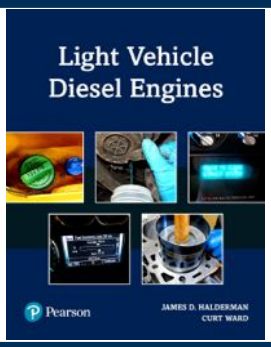
Light Vehicle Diesel Engines

First Edition



Chapter 13
High-Pressure Common Rail Diesel Fuel System

LEARNING OBJECTIVES (1 of 1)

13.1 Prepare for the Light Vehicle Diesel Engine (A9) ASE certification fuel system diagnosis and repair area "F" (Fuel System Diagnosis and Repair).

13.2 Describe the safety concerns related to working with high-pressure fuel systems.

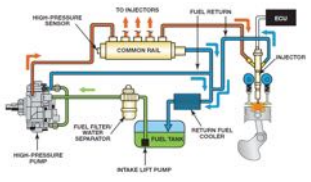
13.3 Identify the components of a high-pressure common rail injection system.

13.4 Discuss the operation of a high-pressure common rail injector.

13.5 Determine the need for service and repair of a high pressure common rail injection systems.

FUNCTIONS OF HIGHPRESSURE INJECTION SYSTEMS (1 of 3)

- **High Pressure Common Rail (HPCR)**
  - Introduced on light-duty diesel vehicles in 1990s
  - Emission standards became more stringent
  - Fuel economy expectations increased



FUNCTIONS OF HIGHPRESSURE INJECTION SYSTEMS (2 of 3)

- **HPCR REASONS**
  - Fuel must be injected with enough velocity
  - Mix with dense air mass
  - As pressure continues to climb, fuel distribution difficult.
  - At higher engine speeds, time available decreases
  - High pressure allows for adequate fuel distributed

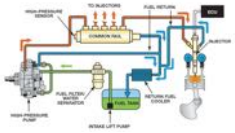


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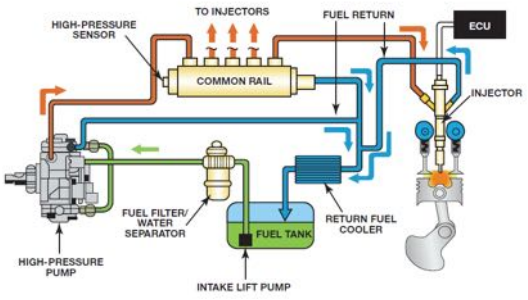
FIGURE 13–1 typical high-pressure common rail (HPCR) diesel fuel system.



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WARNING (1 of 2)

Duel system may be under extreme pressure 30,000 PSI (2,086 BAR). Do not open high pressure fuel system with engine running. Engine operation causes high-fuel pressure. High-pressure fuel spray can cause serious injury or death. SEE FIGURE 13–2.

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FIGURE 13–2 example of an under hood high-pressure fuel warning decal, warning of dangers related to system.

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FUNCTIONS OF HIGHPRESSURE INJECTION SYSTEMS (3 of 3)

- **ADVANTAGES OF COMMON RAIL: Page 142**
- **DISADVANTAGES OF COMMON RAIL: Page 143**

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HIGH PRESSURE COMMON RAIL INJECTION (1 of 6)

- **Common Rail/Tube: Figure 13-3**
  - Supply manifold used to store
  - Distribute pressurized fuel to each injector
  - Match the engine speed and load

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FIGURE 13–3 high-pressure common rail supplies the fuel injectors with the same fuel pressure and act as a pulse dampener as they operate.

