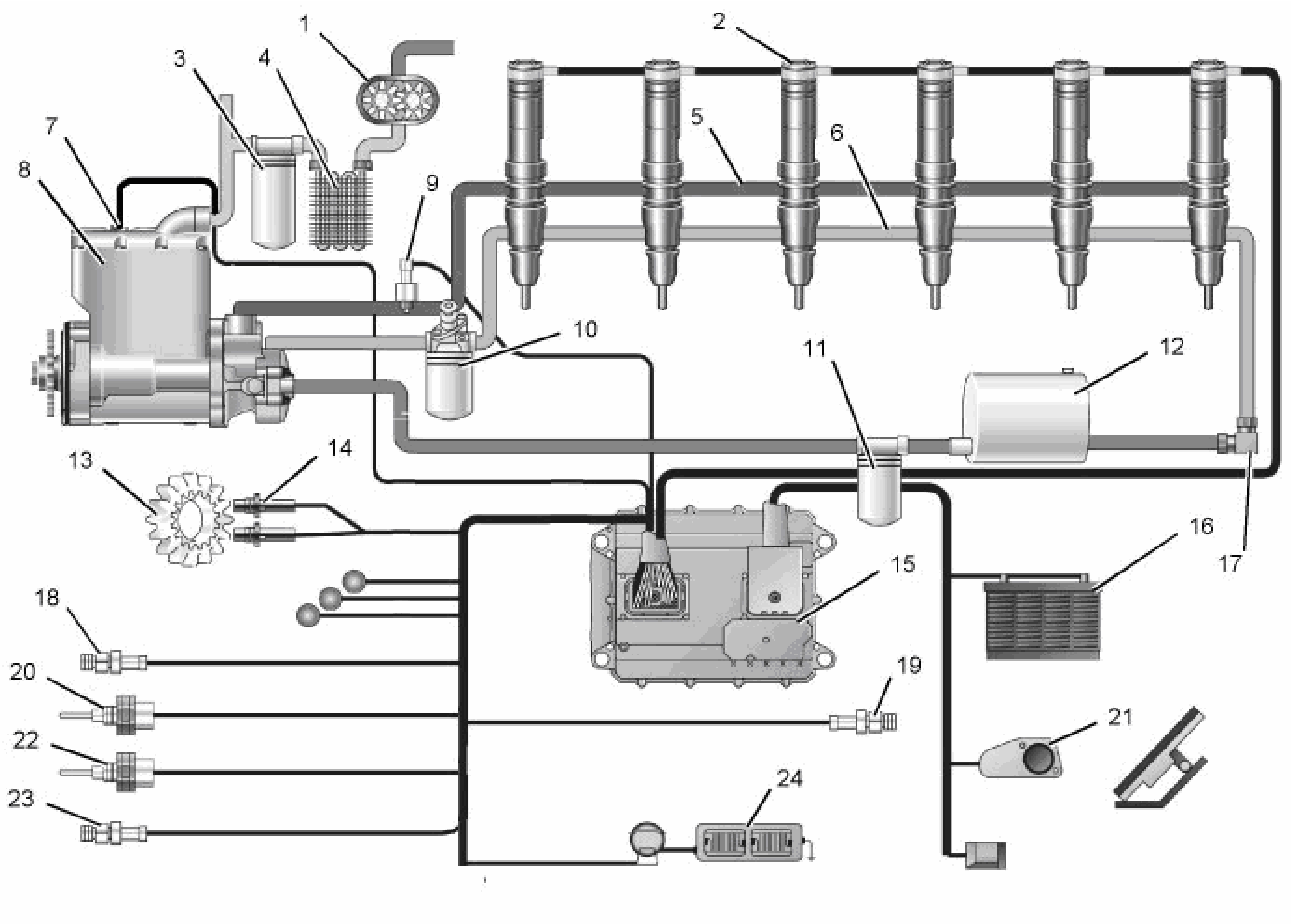
C-9 HUEI Fuel System



(1) Oil pump

(2) Hydraulic electronic unit injectors

(3) Oil filter

(4) Oil cooler

(5) High pressure oil

(6) Fuel

(7) Connector for the Injection Actuation Pressure Control Valve (IAPCV)

(8) Unit injector hydraulic pump

(9) Sensor for the Injection Actuation Pressure (IAP)

(10) Fuel filter

(11) Primary fuel filter and water separator

(12) Fuel tank

(13) Camshaft gear

(14) Speed/Timing sensors

(15) Engine Control Module (ECM)

(16) Battery

(17) Fuel pressure regulator

(18) Boost pressure sensor

(19) Oil pressure sensor

(20) Coolant temperature sensor

(21) Throttle position sensor

(22) Inlet air temperature sensor

(23) Atmospheric pressure sensor

Introduction

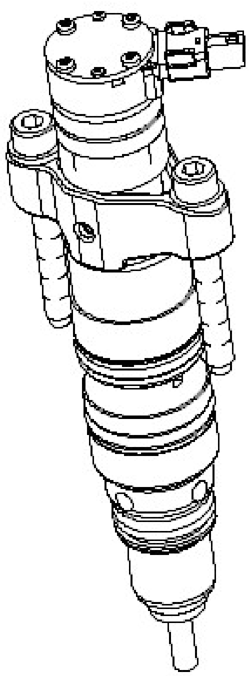
The operation of the Hydraulic Electronic Unit Injector fuel system is completely different from any other fuel system that is actuated mechanically. The HEUI fuel system is completely free of adjustment. Adjustments to the components that are mechanical can not be made. Changes in performance are made by installing different software in the ECM.

This fuel system consists of four basic components:

- Hydraulic Electronic Unit Injector (HEUI)
- ECM
- Unit injector hydraulic pump
- Fuel transfer pump

Note: The fuel transfer pump is a serviceable part. The internal components of the HEUI fuel system are not serviceable. These fuel system components must not be disassembled. Disassembly will damage the components. If the components have been disassembled, Caterpillar may not allow a warranty claim or Caterpillar may reduce the warranty claim.

Component Description



Hydraulic Electronic Unit Injector

The fuel system utilizes a hydraulically actuated electronically controlled unit injector.

All fuel systems for diesel engines use a plunger and barrel in order to pump fuel under high pressure into the combustion chamber. The HEUI uses engine oil under high pressure in order to power the plunger.

The HEUI uses engine lubrication oil that is pressurized from 6 MPa (870 psi) to 28 MPa (4061 psi) in order to pump fuel from the injector. The high pressure oil is called the injection actuation pressure. The HEUI operates in the same way as a hydraulic cylinder in order to multiply the force of the high pressure oil. This multiplication of pressure is achieved by applying the force of the high pressure oil to a piston. The piston is larger than the plunger by approximately six times. The piston that is powered by engine lubrication oil under high pressure pushes on the plunger. The actuation pressure of the oil generates the injection pressure that is delivered by the unit injector. Injection pressure is greater than actuation pressure of the oil by approximately six times.

