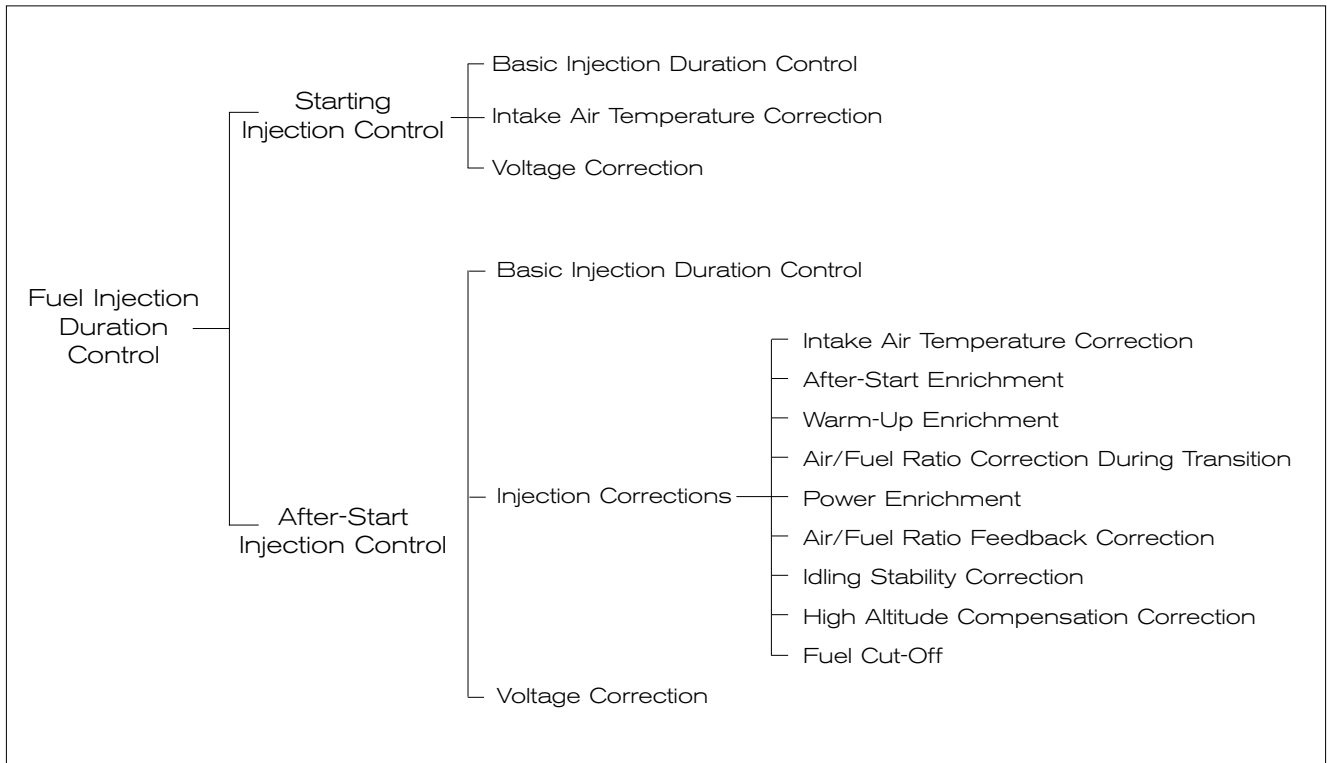


Fuel Systems



- Lesson Objectives**
1. Determine the condition of the fuel delivery system based on fuel pressure
 2. Determine the root cause of a failure(s) in the fuel delivery system using appropriate diagnostic procedures
 3. Determine the condition of the fuel injection system based on engine data
 4. Determine the root cause of a failure(s) in the fuel injection system using the appropriate diagnostic procedures

Fuel Systems

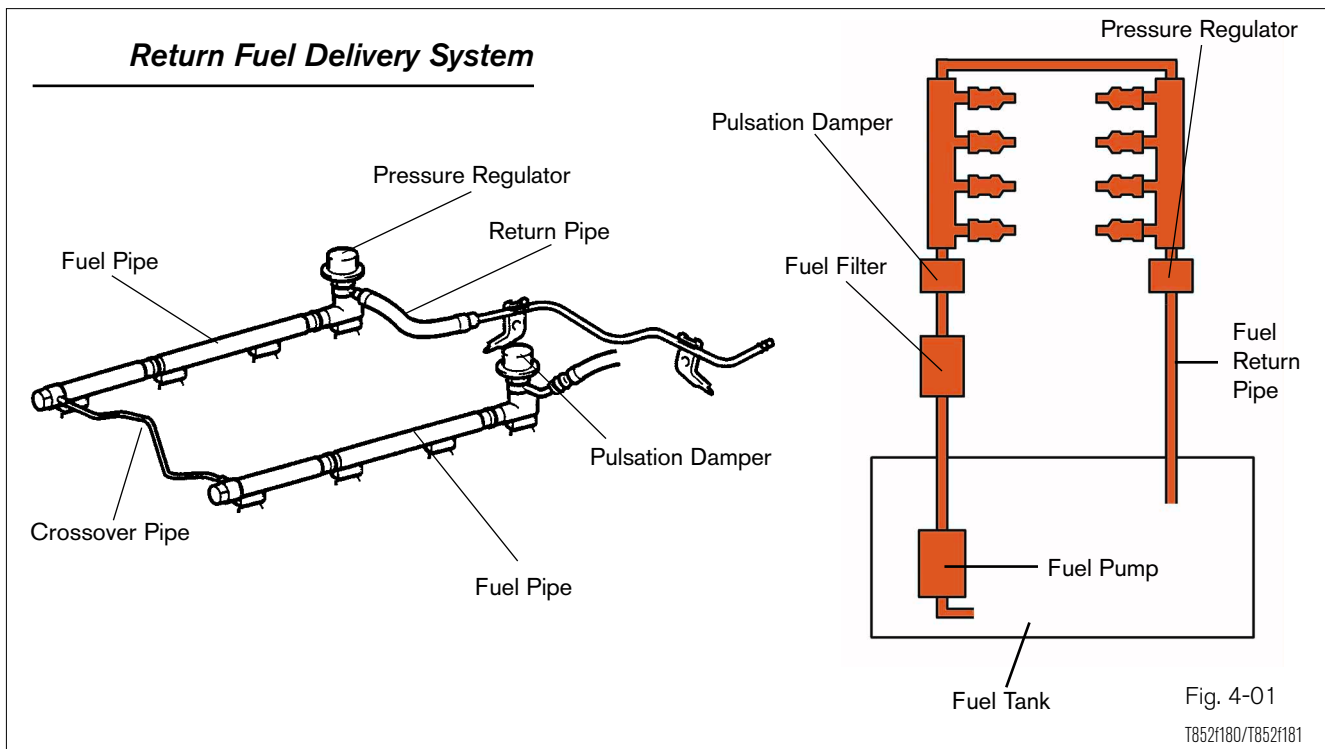
Fuel Injection System

The purpose of the fuel injection system is to precisely inject a metered amount of fuel at the correct time. Based on the input sensor signals, the ECMs programming will decide when to turn each injector on and off.

Fuel Delivery System

The purpose of the fuel delivery system is to quietly deliver the proper volume of fuel at the correct pressure. The fuel delivery system must also meet emission and safety regulations. Major components are:

- Fuel Pump.
- Fuel Pump ECU.
- Pressure Regulator.
- Fuel Pressure Control Circuit.
- Fuel Lines.
- Fuel Tank.
- Fuel Filter.
- Pulsation Damper.
- Fuel Injectors.
- Inertia Switch.



Return Fuel Delivery System

When the fuel pump is activated by the ECM, pressurized fuel flows out of the tank, through the fuel filter to the fuel rail and up to the pressure regulator. The pressure regulator maintains fuel pressure in the rail at a specified value. Fuel in excess of that consumed by engine operation is returned to the tank by a fuel return line. A pulsation damper, mounted on the fuel rail, is used on many engines to dampen pressure variations in the fuel rail. The injectors, when turned on by the ECM, deliver fuel into the intake manifold. When the fuel pump is turned off by the ECM, a check valve in the fuel pump closes maintaining a residual pressure in the fuel system.

Returnless Fuel Delivery System

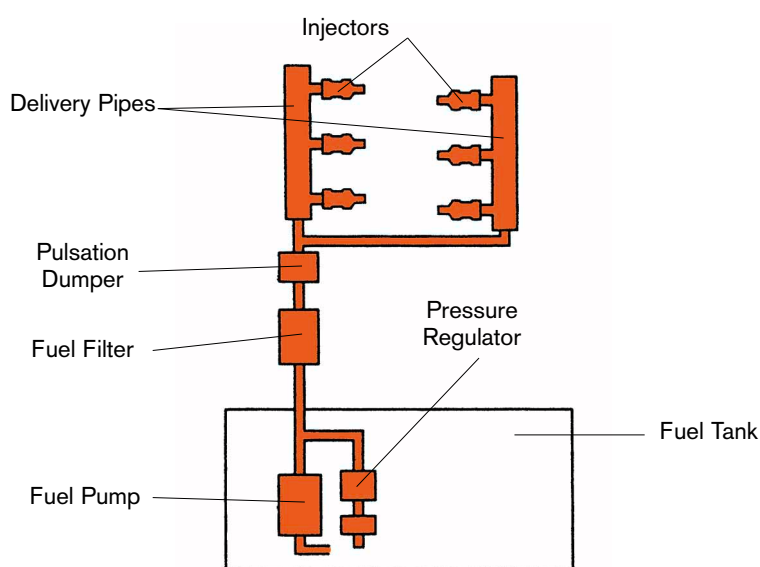


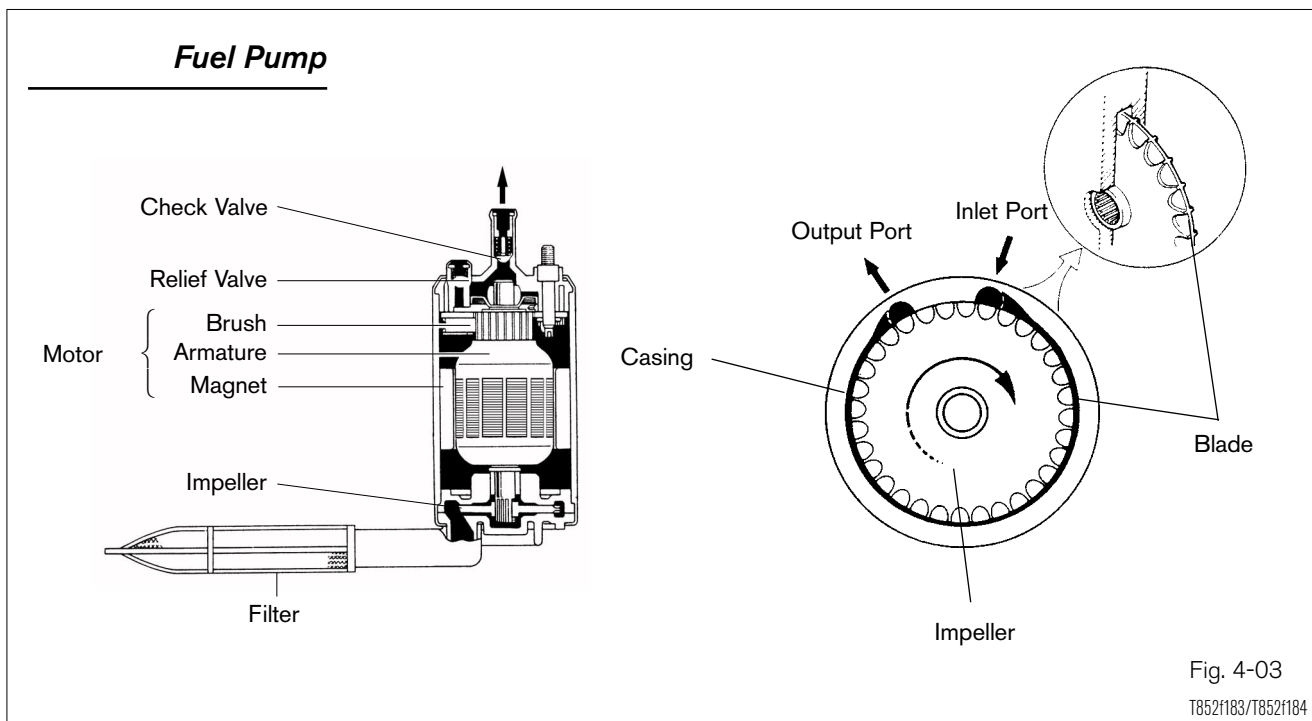
Fig. 4-02
T8521182

Returnless Fuel Delivery System

When the fuel pump is activated by the ECM, pressurized fuel flows from the pump to the pressure regulator. At the pressure regulator excess fuel is directed to the bottom of the fuel tank and pressurized fuel is sent out of the fuel tank, through the fuel filter, pulsation damper, and into the fuel rail. When the ECM turns on the injectors fuel is delivered into the intake manifold.

Fuel pressure in this system is maintained at a constant and higher pressure, 44-50 psi (301-347 kPa) than the return fuel system. ECM programming and a higher fuel pressure eliminates the need for a vacuum modulated pressure regulator.

The returnless fuel delivery system was adopted because it lowers evaporative emissions since no heated fuel is returned to the fuel tank. On the return fuel delivery system, fuel heated by the engine returns to the fuel tank and has warmer fuel creating more fuel vapors.



Fuel Pump The fuel pump is mounted in the tank and immersed in fuel. The fuel cools and lubricates the pump. When current flows through the motor, the armature and impeller rotate. The impeller draws fuel in through a filter and discharges pressurized fuel through the outlet port. The fuel pump's pumping capacity is designed to exceed engine requirements. This insures that there will always be enough fuel to meet engine demands.

An outlet check valve, located in the discharge outlet, maintains a residual fuel pressure in the fuel system when the engine is off. This improves starting characteristics and reduces vapor-lock. Without residual fuel pressure, the system would have to be pressurized each time the engine was started and this would increase engine starting (cranking) time. When a hot engine is shut off, fuel temperature in the lines around the engine increases. Keeping the system pressurized increases the boiling point of the fuel and prevents the fuel from vaporizing.

A pressure relief valve will open if the fuel system becomes restricted. This is a safety device to prevent the fuel lines from rupturing and damage to the pump.

On many models the fuel pump is part of the fuel pump assembly. This assembly contains the filters, pressure regulator (returnless fuel system only), sending unit, and fuel pump. Many of the components can be serviced separately.

