

# Systems Operation

## 3126B and 3126E Truck Engine

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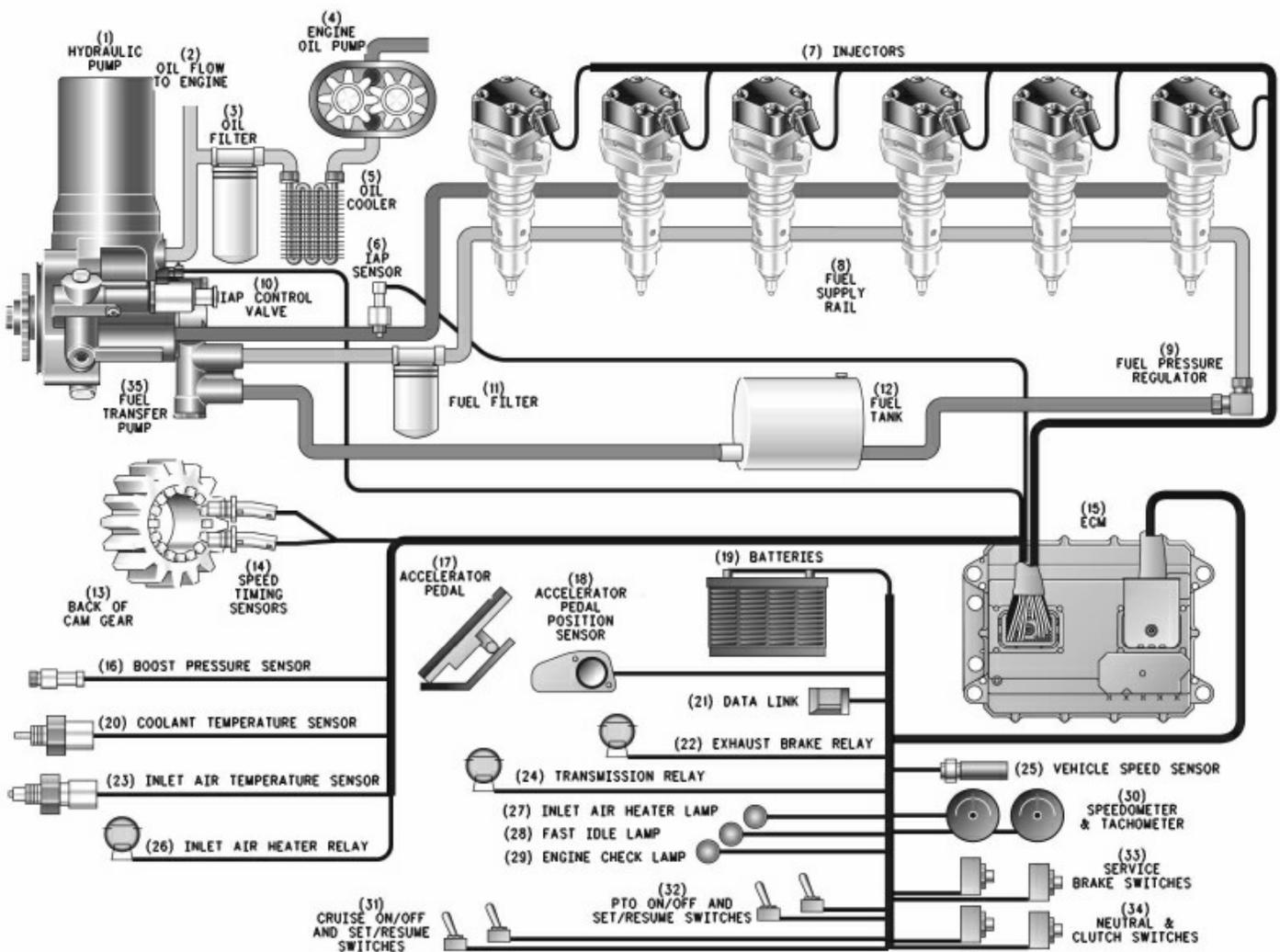
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## Fuel System

SMCS - 1250

## Introduction



**Diagram of components for the HEUI fuel system above**

- (1) Unit injector hydraulic pump
- (2) Oil flow to engine
- (3) Oil filter
- (4) Engine oil pump
- (5) Oil cooler
- (6) IAP sensor
- (7) Injectors
- (8) Fuel supply rail
- (9) Fuel pressure regulator
- (10) IAP control valve
- (11) Fuel filter
- (12) Fuel tank
- (13) Back of cam gear
- (14) Speed/timing sensors
- (15) ECM
- (16) Boost pressure sensor
- (17) Accelerator pedal
- (18) Accelerator pedal position sensor
- (19) Batteries
- (20) Coolant temperature sensor
- (21) Data link
- (22) Exhaust brake relay
- (23) Inlet air temperature sensor
- (24) Transmission relay
- (25) Vehicle speed sensor
- (26) Inlet air heater relay
- (27) Inlet air heater lamp
- (28) Fast idle lamp
- (29) Check engine lamp
- (30) Speedometer and tachometer
- (31) Cruise ON/OFF switch and Cruise SET/RESUME switch
- (32) PTO ON/OFF switch and SET/RESUME switch
- (33) Service brake switches
- (34) Neutral and clutch switches
- (35) Fuel transfer pump

The operation of the Hydraulic Electronic Unit Injector (HEUI) fuel system is completely different from any other type of 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 Engine Control Module (ECM) (15) .

This fuel system consists of six basic components:

- Hydraulic Electronic Unit Injector (HEUI) (7)
- Engine Control Module (ECM) (15)

- Unit injector hydraulic pump (1)
- Injection Actuation Pressure Control Valve (10)
- Fuel Transfer Pump (35)
- Injection Actuation Pressure Sensor (6)

**Note:** The 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 HEUI fuel system utilizes a hydraulically actuated electronically controlled unit injector (7) .

All fuel systems for diesel engines use a plunger and barrel in order to pump fuel under high pressure into the combustion chamber. This fuel is pumped into the combustion chamber in precise amounts in order to control engine performance. The HEUI uses engine oil under high pressure in order to power the plunger. All other fuel systems use a fuel injection pump camshaft lobe in order to power the plunger. Because the HEUI is much different, a technician must use different troubleshooting methods.

The HEUI uses engine lubrication oil that is pressurized from 6 MPa (870 psi) to 27.5 MPa (4000 psi) in order to pump fuel from the injector. The HEUI operates in the same way as a hydraulic cylinder in order to multiply the force of the high pressure oil. By multiplying the force of the high pressure oil, the HEUI can produce injection pressures that are very high. 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. This engine lubrication oil under high pressure is called the actuation pressure of the oil. 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. During conditions of low speed such as idle and start, low injection pressure is utilized.

High actuation pressure of the oil results in high injection pressure of the fuel. During conditions of high speed such as high idle and acceleration, high injection pressure is utilized.

There are many other operating conditions when the injection pressure is between the minimum and the maximum. Regardless of the speed of the engine, the HEUI fuel system provides infinite control of injection pressure.

### Engine Control Module (ECM)

Engine Control Module (ECM) (15) 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. Then, 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. This software is commonly called the personality module.

Some engines use Engine Control Modules (ECM) (15) with a replaceable computer chip. The software has already been installed in the replaceable computer chip. The 3126B and 3126E diesel truck engines do not have a replaceable personality module. The 3126B and 3126E diesel truck engine's personality module are a permanent part of the ECM. The 3126B and 3126E diesel truck engine's personality module can be reprogrammed. Reprogramming of the personality module requires the use of Caterpillar Electronic Technician (Cat ET). The flash function of Cat ET will be used during the reprogramming.

ECM (15) logs faults of engine performance. Also, the ECM is capable of running several diagnostic tests automatically when the ECM is used with an electronic service tool such as the Cat ET.

## **Unit injector hydraulic pump**

Unit injector hydraulic pump (1) (high pressure oil pump) is located at the left front corner of the engine. The unit injector hydraulic pump is a piston pump that has a fixed displacement. The unit injector hydraulic pump uses an axial piston. 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.

## **Injection Actuation Pressure Control Valve (IAP Control Valve)**

Injection actuation pressure control valve (10) (IAP Control Valve) is located on the side of unit injector hydraulic pump (1). Under most conditions, the pump is producing excess oil flow. The IAP Control Valve discharges excess pump flow to the drain in order to control injection actuation pressure to the desired level. The IAP Control Valve is a valve of high precision that controls the actual actuation pressure. The performance maps of ECM (15) contain a desired actuation pressure for every engine operating condition. The ECM sends a control current to the IAP Control Valve. The control current should make the actual actuation pressure equal to the desired actuation pressure.

IAP Control Valve (10) is an actuator. The IAP Control Valve converts an electrical signal from ECM (15) to the mechanical control of a spool valve in order to control pump outlet pressure.

## **Fuel Transfer Pump**

Fuel transfer pump (35) is mounted on the back of unit injector hydraulic pump (1). The fuel transfer pump is used in order to draw fuel from fuel tank (12). Also, the fuel transfer pump is used in order to pressurize the fuel to 450 kPa (65 psi). The pressurized fuel is supplied to injectors (7) .