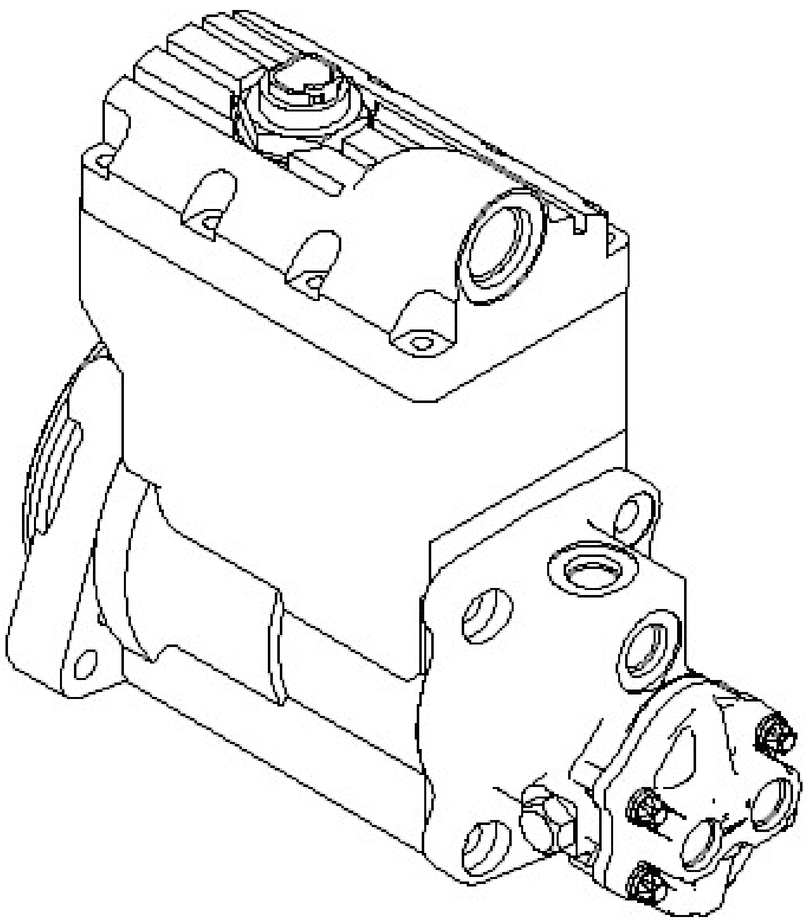
Low actuation pressure of the oil results in low injection pressure of the fuel. High actuation pressure of the oil results in high injection pressure of the fuel.

ECM

The ECM is located on the left side of the engine. The ECM is a powerful computer that provides total electronic control of engine performance. The ECM uses data from engine performance that is gathered by several sensors. The ECM uses this data in order to make adjustments to the fuel delivery, injection pressure and injection timing. The ECM contains programmed performance maps (software) in order to define horsepower, torque curves and rpm.

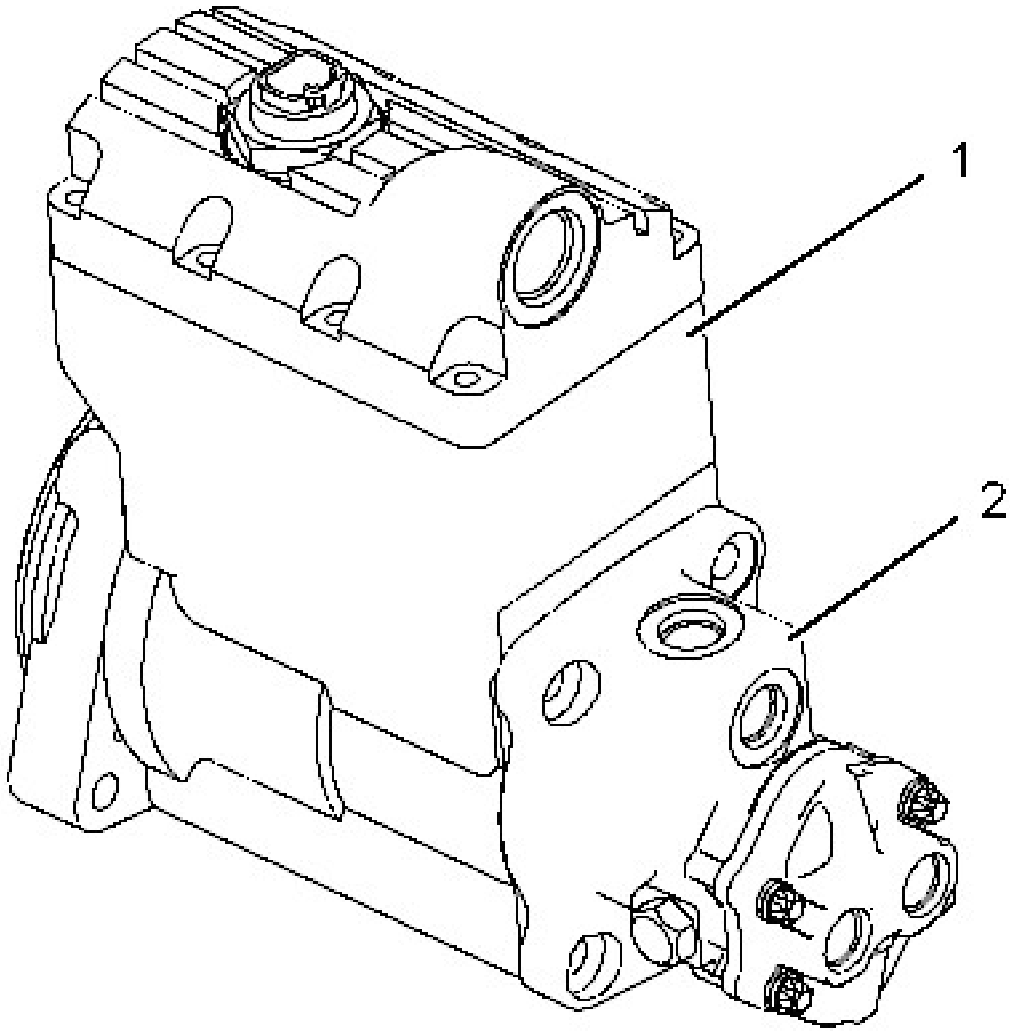
The ECM logs faults of engine performance. The ECM is also capable of running several diagnostic tests automatically when the ECM and Caterpillar Electronic Technician (ET) are used together.

Unit Injector Hydraulic Pump



The unit injector hydraulic pump is a variable delivery piston pump. The unit injector hydraulic pump uses a portion of the engine lubrication oil. The unit injector hydraulic pump pressurizes the engine lubrication oil to the injection actuation pressure that is required in order to power the HEUI injectors.

Fuel Transfer Pump



(1) Unit injector hydraulic pump

(2) Fuel transfer pump

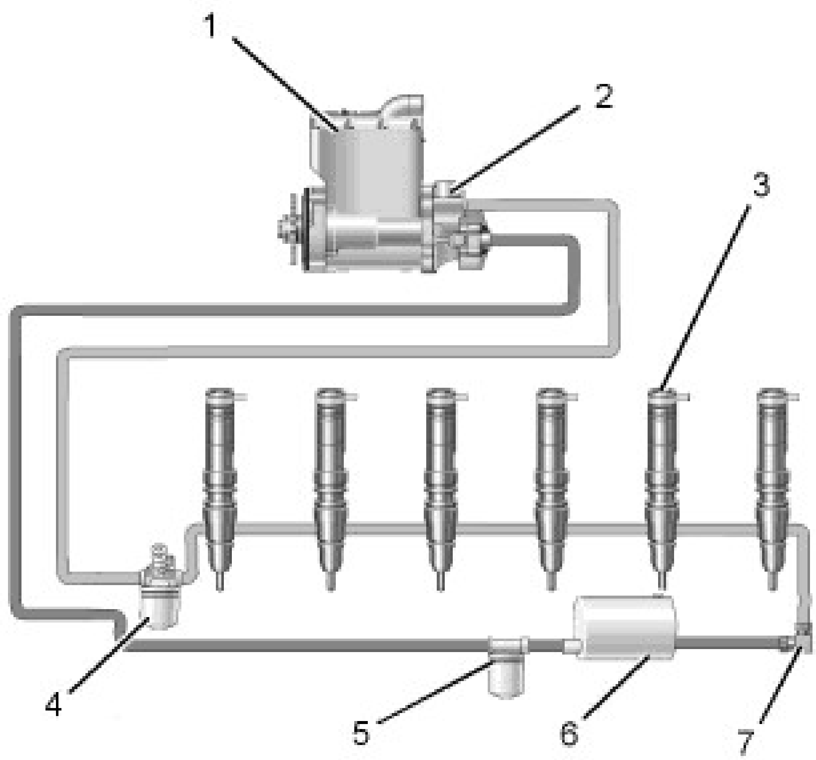
The fuel transfer pump is mounted on the back of the unit injector hydraulic pump. The fuel transfer pump is the only serviceable part of the unit injector hydraulic pump. The fuel transfer pump is used in order to draw fuel from the fuel tank . Also, the fuel transfer pump is used in order to pressurize the fuel to 450 kPa (65 psi). The fuel transfer pump has an internal relief valve in order to protect the system. The pressurized fuel is supplied to the injectors.

