle
    D. vortex

12. Which component of the carburetor holds the fuel for use by the different metering circuits?

    A. metering tube
    B. bowl vent
    C. fuel container
    D. fuel passages

13. **(True or False)** The bowl vent may be an external or internal type.

    A. True
    B. False

14. What is the component that connects the carburetor's bowl to the engine side of the throttle plate?

A. high-speed air bleed
B. idle passage
C. idle air bleed
D. bowl vent

15. Which carburetor system lifts the diaphragm both mechanically and pneumatically?

A. choke
B. primer
C. emission
D. enrichment

16. When using the model number of a Briggs & Stratton carburetor, which number is used to identify the type of carburetor?

A. first
B. second
C. third
D. fourth

17. **(True or False)** On a Vacu-Jet carburetor, multiple fuel pickup tubes are one of the design features.

A. True
B. False

18. The final adjustment on a Vacu-Jet carburetor specifies what rpm?

A. 1675
B. 1700
C. 1750
D. 1775

19. What three components on the Pulsa-Jet carburetor serve the same functions as the gravity feed tank, float, and float chamber on a conventional float-type carburetor?

A. Primer, choke, and fuel tube
B. Fuel tank, fuel pump, and constant level fuel chamber
C. Fuel cup, fuel diaphragm, and constant fuel passage
D. Fuel tank, fuel injector, and constant fuel level float

20. How is the fuel pump actuated on the Pulsa-Jet fuel carburetor?

A. Changes in pressures in the air horn or throat
B. Pulses of air in the fuel nozzle
C. Changes in pressures in the fuel tank
D. Steady pressures in the air horn or throat

21. In a Pulsa-Jet carburetor, the diaphragm separates the air compartment and spring from what compartment?

A. Venturi
B. Oil
C. Lubrication
D. Fuel

22. In a Pulsa-Jet carburetor, what is one the design variations?

A. Adjustable and non-adjustable jets in the fuel pickup
B. Non-integral venturi
C. Non-vented fuel tanks
D. Choke plate shaft dust stop

23. What component does the wet bulb primer eliminate the need of on the Pulsa-Prime carburetor?

A. Manual choke
B. Automatic choke
C. Pump diaphragm
D. Automatic fuel pump

24. Why would you remove the main air jet air bleed on a Pulsa-Jet Prime carburetor?

A. High-altitude compensation
B. Low-altitude compensation
C. Do not really need it
D. Never remove it

25. **(True or False)** The automatic choke on the Vacu-Jet and Pulsa Jet carburetors is opened by atmospheric pressure in front of the venturi.

A. True
B. False

26. During your automatic choke inspection and after going through all the procedures, what may be the cause for the engine to run at idle when you adjust the mixture so lean that the engine should stop and the needle valve is closed?

A. Air leak at the diaphragm
B. Fuel leak in the venturi
C. Fuel leak at the diaphragm
D. Pump spring stuck

27. For the Bimetal choke, the springs have been color coded according to their _______.

A. Function
B. Gauge
C. Length
D. Strength

28. What is the feature related to the Flo-Jet carburetor relating to fuel feed?

A. Gravity fed
B. Pressure fed
C. Vacuum fed
D. Pump fed

29. Once removing the packing nut and high-speed needle valve, what tool do you use to remove the nozzle?

A. Tapered screwdriver
B. Un-tapered screwdriver
C. Phillips screwdriver
D. Needle-nose pliers

30. What is one of the causes for carburetor leak on a Flo-Jet carburetor that is typically caused by transport?

A. Float-bind
B. Float-freeze
C. Float-jump
D. Float-bounce

31. **(True or False**) Lapping compound to remove corrosion is one of the options restore a nozzle of a two-piece Flo-Jet carburetor.

A. True
B. False

32. Which carburetor has the ability to be used regardless of the position of the fuel tank?

A. Flo-Jet
B. Diaphragm without pump
C. Diaphragm with pump
D. Pulsa-Jet

33. In a diaphragm pump, what type of tip may the inlet needle have to resist exotic fuels and wear?

A. Viton
B. Brass
C. Rubber
D. Carbon steel

34. What is required to start a cold engine with a diaphragm pump?

A. Lean fuel mixture
B. Choke wide open
C. Throttle half open
D. Rich fuel mixture

35. Why is it imperative for a proper seal of the pump gasket between the fuel intake chamber, pulse chamber, and the inlet and outlet valve area on a diaphragm pump?

A. To prevent cross-leaking
B. To prevent air choke
C. To prevent fuel choke
D. To prevent oil leak

36. When reinstalling the inlet needle/fulcrum spring, which is a tedious procedure, you can use what type of grease to help the process?

A. Axle
B. Lithium-based
C. Bearing
D. Teflon-based

37. During the initial adjustment of a diaphragm pump, after closing the high-low speed mixture needles, what is the next procedure?

A. Turn them clockwise to unseat them.
B. Turn the idle screw about 1Ii-turns.
C. Turn the screws outward about 1Ii-turns.
D. Turn the screws inward about 1Ii-turns.

38. If you do not have the specification settings available for the final adjustments of the diaphragm carburetor, you can set the idle between what rpm.

A. 1500 and 2000
B. 2000 and 2500
C. 2500 and 3000
D. 3000 and 3500

39. The main components of a fuel injection pump using a sleeve metering fuel system is___________.

A. The housing, plunger, and bushing
B. The body, barrel, and filter
C. The plunger, sleeve, and casing
D. The barrel, plunger, and sleeve

40. In a Caterpillar sleeve metering fuel injection system, fuel injection begins at what point?

A. As the plunger moves upward and closes the inlet port
B. As the plunger moves downward and closes the inlet port
C. As the barrel moves upward and closes the inlet port
D. As plunger moves upward and closes the outlet port

41. After normal start-up, at what rpm does the governor take over in a Caterpillar sleeve metering fuel injection pump?

A. 300
B. 400
C. 500
D. 600

42. The type governor that will most likely be found on a Caterpillar bulldozer is __________.

A. A limiting speed governor
B. A variable speed governor
C. A constant speed governor
D. A wavering speed governor

43. **(True or False)** An over run occurs when the governor allows the engine to exceed its maximum rated speed.

A. True
B. False

44. Hunting or surging is a continuous engine speed fluctuation and can be controlled by a/an___________.

A. Adjustable spring
B. Bumper screw
C. Adjustable screw or bumper screw
D. Adjustable screw or bumper spring

45. A Stanadyne pump has its own mechanical___________.

A. Plunger
B. Head
C. Sleeve
D. Governor

46. What regulates the volume of fuel in the hydraulic head?

A. Metering valve
B. Cam ring
C. Intake valve
D. Metering port

47. In the Stanadyne pump, before reaching the transfer pump the fuel must pass through which components?

A. A water separator and inlet ports
B. A water separator only
C. A water separator and primary fuel filter
D. A water separator and secondary fuel filter

48. When the engine is running, the pump rotates and fuel is pulled into the end plate by the___________.

A. Bypass valve
B. Transfer pump
C. Pump piston
D. Plunger

49. In the discharging cycle of the distributor injection pump, as the rotor continues to revolve, the inlet passages move out of alignment with the charging ports. What happens next?

A. The rotor closes the discharge port to the heads inlet.
B. Fuel is trapped between the plungers.
C. The rotor discharge port opens one of the heads outlets.
D. The rotor injection port closes one of the heads inlets.

50. What keeps the lines full of fuel so that a full charge of fuel can be injected at the next cycle for a cylinder after the discharging cycle?

A. Rotor
B. Delivery port
C. Distributor valve
D. Delivery valve

51. When fuel pressure decreases because of reduction in the engine speed, fuel from the position area drains through the orifice below what to allow the cam ring to retard?.

A. Ball check valve
B. Ball relief valve
C. Retard cam
D. Cam ring valve

52. During the mechanical governor operation of the distributor injection pump, the flyweights transmit force through the thrust valve, causing the lever to __________.

A. Move upward
B. Pivot
C. Rotate
D. Alternate

53. The governor may be equipped with a/an___________housed within the governor control cover.

A. Electrical rotor
B. Mechanical shut-off device
C. Hydraulic shut-off device
D. Electrical shut-off device

54. **(True or False)** Some energized-to-run systems employ a mechanical override device for emergency use if the coil becomes inoperative due to electrical failure.

A. True
B. False

55. What are some of the causes for low pressure in the transfer pump?

A. Restricted fuel supply or air leaks on the suction side of the pump
B. Worn transfer pump blades or a malfunctioning regulator valve
C. Both A and B

56. When you are testing a Stanadyne fuel injection pump, a reading of how many inches of vacuum indicates a restricted fuel supply?

A. 7
B. 8
C. 9
D. 10

57. Each time a fuel injection pump is overhauled, which of the following parts is/are always replaced?

A. Springs
B. Seal Seats
C. O-rings and seals
D. Timing plate

58. Of all the fuel injection systems, what was most readily adaptable of all the fuel injection systems to electronic control?

A. Electronic element injectors
B. Electronic unit injectors
C. Electrical fuel insertion
D. Electronic component module

59. In the Delphi EUI, what component is a solenoid consisting of a coil and armature with an integral poppet control valve?

A. Control cartridge
B. Control cylinder
C. Plunger
D. Pump element

60. The actuator components of the electronic unit injection system use what kind of action to create the pressures needed for injection?

A. Hydraulic
B. Electronic
C. Mechanical
D. Fluid

61. What happens when the solenoid on the EUI is energized and its armature is pulled upward, closing the poppet valve and descending the plunger?

A. Creates a rapid rise in pressure within the fuel supply chamber
B. Causes a decrease in pressure within the fuel supply
C. The spray tip assembly receives air to mix with the fuel
D. Creates a rise in air pressure

62. **(True or False)** An electronic unit injector's start and duration of injection is controlled by the pulse width from the ECM.

A. True
B. False

63. On the Stanadyne electronically controlled distribution pump, if one or two sensors fail, the engine will run only at limited power. If all three sensors fail, the engine will___________.

A. Idle down and stop
B. Run only at idle
C. Increase idle
D. Run normally

64. Which manufacturer developed the pressure-timed fuel injection system?

A. Cummins
B. Caterpillar
C. Detroit Diesel
D. International Harvester

65. In reference to the PT fuel system, what does the T refer to?

A. Time elapsed between injections
B. Time for fuel to flow into injector body
C. Time between piston strokes
D. Time available for the fuel to flow into the injector cup

66. Which of the following is not a function of the pressure-time governed fuel pump?

A. Control of exhaust smoke during acceleration
B. Idle and maximum speed governing
C. Rail pressure to the injectors
D. Startup of the engine

67. What type of governor is installed in a PT fuel pump?

A. Simple flyweight-operated electronic governor
B. Simple flyweight-operated mechanical governor
C. PT pump is unique not having a governor
D. The governor is mounted on the engine separate form pump

68. The engine's power output can be controlled by the operator, within the established governor limits through the use of what?

A. The throttle
B. The rail
C. Governor link

69. When there is little or no air pressure applied to the AFC diaphragm, the maximum fuel pressure and flow are controlled by what?

A. AFC plunger
B. AFC spring
C. Check valve
D. No-air adjusting screw

70. In the PT fuel pump injector operation, when the cam follower roller is on the inner base circle,___________.

A. The injector return spring lifts the plunger.
B. The plunger lifts the return spring.
C. The check ball moves upward.
D. The plunger moves downward.

71. During which stroke(s) is the metering orifice uncovered and fuel flows into the injector cup?

A. Intake stroke only
B. End of intake stroke and beginning of the compression stroke
C. Compression stoke only
D. End of compression stroke and beginning of intake stroke

72. On a PT-type fuel injection system, when should maximum fuel manifold pressure be obtained?

A. At idle
B. Just off idle
C. After the governor cuts in
D. Just before the governor cuts in

73. To remove carbon from the PT fuel injector tips, you use which of the following methods?

A. A wire brush
B. Reverse flushing
C. A pin vise and the proper size fine wire
D. Sand paper

74. **(True or False)** The aneroid controls the exhaust emissions by creating a lag in the fuel system equal to that of the turbocharger.

A. True
B. False

75. You need to take special care of the PT fuel pump when disassembling it because is made of___________.

A. Plastic
B. Cast iron
C. Aluminum
D. Bronze

76. When rebuilding a PT-type fuel pump, parts should be discarded at what point?

A. When they only show minor wear
B. Only after they break
C. When they are worn beyond replacement limits
D. At each overhaul

77. To prevent goring of the PT fuel pump and pump parts in reassembly, the mechanic should use which of the following means?

A. Spring steel lock washers
B. Flat steel washers
C. Torque wrench
D. Extreme pressure lubricant

78. When a PT pump has been rebuilt, it should be run at 1,500 rpm for how long to allow the bearings to seat?

A. 2 minutes
B. 5 minutes
C. 10 minutes
D. 15 minutes

79. When servicing a PT fuel injector, you should NOT take which of the following actions?

A. Use cleaning solvent.
B. Use cleaning wire.
C. Use mineral spirits.
D. Soak the orifices to remove carbon.

80. Scavenging takes place during which strokes in a two-cycle engine?

A. End of downstroke; beginning of upstroke
B. End of upstroke; beginning of downstroke
C. Beginning of intake downstroke; dead center exhaust stroke
D. Dead center downstroke; end intake stroke

81. Superchargers pump a greater amount of air into n engine than could be supplied by normal atmospheric pressure. What is the effect on fuel consumption and power?

A. More fuel is burned; power is decreased
B. Less fuel is burned; power is decreased
C. More fuel is burned; power is increased
D. Less fuel is burned; power is increased

82. What are the three primary components of a turbocharger?

A. Turbine wheel, center housing, and compressor wheel
B. Turbine shaft, center support, and injectors
C. Exhaust tube, air pump, and compressor tube
D. Turbine housing, air injection, and compressor shaft

83. What is the component that sends compressed fresh air to the intake manifold?

A. Air inlet
B. Intake tube
C. Exhaust pipe
D. Crossover tube

84. **(True or False)** Lack of engine power, blue smoke, and increased engine power are some of the symptoms of turbocharger problems.

A. True
B. False

85. While inspecting the turbocharger, you discover the inner heat shield is distorted. What action should you take?

A. Replace with a new shield.
B. Replace the turbocharger.
C. Reuse, since it will straighten when bolted back on.
D. Heat up and straighten.

86. What is the proper shutdown procedure of a turbocharger to prevent bearing damage?

A. Idle down then shut off immediately.
B. Idle the engine for a few minutes.
C. Shutdown at high rpm.
D. None of the above.

87. What type of heater is mounted outside the engine and has the advantage of working in a short period of time?

A. Immersion heater
B. Intake air heater
C. Circulating coolant heater
D. Lube oil heater

88. Where on the engine is the lubricating oil heater generally installed?

A. Drain plug
B. Dipstick opening
C. Oil line
D. Both A and B

89. After the engine starts under cold conditions using a glow plug, how does the glow plug turn off?

A. Operator must turn glow plug switch to OFF
B. Putting transmission into drive
C. Control circuit disconnects glow plug
D. None of the above

90. When may ether be used as a diesel engine cold starting aid?

A. Only in extreme emergencies
B. Only in extreme cold weather
C. Any time
D. When the engine will not start after four attempts

91. **(True or False)** Diesel engines can become "dependent" upon ether.

A. True
B. False

92. Which exhaust emission is produced when unburned fuel escapes from the exhaust system of a poorly running engine?

A. Particulates
B. Oxide of nitrogen
C. Carbon monoxide
D. Hydrocarbons

93. What is the function of the exhaust gas recirculation system?

A. Recirculates engine crankcase fumes back into the combustion chamber
B. Injects burned exhaust gases into the engine to lower combustion temperatures and prevent the formation of NO_x
C. Chemically changes combustion by-products into harmless substances
D. Forces outside air into the exhaust system to help burn unburned fuel

94. Pressure leakage past the piston rings on the blower stroke is referred to as what?

A. Engine blockage
B. Piston blowby
C. Engine blowby
D. Engine pressure

95. The PCV valve controls the air through the PCV system. It can be located in any of the following locations except the___________.

A. Valve cover
B. Intake manifold
C. Side of the engine block
D. Air breather

96. What is the purpose of the evaporative emissions control system?

A. Makes oil vapors condense and flow into the oil pan
B. Prevents toxic fuel vapors from entering the atmosphere
C. Prevents toxic fuel from entering the cylinders
D. Regulates engine crankcase ventilation

97. What is the function of the liquid-vapor separator in the evaporative emissions system?

A. Used to keep fuel from entering the evaporative emission system
B. Carries fuel vapors to a charcoal canister
C. Stores fuel vapors when the engine is not running
D. Prevents fuel vapors from entering the atmosphere

98. What component of the evaporative emissions control system allows the vapors to enter the intake manifold and is pulled into the combustion chambers for burning?

A. Purge line
B. Air dome
C. Purge connector
D. Purge valve

99. On the enhanced evaporative emissions control system, what component monitors internal fuel tank pressure?

A. Canister vent solenoid
B. Rollover valve
C. Fuel tank pressure sensor
D. Service port

100. On the enhanced evaporative emissions control system, what happens when the system is in diagnostic mode?

A. The control module closes the vent solenoid, blocking air flow into the canister.
B. The control module opens the vent solenoid, blocking air flow into the canister.
C. The control module closes the vent solenoid, allowing air flow into the canister.
D. The control module opens the vent solenoid, allowing air flow into the canister.

101. Maintenance on an evaporative emissions control system typically involves cleaning or replacing which component?

A. Filter in the vacuum pump
B. Filter in the pressure canister
C. Filter in the charcoal canister
D. None of the above

102. **(True or False)** One very basic and simple way to quickly test a PCV valve is to pull it from the engine and see if it rattles when shaken.

A. True
B. False

103. **(True or False)** Another procedure to check the PVC valve is to suck on it to check operation

A. True
B. False

104. What component is normally located in the thermostatic air cleaner to control the vacuum motor and heat control door?

A. Heat pressure valve
B. Thermal vacuum valve
C. Vacuum motor
D. Air cleaner inlet

105. If the air cleaner flap does not function on the thermostatic air cleaner, what components should be checked first?

A. Vacuum motor and temperature sensor
B. Vacuum sensor and temperature motor
C. Vacuum hose and temperature valve
D. Gas motor and pressure sensor

106. The exhaust gas recirculation system lowers the amount of what emission in the engine exhaust?

A. Carbon monoxide
B. Hydrocarbons
C. Oxides of nitrogen
D. Particulates

107. On the EGR System, what component may be used to prevent exhaust gas recirculation when the engine is cold?

A. Vacuum line
B. Back pressure valve
C. Coolant pressure valve
D. Coolant temperature switch

108. What is the difference between a single-stage EGR and a multi-stage EGR?

A. Solenoids
B. Exhaust gases
C. Stages
D. Valves

109. While conducting a test on a vacuum type EGR System, you plug the supply vacuum line to the EGR valve and apply vacuum with a hand pump. What should the engine do?

A. Rpms will rise
B. Run smoothly
C. Begin to miss or stall
D. Idle down, then rpms rise

110. While running a test on an electronic type EGR System and after going through the procedures, what should check for after checking the condition of the windings and no voltage is indicated?

A. Check for bad electrical connection
B. Check the ECM
C. There is nothing more, replace EGR
D. Both A and B

111. What component of the air injection system keeps air from entering the exhaust system during deceleration?

A. Air distributor manifold
B. Diverter
C. Exhaust pipe
D. Exhaust manifold

112. When testing the air pump on the air injection system, it should typically produce how much pressure?

A. 2-3 psi
B. 2-6 psi
C. 3-4psi
D. 4-5 psi

113. The following are types of catalytic converters except which one?

A. Dual-bed
B. Two-way
C. Mini-stage
D. Monolithic

114. How does the dual-bed catalytic converter dispose of the NO_x emissions?

A. Returns to cylinders to burn off
B. Filters through converter, released as hydrogen
C. Stores then releases when full
D. Stores then burns off to harmless by-product

115. What may be one of the symptoms of a clogged catalytic converter?

A. Increased power
B. Rotten egg odor
C. Increased pressure
D. Black exhaust

116. When testing for catalytic converter efficiency, you know there is enough oxygen for the catalyst to burn emissions if the oxygen readings are above what percentage?

A. 4
B. 5
C. 6
D. 7

117. **(True or False)** The oxygen sensor monitors the exhaust gases for oxygen content.

A. True
B. False

118. The primary oxygen sensor holds what designation and is located where?

A. Front O_2; near the engine
B. Front O_1; near the engine
C. Front O_2; downstream of the engine
D. Rear O_2; near the engine

119. The difference between the oxygen content in the inner cavity and the oxygen content of the exhaust gases flowing through the sensor's outer surface causes the sensor to generate_________.

A. Amps
B. Voltage
C. Backpressure
D. Negative flow

120. What determination does the ECM make when a titania oxygen sensor's voltage drops below the predetermined value?

A. Mixture too rich
B. Mixture too lean
C. Mixture is correct
D. None of the above

121. A lazy O_2 sensor will not_________its output signal fast enough to maintain an efficient air-fuel ratio.

A. Alter
B. Detect
C. Determine
D. Sense

122. When the oxygen sensor is determined to be defective, what shall be done first before removing it?

A. Disconnect the sensor harness.
B. Disconnect the positive battery cable.
C. Disconnect the negative battery cable.
D. Loosen the sensor.

123. Currently, there are three types of diesel particulate filters as listed below except which one?

A. Precatalyzed
B. Catalyzed
C. Low temperature particulate filters
D. Noncatalyzed

124. What is the idea behind the DPF?

A. Soot collects in the filter system, then burned off.
B. Soot collects in a container, then removed daily.
C. Soot collects on the walls, then rinsed off weekly.
D. Soot collects on the walls, then burned off.

125. **(True or False)** A pyrometer is an instrument only used by the mechanic.

A. True
B. False

126. What is the system on a diesel engine which is comparable to the PCV on gasoline engines?

A. Closed crankcase ventilation
B. Open crankcase ventilation
C. Closed manifold ventilation
D. Closed cylinder ventilation

127. Opacity meter readings are displayed in_________.

A. Percentages
B. Volts
C. Ohms
D. Proportion

128. Before undertaking a snap test, what needs to be considered relating to the exhaust stack?

A. Length
B. Diameter
C. Bends
D. Pressure

129. White smoke is caused by condensing_________.

A. Oil
B. Diesel
C. Fumes
D. Liquid

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Modern Automotive Technology 7th Edition, James Duffy, The Goodheart-Wilcox Company, Inc., 2009. (ISBN: 978-1-59070-956-6)

Diesel Technology 7th Edition, Andrew Norman and John Corinchock, The Goodheart-Wilcox Company, Inc., 2007. (ISBN- 13: 978-1-59070-770-8

Heavy Duty Truck Systems 4th Edition, Sean Bennet, Delmar Cengage Learning, 2006. (ISBN-13:978-1-4018-7064-5)

Medium/Heavy Duty Truck Engines, Fuel & Computerized Management Systems, 2nd Edition, Sean Bennett, Thomson Delmar Learning, 2004. (ISBN- 1-4018-1499-9

Small Engine Technology 2nd Edition, William A. Schuster, Delmar Publishers, 1999. (ISBN 0-8273-7699-5)

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Chapter 6

Troubleshooting Electrical Systems

Topics

To hear audio, click on the box.

Overview

The chapter discusses troubleshooting vehicle electrical systems. Automobiles, trucks, power generation equipment, and construction equipment are as much electrical and electronic as they are mechanical. The era of the backyard mechanic is gone; you must be as well trained in electricity and electronic aspects along with the mechanical workings of CESE. Knowledge of specialized diagnostic equipment, such as the use of on-board diagnostics, is also essential for today's mechanic to troubleshoot equipment systems.

The first topic discussed is alternators, rectifiers, and voltage regulators, their nomenclature, and their function. The next chapter will cover troubleshooting the charging system and its various tests.

The subsequent topics will cover troubleshooting the alternator with emphasis on diodes and windings, the cranking system and its various tests, the ignition system and its components, lighting systems, and electrical accessories.