Fuel transfer pump (35) is a single piston pump that is spring loaded. The shaft of the unit injector hydraulic pump provides power to the transfer pump through an off-center bearing. There are two check valves in the fuel transfer pump. The inlet check valve opens in order to allow fuel from the tank into the pump. The inlet check valve closes in order to prevent fuel leakage back to the fuel tank. The outlet check valve opens in order to supply fuel to the fuel supply passage. The fuel supply passage is located in the cylinder head. The fuel supply passage supplies fuel to injectors (7). The outlet check valve closes in order to prevent pressurized fuel leakage back through the pump.

## **Injection Actuation Pressure Sensor (IAP)**

IAP Sensor (6) is installed in the high pressure oil manifold. The high pressure oil manifold supplies actuation oil in order to power the unit injectors. The IAP Sensor monitors injection actuation pressure. The IAP Sensor



The low pressure fuel system serves three functions. The low pressure fuel system supplies fuel for combustion to injectors (7). Also, the low pressure fuel system supplies excess fuel flow in order to cool the unit injectors and the low pressure fuel system supplies excess fuel flow in order to remove air from the system.

The low pressure fuel system consists of four basic components:

- Fuel pressure regulator (9)
- Fuel filter (11)
- Fuel tank (12)
- Fuel transfer pump (35)

Fuel transfer pump (35) is mounted on the back of unit injector hydraulic pump (1). The fuel transfer pump pushes pressurized fuel out of the outlet port and the fuel transfer pump draws new fuel into the inlet port.

Fuel is drawn from fuel tank (12) and flows through two micron fuel filter (11) .

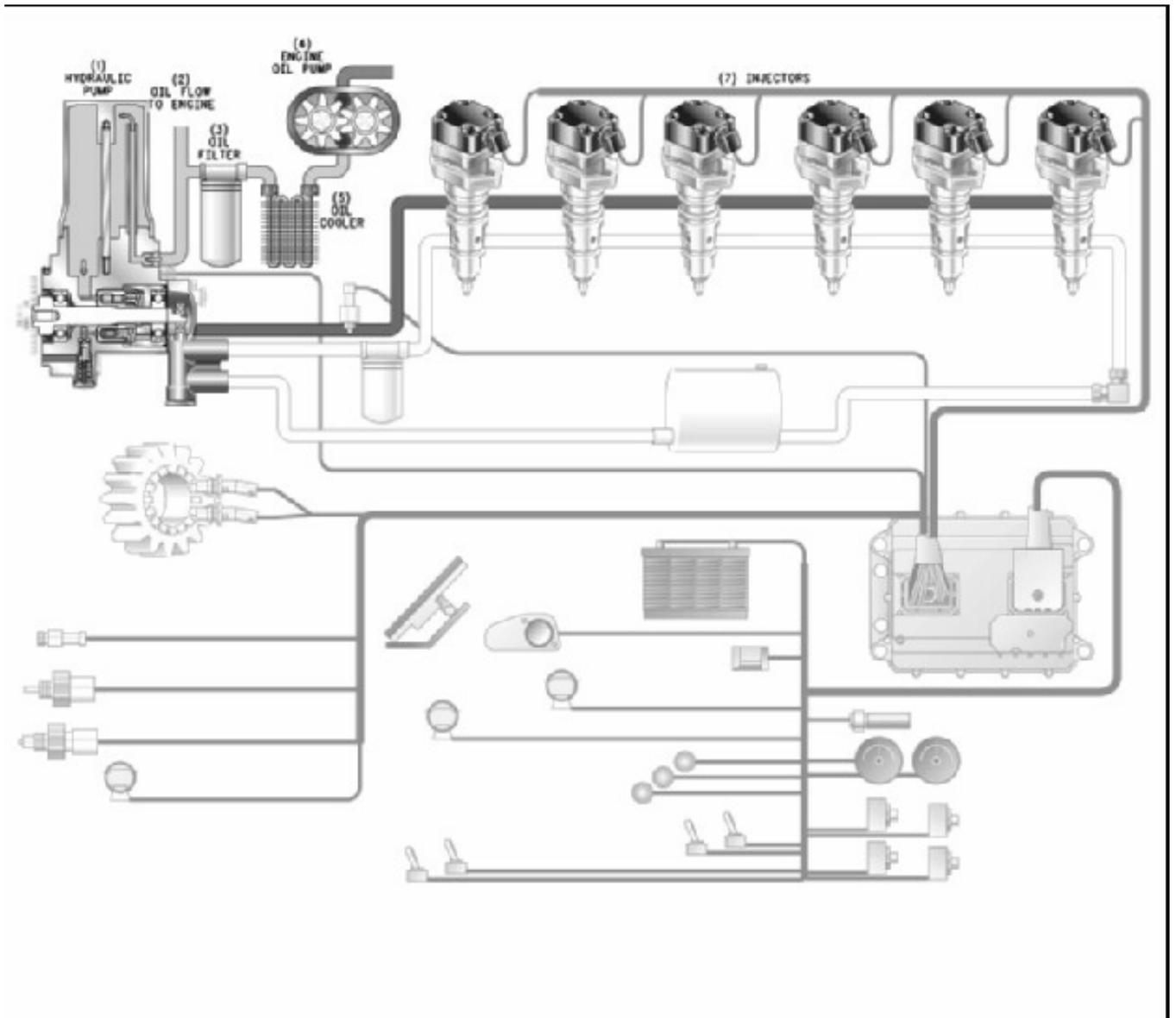
Fuel flows from fuel filter (11) to the inlet side of fuel transfer pump (35). An inlet check valve in the inlet port of the fuel transfer pump opens in order to allow the flow of fuel into the pump. After the fuel flow has stopped, the inlet check valve closes in order to prevent fuel flow out of the inlet port. Fuel flows from the inlet port in the pump to the outlet port, which also has a check valve. The outlet check valve opens in order to allow pressurized fuel flow out of the pump. The outlet check valve closes in order to prevent pressurized fuel leakage back through the pump.

Fuel flows from the outlet port of fuel transfer pump (35) 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 (7). Fuel from the transfer pump flows through the cylinder head to all of the unit injectors. Excess fuel flows out of the back of the cylinder head. After the excess flows out of the back of the cylinder head, the fuel flows into fuel pressure regulator (9) .

Fuel pressure regulator (9) consists of an orifice and a spring loaded check valve. The orifice is a flow restriction that pressurizes the supply fuel. The spring loaded check valve opens at 35 kPa (5 psi) in order to allow the fuel which has flowed through the orifice to return to fuel tank (12). When the engine is off and no fuel pressure is present, the spring loaded check valve closes. The spring loaded check valve closes in order to prevent the fuel in the cylinder head from draining back to the fuel tank.

# Injection Actuation System

## Actuation Oil Flow



Flow path of the injection actuation oil

- (1) Unit injector hydraulic pump
- (2) Oil flow to engine
- (3) Oil filter
- (4) Engine oil pump
- (5) Oil cooler
- (7) Injectors

The injection actuation system serves two functions. The injection actuation system supplies high pressure oil in order to power HEUI injectors (7). Also, the injection actuation system controls the injection pressure that is produced by the unit injectors by changing the actuation pressure of the oil.

The injection actuation system consists of five basic components:

- Engine oil pump (4)
- Engine oil filter (3)
- Unit injector hydraulic pump (1)
- Injection actuation pressure control valve (IAP Control Valve) (10)
- Injection actuation pressure sensor (IAP Sensor) (6)

Oil from engine oil pump (4) supplies the needs of the engine lubrication system. Also, oil from the engine oil pump supplies the needs of unit injector hydraulic pump (1) for the fuel system. The capacity of the engine oil pump has been increased in order to meet the additional flow requirement that is necessary.

Oil that is drawn from the sump is pressurized to the lubrication system oil pressure by engine oil pump (4). Oil flows from the engine oil pump through engine oil cooler (5), through engine oil filter (3), 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 unit injector hydraulic pump (1). 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.