Injection Actuation Pressure Sensor (IAP)

The IAP Sensor monitors injection actuation pressure. The IAP Sensor sends a continuous voltage signal back to the ECM . The ECM interprets the signal. The ECM is aware of the injection actuation pressure at all times. The ECM analyzes the voltage from the sensor. The ECM then adjusts the current to the solenoid.

HEUI Fuel System

Low Pressure Fuel System



(1) Unit injector hydraulic pump

(2) Fuel transfer pump

(3) Hydraulic electronic unit injector

(4) Secondary fuel filter

(5) Primary fuel filter and water separator

(6) Fuel tank

(7) Fuel pressure regulator

The low pressure fuel system serves two functions. The low pressure fuel system supplies fuel for combustion to injectors. The low pressure fuel system also supplies excess fuel flow in order to remove air from the system.

The low pressure fuel system consists of five basic components:

- Fuel tank
- Primary fuel filter/water separator
- Two micron secondary fuel filter
- Fuel transfer pump
- Fuel pressure regulator

Fuel is drawn from the fuel tank and flows through a thirteen micron primary fuel filter/water separator. The primary fuel filter/water separator removes large debris from the fuel. The primary filter element also separates water from the fuel. The water is collected in the bowl at the bottom of the primary fuel filter/water separator.

Fuel flows from the primary fuel filter/water separator to the inlet side of fuel transfer pump. An inlet check valve in the inlet port of the fuel transfer pump opens in order to allow the flow of fuel into the pump. After the fuel flow has stopped, the inlet check valve closes in order to prevent fuel flow out of the inlet port. Fuel flows from the inlet port in the pump to the outlet port. Pressurized fuel flows from the outlet port of the pump to the two micron secondary fuel filter. A two micron secondary fuel filter is standard on all Caterpillar engines. These fuel filters are high efficiency. This filter removes very small abrasive contaminants from the fuel.

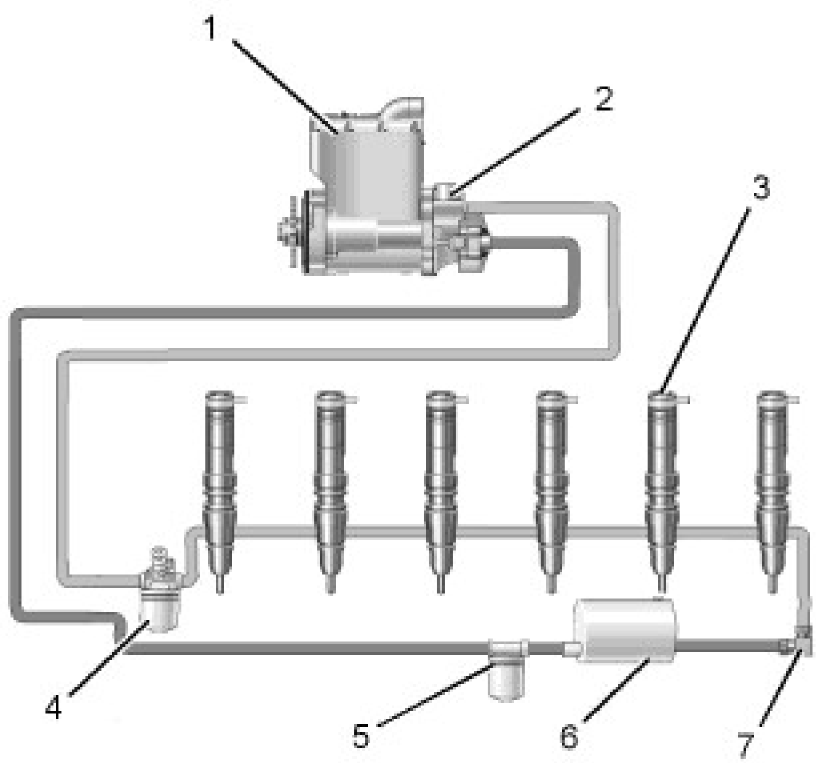
The primary fuel filter/water separator will not trap these small contaminants. Very small abrasive particles in the fuel cause abrasive deterioration of the unit injectors. The secondary fuel filter removes particles in the size of two microns in size or particles that are greater than two microns in size. The use and regular maintenance of this two micron filter will provide a significant improvement in injector life.

Fuel flows from the two micron secondary filter to the fuel supply passage in the cylinder head. The fuel supply passage is a drilled hole which begins at the front of the cylinder head. The fuel supply passage extends to the back of the cylinder head. This passage connects with each unit injector bore in order to supply fuel to unit injectors. The excess fuel flows out of the back of the cylinder head. The fuel flows into the fuel pressure regulator.

The fuel pressure regulator consists of an orifice and a check valve that is spring loaded. The orifice is a flow restriction that pressurizes the supply fuel. The check valve that is spring loaded will open at 35 kPa (5 psi) in order to allow the fuel that has flowed through the orifice to return to the fuel tank. When the engine is off, there is no fuel pressure that is acting on the check valve. With no fuel pressure on the check valve, the check valve will close. The check valve will close in order to prevent the fuel that is in the cylinder head from draining back to the fuel tank.

Injection Actuation System

Actuation Oil Flow



(1) Unit injector hydraulic pump

(8) Oil filter

(9) Oil cooler

(10) Engine oil pump

(11) High pressure oil

The injection actuation system serves two functions. The injection actuation system supplies high pressure oil in order to power the injectors. Also, the injection actuation system regulates the injection pressure that is produced by the unit injectors by changing the actuation pressure of the oil.