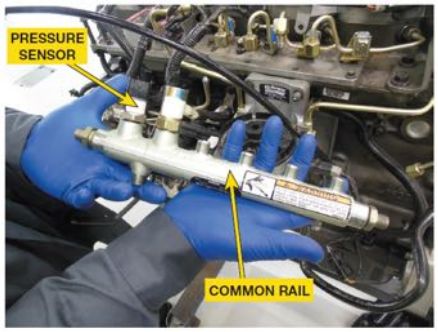

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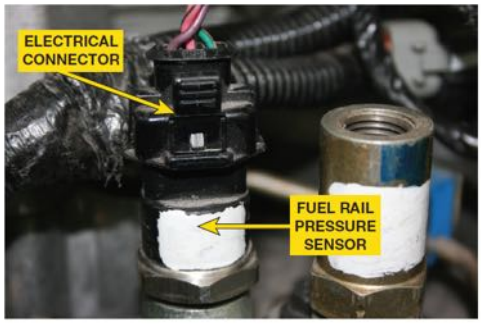
FIGURE 13–4 fuel rail pressure sensor provides feedback to the powertrain control module so the high-pressure fuel pump can operate most efficiently.



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HIGH PRESSURE COMMON RAIL INJECTION (2 of 6)

- **Fuel Rail Pressure Sensor**
  - Monitors fuel pressure in rail
  - Sends info to PCM
  - Uses info as part of calculation for desired fuel pressure
  - Piezo-resistive-type or variable capacitance type
  - Both supplied reference voltage & ground
  - Signal sent on third wire
  - Serviced separately, or part of common rail

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FIGURE 13–5 typical fuel rail pressure sensor wiring diagram.

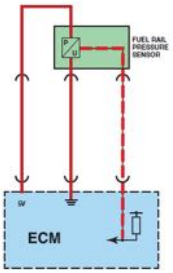

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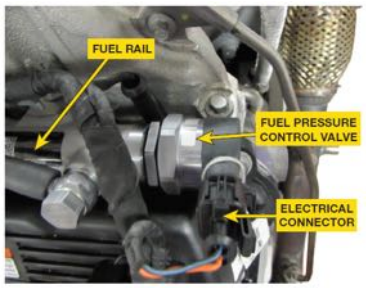
FIGURE 13–6 high-pressure common rail supplies the fuel injectors with the same fuel pressure, and acts as a pulse dampener as they operate.



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HIGH PRESSURE COMMON RAIL INJECTION (3 of 6)

- **Fuel Rail Temperature Sensor**
  - Located on fuel rail downstream in fuel system
  - Two-wire sensor with reference voltage & Return
  - Temperature has an effect on fuel viscosity

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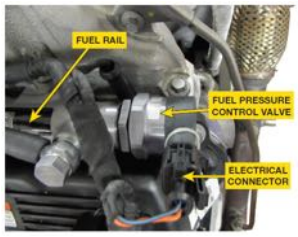
HIGH PRESSURE COMMON RAIL INJECTION (4 of 6)

- **Fuel Pressure Relief Valve/Fuel Pressure Control Valve**
  - Normally open, pulse width modified (PWM)
  - Along with volume control valve
  - ON high-pressure pump
  - **Regulates fuel rail pressure**



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HIGH PRESSURE COMMON RAIL INJECTION (5 of 6)

- **Fuel Injector Supply Lines Page 145**
- **Transfer Tubes Figure 13-7 Page 145**
  - **P0087 code for fuel rail/system pressure too low**
  - **P0093 for a fuel system large leak detected**
- **Return Lines Page 145**

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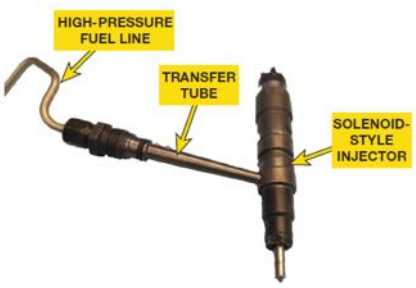
FIGURE 13–7 fuel line is threaded onto transfer tube. Transfer tube allows the fuel to flow to the injector. Components must be precisely oriented and torqued to ensure system is sealed properly.



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Case of the Loose Transfer Tubes (1 of 2)

REAL WORLD FIX

2010 Dodge Ram equipped with 6.7 liter Cummins diesel engine is in shop with rough running engine. Service history revealed vehicle had recently had injectors and connecting tubes replaced for a similar complaint. Inspection of work previously performed found the retaining nuts for #5 and #6 connecting tubes below the OEM torque specification. Re-torqueing retaining nuts to specifications eliminated rough running condition. System did not have any internal leaks, however, the under-torqued retaining nuts allowed air to be drawn into the high-pressure fuel system, creating rough running condition.

