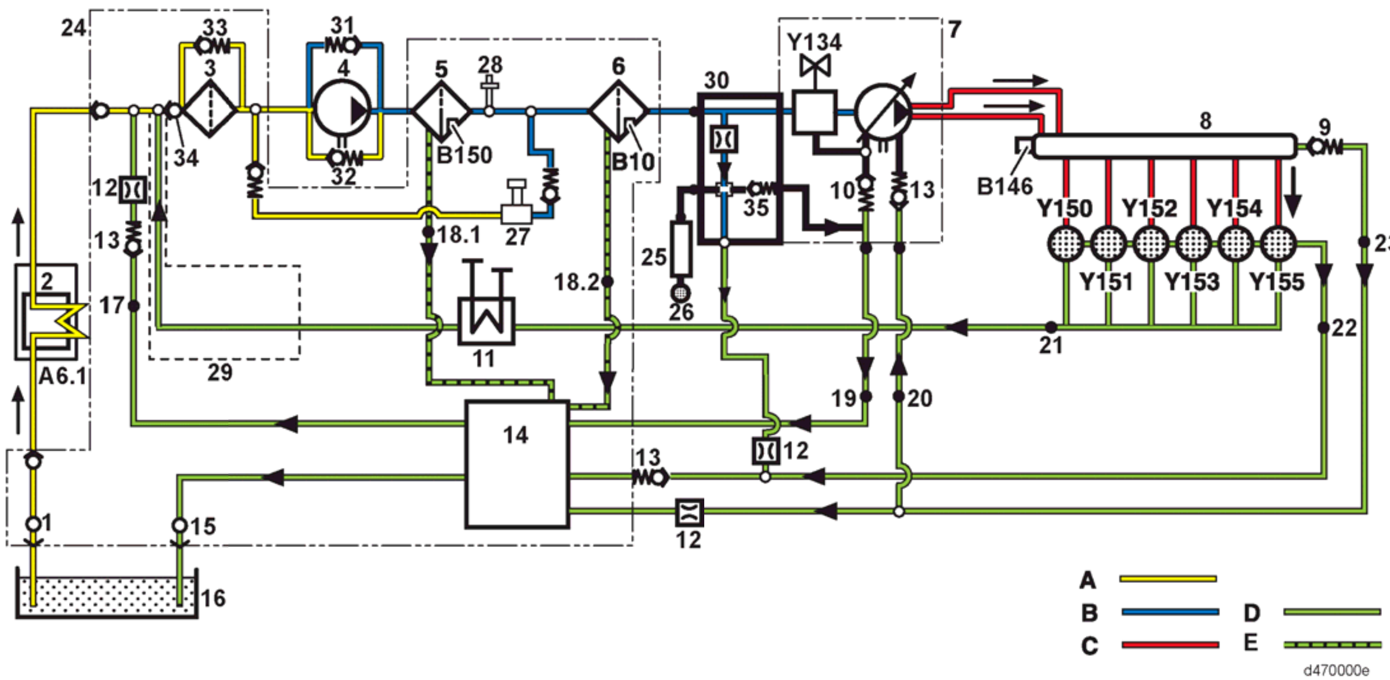
Section 1
The Fuel System

The fuel supply ensures that the fuel required for combustion is available under all operating conditions in sufficient quantity, in the correct sequence and at the required pressure. Fuel to the individual cylinders is supplied from the Amplified Pressure Common Rail System. Fuel is supplied to the (APCRS) from the fuel low pressure circuit.

The fuel low pressure circuit ensures that the fuel is cleaned and is provided in sufficient quantities and at the required pressure to the APCRS.



1. Shutoff valve in the fuel feed (locked in open position)
2. Fuel Heat Exchanger
3. Fuel Prefilter
4. Low Pressure Fuel Pump
5. Water Separator
6. Final Filter
7. High Pressure Fuel Pump
8. Fuel Rail
9. Pressure Limiting Valve
10. Two-stage Valve
11. Fuel Cooler
12. Throttle Valve
13. Regulator
14. Fuel Accumulator
15. Shutoff Valve in the fuel return (locked in open position)
16. Fuel Tank
17. Fuel Return (Bypass Valve at Module)

18.1 Vent Line from Water Separator

18.2 Vent Line from Fuel Filter

19. Fuel Return from Quantity Control Valve
20. Emergency Lubrication Line
21. Fuel Return from Injector Amplifiers
22. Fuel Return from Injector Needle Valves
23. Fuel Return from Pressure Limiting Valve
24. Fuel Filter Module
25. Doser Block Assembly
26. Fuel Doser Valve
27. Hand Primer Pump
28. Priming Port
29. Amplifier Return Line (external to module)
30. High Pressure manifold
31. Pressure Relief Valve for Low Pressure Pump
32. Bypass Valve (Low Pressure Pump)
33. Bypass Valve (Prefilter)
34. Check Ball (Prefilter Stand Pipe)
35. Doser Block Pressure Regulator

A Fuel Feed/Suction side
B Fuel Feed (Pressure side)
C Fuel High-Pressure
D Fuel Return Flow
E Air Vent Passage

A6.1 Motor Control Module (MCM)
B10 Supply Fuel Temperature Sensor
B146 Rail Pressure Sensor
B150 Water-in-fuel Sensor
Y134 Quantitiy Control Valve
Y150 Injector (Cylinder 1)
Y151 Injector (Cylinder 2)
Y152 Injector (Cylinder 3)
Y153 Injector (Cylinder 4)
Y154 Injector (Cylinder 5)
Y155 Injector (Cylinder 6)

The low pressure fuel pump (4), which is a gear pump, supplies fuel to the fuel low pressure circuit. When the engine is started, the fuel pump (4) pulls fuel from the fuel tank (16) and delivers it through the shutoff valve in the fuel feed (1) line to the fuel filter module (24). The shutoff valve in the fuel feed (1) prevents fuel leaking out when disassembling the fuel line between the fuel tank (16) and the fuel filter module (24). The fuel flows from the fuel filter module (24) to the fuel heat exchanger (2) located on the Motor Control Module (MCM) (A6.1). The electronic components of the MCM (A6.1) are cooled via the fuel heat exchanger (2). The fuel in the fuel filter module (24) first passes into the fuel prefilter (3) where large dirt particles greater than 100 micron are filtered out. A check ball which is located at the fuel inlet of the fuel prefilter (3) prevents emptying of the suction line to the fuel tank (16).