The senior construction mechanic, whether in the Naval Mobile Construction Battalion, Public Works, State Department, Seal Team support, or MUSE, is going to have to take on the responsibility of keeping up with the rapid changes in technology for automotive, truck, power generation, and construction equipment electricity and electronic systems, along with their diagnostic procedures.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Understand and identify the components of AC charging systems.
2. Understand how to use a voltampere tester to troubleshoot a charging system.
3. Understand how to use the engine analyzer to troubleshoot an alternator.
4. Understand how to troubleshoot the cranking system.
5. Understand and identify the ignition system.
6. Understand how to troubleshoot ignition systems.
7. Understand how to troubleshoot lighting systems and accessory systems.

Prerequisites

None

This course map shows all of the chapters in Construction Mechanic Advanced. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Air Conditioning Systems	↑	C M
Air Compressor Overhaul		
Inspecting and Troubleshooting Brake Systems		A
Hydraulic Systems		D
Wheel and Track Alignment		V
Troubleshooting Transmissions, Transfer Cases and Differentials		A
Clutches and Automatic Transmissions		N
Troubleshooting Electrical Systems		C
Fuel System Overhaul		E
Engine Troubleshooting and Overhaul		D
The Shop Inspectors		
Alfa Company Shop Supervisor		
Public Works Shop Supervisor		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.

- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 AC CHARGING SYSTEMS

The starting system draws a tremendous amount of current from the battery. This runs down, or discharges, the battery. The system to recharge the battery is the charging system*. Figure 6-1* shows a basic charging circuit.

The charging system forces current back through the battery for recharging and also provides electricity for all the electrical devices when the engine is running. This system serves as the electrical power supply under normal operating conditions. The charging system comprises of the battery, the alternator, the voltage regulator, ignition switch, and indicator light.

The alternator, sometimes called generator, produces the current output. This current is fed to the battery and to other electric-electronic systems.

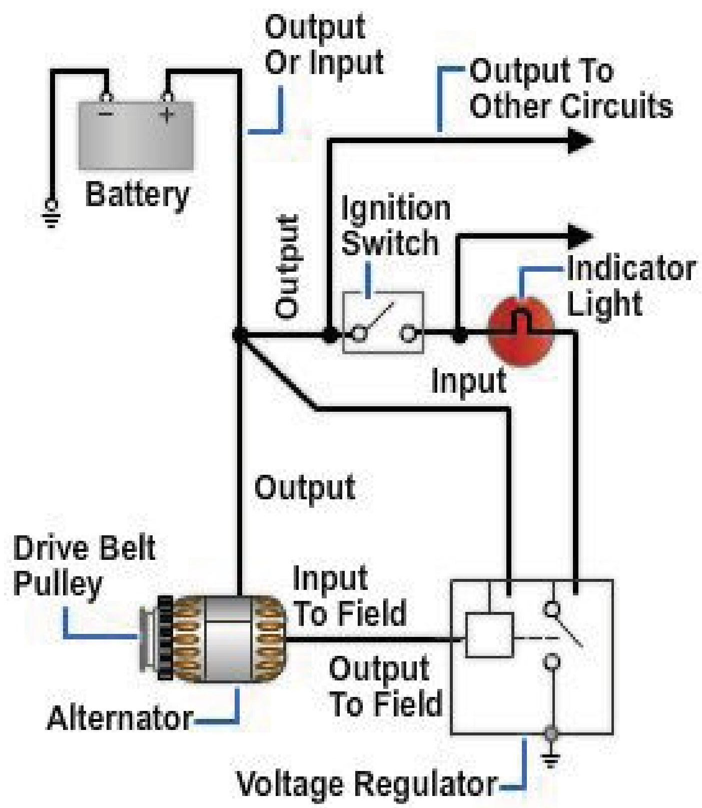

Figure 6-1 – Schematic of a basic charging circuit.

The voltage regulator maintains an alternator output of approximately 13 to 15 volts. This is higher than battery voltage, which is 12.6 volts (12 volt battery). This higher voltage is needed to recharge the battery. The charging system can affect the operation of the rest of the vehicle. Undercharging will allow the battery to become weak, making the vehicle hard to start. Overcharging can damage the battery and other vehicle components. Overcharging can affect the operation of the ECM by creating voltages that are beyond the normal range of ECM operation.

1.1.1 Alternators

The alternator is a compact electrical component that changes rotational movement into electricity by using magnetism. The alternator consists of a set of rotating windings, called a rotor, and a set of stationary windings, called a stator. The alternator rotor is turned by the engine crankshaft through a drive belt and is magnetized by battery current delivered through slip rings and brushes, as illustrated in *Figure 6-2.* The typical components of an alternator include:

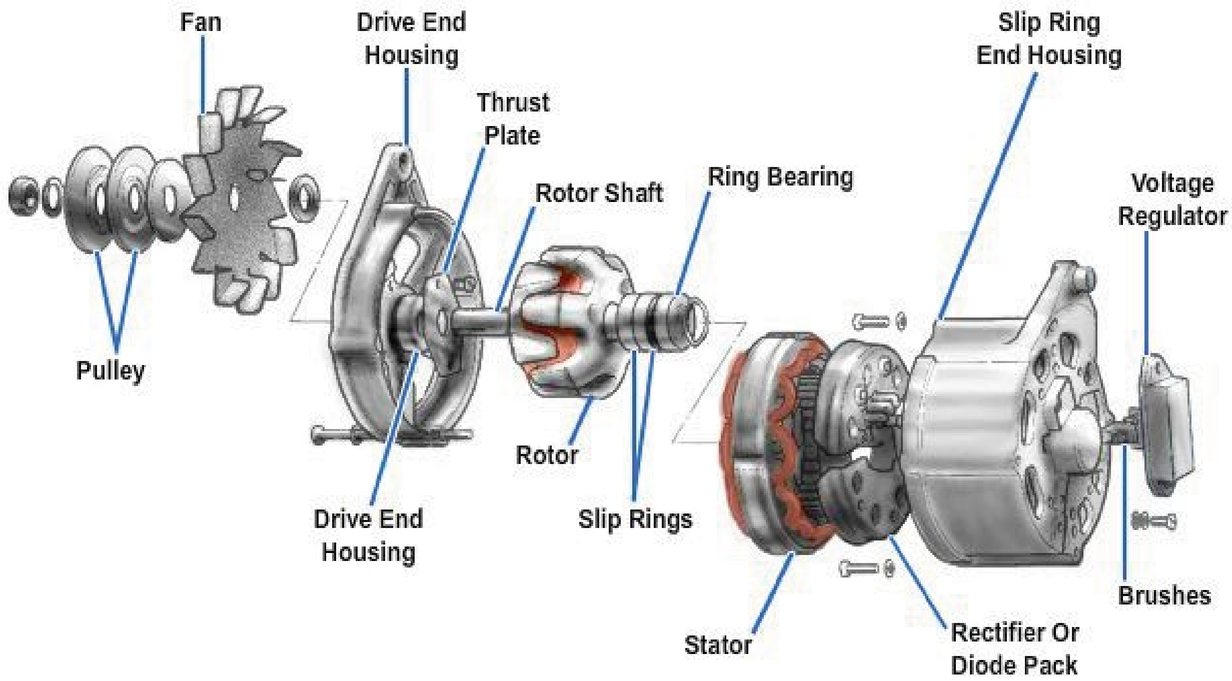

Figure 6-2 – Exploded view of an alternator.

1. Rotor assembly (field windings, claw poles, rotor shaft, and slip rings)
2. Stator assembly (three stator windings or coils, stator core, and output wires)
3. Brush assembly (brush housing, brushes, brush springs, and brush wires)
4. Rectifier assembly (diodes, heat sink or diode plate, and electrical terminals)
5. Housing (drive end frame, slip ring end frame, and frame bolts)
6. Fan and pulley assembly (fan, spacer, pulley, lock washer, and pulley nut).
7. Integral regulator (electronic voltage regulator mounted in or on rear of alternator).

Rotor and stator operation. The rotor is a spinning magnetic field. It fits in the center of the alternator housing. The fan belt turns the rotor, making the field spin.

The stator is a stationary set of windings in the alternator. The stator surrounds the rotor. The stator serves as the output winding of the alternator. *Figure 6-3* shows an illustration of a rotor and stator.

When the rotor spins, its strong magnetic field cuts across the stator windings as depicted in *Figure 6-4*. This spinning induces current in the stator windings. If the stator windings are connected to the load, such as a light bulb, the load will operate.

Rotor. An alternator rotor consists of field coil windings mounted on a shaft. *Figure 6-5* shows the components of a rotor. Two claw-shaped pole pieces surround the field windings to increase magnetic field strength. The rotor is mounted on roller or needle bearings so the rotor can turn freely, as illustrated in *Figure 6-6.*

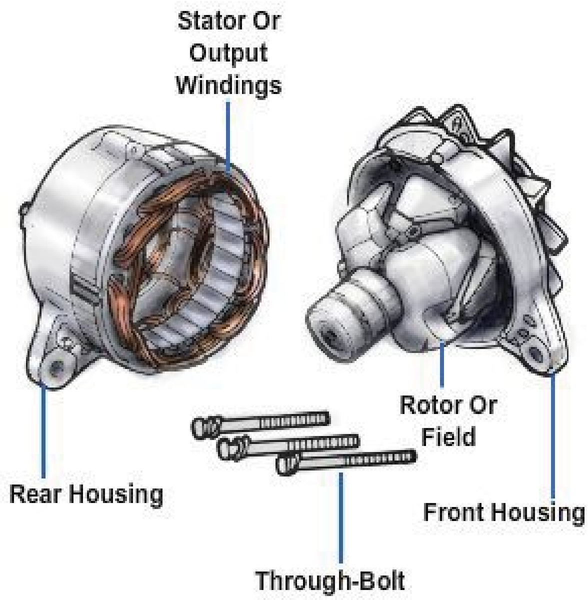

Figure 6-3 – The rotor mounts inside the stator.

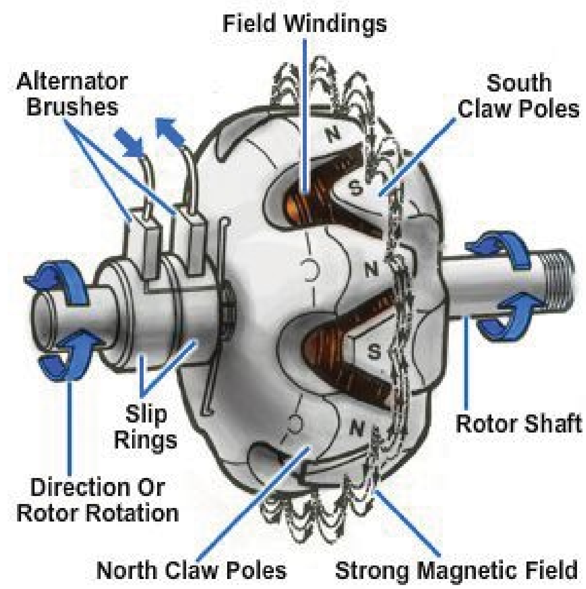

Figure 6-4 – The rotor has claw poles that surround its windings.

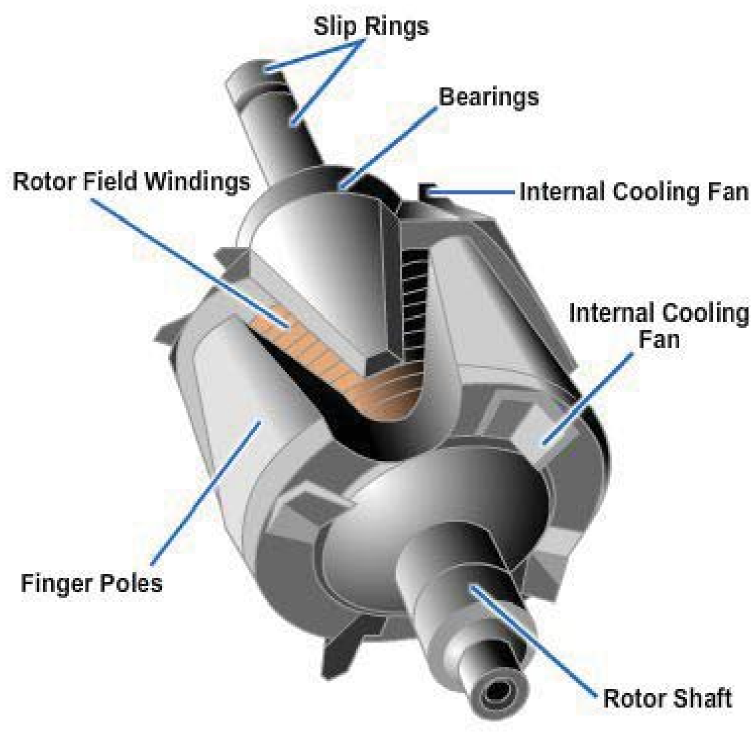

Figure 6-5 – Components of a rotor.

The claw on one of the pole pieces produces S (south) poles. The claws on the other pole form N (north) poles. As the rotor spins inside the alternator, an alternating N-S-N-S polarity and AC current is produced. This pulls one way and then the other to produce AC.

Slip rings. Slip rings are mounted on the rotor shaft to feed a small current into the rotor windings, as illustrated in *Figure 6-7*. Each end of the field coil connects to one of the slip rings. An internal source of electricity is needed to excite the field and produce a magnetic field.

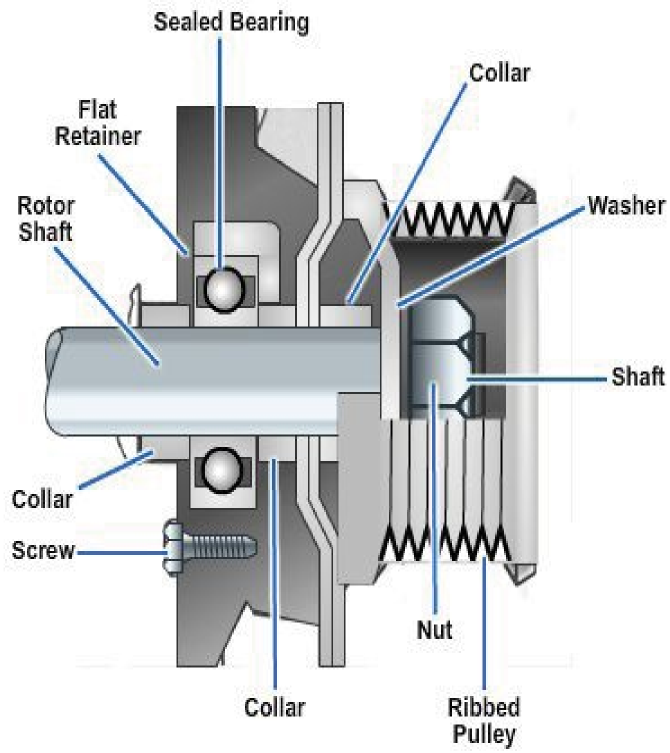

Figure 6-6 – Rotor shaft and bearings.

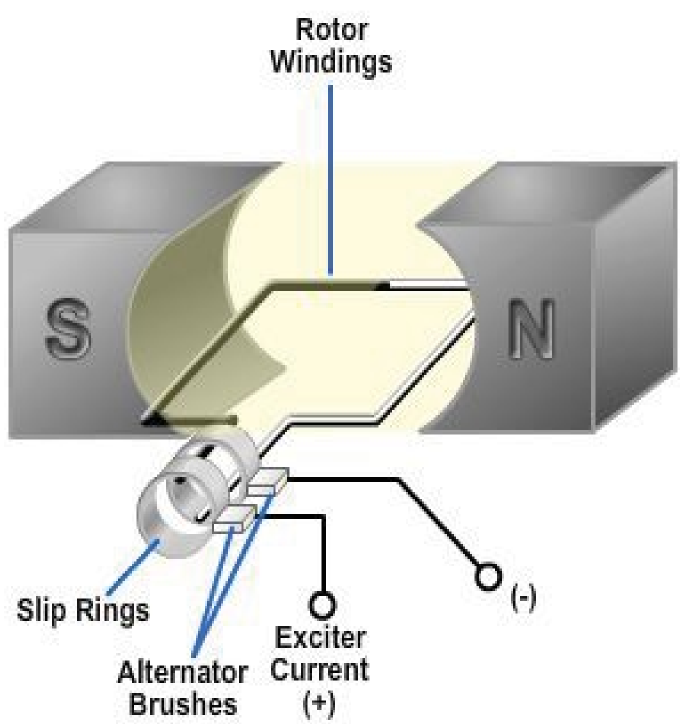

Figure 6-7 – Brushes and slip rings allow current to be fed into rotor windings.

Alternator brushes. Alternator brushes ride on the slip rings to make a sliding electrical connection. The brushes feed current into the slip rings and rotor windings.

Small brush springs push the brushes out and into contact with the slip rings. Since current flow into the rotor windings is low, the brushes are small compared to motor brushes.

A brush holder encloses the brush springs and brushes. It holds the brushes in alignment with the rotor slip rings. The brush holder is made of insulating material to prevent brush grounding; refer to *Figure 6-8*.

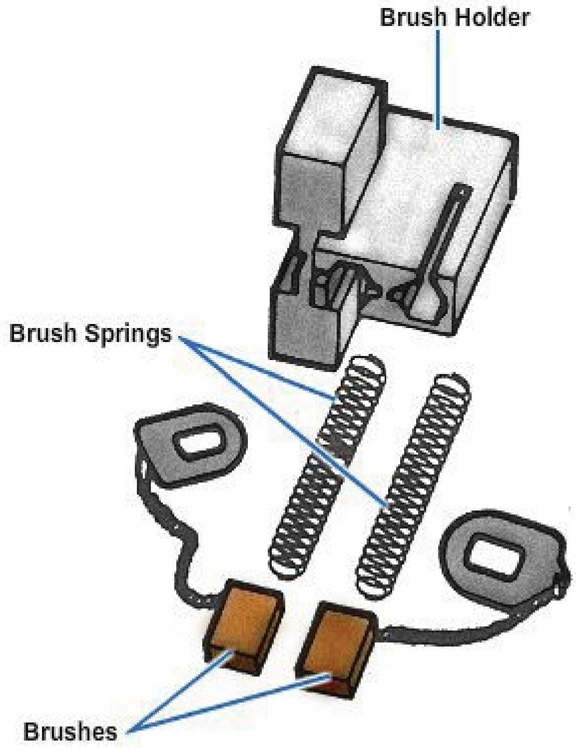

Figure 6-8 - Brushes and brush holder.

Stator. Previously mentioned, the stator is a stationary set of windings mounted between the end frames. The stator usually consists of three coils wrapped around an iron core. The iron core increases the field strength so that more current can be induced into the stator by the rotor field. The output of the stator is AC and is fed into the diodes that convert to DC.

A **Y-type stator** has the wire ends from the stator windings connected to a neutral junction. The circuit looks like the letter "Y". A Y-type stator provides good current output at low engine speeds; see *Figure 6-9*.

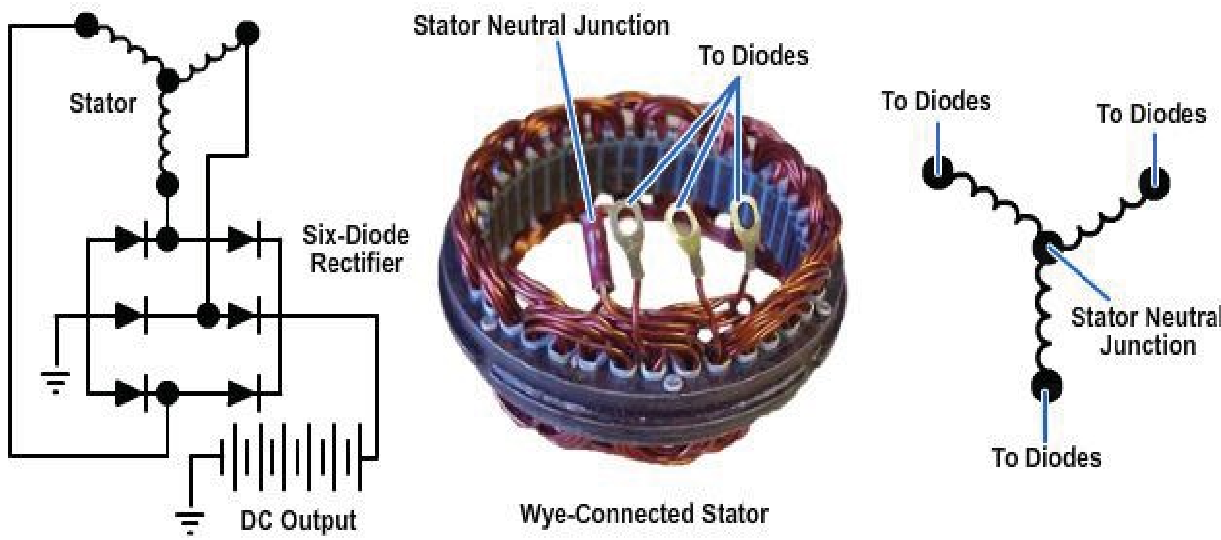

Figure 6-9 - Y-type stator windings.

A **Delta type stator** has the stator wires connected end to end. With no neutral junction, two circuit paths are formed between the diodes during each phase. A delta wound stator is used in high output alternators; see *Figure 6- 10*.

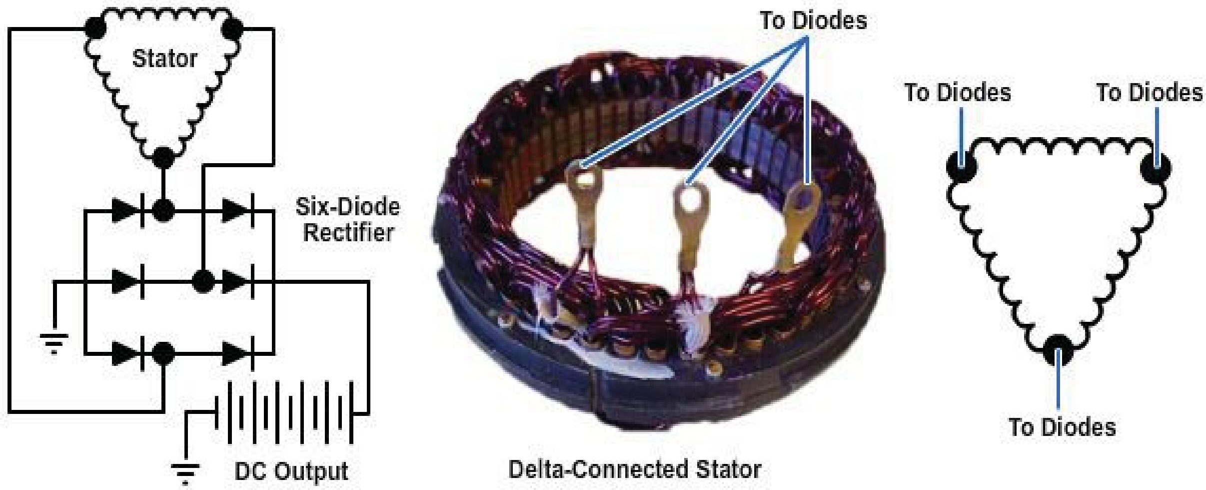

Figure 6-10 - Delta-type stator windings.

Bearings. Needle or ball-type alternator bearings are commonly used to produce a low friction surface for the rotor shaft. These bearings support the rotor and shaft as they spin inside the stator.

The alternator bearings are normally packed with grease. The front bearing is frequently held in place with a small plate and screws. The rear bearing is usually press-fit into place.

Cooling Fan. Behind the drive pulley on most alternators is a cooling fan that rotates with the rotor. This cooling fan draws air into the housing through the openings at the rear of the housing. The air leaves through the openings behind the cooling fan, as illustrated in *Figure 6-11*. The moving air pulls heat from the diodes, and their heat decreases.

Cooling the diodes is important for the efficiency and durability of the alternator. Several different alternator designs have been introduced that increases the cooling efficiency of an alternator. One of these alternators is lighter in weight and capable of very high output and contains two internal fans rather an external fan.