Typical Fuel Pump Assembly

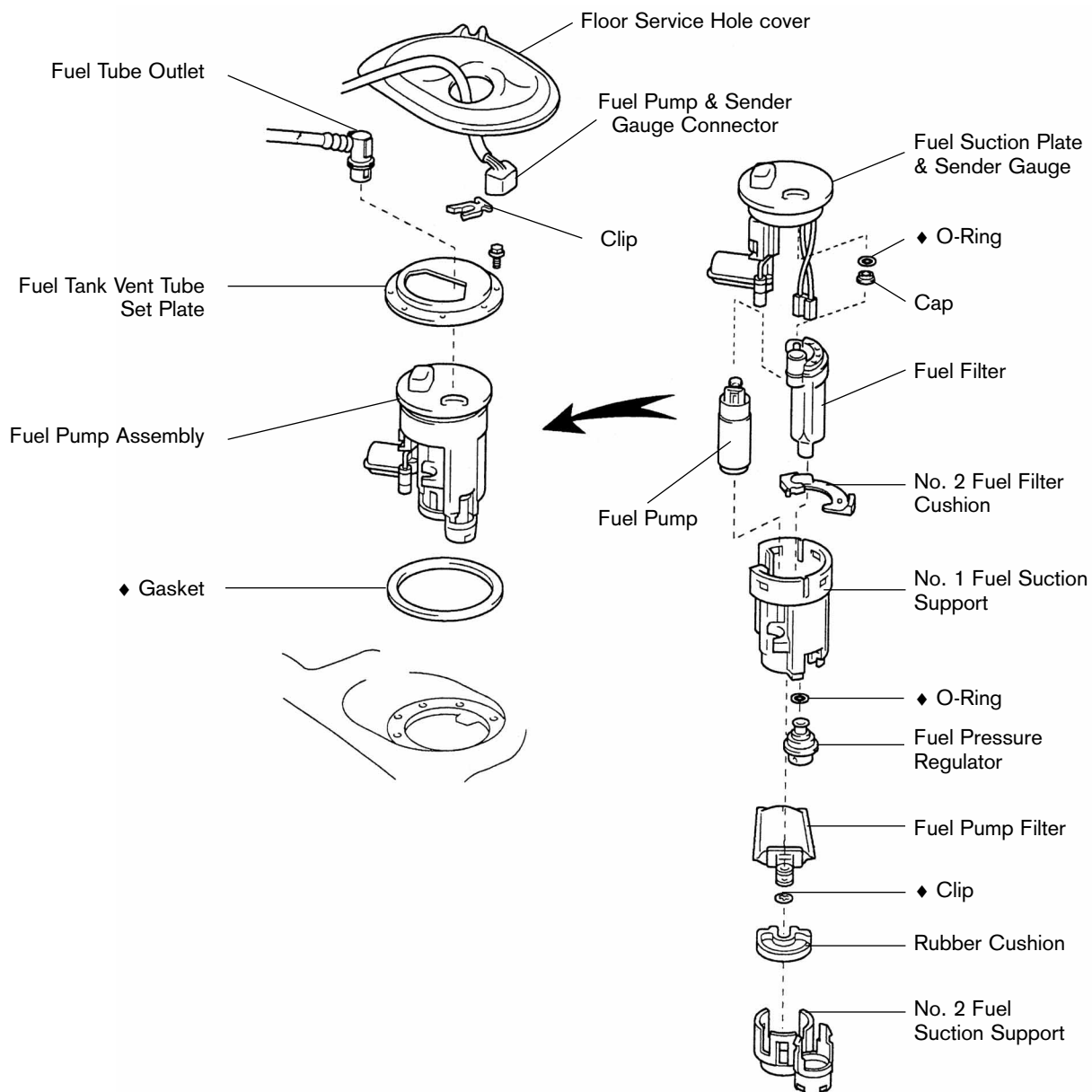


Fig. 4-04

T8521185

Jet Pump

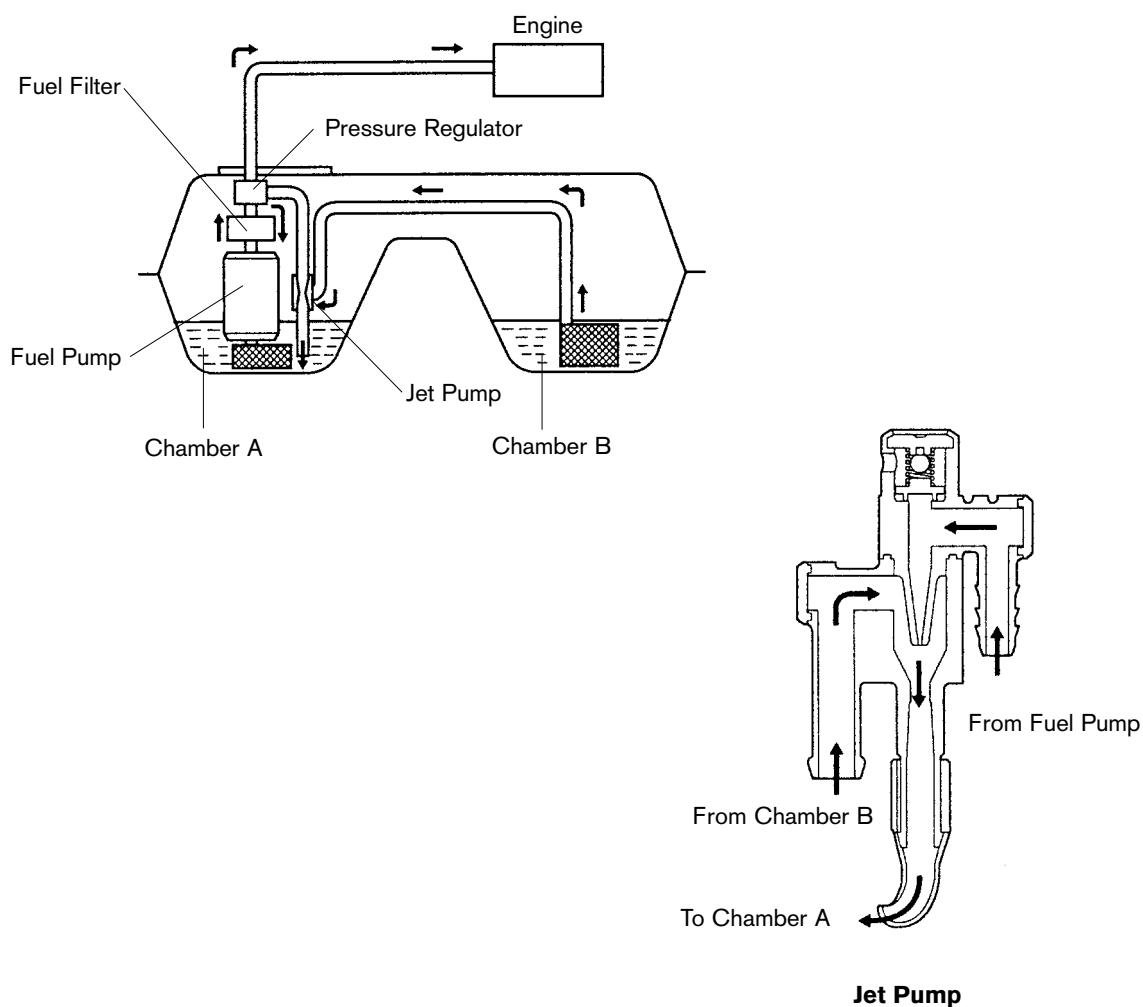


Fig. 4-05

T852f186/T852f187

Jet Pump The jet pump is an additional pump used when the fuel tank bottom is divided into two chambers. Excess fuel flowing through the fuel return passes through a venturi. This creates a low pressure area around the venturi, and this action will draw the fuel out of Chamber B, and sends it into Chamber A.

Fuel Pump Control

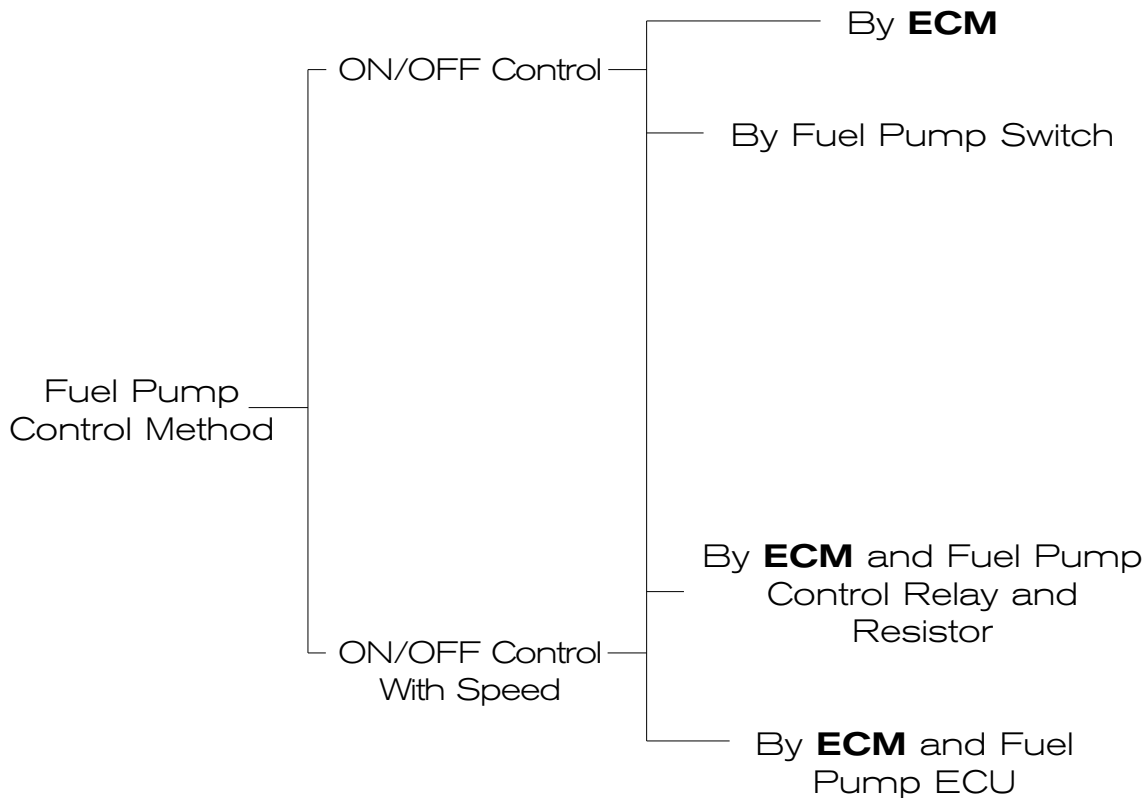


Fig. 4-06

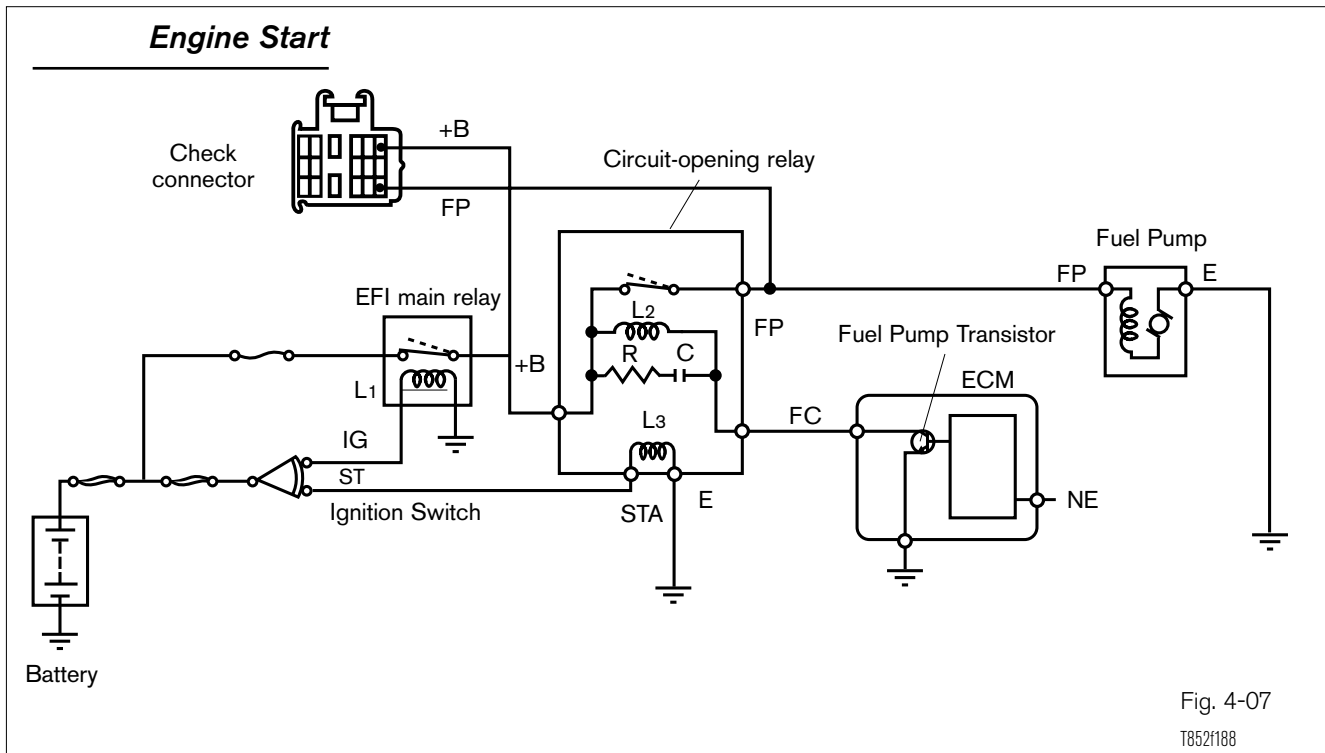
Fuel Pump Controls

A variety of fuel pump control circuits and controls have been used over the years. The following basic methods are:

- ON/OFF Control by ECM.
- ON/OFF Control by Fuel Pump Switch.
- ON/OFF Two Speed Control with a Resistor.
- ON/OFF Two Speed Control with Fuel Pump ECU.
- ON/OFF Three Speed Control with Fuel Pump ECU.

The most accurate way of determining the type of fuel control circuit is to look up the circuit in the appropriate EWD.

The following describes the basic methods of fuel pump control. An essential point to remember is that the fuel pump operates only when the engine is cranking or running.



ON/OFF Control The following is an explanation of how the fuel pump circuit is by ECM activated.

Engine Start When the engine is cranking, current flows from the IG terminal of the ignition switch to the L1 coil of the EFI main relay, turning the relay on. At the same time, current flows from the ST terminal of the ignition switch to the L3 coil of the circuit opening relay, turning it on to operate the fuel pump. The fuel pump is now supplying fuel to the fuel injection system.

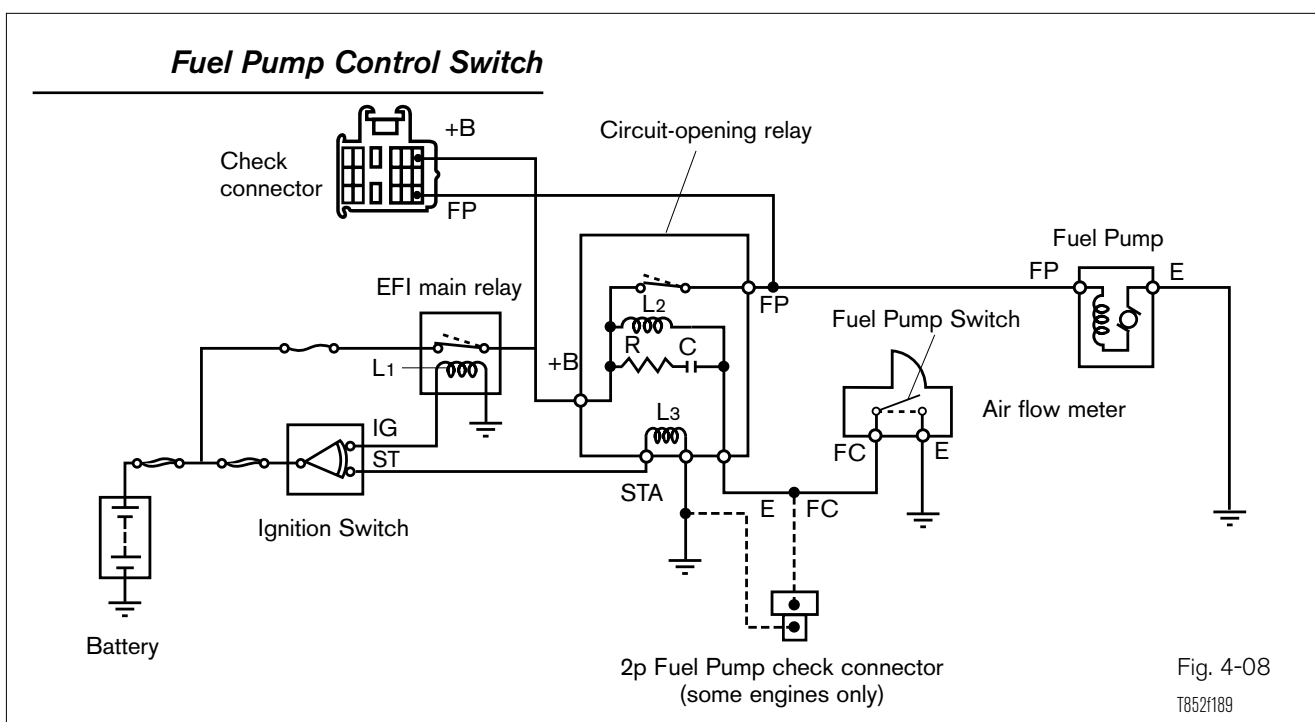
NOTE The circuit opening relay in this example is ground side switched.