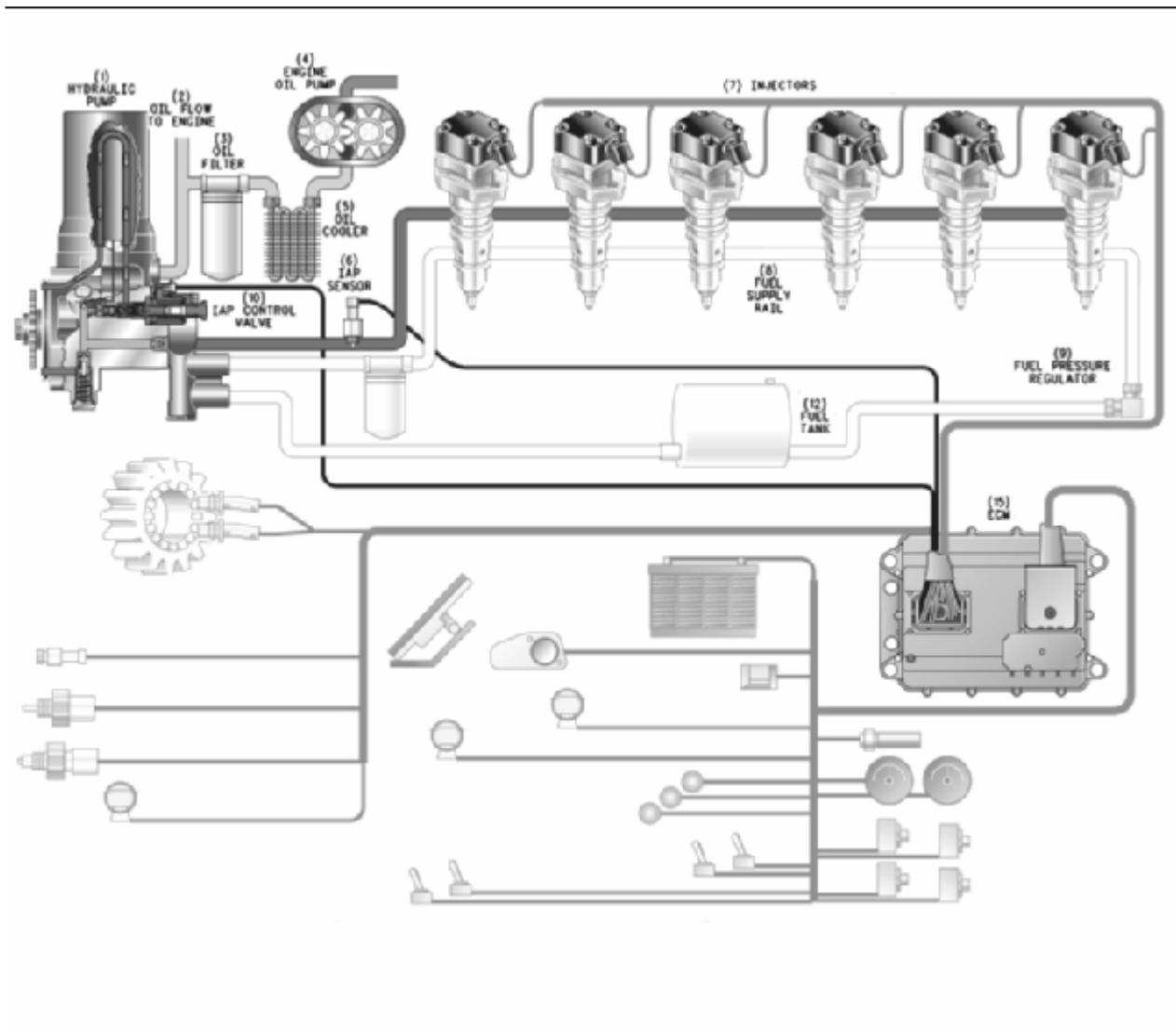
Oil flows into the inlet port of unit injector hydraulic pump (1) and the oil fills the pump reservoir. The pump reservoir provides oil to the unit injector hydraulic pump during start-up. Also, the pump reservoir provides oil to the unit injector hydraulic pump until the engine oil pump can increase pressure.

The pump reservoir also provides makeup oil to the high pressure oil passage in the cylinder head. When the engine is off and the engine cools down, the oil shrinks. A check valve in the pump allows oil to be drawn from the pump reservoir in order to keep the high pressure oil passage full.

Oil from the pump reservoir is pressurized in unit injector hydraulic pump (1) 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.

The high pressure oil passage connects with each unit injector bore in order to supply high pressure actuation oil to unit injectors (7). Actuation oil that is under high pressure flows from unit injector hydraulic pump (1) 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



### Injection Actuation Oil Pressure Control

- |                                  |                             |                        |
|----------------------------------|-----------------------------|------------------------|
| (1) Unit injector hydraulic pump | (5) Oil cooler              | (10) IAP control valve |
| (2) Oil flow to engine           | (6) IAP sensor              | (12) Fuel tank         |
| (3) Oil filter                   | (7) Injectors               | (15) ECM               |
| (4) Engine oil pump              | (8) Fuel supply rail        |                        |
|                                  | (9) Fuel pressure regulator |                        |

Unit injector hydraulic pump (1) is a fixed displacement axial piston pump. The pump is designed in order to generate adequate flow under the conditions that are the most demanding. Under most operating conditions, unit injector hydraulic pump (1) is producing excess flow. This excess flow must be discharged to a drain in order to control the system's pressure. IAP Control Valve (10) regulates system pressure by discharging the precise amount of oil to the drain. This discharging of oil is required in order to maintain the desired actuation pressure.

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 ECM (15). The ECM selects the desired actuation pressure. The ECM bases the selection on the signal inputs from many sensors. Some of the sensors that are supplying signal inputs to the ECM are accelerator pedal position sensor (18), boost pressure sensor (16), speed/timing sensors (14), and coolant temperature sensor (20). The desired actuation pressure is constantly changing due to changing engine speed and due to changing engine load. 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 (7). IAP Control Valve (10) is constantly changing the amount of pump flow that is discharged to the drain. The pump flow is discharged to the drain in order to match the actual actuation pressure to the desired actuation pressure.

Three components operate together in order to control injection actuation pressure:

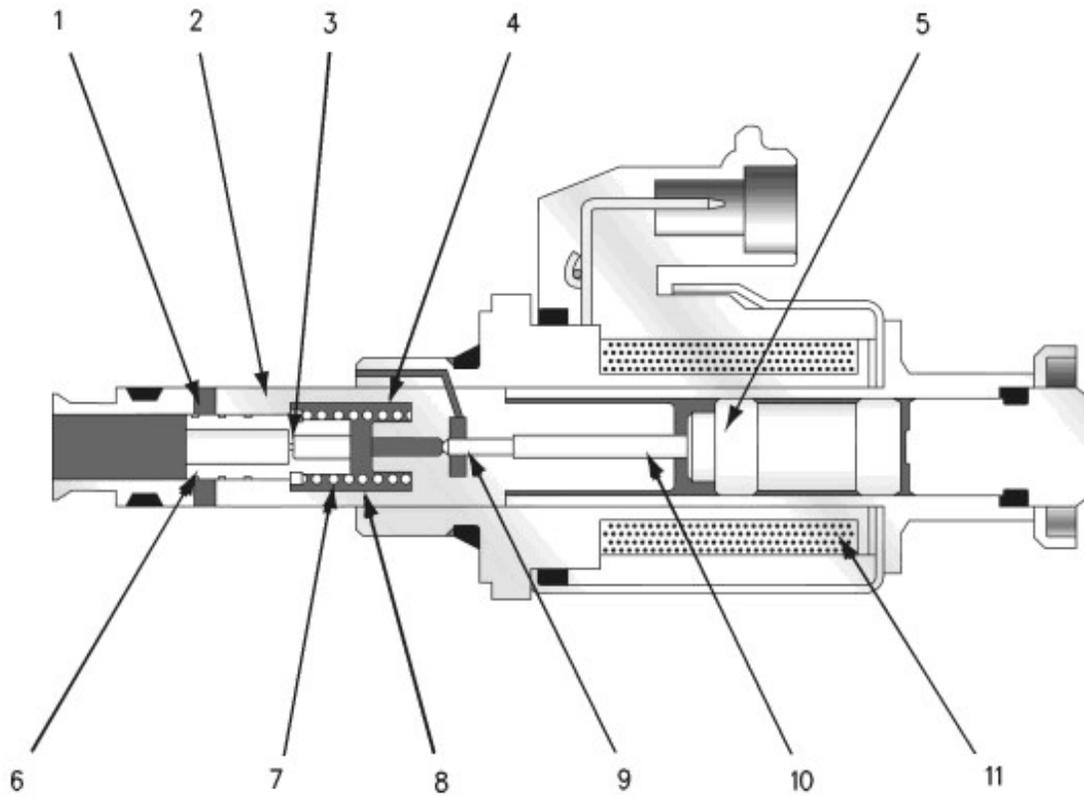
- ECM (15)
- IAP Control Valve (10)
- IAP Sensor (6)

ECM (15) selects the desired actuation pressure. The desired actuation pressure is based on both the sensor input and the performance maps. The ECM sends a control current to IAP Control Valve (10) in order to change the actual actuation pressure. The IAP Control Valve reacts to the electrical current from the ECM in order to change the actual actuation pressure. The actual actuation pressure is changed when the IAP Control Valve discharges pump flow to the drain. The IAP Control Valve acts as an electrically controlled relief valve. IAP Sensor (6) monitors the actual actuation pressure in the high pressure oil passage. The IAP Sensor reports the actual actuation pressure to the ECM by sending a signal voltage to the ECM.

The injection actuation pressure control system operates in a cycle. ECM (15) selects the desired actuation pressure. Then, the ECM sends an electrical current to IAP Control Valve (10) that should produce that pressure. The IAP Control Valve reacts to the electrical current from the ECM by changing the pressure relief setting, which changes the actual actuation pressure. IAP Sensor (6) monitors the actual actuation pressure and the IAP Sensor sends a signal voltage back to the ECM. The ECM interprets the signal voltage from the IAP Sensor in order to calculate the actual actuation pressure. Then, the ECM compares the actual actuation pressure to the desired actuation pressure in order to adjust the electrical current to the IAP Control Valve. The IAP Control Valve responds to the change in electrical current by changing the actual actuation pressure. This process is repeated 67 times per second. This cycle of constant repetition is called a closed loop control system.

Most of the high pressure oil flow from unit injector hydraulic pump (1) is used in order to power unit injectors (7). Excess flow is the amount of pump flow that is not required in order to meet the desired actuation pressure. The excess flow is returned to the drain through IAP Control Valve (10). Excess flow from the IAP Control Valve flows upward through a U-shaped tube in the pump reservoir. The excess flow travels through a drilled passage to the front of the pump. Drain oil flows out of the front of the pump over the pump drive gear and flows down the engine front gear train to sump.