The fuel which has been cleaned by the fuel prefilter (3) passes out of the fuel filter module (24) to the low pressure fuel pump (4). From there the fuel is delivered back into the fuel filter module (24) and to the water separator (5). The water inside the fuel is separated out by the water separator (5) and begins to fall into the water accumulator. If the water level in the water accumulator reaches its maximum level, this will be detected by the Water-in-Fuel sensor (B150). The MCM (A6.1) transmits an appropriate message for illuminating the indicator lamp. At this point, the indicator lamp will inform the driver that the separated water needs to be drained off. After leaving the water separator (5) the fuel flows through the final filter (6). Both the water separator (5) and final filter (6) elements filter out fine-grained contaminants greater than 3 to 5 microns.

A Supply Fuel Temperature Sensor (B10) located on the bottom of the fuel filter module detects the current fuel temperature. The MCM interrupts this information and uses it for fuel mass calculations.

Designed into the water separator (5) and final filter (6) elements, is a ventilation bore that allows trapped air to escape. If air is trapped in the water separator (5) or the final filter (6), for example due to replacement of a filter element, the trapped air will escape through the ventilation bore and vent lines (18.1, 18.2) into the fuel accumulator (14). From there the air is then dissipated into the fuel tank (16). Once all of the contaminants have been filtered out by the final filter (6), the fuel is delivered out of the fuel filter module (24) to the quantity control valve (Y134). The high pressure fuel pump (7) pressurizes the fuel up to 900 Bar (13,053 psi) and is then fed to the fuel rail (8). The excess fuel from the quantity control valve (Y134) and high pressure fuel pump (7) is routed past the 2-stage valve (10). The excess fuel is then routed to the fuel accumulator (14).

The two-stage valve (10) has a number of tasks:

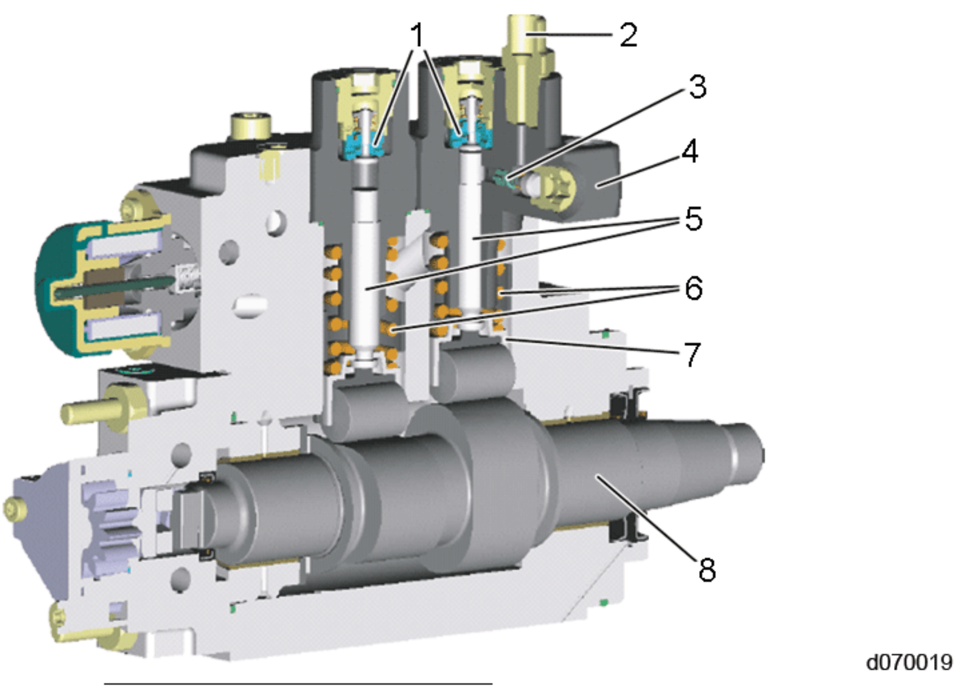
- It is closed at pressures in the low pressure circuit below 3 Bar relative to high pressure pump backflow pressure to ensure best filling under cranking speed where low pressure pump flow is low.
- It guarantees lubrication of the high pressure fuel pump components if the pressure in the low pressure circuit is above 3 Bar relative to high pressure pump backflow pressure. The lubrication path is fully open at 3.5 Bar.
- It ensures that in overrun conditions the pressure at the inlet to the high pressure pump is limited by opening of the backflow path. This function avoids pressures above burst pressure level of the filter module. If the pressure at the high pressure pump inlet exceeds 4.7 bar relative to backpressure, excess fuel is routed to the return path.

If the maximum rail pressure is exceeded (leakage at 1075 bar, open at 1250 bar), the pressure limiting valve (9) opens and passes the excess fuel to the fuel return. If the system pressure drops below 3 bar (43 psi) due to the opened pressure limiting valve (9), part of the excess fuel is taken from the fuel return from the pressure limiting valve (23) to be used for lubrication of the high pressure fuel pump. The fuel taken for lubrication is fed through the emergency lubrication line (20) and the regulator (13) to the fuel high pressure pump (7). The head pressure required to do this is generated by the throttle valve (12) which is located upstream of the fuel accumulator (14). The excess and warmed fuel from the amplifier circuits of each individual injector is routed through a passage within the cylinder head. This fuel is fed via the amplifier fuel return (21) line through the fuel cooler (11), throttle (12), and finally a regulator (13). This fuel is feed to the fuel filter module in front of the prefilter (3). The fuel cooler (11) serves to lower the temperature of the fuel to about 120°C. The throttle valve (12) in the amplifier fuel return (21) line dampens pressure peaks which occur during activation of the injector amplifiers.

The excess fuel for the injector needle valves is also routed through a bore in the cylinder head. The fuel return from the injector needle valves (22) flows through a regulator (13) and into the fuel accumulator (14). The regulator (13) has the task of regulating back pressure of about 1 bar (14.5 psi) relative to back pressure while the engine is running. From the fuel accumulator (14) part of the returned fuel is delivered directly upstream of the fuel prefilter (3) in the fuel low pressure circuit.

The fuel quantity is determined by the throttle valve (12) and the regulator (13) in the fuel return (17) bypass. This returned fuel leads to a lower suction load for the low pressure fuel pump (4). The remaining fuel from the fuel accumulator (14) is led back to the fuel tank (16). The shutoff valve in the fuel return (15) prevents fuel leaking out when disassembling the fuel line between the fuel tank (16) and the fuel filter module (24).

High Pressure Pump



1. Intake Valve
2. High Pressure Connection
3. High Pressure Valve
4. High Pressure Pump Housing
5. High Pressure Piston
6. Compression Spring
7. Roller Tappet
8. Camshaft

The camshaft (8) for the high pressure fuel pump is driven by the pinion gear drive.