Engine Running Once the engine starts and the ignition key is moved to the ON (IG) position, current to the L3 coil is shut off, but the ECM will keep the fuel pump on through coil L2 as long as the ECM receives an NE signal. If the NE signal is lost at any time after starting, the ECM turns the fuel pump off.

Engine Stopped	When the engine stops, the NE signal to the ECM stops. This turns off the transistor, thereby cutting off the flow of current to the L2 coil of the circuit opening relay. As a result, the circuit opening relay opens turning off the fuel pump.
----------------	--

NOTE

The resistor R and the capacitor C in the circuit-opening relay are for the purpose of preventing the relay contacts from opening when current stops flowing in coil L2 due to electrical noise (fuel pumps controlled by the ECM) or to sudden drops in the intake air volume (fuel pumps controlled by fuel pump switch). They also serve to prevent sparks from being generated at the relay contacts. On some models, an L3 coil is not provided in the circuit-opening relay.



ON/OFF Control by Fuel Pump Switch

The fuel pump switch is found on older vehicles using a Vane Air Flow Meter. The air moves the vane when the engine is running closing the fuel pump switch. The following is an explanation of circuit operation.

Engine Start

When the engine is cranking, current flows from the IG terminal of the ignition switch to the L1 coil of the EFI main relay, turning the relay on. Current also flows from the ST terminal of the ignition switch to the L3 coil of the circuit-opening relay, turning it on to operate the fuel pump. After the engine starts, the cylinders begin drawing in air, causing the measuring plate inside the air flow meter to open. This turns on the fuel pump switch, which is connected to the measuring plate, and current flows to the L2 coil of the circuit-opening relay.

Engine Running After the engine starts and the ignition switch is turned from ST back to IG, current flowing to the L3 coil of the circuit-opening relay is cut off. However, current continues to flow to the L2 coil while the engine is running due to the fuel pump switch inside the air flow meter being on. As a result, the circuit-opening relay stays on, allowing the fuel pump to continue operating.

Engine Stopped When the engine stops, the measuring plate completely closes and the fuel pump switch is turned off. This cuts off the flow of current to the L2 coil of the circuit-opening relay. As a result, the circuit-opening relay goes off and the fuel pump stops operating.

Two Speed Fuel Pump Control Large displacement engines require a higher volume of fuel during starting and heavy load conditions than small displacement engines. High capacity fuel pumps are used to meet the demand, but they produce more noise and consume more power. To overcome these disadvantages and increase pump life, a two speed fuel pump control is used.

ON/OFF Two Speed Control with a Resistor This type uses a double contact relay and a series limiting resistor.

Two Speed Fuel Pump Control with Resistor at Low Speed

When the engine is idling, or under normal driving conditions (when a small amount of fuel is required), the ECM turns on the fuel pump control relay. The relay switches to contact B, sending current through the resistor. This reduces the available current and voltage to the fuel pump, causing it to run at low speed.

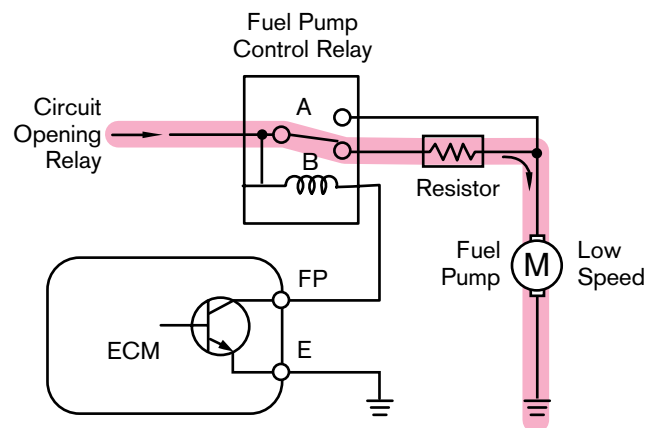


Fig. 4-09
T8521190

High Speed

When the engine is operating at high speeds or under heavy loads, the ECM turns off the fuel pump control relay. The relay switches to contact A, and the current to the fuel pump flows directly to the pump bypassing the resistor, causing the fuel pump to run at high speed.

The fuel pump also runs at high speed while the engine is starting.

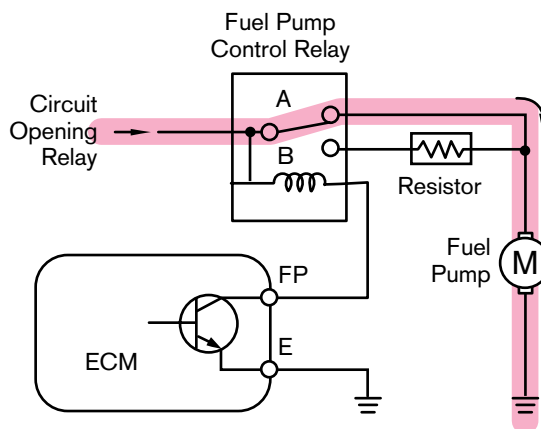


Fig. 4-10
T852f191

Two Speed Control with Fuel Pump ECU

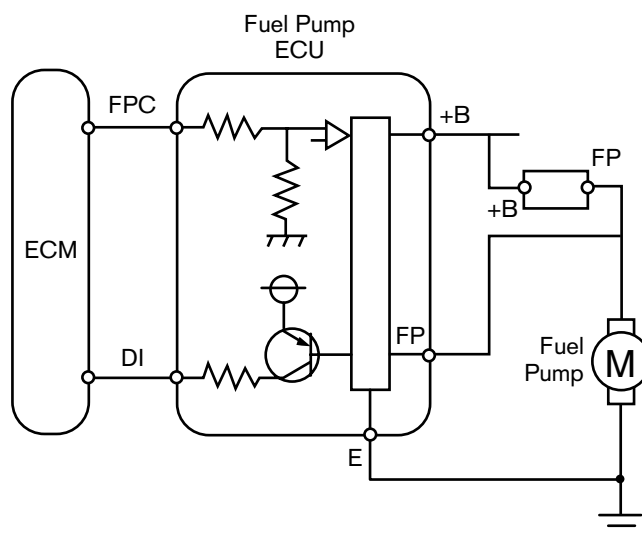


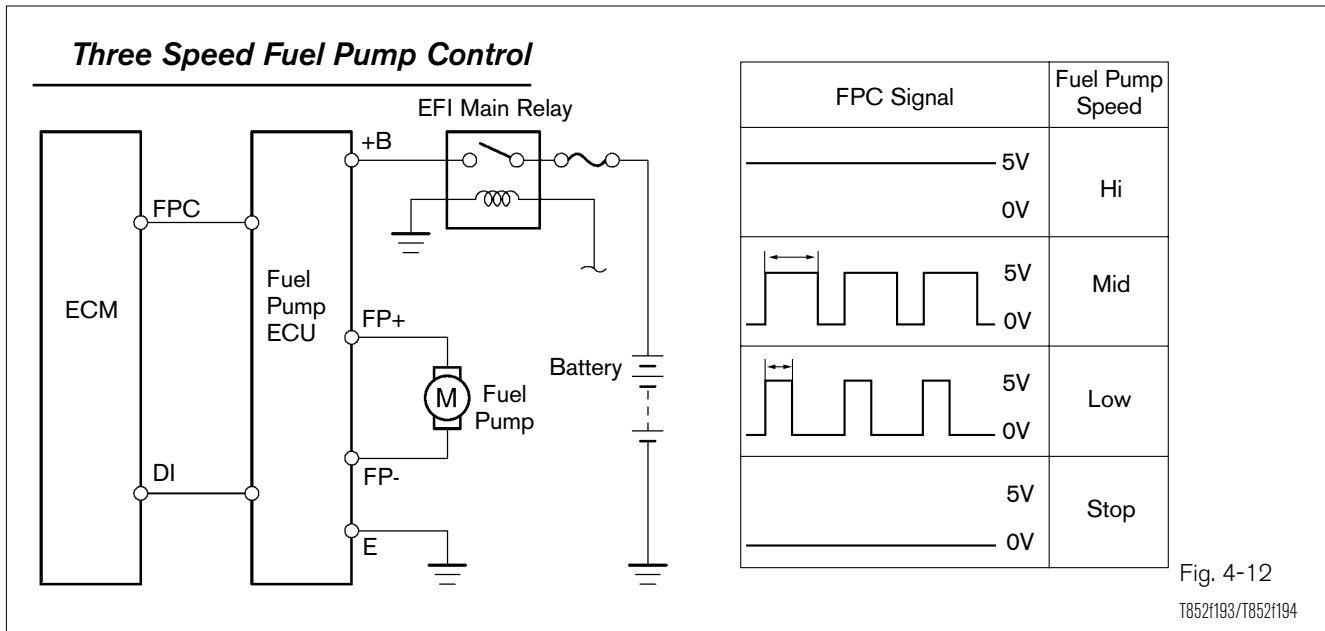
Fig. 4-11
T852f192

ON/OFF Two Speed Control with Fuel Pump ECU

This type is similar to other systems, but uses a Fuel Pump ECU. In this system, however, ON-OFF control and speed control of the fuel pump is performed entirely by the Fuel Pump ECU based on signals from the ECM. In addition, the Fuel Pump ECU is equipped with a fuel pump system diagnosis function. When trouble is detected, signals are sent from the DI terminal to the ECM.

High Speed During starting and heavy load condition, the ECM sends a HI signal (about 5 volts) to the FPC terminal of the Fuel Pump ECU. The Fuel Pump ECU then supplies full battery power to the fuel pump.

Low Speed After the engine starts, during idle and light loads, the ECM outputs a low signal (about 2.5 volts) to the Fuel Pump ECU. Then, the Fuel Pump ECU supplies less voltage (about 9 volts) to the fuel pump.



Three Speed Fuel Pump Control With this system, the fuel pump is controlled in 3 steps (high speed, medium speed, and low speed).

High Speed When the engine is operating under a heavy load at high RPM or starting, the ECM sends a 5 volt signal to the fuel pump ECU. The fuel pump ECU then applies battery power to the fuel pump causing the fuel pump to operate at high speed.

Medium Speed Under heavy loads at low speed, the ECM sends a 2.5 volt signal to the fuel pump control. The fuel pump ECU applies about 10 volts to the fuel pump. This is considered medium speed.

Low Speed When idling or under light loads, the ECM sends a 1.3 volt signal to the fuel pump ECU. The fuel pump ECU applies 8.5 volts to the fuel pump, preventing excessive noise and decreasing power consumption.

Fuel Pump Inertia Switch

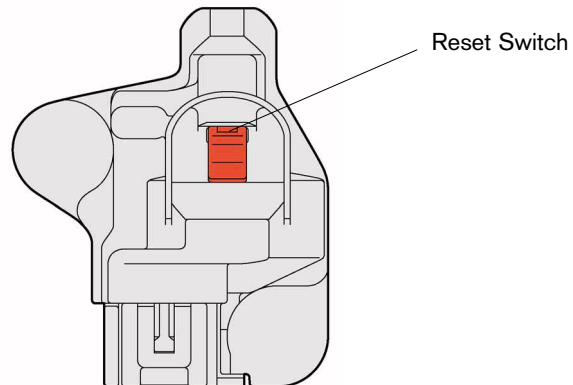


Fig. 4-13
T8521195

Inertia Switch The fuel pump inertia switch shuts off the fuel pump when the vehicle is involved in a collision, minimizing fuel leakage.

Inertia Switch Location

The inertia switch is mounted on the floor pan.

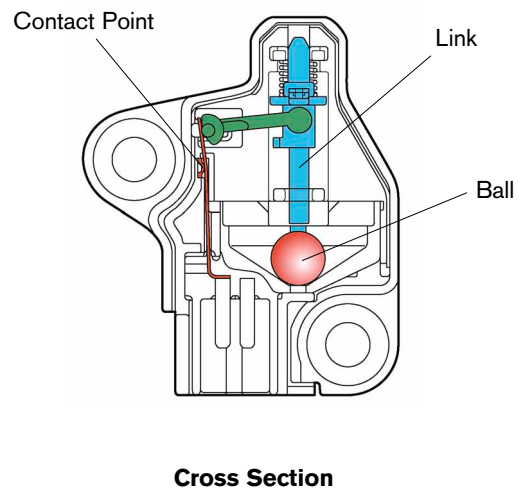
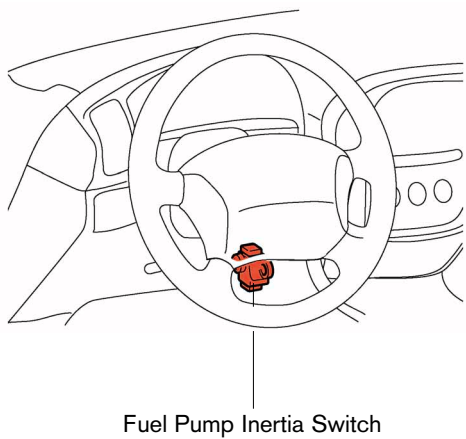


Fig. 4-14
T8521196/T8521197

Fuel Pump Inertia Circuit

Electrically, the fuel pump inertia switch is located between the ECM and Fuel Pump ECU.

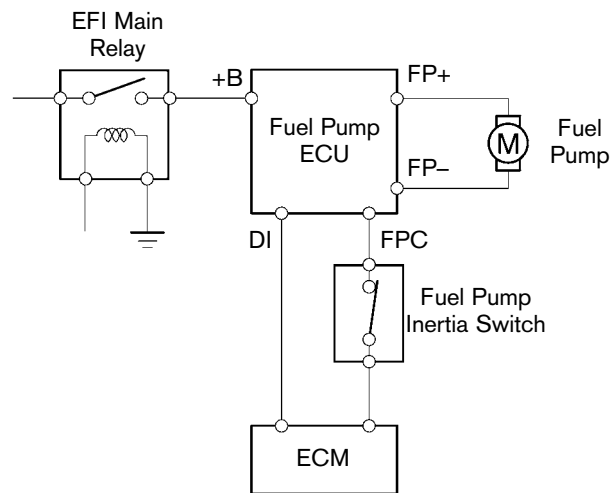


Fig. 4-15
T852f198

Inertia Switch Operation

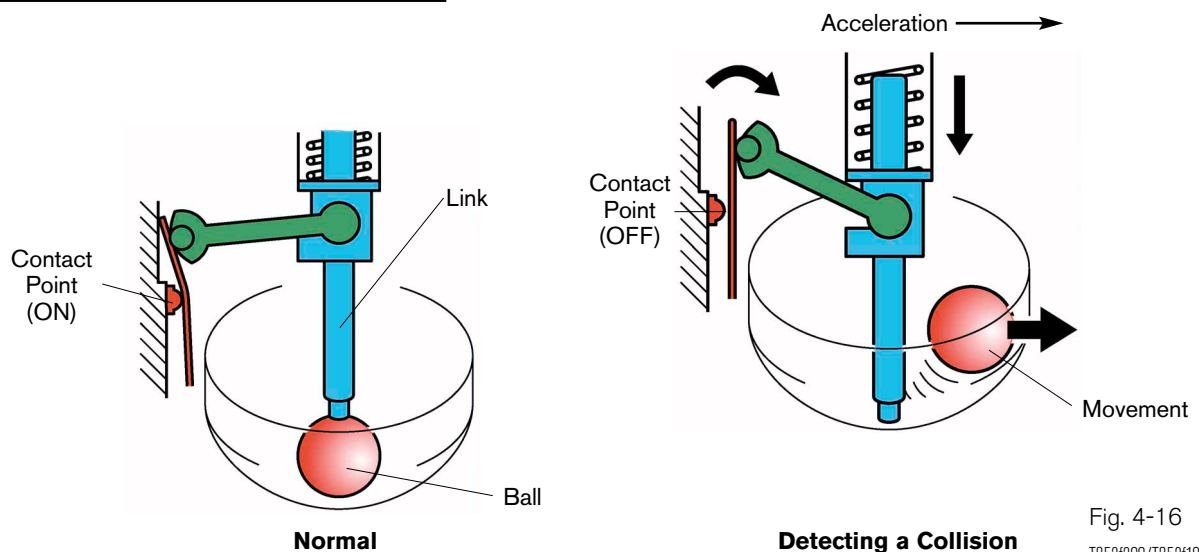


Fig. 4-16
T852f200/T852f199

Operation The inertia switch consists of a ball, spring loaded link, contact point, and reset switch. If the force of the collision exceeds a predetermined value, the ball will move causing the spring loaded link to drop opening the contact point. This opens the circuit between the ECM and Fuel Pump ECU causing the fuel pump to turn off. If the fuel pump inertia switch has been tripped, it can be reset by pushing up on the reset switch for at least 1 second.