## Operation of the Injection Actuation Pressure Control Valve



Injection actuation pressure control valve

(1) Drain port

(2) Valve body

(3) Control orifice

(4) Spool chamber

(5) Armature

(6) Valve spool

(7) Spool spring

(8) Reduced pressure oil

(9) Poppet

(10) Push pin

(11) Solenoid

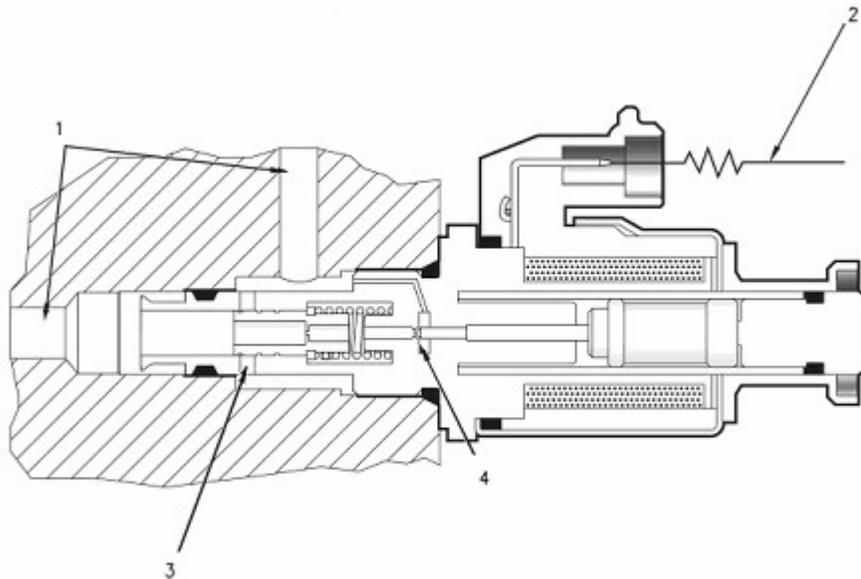
The IAP Control Valve is an electrically controlled pilot operated pressure control valve. The Injection Actuation Pressure Control Valve is used in order to maintain selected actuation system pressure. The selected actuation system pressure is maintained regardless of engine speed, pump flow, and variable oil demand of the unit injectors. The IAP Control Valve consists of six basic components:

- Armature (5)
- Valve spool (6)
- Spool spring (7)
- Poppet (9)
- Push pin (10)
- Solenoid (11)

The IAP Control Valve operates by using a variable electrical current from the ECM in order to create a magnetic field in the solenoid (11). This magnetic field acts on armature (5) and the magnetic field generates a mechanical force. This mechanical force pushes armature (5) to the left. The mechanical force travels through push pin (10) to poppet (9) .

The magnetic force that is holding poppet (9) closed is opposed by reduced hydraulic pressure inside the spool chamber. The reduced hydraulic pressure inside the spool chamber is trying to open poppet (9). This reduced hydraulic pressure increases until the reduced hydraulic pressure overcomes the mechanical force of solenoid (11). When the reduced hydraulic pressure overcomes the mechanical force of solenoid (11), poppet (9) opens. The open poppet allows a flow path to drain for some of the reduced pressure oil (8). Discharging part of reduced pressure oil (8) to drain lowers the hydraulic pressure. When the hydraulic pressure of reduced pressure oil (8) decreases below the magnetic force on poppet (9), the poppet closes again.

### Valve Operation for ENGINE OFF



Operation of the injection actuation pressure control valve (engine off)

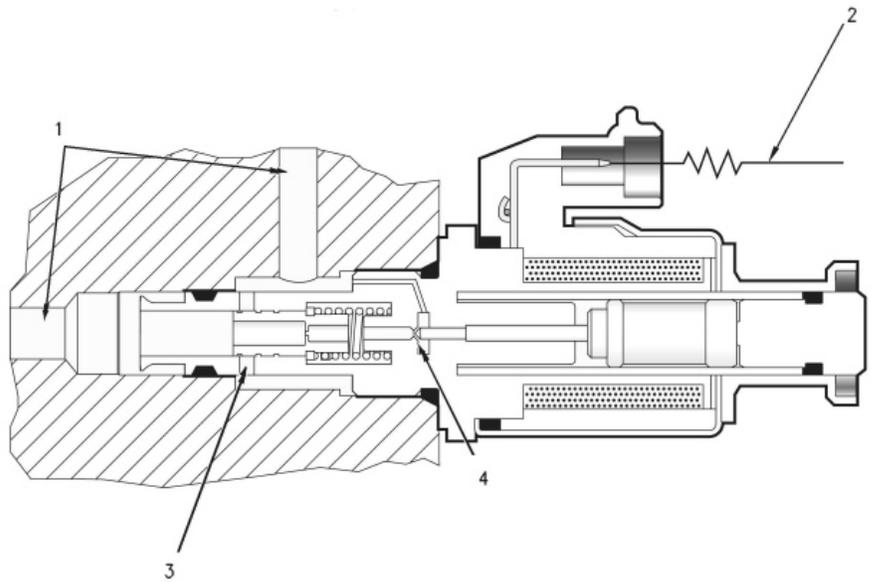
- (1) Pump outlet pressure (none)
- (2) Current from ECM (none)
- (3) Closed drain port
- (4) Poppet (open position)

When the engine is off, there is no pump outlet pressure (1) from the pump and there is no current to the solenoid from the ECM (2). The spool spring pushes the spool valve completely to the left. When the spool spring pushes the spool valve completely to the left, drain port (3) is completely blocked.

## Valve Operation for ENGINE CRANKING

Operation of the injection actuation pressure control valve (engine cranking)

- (1) Pump outlet pressure
- (2) Current from the ECM
- (3) Drain port (blocked position)
- (4) Poppet (closed position)



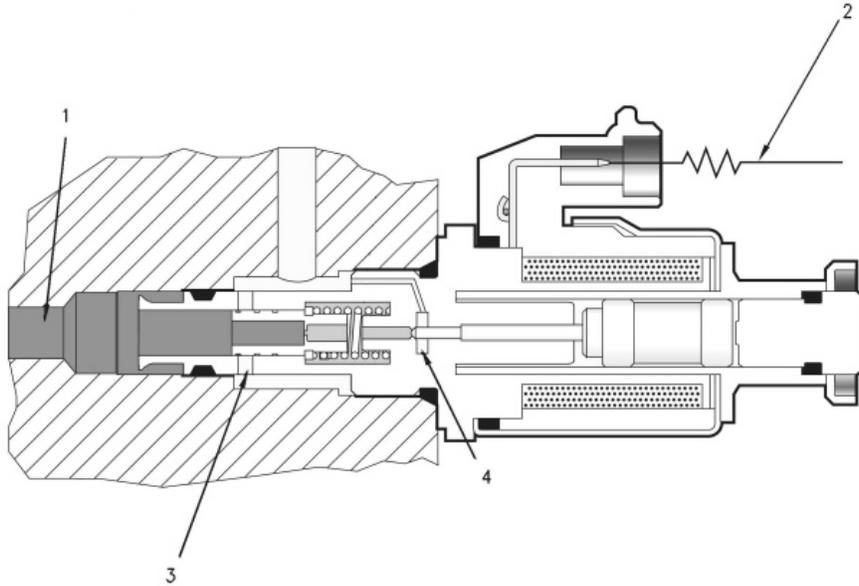
During engine start-up, approximately 6 MPa (870 psi) of injection actuation pressure is required in order to activate the unit injector. This low injection actuation pressure generates a low fuel injection pressure of about 35 MPa (5000 psi). This low fuel injection pressure aids cold starting.

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 (2) to the IAP Control Valve in order to keep the spool closed. With the spool in the closed position, all of the flow to drain port (3) is blocked. The flow to drain port (3) remains blocked until the actual actuation pressure of 6 MPa (870 psi) is reached. The unit injectors are not fired until the 6 MPa (870 psi) actual actuation pressure is reached.

**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 IAP Control Valve. The ECM and the IAP Control Valve maintain the actual 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 IAP Control Valve. 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 IAP Control Valve in order to make the actual actuation pressure equal to the desired actuation pressure.

## Oil Flow for ENGINE CRANKING



Pump outlet pressure (1) enters the end of the valve body and pump outlet pressure acts against the valve spool. The pump outlet pressure tries to push the valve spool to the right (open). A small amount of oil also flows through the center of the spool, through the spool control orifice and into the spool spring chamber. The current from the ECM (2) causes the solenoid to generate a magnetic field which pushes the armature to the left. The armature exerts a force on the push pin and the poppet which holds the poppet closed. The

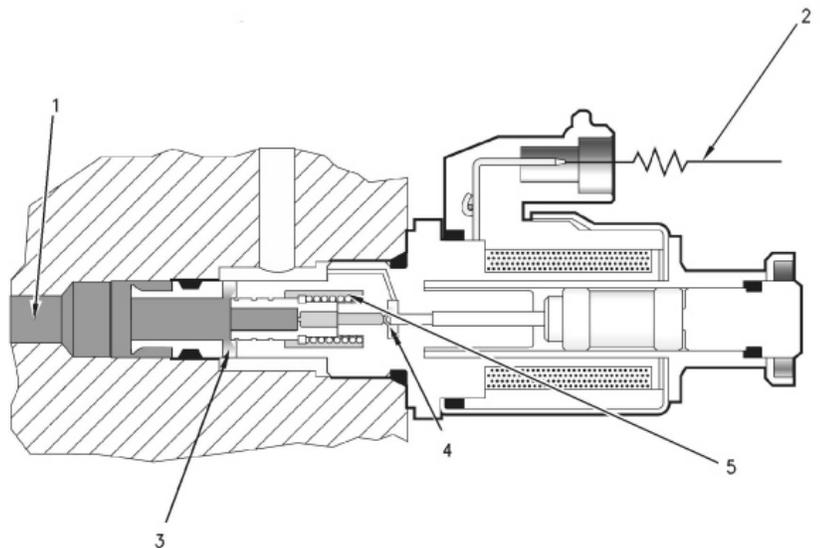
poppet is the only path to the drain for the oil in the spool spring chamber. Pump outlet pressure (1) flows through the spool control orifice and into the spool spring chamber. This flow of pump outlet pressure allows spring chamber pressure to build up. Because the spring chamber path to the drain is blocked by the poppet, the pressure in the spring chamber is equal to pump outlet pressure (1).