The fuel is compressed by two high pressure pistons (5) and feeds the high pressure connection and corresponding high pressure lines to the rail. The two roller tappets (7) on the double cams of the camshaft (8) are pressed together by two push springs (6) which are offset by 90°. With this configuration, two pressure strokes occur for one camshaft revolution for each high pressure piston (5). If the high pressure piston (5) is in a downward movement, the fuel can flow over the corresponding intake valve (1) into the clearance volume of the high pressure piston (5). If the high pressure piston (5) now changes to an upward movement, the corresponding intake valve (1) is closed by the compression pressure rising and the fuel in compressed until the high pressure valve (3) opens a transfer duct between the high pressure compartment and the corresponding high pressure connection. The highly compressed fuel can now flow into the rail. If the high pressure piston (5) again changes to a downward movement, the transfer duct is closed again by the spring-loaded high pressure valve (3) and new fuel can flow through the opened intake valve (1) into the clearance volume.

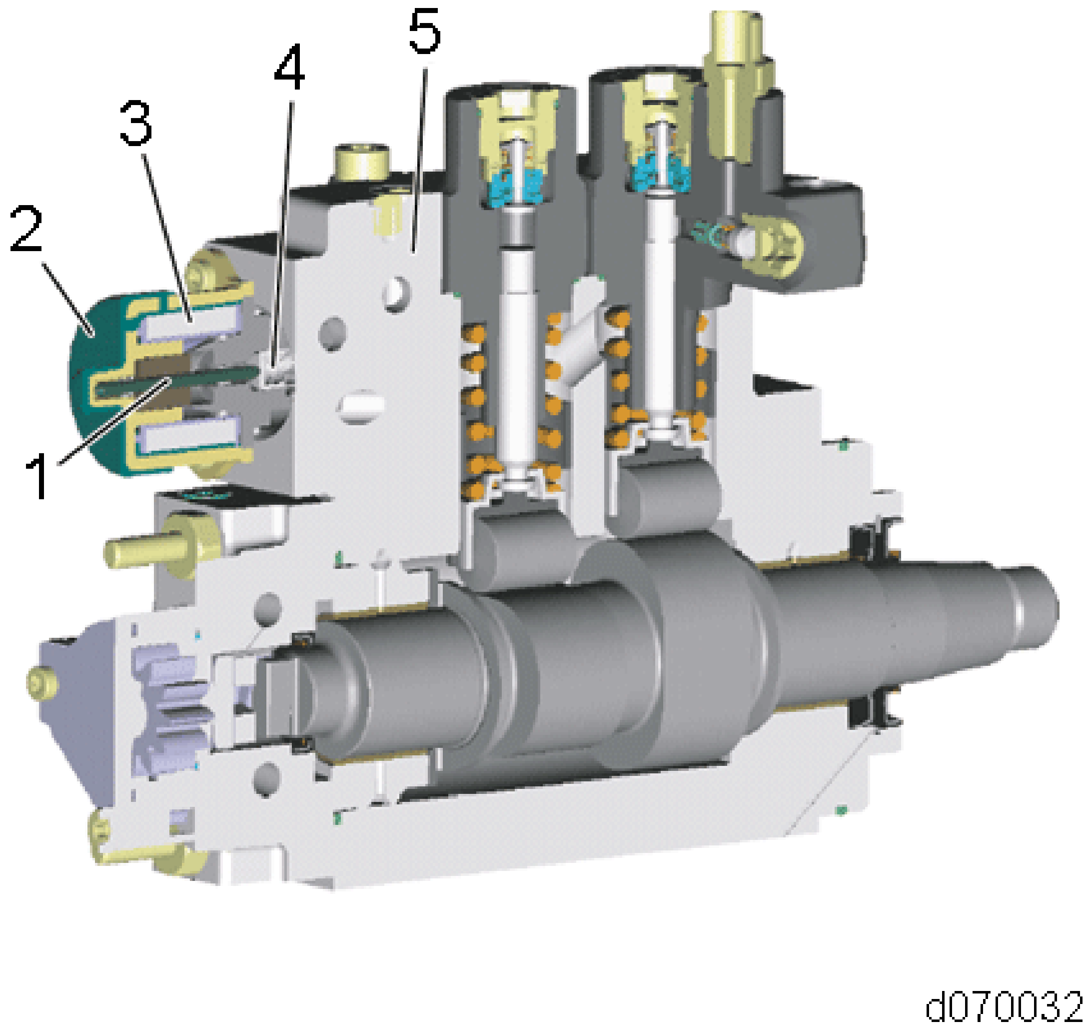
Section 3.6.1
Two–Stage Valve

Internal to the high pressure fuel pump is a two-stage valve. The excess fuel from the quantity control valve and high pressure fuel pump is routed past the two-stage valve.

The two-stage valve has a number of tasks:

- It is closed at pressures in the low pressure circuit below 3 bar relative to high pressure pump backflow pressure. This will ensure best filling for the pumping elements under cranking speed where low pressure pump flow is low.
- It guarantees lubrication of the high pressure fuel pump components if the pressure in the low pressure circuit is above 3 bar relative to high pressure pump backflow pressure. The lubrication path is fully open at 3.5 bar.
- It ensures that in overrun conditions the pressure at the inlet to the high pressure pump is limited by opening of the backflow path. This function avoids pressures above burst pressure level of the filter module. If the pressure at the high pressure pump inlet exceeds 4.7 bar relative to backpressure, excess fuel is routed to the return path.

Section 3.7
Quantity Control Valve



1. Float Needle
2. Quantity Control Valve
3. Coil
4. Valve Spring
5. High Pressure Pump

The quantity control valve (2) is located on the fuel high pressure pump (5). The quantity control valve has the following tasks:

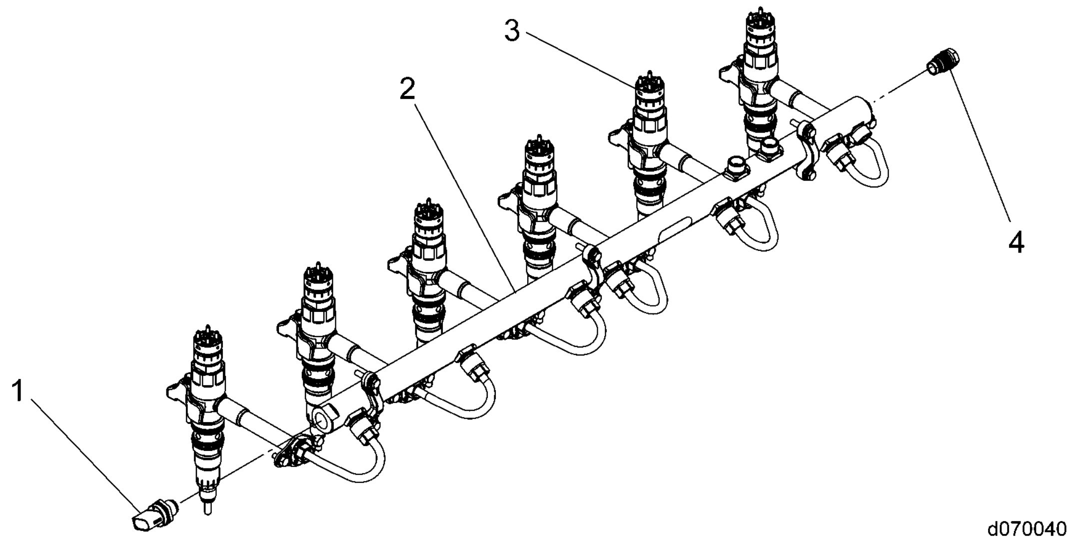
- Regulation of the fuel feed to the high pressure fuel pump (5)
- Regulation of the rail pressure

