Chapter 19 - Common Rail High Pressure Fuel Injection Systems

Diesel Engine Technology For Automotive Technicians

Understanding & Servicing Contemporary Clean Diesel Technology
What is Common Rail?

Bosch Common Rail System for Passenger Cars

1. Air mass meter
2. Engine ECU
3. High pressure pump
4. Common rail
5. Injectors
6. Engine speed sensor
7. Coolant temp. sensor
8. Filter
9. Accelerator pedal sensor

Common rail fuel systems represent the most recent technological achievements in clean diesel engine fuel injection technology.
Conventional Fuel System
Disadvantage

- Camshaft actuated fuel systems plunger velocities are low at slow engine speeds. Poor pressurization and atomization results.
- Timing and rate control are fixed in camshaft geometry.
What is Common Rail?

CR pressurizes fuel *independently* of engine speed. Availability of high fuel pressure over all engine speeds = *Lower emissions, improved power and fuel economy!*

Common rail fuel systems pressurize fuel independently of engine speed.
What is Common Rail?

- A variety of subcategories of common rail fuel systems exist.
- Generally, common rail refers to a fuel rail system which supplies fuel at injection pressure to all injectors.
Common Rail – Features

- High-pressure common rail supplies fuel at injection pressure to injectors
The latest high pressure common rail systems are capable of different injection events in one combustion cycle.
Common Rail Advantages - Injection Rate Shaping

- The quantity of fuel injected per degree of crank angle rotation is referred to as the fuel rate.
- Injection rate affects emissions, performance, fuel economy and even engine noise levels.
- A specific injection rate will correspond to any given engine speed and load condition as well as operating condition (i.e. oil, fuel and air temperature, boost pressure etc..)
Common rail systems have the flexibility to meet the highest requirements for a fuel injection systems – high pressure, short injection duration, rate shaping and precise metering capabilities.
Common rail has the capability to inject fuel very late during the power stroke or exhaust stroke.

The fuel is used to raise the temperature of the filter during active regeneration. (Burning away trapped soot)
Common Rail - Components

All common rail systems have the following parts in common:

- Injectors
- High pressure pump
- Fuel rail
- Relief valve
- Rail pressure sensor
- Fuel pressure regulator
This 3-cylinder CR diesel used in the MB Smart car achieves 4.2L/110km combined fuel mileage. (56-mpg US)
Common Rail – Typical Fuel Circuits

- High Pressure Common Rail
- Fuel Rail Pressure Relief Valve
- High Pressure Connectors
- Cylinder Head
- Injectors
- Fuel Return
- Fuel Out
- Fuel Tank
- Hand Primer Pump
- Primary Filter
- Secondary Filter
- Fuel Gear Pump
- H.P. Fuel Pump
- High Pressure Fuel Line to Rail
- ISB CM2150 Engine

CR Injectors

Technical development common rail for passenger cars

- High pressure common rail is a recent innovation.
- The technology did not exist to switch fuel injection on and off at pressures exceeding 20K-psi at the speeds required for combustion.
CR Injectors - Types

These DMAX injectors represent the two types of CR injectors.

1. Electromagnetic solenoids
2. Piezoelectric inline actuators
CR Injector Comparisons

Common Rail Injectors with Magnetic Actuators and Piezo Actuators

Advantages of Injectors with Piezo Actuators

- More flexible injection strategies
- Very small pilot-injection quantities
- Flexible start of injection and injection pause
- Compact design

BOSCH
CR Injectors – Solenoid Type

Solenoid injectors use an electromagnet to control injection events.
Solenoid CR Injection

- Injection events are triggered electrically but the main actuation forces are hydraulic.

- The solenoid armature is a pilot needle valve which controls the flow of fuel out of a pressure chamber above the needle valve.
Solenoid CR Injection Sequence

- Important note – high pressure fuel (yellow) holds the nozzle valve against its seat.

Pressure above the needle valve is slightly greater than below so injection cannot take place.
Solenoid CR Injection

1. The injector at rest

High pressure fuel is at the bottom and top of the needle valve but no injection takes place since the larger surface area on top of the needle valve hold the nozzle against its seat.
2. Injection

The solenoid is energized and lifts the pilot needle or check ball from its seat above the needle valve.

Fuel pressure above the needle valve drops and fuel pressure below the valve forcing the nozzle from its seat.

Fuel cannot fill the chamber above the needle valve quickly since there is a restriction in the passageway between the rail pressure fuel and pressure chamber.
Solenoid CR Injection

3. End of Injection

The solenoid is de-energized and the check ball return to its seat.

Fuel at rail pressure builds-up quickly above the needle valve forcing it against it’s seat thus ending injection.
Adaptive Cylinder Balance

This 2004 6.6L DMAX engine is adjusting fuel rate at idle to each injector to enable smoother engine operation.
Pilot Injection

Note pilot injection factors are variable for CR engines. Unlike HEUI and other fuel systems where pilot injection is mechanical, CR engines it is achieved electronically – *microseconds in duration!* (2004 6.6L DMAX)
Piezo-electric Actuated Injectors

- Piezo technology enables the fastest switching time for injectors currently allowing up to seven injection events in one injection sequence.

- The mass of the inline actuators is less than solenoid actuated injectors
Piezo-electric Actuated Injectors

- Comparisons of injector response time (top solenoid, bottom piezo-electric actuation.
Piezo-electric injectors can achieve lower emission reduction with improved rate shaping and multiple injection events.
Piezo-electric Principles

- Piezo crystals expand when current is applied to a stack of crystals and contract when the current's polarity is reversed.
- Note the change in current direction and the shape of the crystals.
Piezo-electric Principles

Stacks of piezo crystals deform when energized with electrical current.