The combination of spool spring force and spring chamber pressure hold the spool to the left. When the spool is held to the left, the drain ports are closed. All pump flow is directed to the high pressure oil manifold until an actual actuation pressure of 6 MPa (870 psi) is reached.

## Valve Operation for RUNNING ENGINE

Operation of the injection actuation pressure control valve (running engine)

- (1) Pump outlet pressure
- (2) Current from the ECM
- (3) Drain port (open)
- (4) Poppet (open)
- (5) Reduced pressure oil



Once the engine starts, the ECM controls the current (2) to the IAP 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. When these pressures do not match, the ECM adjusts the current levels (2) to the IAP Control Valve in order to make the actual injection actuation pressure equal to the desired injection actuation pressure.

The amount of current that is sent to the solenoid regulates the amount of magnetic force that is trying to hold the poppet closed. The solenoid, the armature and the push pin simulate a variable spring that is electronically controlled. Increased current results in increased force. Decreased current results in decreased force.

The magnetic force that is applied to the poppet holds the poppet closed. When the poppet is closed, the pressure in the spool spring chamber increases. When the pressure in the spool spring chamber exceeds the magnetic force that is holding the poppet closed, the poppet (4) will move to the right. When the poppet (4) moves to the right, some of the pressure oil in the spool spring chamber escapes to the drain. This causes the pressure in the spring chamber to drop. When the pressure in the spring chamber drops, the poppet closes. When the poppet closes, the pressure again begins to increase and the cycle is repeated. This process controls the reduced pressure oil (5) in the spool spring cavity. The reduced pressure oil (5) in the spool spring cavity acts on the spool. The reduced pressure oil (5) in the spool spring cavity tries to move the spool to the left. When the spool is moved to the left, the drain port (3) is blocked.

The combined force of the mechanical spring and reduced pressure oil in the spool spring chamber try to move the spool to the left in order to block the drain port (3). When the drain port is blocked, pump outlet pressure (1) rises and the increased pump outlet pressure moves the spool to the right (open).

Because the mechanical spring has a fixed spring rate, the reduced pressure oil (5) in the spool must be adjusted in order to control pump outlet pressure (1). The reduced pressure oil (5) in the spool can be raised in order to control pump outlet pressure (1) or the reduced pressure oil (5) in the spool can be lowered in order to control pump outlet pressure (1). The reduced pressure oil (5) is controlled by the amount of electrical current from the ECM (2). Most of the time, the poppet and the spool operate in a partially open position. The poppet and the spool are completely open or completely closed only during the following conditions:

- Acceleration
- Deceleration
- Rapidly changing engine loads

## **Oil Flow for RUNNING ENGINE**

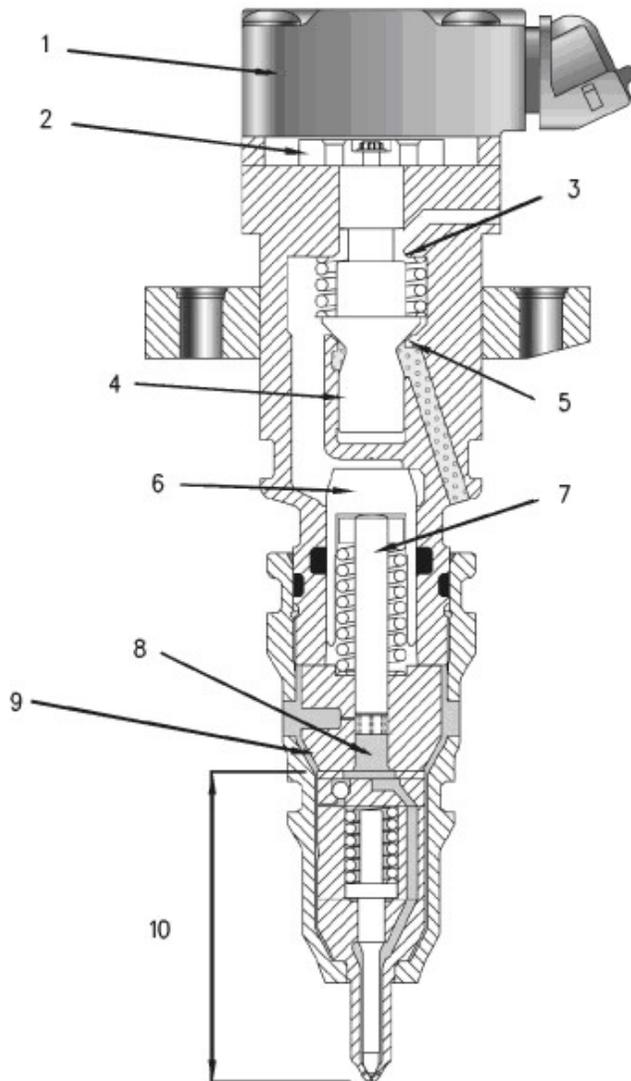
When pump outlet pressure (1) enters the end of the valve body, a small amount of oil flows into the spool spring chamber through the control orifice in the spool. The pressure in the spool spring chamber is controlled by adjusting the force on the poppet (4). Adjusting the force on the poppet (4) allows the poppet to drain off some of the oil in the spool spring chamber. The force on the poppet is controlled by the strength of the magnetic field that is produced from the electrical current from the ECM (2). The spool responds to pressure changes in the spool spring chamber. The spool changes positions in order to balance the force on the spool. The spool tries to make the force on the right side of the spool equal to the force on the left side of the spool. The spool position dictates the amount of the surface area of the drain ports (3) that is open.

The open area of the drain port controls the amount of oil that is drained off from the pump outlet. The oil is drained off from the pump outlet in order to maintain the desired actuation pressure. The process of responding to pressure changes on either side of the spool occurs so rapidly that the spool is held in a partially open position and pump outlet pressure (1) is closely controlled. The IAP Control Valve allows infinitely variable control of pump outlet pressure (1) between 6 MPa (870 psi) and 27.5 MPa (4000 psi).

# Components of the HEUI Injector

The HEUI injector serves four functions. The HEUI injector pressurizes supply fuel from 450 kPa (65 psi) to 162 MPa (23500 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.

Component of the HEUI injector



- (1) Solenoid
- (2) Armature
- (3) Upper poppet seat
- (4) Poppet valve
- (5) Lower poppet seat
- (6) Intensifier piston
- (7) Plunger
- (8) Plunger cavity
- (9) Barrel
- (10) Nozzle assembly

The HEUI injector consists of five basic components:

- Solenoid (1)
- Poppet valve (4)
- Intensifier piston (6) and plunger (7)
- Barrel (9)
- Nozzle assembly (10)

## Solenoid

The solenoid (1) is an electromagnet. When the solenoid is energized, the solenoid creates a very strong magnetic field. This magnetic field attracts the armature (2) which is connected to the poppet valve (4) by an armature screw. When the armature moves toward the solenoid, the armature lifts the poppet valve off the poppet valve's lower seat (5). Energizing the solenoid and lifting the poppet valve off the poppet valve's lower seat is the beginning of the fuel injection process.

## Poppet Valve

The poppet valve (4) has two positions which are opened and closed. In the closed position, the poppet is held on the lower poppet seat (5) by a spring. The closed lower poppet seat prevents high pressure actuation oil from entering the unit injector. The open upper poppet seat (3) vents oil in the cavity that is above the intensifier piston (6) to the atmosphere. The oil is vented to the atmosphere through the upper portion of the unit injector. In the open position, the solenoid (1) is energized and the poppet valve is lifted off the poppet valve's lower seat. When the poppet valve is lifted off the poppet valve's lower seat, the lower poppet seat opens allowing high pressure actuation oil to enter the unit injector. When the high pressure actuation oil enters the unit injector, the high pressure actuation oil pushes on the top of intensifier piston (6). The upper poppet seat (3) of poppet valve (4) closes and upper poppet seat (3) of poppet valve (4) blocks the path to the drain. Blocking the path to the drain prevents the leakage of high pressure actuation oil from the unit injector.