The MCM actuates the coil (3) of the quantity control valve (2) using a pulse width modulated signal. The magnetic field of the coil (3) influences the position of the float needle (1) and thus the flow in the quantity control valve (2). At engine off the float needle is pushed back by the valve spring (4) and the fuel flow is interrupted.

Fuel Rail

The fuel rail incorporates the Fuel Rail Pressure Sensor and pressure limiting valve. The fuel rail attaches to the side of the camshaft frame with brackets.

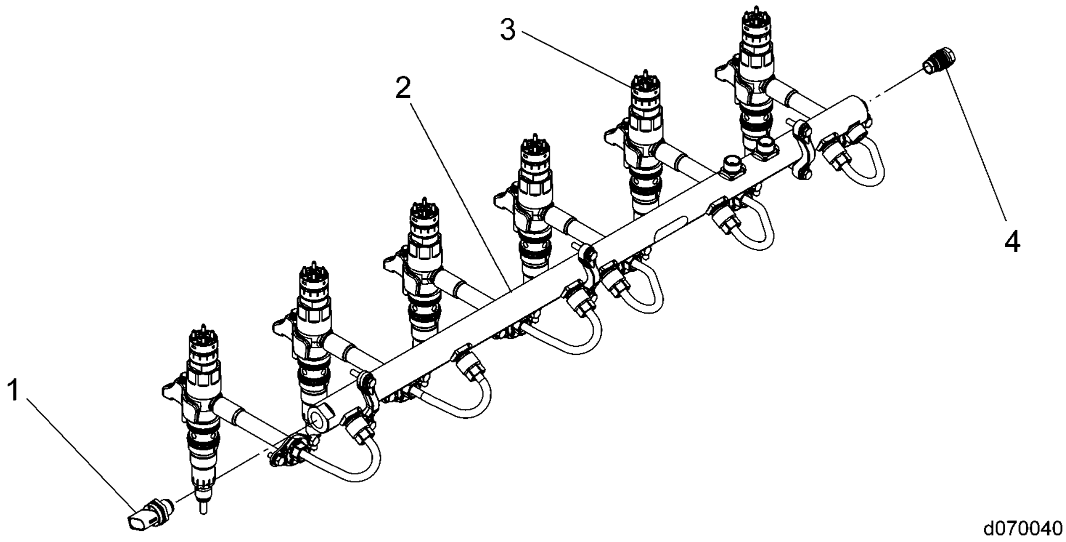
Section 3.8.1
Fuel Rail Pressure Sensor



1. Fuel Rail Pressure Sensor
2. Fuel Rail
3. Injector
4. Pressure Limiting Valve

The Fuel Rail Pressure Sensor (1) uses a sensor element and a hybrid element. As pressure increases the sensor membrane will distort. There are four pressure-dependent resistances (strain measuring resistors) on the sensor membrane. Its bridge circuit is supplied with voltage by an electronic analysis system which also serves for signal amplification and signal correction. The electronic analysis system itself is supplied a 5 V DC voltage by the MCM. The resistors in the sensor membrane are arranged in a way that when deforming the sensor membrane two resistors will contract and two resistors will expand. Contracting and expanding changes the electrical resistance and in turn has effects upon the measurement voltage, which is being applied to the electronic analysis system. The electronic analysis system amplifies the measurement voltage, compensating for possible temperature fluctuations or balancing out possible manufacturing tolerances and passes the cleaned measurement voltage to MCM.