Liquid cooled. A recent design uses liquid cooling. Using water or coolant to cool an alternator is a very efficient way to keep

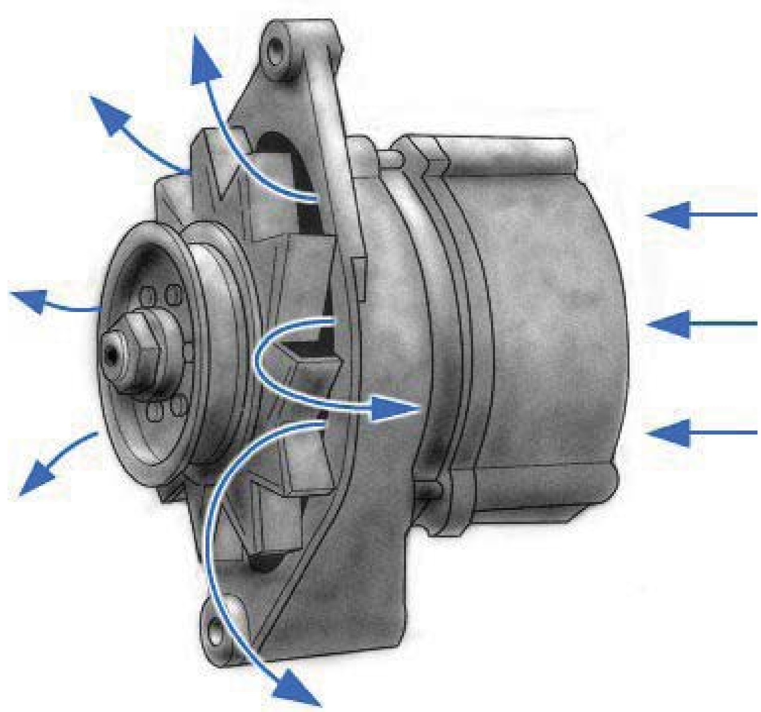

Figure 6-11 -Cooling fan draws air through to cool the diodes.

diode temperature down. One other reason to for eliminating the fan and using liquid to cool the alternator is to reduce noise. The rotating fan is a source of underhood noise that was essential to eliminate. These new alternators have water jackets cast into the housing. Hoses connect the housing to the engine's cooling system. Not only do these alternators make less noise, they have higher output and should last longer in the high temperature environment.

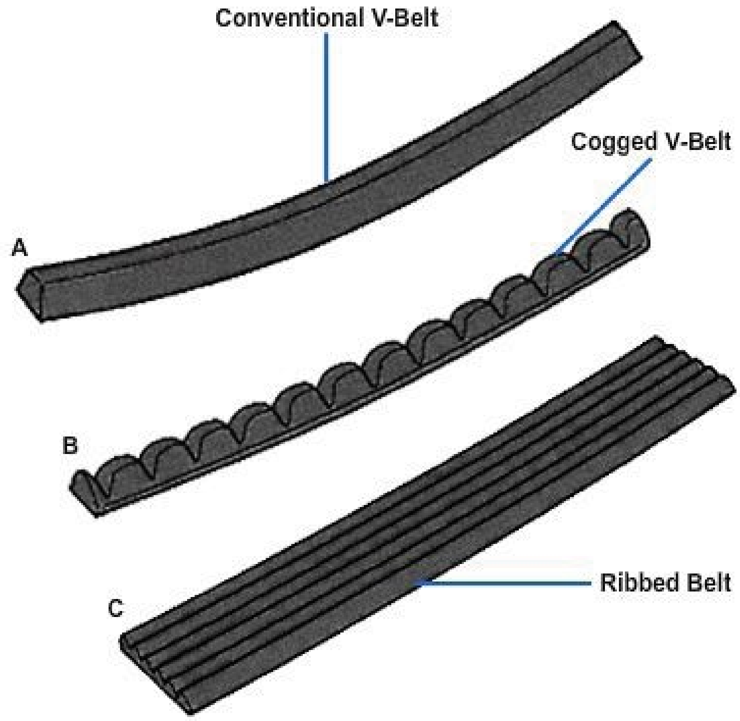

Figure 6-12 -Alternator belts.

Pulley and belt. An alternator pulley is secured to the front of the rotor shaft by a large nut. It provides a means of spinning the rotor through the use of a belt.

An alternator belt, running off the crank pulley, turns the alternator pulley and rotor. One of three types of belts may be used; V-belt, cogged V-belt, and ribbed belt, as shown in *Figure 6-12*.

1.2.0 Rectifiers

An alternator rectifier assembly, also known as a diode assembly, commonly uses six diodes to convert stator output (alternating current) to direct current. The diodes are usually wired as shown in *Figure 6-13*. The rectifier provides full-wave rectification (changes both positive and negative outputs into direct current) as the different polarity rotor claws pass the stator windings.

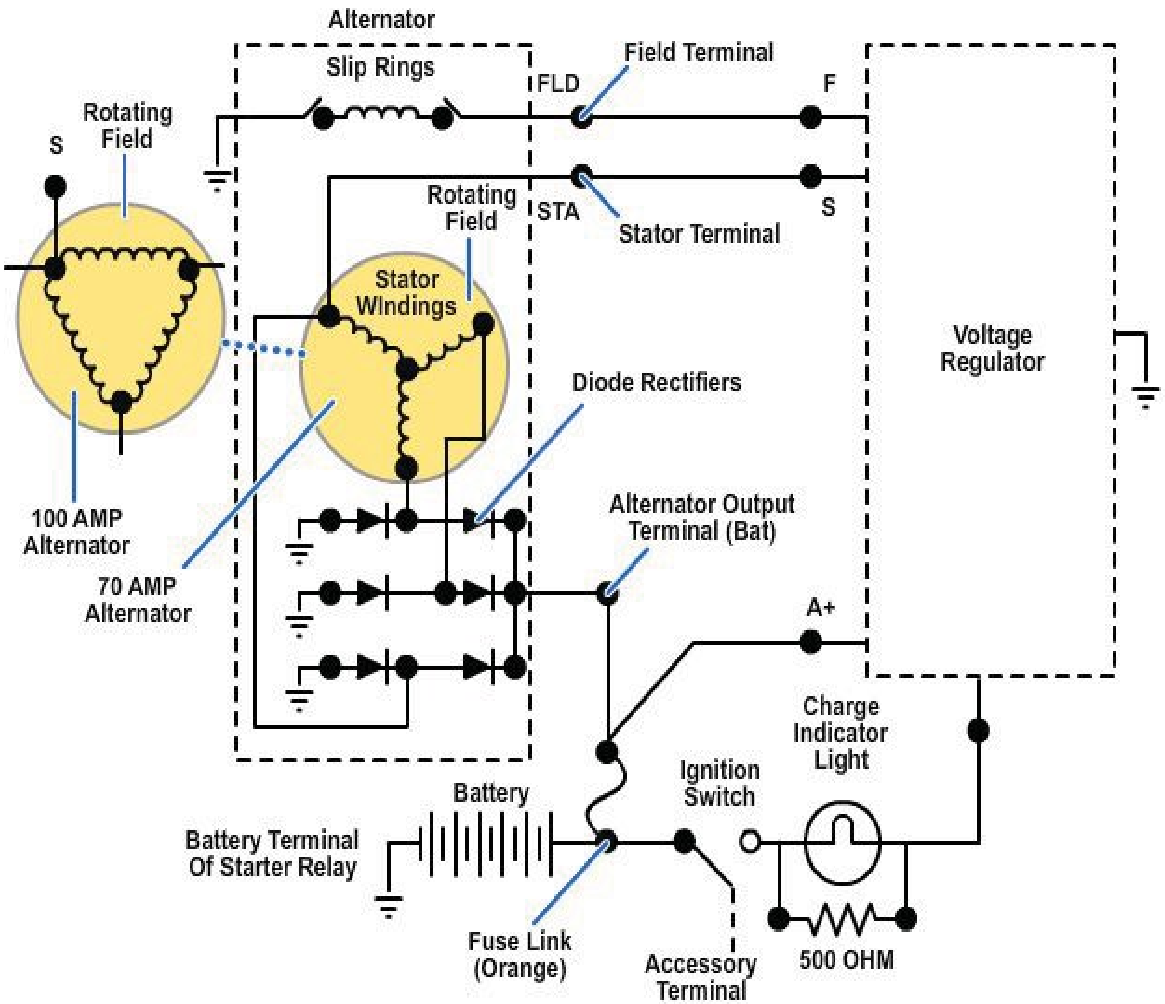

Figure 6-13 - Wiring diagram showing the relationship between stator windings, rotor windings, diodes, and electrical connections.

A diode trio may be used to supply current to the rotor field windings. In a diode trio, three diodes are connected to the field through a connection in the voltage regulator. The stator output feeds the diode trio.

The rectifier diodes are mounted in a diode frame or heat sink (metal mount for removing excess heat from electronic parts). Three positive diodes are press-fit in an insulated frame, and three negative diodes are mounted in an uninsulated or grounded frame.

AC output. AC flows one way and then the other. As the rotor turns into one stator winding, current is induced in one direction. Then, when the same rotor pole moves into the other stator winding, current reverses and flows out in the other direction.

Rectified AC current. An electrical system is designed to use DC or direct current that only flows in one direction. It could not use alternating current as it comes out of the alternator stator. Alternator current must be rectified (changed) into DC current before entering the electrical system, see *Figure 6-14.*

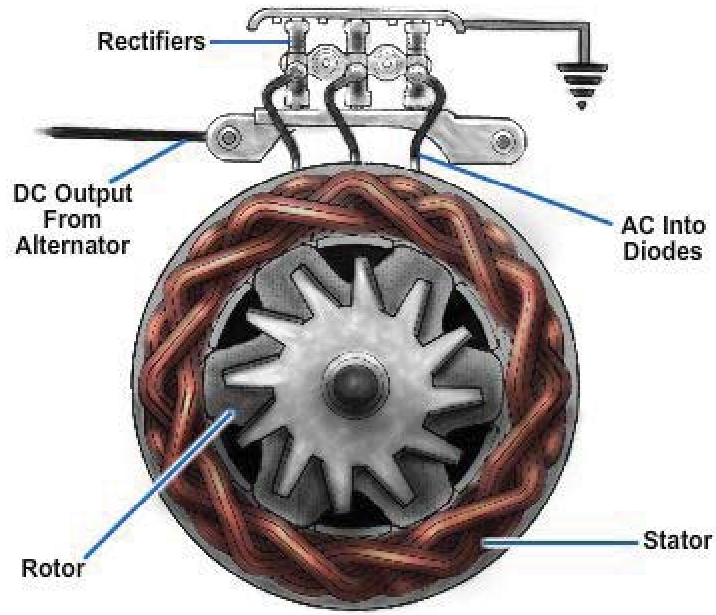

Figure 6-14 – Converting AC to DC.

A diode is a semi-conductor that allows current to flow in only one direction. Diodes are one-way check valves for electricity, becoming a conductor or insulator, depending on which way the current tries to flow. In *Figure 6-15, View A,* when polarity is connected one way, current flows. *Figure 6-15, View B* shows when polarity is reversed, current is blocked.

When a diode is connected to a voltage source in where the current passes through the diode, the diode is said to be forward biased. A forward-biased diode acts as a conductor.

When reverse biased, the diode is connected to a voltage source in such a way that current does not pass through. A reverse-biased diode acts like an insulator.

If a diode were placed on the stator output of a simple alternator, current would only flow out through the circuit in one direction.

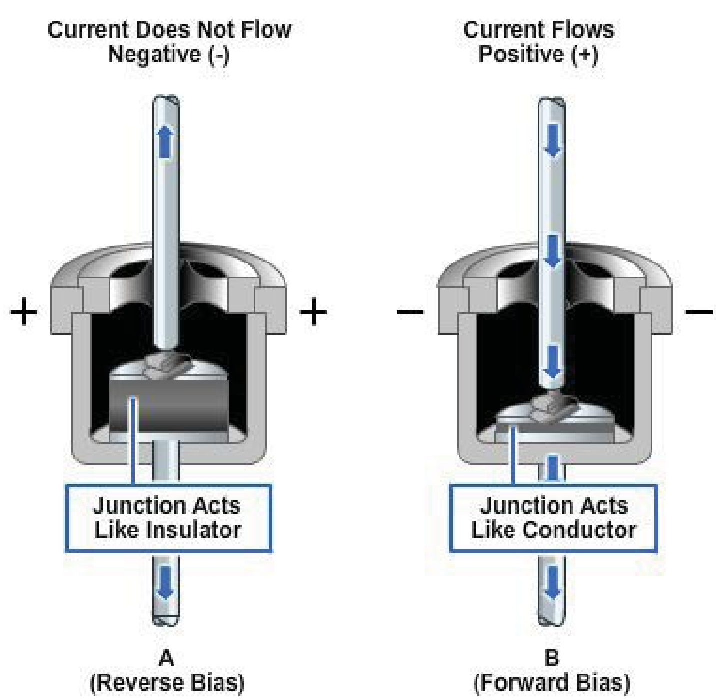

Figure 6-15 - Cutaway view showing diode operation.

A single diode would not use the entire alternator's output. It would result in pulsing direct current, not smooth current flow. Therefore, an alternator uses several diodes connected into a rectifier circuit. This produces more efficient alternator output, as demonstrated in *Figure 6-16.*

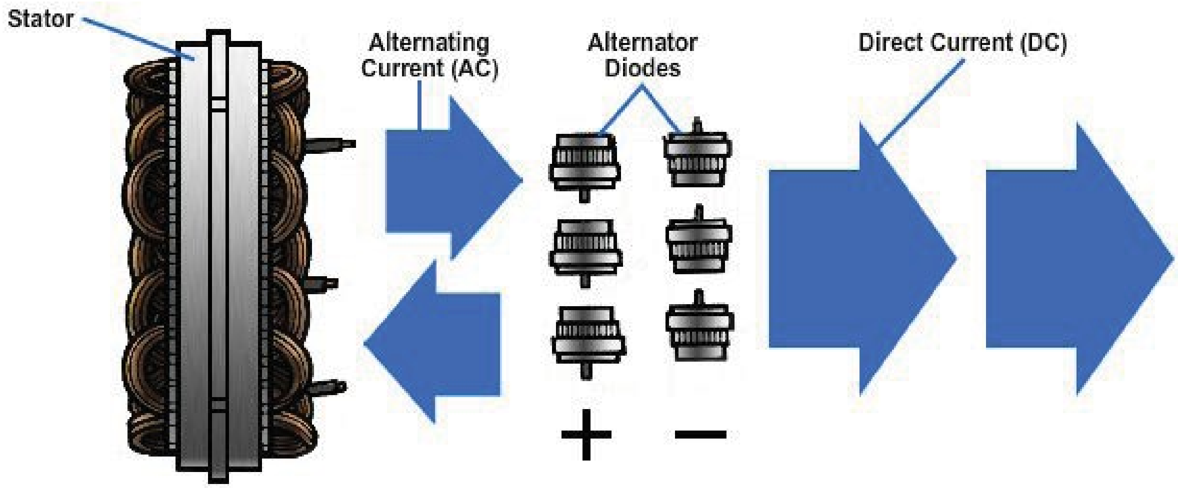

Figure 6-16 – Several diodes are needed to convert AC into DC.

1.3.1 Voltage Regulators

A voltage regulator controls alternator output by changing the amount of current flowing through the rotor field windings. Any change in rotor winding current changes the field strength acting on the stator or output windings. In this way, the voltage regulator can maintain a preset charging voltage.

The voltage regulator keeps alternator output at a preset charging voltage of approximately 13 to 15 volts. Since this is higher than the battery voltage (12.6 volts), current flows back into the battery and recharges.

Current also flows to the ignition system, electronic fuel system, on-board computer, radio, or any other device using electricity.

There are four basic types of voltage regulators:

1. Electric voltage regulator mounted inside the alternator
2. Electronic regulator mounted away from alternator in engine compartment
3. Electronic voltage regulator mounted on rear of the alternator
4. Contact point type regulator mounted in engine compartment.

Electronic voltage regulator. An electronic voltage regulator uses an electronic circuit to control rotor field strength and alternator output. A circuit diagram for an alternator and regulator is shown in *Figure 6-17*.

An electronic voltage regulator is a sealed unit and is not repairable. The electronic circuit must be sealed because it can be damaged by moisture, excessive heat, and vibration. Usually the circuit is surrounded by a rubber-like gel for protection.

An integral voltage regulator is an electronic regulator mounted inside or on the rear of the alternator. This is the most common type used today. It is very small, efficient, and dependable. Most use an integrated circuit to provide alternator regulation.

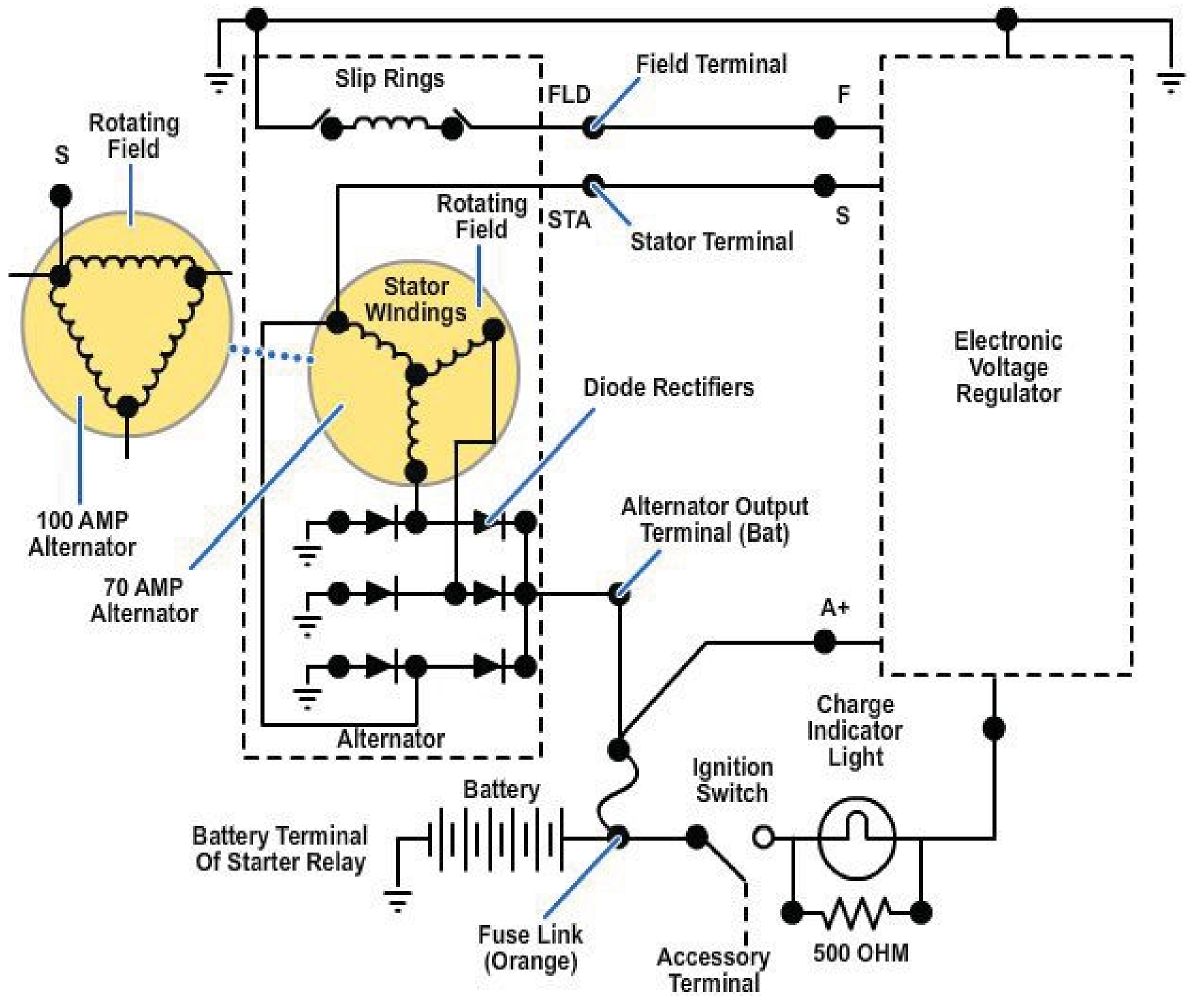

Figure 6-17 - Schematic with electronic voltage regulator.

Electronic voltage regulator operation. To increase alternator output, the electronic voltage regulator allows more current into the rotor windings. This strengthens the magnetic field around the rotor. More current is then induced into the stator windings and out of the alternator.

To reduce alternator output, the electronic regulator places more resistance between the battery and the rotor windings. Field strength drops, and less current is induced in the stator windings.

Alternator rpm and electrical load determine whether the regulator increases or decreases charging output. If load is high or rotor speed is low, such as engine idling, the regulator will sense a drop in system voltage. The regulator then increases rotor current until a preset output voltage is obtained. If load drops or rotor speed increases, the opposite occurs.

An electronic voltage regulator must be replaced when it is not operating properly.

Temperature compensation. Some newer electronic regulators are temperature compensating regulators. This means the regulator changes alternator output as the outside temperature changes. In cold weather, alternator output voltage is increased. This helps recharge the battery more quickly. Cranking loads are higher in cold weather and battery drain is more severe. A temperature compensating regulator will decrease alternator output voltage in warm weather.

Diode trio. The diode trio consists, as the name suggests, of three diodes, one per phase. A diode can be used to feed current to the rotor field through the electronic regulator. As diagramed in *Figure 6-18*, the stator coils are connected to each diode in the trio. This rectifies the current entering the voltage regulator and field or rotor windings.

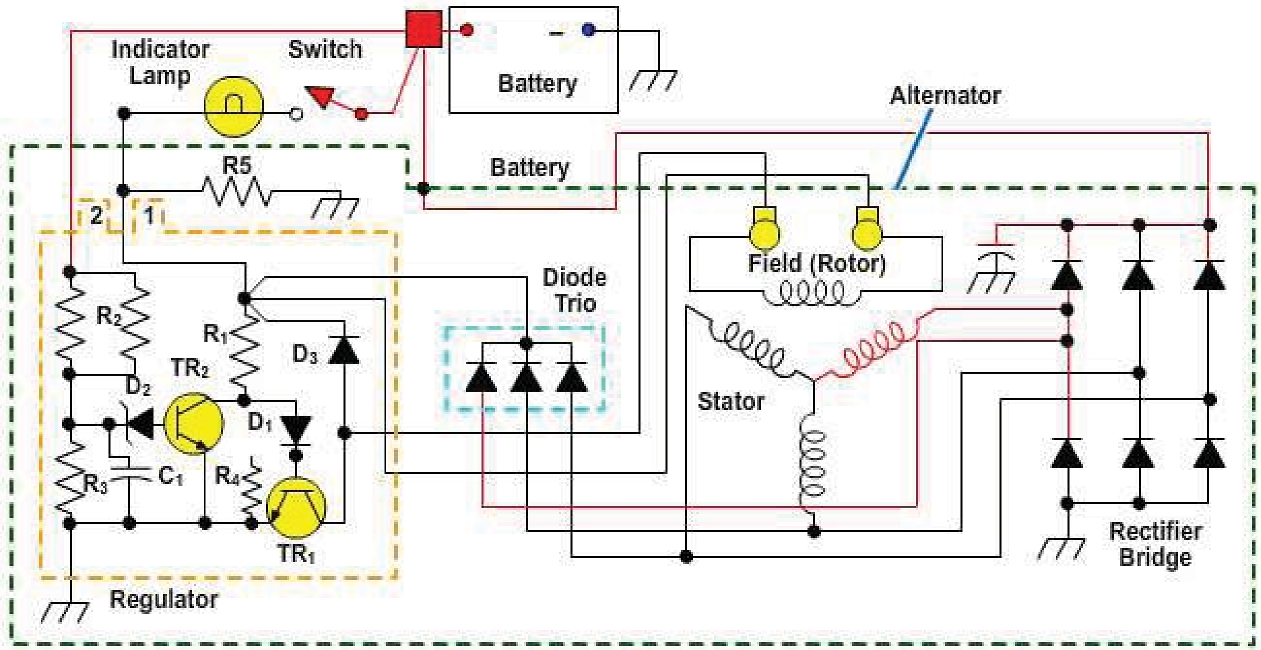

Figure 6-18 – Wiring diagram of a charging circuit with a diode trio.