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Case of the Loose Transfer Tubes (2of 2)

REAL WORLD FIX

- **Summary:**
  - **Complaint** – The customer complained of a rough running engine.
  - **Cause** – The #5 and #6 transfer tube retaining nuts were under-torqued.
  - **Correction** – Re-torqued the transfer tube retaining nuts to specifications.

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HIGH PRESSURE COMMON RAIL INJECTION (6 of 6)

- **Return Lines**
  - May be in various locations
  - Based on high-pressure fuel system design
  - Small amounts of fuel returned from injectors
  - High-pressure pump, and the rail FIGURE 13–9.

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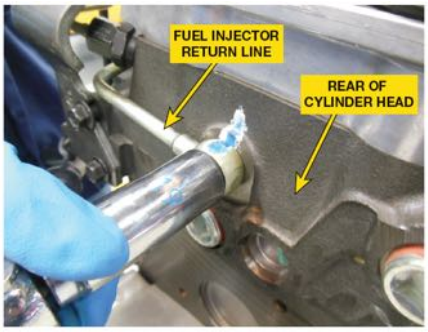
FIGURE 13–9 return line allows a small amount of fuel from the injectors and the high-pressure pump to be returned to the tank.



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HIGH-PRESSURE PUMP (1 of 5)

- **High-Pressure Pumps**
  - Developing pressure required for injection
  - Create enough volume
  - vary with some pump pistons configured
  - inline and others in a radial configuration
  - Older systems favor inline configuration
  - Newer systems radial configuration

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FIGURE 13–11 example of a multi-piston pump that uses a three-lobe cam as the actuator.

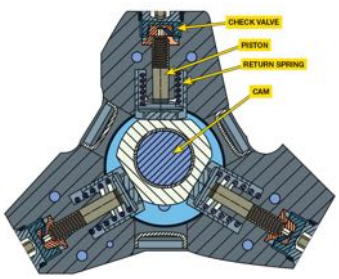

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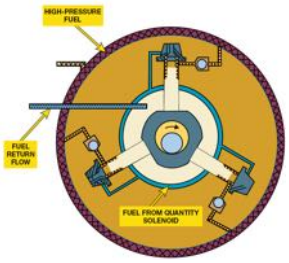
FIGURE 13–12 example of how fuel is fed into pumping chamber and how it is delivered under high pressure. The lubrication circuit is also depicted.



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HIGH-PRESSURE PUMP (2 of 5)

- **Single piston pumps in smaller displacement**
- **Multiple piston pumps on larger displacement**
  - Driven by camshaft or crankshaft gear
  - Timed for purpose of fuel delivery or vibration
  - Each high-pressure pump piston
    - Compressed by an eccentric cam
    - Return facilitated by return spring
    - Piston chamber has inlet & outlet check valve
    - Controls the flow of fuel into the cylinder

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HIGH-PRESSURE PUMP (3 of 5)

- **High-pressure Pump**
- **Depending on Design, House:**
  - Fuel Quantity Solenoid,
  - Volume Control Valve
  - Electronic Fuel Control Actuator,
  - Cascade Overflow Valve
    - Regulate Amount Of Fuel Through Pump
    - Minimize Parasitic Losses

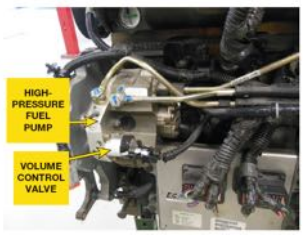

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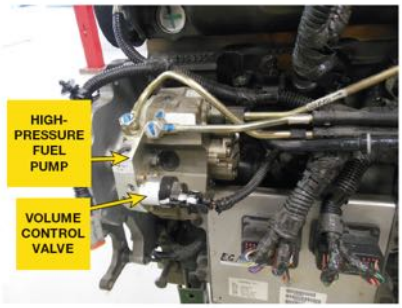
FIGURE 13–13 volume-control valve (Fuel Pressure Control Valve) meters fuel from low-pressure system into high-pressure pump to minimize parasitic loss.