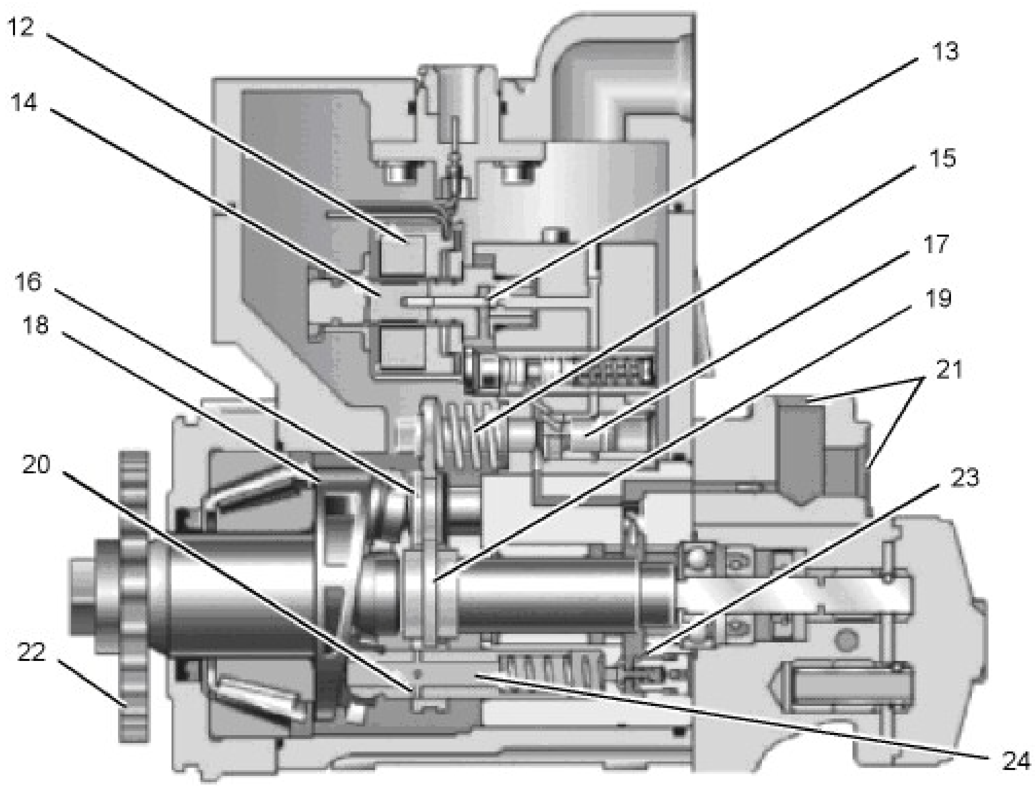
The injection actuation system consists of four basic components:

- Engine oil pump
- Engine oil filter
- Unit injector hydraulic pump
- Injection actuation pressure sensor (IAP Sensor)

Oil that is drawn from the sump is pressurized to the lubrication system oil pressure by the engine oil pump. Oil flows from the engine oil pump through the engine oil cooler, through the engine oil filter, and then to the main oil gallery. A separate circuit from the main oil gallery directs a portion of the lubrication oil in order to supply the unit injector hydraulic pump. A steel tube on the left side of the engine connects the main oil gallery with the inlet port of the unit injector hydraulic pump. The connection point is the top port of the manifold on the engine side cover. Oil flows into the inlet port of the unit injector hydraulic pump and the oil fills the pump reservoir. The pump reservoir provides oil to the unit injector hydraulic pump during start-up. Also, the pump reservoir provides oil to the unit injector hydraulic pump until the engine oil pump can increase pressure.

Oil from the pump reservoir is pressurized in the unit injector hydraulic pump and the oil is pushed out of the outlet port of the pump under high pressure. Oil then flows from the outlet port of the unit injector hydraulic pump to the high pressure oil passage in the cylinder head. Actuation oil that is under high pressure flows from the unit injector hydraulic pump through the cylinder head to all of the injectors. Oil is contained in the high pressure oil passage until the oil is used by the unit injectors. Oil that has been exhausted by the unit injectors is expelled under the valve covers. This oil returns to the crankcase through oil drain holes in the cylinder head.

Actuation Oil Pressure Control



(12) Control valve solenoid

(13) Poppet valve

(14) Armature

(15) Actuator spring

(16) Sliding sleeve

(17) Actuator piston

(18) Eccentric drive plate

(19) Idler

(20) Spill port

(21) Pump outlet ports

(22) Drive gear

(23) Check valve

(24) Piston

The unit injector hydraulic pump is a variable delivery piston pump. The variable piston pump uses an angled drive plate which rotates. The pistons do not rotate. The pistons move in relation to the angled drive plate. The pistons move in the sliding sleeves.

The unit injector hydraulic pump is driven by the gear train on the front of the engine. The drive gear on the front of the pump turns the common shaft. The angled drive plate is mounted on the common shaft. The rotation of the angled drive plate causes the pump piston to move in and out within the sliding sleeves.

As the pistons move out of the sliding sleeves, oil is drawn into the inside of the pistons through the passage in the drive plate. Oil is forced out of the piston when the piston is pushed back into the sliding sleeve and the ports are exposed.

Changing the relative position of the sliding sleeve to the spill port changes the volume of oil in the piston. The location of the sliding sleeve is continuously changing. The location of the sliding sleeve is determined by the ECM. Changing the location of the sliding sleeves changes the flow of the pump. The result is the amount of oil that can be pressurized.

The pressure of the injection actuation system is controlled by matching pump outlet flow and resulting pressure to the pressure demand for the injection actuation system. The position of the sliding sleeves is changed in order to control the pump outlet flow. Moving the sleeves to the left covers the spill port for a longer distance. This increases effective pumping stroke and pump outlet flow. Moving the sleeves to the right covers the spill ports for a shorter distance which reduces the effective pumping stroke. This also reduces the pump outlet flow.

The sliding sleeves are connected by an idler. One sleeve is connected to an actuator piston. Moving the actuator piston right or left causes the idler and sleeves to move the same distance to the right or to the left.

Control pressure is determined by the amount of current from the ECM to the solenoid. A small amount of pump outlet flow goes through a small passage in the actuator piston. This small amount goes out of an orifice and into the control pressure cavity. The pressure in this cavity is limited by a small poppet valve. The opening of the poppet valve allows a portion of the oil in the cavity to flow to drain. A force holds the poppet valve closed. This force on the poppet valve is created by a magnetic field that acts on an armature. The strength of the magnetic field determines the required pressure in order to overcome the force of the actuator spring.

An increase of current to the solenoid causes an increase to the following items:

- The strength of the magnetic field
- The force on the armature and poppet valve
- The control pressure which causes the actuator piston to move to a position that results in more flow

A reduction of current to the solenoid causes a reduction to the following items:

- The strength of the magnetic field
- The force on the armature and poppet valve
- The control pressure which causes the actuator piston to move to a position that results in less flow

The ECM monitors actuation pressure. The ECM constantly changes current to the pump control valve in order to control actuation pressure. Three components work together in a closed loop circuit in order to control actuation pressure:

- ECM
- Sensor for the Injection Actuation Pressure (IAP)
- Pump control valve

The closed loop circuit works in the following manner:

- The ECM determines a desired actuation pressure by gathering information from sensor inputs and software maps.
- The ECM monitors actual actuation pressure through a constant signal voltage from the IAP sensor.
- The ECM constantly changes control current to the pump control valve. This changes the pump outlet flow.

There are two types of actuation pressure:

- Desired actuation pressure
- Actual actuation pressure

Desired actuation pressure is the injection actuation pressure that is required by the system for optimum engine performance. The desired actuation pressure is established by the performance maps in the ECM. The ECM selects the desired actuation pressure. The selection is based on the signal inputs from many sensors. The ECM is getting signal inputs from some of the following sensors: throttle position sensor, boost pressure sensor, speed-timing sensors and coolant temperature sensor . The desired actuation pressure is constantly changing. The change is based on various signal inputs. The changing engine speed and engine load also cause the desired actuation pressure to change. The desired actuation pressure is only constant under steady state conditions (steady engine speed and load).

Actual actuation pressure is the actual system pressure of the actuation oil that is powering the injectors. The ECM and the pump pressure regulator are constantly changing the amount of pump outlet flow. This constant changing makes the actual actuation pressure equal to the desired actuation pressure.