Field circuit modulation. Field circuit modulation refers to how the voltage regulator can cycle the rotor field current on and off to control charging system output.

For example, if the battery is discharged, the regulator may cycle the field current on 90% of the time. This will increase output. If the electrical load is low, the regulator may cycle the field current off 90% of the time to decrease output. By controlling what percent of the time current is flowing through the rotor field, the modulating-type regulator can control the alternator.

Alternator capacitor. An alternator capacitor or condenser can be used to prevent radio noise. It absorbs alternating current inside the alternator. The capacitor can also protect the rectifying diodes from high voltage spikes and damage.

Contact point voltage regulator. A contact point voltage regulator uses coils, set of points, and resistors to control alternator output. This is an older type of regulator that has been replaced by electronic or solid state regulators.

When alternator output is too high, high current flow through the voltage regulator coil pulls the moveable contact down against the ground contact. This bypasses the current flowing to the alternator field, which causes the field current and the alternator output to decrease.

When charging output is too low, less current flows through the regular coil. The spring on the moveable contact then pulls the contact up. This connects the alternator field circuit to battery voltage. Current enters the alternator field and output increases. The coil points cycle at about 100 times per second to provide smooth regulation.

The field relay coil simply disconnects power from the charging system when the ignition switch is OFF.

2.1.1 TROUBLESHOOTING the CHARGING SYSTEM with a VOLT-AMPERE TESTER

Charging system precautions. Observe the following rules when working on a charging system. They will prevent possible damage to electrical-electronic systems:

- Disconnect the battery before moving any charging system component. If a hot wire touches ground, parts could be ruined. Disconnect the battery before connecting it to a battery charger. A voltage surge or high voltage can damage electronic components in the alternator, regulator, and other computerized systems.
- Never reverse polarity. If the battery or jumper cables are connected backwards, serious electrical damage can occur. Reversing polarity can damage the diodes in the alternator, ruin the circuit in the regulator, and burn electronic components in other computer systems.
- Do not operate the alternator with the output wire disconnected. If the alternator is operated with the output wire disconnected, alternator voltage can increase above normal levels. Alternator or charging circuit damage could result.
- Never short or ground any charging system terminal unless instructed to do so by a shop manual. Some circuits can be grounded or shorted without damage; others will be seriously damaged. Refer to service manual when in doubt.
- Do not attempt to polarize an alternator. DC generator systems had to be polarized (voltage connected to generator field) after repairs. This must not be done with an alternator.

2.1.0 Alternator Test

Charging System Tests. Charging system tests should be done when symptoms point to low alternator voltage and current. These tests will quickly determine the operating condition of the charging system.

Charging system tests are performed in three ways: using a load tester, which is the same tester used to check the battery and starting system; a scope tool; or a volt-ohm-milliammeter (VOM).

A load tester provides the most accurate method of checking a charging system, as shown in *Figure 6-19*.

Figure 6-19 – Load tester.

Before testing the charging system, it is common practice to check the condition of the battery. Although charging system problems often show up as a dead battery, do not forget that the battery itself may be bad. Measure the battery's state-of-charge and perform a battery load test. Then, you will be sure that the battery is not affecting your charging system tests.

2.2.0 Excessive Output Test

To conduct an excessive output test, set the voltmeter to the correct voltage range and the volt lead selector to the required position. Connect the black external volts lead to the generator armature terminal and the red external volts lead to the generator frame for a good ground. While observing the voltmeter scale for the highest voltmeter reading, start the engine and slowly increase its speed. If the voltmeter reads less than 16 volts (12-volt system) or 8 volts (6-volt system), the current limiter relay of the regulator is the reason for the high output. If the voltmeter reads more than 16 volts (12-volt system) or 8 volts (6-volt system), remove the field wire at the regulator and observe the ammeter scale. When the ammeter reading shows no output, you have a defective regulator, which should be repaired or replaced. When the ammeter reading indicates a current flow, remove the field wire at the generator and observe the ammeter. If the ammeter reading then shows no output, you have a shorted field wire. Replace the field wire and connect the generator to the regulator. On the other hand, if the ammeter shows that current is flowing, then the generator has a grounded field.

Another component of the vehicle charging system you should test is the voltage regulator**.** If the results of the test indicate the voltage is too high or too low, a faulty regulator voltage limiter or a high-series resistance in the charging system could be causing the trouble. Erratic or unstable voltage indicates poor circuit electrical connections, faulty regulator contacts (burned or oxidized), or damaged regulator resistors. In any case, you should proceed with a charging system circuit resistance test.

2.3.0 Charging System Circuit Resistance Test

Circuit resistance tests are used to locate wiring problems in a charging system: loose connections, corroded terminals, partially burned wires, and similar troubles. Resistance tests should be performed when symptoms point to problems other than the alternator or regulator. Two common circuit resistance tests are the insulated-circuit resistance test and ground-circuit resistance test.

In a ground-circuit resistance test, the voltmeter is placed across the negative battery terminal and alternator housing.

The voltmeter should not read over 0.1 volt per electrical connection. If the voltmeter reading is higher, look for loose connections, a burned plug socket, or similar problems.

To do an insulated-circuit resistance test on a charging system, connect the tester as described by the manufacturer. The voltmeter leads are connected across the alternator output terminal and positive battery terminal.

With the vehicle running at a fast idle, turn the load control to obtain a 20-amp current flow. All lights and accessories should be off. Read the meter.

If the circuit is in good condition, the voltmeter should not read over about 0.7 volts (0.1 volt per electrical connection). If the voltage drop is higher than 0.7 volts, circuit resistance is high. A poor connection exists in that section of the charging circuit.

2.4.0 Charging System Ground Circuit Test

This test measures voltage drop within the system wiring. It helps pinpoint corroded connections or loose or damaged wirings.

Circuit resistance is checked by connecting a voltmeter to the positive battery terminal and the output, or battery terminal of the alternator. The positive lead of the meter should be connected to the alternator output terminal and the negative lead to the positive battery terminal. To check the voltage drops across the ground circuit, connect the positive lead to the alternator housing and the negative meter lead to the battery negative terminal. When measuring the voltage drop in these circuits, a sufficient amount of current must be flowing through the circuit. Therefore, turn on the headlights and other accessories to ensure the alternator is putting out at least 20 amps. If a voltage drop of more than 0.5 volt is measured in either circuit, there is a high resistance problem in that circuit.

2.5.0 Regulator Ground Circuit Resistance Test

To conduct this test, set the volt lead selector to the INT VOLTS position. Then, observing polarity, connect the external volts lead to the generator or alternator ground terminal and to the regulator ground terminal, as shown in *Figure 6-20*. Adjust the load increase knob until the ammeter scale indicates a current of 10 amperes. Also observe the reading on the (3-volt) voltmeter scale and compare it with the specifications. If the voltmeter reading exceeds 0.01 volt, excessive resistance is in the ground circuit between the regulator and the generator or alternator. Check the regulator ground system for loose mounting bolts or a damaged ground strap.

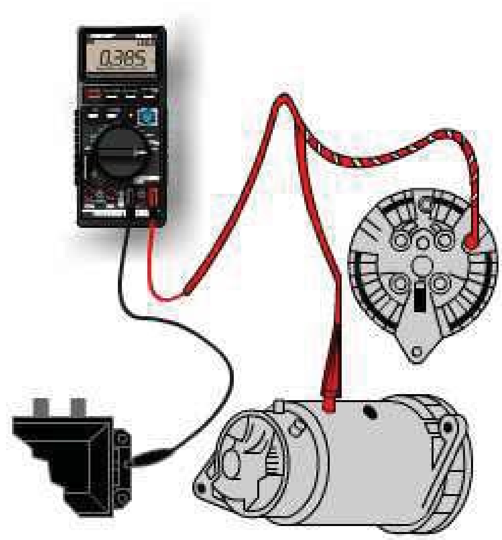

Figure 6-20 – Regulator ground circuit resistance test.

2.6.1 Battery Drain Test

A battery drain test will check for an abnormal current draw with the ignition key off. When a battery goes dead without being used, you may need to check for a current drain. It is possible that there is a short or other problem constantly discharging the battery.

A battery can be discharged if an electrical accessory remains on when the ignition is shut off. For example, a short in a switch could cause a glove box light to always stay on. This could slowly drain the battery and cause a starting problem.

To perform the ammeter current drain test:

1. Turn off all accessories and close the door.
2. Remove the underhood lamp, if equipped.
3. Disconnect the negative battery cable.
4. Attach the ammeter, as shown in *Figure 6-21*.
5. Zero the ammeter.
6. Read the ammeter.

CAUTION

To prevent damage, do not operate starting motor or any high-current-draw device with a meter connected in series for measuring current drain. High current draw will blow the meter fuse or damage the meter.

If everything is off (good condition), the ammeter should read almost zero or only a few milliamps (10 mA, typically). However, an ammeter reading above this would point to a drain problem. To pinpoint a drain, pull fuses one at a time. When the ammeter reads zero, the problem is in the circuit on that fuse.

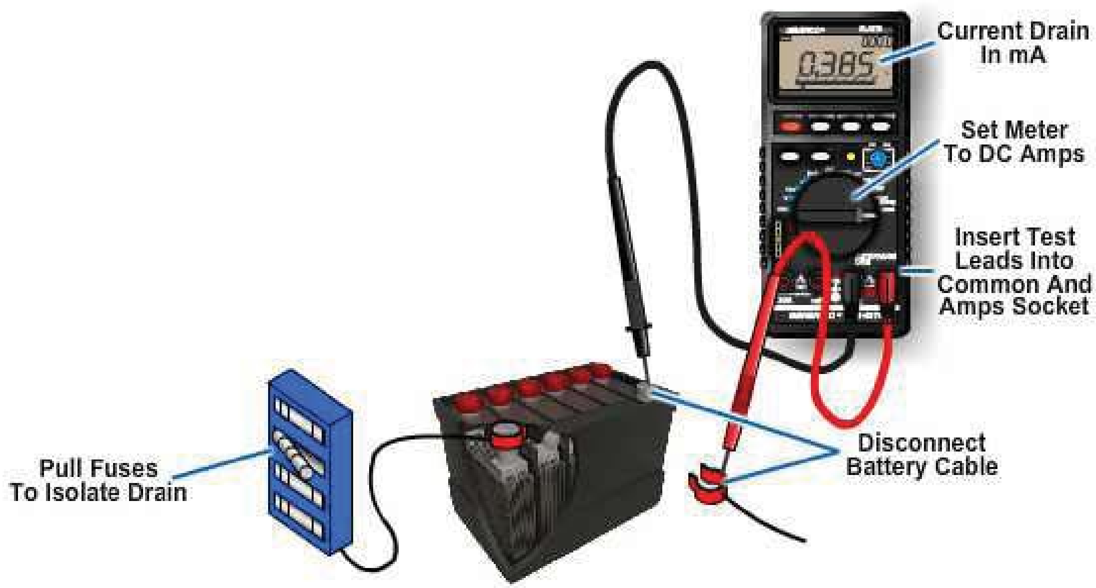

Figure 6-21 – Battery drain test.

Remember that normal parasitic current drain for the clock and computers can discharge a battery if the vehicle sits unused for an exceeded period of time. Also account for this small current draw when checking for a battery drain.

3.1.1 TROUBLESHOOTING the ALTERNATOR USING the ENGINE ANALYZER SCREEN

Normally, when an engine analyzer is available for use, it is in the electrical shop. The following information explains how to use the analyzer to test alternators. In considering this information, remember the following points:

1. The example shown is one of several manufactured.
2. The analyzer will do much more than just test alternators.
3. Always refer to the manufacturer's manual of the analyzer and the unit being tested before making any connections.

3.1.0 Charging Circuit Diodes

Bad alternator diodes reduce alternator output current and voltage and may also cause voltage ripple that can upset computer system operation. Faulty diodes are a frequent cause for alternator failure. It is important to check the condition of the diodes when rebuilding an alternator.

There are various methods used to test alternator diodes: ohmmeter, test light, diode tester, and scope test. The ohmmeter is the most common testing tool used when the alternator is disconnected.

When using an ohmmeter or a test light, the diodes must be unsoldered and isolated from each other. Some special diode testers, however, will check the condition of the diodes with all the diodes still connected to each other.

When an alternator fully produces, each of its diodes conducts an equal share of the current. This condition is indicated by a ripple pattern that appears on the screen of the engine analyzer. But a single non-conducting diode places a strain on the charging circuit, which causes a decrease in the output of the alternator. Whereas an ammeter or voltmeter may not detect this strain, the analyzer can do so easily. The strain brought on by an open field condition, for example, will stop the alternator output ripple entirely.

A likely result of decreased alternator output is an undercharged battery, and without a fully charged battery, there may not be enough current available to start the engine or meet the demands of the electrical circuits. When a good battery cannot be fully charged, the fault is usually in the alternator or voltage regulator. The engine analyzer can help you determine which is at fault. However, the regulator has to be bypassed altogether, and battery voltage must be applied to the field terminal of the alternator. Not all alternators can be full fielded. Refer to the manufacturer's field test procedure.

3.2.0 Open and Shorted Diodes

To use an ohmmeter to test the diodes, connect the meter to each diode in one direction and then the other, as indicated in *Figure 6-22*. The meter should read high resistance in one direction and low resistance in the other. This will show you that the diode is functioning as an "electrical check valve." The test should be performed on each diode.

A bad diode can either be shorted or opened. An open diode will have a high (infinite) resistance in both directions. A shorted diode will have a low (zero) resistance in both directions. In either case, the diode must be replaced. Press a new diode or obtain a new diode pack.

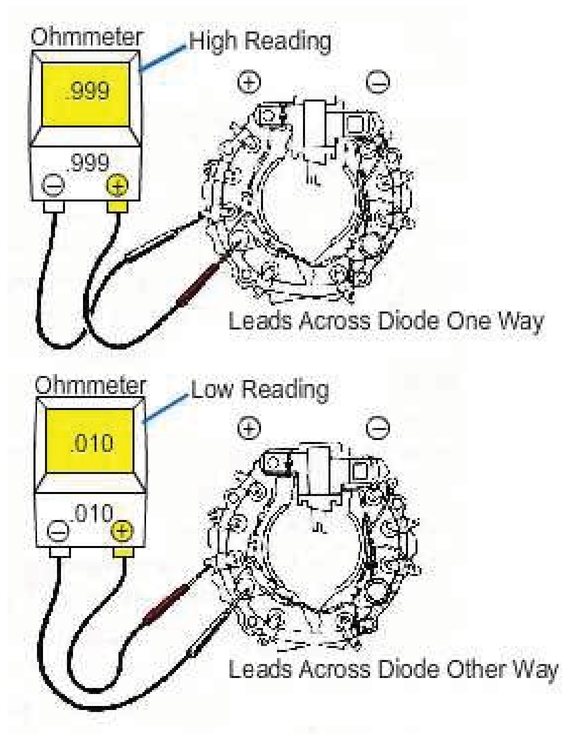

Figure 6-22 – Testing diodes.

If diodes were unsoldered for testing or replacement, they must be resoldered. Use a soldering gin and rosin-core solder to attach the diode leads as demonstrated in *Figure 6-23*.

A shorted diode or shorted winding will usually burn itself open. The pattern on the screen will show a shorted diode or open diode. Notice the similarity in the patterns. At any rate, the alternator will require service or replacement even though both output current and voltage regulation appear to be acceptable. As a general rule, a shorted diode affects the output more than an open diode does. It not only reduces the output, but it also opposes the next pulse by allowing the current to flow back through the winding containing the shorted diode.

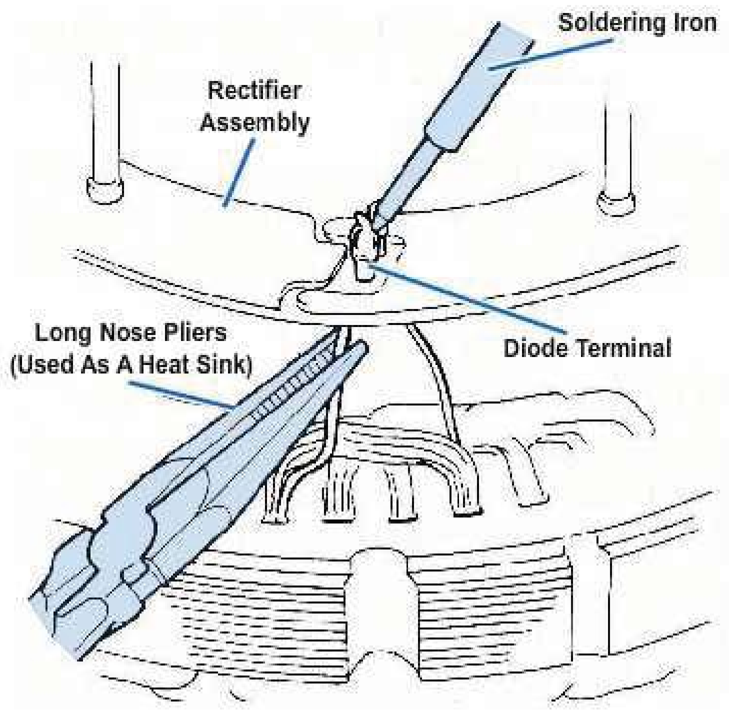

Figure 6-23 – Soldering diode leads or stator to rectifier wires.

3.3.0 Weak Diodes

As you can see from the screen pattern in *Figure 6-24*, there is no interruption in the rectification of the diodes. However, there is a high and low peak every sixth pulse, indicating that the output of one diode is low and that it may be deteriorating (high resistance). This pattern may also occur due to a shorted winding since the number of windings determines the amount of output as well as the condition (resistance) of the diodes.

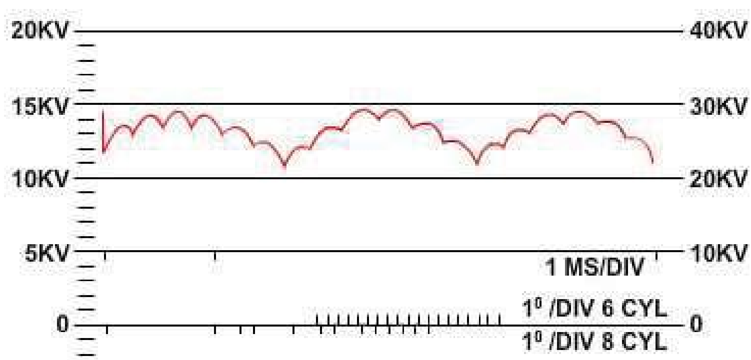

Figure 6-24 – Poor diode pattern.

3.4.0 Shorted Windings

A bad alternator stator can have shorted or open windings. Inspect the stator windings for signs of burning (darkened windings with a burned insulation smell). An open winding is usually detected using an ohmmeter.

To test a stator for open or grounded windings, connect an ohmmeter to the stator leads, as shown in *Figure 6-25*. Connections A and B will check for stator opens. They shall produce a low ohmmeter reading. If the reading is high (infinite), the windings are broken and the stator is defective.

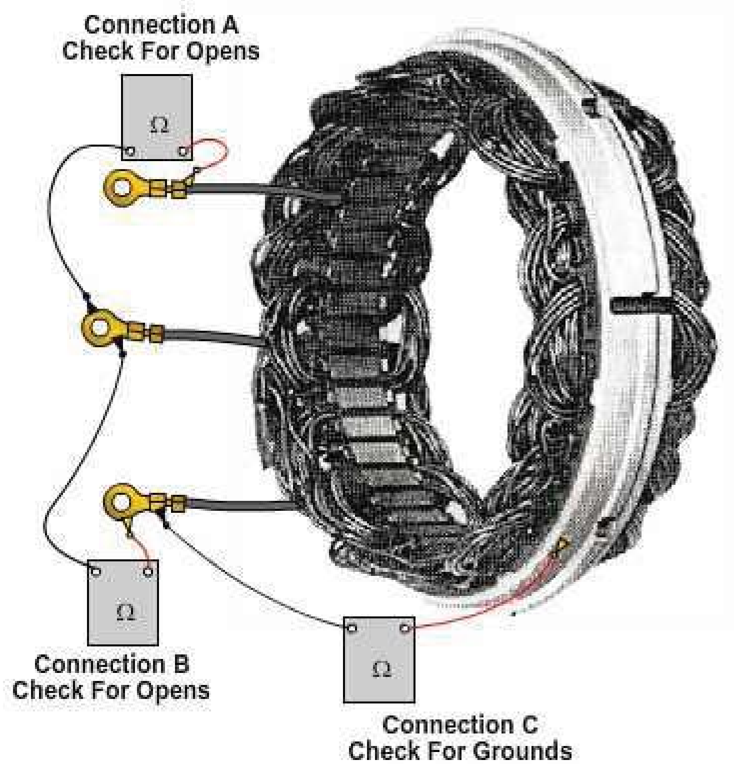

Figure 6-25 – Stator test.

4.0.0 TROUBLESHOOTING the CRANKING SYSTEM USING the BATTERY STARTER TEST

A dead or discharged battery is one of the most common reasons the starting system fails to crank the engine properly. The starting motor draws much more current (over 200 amps) than any other electrical component. A discharged or poorly connected battery can operate the lights, but it may not have enough power to operate the starter motor.

If needed, load-test the battery and make sure the battery is in good condition and is fully charged. A starter motor will not function without a fully charged and well-connected battery.

5.0.0 CRANK VOLTAGE TEST

The cranking voltage test measures the available voltage to the starter during cranking. To perform the test, disable the ignition or use a remote starter switch to bypass the ignition switch. Normally, the remote starter switch leads are connected to the positive terminal of the battery and the starter terminal of the solenoid or relay, as illustrated in *Figure 6-26*. Refer to the service manual for specific instructions on the model of vehicle being tested. Connect the voltmeter's negative lead to a good chassis ground. Connect the positive lead to the starter motor feed at the starter relay or solenoid. Activate the starter motor and observe the voltage reading. Compare the reading to the specifications given in the service manual. The normal voltmeter readings should be as follows:

4.8 volts or more for a 6-volt system

9.6 volts or more for a 12-volt system

18 volts or more for a 24-volt system

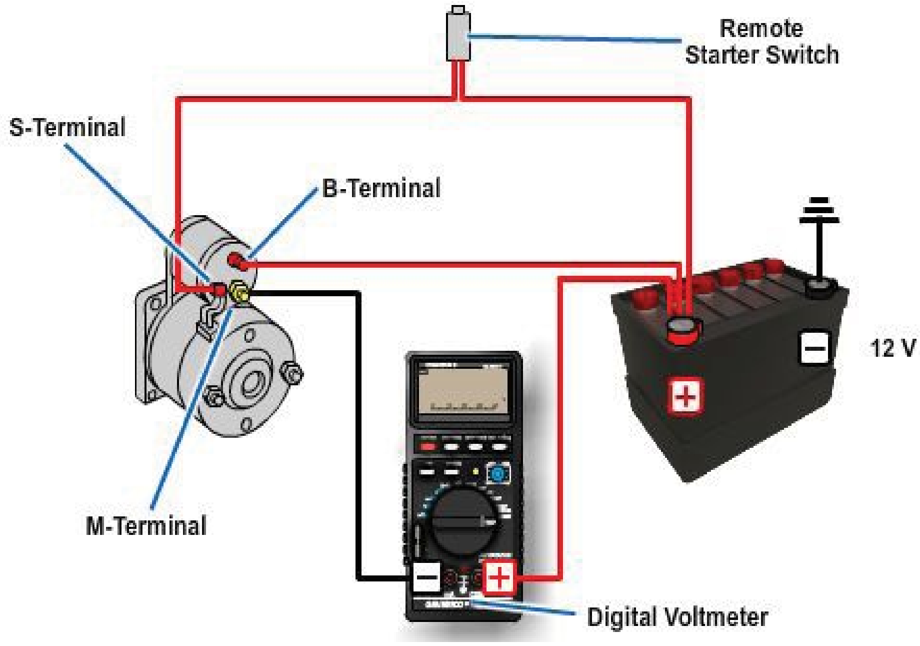

Figure 6-26 - Using a remote starter switch to bypass the control circuit and ignition system.