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HIGH-PRESSURE PUMP (4 of 5)

- **Volume Control Valve**
  - **Fuel Pump Actuator or Fuel Quantity Solenoid**,
  - Normally open, PWM controlled fuel volume
  - From low-pressure system into high-pressure pump
  - PCM controls operation of volume control valve
  - Reduce/increase fuel amoun
  - Absence of signal valve defaults to wide open

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HIGH-PRESSURE PUMP (5 of 5)

- **Cascade Overflow Valve**
  - Regulates fuel pressure to volume control valve
  - Diverts excess fuel back to tank
  - Via low-pressure return system

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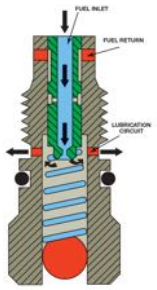
FIGURE 13–14 cascade overflow valve is a serviceable component of the high-pressure pump that determines flow rate and allows for lubrication of internal pump components.



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COMMON RAIL INJECTOR (1 of 4)

- **Meet Injection Requirements Of Diesel Engine**
  - Number of manufacturers
  - Fall into one of two designs:
    - **1. Solenoid Controlled**
    - **2. Piezoelectric Actuated**

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COMMON RAIL INJECTOR (2 of 4)

- **Deliver fuel to meet torque and horsepower**
- **Deliver clean tailpipe emissions**
  - Range 19,000 to 23,000 PSI (13,000 to 159,000 kPa)
  - Versions delivered fuel at pressures that exceed
  - 35,000 PSI (240,000 kPa).

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COMMON RAIL INJECTOR (3 of 4)

- **Solenoid Injector**
  - Uses electromagnetic field generated by solenoid and
  - Hydraulic pressure of fuel to open and close injector

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COMMON RAIL INJECTOR (4 of 5)

- **Piezoelectric Injectors**
  - Require electrical current, high-pressure fuel
  - Reversed electrical current to inject fuel
  - Solenoid replaced with stack of piezo ceramic discs
  - Changes shape when electrical current introduced

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COMMON RAIL INJECTOR (5 of 5)

- **Piezoelectric Injectors**
  - When energized, piezo stack becomes shorter
  - Reduces hydraulic pressure on top of nozzle valve
  - Allows injector to open and fuel be delivered.
  - Piezo stack de-energized, stack returns to original height,
  - Closes hydraulic leak, allowing pressure to equalize

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CHART 13-1 type of fuel injector used, sorted by manufacturer and model year.

DIESEL INJECTOR–SOLENOID VERSUS PIEZOELECTRIC

Manufacturer and Engine	Type
Ford	
2008–2010 6.4 liter Powerstroke	Piezoelectric
2011–Current 6.7 Liter Powerstroke	Piezoelectric
Nissan	
2016–Current 5.0 liter Cummins	Piezoelectric
Dodge/Fiat	
2003–2007 5.9 liter Cummins	Solenoid
2007.5–Current 6.7 liter Cummins	Solenoid
2014–Current 3.0 liter Ecoboost	Solenoid
Chevrolet/GMC	
2001–2010 6.6 liter Duramax	Solenoid
2011–2016 6.6 liter Duramax	Piezoelectric
2017–6.6 liter Duramax	Solenoid

CHART 13–1

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FIGURE 13–15 Sequence of a solenoid high-pressure common rail injector going through an injection cycle.

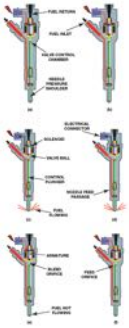

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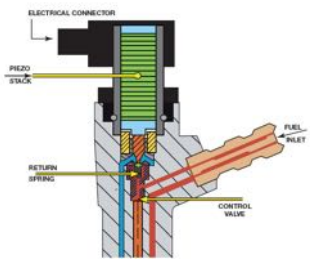
FIGURE 13–16 Sequence of piezoelectric high-pressure common rail injector going through a fuel cycle.