Pump Control Valve Operation

The pump control valve has the following three stages:

- Valve operation (engine off)
- Valve operation (cranking the engine)
- Valve operation (running engine)

Valve Operation (ENGINE OFF)

When the engine is off, there is no pump outlet pressure from the pump and there is no current to the control valve solenoid from the ECM. The actuator spring pushes the actuator piston completely to the left. The idler which is not shown and the sliding sleeves are moved to the left also. At this point, the pump is in the position of maximum output.

Valve Operation (ENGINE CRANKING)

During engine start-up, approximately 6 MPa (870 psi) of injection actuation pressure is required in order to activate the unit injector. This low injection actuation pressure generates a low fuel injection pressure of about 35 MPa (5000 psi). This low fuel injection pressure aids cold starting.

In order to start the engine quickly, the injection actuation pressure must rise quickly. Because the unit injector hydraulic pump is being turned at engine cranking speed, pump flow is very low. The ECM sends a strong current to the control valve solenoid in order to keep the poppet valve closed. With the poppet valve in the closed position, all of the flow to the drain is blocked. The hydraulic forces that act on each side of the actuator piston are equal. The actuator spring holds the actuator to the left. The pump produces maximum flow until the 6 MPa (870 psi) desired pressure is reached. Now, the ECM reduces the current to the pressure regulator solenoid in order to reduce control pressure. The reduced control pressure allows the actuator piston to move to the right. This reduces pump outlet flow in order to maintain the 6 MPa (870 psi) desired pressure.

Note: If the engine is already warm, the pressure that is required to start the engine may be higher than 6 MPa (870 psi). The values for the desired actuation pressures are stored in the performance maps of the ECM. The values for desired actuation pressures vary with engine temperature.

Once the unit injectors begin to operate, the ECM controls the current to the control valve. The ECM and the control valve solenoid will maintain the actuation pressure at 6 MPa (870 psi) until the engine starts. The ECM monitors the actual actuation pressure through the IAP Sensor that is located in the high pressure oil manifold. The ECM establishes desired actuation pressure by monitoring several electrical input signals and the ECM sends a predetermined current to the control valve solenoid. The ECM also compares the desired actuation pressure to the actual actuation pressure in the high pressure oil passage. The ECM adjusts the current levels to the control valve solenoid in order to make the actual actuation pressure equal to the desired actuation pressure.

Valve Operation (RUNNING ENGINE)

Once the engine starts, the ECM controls the current to the pump control valve in order to maintain the desired actuation pressure. The IAP Sensor monitors the actual actuation pressure in the high pressure oil passage in the cylinder head. The ECM compares the actual actuation pressure to the desired actuation pressure 67 times per second. The ECM adjusts the current levels to the pump control valve when the actual actuation pressure and the desired actuation pressure do not match. These adjustments make the actual injection actuation pressure equal to the desired injection actuation pressure.

Oil Flow (ENGINE RUNNING)

A small amount of pump outlet flow flows through the actuator piston and into the control pressure cavity. Control pressure increases and the increased pressure unseats the poppet valve. The open poppet valve allows flow to the drain. The ECM changes control pressure by increasing or reducing the current to the control valve solenoid and resultant force on the poppet.

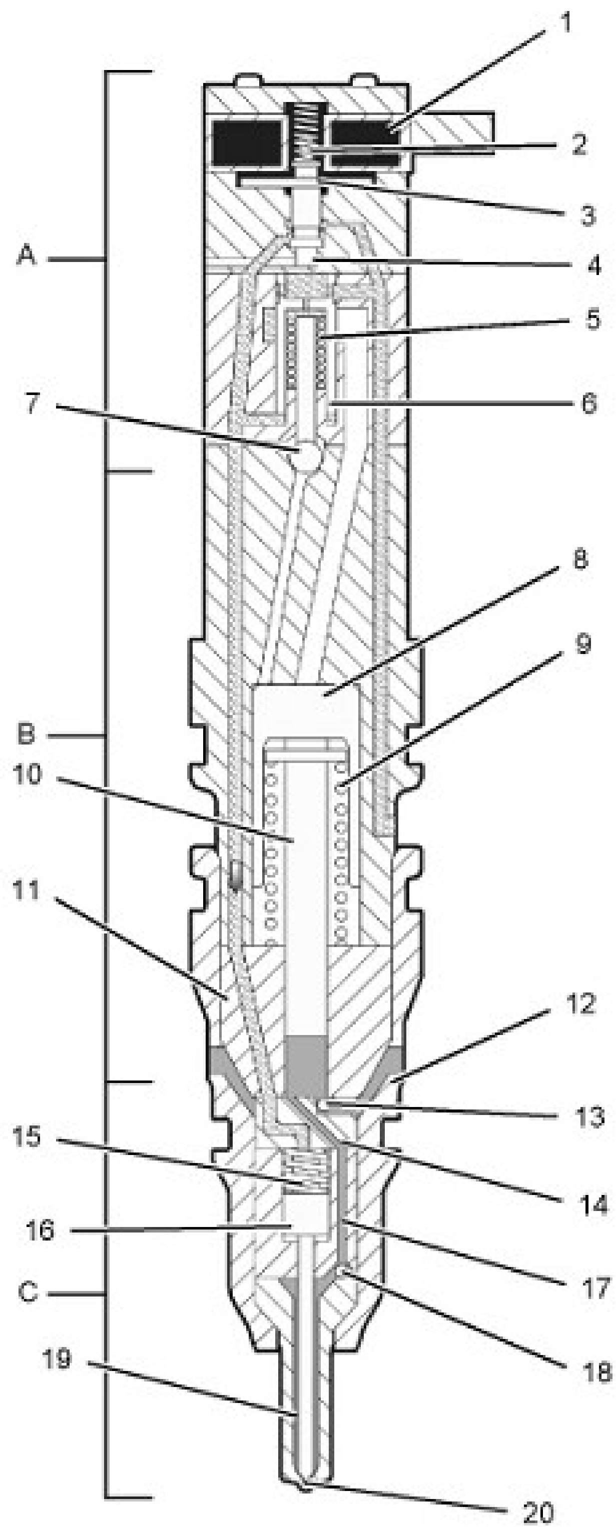
The following items create a closed loop system:

- ECM
- IAP
- Pressure Regulator

This closed loop system provides infinitely variable control of pump outlet pressure. This pump outlet pressure has a range from 6 MPa (870 psi) to 28 MPa (4061 psi).

HEUI Injector (Components)

The HEUI injector serves four functions. The HEUI injector pressurizes supply fuel from 450 kPa (65 psi) to 175 MPa (25382 psi). The HEUI injector functions as an atomizer by pumping high pressure fuel through orifice holes in the unit injector tip. The HEUI injector delivers the correct amount of atomized fuel into the combustion chamber and the HEUI injector disperses the atomized fuel evenly throughout the combustion chamber.