## Intensifier Piston

The surface area of intensifier piston (6) is six times larger than the surface area of plunger (7). This larger surface area provides a multiplication of force. This multiplication of force allows 27.5 MPa (4000 psi) of actuation oil to produce 162 MPa (23500 psi) of fuel injection pressure. When poppet valve (4) moves away from lower poppet seat (5), high pressure actuation oil enters the unit injector. When the high pressure actuation oil enters the unit injector, the high pressure actuation oil pushes on the top of intensifier piston (6). Pressure rises on top of the intensifier piston and the pressure pushes down on intensifier piston (6) and plunger (7). The downward movement of the plunger pressurizes the fuel in plunger cavity (8). The pressurized fuel in the plunger cavity causes nozzle assembly (10) to open. When the nozzle assembly opens, the fuel delivery into the combustion chamber begins. A large O-ring around the intensifier piston separates the oil above the intensifier piston from the fuel below the intensifier piston.

## Barrel

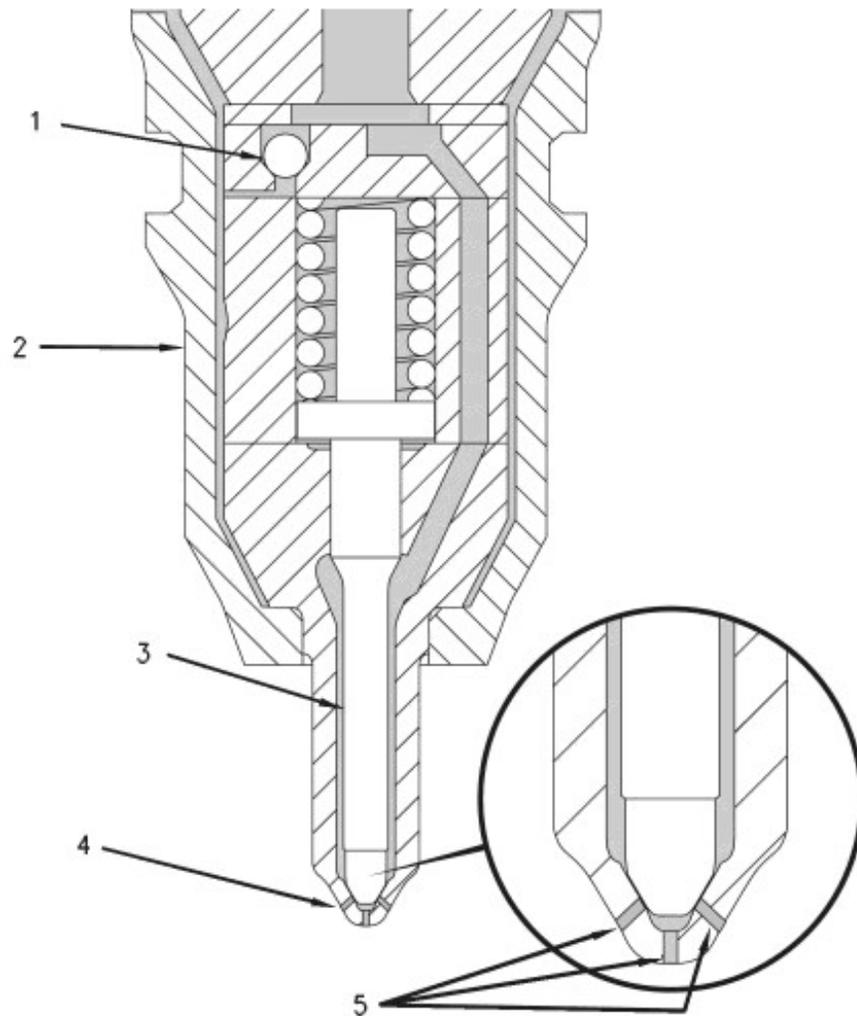
The barrel (9) is the cylinder that holds plunger (7). The plunger moves inside the barrel. The plunger and barrel together act as a pump. Both the plunger and the barrel are precision components that have a working clearance of only 0.0025 mm (.00010 inch). These tight clearances are required in order to produce injection pressures over 162 MPa (23500 psi) without excessive leakage.

**Note:** A small amount of controlled leakage is required in order to lubricate the plunger which prevents wear.

The barrel (9) also contains the PRIME spill port.

The PRIME spill port is a small hole with a high precision tolerance. The PRIME spill port is machined through the side of barrel (9) into plunger (7). This port momentarily vents fuel injection pressure during the downward stroke of the plunger.

## Nozzle Assembly



Nozzle assembly

(1) Inlet fill check ball

(2) Case

(3) Check

(4) Tip

(5) Tip orifice holes

The nozzle assembly is similar to all other unit injector's nozzle assemblies. Fuel that has been pressurized to the injection pressure flows from the plunger cavity through a passage in the nozzle to the nozzle tip (4). Fuel flow out of the tip is stopped by check (3), which covers the tip orifice holes (5) in the end of the tip (4). The force of a spring holds the check down in the closed position. This prevents the leakage of fuel out of tip (4) and this prevents the leakage of combustion gas into the unit injector when the cylinder fires.

When the injection pressure increases to approximately 28 MPa (4000 psi), the hydraulic force that is pushing on check (3) becomes greater than the spring force that is holding the check down. When the spring force is overcome by the hydraulic force, the check moves away from tip (4). When the check moves away from the tip, the check is in the open position. The amount of pressure that is required to open the check is called the Valve Opening Pressure (VOP). The fuel flows out of tip orifice holes (5) in the end of the tip and the fuel flows into the combustion chamber. The check remains open and fuel continues to flow out of the tip until fuel injection pressure drops below 28 MPa (4000 psi). When the pressure drops, the check closes and fuel injection is stopped. The amount of pressure that allows the check to close is called the Valve Closing Pressure (VCP).

**Note:** Valve Opening Pressures (VOP) and Valve Closing Pressures (VCP) vary among applications and horsepower ratings in order to meet exhaust emission standards. The above values were used as illustrations only.

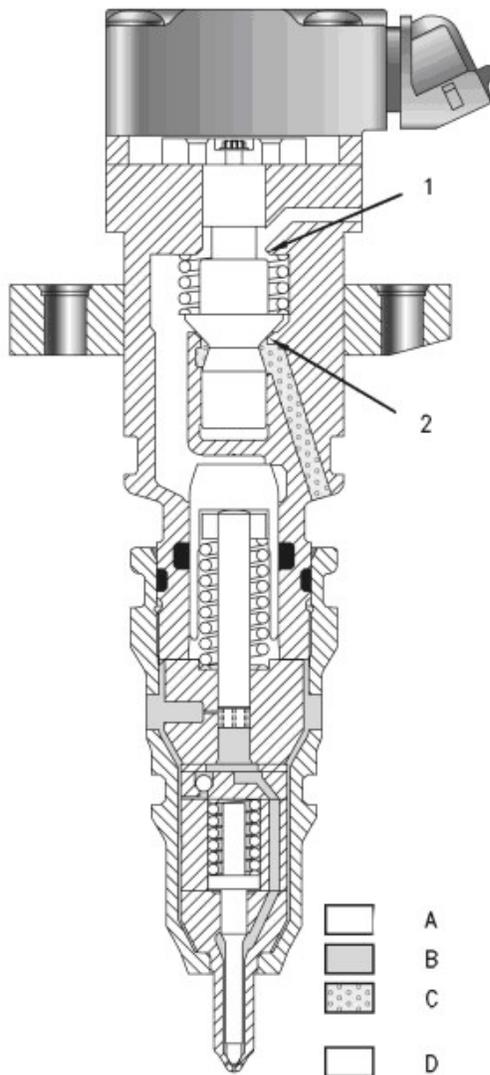
The inlet fill check ball (1) unseats during upward travel of the plunger in order to allow the plunger cavity to refill. The inlet fill check ball seats during the downward stroke of the plunger and the inlet fill check ball seals during the downward stroke of the plunger. The inlet fill check ball seals during the downward stroke of the plunger in order to prevent fuel injection pressure leakage into the fuel supply.

## Operation of the HEUI Fuel Injector

There are five stages of injection with the HEUI injector:

- Pre-injection
- Pilot injection
- Delay
- Main injection
- End of injection

## Pre-Injection



HEUI injector (Pre-injection)

(1) Upper poppet seat (open position)

(2) Closed lower poppet seat

(A) Drain (atmosphere)

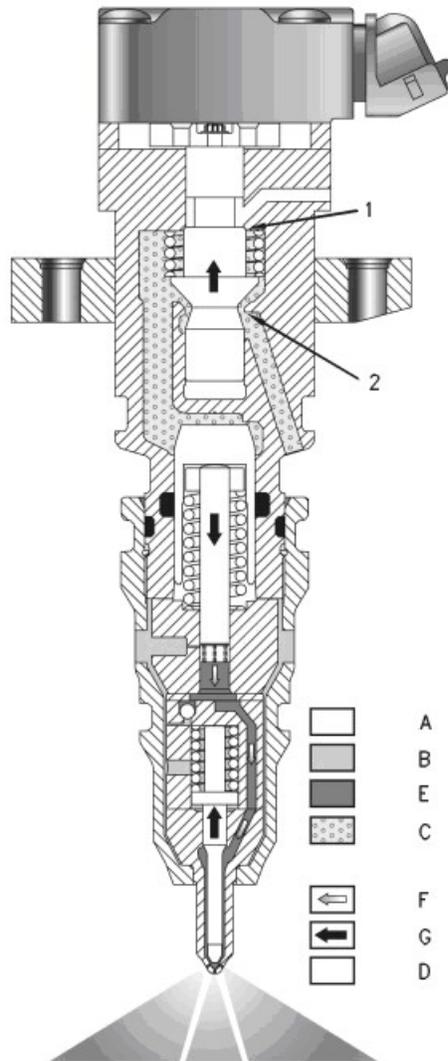
(B) Fuel supply pressure

(C) Actuation oil pressure

(D) Moving parts

All of the internal components have been returned to the spring loaded position during the pre-injection. The solenoid is not energized and the lower poppet seat (2) is closed. When the lower poppet seat is closed, the lower poppet seat blocks high pressure actuation oil from entering the unit injector. The plunger and the intensifier piston are at the top of the bore and the plunger cavity is full of fuel. Fuel pressure in the plunger cavity is equal to the fuel supply pressure. The fuel supply pressure is approximately 450 kPa (65 psi).