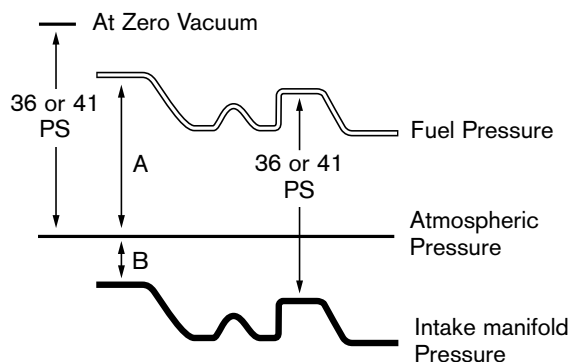
Pressure Regulators

The pressure regulator must consistently and accurately maintain the correct fuel pressure. This is important because the ECM does not measure fuel system pressure. It assumes the pressure is correct. There are two basic types of pressure regulators.

Modulated Pressure Regulators

The return fuel delivery system uses a pressure regulator located on the fuel pressure rail between the fuel pressure rail and the return line to the fuel tank. There are two types of pressure regulators. One type is modulated by vacuum, the other by atmospheric pressure.

Vacuum Modulated Pressure Regulator



Intake Manifold Pressure	Low	High
Effective Spring Tension	Small	Large
Fuel Pressure	Low	High
Injection Volume	Same	Same

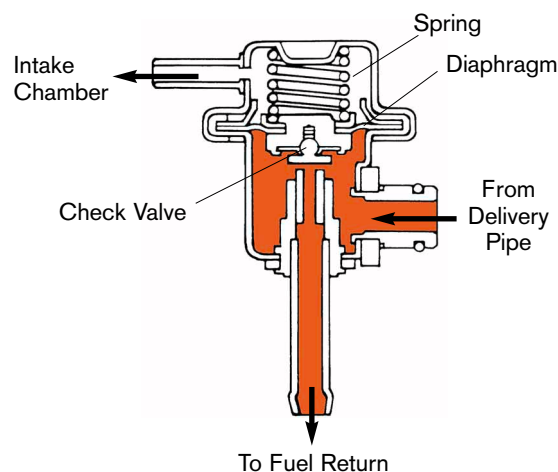


Fig. 4-17

T8521201/T8521202

Vacuum Modulated Pressure Regulator

To maintain precise fuel metering, the vacuum modulated pressure regulator maintains a constant pressure differential across the fuel injector. This means that fuel rail pressure will always be at a constant value above manifold absolute pressure.

Low intake manifold pressure (idle for example) pulls on the diaphragm decreasing spring pressure. This allows more fuel to return to the fuel tank decreasing pressure in the fuel rail. Opening the throttle increases manifold pressure. With less vacuum on the diaphragm spring pressure will increase restricting fuel flow to the fuel tank. This increases pressure in the fuel rail.

Atmospheric Modulated Pressure Regulator

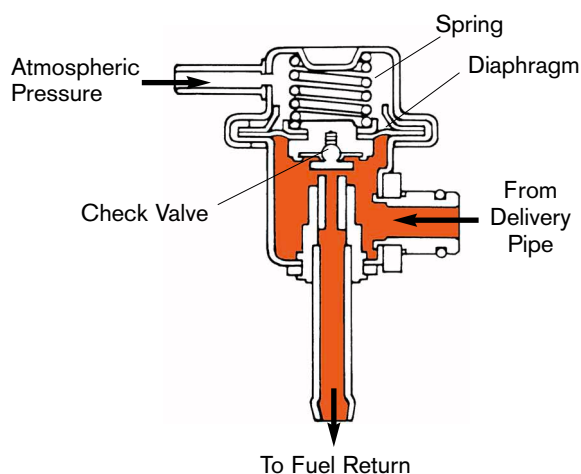


Fig. 4-18

T8521202

Atmospheric Modulated Pressure Regulator The atmospheric modulated pressure regulator modifies fuel pressure with changes in atmospheric pressure. A hose is connected from the pressure regulator to the air intake hose between the air filter and throttle plate. Spring pressure and atmospheric pressure keep the fuel pressure at a constant value, 226-265 kPa (38-44 psi). As air pressure changes, such as climbing from low to high altitude, fuel rail pressure decreases because there is less force on the diaphragm.

Constant Pressure Regulator

The O-Ring must be properly seated to prevent leakage.

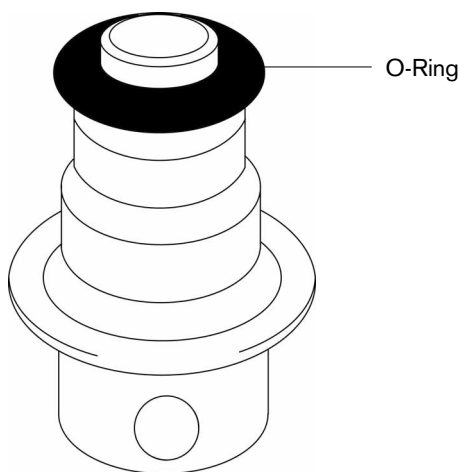


Fig. 4-19

T8521203

Constant Pressure Regulator (Returnless Fuel Delivery System)

The Returnless Fuel Delivery System uses a constant pressure regulator located above the fuel pump in the fuel tank. This type of regulator maintains a constant fuel pressure regardless of intake manifold pressure. Fuel pressure is determined by the spring inside the regulator. Fuel from the fuel pump overcomes spring pressure and some fuel is bypassed into the fuel tank. Fuel pressure is non-adjustable.

High Temperature (Pressure Up) Fuel Pressure Control

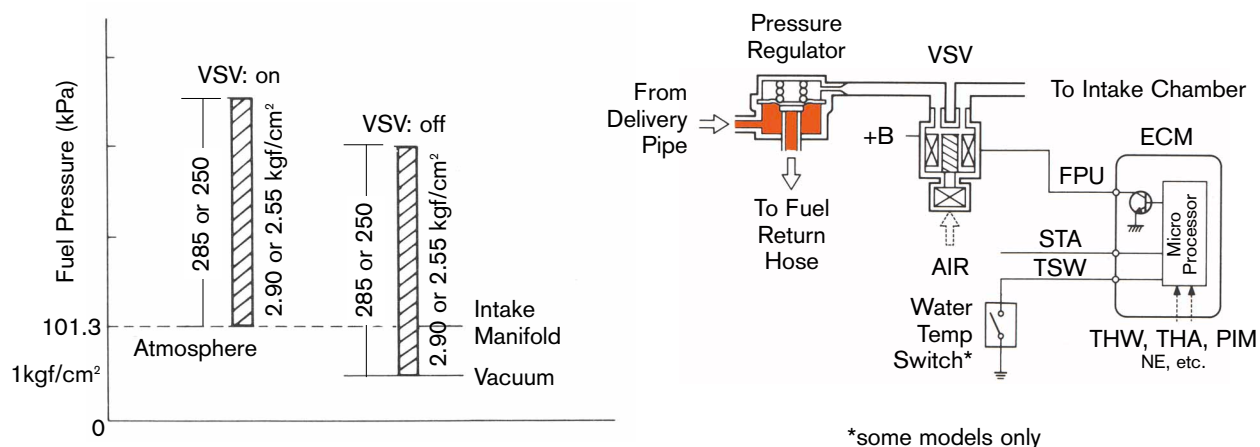


Fig. 4-20

T8521204/T8521205

High Temperature (Pressure Up) Fuel Pressure Control

Some engines are equipped with a high temperature fuel pressure control to prevent vapor lock for easier starting and better driveability. A three way VSV is connected to the fuel pressure regulator vacuum line. Under normal conditions, the VSV is off and engine vacuum regulates the pressure regulator. If the engine is started when the coolant temperature is 85°C (185°F) or higher and the intake air temperature is above predetermined level, the ECM will turn on the VSV. Engine vacuum is closed off and atmospheric pressure is applied to the pressure regulator diaphragm. This increases fuel pressure preventing vapor lock. Once the engine is started, the VSV may remain on for about 120 seconds.

Fuel Delivery Components Today's vehicles use a variety of materials and connectors for fuel lines. Steel and synthetic materials are used, depending on location and model year. It is critical that the correct procedures be followed when servicing the fuel lines.

Connectors can be the threaded type or the quick connector style.

Styles of Quick Connectors

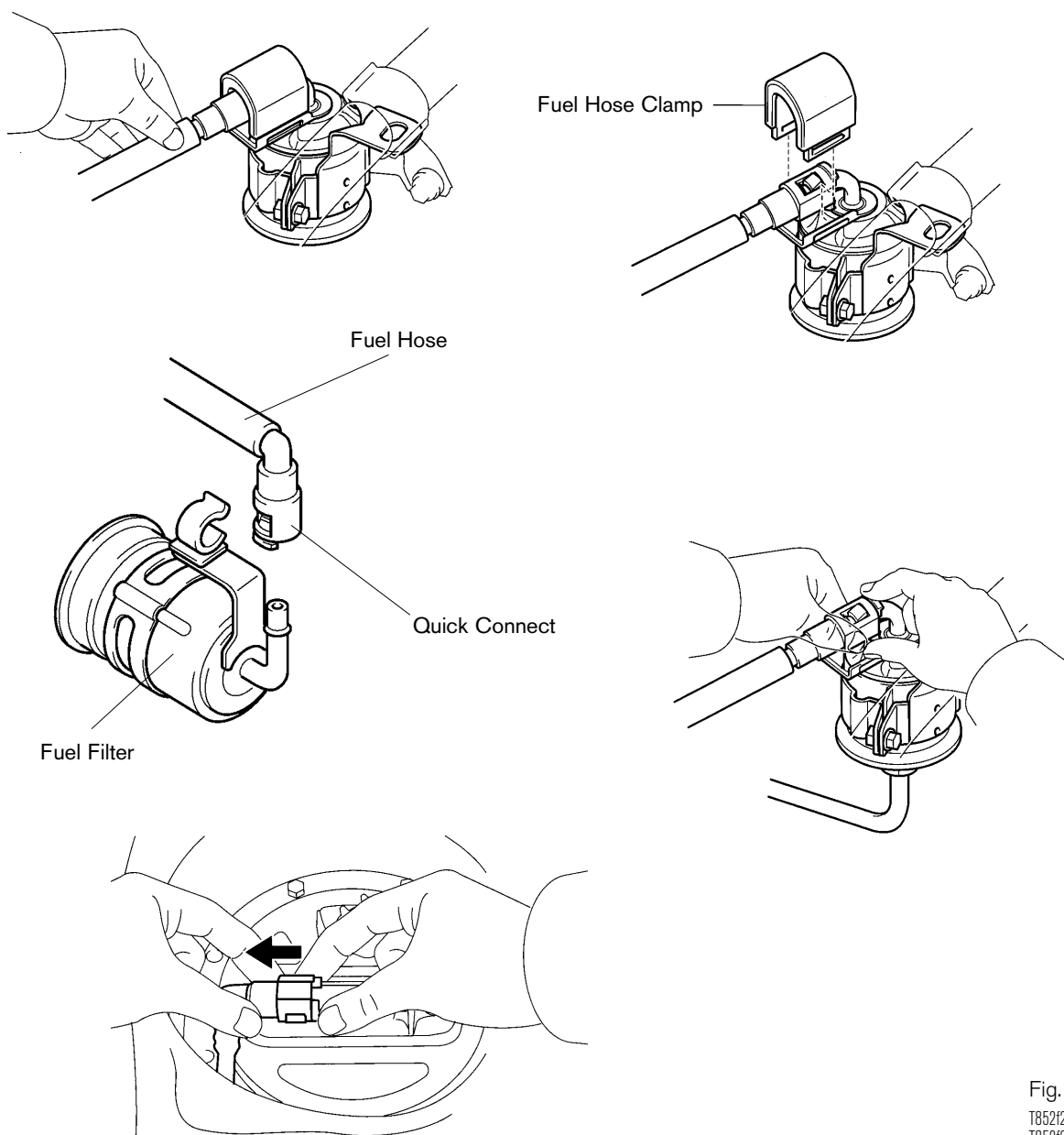
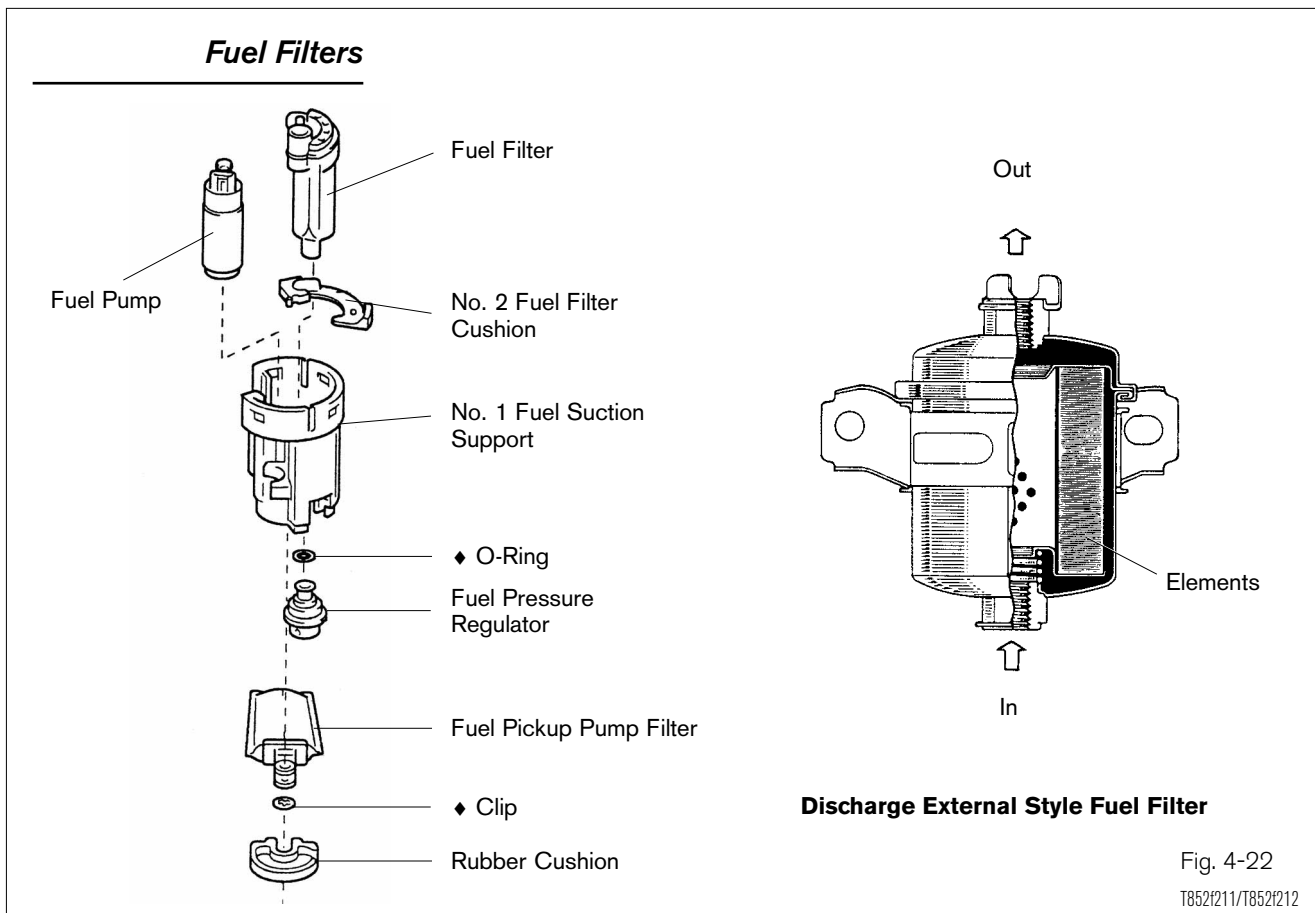


Fig. 4-21
T852f206/T852f207
T852f208/T852f209
T852f210

Fuel Tank The fuel tank is designed to safely contain the fuel and evaporative emissions. Typically, it houses the fuel pump assembly and rollover protection valves.