Cross section of HEUI injector

(1) Solenoid

(2) Armature spring

(3) Armature

(4) Seated pin

(5) Spool spring

(6) Spool valve

(7) Check ball for intensifier piston

(8) Intensifier piston

(9) Return spring

(10) Plunger

(11) Barrel

(12) Nozzle case

(13) Inlet fill check

(14) Stop

(15) Nozzle spring

(16) Check piston

(17) Sleeve

(18) Reverse flow check valve

(19) Nozzle check

(20) Nozzle tip

The HEUI injector consists of three major parts:

- Upper end, or actuator (A)
- Middle, or pumping unit (B)
- Lower end, or nozzle assembly (C)

The upper end (A) consists of the following items:

- Solenoid (1)
- Armature spring (2)
- Armature (3)
- Seated pin (4)
- Spool spring (5)
- Spool valve (6)
- Check ball for intensifier piston (7)

The middle of the injector (B) contains the following items:

- Intensifier piston (8)
- Return spring (9)
- Plunger (10)
- Barrel (11)

The lower end of the injector (C) consists of the following items:

- Nozzle case (12)
- Inlet fill check (13)
- Stop (14)
- Nozzle spring (15)
- Check piston (16)
- Sleeve (17)
- Reverse flow check valve (18)
- Nozzle check (19)
- Nozzle tip (20)

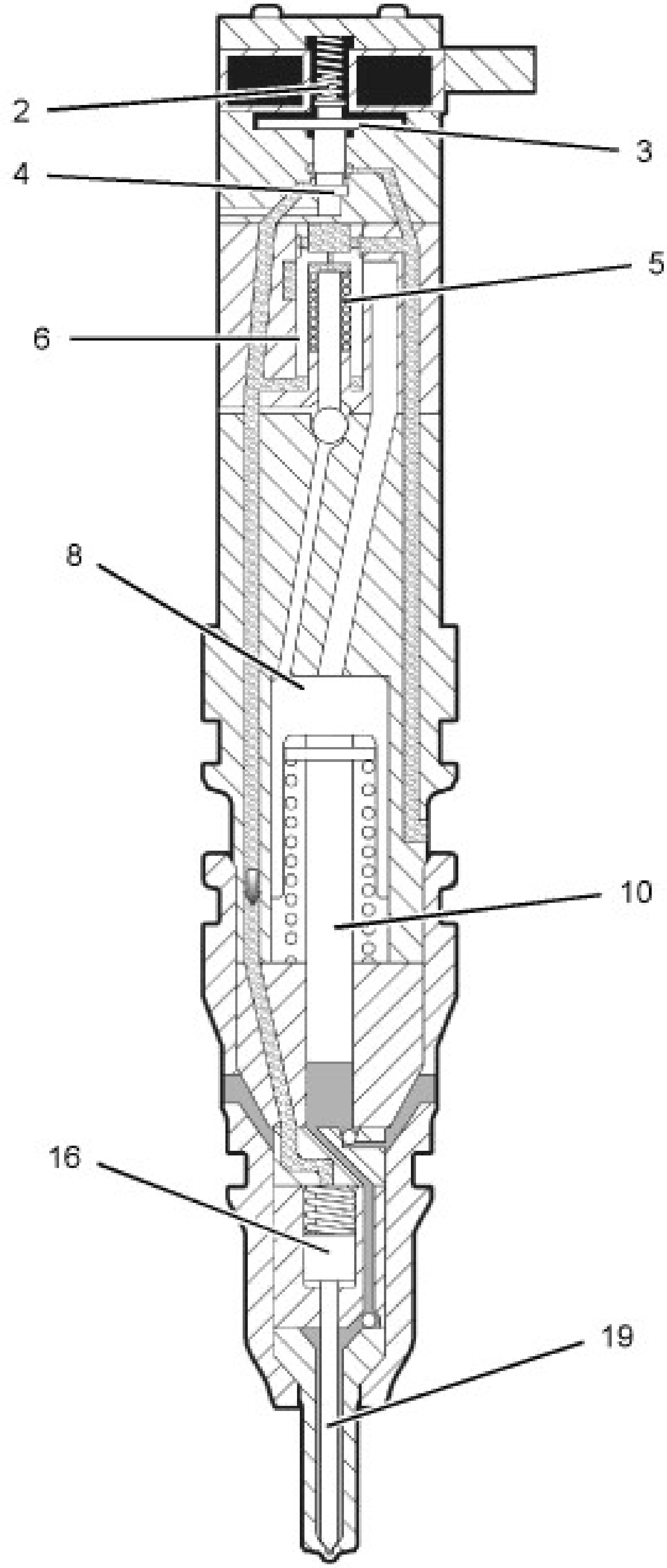
These components work together in order to produce different rates for fuel injection. The rates for fuel injection are electronically controlled by performance software in the ECM.

HEUI Fuel Injector (Operation)

The HEUI injector operates with a split injection cycle. The split injection cycle has five phases of injection:

- Pre-injection
- Pilot injection
- Injection delay
- Main injection
- Fill

Pre-Injection



Cross section of pre-injection cycle

(2) Armature spring

(3) Armature

(4) Seated pin

(5) Spool spring

(6) Spool valve

(8) Intensifier piston

(10) Plunger

(16) Check piston

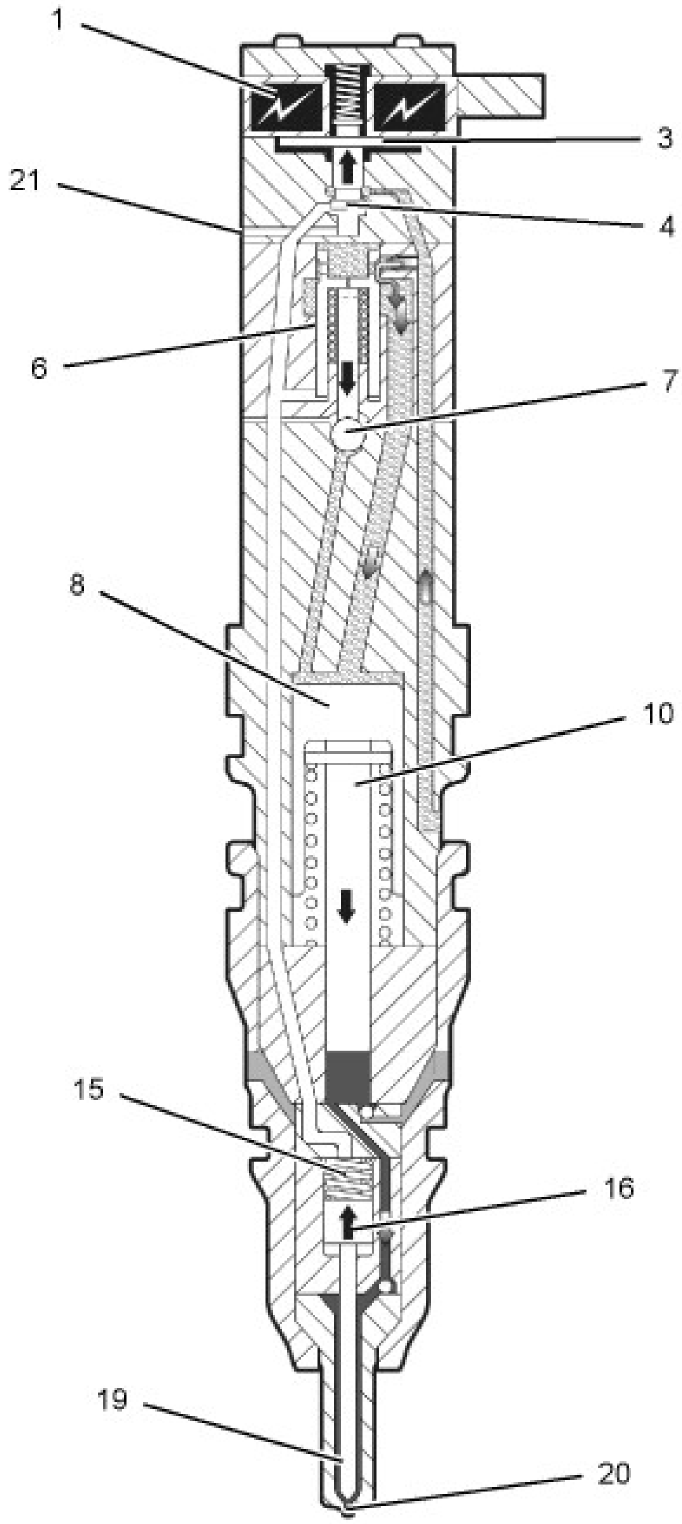
(19) Nozzle check

The injector is in the phase of pre-injection when the engine is running and the injector is between firing cycles. Plunger (10) and the intensifier piston (8) are at the top of the piston bore. The cavity below the plunger is full of fuel.