If the reading is above specifications but the starter motor still cranks poorly, the starter motor is faulty. If the voltage reading is lower than specifications, a cranking current test and circuit resistance test should be performed to determine if the problem is caused by high resistance in the starter circuit or an engine problem.

To check an excessive starting motor current, you can perform a starting motor current draw test of the 6-, 12-, or 24-volt series system.

6.0.0 STARTING MOTOR CURRENT DRAW TEST

A current draw test measures the current used by the starting system. It will quickly tell you about the starting motor and other system parts. If current draw is higher or lower than specifications, there is a problem.

To perform a current draw test, connect meters to measure the battery voltage and the current flow out of the battery. A load tester may also be used. Two testing methods are shown in *Figures 6-27.* In *Figure 6-27, View A,* a voltmeter and an ammeter are being used to measure starter current flow. A voltmeter reading is needed to compare different battery conditions. If current draw is not within specifications, there are starting system troubles.

Figure 6-27, View B is showing a battery load tester being used to check the starter current draw. Crank the engine and note the voltage reading. Then, load the battery to obtain the same voltage. This will equal the current draw of starting motor.

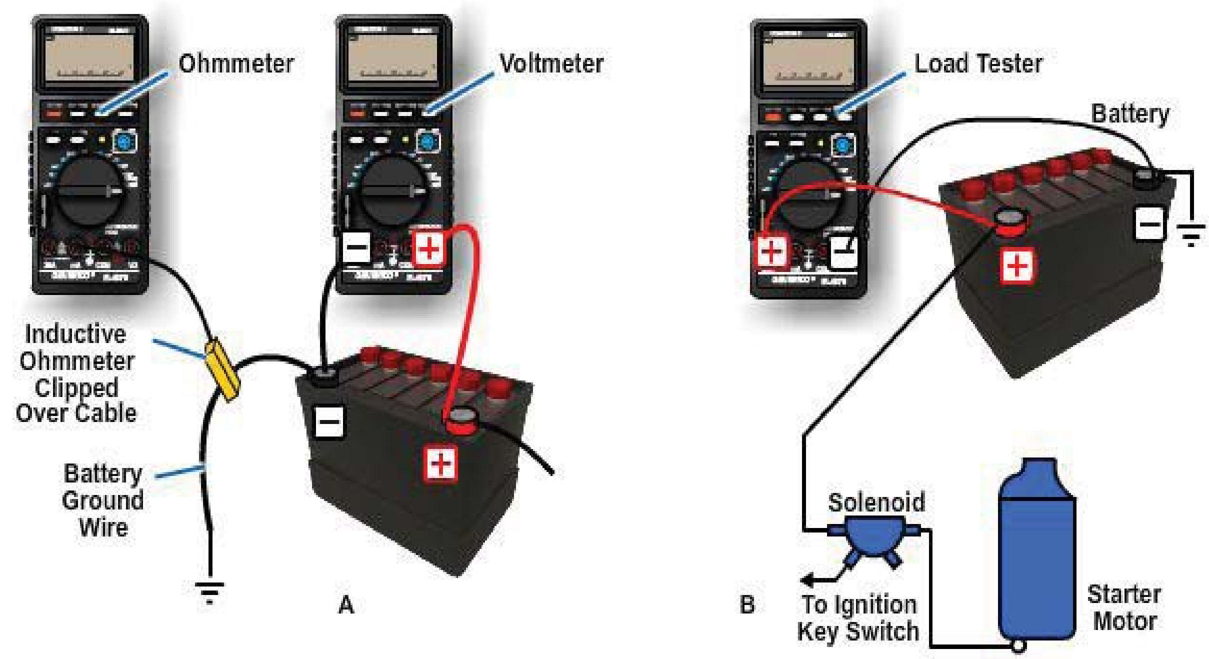

Figure 6-27 – Starter current draw test.

To keep the engine from starting during the test, disconnect the coil primary supply wire or ground the coil wire. You can also pull the fuse for the electric fuel pump if this is easier (direct ignition systems).

With a diesel engine, you must disable the injection system. You may have to unhook the fuel shutoff solenoid. Check the shop manual for specific details.

⚠ CAUTION ⚠

Do not crank the engine for more than 15-30 seconds or starter damage may result. Allow the starter to cool off for a few minutes if more cranking time is needed.

Crank the engine and note the voltage and current readings. If they are not within specifications, something is wrong in the starting system or engine. Further tests are needed.

7.0.0 STARTER INSULATED CIRCUIT RESISTANCE TEST (CABLE and SWITCHES)

The complete starter circuit is made up of the insulated circuit and the ground circuit. The insulated circuit includes all of the high current cables and connections from the battery to the starter motor.

To test the insulated circuit for high resistance, disable the ignition or bypass the ignition switch with a remote starter switch. Connect the positive (+) lead of the volt meter to the battery's (+) terminal post or nut. By connecting the lead to the cable, the point of high resistance (cable-to-post connection) may be bypassed. Connect the (-) lead of the voltmeter to the starter terminal at the solenoid or relay. Crank the engine and record the voltmeter reading. If the reading is within specifications (usually 0.2.and 0.6 voltage drop), the insulated circuit does not have excessive resistance. Proceed to the ground circuit test. If the reading indicates a voltage loss above specifications, move the negative lead of the tester progressively closer to the battery, cranking the engine at each test point. Normally, a voltage drop of 0.1 volt is the maximum allowed across a length of cable.

When excessive voltage drop is observed, the trouble is located between that point and the preceding point tested. It is a damaged cable or poor connection, an undersized wire, or possibly a bad contact assembly within the solenoid. Repair or replace any damaged wiring or faulty connections.

Refer to *Figure 6-28*. When you test a 6-volt system, the completed circuit shown in *View* A allows a 0.2-volt loss and that of *view* B allows a 0.3-volt loss. When you test a 12-volt system, the completed circuit, as shown in *Figure 6-28, View* A, allows a 0.4-volt loss and that of *View* B, a 0.3-volt loss, and that of view C, a 0.1 volt loss. If testing a 24- or 32-volt system, refer to the manufacturer's specifications. If the voltmeter reading is more than specified for the type of system being tested, high resistance is indicated in the cables, switches, or connections. Repeat the test with the voltmeter connected to each cable, switch, and connector of the circuit. The maximum readings taken across these parts should not exceed the values listed below.

	6-Volt System	12-Volt System
Each cable	0.1 volt	0.2 volt
Each switch	0.1 volt	0.1 volt
Each connector	0.0 volt	0.0 volt

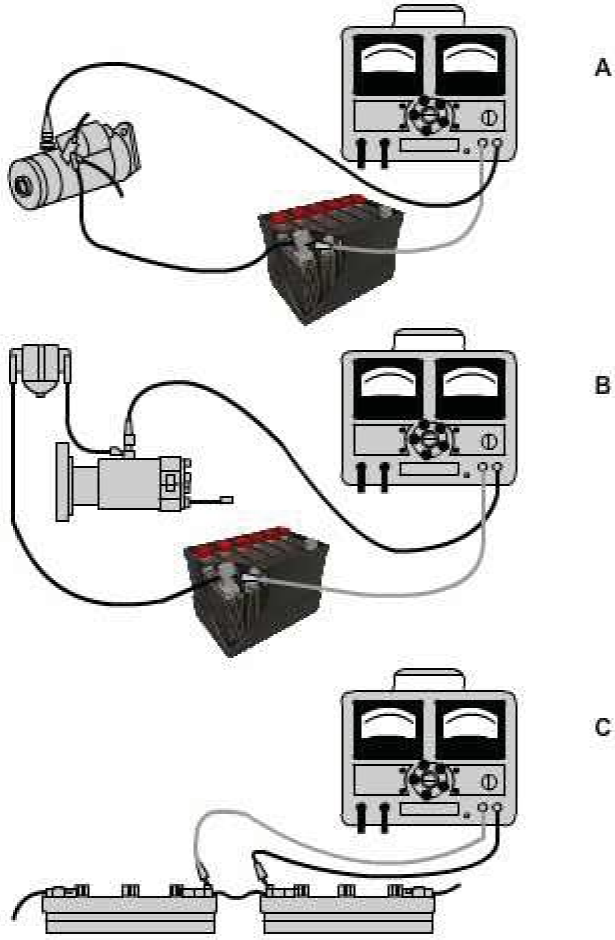

Figure 6-28 - Starter insulated circuit resistance test.

8.0.0 STARTER GROUND CIRCUIT RESISTANCE TEST

The ground circuit provides the return path to the battery for the current supplied to the starter by the insulated circuit. The circuit includes the starter-to-engine, engine-to-chassis, and chassis-to-battery ground terminal connections.

To test the ground circuit for high resistance, disable the ignition or bypass the ignition switch with a remote starter switch. Refer to *Figure 6-29* for the proper test connection. Crank the engine and record the voltmeter reading.

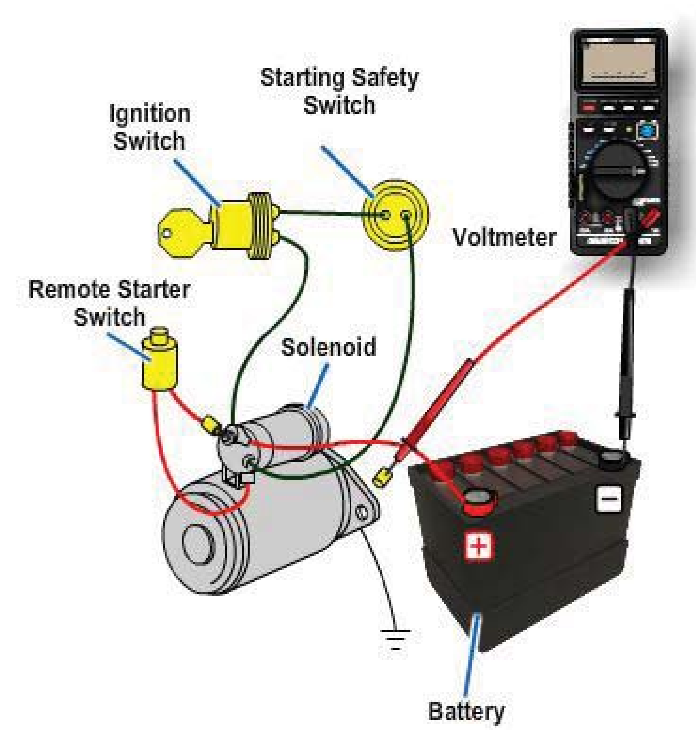

Figure 6-29 - Starter ground circuit resistance test.

Good results would be less than 0.2-volt drop for a 12-volt system. A voltage drop in excess of this indicates the presence of a poor ground circuit connection resulting from a loose starter motor bolt, a poor battery ground terminal post connector, or a damaged undersized ground system wire from the battery to the engine block. Isolate the cause of excessive voltage drop in the same manner as recommended in the insulated circuit resistance test by moving the positive (+) voltmeter lead progressively closer to the battery. If the ground circuit tests out satisfactorily and a starter problem exists, move on to the control circuit test.

9.1.1 IGNITION SYSTEMS

The ignition system of a spark-ignition engine produces the high voltage needed to ignite the fuel charges in the cylinders. The system must create an electric arc across the gaps at the spark plugs. These arcs must be timed so they happen exactly as each piston nears the top of its compression stroke. The heat of the arcs starts combustion and produces the engine's power stroke.

More recently, ignition systems have been developed to reduce emissions and improve engine performance, fuel economy, and dependability.

An ignition system performs the following six functions:

1. Provides a method of turning a spark ignition on and off
2. Operates on various supply voltages (battery or alternator voltage)
3. Produces high-voltage arcs at the spark plug electrodes to start combustion
4. Distributes high-voltage pulses to each spark plug in the correct sequence
5. Times the spark so that it occurs as the piston nears TDC on the compression stroke
6. Varies spark timing as engine speed, load, and other conditions change

The ignition system changes battery voltage to a very high voltage and then sends the high voltage to the spark plugs. The parts needed to do this include the following:

1. Battery-provides power for the system.
2. Ignition switch-allows driver to turn ignition on and off.
3. Ignition coil-changes battery voltage into 30,000 volts or more during normal operation. It has the potential to produce up to 60,000 volts.
4. Switching device-uses high voltage from the ignition coil to produce an arc, igniting the fuel charge.
5. Ignition system wires-connect ignition system components.

When the ignition switch is on and the switching device is closed (conducting current), current flows through the ignition coil. When the piston is near TDC on its compression stroke, the switching device opens to stop current flow through the ignition coil. This causes the coil to produce a high-voltage surge, which flows through the spark plug wire and arcs across the spark plug's electrodes.

The electric arc, or spark, at the spark plug ignites the fuel mixture. The mixture begins to burn, forming pressure in the cylinder for the engine's power stroke.

When the ignition key is turned off, an arc cannot be produced at the spark plugs and the engine stops running.

An actual ignition system is much more complex than the one just discussed. Vehicles have multiple-cylinder engines, and the timing of the spark must vary with operating conditions.

9.1.1 Computerized Ignition System

The computer ignition system is known as an electronic spark advance system or also as computer-controlled spark advance system that uses engine sensors, an ignition control module, and/or a computer (engine control module or power train control module) to adjust ignition timing. A distributor may or may not be used in this type of system. If a distributor is used, it will not contain centrifugal or vacuum advance mechanisms.

The engine sensors check various operating conditions and send data representing these conditions to the computer. The computer can then analyze the data and change ignition timing for maximum engine efficiency.

Sensors that can affect the ignition system include:

- Crankshaft position sensor-reports piston position.
- Engine speed sensor-reports engine rpm to the computer.
- Intake vacuum sensor-measures engine vacuum, an indicator of load.
- Camshaft position sensor-tells the computer which cylinder is on its power stroke.
- Manifold absolute pressure sensor-measures engine intake manifold vacuum, an indicator of load.
- Intake air temperature sensor-checks temperature of air entering the engine.
- Engine coolant temperature sensor-measures the operating temperature of the engine.
- Knock sensor-allows the computer to retard timing when the engine pings or knocks.
- Throttle position sensor-notes the position of the throttle.
- Transmission/transaxle sensor-detects gear selection.

The computer receives input signals (different current or voltage levels) from these sensors. It is programmed (preset) to adjust ignition timing to meet different engine conditions. The computer may be mounted on the air cleaner, on the fender inner panel, under the dash, or under a seat.

The computer can also measure battery voltage to compensate for voltage variations due to battery state of charge, accessory loads, etc.

Electronic Spark Advance Operation. Let us discuss a sample situation of an electronic advance operation. A vehicle is travelling down the highway at 55 mph. The crankshaft sensor detects moderate engine rpm. The throttle position sensor detects part throttle. The intake air and coolant temperature sensors report normal operating temperatures. The manifold absolute pressure sensor sends high vacuum signals to the computer.

The computer could then calculate that the engine needs almost maximum spark advance. The timing occurs several degrees before TDC on the compression stroke. This ensures that the engine attained high fuel economy on the highway. There is enough time for all the fuel to burn and produce maximum pressure on the downward motion of the pistons.

If the operator began to pass a vehicle, engine intake manifold vacuum will drop to a very low level. The manifold absolute pressure sensor signal is fed to the computer. The throttle position sensor signal will detect wide open throttle. Other sensor outputs will stay about the same. Based on the signals from the manifold absolute pressure sensor and throttle position sensor, the computer could then retard ignition timing to prevent spark knock or ping. Since computer systems vary, refer to a service manual for specific procedures on the operation of your particular model.

9.2.1 Electronic Ignition System

An electronic ignition system, also called a solid state or transistor ignition system, uses an electronic control circuit and a distributor pickup coil to operate the ignition coil. *Figure 6-30* shows a typical circuit for an electronic ignition.

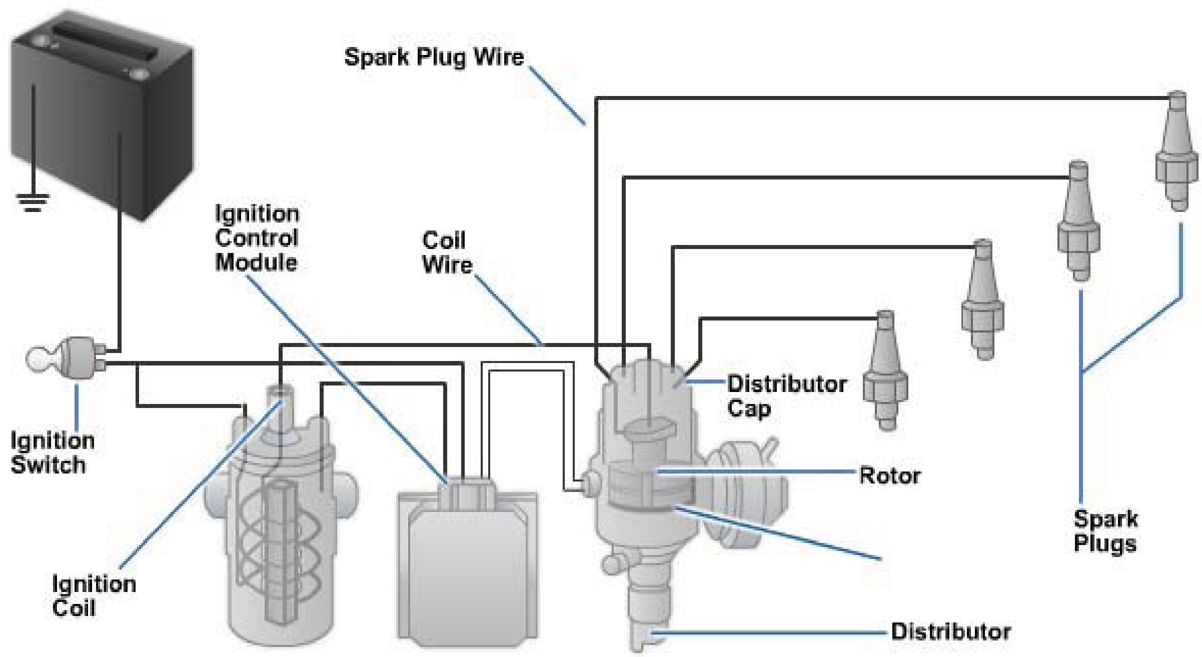

Figure 6-30 - Electronic ignition system.

An electronic ignition is more dependable than a contact point type. There are no mechanical breakers to wear or burn. This helps avoid trouble with ignition timing and dwell.

An electronic ignition is also capable of producing much higher secondary voltages than a breaker point ignition. This is an advantage because wider spark plug gaps and higher voltages are needed to ignite lean air-exhaust emissions and fuel consumption.

Ignition control module. The ignition control module (ICM) is an "electronic switch" that turns the ignition coil primary current on and off. The ICM does the same thing as contact points but more efficiently.

An ignition control module is a network of transistors, resistors, capacitors, and other electronic components. The circuit is sealed in a plastic or metal housing and can be located a couple of locations such as:

- On the side of the distributor
- In the engine compartment

- Inside the distributor
- Under the car dash

Trigger Wheel. The trigger wheel, also called the reluctor or pole piece, is fastened to the upper end of the distributor shaft, as shown in *Figure 6-31*. The trigger wheel replaces the distributor cam used in a contact point distributor. One tooth is normally provided on the wheel for each engine cylinder.

Pickup coil. The pickup coil, also called the sensor assembly or sensor coil, produces tiny voltage pulses that are sent to the ignition control module, as illustrated in *Figure 6-31*. The pickup coil is a small set of windings that forms a coil.

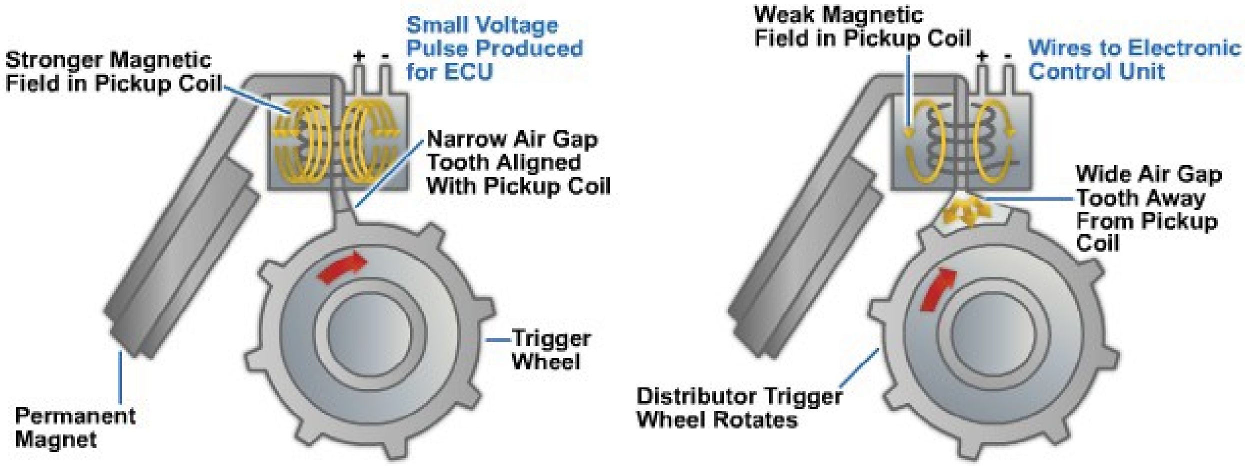

Figure 6-31 - Electronic ignition system trigger wheel and pickup coil.

As a trigger wheel tooth passes the pickup coil, it strengthens the magnetic field around the coil. This causes a change in the current flow through the coil. As a result, an electrical impulse (voltage or current change) is sent to the ignition control module as each trigger wheel tooth passes the pickup unit.

Hall-effect pickup. A hall-effect pickup is a solid-state chip or module that produces an electrical signal when triggered by a slotted wheel. A constant amount of current is sent through the device. A permanent magnet is located next to the Hall-effect chip, as shown in *Figure 6-32*.

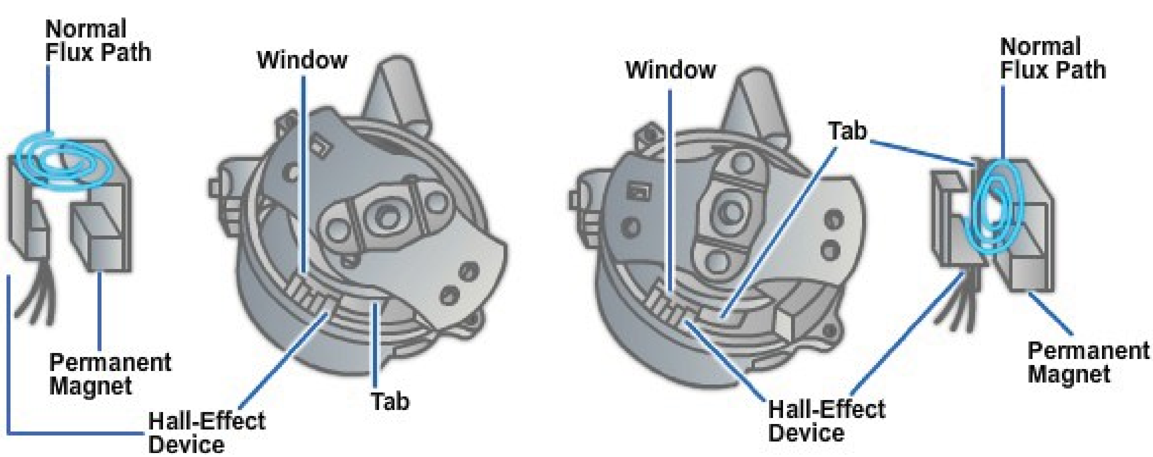

Figure 6-32 - Hall-effect pickup.