Fuel Filters Typically, there are two fuel filters in the fuel delivery system. The first filter is the fuel pump filter located on the suction side of the fuel pump. This filter prevents debris from damaging the fuel pump. The second filter, located between the pump and fuel rail, removes dirt and contaminants from the fuel before it is delivered to the injectors. This filter removes extremely small particles from the fuel, the injectors require extremely clean fuel.

The filter may be located in the fuel tank as part of the fuel pump assembly or outside the tank in the fuel line leading to the fuel rail. The filter is designed to be maintenance-free with no required service replacement.

A restricted fuel filter will prevent fuel from reaching the injectors. Therefore, the engine may be hard starting, surge, or have low power under loads. A completely clogged filter will prevent the engine from starting.

Pulsation Damper

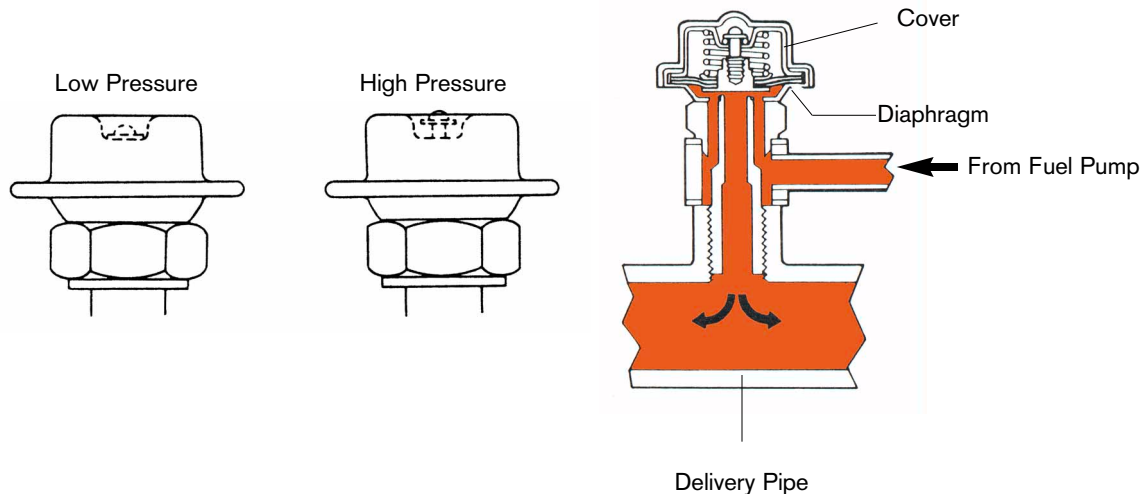


Fig. 4-23

T8521213/T8521214

Pulsation Damper The rapid opening and closing of the fuel injectors cause pressure fluctuations in the fuel rail. The result is that the amount of injected fuel will be more or less than the desired amount. Mounted on the fuel rail, the pulsation damper reduces these pressure fluctuations. When pressure suddenly begins to increase the spring loaded diaphragm retracts slightly increasing fuel rail volume. This will momentarily prevent fuel pressure from becoming too high. When pressure suddenly begins to drop, the spring loaded diaphragm extends, slightly decreasing effective fuel rail volume. This will momentarily prevent fuel pressure from becoming too low. Not all engines require the use of a pulsation damper.

The screw mounted at the top of the damper provides an easy check for fuel system pressure. When the screw is up it means the fuel rail is pressurized. Under most conditions, this check is adequate. The screw is non-adjustable and it is used to calibrate the damper at the factory.

Fuel Injector

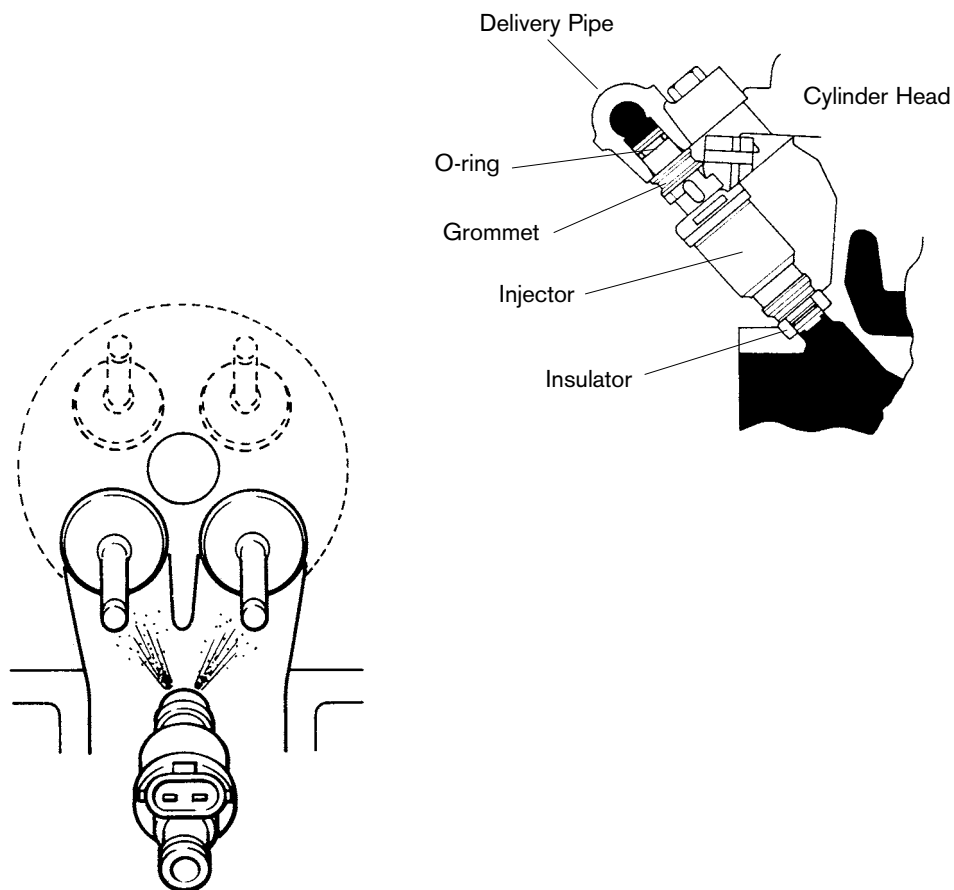


Fig. 4-24

T852f215/T852f216

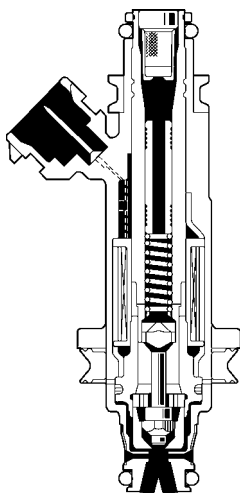
Fuel Injection Operation

The fuel injector, when turned on by the ECM, atomizes and directs fuel into the intake manifold.

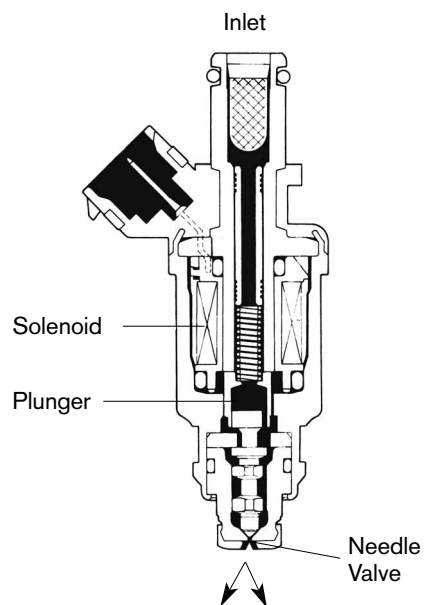
Fuel Injectors

There is one injector per cylinder mounted in the intake manifold before the intake valve(s). The injectors are installed with an insulator/seal on the manifold end to insulate the injector from heat and prevent atmospheric pressure from leaking into the manifold. The fuel delivery pipe secures the injector. An O-ring between the delivery pipe and injector prevents the fuel from leaking.

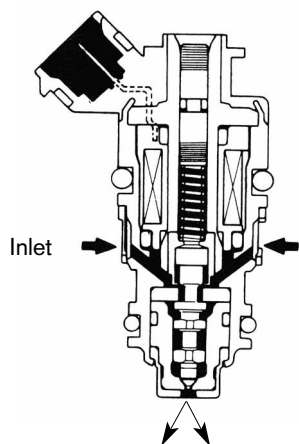
Different Styles of Fuel Injectors



Compact 4 Hole Type



Top Feed Type



Side Feed Type

Fig. 4-25

T8521217/T8521218
T8521219

Different engines require different injectors. Injectors are designed to pass a specified amount of fuel when opened. In addition, the number of holes at the tip of the injector varies with engines and model years. When replacing an injector it is critical that the correct injector be used.

Air Assist Fuel Injector

The one on the right is for the air assist system. During idle air is directed into the air gallery. The smaller tubes increase the air velocity and therefore mixes easily with the fuel for better combustion.

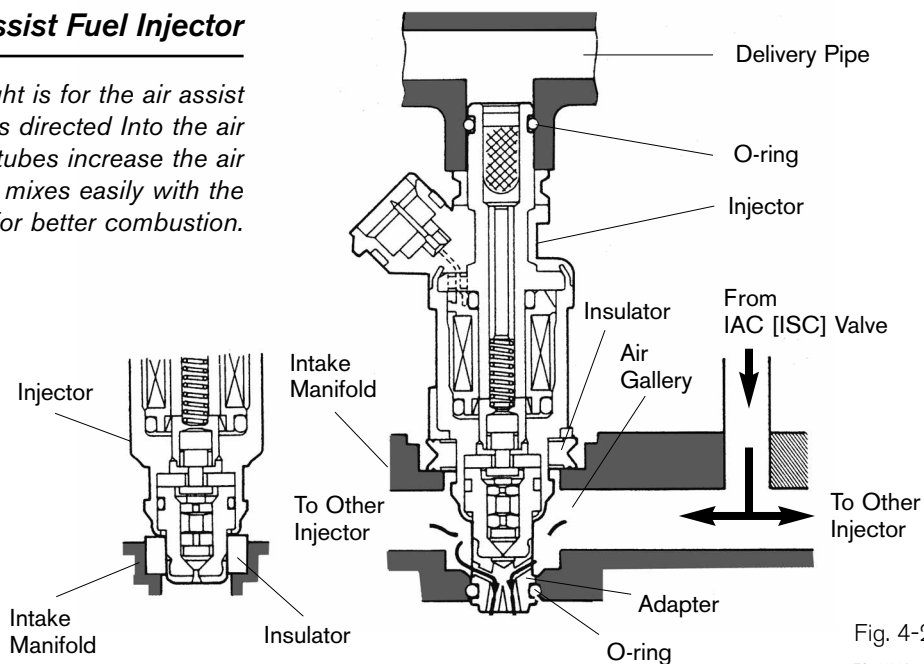


Fig. 4-26
T8521220

Inside the injector is a solenoid and needle valve. The fuel injector circuit is a ground switched circuit. To turn on the injector, the ECM turns on a transistor completing a path to ground. The magnetic field pulls the needle valve up overcoming spring pressure and fuel now flows out of the injector. When the ECM turns off the circuit, spring pressure will force the needle valve onto its seat, shutting off fuel flow.

Grouped Injection

This is one style of grouped injection.

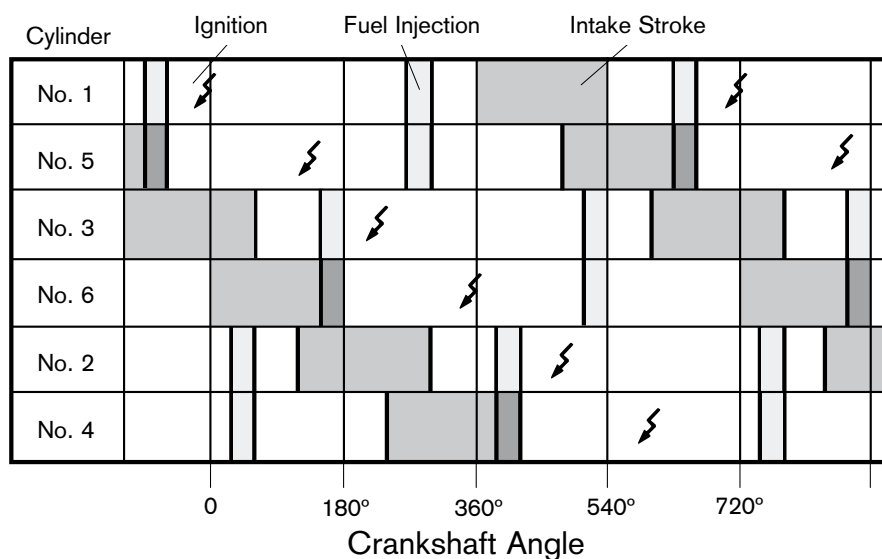


Fig. 4-27
T8521221

Sequential Injection

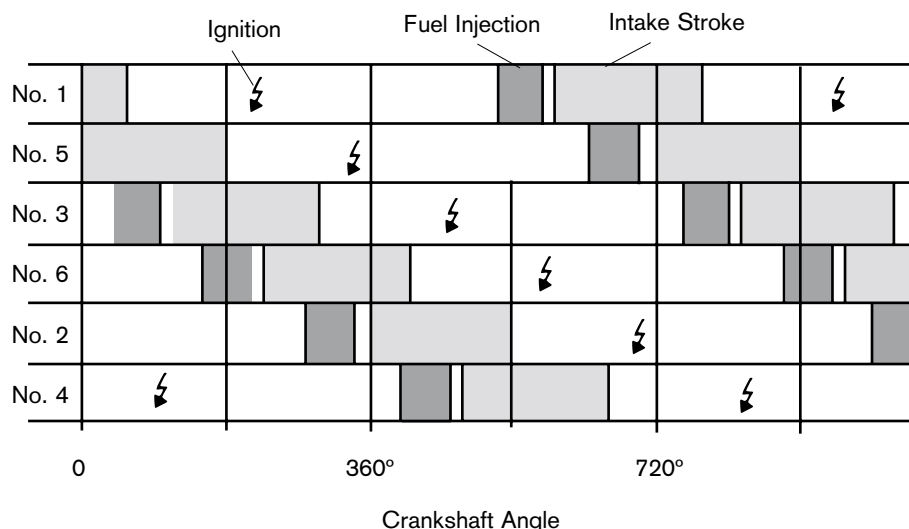


Fig. 4-28
T8521222

Injector Timing/Drive Circuits

The design of the injector drive circuit and ECM programming determines when each injector delivers fuel in relation to the operating cycle of the engine. If the injectors are turned on according to the crankshaft position angle, it is called synchronous injection. That is, the injectors are timed to turn on according to crankshaft position. Depending on engine application, the three main types of synchronous injection designs are: Simultaneous, Grouped, or Sequential. In all these types, voltage is supplied to the injectors from the ignition switch or EFI main relay and the ECM controls injector operation by turning on the driver transistor grounding the injector circuit. Simultaneous and grouped are the oldest styles, and are no longer used.

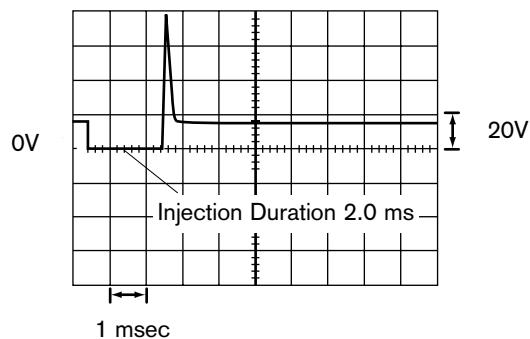
On simultaneous, all injectors are pulsed at the same time by a common driver circuit. Injection occurs once per engine revolution, just prior to TDC No. 1 cylinder. Twice per engine cycle, one-half of the calculated fuel is delivered by the injectors. With grouped drive circuits, injectors are grouped in combinations. There is a transistor driver for each group of injectors. On sequential drive circuits, each injector is controlled separately and is timed to pulse just before the intake valve opens.

There are times when the ECM needs to inject extra fuel into the engine regardless of crankshaft position and this is called asynchronous injection. Asynchronous injection is when fuel is injected into all cylinders simultaneously when predetermined conditions exist without relation to the crankshaft angle. Two common conditions are starting and acceleration.