Piezo crystals respond much faster than electromagnetic solenoids.
Piezoelectric actuators operate a servo valve to change hydraulic pressure acting on the needle valve holding the nozzle closed.
2008MY Ford 6.4L Powerstroke Diesel uses piezo electric actuated CR injectors manufactured by Siemens
Piezo-electric CR Injection Sequence

The Ford nozzle has a conventional type of nozzle.
Piezo-electric CR Injection Sequence

- Like solenoid type CR injectors, in a piezo injector the nozzle needle valve is held in place by hydraulic force of pressurized fuel.
- A mushroom shaped valve controls the exit of fuel pressure above a control piston holding the needle valve on its seat.
Piezo-electric CR Injection Sequence

- High pressure fuel forces the control piston against the needle valve
Piezo-electric CR Injection Sequence

Applying current to the piezo crystals forces the mushroom valve downward releasing pressure above the control piston to the lower pressure fuel inlet.

Fuel pressure below the needle valve force the valve upwards and injection begins.
The injection event can end quickly by changing the direction of current flow through the stack of piezo crystals.

Without pressure from the piezo crystals, hydraulic force closes the mushroom valve and pressure returns to the top of the control piston.
Hydraulically Amplified CR Injectors

Hydraulically Amplified Diesel Injector (HADI)

**Injector Characteristics**
- System pressure up to 1.350 bar
- Pressure amplification ≈1:2
- Pressure at the nozzle up to 2.200 bar
- Pressure/lift controlled needle
- Ramp rate shape
- Space requirements as CR12
- Conventional nozzle

Current heavy-duty diesel are using hydraulically amplified CR injectors.

These injectors use an internal amplifier/intensifier piston similar in principle to HEUI injectors.
Co-Axial Nozzle CR Injectors

Piezo-Injector with Coaxial-Vario-Nozzle CRI4-PV

- Basis: CRI3
- System pressure 1600/1800 bar
- Space requirement as CRI3
- One row for part load
- Both rows for full load

- Two rows of spray orifices are used in a co-axial nozzle to achieve more sophisticated rate shaping of injection
CR Injectors are very sensitive to dirt.

The smallest particle of dirt causing a solenoid or mushroom valve to stay open could allow the injector to continuously inject fuel.

This overheated cylinder which damaged valves was caused by an injector “stuck open”.

CR Injector Failure
The injector and lines on the 2006 6.6L DMAX engine are all located outside the scalloped valve covers to prevent fuel leaks into the engine.
CR Injectors – Lines

These Cummins B series injectors use a quill tube to connect an external injector line with the injector.

These tubes must be carefully tightened and the high-pressure connection cleaned during assembly to prevent leakage!
This early 6.6l DMAX has line fitting clamps to prevent loosening and leakage of lines.
Never crack-open a high pressure line when running an engine. Cylinder misfires cannot be detected and high pressure fuel can penetrate the skin.
Ford Duratorq I-4 CR Engine

- The hugely popular European Ford TDCi 2.0L Duratorq engine (Ford Galaxy van shown)
CR Injector Trim Codes

- Characteristics of CR injectors cause fuel delivery variations over a wide range of operation (pressure & actuation time)

![Graph showing injected fuel quantities at different injection pressures]

- Injected fuel quantities at different injection pressures:
  - a 1,500 bar
  - b 1,200 bar
  - c 1,000 bar
  - d 800 bar
  - e 250 bar
CR Injector Trim Codes

Trim codes or injection quality adjustment (IQA) codes for each injector are entered in the ECM module and used to compensate for delivery quantity variations.
High pressure pumps take low transfer fuel pressure and pressurize the fuel to the for injection.
A Bosch CP-3 Pump is commonly used in automotive applications.
High Pressure Pumps

Bosch CP-3 High Pressure Pump

Fuel Return
Fuel Inlet
Fuel Pressure Regulator
High Pressure Pumps

Location of the high-pressure pump on a 2007 6.6L DMAX
High Pressure Pumps

- Rear geartrain mounted pump of the 6.7L Cummins diesel
High Pressure Pumps

Location of the high pressure pump on the 2008MY Powerstroke
Radial plunger pumps use three lobed cams to driven by the engine to pressurize fuel.

Check valves in the end of the plunger pistons operate to control flow of fuel in and out of the pumping chambers.
A fuel pressure regulating valve controls fuel pressure using a PWM signal sent from the ECM.

With no signal, all pressurized fuel is sent to the fuel rail.

Increasing the PWM signal lowers fuel pressure to the rail.
High Pressure Pumps – Pressure Regulation

Note the duty-cycle reported for the fuel pressure regulator (35%)

Fuel temperature is calculated through ECM measurement of the resistance of the pressure regulator coil.
To reduce parasitic power loss some pumps such as used on the Powerstroke regulate the amount of fuel admitted into the pump using a volume control regulator.
The fuel rail is common to several cylinders.

Internal orifices dampen pressure pulses
This Ford Dura-torque diesel uses a circular shaped fuel rail (Delphi) for packaging reasons.
To protect the high pressure system from over pressurization a pressure limiting valve is used in the high pressure section.
Pressure Protection

The function block on this DMAX contains the pressure limiting valve.