## Pilot Injection



HEUI injector (Pilot Injection)

(1) Upper poppet seat (closed position)

(2) Lower poppet seat (open position)

(A) Drain (atmosphere)

(B) Fuel supply pressure

(C) Actuation oil pressure

(D) Moving parts

(E) Injection pressure

(F) Fuel flow

(G) Mechanical movement

When the ECM activates the unit injector, the ECM sends a current to the unit injector solenoid. The current causes the solenoid to produce a strong magnetic field which creates a pull on the armature. The armature is mechanically connected to the poppet valve by a screw. The magnetic pull of the solenoid overcomes the spring tension that is holding the poppet valve closed. When the poppet valve opens, the poppet moves away from the lower poppet seat.

When the poppet valve opens, the upper poppet seat (1) blocks the path to the drain and the lower poppet seat (2) opens the poppet chamber to incoming high pressure actuation oil. High pressure oil flows around the poppet. The high pressure oil flows through a passage onto the top of the intensifier piston. High pressure oil acts on the top of the intensifier piston. The piston and the plunger are pushed down by the high pressure oil. The downward movement of the plunger pressurizes the fuel in the plunger cavity and nozzle assembly. When the pressure reaches Valve Opening Pressure (VOP) of approximately 28 MPa (4000 psi), the check lifts up from the seat in the tip. When the check lifts up from the seat in the tip, injection begins.

## Pre-Injection Metering (PRIME)

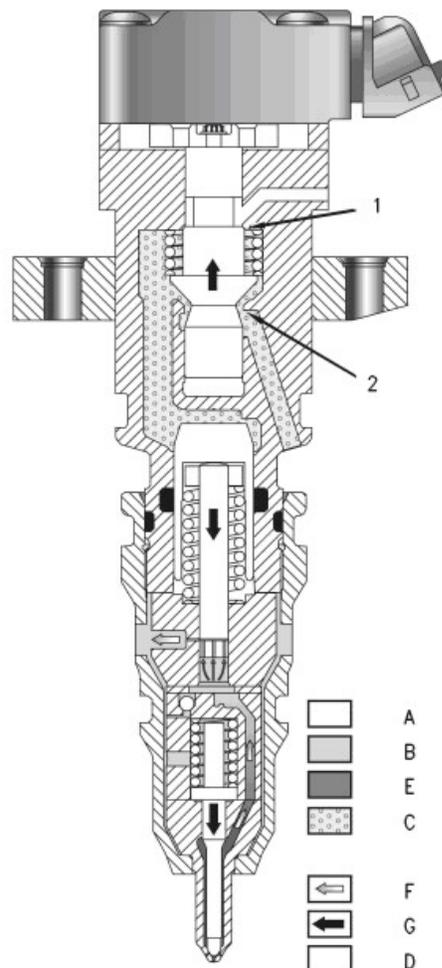
The 3126B and 3126E diesel engine's fuel system has a unique feature that is called PRIME. Pre-Injection Metering (PRIME) is a feature that offers a significant benefit in lower emissions.

Also, PRIME offers a significant benefit in reducing combustion noise. While other fuel systems deliver a single large quantity of fuel into the combustion chamber, PRIME injectors break the delivery into two separate quantities. The first quantity is a small pilot injection which is followed by a short delay. Then, the injector delivers a large main injection. The pilot injection is not intended to produce power. The pilot injection is intended to establish a flame front. The pilot injection will help the larger main injection burn more completely and the pilot injection will help the larger main injection burn in a controlled manner.

Under certain engine operating conditions, when fuel is delivered in one large injection, the fuel tends to explode rather than burn in a controlled manner. This results in engine knock. When fuel explodes rather than burns in a controlled manner, engine knock and excess NOx emissions result.

The PRIME feature produces a small pilot injection that is followed by a brief delay. The brief delay gives the pilot injection the time that is required to start burning. The main injection follows the pilot injection and the main injection is delivered into the flame front that was established by the pilot injection. The main injection is immediately ignited. The main injection burns smoothly and the main injection burns completely. This complete combustion significantly reduces particulate emission (soot) and NOx. This complete combustion also reduces combustion noise from the engine up to 50 percent. This reduction of combustion noise from the engine results in noticeably quieter engine operation. The actual operation of PRIME is described in the following information.

## Injection Delay

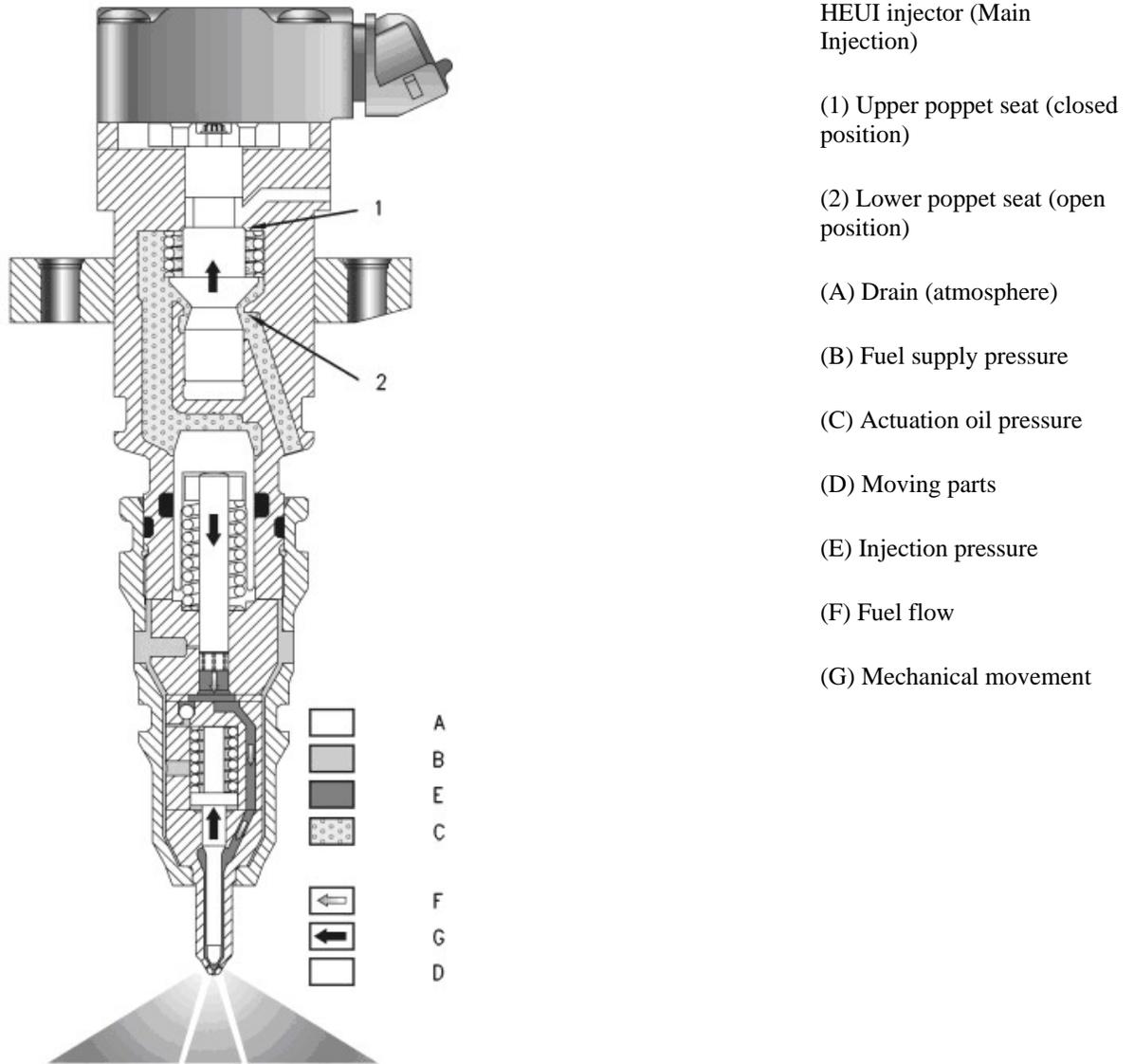


HEUI injector delay

- (1) Upper poppet seat (closed position)
- (2) Lower poppet seat (open position)
- (A) Drain (atmosphere)
- (B) Fuel supply pressure
- (C) Actuation oil pressure
- (D) Moving parts
- (E) Injection pressure
- (F) Fuel flow
- (G) Mechanical movement