When the slotted wheel's tab passes between the permanent magnet and the Hall-effect chip, the magnetic field is blocked, decreasing the chip's output voltage (sensor or switch off). When the slotted wheel's tab moves out from between the magnet and chip, magnetic field action increases the chip's voltage output (sensor or switch on). This on/off action operates the ignition control module.

Optical pickup. An optical pickup uses light-emitting diodes (LED) and photo diodes (light sensors) to produce an engine speed signal for the ignition system. The rotor plate rotates between the light-emitting diodes and the photo diodes. When a slot, or window, passes between the two diodes, light from the LEDs strikes the photo diodes and an electrical signal is generated.

An optical pickup is seldom used because its operation is adversely affected by a dirt buildup on the LEDs and photo diodes.

Electronic ignition system operation. With the engine running, the trigger wheel spins inside the distributor. As the teeth pass the pickup, a change in the magnetic field causes a change in output voltage, or current. This output voltage, which represents engine rpm, is sent to the ignition control module.

The ignition control module increases these tiny pulses into on/off current cycles for the ignition coil. When the module is on, current flows through the primary windings of the ignition coil, developing a magnetic field. Then, when the trigger wheel and pickup turn off the module, the ignition coil field collapses and fires a spark plug.

Dwell time (number of degrees of camshaft rotation that the circuit conducts current to the ignition coils) is designed into the ignition control module's electronic circuit. It is not adjustable.

9.2.1 Distributorless Ignition System

A distributorless ignition, also referred to as a computer-coil ignition, uses multiple ignition coils, a coil control unit, engine sensors, and a computer (engine control module) to operate the spark plugs. A distributor is not needed in this type, as depicted in the diagram *Figure 6-33*.

An electronic coil module consists of two or more ignition coils and a coil control unit (electronic circuit) that operates the coils. Each coil in the coil module serves two cylinders. Therefore, a four-cylinder engine has a coil module with two ignition coils. A six-cylinder engine, on the other hand, needs a coil module with three ignition coils.

The coil control unit performs about the same function as the ignition module in an electronic ignition. It is more complex, however, because it must analyze data from the engine sensors and the engine control module.

The coils in the distributorless ignition system are wired so they fire two spark plugs at once. One spark plug fires during its cylinder's exhaust stroke. The other plug fires during its cylinder's power stroke, so its spark has no effect on engine operation.

A camshaft position sensor sends electrical pulses to the coil control unit, providing data on camshaft and valve position. The crankshaft position sensor feeds pulses to the control unit that show engine speed and piston position. A knock sensor may be used to allow the system to retard timing if the engine begins to ping or knock.

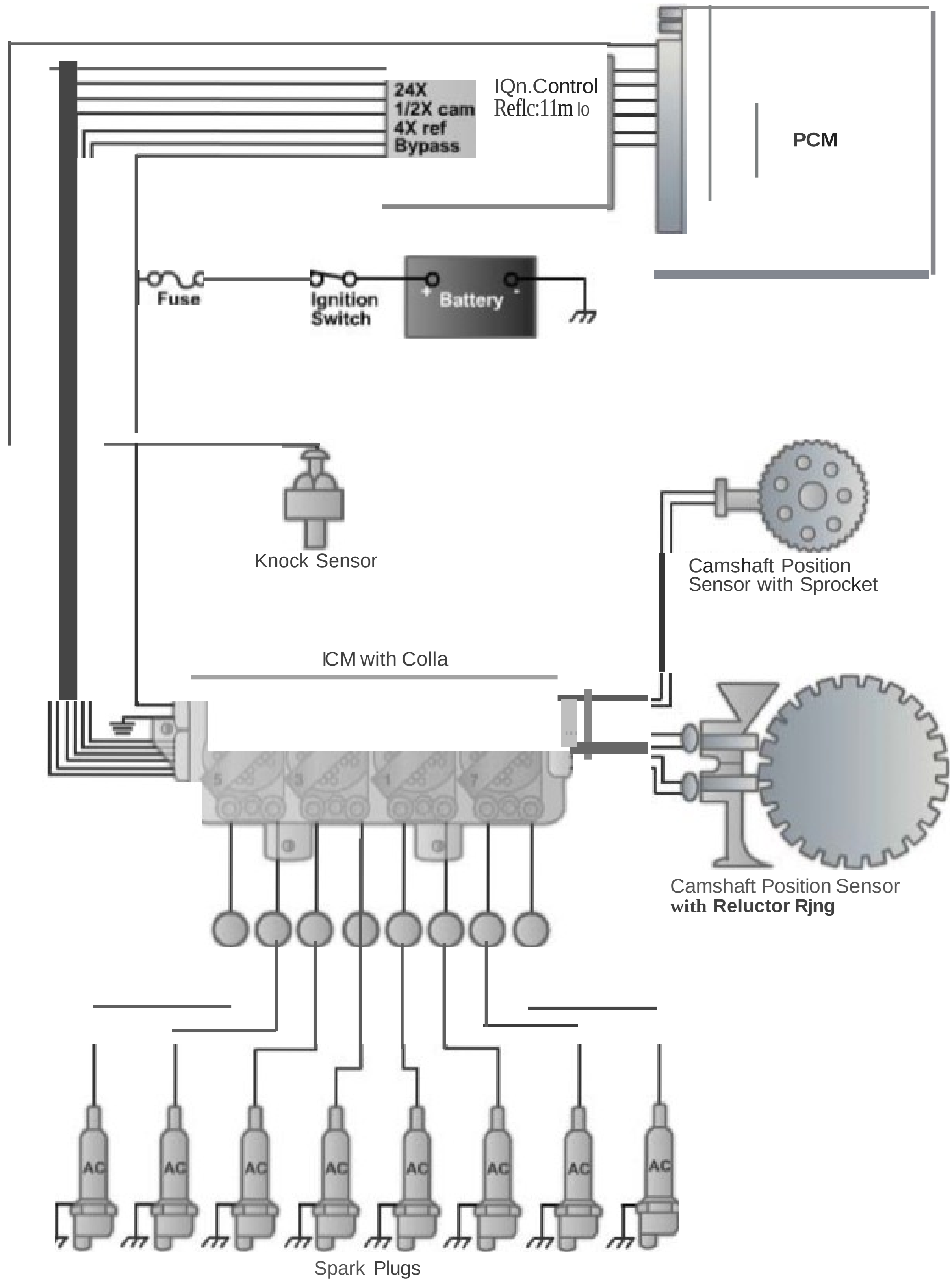

Figure 6-33 - Schematic distributorless ignition system.

9.2.2 Distributorless Ignition System Operation

Operation. The on-board computer monitors engine operating conditions and controls ignition timing. Some sensor data is also fed to the electronic coil module, illustrated in *Figure 6-34*.

When the computer and sensors send correct electrical pulses to the coil module, the module fires one of the ignition coils.

Since each coil secondary output is wired to two spark plugs, both spark plugs fire. One produces the power stroke. The other spark plug arc does nothing because that cylinder is on the exhaust stroke. Burned gases are simply being pushed out of the cylinder.

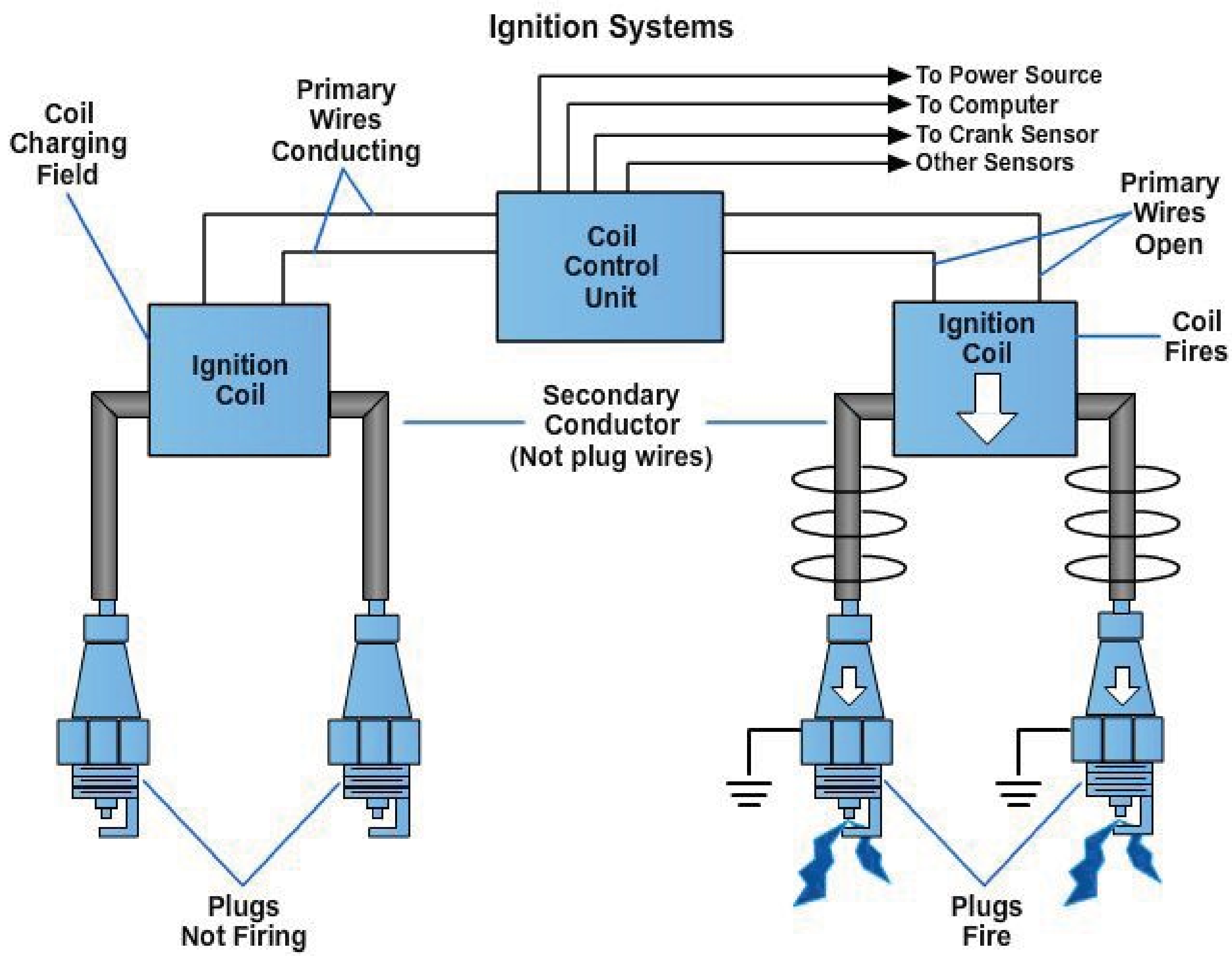

Figure 6-34 - Illustration of a distributorless ignition operation.

When the next pulse ring tooth aligns with the crank sensor, the next ignition coil fires. Another two spark plugs arc for one more power stroke. This process is repeated over and over as the engine runs.

Advantages.

A distributorless ignition system has several possible advantages over ignition systems with a distributor. Some of these include:

1. No rotor or distributor cap to burn, crack, or fail
2. All computer controlled advance - no mechanical weights to stick or wear, no vacuum advance diaphragm to rupture or leak

3. Play in timing chain and distributor drive gear eliminated as a problem that could upset ignition timing; crank sensor unaffected by slack in timing chain or gears
4. More dependable due to fewer moving parts to wear and malfunction
5. Requires less maintenance; ignition timing is usually not adjustable.

9.3.1 Integrated Direct Ignition

In a direct ignition system, one coil assembly is mounted directly above each spark plug. This eliminates the need for spark plug wires. It also allows the use of smaller ignition coils. A four-cylinder engine uses four ignition coils. A direct ignition is very similar to a disributorless ignition, except for the lack of spark plug wires and the increased number of coils. The other components in a direct ignition system (computer, sensors, etc.) are the same as those used in a distributorless system.

The direct ignition coils fire only on the power strokes. They do not fire on the exhaust strokes like wasted spark ignition systems. *Figure 6-35* shows a cutaway of the direct ignition coils for a four-cylinder engine.

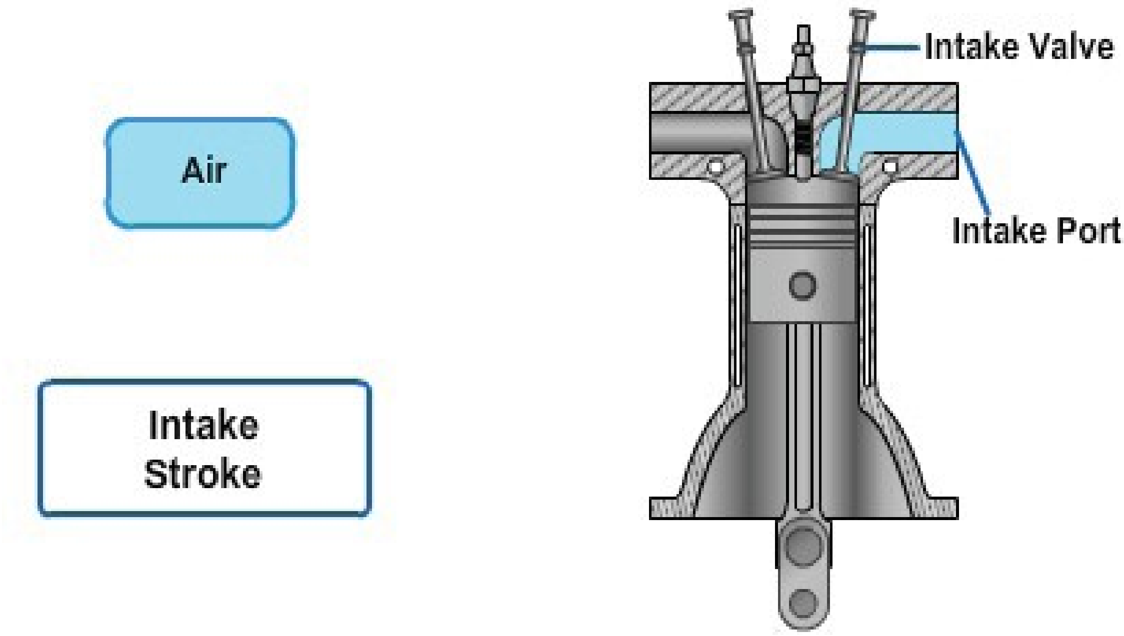

Figure 6-35 – Cutaway of an ignition coil for a direct ignition system for a four cylinder engine.

Sensor inputs allow the electronic control module to alter ignition timing with changes in operating conditions. The control unit can then make and break primary current into the correct ignition coil to make it produce high voltage.

On occasion there is "confusion" in the shops and even in the service manuals over the terms distributorless ignition and direct ignition, and they are misused or get switched. Just keep this in mind when reading the manuals or discussing the systems:

- A distibutorless ignition may or may not use spark plug wires, but it will have some form of conductor between the coils and spark plugs.
- A direct ignition system mounts one ignition coil over the top of the each spark plug without a spark plug wire.

Some mechanics mistakenly call a distributorless ignition a direct ignition system when high-voltage output is not directly fed to each spark plug.

In some multi-coil ignition systems, the engine control computer measures the time needed to charge each ignition coil. Charge time varies with each coil's resistance/inductance and with the output voltage from the alternator. The computer uses this charge time to determine the ignition coil on-time for optimum spark plug arc duration and spark timing.

10.0.0 TROUBLESHOOTING

An ignition system is one of the most important systems on a gasoline-powered engine. If a problem exists in the ignition, engine performance and emissions will suffer. As a mechanic, you must be able to quickly and accurately correct ignition system troubles.

10.1.0 Computerized Ignition System

Many of the components of a computer controlled ignition system are similar to those of electronic or contact point ignition systems. This makes testing about the same for many parts (spark plugs, secondary wires, ignition coil). However, the computerized ignition has engine sensors and a computer, which add to the complexity of the system.

Computer self-diagnosis mode. Most computerized systems have a check engine light in the dash that glows when a problem exists. The computer can be activated to produce a number code. The code can be compared to information in the vehicle's service manual to pinpoint the source of a problem. This makes testing and repairing a computerized system much easier.

WARNING

A computerized ignition system can be seriously damaged if the wrong wire is shorted to ground or if a meter is connected improperly. Always follow manufacturer's testing procedures.

Computer ignition testers. Most auto makers provide specialized testing equipment for their computerized ignition systems. Like an ignition control module tester, the computer system tester plugs into the wiring harness. It will then measure internal resistances and voltages in the system to determine where a problem is located.

Ignition control module. A faulty ignition control module will produce a wide range of problems: engine stalls when hot, engine cranks but fails to start, engine misses at high or low speeds, etc. Quite often, an ignition control module problem will show up after a period of engine operation. Engine heat will soak into the module, raising its temperature. The heat will upset the operation of the electronic components in the unit.

Testing and ignition control module. You will generally find that service manuals list the ignition control module as one of the last components to test when troubleshooting an ignition system. If all the other components are in good working order, then the problem might be in the ignition control module.

If a specialized tester is available, it may be used to quickly determine the condition of the ignition control module. The wires going to the module are unplugged and the tester is connected to the module. The tester will then indicate whether an ignition control module fault exists.

Heating an ignition control module. The microscopic components (transistors, diodes, capacitors, resistors) inside the ignition control module are very sensitive to high temperatures and vibration.

When testing the control module, many mechanics use a heat gun or light bulb to warm the unit. This will simulate the temperature in the engine compartment after the engine has been running. The heat may make the control module act up and allow you to find an intermittent problem.

Do not apply too much heat to an ignition control module or it may be ruined. Only heat the unit to a temperature equal to its normal operating temperature.

10.2.1 Electronic Ignition System

Electronic ignition system service. As you have just learned, most electronic ignition systems use a pickup coil to sense trigger wheel (distributor shaft) rotation. The pickup coil sends small electrical impulses to the ignition control module.

If the distributor fails to operate properly, the complete ignition system can stop functioning. It is important to know how to make several basic tests on an electronic ignition system.

Pickup coil service. A bad pickup coil can produce a wide range of engine problems:stalling, missing, no-start troubles, and loss of power at specific speeds. If the tiny windings in the pickup coil break, they can cause problems that only occur under certain conditions. Also, because of vibration and movement, the thin wire leads going to the pickup coil can break. Though the insulation may look fine, the conductor could be damaged inside the insulation. When this happens, the engine may lope, miss, or not run.

Testing a magnetic pickup coil. A magnetic pickup coil or a speed sensor can be located in the distributor or on the engine block (crankshaft speed or position sensor). Tests for either type are similar.

Your scan tool may show a readout of primary circuit problems with a bad pickup coil or crankshaft sensor. Refer to your service manual for in-depth details.

A magnetic pickup coil test compares actual sensor resistance or voltage output with specifications. If resistance or voltage output is too high or low, the unit is bad.

To perform a pickup coil test:

1. Connect an ohmmeter or low-reading AC voltmeter across the pickup coil output leads, as shown in *Figure 6-36*.
2. Observe the meter reading. Ohmmeter readings will usually vary between 250 and 1500 ohms. If an AC voltmeter is used, a small AC voltage (3-8 volts) should be produced by the magnetic pickup coil when the engine is cranked.

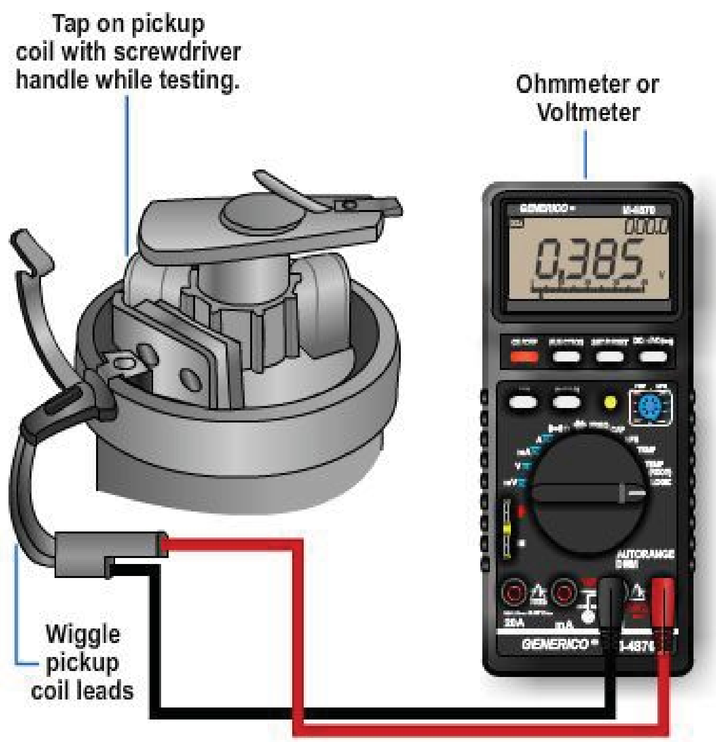

Figure 6-36 - Testing magnetic pickup coils.

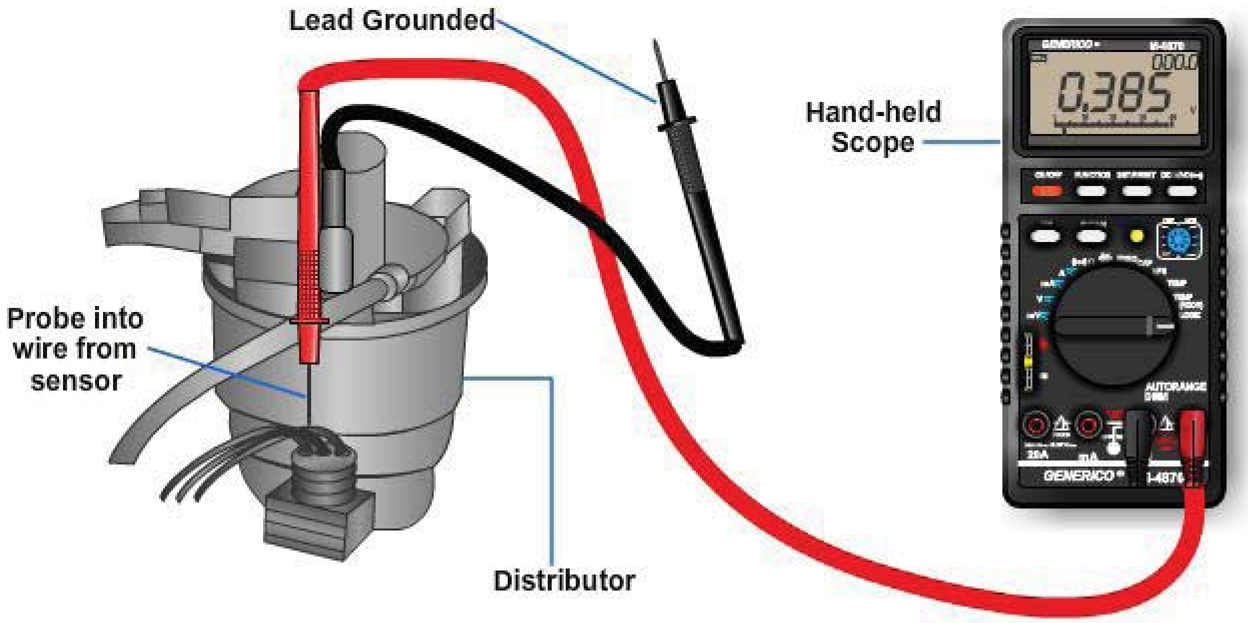

Figure 6-37 - Testing a Hall-effect sensor.

Check a service manual for the exact specifications.

3. Wiggle the wires to pickup coil while watching the meter. This will help locate a break in the leads to the pickup. Also, lightly tap on the coil with the handle of a screwdriver. This could uncover any break in the coil windings.
4. If the meter reading is not within specifications, or if the reading changes when the leads are moved or the coil is tapped, replace the pickup coil.