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POWERTRAIN CONTROL MODULE (1 of 2)

- **Contains Driver Circuits Needed**
  - Operate HPCR rail injector
  - May contain DC-DC converter
  - Step up system voltage to operate injectors
  - Voltage as high as 250 volts
    - 19 amps
  - Monitors operation of injectors
  - Store codes
  - Freeze frame data if failure occurs

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FIGURE 13–17 powertrain control module contains driver circuits and DC-DC converter needed to operate injectors.

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POWERTRAIN CONTROL MODULE (2 of 2)

- **DC-to-DC Converters**
  - Transform DC voltage from one lev of DC voltage to another higher or lower level
    - Converts 14 volts to 5 volts V-Ref
    - Transformer isolates input (42 V) from output (14 V)
      - Power transistor pulses high-voltage c of transformer
      - Resulting changing magnetic field induces voltage in coil windings of lower-voltage side of transformer

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FIGURE 13–18 DC-DC converter in this example is used to create the 5 volts used for the v-reference signal.

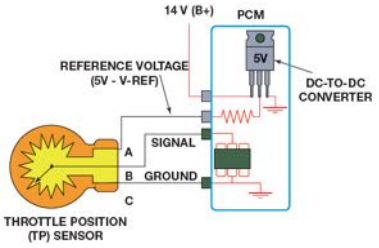

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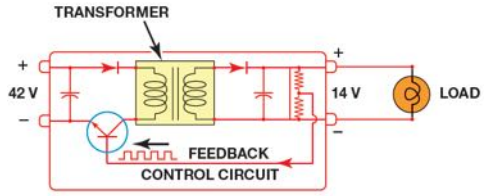
FIGURE 13–19 DC converter is used to convert system voltage (14 volts) to the 42 volts needed for operation.



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HIGH-PRESSURE COMMON RAIL (HPCR) FUEL SYSTEM SERVICE PROCEDURES (1 of 2)

- **Many Fuel & Air Management System OEMS**
  - Kits that provide caps and covers
  - For fuel and air management systems that
  - Open due to testing by service technician

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FIGURE 13–20 Cummins Clean Care kit. Kit is used to seal air management system during testing.

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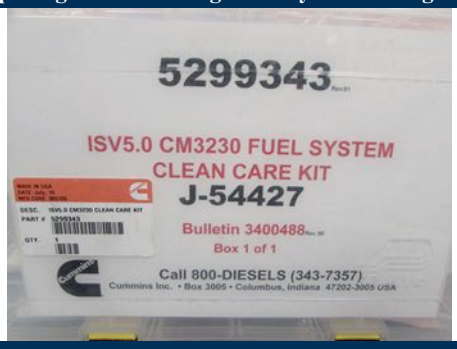
FIGURE 13–21 Cummins Clean Care kit. Kit is used to seal openings in fuel management system during testing.



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Case of High-Pressure Fuel System Components Failure (1 of 3)

REAL WORLD FIX

2012 Ford with a 6.7 liter Power Stroke diesel engine in the shop with complaint of being hard to start and running rough. MIL illuminated. DTC P1292 (injector shorted to voltage or ground) found. A test of the high-pressure fuel system return volume to tank revealed an amount above specifications. It was determined that the high-return volume was a result of internal wear in the numerous injectors. Further investigation revealed that the wear was due to fuel contamination by DEF) The presence of DEF in the injectors was also responsible for the P1292 code. DEF crystals were found in the primary fuel filter. To correct the condition, fuel system was cleaned, the fuel filters were replaced, and all eight injectors were replaced per the Ford Technical Service Bulletin # 11-10-10.

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Case of High-Pressure Fuel System Components Failure (2 of 2)

REAL WORLD FIX

- **Summary:**
  - **Complaint** – The customer complained vehicle was hard to start, the engine ran rough, and the MIL was illuminated.
  - **Cause** – The failure was a result of diesel exhaust fluid (DEF) in the fuel system.
  - **Correction** – Per the Ford TSB #11-10-10, fuel system was cleaned, the fuel filters were replaced, and all eight injectors were replaced.