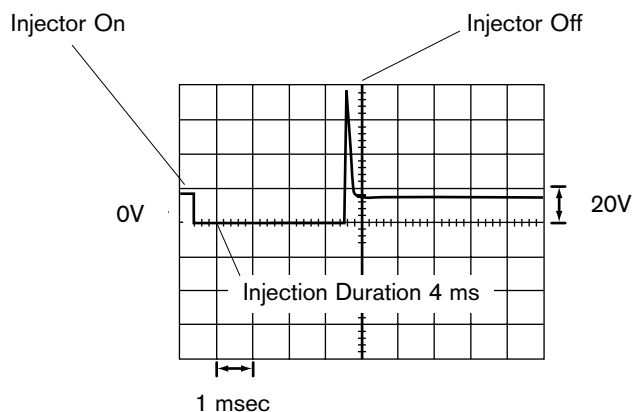
NOTE The EWD injector circuit can identify if the injection system is a grouped or sequential. A sequential system will have one injector per injector driver.

Injector Wave Pattern

Injection duration, when the injector is turned on and off, can be seen on the oscilloscope wave pattern.



• Engine running condition: Idling.



• Engine running condition: Heavy Load.

Fig. 4-29

T8521223/T8521224

Fuel Injection Volume Control

The amount of fuel injected depends on fuel system pressure and the length of time the injector is turned on. Fuel system pressure is controlled by the pressure regulator, and injector on time is controlled by the ECM. The time the injector is on is often called duration or pulse width, and it is measured in milliseconds (ms). Cold starting requires the highest pulsewidth. Pulsewidth is dependent primarily on **engine load and engine coolant temperature**. The higher the engine load and the more the throttle is opened to let air in, the pulsewidth increases. The ECM determines the duration based on the input sensor signals, engine conditions, and its programming.

Fuel Injection Duration Control Modes and Corrections

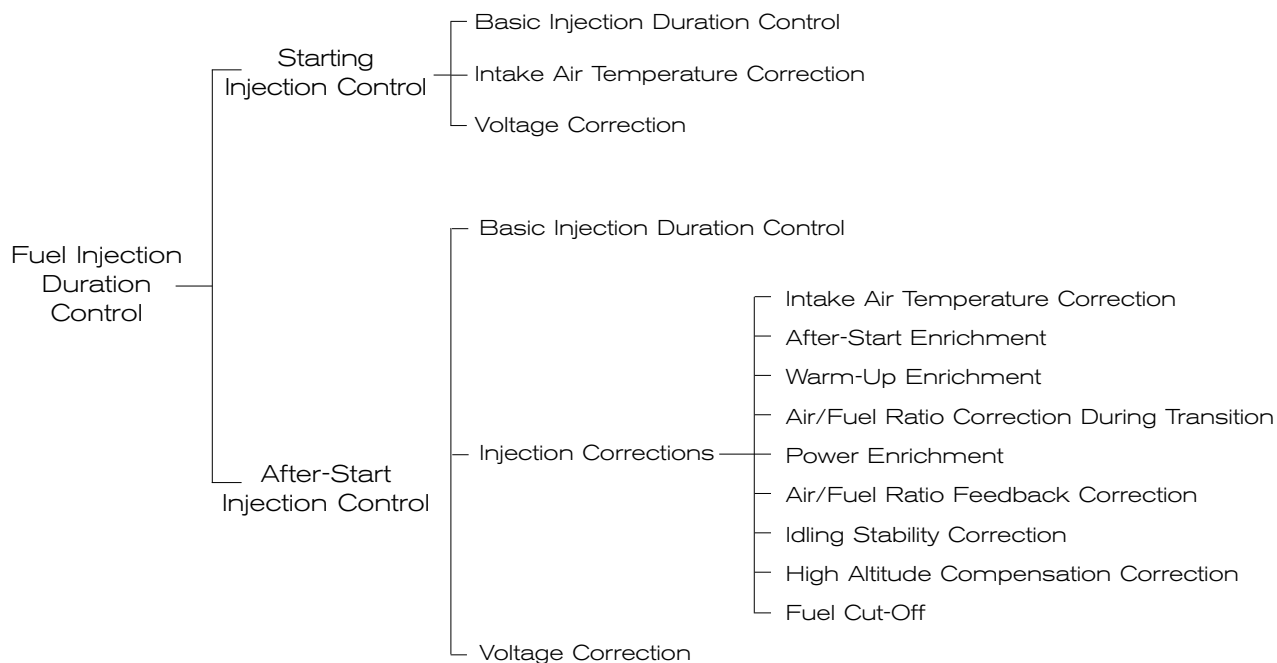


Fig. 4-30

Injection Start Mode

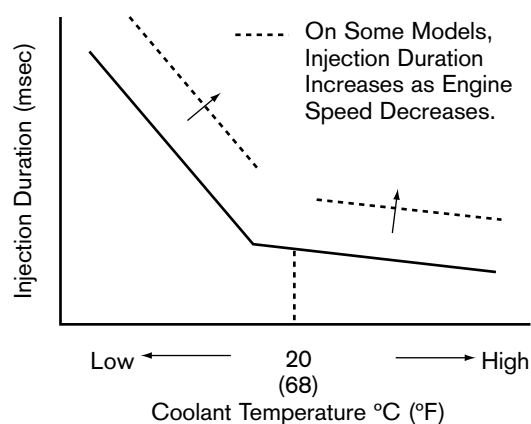
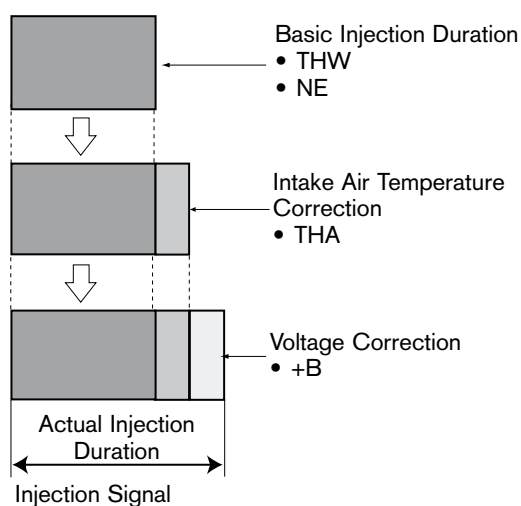


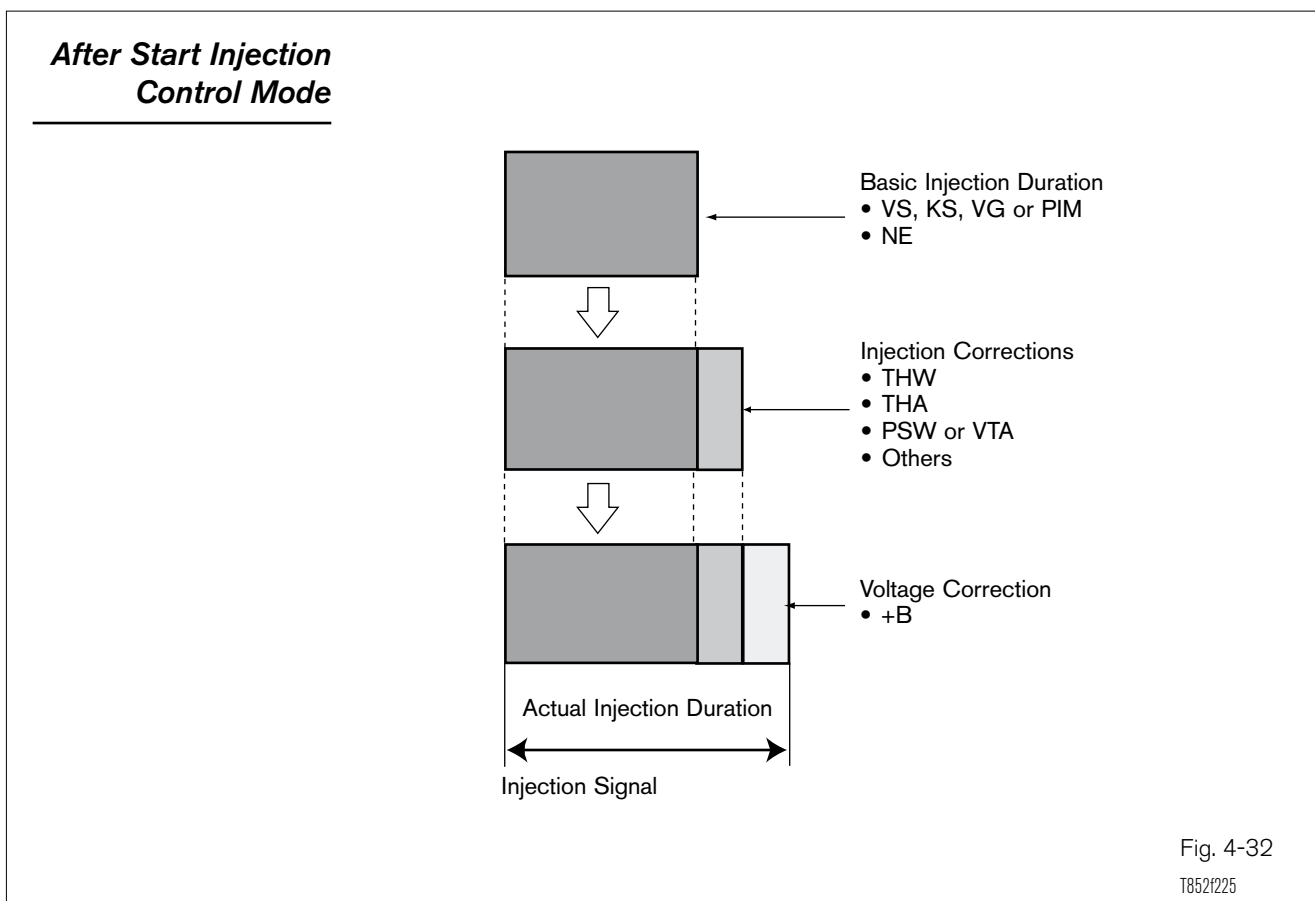
Fig. 4-31

T852f225/T852f226

Start Mode When the ignition switch is in the Start position, the ECM receives a voltage signal at the STA terminal. The ECM determines basic injection duration based on the ECT (THW) signal. On MAP sensor equipped engines the ECM will then modify this duration based on the IAT (THA) signal.

The ECM will adjust the duration based on battery voltage. During cranking, battery voltage is much lower causing the injector valve to lift slowly. The ECM corrects for this by increasing injection duration.

When the ECM receives the NE signal (Crankshaft Position Sensor), all the injectors are turned on simultaneously. This insures there is enough fuel for starting the engine. Note that below freezing, injection duration increases drastically to overcome the poor vaporization characteristics of fuel at these temperatures.



Engine Running (After Start) Injection Duration Control

Total fuel injection duration is determined in three basic steps:

- Basic injection duration.
- Injection corrections.
- Voltage correction.

Basic injection duration is based on air volume and engine RPM. Air volume on MAF equipped engines is determined by the MAF voltage signal.

On MAP sensor equipped engines, the ECM calculates air volume based on the PIM signal, engine RPM, THA signal, and volumetric efficiency values stored in the ECM.

Injection corrections adjust the basic injection duration to accommodate different engine modes and operating conditions. It is based on a variety of input signals.

Voltage correction adjusts the injection duration to compensate for differences in the electrical system voltage.

After Start Enrichment & Warm Up Correction

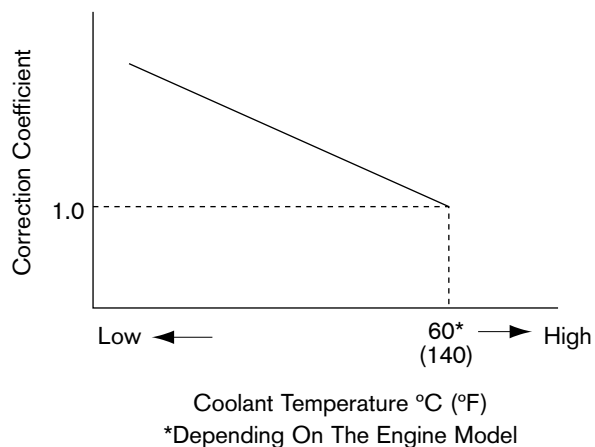


Fig. 4-33
T8521227

After Start Enrichment Immediately after starting (engine speed above a predetermined level), the ECM supplies an extra amount of fuel for a certain period of time to stabilize engine operation.

This correction volume is highest immediately after the engine has started and gradually decreases. The maximum correction volume value is based on engine coolant temperature. The hotter the engine, the less volume of fuel injected.

Warm-Up Enrichment A rich fuel mixture is needed to maintain driveability when the engine is cold. The ECM injects extra fuel based on engine coolant temperature. As the engine coolant warms up, the amount of warm-up enrichment decreases. Depending on the engine, warm-up enrichment will end at approximately 50°C–80°C (122°F–176°F).

If the ECM is in Fail-Safe Mode for DTC P0115, the ECM substitutes a temperature value, usually 80°C (176°F).

Correction Based on Intake Air Temperature (MAP Sensor Equipped Engines)

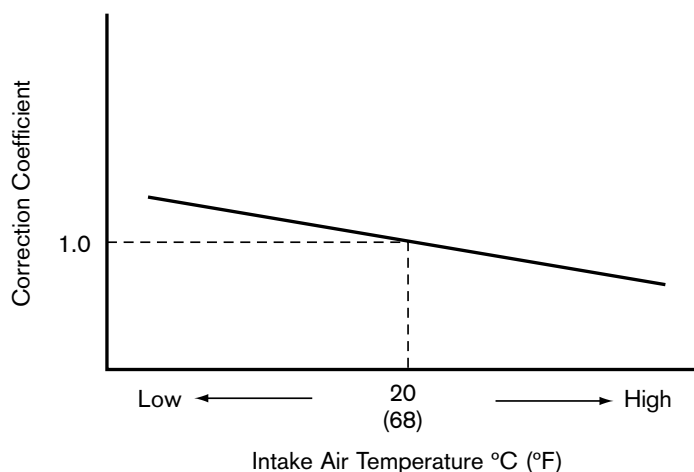


Fig. 4-34

T852f228

Correction Based on Intake Air Temperature (MAP Sensor Equipped Engines) The density of the intake air decreases as temperature increases. Based on the IAT (THA) signal, the ECM adjusts the fuel injection duration to compensate for the change in air density. The ECM is programmed so that at 20°C (68°F), no correction is needed. Below 20°C (68°F), duration is increased, above 20° (68°F), duration is decreased.

If the ECM is in Fail-Safe Mode for DTC P0110, the ECM substitutes a temperature value of 20°C (68°).

Power Enrichment Correction When the ECM determines the engine is operating under moderate to heavy loads, the ECM will increase the fuel injection duration. The amount of additional fuel is based on the MAF or MAP sensors, TPS, and engine RPM. As engine load (and air volume) increases, fuel injection duration increases. As engine RPM increases, injection frequency increases at the same rate.

Acceleration Correction On initial acceleration, the ECM extends the injection duration richening the mixture to prevent a stumble or hesitation. The duration will depend on how far the throttle valve travels and engine load. The greater the throttle travel and engine load, the longer the injection duration.

Deceleration Fuel Cut

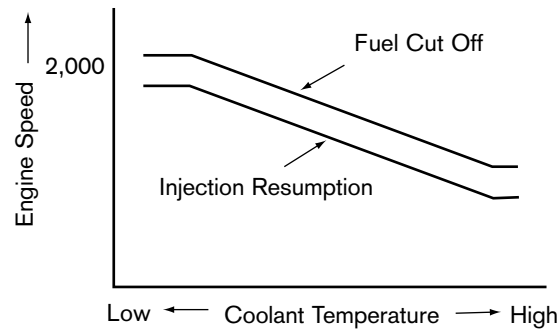


Fig. 4-35

T8521229

Deceleration Fuel Cut During closed throttle deceleration periods from moderate to high engine speeds, fuel delivery is not necessary or desirable. To prevent excessive decel emissions and improve fuel economy, the ECM will not open the injectors under certain decel conditions. The ECM will resume fuel injection at a calculated RPM.