Testing Hall-effect and optical sensors. Hall-effect and optical sensors are tested in much the same way as the more common magnetic sensor. You can check their output signals and compare them to specifications. However, they are often tested with a scope to analyze more accurately their output signals.

Hall-effect sensor. A Hall-effect sensor test is best done by checking the sensor's output waveform with an oscilloscope. Without disconnecting the circuit reference voltage, probe the output wire at the sensor connector. The service manual will give pin numbers for probing, as shown in *Figure 6-37, View A*.

A Hall-effect sensor waveform should switch rapidly, have vertical sides, and have the specified voltage output (typically about 4-5 volts peak-to-peak). The top of the square wave should reach reference voltage and the bottom should reach ground, or zero. Signal frequency should change with engine cranking speed or engine rpm, as shown in *Figure 6-37, View B.*

Hall-effect pickups can be found in distributors and some crankshaft position sensors. Refer to the service manual for your vehicle.

Optical sensor testing. An optical sensor can also be tested with an oscilloscope. You can probe the output wires from the sensor and compare the waveform to specifications.

An optical pickup test measures the output generated by the photo diodes as they are energized by the LEDs. It is also easily done with a hand-held scope probing into the sensor's electrical connector. Again, refer to the service manual to find the connector pin numbers for the optical pickup's output wire. Optical sensors are used in a few distributor designs and are never used in crankshaft sensors.

An optical sensor's waveform should have straight sides and adequate voltage output. The upper horizontal line on the waveform should almost reach reference voltage. The bottom horizontal line should almost reach ground, or zero, as shown in *Figure 6-38*.

Remember that optical sensors are susceptible to dirt. An oil mist or a film of dirt can prevent light transfer from the LEDs to the photo diodes. Again, refer to the service manual for specifications.

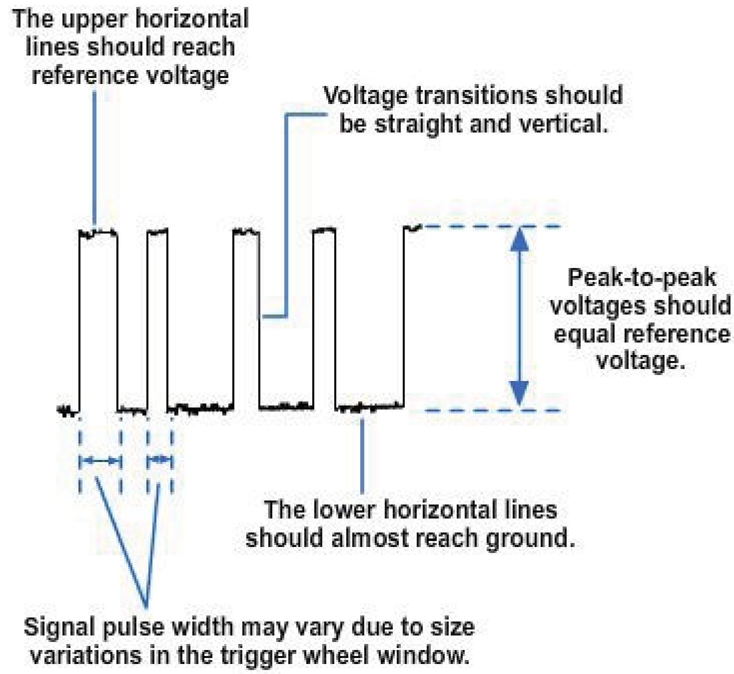

Figure 6-38 - Typical waveform generated by an optical sensor.

10.2.1 Distributorless Ignition System

Distributorless ignition system service. Many of the components used in a computer-controlled ignition system are similar to those found in older electronic or contact point systems. Testing procedures for parts, such as spark plugs, secondary wires, ignition coils, etc., remain the same. However, the computerized ignition system contains engine sensors and a computer, which make it more difficult to troubleshoot and service these systems.

In systems containing a coil pack that fires two spark plugs at the same time, a bad ignition coil will kill two cylinders. For example, if a four-cylinder engine has two ignition coils, one bad coil will make the engine run on two cylinders, producing a very rough idle. If two dead cylinders correspond to a specific coil, test that ignition coil.

10.3.0 Integrated Direct Ignition System

Direct ignition system service. The procedures for servicing a direct ignition system are similar to the procedures described for other types of ignition systems. The main difference is that a direct ignition system has a coil for each cylinder.

A direct ignition coil is tested like other ignition coils. Measure both primary and secondary winding resistance. Also, make sure you are getting primary voltage to the coil.

There are tricks for working on a direct ignition system. Remove the coil cover and connect conventional spark plug wires between the coil output terminals and the spark plugs. This will let you connect a timing light, an inductive tachometer, a spark tester, etc., to the system.

Checking with an oscilloscope. Oscilloscopes can display distributorless and direct ignition system patterns. To read the distributorless ignition system (DIS) pattern, the oscilloscope has leads that are attached to each plug wire. Since direct systems have no plug wires, connections must be made to the primary side of the ignition system. If the scope was originally designed for distributor ignitions, an adapter must be used to sort out the patterns developed by the individual coils. Newer oscilloscopes are able to read the direction of the current flow in each wire. They use the current direction information to determine the firing order and which coils fire which plugs. Most scopes today can also measure the voltage and amperage of individual coils.

Oscilloscopes setup for distributorless ignition systems and direct systems is similar to that for a system with a distributor. To check a DIS ignition, make the primary and secondary wire connection as instructed by the scope's operating manual. Once the connections are made, set the oscilloscope controls to the DIS settings. Then start the engine and observe the secondary pattern. The scope pattern will resemble the pattern produced by a distributor ignition. Look for high or low firing lines that indicate fouled plugs or faulty secondary wires. As with a distributor system, a lack of oscillations often indicates a shorted coil winding.

Before deciding that the system is okay, check the DIS primary pattern. The primary pattern may show problems that are not visible in the secondary pattern. On a direct ignition system, only the primary pattern can be displayed. *Figure 6-39* shows the primary voltage and amperage in a DIS coil during two firing cycles. Comparing this pattern to a known good pattern enables the mechanic to locate a problem in the coil, module, or primary side connections.

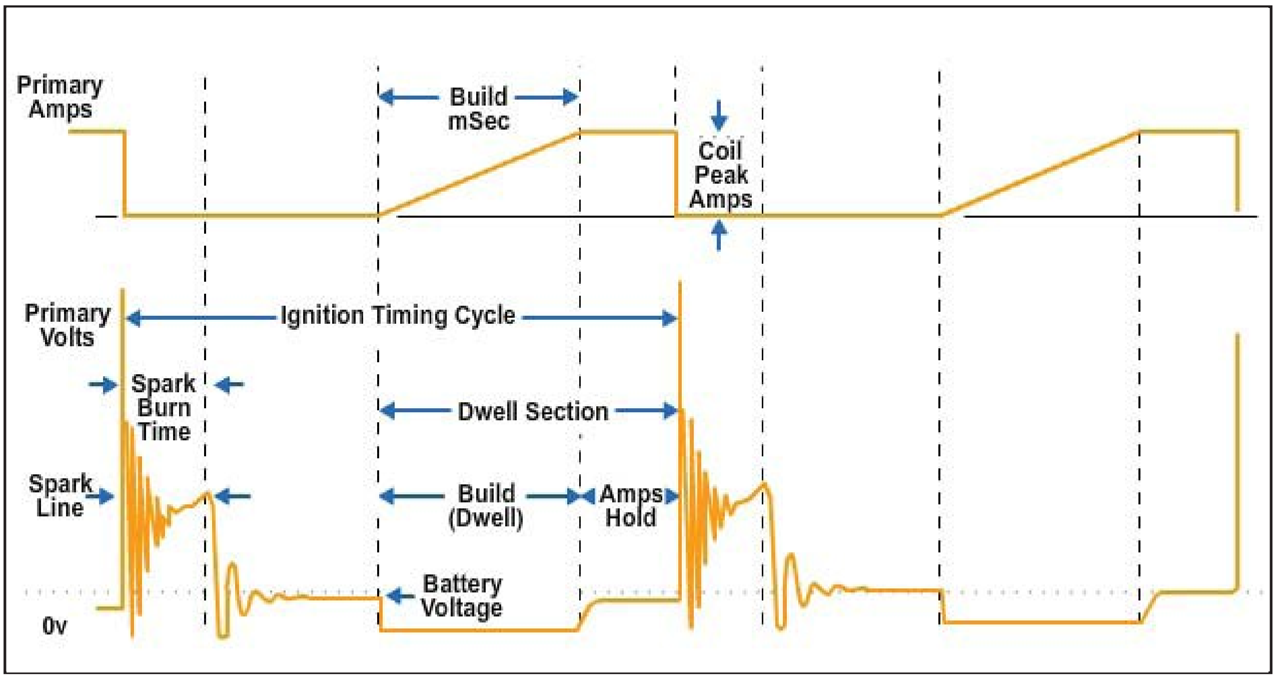

Figure 6-39 - An illustration showing the primary pattern of a DIS system.

One advantage of testing a DIS or direct ignition system with multiple coils is that the operation of the coils can be compared to determine if one of them is not working properly. *Figure 6-40* shows DIS coil amperage draws for a V8 engine. All the coils are drawing about the same amount of current, indicating that all are performing at the same level. If one coil draws much more or much less current than the others, there is a problem. The problem could be in the coil itself or in the associated plugs or wires. Sometimes the ignition module driver for the coil in question has failed, but this is rare.

11.0.0 TROUBLESHOOTING LIGHTING SYSTEMS and ELECTRICAL ACCESSORIES

11.1.0 Headlights

Sealed-Beam Headlights. The standard sealed-beam headlight is an air-tight assembly with a filament, reflector, and lens fused together. The parabolic reflector is sprayed with vaporized aluminum and the inside of the lamp is typically filled with argon gas. The reflector intensifies the light produced by the filament, and the lens directs the light to form the required light beam pattern. The lens is designed to produce a broad, flat beam pattern. The light from the reflector is passed through the concave prisms in the glass lens.

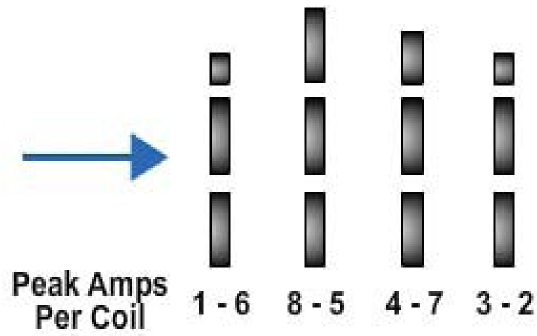

Figure 6-40 – DIS coil amperage draw.

Today, most commonly used sealed-beam headlight is the halogen type. A halogen lamp typically consists of a small bulb filled with iodine vapor. The bulb is made of high-temperature-resistant glass and it surrounds a tungsten filament. The halogen-filled inner bulb is then installed in a sealed glass or plastic housing, as shown in *Figure 6-41.* With the halogen added to the inner bulb, the tungsten filament is capable of withstanding higher temperatures, and it can burn more brightly.

Halogen is the term used to identify a group of chemically related nonmetallic elements. These elements include chlorine, fluorine, and iodine.

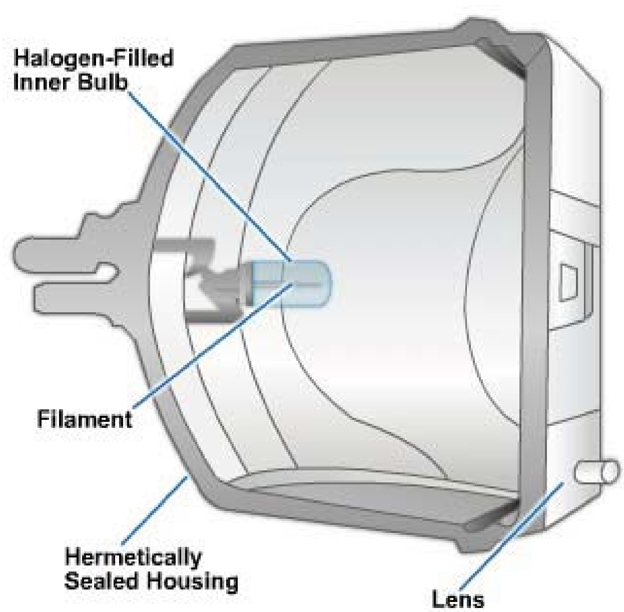

Figure 6-41 - Halogen sealed-beam headlight with an iodine vapor light.

NOTE

Because the filament is contained in the inner bulb, cracking or breaking of the housing or lens does not prevent a halogen bulb from working. As long as the filament envelope has not been broken, the filament will continue to operate. However, a broken lens results in poor light quality and the lamp assembly should be replaced.

Low- and high-beam filaments are placed at slightly different locations within a sealed-beam bulb. The filament location, relative to the reflector, determines how light passes through the bulb's lens (*Figure 6-42*), which in turn determines the direction in which the light shines. In a dual filament lamp, the lower filament is used for the high beam and the upper filament is used for the low beam.

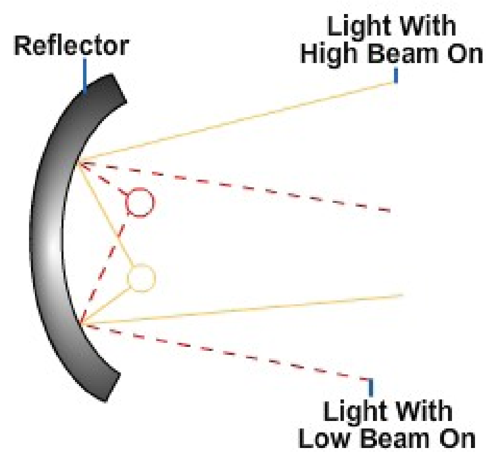

Figure 6-42 – Light beam projection is controlled by filament placement.

Various methods are used to identify sealed-beam headlights, such as 1, 2, and the "halogen" or "H" marking molded on the front of the headlight lens.

- Type 1 has a high beam only and has two electrical terminals on its back.
- Type 2 has both low and high beam and three terminals.

When a type 2 is switched to low beam, only one of its filaments is lit. When the high beam is selected, the second filament lights in addition to the low beam.

If a sealed-beam headlamp has condensation on the lens or inside the assembly or if it is cracked, the headlamp will not work and can only be repaired by replacing it.

Composite Headlights. Many vehicles have halogen headlight systems that use a replaceable bulb, as illustrated in *Figure 6-43*. These systems are called composite headlights. By using the composite headlight system, the manufacturers are able to produce any style of headlight lens they desire *(Figure 6-43)*, which improves the aerodynamics, fuel economy, and styling of the vehicle.

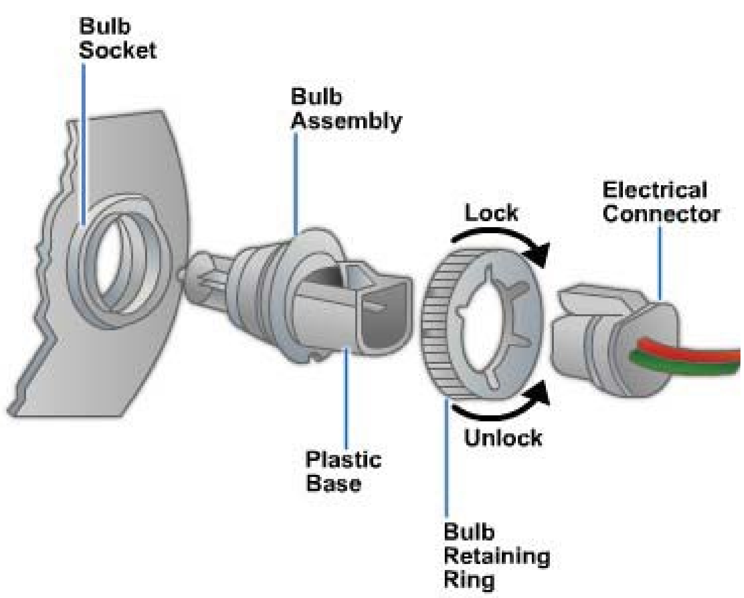

Figure 6-43 - Typical mounting assembly of a replaceable halogen light.

Many manufacturers vent the composite headlight housing due to the intense heat developed by these bulbs. Because the housings are vented, condensation may develop inside the lens assembly. This condensation is not harmful to the bulb and does not affect headlight operation. When the headlights are turned on, the heat generated by the halogen bulb dissipates the condensation quickly. Ford uses integrated non-vented composite headlights so condensation is not normal and the assembly should be replaced.

CAUTION

Whenever you replace a composite lamp, be careful; do not to touch the lamp's envelope with your fingers. Staining the bulb with skin oil can substantially shorten the life of the bulb. Handle the bulb only by its base, as shown in *Figure 6-44*. Also dispose of the bulb properly.

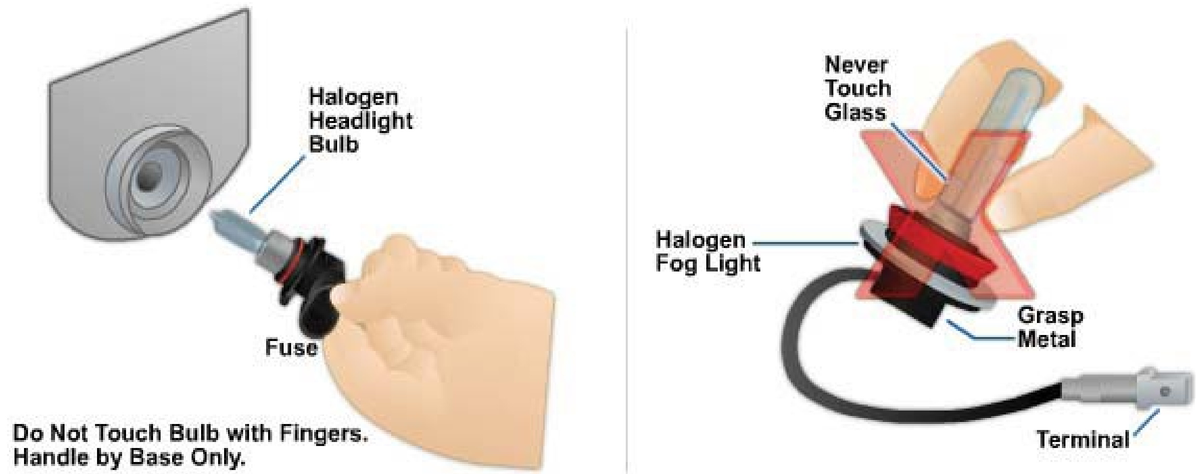

Figure 6-44 - Handle a high-intensity halogen light properly.

Headlight Service. When there is a headlight failure, it is typically caused by a burned-out bulb or lamp, especially if only one lamp fails. However, it is possible that the circuit for that one lamp has an open or high resistance. Check for voltage at the bulb before replacing the bulb. If there is no voltage present, the circuit needs work and the original bulb may still be good. If more than one lamp (including the rear lights) is not working, carefully check the circuit. If the charging system is not being regulated properly, the high voltage will cause lamps to burn out prematurely.

Headlights Replacement. A burned-out bulb has the filament melted in half. Sealed-beam headlamps are usually held in place with small screws and a retaining ring. Halogen insert bulbs normally fit into the rear of the bulb housing. You must push and twist to install some headlamp bulb inserts. Sometimes a small ring screws over and secures the halogen insert. Spring clips can secure halogen fog lamp bulbs.

Most incandescent bulbs are housed in a lens. They are normally held in the socket by a spring and small dowels or a press fit. You may have to remove the lens or reach behind the housing to access the bulb.

No-Light Problem. A no-light problem is a total failure of the light circuit or bulb. First, check to see if the bulb is burned out. Close inspection of the filament will show whether it has burned. If the bulb is good, check for power to the bulb socket.

Figure 6-45 shows how to check for current in a bulb socket. With the light turned on, there is a socket or circuit problem if the test light does not glow. If you do not have power to the socket, trace back through the circuit to find the open preventing current flow.

Flickering Light Problem. Flickering lights (lights going on and off) point to a loose electrical connection or a circuit breaker that is kicking out because of a short.

If all or several of the lights flicker, the problem is in a section of the circuit common to those lights. Check to see if the lights flicker only with the light switch in one position. For example, if the lights flicker only when the headlights are on high beam, you should check the components and wiring in the high beam section of the circuit.

If only one light flickers, the problem is in that section of the circuit. Check the bulb socket for corrosion. Clean the socket. Also, make sure the bulb terminals are not worn. This could upset the electrical connection. If needed, replace the bulb socket and bulb.

Headlamp diagnosis. *Figure 6-46* provides you a quick reference for headlamp diagnosis. As always, refer to the service manual for more detailed information for troubleshooting.

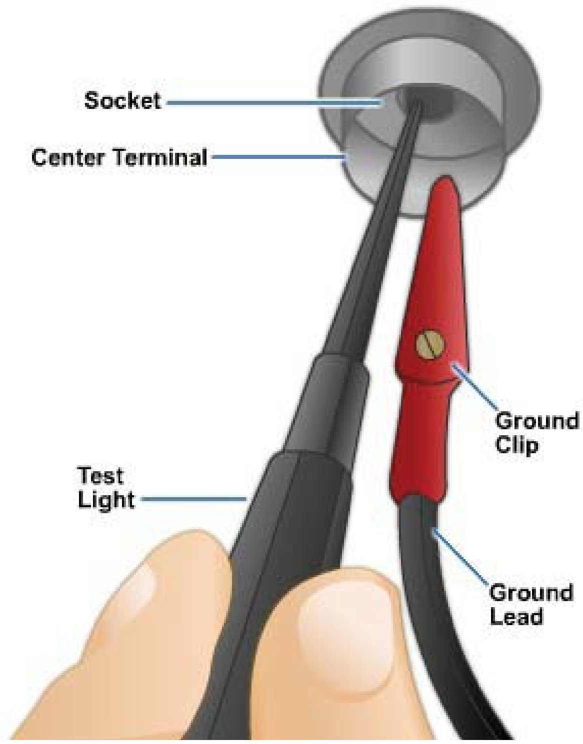

Figure 6-45 – Check the socket with a test light.

Headlamp Diagnosis		
Condition	**Possible Cause**	**Correction**
Head lamps are dim with the engine off or idling.	1. Loose or corroded battery cables 2. Loose or worn alternator drive belt 3. Charging system output too low 4. Battery has insufficient charge 5. Battery is sulfated or shorted 6. Faulty lighting circuit 7. Both headlamp bulbs defective	1. Clean and tighten battery cable clamps and posts. 2. Adjust or replace alternator drive belt. 3. Test and repair charging system. 4. Test battery state-of-charge. Recharge or replace battery. 5. Perform load test. Recharge or replace battery. 6. Test and repair circuit. 7. Replace both bulbs.
Headlamp bulbs burnout frequently.	1. Charging system output too high 2. Loose or corroded terminals or splices in circuit	1. Test and repair charging system. 2. Inspect and repair all connectors and splices.
Headlamps are dim with engine running above idle.	1. Charging system output too low 2. Faulty headlamp circuit 3. High resistance in headlamp circuit 4. Both headlamp bulbs defective	1. Test and repair charging system. 2. Test and repair circuit as necessary. 3. Test amperage draw of headlamp circuit. 4. Replace both bulbs.
Headlamps flash randomly.	1. Poor headlamp circuit ground 2. High resistance in headlamp circuit 3. Faulty headlamp switch 4. Loose or corroded terminals or splices in circuit.	1. Repair circuit ground. 2. Test amperage draw of headlamp circuit. 3. Replace headlamp switch. 4. Repair terminals or splices.
Headlamps do not illuminate.	1. No voltage to headlamps 2. No ground at headlamps 3. Faulty headlamp switch 4. Faulty headlamp dimmer switch 5. Faulty headlamp circuit	1. Replace fuse. 2. Repair circuit ground. 3. Replace headlamp switch. 4. Replace headlamp dimmer switch 5. Repair circuit.

Figure 6-46 - Quick reference for headlamp diagnosis.