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WARNING (2 of 2)

Duel system may be under extreme pressure 30,000 PSI (2,086 BAR). Do not open high pressure fuel system with engine running. Engine operation causes high-fuel pressure. High-pressure fuel spray can cause serious injury or death.

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HIGH-PRESSURE COMMON RAIL (HPCR) FUEL SYSTEM SERVICE PROCEDURES (2 of 2)

- **High-Pressure Fuel System Leaks**
  - Difficult & dangerous to locate
    - Diagnostic Process #1: Many manufacturers' instructions recommend using a piece of cardboard to find the fuel leak
    - Diagnostic Process #2:dye should be added to fuel system.

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FIGURE 13–22 Fuel system fluorescent dye is readily available. In many cases, the dye can be used for more than one system.

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FIGURE 13–23 Using a black light, fluorescent dye is visible at the location of high-pressure fuel leak.

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Case of High-Pressure Fuel System Components Failure (2 of 3)

REAL WORLD FIX

2012 Ford with a 6.7 liter Power Stroke diesel engine in the shop with complaint of being hard to start and running rough. MIL illuminated. DTC P1292 (injector shorted to voltage or ground) found. A test of the high-pressure fuel system return volume to tank revealed an amount above specifications. It was determined that the high-return volume was a result of internal wear in the numerous injectors. Further investigation revealed that the wear was due to fuel contamination by DEF) The presence of DEF in the injectors was also responsible for the P1292 code. DEF crystals were found in the primary fuel filter. To correct the condition, fuel system was cleaned, the fuel filters were replaced, and all eight injectors were replaced per the Ford Technical Service Bulletin # 11-10-10.

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Case of High-Pressure Fuel System Components Failure (3 of 3)

REAL WORLD FIX

- **Summary:**
  - **Complaint** – The customer complained vehicle was hard to start, the engine ran rough, and the MIL was illuminated.
  - **Cause** – The failure was a result of diesel exhaust fluid (DEF) in the fuel system.
  - **Correction** – Per the Ford TSB #11-10-10, fuel system was cleaned, the fuel filters were replaced, and all eight injectors were replaced.

Case of the Multiple Injector Washers (1 of 2)

REAL WORLD FIX

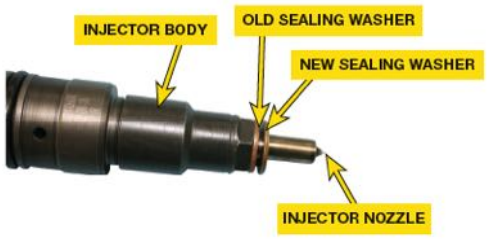
2009 Dodge Ram with 5.9 liter Cummins in the shop with a complaint of hard to start and lack of power on acceleration. The vehicle had all 6 injectors replaced recently at another shop. A test of fuel return volume indicated an abnormally high return volume. After removing all six of the previously installed injectors, the number five injector was found to have 2 sealing washers at the tip. One of the washers was new and the other washer was original to the engine and was not removed when the injector was replaced. The additional washer caused damage to the new injector and the cylinder head. Both the cylinder head and the new injector had to be replaced to solve the customer concern: **FIGURE 13-24**

Case of the Multiple Injector Washers (2of 2)

REAL WORLD FIX

- **Summary:**
  - **Complaint** – customer complained vehicle was hard to start and lacked power on acceleration
  - **Cause** – number five replacement injector was installed with two sealing washers (the original and replacement), causing damage to the cylinder head and the injector
  - **Correction** – cylinder head and the injector were both replaced

FIGURE 13–24 failure to install injector with its sealing washers properly can lead to leakage and system performance problems.



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HIGH-PRESSURE COMMON RAIL (HPCR) FUEL SYSTEM SERVICE PROCEDURES (3 of 3)

- **Injector Replacement**
- **Injector Quantity Adjustment**
  - Many HPCR injectors have injector classification code
  - Assigned to them at time of manufacturing.
    - SEE FIGURE 13–25
- **HP Pump Replacement Page 154**
  - **CAUTION: When servicing high-pressure fuel system components, refer to service information for correct reuse policy. Many components must be replaced and cannot be reused even when no visible damage is noted.**

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FIGURE 13–25 calibration code must be programmed into PCM when injector is replaced. The calibration allows PCM to make the proper adjustments to fuel delivery of that cylinder, resulting in smoother operating engine.