Referring to the graph, fuel cut-off and resumption speeds are variable, depending on coolant temperature, A/C clutch status, and the STA signal. Essentially, when extra engine loads are present, the ECM will begin fuel injection earlier.

Fuel Tau Cut is a mode employed on some engines during long deceleration time with the throttle valve closed. During these times, excess oxygen would enter the catalytic converter. To prevent this, the ECM will very briefly pulse the injectors.

Engine Over-Rev To prevent engine damage, a rev-limiter is programmed into the ECM.

Fuel Cutoff Any time the engine RPM exceeds the pre-programmed threshold, the ECM shuts off the injectors. Once RPM falls below the threshold, the injectors are turned back on. Typically, the threshold RPM is slightly above the engine's redline RPM.

Vehicle Over-Speed On some vehicles, fuel injection is halted if the vehicle speed exceeds a predetermined threshold programmed into the ECM. Fuel injection resumes after the speed drops below this threshold.

Battery Voltage Correction

With lower battery voltage, a longer injector ON time is needed.

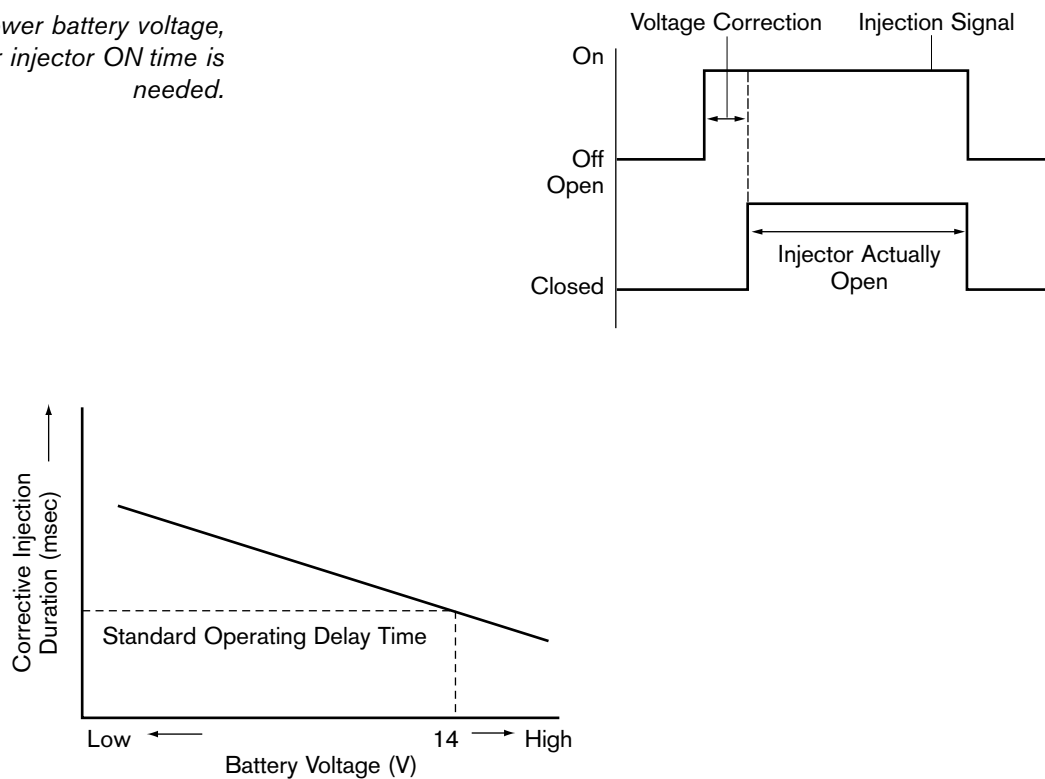


Fig. 4-36

T8521230/T8521231

Battery Voltage Correction The applied voltage to the fuel injector will affect when the injector opens and the rate of opening. The ECM monitors vehicle system voltage and will change the injection on time signal to compensate. If system voltage is low, the injection on time signal will be longer, but the actual time the injector is open will remain the same (if system voltage were higher).

High Altitude Compensation

To compensate for less air at higher altitudes, fuel injection duration is decreased.

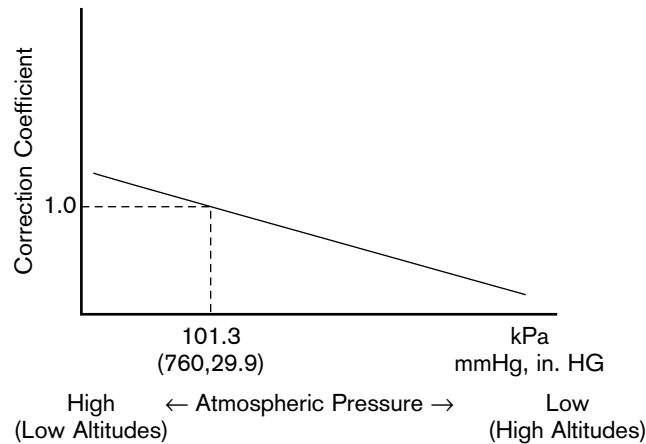


Fig. 4-37

T8521232

EVAP Purge Compensation When the evaporative purge valve is on, fumes from the charcoal canister are drawn into the intake manifold. The ECM will compensate based on the oxygen sensor output and shorten the injector pulse width.

Closed Loop Systems A system that controls its output by monitoring its output is said to be a closed loop system. An example of a closed loop system is the vehicle's charging system. The voltage regulator adjusts the voltage output of the alternator by monitoring alternator voltage output. If voltage is too low, the voltage regulator will increase alternator output. Without the voltage regulator, alternator output could not be adjusted to match the electrical loads. Many systems are closed loop systems. Some other examples are: cruise control, ignition system knock control, idle speed control, and closed loop air/fuel ratio correction control. When the ECM corrects the air/fuel ratio based on the oxygen or air/fuel ratio sensor, the system is said to be in closed loop.

Open Loop Systems An open loop system does not monitor its output and make adjustments based on its output. The temperature control in a vehicle not equipped with automatic air conditioning serves as an example.

Closed Loop Fuel Control The ECM needs to monitor the exhaust stream and adjust the air/fuel ratio so that the catalytic converter will operate at peak efficiency, reducing regulated emission gases. Measuring the amount of oxygen remaining after combustion is a means to indicate the air/fuel ratio. A richer mix-

ture will consume more oxygen during combustion than a leaner mixture. The oxygen sensor or air/fuel ratio sensor measures the amount of oxygen remaining after combustion in the exhaust stream. From this information, the ECM will control the injection duration to achieve the desired, ideal air/fuel ratio of 14.7:1. This is necessary so the catalytic converter will operate at peak efficiency.

NOTE

The engine operation often requires different air/fuel ratios for starting, maximum power, and maximum fuel economy. The 14.7:1 ratio is for catalytic converter efficiency.

Stoichiometry and Catalyst Efficiency

Catalytic converter efficiency is nearly 100% when the air/fuel ratio is approximately 14.7:1.

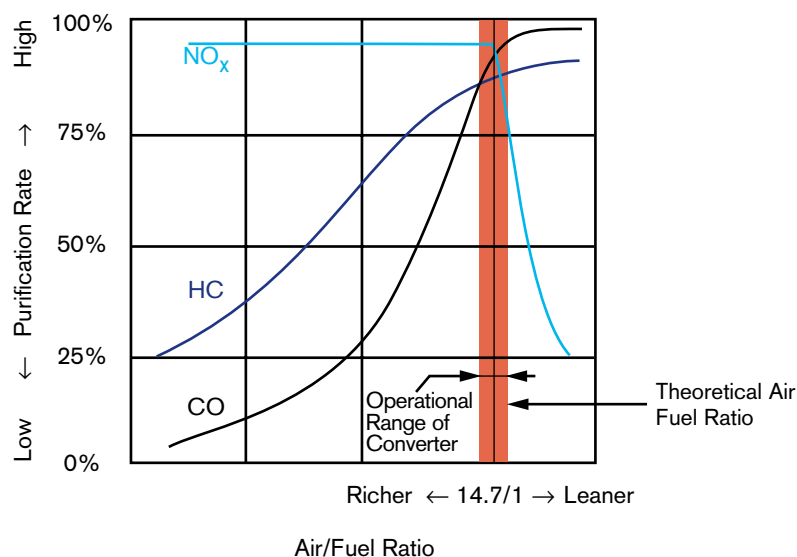


Fig. 4-38

T852/233

Stoichiometry and Catalyst Efficiency

For the catalytic converter to operate at peak efficiency, the air/fuel ratio must be at the ideal stoichiometric ratio of 14.7 parts air to one part fuel as measured by weight. This why the ECM tries to maintain a 14.7 to 1 ratio whenever possible.

Open Loop Mode

When in open loop, the ECM does not use the oxygen sensor or A/F sensor to adjust the injector duration.

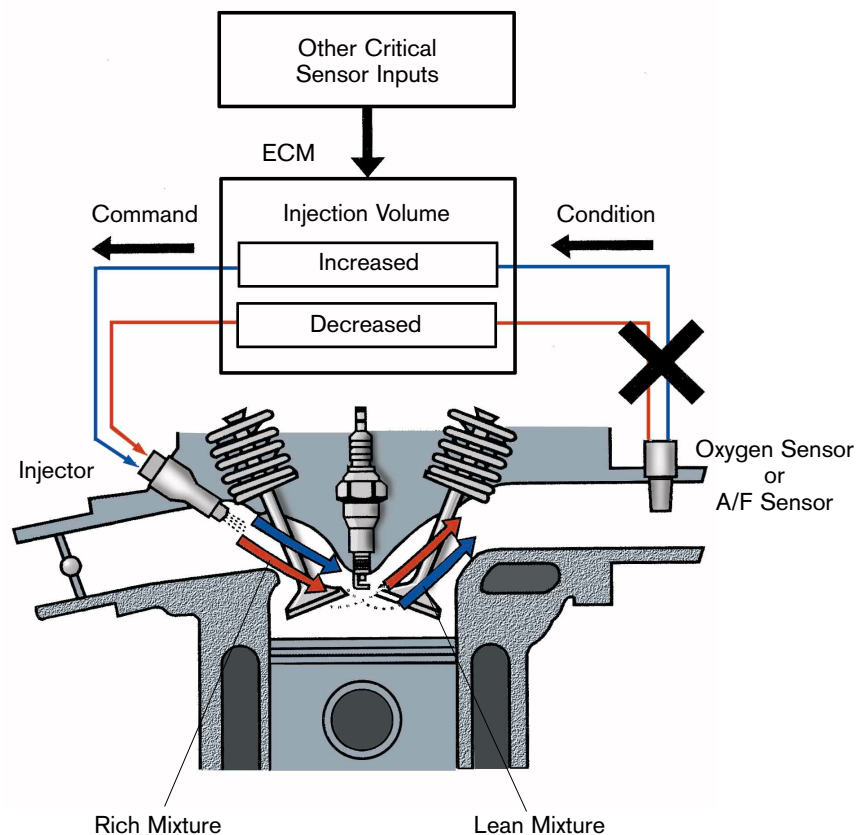


Fig. 4-39

T8521234

Open Loop Mode The ECM will be in open loop mode when:

- starting the engine.
- the engine is cold.
- hard acceleration.
- during fuel cut-off.
- wide open throttle.

If the engine will not go into closed loop mode, the problem may be insufficient engine temperature, no response from the oxygen sensor or air/fuel sensor, or the heater circuit is inoperative. Usually, no response from the oxygen or A/F sensor will set DTC P0125.

If there is a driveability problem only in closed loop, anything that disrupts air/fuel ratio, the oxygen or A/F sensor circuit may be the cause.

Closed Loop Fuel Control

Now, the ECM will adjust injector duration using the oxygen sensor or A/F sensor signal.

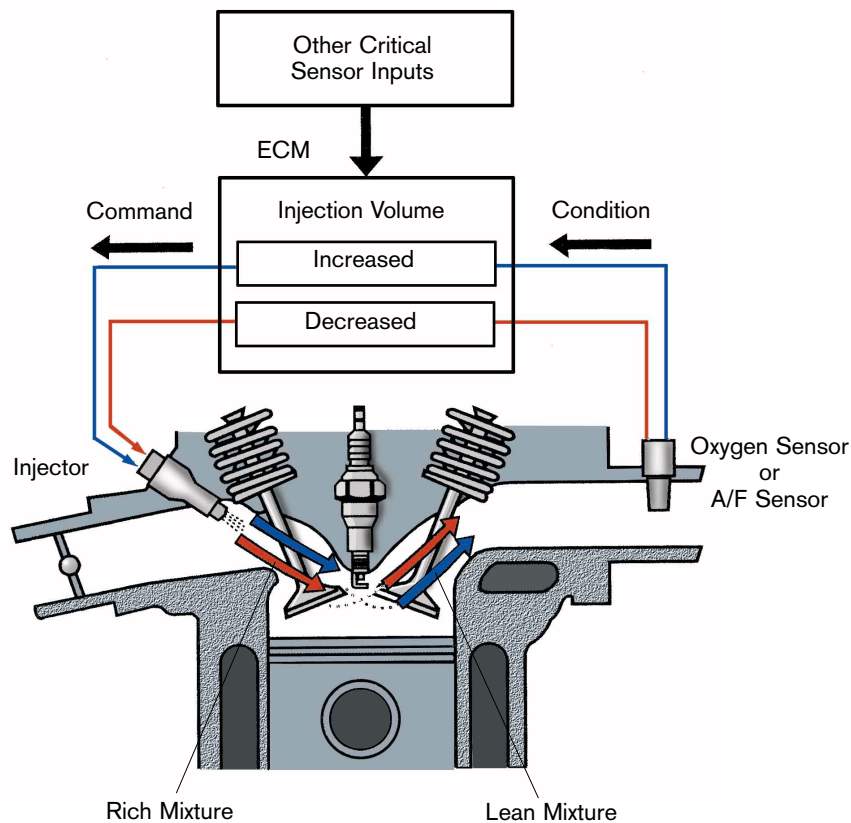


Fig. 4-40

T8521235

Closed Loop Operation/Oxygen Sensor When in closed loop, the ECM uses the oxygen sensor voltage signal to make minor corrections to the injection duration. This is done to help the catalytic converter operate at peak efficiency.

When the voltage is higher than 450 mV, the air/fuel ratio is judged to be richer than the ideal air/fuel ratio and the amount of fuel injected is reduced at a constant rate. The reduction in the duration continues until the oxygen sensor signal switches to a low voltage (lean air/fuel ratio).

Exhaust Oxygen Content	Oxygen Sensor Output	Air/Fuel Mixture Judged To Be:
Low	High, Above 0.45 volts	Rich
High	Low, Below 0.45 volts	lean

When the voltage signal is lower than 450 mV, the air/fuel ratio is judged to be leaner than the ideal air/fuel ratio so the amount of fuel injected is increased at a constant rate. The increase in duration continues until the oxygen sensor switches to high voltage (rich air/fuel ratio). At this point, the ECM will slowly decrease the amount of fuel, therefore the air/fuel ratio oscillates slightly richer or leaner from the ideal air/fuel ratio. The result is an average of approximately 14.7:1. This produces the proper mixture of exhaust gases so that the catalytic converter operates at its most efficient level.

The frequency of this rich/lean cycle depends on exhaust flow volume (engine RPM and load), the oxygen sensor response time, and the fuel control programming. At idle, exhaust flow volume is low, and the switching frequency of the oxygen sensor is low. As engine speed increases, the switching frequency of the oxygen sensor increases, generally eight or more times at 2,500 RPM in ten seconds.

Closed Loop Operation With an A/F sensor, air/fuel mixture correction is faster and more precise. An oxygen sensor signal voltage abruptly changes at the ideal A/F ratio and changes very little as the air/fuel ratio extends beyond the ideal ratio. This makes fuel control less precise, for the ECM must gradually and in steps change the injection duration until the oxygen sensor signal abruptly switches.

By contrast, the A/F sensor outputs a voltage signal that is relatively proportional to the A/F ratio. The ECM now knows how much the A/F ratio has deviated from the ideal, and thus, the fuel control program can immediately adjust the fuel injection duration. This rapid correction reduces emission levels because the ECM can more accurately maintain the ideal air/fuel ratio for the best catalytic converter efficiency.