11.2.1 Fuses and Circuit Breakers

The main types of circuit protection devices used in electrical systems are fuses, circuit breakers, and fusible links. Each of these devices is designed to be the weak point of a circuit and open before the wiring gets too hot. Typical symbols for protection devices are shown in *Figure 6-47*.

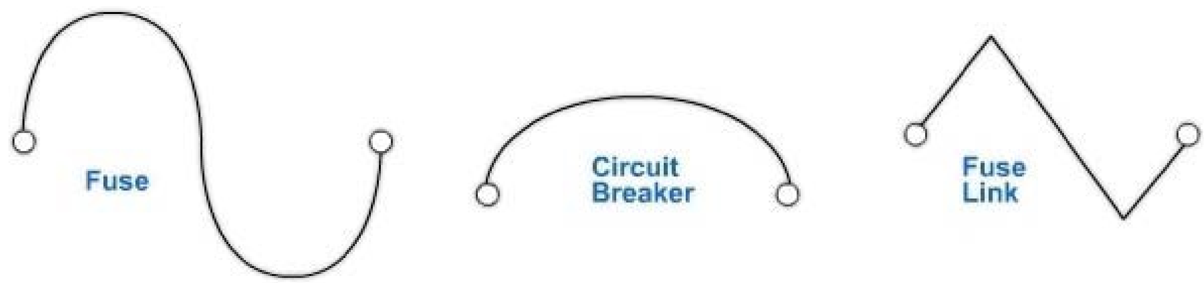

Figure 6-47 - Electrical symbols for common circuit protection devices.

Fuses. Fuses have a specific current rating. Fuses for truck electrical systems are available that are designed to open with less than 1A of current flow to more than 200A of current flow. Fuses also have a voltage rating. The voltage rating indicates the maximum voltage that the fuse is designed to interrupt. Most fuses designed for truck electrical systems have a voltage rating of 32V.

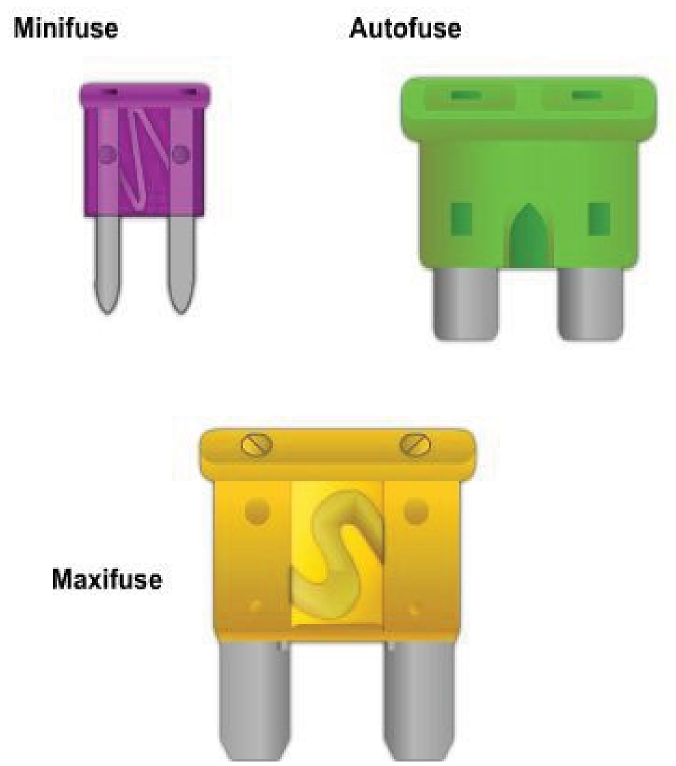

Figure 6-48 – Examples of fuses used in electrical systems.

Fuses are also classified by how long it takes for the fuse to open with a given percentage of current overload. Fuses may be classified as fast-acting or time-delay fuses. Any fuse opens based on a combination of current and time. A 20A fuse does not open just as soon as current flow through the fuse reaches 21A. Most fuses are designed to maintain a 110 percent overload current indefinitely, so a 20A fuse will probably never blow if 21A of current is flowing through the fuse. At a 150 percent current overload (30A of current flow for a 20A rated fuse), a 20A fuse may blow after 2 seconds for a fuse classified as a time delay fuse. The in rush current of devices controlled by the circuit that the fuse protects determines what type of fuse is necessary.

Most vehicles fuses are blade-type fuses. The blades of the fuse are male terminals, as the samples shown in *Figure 6-48)*. A blade fuse has colored, translucent plastic housing. This allows the fuse element to be visible for inspection. A fuse that is blown may have a visible gap in the element or the plastic housing may be blackened from heat, depending on the amount of current that caused the fuse to blow. The colored fuse housing is colored based on the fuse's current rating. The color of the housing for a particular fuse current has been standardized in the industry. Standardized fuse colors throughout the automotive industry help make sure that the correct value of fuse for each circuit is installed in the fuse box.

Blade fuses are available in a variety of sizes. Most new vehicles use SAE (Society of Automotive Engineers) J2077 fuses. The J2077 designation refers to the SAE specification number that defines this fuse. These small fuses are often called by trade name Mini® or ATM® fuses. These small fuses are classified as fast-acting fuses. This means that the fuse will open relatively rapidly if current flow through the fuse exceeds the designated amperage. SAE J2077 fuses are available from 2A to 30A current ratings.

The next larger blade-type fuse is an SAE J1284 fuse. The fuse is also known as ATC®, ATP®, or auto fuse. These fuses are somewhat larger than the SAE J2077 fuses and were the standard fuse in vehicles for a long period. These fuses are also classified as fast-acting fuses. SAE J1284 fuses are available from 1A to 40A.

An even larger blade-type fuse is an SAE J1888 fuse. This fuse is also known as a Maxi® fuse. These fuses are classified as time-delay fuses, so they are often used to protect circuits connected to devices with high inrush currents, such as electric motors. SAE J1888 fuses are available from 20A to 80 A.

Standard blade fuse housing colors for each SAE classification are shown in *Figure 6-49.*

Autofuse		Maxifuse		Minifuse	
Current rating	Color	Current rating	Color	Current rating	Color
3	Violet	20	Yellow	5	Tan
5	Tan	30	Green	7.5	Brown
7.5	Brown	40	Amber	10	Red
10	Red	50	Red	15	Blue
15	Blue	60	Blue	20	Yellow
20	Yellow	70	Brown	25	White
25	Natural	80	Natural	30	Green
30	Green				

Figure 6-49 - Standardized blade fuse colors

Prior to the development of blade fuses, glass cartridge fuses were the standard. A glass cartridge fuse is a small glass tube with a fuse element running the length of the tube. Each end of the glass tube has a metal cap that connects to the fuse element. The fuse current and voltage ratings are stamped into the caps. There are many types of glass cartridge fuses, but the most popular types used are SFE and AGC types.

SFE fuses all have the same physical dimension regardless of the fuse current rating. AGC-type fuses increase in length as the fuse's current rating increases. The fuse block for AGC fuse is designed so that only fuses of the correct length can be placed in the corresponding fuse block cavity. This prevents a fuse with a too high a current rating from being installed in a particular fuse block cavity because such a fuse would be too long for the cavity.

There are several other types of fuses that are found in trucks. A very large bolt-in type fuse, called a Meg® or AMG® fuse, is commonly used to protect the main battery power feed cable that supplies the cab electrical system. These bolt-in fuses have current ratings up to 500A, but a typical current rating for bolt-in fuse used to protect the cab power feed cable is 100A to 150A.

Fuse link. A fuse link, or fusible link, is a small section of wire connected in series with the larger wire. It is designed to serve as a very large fuse, (*Figure 6-50*).

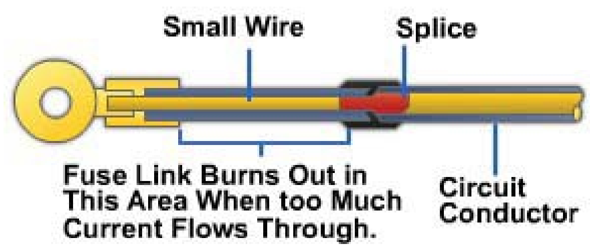

Figure 6-50 – A typical fuse link.

Fuse links are normally located in the engine compartment where power feeds off the battery or starter solenoid. They provide circuit protection before the fuse box in the passenger compartment. If a wire is shorted to ground before the fuse panel, the fuse link can overheat and burn in half. This will protect the rest of the wiring from major damage.

The wire gauge of a fusible link is typically selected so that it is four American Wire Gauge (AWG) sizes smaller than the smallest wire that it is directly protected by the fusible link. In the event of a short to ground in a circuit protected by a fusible link, the fusible link heats up more than any wire that is protected by the fusible link. Excessive current flow through the fusible link causes the wire to melt like a large fuse element. The special insulation material used in fusible links does not melt off the fusible link nor does it support a flame, like many types of standard wire insulation. Fusible links are like fuses in that once they have melted, they must be replaced.

Fusible links are somewhat difficult to replace because unlike a fuse, they do not merely connect to the fuse block like a blade or cartridge fuse. Replacing a fusible link involves cutting the damaged fusible link out of the wire harness and splicing a new fusible link in its place. This can be a very time-consuming process because fusible links are located near the motor and are difficult to access. However, fusible links are normally limited to protecting high-current circuits, such as alternator charging circuits and cab power supply cables. These types of circuits should rarely be subjected to currents high enough to cause the fusible link to burn open. The circuits that fusible links supply are normally branched into other sub-circuits that are protected by smaller circuit protection devices, such as fuses and circuit breakers.

Unlike fuses, fusible links do not have a current rating. Instead, fusible links are rated by conductor diameter. The size of the fusible link conductor is stamped on the insulation. Often, fusible links are sold in metric sizes and converted to the closest AWG size.

A fusible link that has been burned open must be replaced with another fusible link of the same length and gauge. It is critical that the fusible link be replaced only with fusible link wiring of the correct gauge for the application. The fusible link must be the smallest diameter circuit to provide adequate wire harness protection.

WARNING

A fusible link that has burned open must only be replaced with the same size of special fusible wiring. Installing a larger gauge of fusible link is like installing a larger fuse and can result in a fire. NEVER replace a fusible link with standard wire. The insulation material on standard wire can ignite, resulting in a fire.

The routing of a fusible link must also be placed so that the fusible link is not contacting anything flammable. The excessively high current flow through a fusible link causes the fusible link wire conductor to glow red hot before it melts to interrupt the circuit. The heat given off by the hot fusible ink wire is significant and can cause surrounding material to ignite.

Circuit breakers. Circuit breakers are thermal devices that use current flow to heat a thin piece of bimetallic strip, as shown in *Figure 6-51*. If the bimetal strip is sufficiently heated, the strip will bend or snap, causing a pair of contacts to open and interrupt current flow in a circuit. An open circuit breaker is referred to as being tripped. When the circuit breaker cools down, the circuit breaker can be reset, which causes the contacts to close again and restore current flow in the circuit. Because a circuit breaker can be reset, this provides an advantage over a fuse, which must be replaced if blown. Like fuses, circuit breakers have a current rating and voltage rating. Circuit breakers generally require longer to open than a comparable fuse for a given amount of excess current, so they are considered time delay.

The schematic symbol for a circuit breaker is CB. The current rating of the circuit breaker is often displayed next to the schematic symbol, such as 20A, along with an identification, such as CB3.

Circuit breakers are classified by Society Automotive Engineers (SAE) into three different categories:

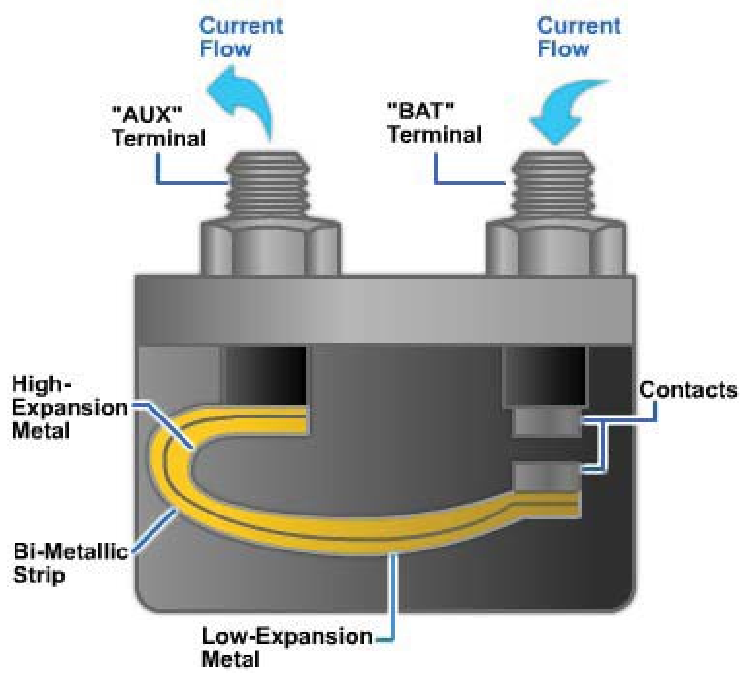

Figure 6-51 – Cutaway view of a circuit breaker.

1. Type I circuit breakers are automatic reset devices. Type I breakers reset automatically without operator intervention after the bimetallic strip cools down. The reset action causes the contacts to close and restore current flow to the circuit. If the circuit is still drawing too much current, the breaker will open or trip again repeatedly. Type I circuit breakers are commonly used in windshield wiper and headlamps where the automatic reset feature is desirable. However, the constant reset action of Type I circuit breakers can cause the

circuit breaker contacts to become damaged from excessive making and breaking of a high-current circuit.

2. Type II circuit breakers are modified automatic reset devices. Type II circuit breakers reset automatically after the cause of the excess current to the circuit is no longer present. Type II circuit breakers also reset when the voltage supply for the circuit breaker, such as ignition voltage, is switched off for a few minutes. Type II circuit breakers contain a heating element that causes the bimetallic strip to open. Type II circuit breakers are designed so that as the current flow through the heating element decreases, the bimetallic strip cools and automatically closes again like a Type I circuit breaker.
3. Type III circuit breakers are manual reset devices. A trip-indicating button or lever pops up when the breaker is tripped. After the bimetallic strip cools sufficiently, the button can be depressed to reset the breaker. Depressing the reset before the bimetallic strip has cooled enough to cause the button to pop back up when released. If the cause of the excess current is still present after the bimetallic strip has cooled, the circuit breakers will trip again when the bimetallic strip heats up sufficiently.

Like blade fuses, blade-type circuit breakers are common on new trucks. Blade-type circuit breakers are designed to fit into the same fuse block cavities as blade fuses. The footprint of the terminals is the same as the blade fuses, but the circuit breaker may be wider, thicker, and taller than the blade fuse. The housing or reset button of most blade-type circuit breakers has the current rating stamped on the circuit breaker housing and has no color coding.

Besides blade-type circuit breakers, some circuit breakers have threaded stud-type connections. These are designed to accommodate wiring with ring terminals and are common on trailer and older trucks.

11.3.0 Directional (Turn) Signals

The directional (turn) signal system consists of a fuse, turn signal switch, flasher unit, turn signal bulbs, indicator bulbs, and related wiring. When the steering column-mounted switch is activated, it causes the right- or left-side turn lamps to flash. Turn indicator lights in the instrument panel or on the fenders, if equipped, also flash.

The turn signal switch may be mounted in the center of the steering column, behind the steering wheel. A multifunction switch can also be used to control turn lights, horn, and dimmer switch.

The turn signal flasher automatically opens and closes the turn signal circuit, causing the bulb to flash. The flasher unit contains a temperature-sensitive bimetallic strip and heating element. The bimetal strip is connected to a set of contact points and to the fuse panel.

When the current flows through the turn signal flasher, the bimetallic strip is heated and bends. This opens the contact points and breaks the circuit. As the bimetallic strip rapidly cools, it closes the points and again completes the circuit. This heating and cooling cycle takes place in about a second. The turn lights flash as the points open and close.

Flashers are designed to flash at a rate of about 70 to 110 times per minute. This rate may slow considerably in very cold weather because of the bimetallic strip. The flash rate is also greatly affected by electrical system voltage. The flash rate decreases as system voltage decreases because of the corresponding reduction in heating element current.

The flasher's opening and closing action also causes the familiar clicking sound to provide an audible indication that turn signals or hazard flashers are active.

There are several different classifications of bimetallic flashers, even though most have the same two-terminal footprint. Bimetallic flashers are usually designed to flash a specific number of lamps. The flasher may also provide an indication of lamp outage by changing the flash rate when a lamp circuit is open, as with a burned-out bulb.

Some bimetallic flashers may be designed for turn signals only. These types of flashers have a specific lamp rating of 2 to 5 lamps. The flasher rating indicates how many turn signal lamps the flasher is expected to flash. Other bimetallic flashers may be designed for both turn signals and hazard warning lamps. These flashers have a rating that indicates both the number of turn signals and the number of hazard lamps the flasher is designed to control. For example, a 2/4 lamp flasher is rated for two turn signal lamps and four hazard lamps.

Hybrid flashers. Hybrid flashers contain an electronic circuit used to control an electromechanical relay. The electronic circuit provides a precise flasher rate that is not dependent on temperature and system voltage. Hybrid flashers generally have a longer service life than bimetallic flashers due to the lack of a heating element. The long service life of hybrid flashers makes them ideal for truck electrical systems.

Hybrid flashers may also have lamp outage detection. The flasher monitors lamp current and causes the flash rate to increase if one of the turn signal lamps is burned out or a lamp circuit is otherwise open. This is unlike the bimetallic flasher, which causes the flasher rate to decrease or stop flashing altogether with an open lamp circuit or a burned-out lamp.

Solid-state flashers. Solid-state flashers typically contain a power metal-oxide-semiconductor field-effect transistor (MOSFET) acting as a switch and have no moving contacts. An electronic circuit controls the MOSFET and provides precise rates in all conditions. These flashers are more expensive than hybrid flashers but have a very long service life.

Turn signal problems. If the turn signals do not flash, check first for a burned-out bulb. Even one burned-out bulb will reduce current and prevent the flasher unit from functioning. A burned-out bulb is the most common cause of turn signal problems.

If both right and left turn signals do not work, check the fuse and flasher unit. The problem may also be in the turn signal or malfunction switch. It is prone to wear and failure after prolonged service. Something common to both sides of the circuit may be at fault if no bulb is coming on.

Figure 6-52 provides a quick reference for turn signal diagnosis. You should refer to the service manual for any detailed information for troubleshooting procedures.

Turn Signal Diagnosis		
Condition	**Possible Cause**	**Correction**
Turn signal flashes at twice the normal rate.	1. Faulty external lamp 2. Poor ground at lamp 3. Open circuit in wiring to external lamp 4. Faulty contact in turn signal switch	1. Replace lamp. 2. Check and repair wiring. 3. Repair wiring harness. Check connections. 4. Replace switch.
Dash indicator lamp is illuminated brightly; external lamp glows dimly and flashes at a rapid rate.	1. Loose or corroded external lamp 2. Poor ground circuit at external lamp	1. Tighten or replace connection. 2. Check and repair wiring.
Hazard warning system does not flash.	1. Faulty fuse 2. Faulty flasher 3. Open circuit in wiring to turn signal switch 4. Faulty contact in turn signal switch 5. Open or grounded circuit in wiring to external lamp	1. Replace fuse. 2. Replace flasher. 3. Repair wiring. 4. Replace switch. 5. Repair wiring.
Indicator lamp illuminates brightly, but external lamp does not light.	1. .Open circuit in wire to external lamp 2. Burned out lamp	1. Repair wiring. 2. Replace lamp.
System does not flash on either side.	1. Faulty fuse 2. Faulty flasher unit 3. Loose bulkhead connector 4. Loose or faulty rear wiring harness or terminals 5. Open circuit to flasher unit 6. Open circuit in feed wire to turn signal switch 7. Faulty switch connection in turn signal switch 8. Open or grounded circuit in wiring to external lamps	1. Replace fuse. 2. Replace flasher. 3. Tighten connector. 4. Repair wiring. 5. Check and repair wiring harness. 6. Check and repair wiring harness. 7. Test and replace. 8. Check and repair wiring harness.
System does not cancel after completion of the turn.	1. Broken canceling finger on turn signal switch 2. Broken or missing canceling cam on clockspring	1. Replace spring. 2. Replace clockspring.
External lamps operate properly; no indicator lamp operation.	1. Faulty indicator lamp in instrument cluster	1. .Replace lamp.

Figure 6-52 - Quick reference for turn signal diagnosis.

11.4.0 Brake Lights

The brake light system is commonly made up of a fuse, brake light switch, rear lamps, and related wiring. The brake light switch is normally mounted on the brake pedal, as illustrated in *Figure 6-53*. Battery power is fed to the brake light switch from the ignition switch. When the brake pedal is pressed, it closes the switch, and current flows through the wiring to the brake lights.

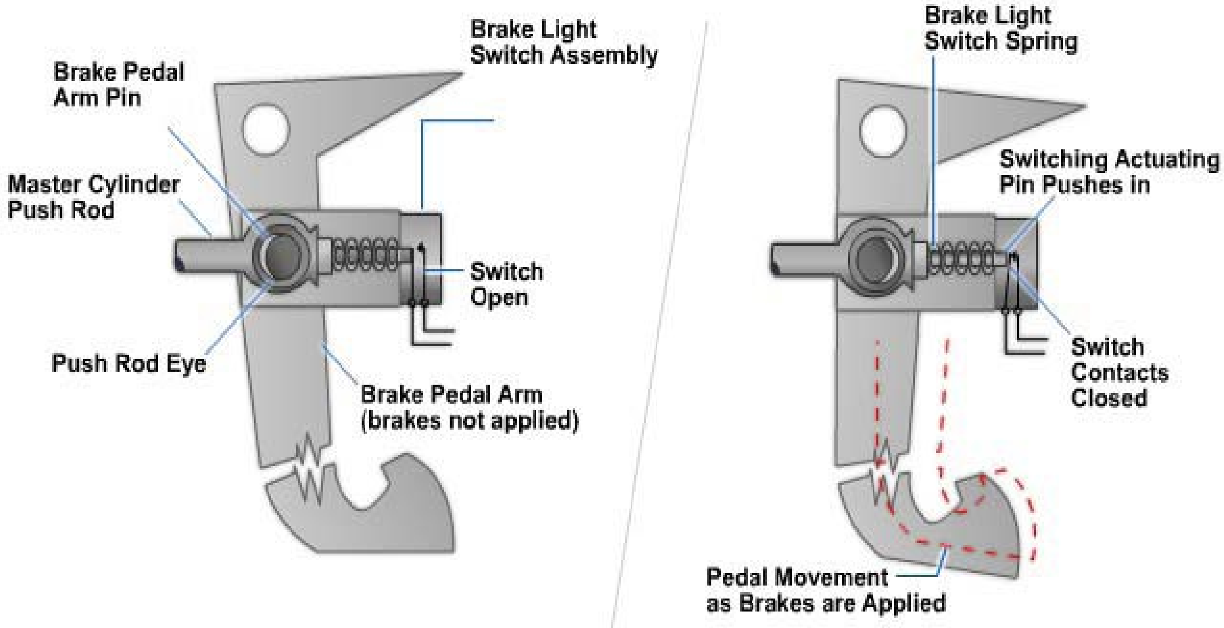

Figure 6-53 – Brake light switch action.

The brake light switch can also be located on the master cylinder with a T-fitting or connected to the brake line. In these switches, hydraulic pressure from the brake system closes the switch to turn on the brake lights.

Brake light problem. If none of the brake lights are working, something common to all the bulbs is at fault, such as the brake light switch or feed circuit. If only one bulb is not working, the bulb and its section of the circuit should be checked.

11.4.1 Trailer Lighting

The voltage source for lighting on trailers is supplied by the tractor. The electrical connection between the tractor and trailer is provided through a seven-wire trailer electrical cable with a plug on either end. The trailer cable is like a seven-wire electrical cord but has the same plug on both ends. This trailer wiring cable is usually coiled to permit movement between the truck and trailer, such as when turning.