In the upper end, the armature (3) and the seated pin (4) are held down by the armature spring (2) . High pressure actuation oil flows into the injector. The oil then flows around the seated pin to the top of the check piston (16) . This provides a positive downward force on the nozzle check (19) at all times when fuel is not being injected.

The spool valve (6) is held in the top of the bore for the spool valve by the spool spring (5) . In this position, the spool valve blocks actuation oil from reaching the intensifier piston. Actuation pressure is felt on both the top and bottom of the spool, so hydraulic forces on the spool are balanced. The spool valve is held in the up position or the closed position by the force of the spool spring.

Pilot Injection



Cross section of pilot injection cycle

(1) Solenoid

(3) Armature

(4) Seated pin

(6) Spool valve

(7) Check ball for intensifier piston

(8) Intensifier piston

(10) Plunger

(15) Nozzle spring

(16) Check piston

(19) Nozzle check

(20) Nozzle tip

(21) Drain

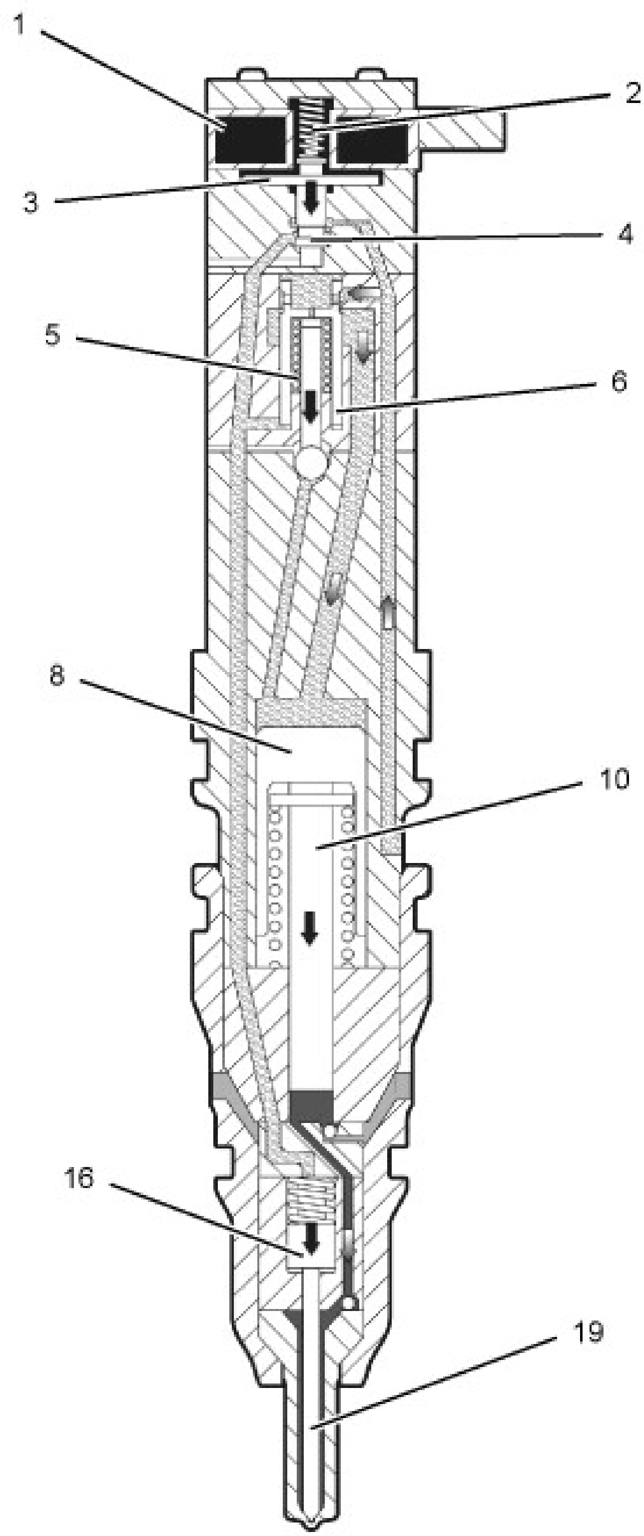
Pilot injection occurs when the ECM sends a control current to the solenoid (1) . The current creates a magnetic field which lifts the armature (3) and the seated pin (4) . The seated pin has a lower seat and an upper seat. When the seated pin is lifted by the armature, the upper seat closes off the flow of actuation pressure to the check. The lower seat opens. This allows the actuation oil on top of check piston (16) to flow to drain (21) . Actuation oil that is trapped below spool (6) will also flow to drain (21) . The actuation oil drains through a vent hole in the side of the injector.

The drop in pressure under the spool causes a hydraulic difference that acts on the spool. The spool moves into the open position when hydraulic pressure acts on the top of the spool. This hydraulic pressure forces the spool downward. The downward movement of the spool is stopped when the spool and the pin force the check ball (7) for the intensifier piston onto the ball seat in the closed position. This prevents any actuation pressure from escaping from the cavity for the intensifier piston (8) . This drop in the actuation pressure also removes the downward force on the check piston.

Actuation oil now flows past the open spool and to the top of the intensifier piston. The downward movement of the piston and plunger (10) pressurizes the fuel in the plunger cavity to the nozzle tip (20) . Pilot injection begins when the injection pressure increases in order to overcome the force of the nozzle spring (15) which lifts the nozzle check (19) .

Pilot injection will continue if the following conditions exist:

- The solenoid is energized.
- The spool remains open.
- There is no actuation pressure on top of the check piston.