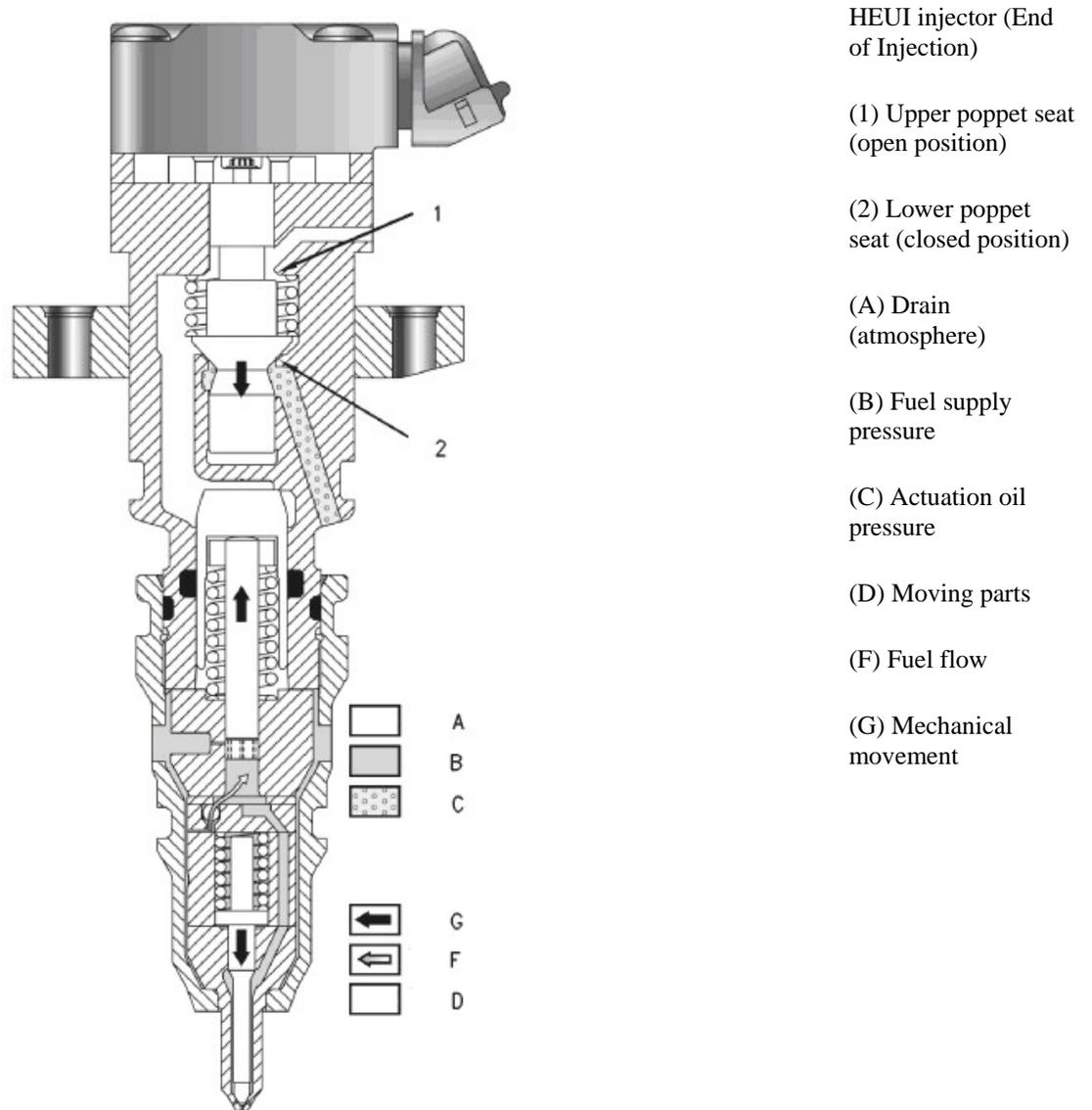
The plunger continues moving downward and the plunger continues to inject fuel into the combustion chamber. Until the PRIME groove in the plunger lines up with the PRIME spill port in the barrel, the plunger continues to inject fuel into the combustion chamber. When the groove in the plunger aligns with the spill port, high pressure fuel under the the plunger can flow upward. The high pressure fuel flows through three holes in the bottom of the plunger. Then, the high pressure fuel flows out of the groove of the plunger and the spill port and the fuel flows back into the fuel supply passage. This loss of high pressure fuel causes injection pressure to drop below Valve Closing Pressure (VCP). The spring force overcomes the hydraulic force of the reduced injection pressure. When the spring force overcomes the hydraulic force of the reduced injection pressure, the check closes and fuel injection stops. This is the end of the pilot injection and the start of the short injection delay period.

## Main Injection



While the solenoid is energized, the poppet valve remains open. While the poppet valve is open, high pressure oil continues to flow. The flow of the high pressure oil pushes downward on the intensifier piston and the plunger. The injection pressure fluctuates between 34 MPa (5000 psi) and 162 MPa (23500 psi). The injection pressure depends on the engine's requirements. Injection continues until either the solenoid is de-energized or the intensifier piston hits the bottom of the bore. When the solenoid is de-energized, the poppet spring is allowed to close the poppet valve. When the poppet valve closes, high pressure oil is shut off.

## End of Injection

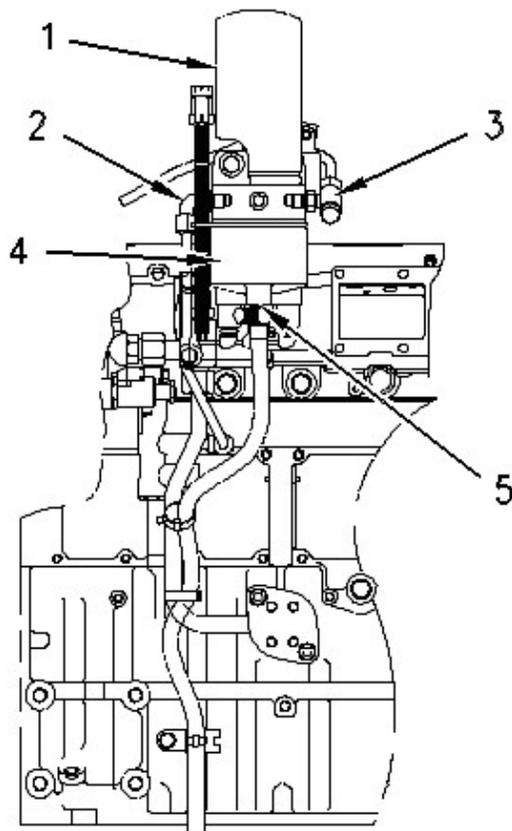


The end of the injection cycle begins when the ECM stops the current to the unit injector solenoid. The magnetic field of the solenoid breaks down and the magnetic field is unable to overcome the spring force of the poppet. The poppet returns to the lower poppet seat which closes the poppet valve. When the poppet valve closes, high pressure oil is stopped from entering the unit injector. As the lower poppet seat closes, the upper poppet seat opens to the drain. When the upper poppet seat opens to the drain, the actuation pressure of the oil drops off. Fuel injection pressure under the plunger exerts an upward force on the plunger and the intensifier piston. As the pressure of the actuation oil above the intensifier piston drops off, the downward force on the intensifier piston drops off. The upward force of the fuel injection pressure under the plunger suddenly becomes greater than the downward force on the intensifier piston. The downward motion of the intensifier piston and the plunger stops. The exhaust oil on top of the intensifier piston can flow to the drain through the open upper poppet seat. Then, the oil flows through a vent hole to the rocker arm compartment under the valve cover. When the downward travel of the plunger stops, fuel flow also stops. While the check is still open, the remaining fuel pressure pushes a small amount of fuel out of the orifice holes. This causes a large pressure drop which lowers injection pressure below Valve Closing Pressure (VCP). Spring tension on the check now reseats the check into the tip and injection stops. When the check closes, injection stops. When injection stops, the fill cycle starts. The area above the intensifier piston cavity is open to atmospheric pressure through the upper poppet seat.

Pressure drops very rapidly in the cavity above the intensifier piston to near zero. The return spring of the plunger pushes up on the plunger and the intensifier piston. As the plunger and the intensifier piston move upward, oil is forced around the upper poppet seat. After the oil is forced around the upper poppet seat, the oil is forced out of a vent hole.

As the plunger rises, pressure in the plunger cavity also drops to near zero. The fuel supply pressure is 450 kPa (65 psi). Fuel supply pressure unseats the plunger fill check in order to fill the plunger cavity with fuel. When the intensifier piston is pushed to the top of the bore, the fill cycle ends. When the fill cycle ends, the plunger cavity is full and the inlet fill check ball is reseated. Pressure above the intensifier piston and the poppet chamber is zero. The fuel injection cycle is complete and the unit injector is ready to begin again. The unit injector is now back in the pre-injection cycle.

## Fuel Heater And Water Separator (If Equipped)



- (1) Fuel filter
- (2) Fuel inlet
- (3) Fuel outlet
- (4) Fuel heater and water separator
- (5) Drain valve

Some engines may have a combination of a fuel heater and a water separator. The fuel heater is controlled by a thermostat that is located in the base of the unit. The thermostat is preset. When the fuel temperature is below 4°C (40°F), the thermostat will turn on the heater. When the fuel temperature is 15°C (60°F), the thermostat will turn off the heater.

Water that has been separated from the fuel can be drained from the unit by lifting up on drain valve (5)