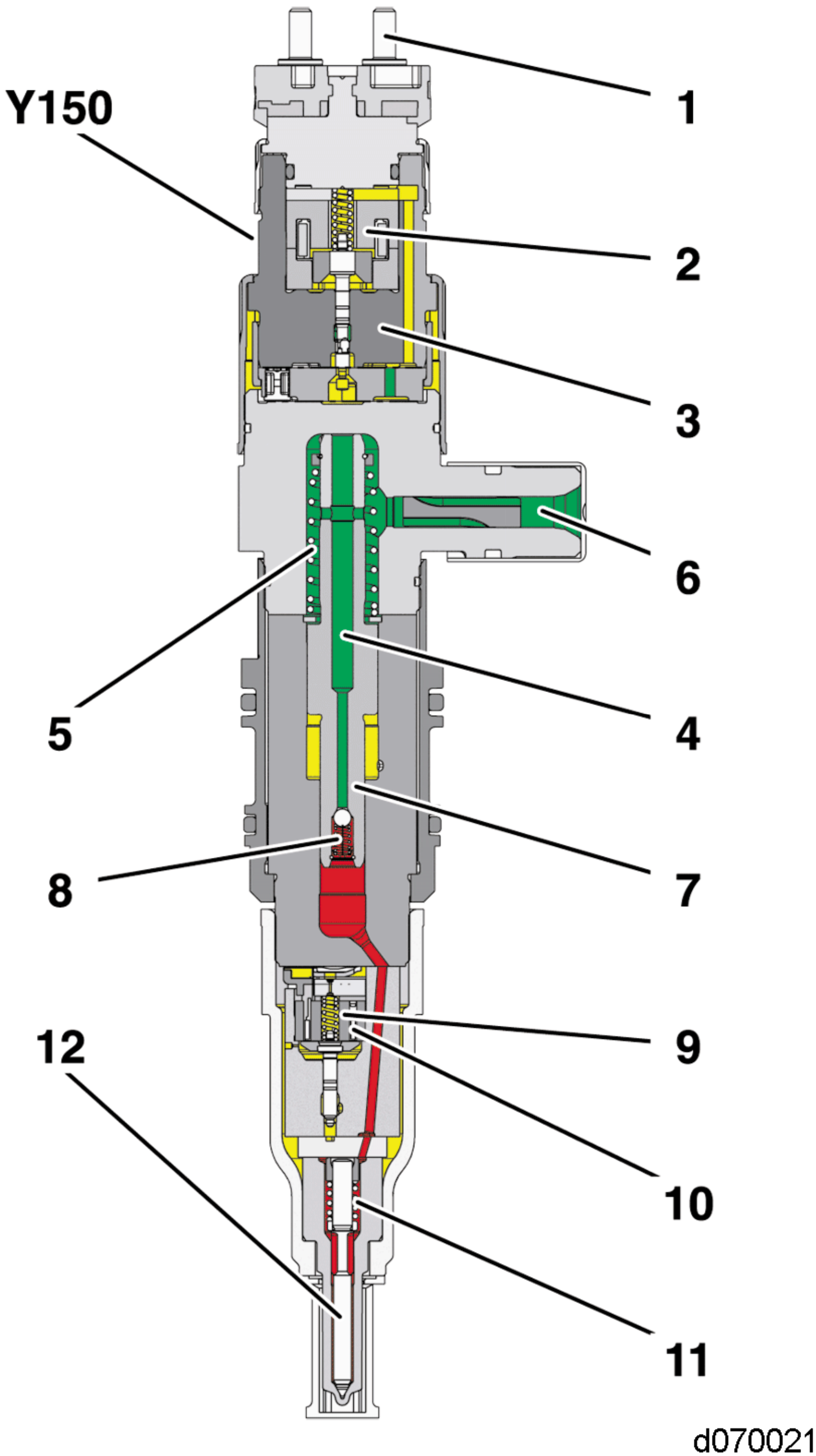
Section 3.8.2
Pressure Limiting Valve



1. Fuel Rail Pressure Sensor
2. Fuel Rail
3. Injector
4. Pressure Limiting Valve

The pressure limiting valve (4) is a safety element which limits the maximum rail pressure in the injection system to about 1280-1380 bar. If the current rail pressure exceeds the maximum rail pressure of about 1280 - 1380 bar, the push spring is pressed together by the pressure plate. A connection is opened at the same time to the cutoff bore, and the excess fuel flows into the return.

Fuel Injectors


Y150
1
2
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11
d070021

1. Electrical Connector
2. Coil
3. Pressure Converter Control Module
4. Pressure Converter Piston
5. Return Spring
6. High Pressure Feed
7. Pressure Converter
8. Check Valve
9. Solenoid Valve
10. Coil
11. Spring
12. Injector Needle

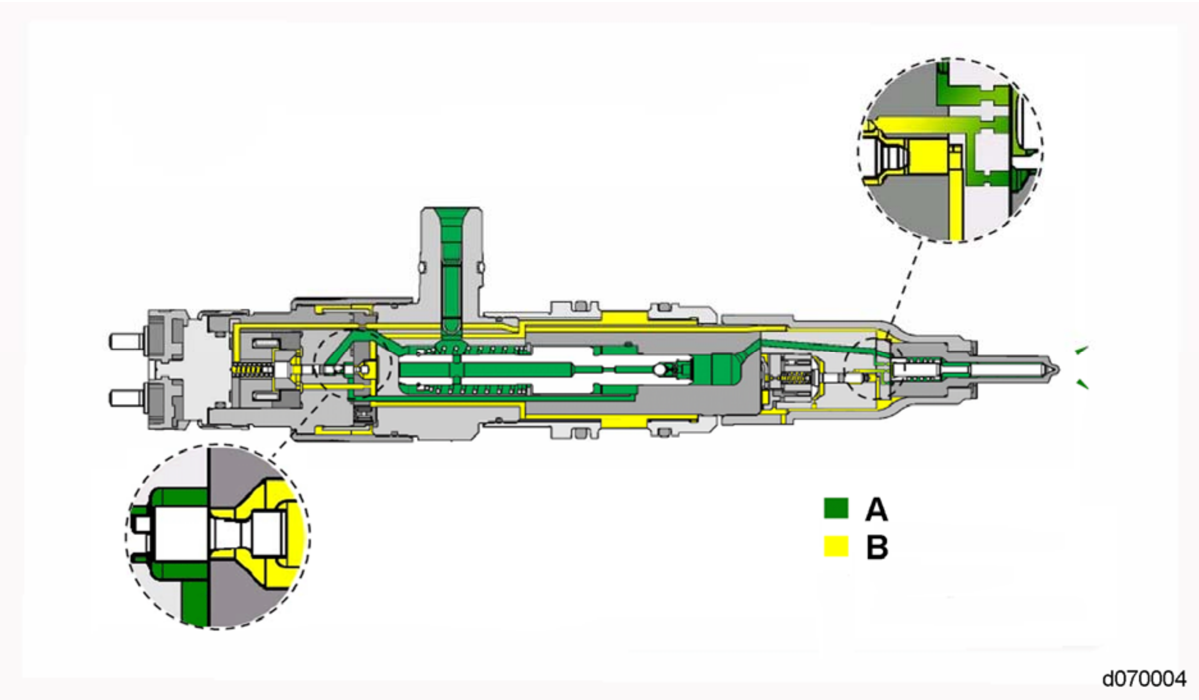
Y150 Injector (Cylinder 1)

The fuel injectors (Y150 to Y155) are fixed by means of a hold down clamp inside the camshaft frame and located centrally between the valves of the respective cylinder. All injectors have a 6-digit code, the injector quantity compensation coding, which is located on the upper side of the injector. This code describes the quantity characterization of the respective injector. If an injector is replaced then this code must be reported to the Motor Control Module (MCM) using DDDL 7.0.

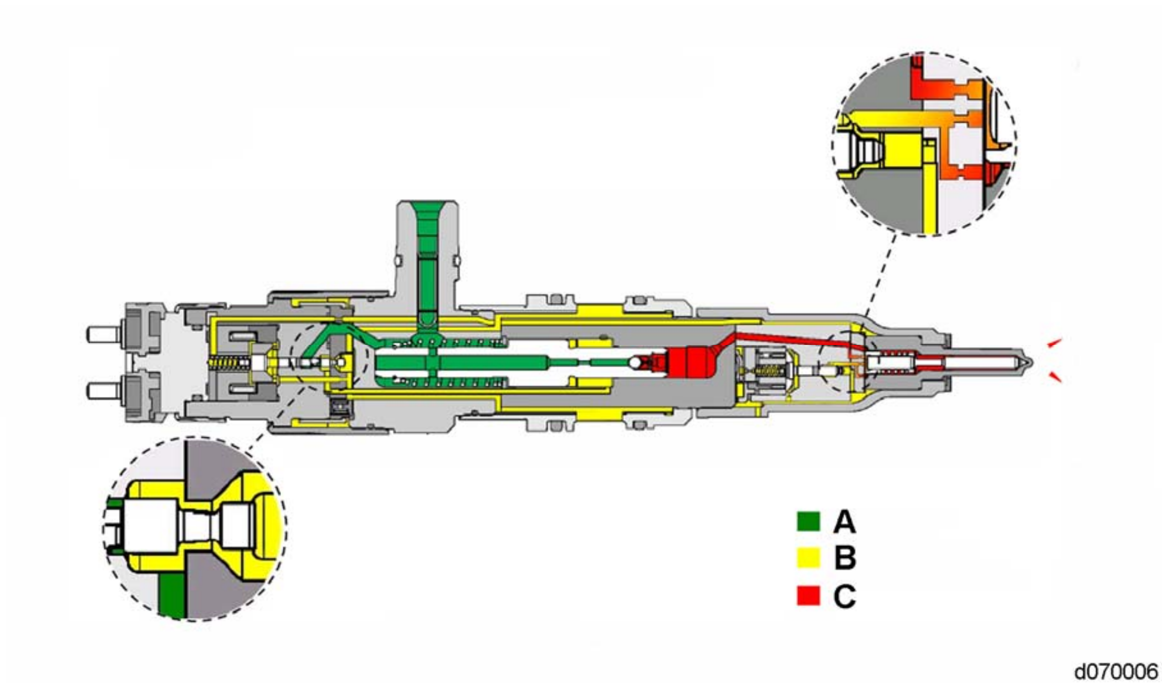
The injectors have the task of injecting the fuel under high pressure into the cylinders. The injection timing, injection period, and the injection variants (e.g. with or without amplification) are established by the MCM.