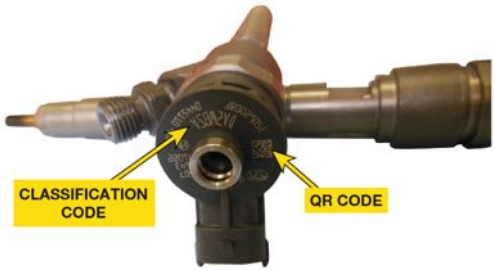

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FIGURE 13–26 scan tool shows the list of calibration codes that are programmed into the powertrain control module for that vehicle. A technician can compare those values to the actual injectors to ensure they were properly programmed.

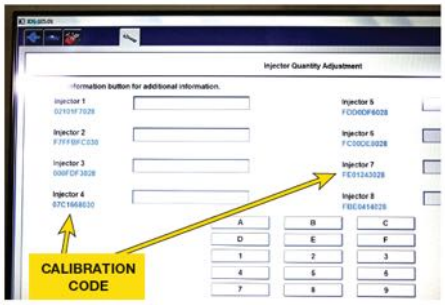

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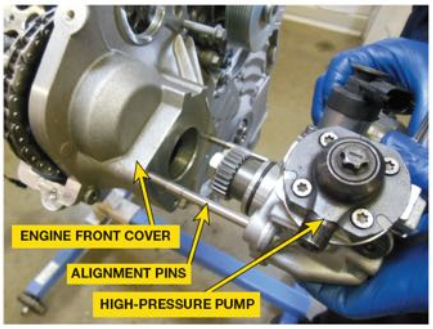
FIGURE 13–27 pump and its gear are aligned with cam gear to ensure there are no abnormal engine vibrations in engine as pump generates high rail pressures.



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What Is Needed to Install a New High-Pressure Pump?

FREQUENTLY ASKED QUESTION

Many OEMS require specific tools used in process. Special tools include index tools, alignment pins, degree wheels, and more. Camshaft & crankshaft position will need to be verified & pump will need to be positioned properly prior to installation. Failure to follow procedure may result in low or no fuel pressure or vibration.

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How Do I Inspect the Pump-Line-Nozzle (PLN E) Fuel Systems on Older Diesel Engines?

FREQUENTLY ASKED QUESTION

Pump-line-nozzle (PLN-E) systems are found on older diesel engines where fuel delivery was timed to engine speed. Most OEMS used a nozzle pop-tester to determine if nozzle opened at correct pressure and a traditional pressure gauge was used to measure fuel pressure. Refer to the OEM service information

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FIGURE 13–28 A typical pop tester used to check the spray pattern of a diesel engine injector.

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QUESTION 1

- What are the components in a typical high-pressure common rail injection system?

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ANSWER 1

- Components that are mounted on the common rail tube are the pressure relief, or pressure control valve, the fuel pressure sensor, the injector supply lines, and the return line.

Summary (1 of 2)

- The high-pressure fuel system is responsible for receiving the fuel from the low-pressure system and injecting it into the combustion chamber.
- High-pressure common rail (HPCR) fuel systems were introduced on light-duty diesel vehicles in the early 1990s as diesel emission standards began to become more stringent and fuel economy expectations increased.
- Components that are mounted on the common rail tube are the pressure relief, or pressure control valve, the fuel pressure sensor, the injector supply lines, and the return line.

Summary (2 of 2)

- The high-pressure pump is responsible for developing the pressure required for injection under all operating conditions. They create enough volume so that when they are subjected to the normal system restrictions, they create adequate pressure. High-pressure pump applications vary with some pump pistons configured inline and others in a radial configuration.
- Although there are a number of manufacturers of high pressure common rail injectors, they fall into one of two designs: Solenoid controlled & Piezoelectric actuated
- Dirt and debris that enters the fuel system and the air induction system are the root cause of many high-pressure fuel system failures.