Injection Delay

Cross section of injection delay

(1) Solenoid

(2) Armature spring

(3) Armature

(4) Seated pin

(5) Spool spring

(6) Spool valve

(8) Intensifier piston

(10) Plunger

(16) Check piston

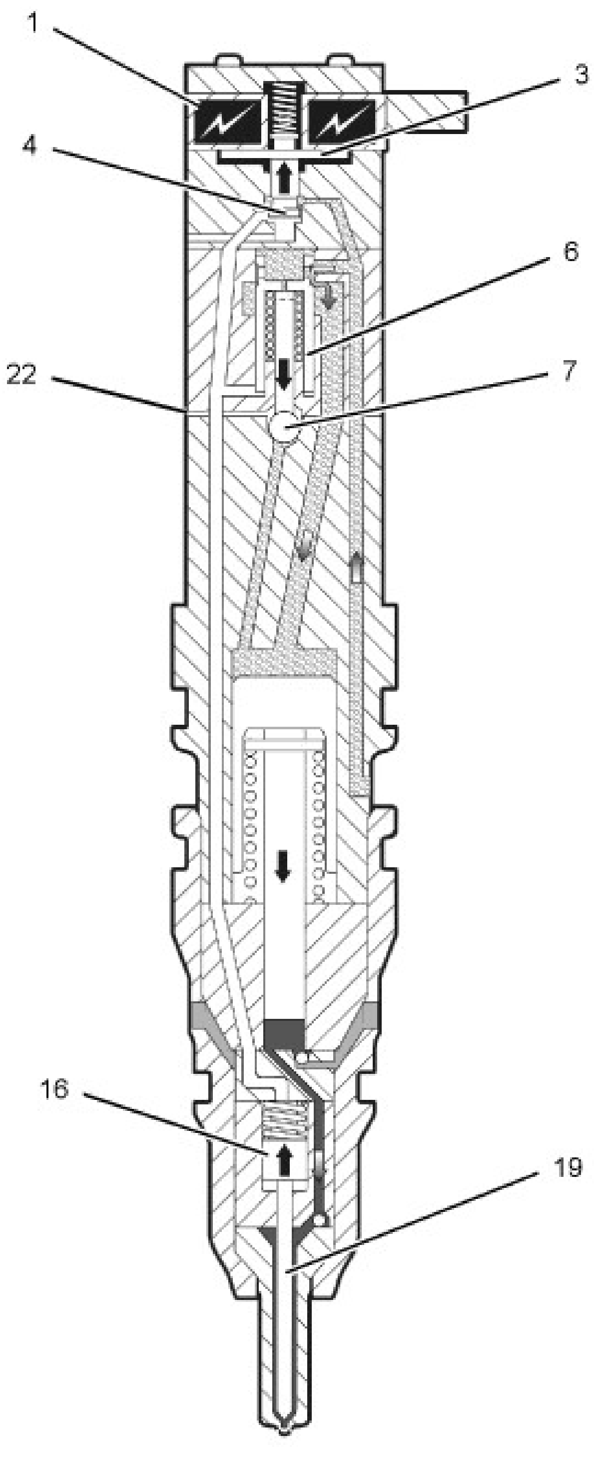
(19) Nozzle check

Injection delay begins when the control current to the solenoid (1) stops and the solenoid is de-energized. The armature (3) is held in the up position by a magnetic field. When the magnetic field is de-energized, the armature spring (2) pushes the armature and the seated pin (4) downward. The seated pin closes the lower seat and the seated pin opens the upper seat. This allows the actuation pressure to flow to the top of the check piston (16) . The hydraulic force on the check piston quickly overcomes the injection pressure and the nozzle check (19) closes. Injection stops at this point.

Actuation pressure increases under the spool valve (6) that creates the balance of hydraulic force on the top and bottom of the spool.

The weak spool spring (5) now acts on the spool. This closes the spool very slowly. As the spool remains open, actuation pressure continues to flow past the spool to intensifier piston (8) and to plunger (10) . The injection pressure in the nozzle and in the plunger cavity increases very quickly when the nozzle check is held in the closed position.

Main Injection



Cross section of main injection cycle

(1) Solenoid

(3) Armature

(4) Seated pin

(6) Spool valve

(7) Check ball for intensifier piston

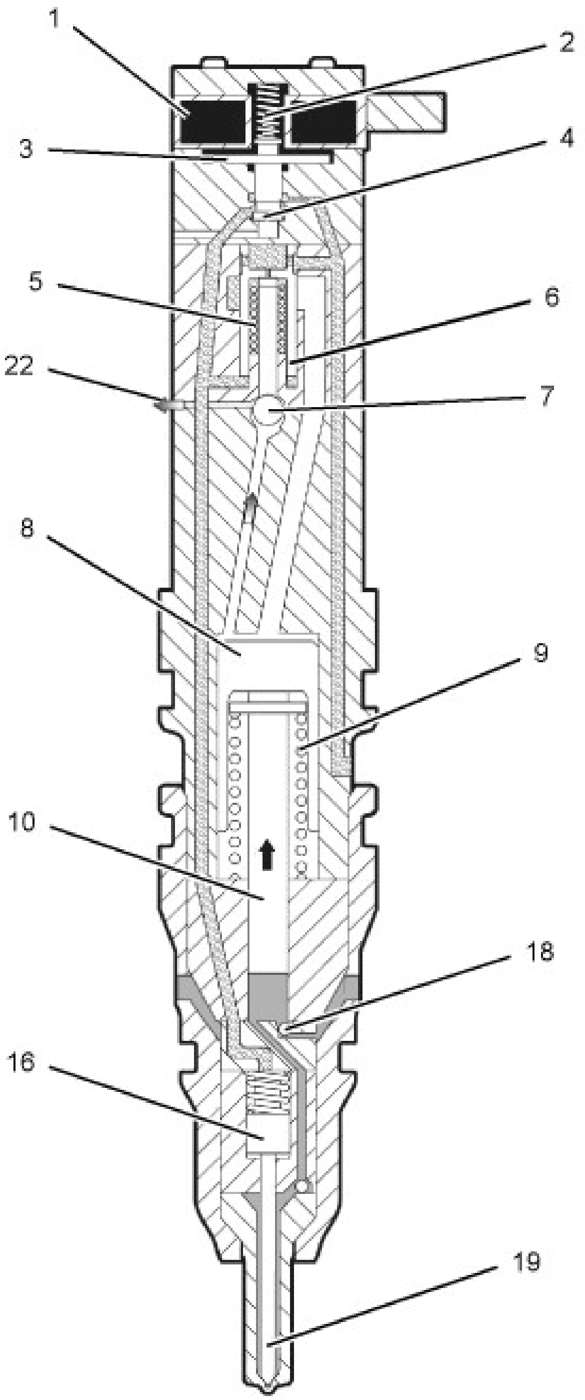
(16) Check piston

(19) Nozzle check

(22) Drain

Main injection begins when the solenoid (1) is re-energized. The magnetic field is instantly created and the force of the magnetic field lifts the armature (3) and the seated pin (4) . The upper seat closes off the flow of actuation pressure and the upper seat opens the check piston (16) and the bottom of the spool (6) to the drain (22) . The hydraulic force that holds the nozzle check (19) closed quickly dissipates and the injection pressure opens the nozzle check. This is the start of main injection. A difference in hydraulic forces on the spool is also created. This difference forces the spool downward. The check ball (7) for the intensifier piston is held in the closed position when the spool is in this position. Main injection continues if the solenoid remains energized.

Fill



Cross section of fill cycle

(1) Solenoid

(2) Armature spring

(3) Armature

(4) Seated pin

(5) Spool spring

(6) Spool valve

(7) Check ball for intensifier piston

(8) Intensifier piston

(9) Return spring

(10) Plunger

(16) Check piston

(18) Reverse flow check valve

(19) Nozzle check

(22) Drain

The fill cycle begins when the solenoid (1) is de-energized. The armature (3) and the seated pin (4) are forced down by the armature spring (2) . The seated pin closes the lower seat and the seated pin opens the upper seat. Actuation pressure is restored to the top of the check piston (16) . This closes the nozzle check (19) and injection ends. Actuation pressure is also felt under the valve spool (6) . This restores the hydraulic balance on the spool. The valve spring (5) slowly closes the spool. This stops the flow of actuation oil to the intensifier piston (8) .

As the spool raises, the check ball (7) for the intensifier piston is no longer held closed. Oil in the cavity for the intensifier piston lifts the check off the seat and flows to the drain (22) through a vent hole in the side of the injector. Return spring (9) pushes up plunger (10) and the intensifier piston. This pushes all of the oil out of the cavity for the intensifier piston. The check valve (18) for the fuel inlet is taken off of the valve seat as the plunger lifts up. This allows supply fuel to flow into the plunger cavity. The fill cycle is complete when the plunger and the piston are at the top of the bore and the plunger cavity is full of fuel.