The injectors are fitted with an amplifier circuit. This allows for two modes of injection: without amplification and with amplification.

In the case of injection without amplification the injection pressure is determined by the rail pressure (about 900 bar).

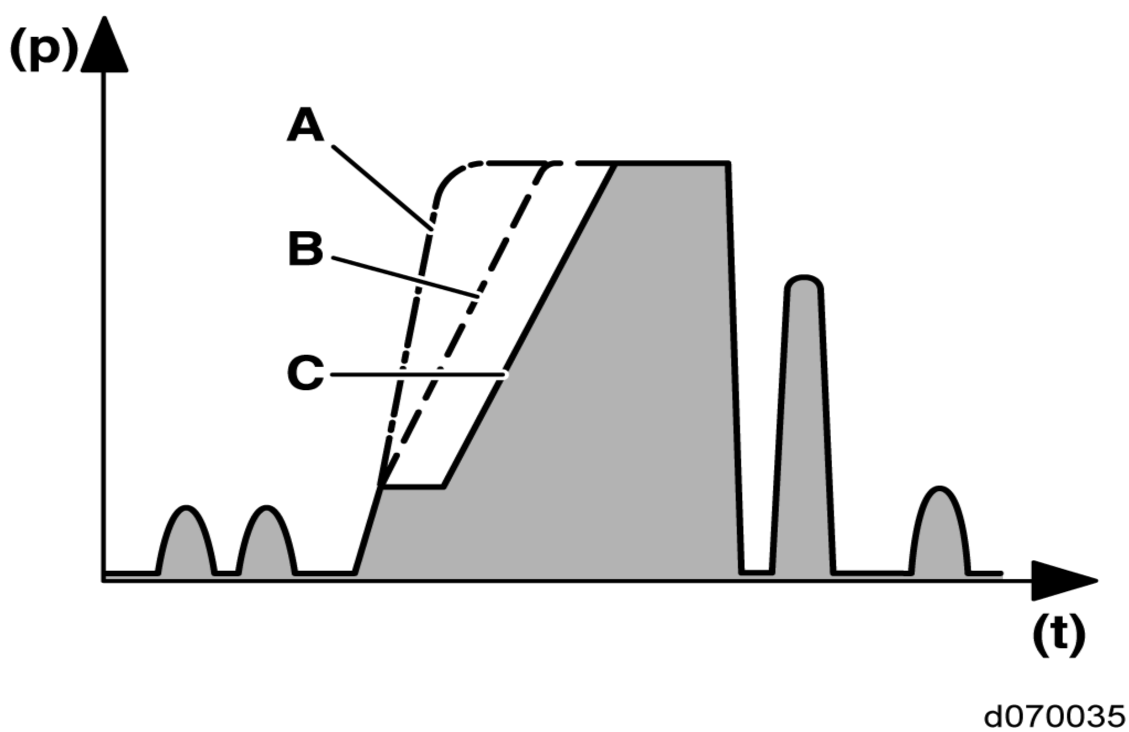


In the case of injection with amplification the injection pressure of up to 2100 bar is generated in the injector



Use of an amplifier within an injector offers the following advantages:

- The leak oil losses in the high pressure area are reduced.
- The pressure load of the high pressure pump, the fuel rail, and the high pressure lines is reduced since only a few components have high pressure applied to them.



A. (Square) Actuation of the amplifier control module before actuation of the needle solenoid valve

B. (Ramp) Actuation of the amplifier control module parallel to actuation of the needle solenoid valve

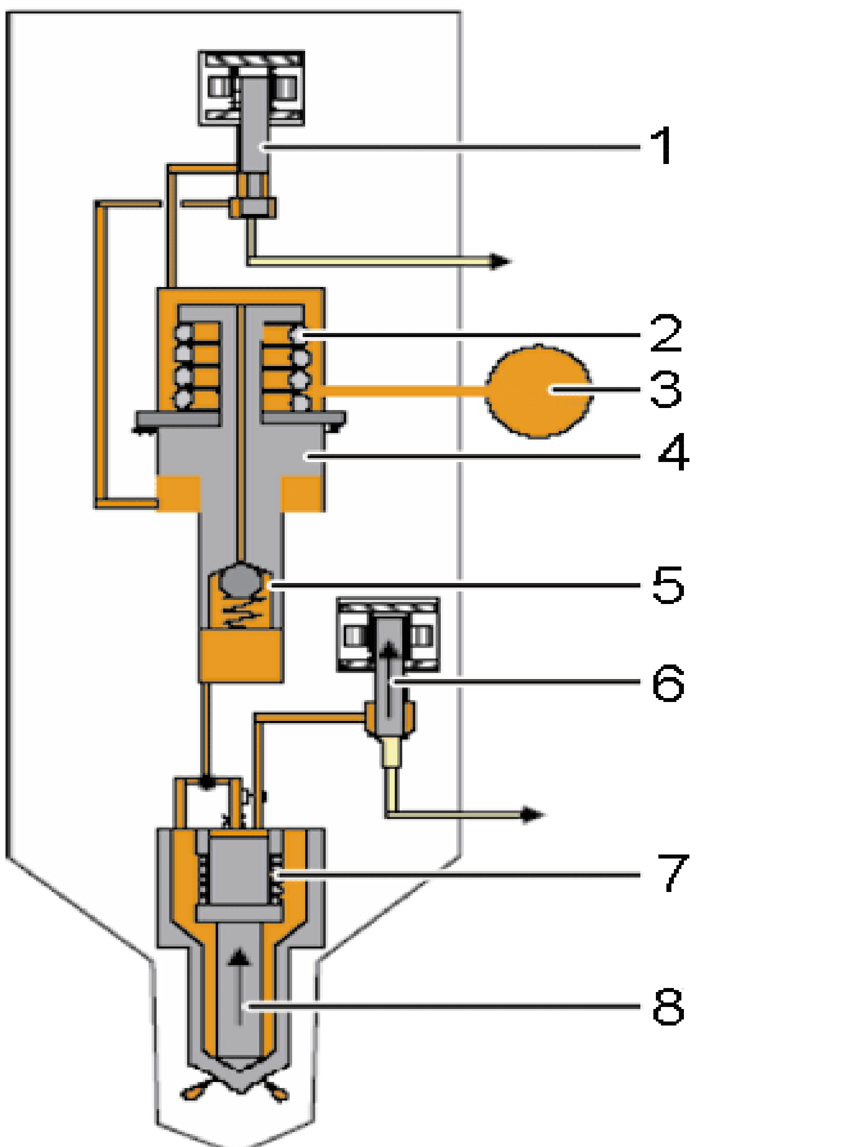
C. (Boot) Actuation of the amplifier control module after actuation of the needle solenoid valve