Therefore, when observing A/F sensor voltage output, the output is relatively constant because there is no cycling between rich and lean.

Fuel Trim As the engine and sensors change over time, the ECM needs a method to adjust the injection duration for improved driveability and emission performance. Fuel trim is a program in the ECM designed to compensate for these changes.

When in closed loop, the ECM modifies the final injection duration based on the oxygen sensor. These minor corrections are needed to maintain the correct air/fuel ratio. However, if more correction than normal (as determined by the ECM) is needed, the ECM will use the fuel trim strategy to compensate. Fuel trim allows the ECM to learn and adjust the injection

duration quickly by reducing the correction time back to normal. This means that driveability and performance will not suffer.

Fuel trim can be observed on the Diagnostic Tester as a percentage. A positive percentage means that the ECM has increased the duration and a negative percentage means the ECM has decreased the duration.

There are two different fuel trim values that affect final injection duration and can be observed by the technician; short term fuel trim (SHORT FT) and long term fuel trim (LONG FT). SHORT FT is a temporary addition or subtraction to the basic injection duration. LONG FT is part of the basic injection duration calculation and it is stored in the ECM's memory.

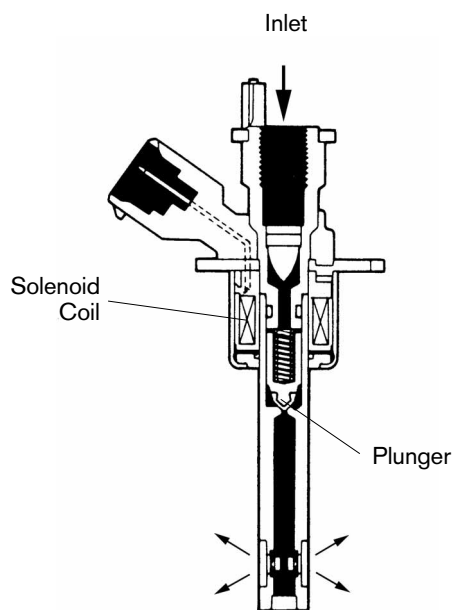
SHORT FT SHORT FT is based on the oxygen sensor, and therefore, it only functions in closed loop. SHORT FT responds rapidly to changes in the oxygen sensor. If SHORT FT is varying close to 0%, little or no correction is needed. When SHORT FT percentage is positive, the ECM has added fuel by increasing the duration. A negative percentage means the ECM has subtracted fuel by decreasing the duration. The SHORT FT value is temporary and not stored when the ignition key is turned off.

SHORT FT is used to modify the long term fuel trim. When the SHORT FT remains higher or lower longer than expected, the ECM will add or subtract this value to the LONG FT.

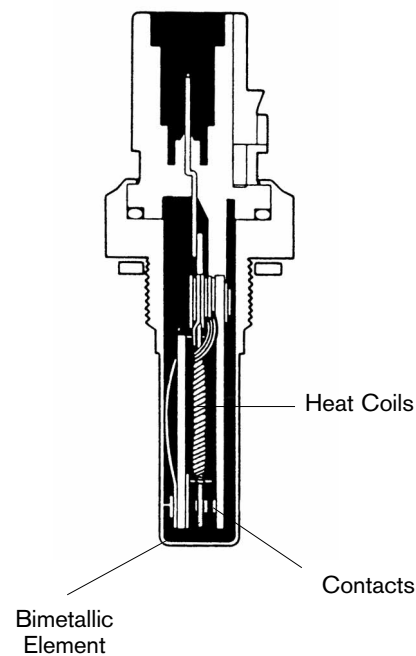
LONG FT LONG FT is stored in memory because it is part of the basic injection duration calculation. The ECM uses the SHORT FT to modify the LONG FT. The LONG FT does not react rapidly to sudden changes, it only changes when the ECM decides to use the SHORT FT value to modify the LONG FT. LONG FT is stored in the ECM's memory and it is not erased when the ignition key is turned off. Because LONG FT is part of the basic injection duration, it affects injection duration in closed and open loop. Like the SHORT FT, when LONG FT is at 0% there has been no modification to the basic injection duration. A positive percentage means the ECM is adding fuel; a negative percentage, subtracting fuel.

Fuel System Monitor The fuel system monitor is designed to set a DTC if the fuel injection system is going to exceed emission standards. This monitor uses the fuel trim correction levels for detection. The amount of fuel trim correction that will set a DTC varies with each engine type and model year.

Cold Start Injector and Time Switch



Injector



Time Switch

Fig. 4-42

T8521236/T8521237

Cold Start Injector System Cold start injector systems are no longer used, but they were very common for many years. The function of the cold start injector is to maintain engine startability when the engine is cold. This injector operates only during cranking when the coolant temperature is low. The function of the start injector time switch is to control the maximum injection duration of the cold start injector.

Non-ECM Controlled Cold Start Timer Circuit

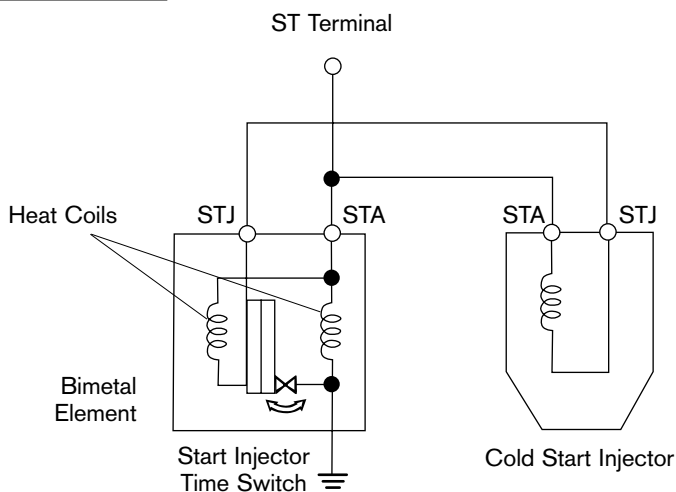


Fig. 4-43

T852/238

Non-ECM Controlled Cold Start Circuit

When the engine is cranked while the engine coolant temperature is low, the duration of cold start injector operation is controlled by the start injector time switch. When the bimetal contacts are closed, current flows through the cold start injector. Simultaneously, current is flowing through the heat coils. Heat will flex the bimetal element opening the contacts. The length of time depends on engine temperature.

Cold Start Injector Duration

Duration is determined by engine coolant temperature. ON or OFF depending on engine model.

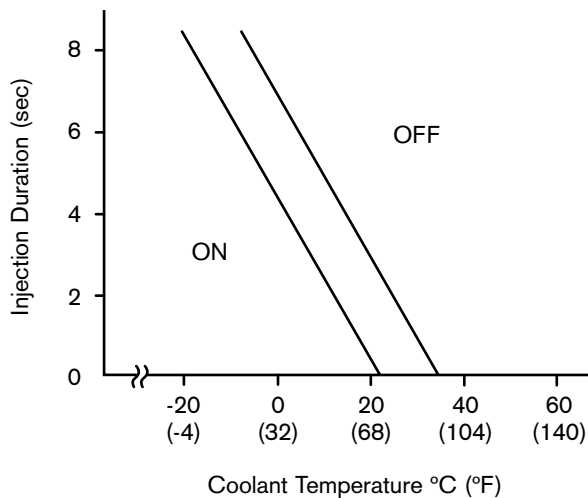


Fig. 4-44

T852/239

ECM Controlled Cold Start Injector System

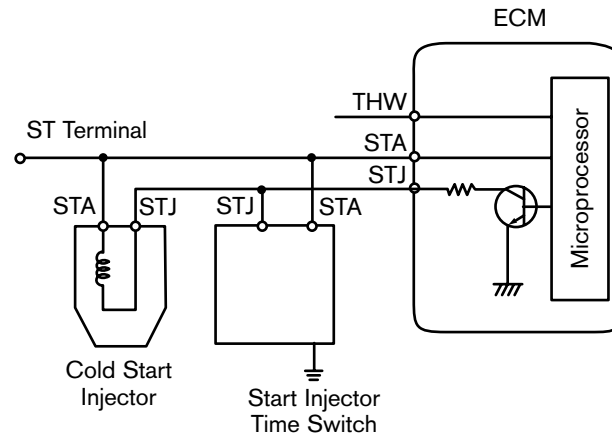


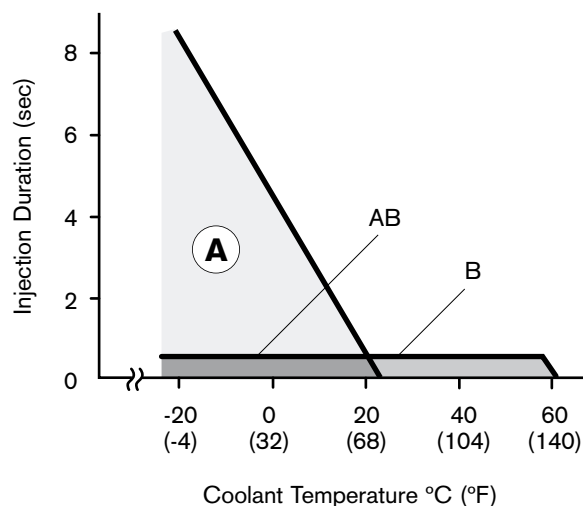
Fig. 4-45

T85212240

ECM Controlled Cold Start Injector System In order to improve startability when the engine is cold, the injection duration of the cold start injector is controlled not only by the injector time switch but also by the ECM in accordance with the coolant temperature.

ECM and Injector Time Switch

Control of the injection duration of the cold start injector continues to be carried out by the start injector time switch, as shown by shaded area A, but control is also exercised by the ECM, as shown by shaded area B.



- A: Controlled By Start Injector Time Switch
- B: Controlled By ECM
- A,B: Controlled By Start Injector Time Switch and ECM

Fig. 4-46

T8521241



Notes



WORKSHEET 4-1

Fuel Delivery System

Vehicle	Year/Prod. Date	Engine	Transmission
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Technician Objectives

With this worksheet, you will learn to test fuel delivery systems using the required tools and equipment, retrieve and apply the needed service information, retrieve and interpret service data information.

Tools and Equipment

- Vehicle Repair Manual
- Vehicle EWD
- Diagnostic Tester
- Hand Tool Set

Section 1

Testing Fuel Delivery System

1. Using a copy of the EWD/RM electrical circuit for the fuel pump, trace the power flow with a marker. Use orange for power side, green/yellow for ground.

2. What relay activates the fuel pump?

3. Is the relay supply side or ground side switched?

4. What fuse(s) feed the fuel pump circuit?

Section 2

1. According to the Repair Manual, use Active Test on the DT to operate the fuel pump. What component can be used to indicate fuel pressure?

2. How could the fuel pump be operated without the DT?

3. What is the recommended method for depressurizing the system?

Section 3

1. On three speed fuel pumps, what signal does the ECM use to vary fuel pump speed? What is the voltage signal level for low, medium, and high?

Section 4

Using the Repair Manual and Technician Handbook, answer the following questions.

1. A disconnected hose on a vacuum modulated pressure regulator will cause fuel pressure to:

2. If the fuel has no residual fuel pressure, list three possible causes.

3. If fuel pressure is too high, list two possible causes:

4. List four causes of low fuel pressure.

5. If there is no fuel pressure, list six possible causes for this condition.

6. List five symptoms lower than normal fuel pressure will have on driveability.

Fuel Delivery System

Name _____ Date _____

Review this sheet as you are doing the worksheet. Check each category after completing the worksheet and instructor presentation. Ask the instructor if you have questions. The comments section is for you to write where to find the information, questions, etc.

Topic	<div style="border: 1px solid black; padding: 5px; display: inline-block;"> <i>I have questions</i> </div>	<div style="border: 1px solid black; padding: 5px; display: inline-block;"> <i>I know I can</i> </div>	Comment
Locate components in the fuel delivery system using the EWD and RM			
Find wire colors, pin numbers in the fuel delivery electrical circuits using the EWD and RM			
Locate the Fuel Pump status in the Data List and compare to specifications to determine condition			
Activate fuel pump with Active Test			
Activate fuel pump using test leads			
Test fuel pump and compare to specifications to determine condition			
Test fuel system pressure and compare to specifications to determine condition			
Test fuel pump relay/ECU and compare to specifications to determine condition			
Check and retrieve relevant DTCs			
Properly disconnect and reconnect fuel lines			
Locate in the RM three sections related to fuel delivery system concerns			



Notes



WORKSHEET 4-2 Fuel Injector Systems

Vehicle	Year/Prod. Date	Engine	Transmission
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Technician Objectives

With this worksheet, you will learn to test fuel injection systems using the required tools and equipment, retrieve and apply the needed service information, retrieve and interpret service data information.

Tools and Equipment

- Vehicle Repair Manual & EWD
- Diagnostic Tester & Noid Light
- Hand Tool Set
- Vehicle

Section 1

1. Connect a DT to a vehicle, measure injector pulsewidth and MAF/MAP output with DT using Data List.

Diagnostic Tester	Pulsewidth at Idle	2000 RPM	In Drive at Idle (prk brk set, foot on brake)	In Drive at 1500 RPM (prk brk set, foot on brake)
Fuel Injector Pulsewidth				
MAF/MAP Output				

2. Compare MAF/MAP output to injector pulsewidth. What is your conclusion?

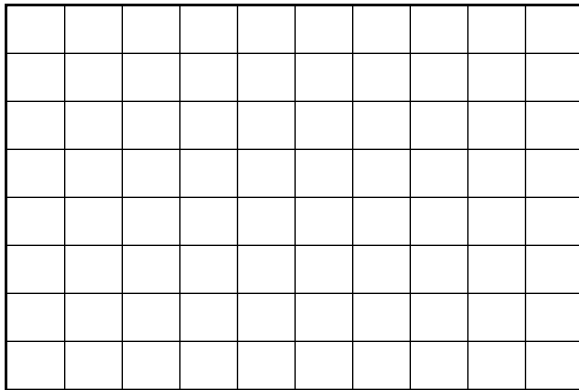
Section 2

1. According to the Repair Manual, display the injector waveform on the oscilloscope.

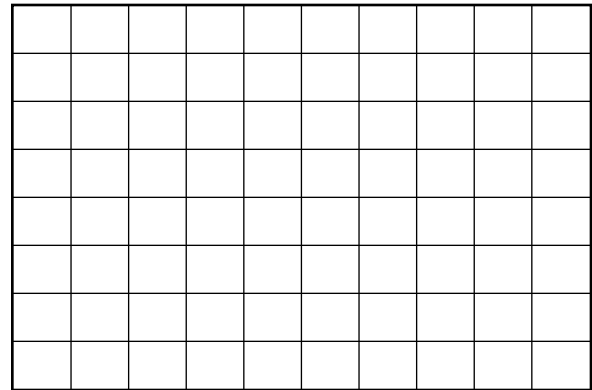
2. Does the waveform match the Repair Manual waveform?

3. Draw or print the waveform.

IDLE



**In Drive at 1500 RPM
(prkbrkset, foot on brake)**



4. Identify on the waveform injector on time and when the injector is turned off.

Section 3

1. Connect a noid light. Crank the engine. What did the noid light do?

2. Disconnect the crank sensor. Crank the engine. What did the noid light do? Why?

3. Measure injector coil resistance? specifications

4. An open injector coil may set DTC

Section 4

1. List five symptoms a failed injector will have on driveability.

Fuel Injector Systems

Name _____ Date _____

Review this sheet as you are doing the worksheet. Check each category after completing the worksheet and instructor presentation. Ask the instructor if you have questions. The comments section is for you to write where to find the information, questions, etc.

Topic	<div style="border: 1px solid black; padding: 5px; display: inline-block;"> <i>I have questions</i> </div>	<div style="border: 1px solid black; padding: 5px; display: inline-block;"> <i>I know I can</i> </div>	Comment
Locate components in the fuel injection system using the EWD and RM			
Find wire colors, pin numbers in the fuel injection electrical circuits using the EWD and RM			
Locate the Injector on time in the Data List and compare to specifications to determine condition			
Measure injector pulsewidth with DT			
Examine injector pattern with oscilloscope			
Test injector coil resistance and compare to specifications to determine condition			
Check and retrieve relevant DTCs			
Properly remove and install fuel injectors			
Locate in the RM three sections related to fuel injection system concerns			