(p). Injection pressure

(t). Time

- During injection with amplification the injection process is determined by actuation of the needle solenoid valve and the amplifier control module either at other times or simultaneously.

Section 3.9.1
injection without Amplification

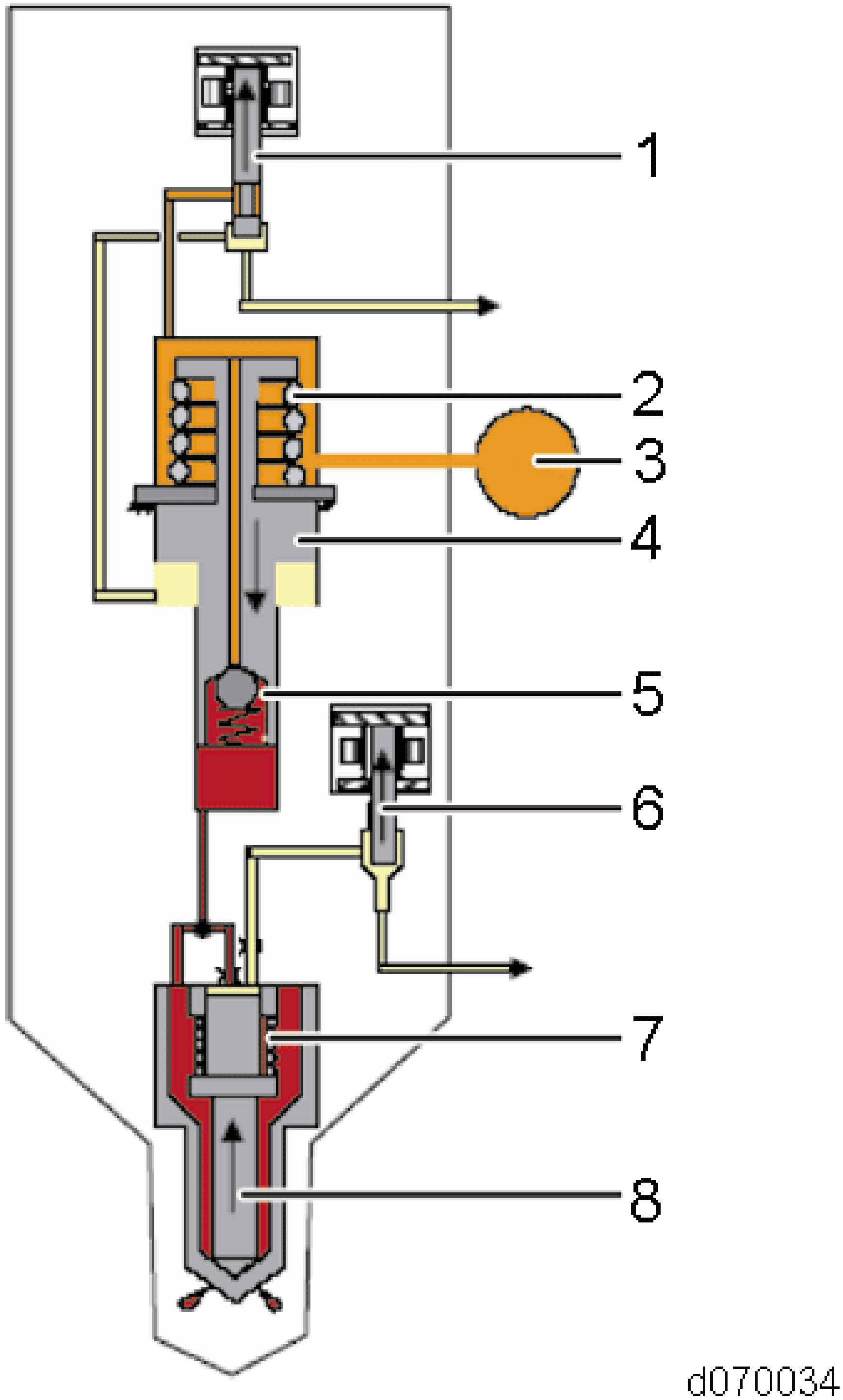


1. Amplifier Control Module
2. Return Spring
3. High Pressure Feed
4. Amplifier
5. Check Valve
6. Needle Solenoid Valve
7. Spring
8. Injector Needle

The amplifier control module (1) is not actuated during this process. The fuel internal to the injector is at rail pressure above and below the amplifier (4) piston.

The compressed fuel from the rail enters the injector needle (8) through the center of the amplifier (4) and through the check valve (5) at the bottom of the amplifier (4). If the MCM actuates the needle solenoid valve (6) then the fuel pressure in the control compartment above the injector needle (8) is allowed to escape through the injector needle return. The injector needle (8) is then lifted due to the rail pressure being greater than the needle spring (7) pressure combined with the reduction of pressure in the control department. The fuel is injected at the specified rail pressure into the respective cylinder. If the MCM deactivates the needle solenoid valve (6), the pressure in the control compartment above the injector needle (8) builds up again. The injector needle (8) is returned to its seat with the aid of the spring (7) and fuel system pressure. At this point the injection process stops.

Section 3.9.2
Injection with Amplification



1. Amplifier Control Module
2. Return Spring
3. High Pressure Feed
4. Amplifier
5. Check Valve
6. Needle Solenoid Valve
7. Spring
8. Injector Needle

Use of an amplifier (4) within an injector offers the following advantages:

- The leak oil losses in the high pressure area are reduced.

- The pressure load of the high pressure pump, the fuel rail, and the high pressure lines is reduced since only a few components have high pressure applied to them.
- During injection with amplification (3) the injection process is determined by actuation of the needle solenoid valve (6) and the amplifier control module (1) either at other times or simultaneously.

Actuation of the amplifier control module (1) before actuation of the needle solenoid valve (6) (Square)

The amplifier control module (1) is actuated before the needle solenoid valve (6). The rail pressure applied below the amplifier (4) is routed to the injector return passage inside the injector. This difference in pressure allows the amplifier (4) to move. The fuel within the amplifier circuit is compressed by the amplifier (4) piston up to a higher fuel pressure level (red). If the MCM actuates the needle solenoid valve (6) the fuel pressure in the control compartment above the injector needle (8) is allowed to escape through the injector needle return. The injector needle (8) is then lifted due to the rail pressure being greater that the needle spring (7) pressure.

The fuel is injected with the fuel pressure increased by the amplifier into the respective cylinder. The level of the fuel pressure is dependent on the point in time of the initial actuation of the amplifier control module (1). If the MCM deactivates the amplifier control module (1), the pressure in the control compartment under the amplifier (4) builds up and the amplifier (4) returns to its starting position. If the MCM deactivates the needle solenoid valve (6), the pressure in the control compartment above the injector needle (8) builds up again. The injector needle (8) is returned to its seat with the aid of the spring (7) and fuel system pressure. At this point the injection process stops.

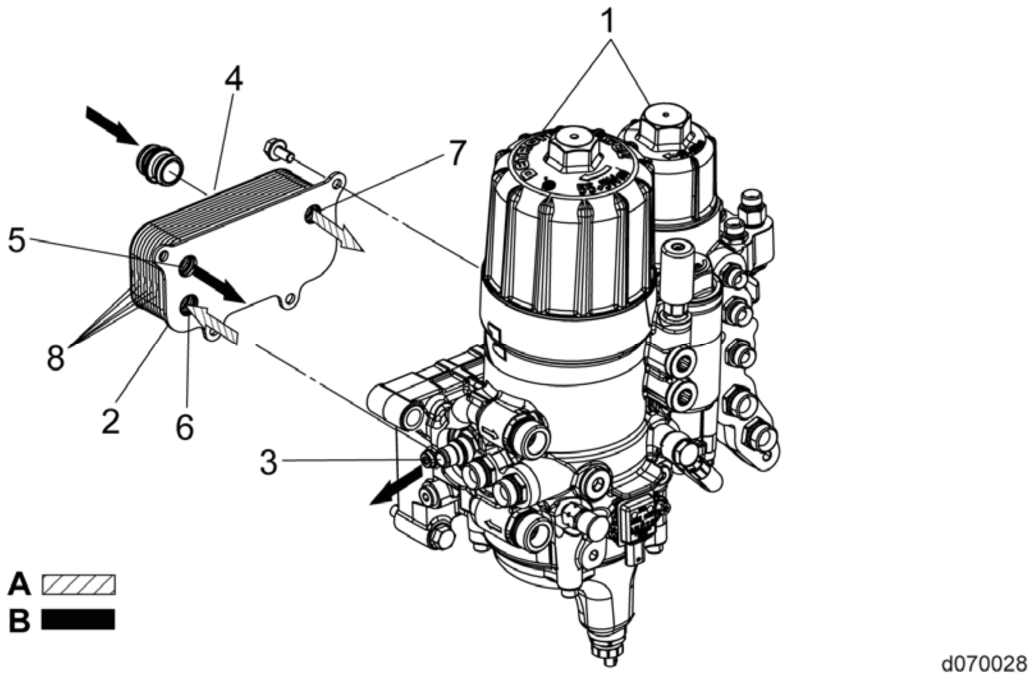
Actuation of the amplifier control module (1) parallel to actuation of the needle solenoid valve (6) (Ramp)

The amplifier control module (1) and the needle solenoid valve (6) are actuated at the same time by the MCM. The rail pressure applied below the amplifier (3) is routed to the injector return passage inside the injector. This difference in pressure allows the amplifier (3) to move. The injector needle (8) is lifted first by the rail pressure. Next, the fuel within the amplifier circuit is compressed by the amplifier (3) piston up to a higher fuel pressure level (red). Thus, during the complete injection phase the fuel pressure increases. If the MCM deactivates the amplifier control module (1), the pressure in the control compartment under the amplifier (3) builds up and the amplifier (3) returns to its starting position. The amplifier (3) goes back into its starting position. If the MCM deactivates the needle solenoid valve (6), the pressure in the control compartment above the injector needle (8) builds up again. The injector needle (8) is pressed onto its seat with the aid of the spring (7) and the injection process stops.

Actuation of the amplifier control module (1) after actuation of the needle solenoid valve (6) (Boot)

The MCM actuates the needle solenoid valve (6) to allow the fuel pressure in the control compartment above the injector needle (8) to escape through the injector needle return. The injector needle (8) is then lifted due to the rail pressure being greater than the needle spring (7) pressure. The fuel is then injected at the prescribed rail pressure.

After the beginning injection, the rail pressure applied below the amplifier (3) is routed to the injector return passage inside the injector. The fuel within the amplifier circuit is compressed by the amplifier (3) piston up to a higher fuel pressure level (red). If the MCM deactivates the amplifier control module (3), the pressure in the control compartment under the amplifier (3) builds up and the amplifier (3) returns to its starting position. If the MCM deactivates the needle solenoid valve (6), the pressure in the control compartment above the injector needle (8) builds up again. The injector needle (8) is pressed onto its seat with the aid of the spring (7) and the injection process stops.



1. Fuel Filter Module
2. Fuel Cooler
3. Coolant Outlet for Fuel Filter Module
4. Coolant Inlet
5. Coolant Outlet
6. Fuel Inlet
7. Fuel Outlet
8. Fuel Cooling ducts

A. Fuel Circuit
B. Cooling Circuit

The fuel cooler (2) is located behind the fuel filter module (1). The fuel cooler (2) cools the warmed fuel which comes from the injector amplifiers to the fuel filter module (1). The fuel cooler (2) is designed as a shell cooler. The warmed fuel from the injector amplifiers flows via the fuel inlet (6) through the fuel cooling ducts (8) to the fuel outlet (7). The cooled fuel then passes from there to the fuel filter housing and mixes with the colder fuel from the low pressure pump. The fuel cooler (2) is supplied coolant through a passage in the block. Coolant exits the fuel cooler and enters the fuel filter module (1) through an internal passage. From there the coolant exits (3) the fuel filter module and returns to the oil/coolant module.