Welcome
to a technical overview of
Common Rail Diesel Fuel Systems

presented by
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Foreword

Tony Kitchen (AK Training) offers professional technical courses for those working in the motor industry wanting to improve their knowledge and skills and who are serious about personal development. Courses are based upon 25 years practical experience and extensive hands on technical knowledge of subject matter (not possible to obtain from reading a book or watching a CD)!

A comprehensive programme of courses is available from AK Training. Courses run from regular venues in the Milton Keynes, Northampton and Buckingham area. Courses can also be delivered on site at clients premises anywhere in the UK. Overseas training services are also available. This presentation forms the basis for a generic common rail diesel course which is now undergoing development and will be available in the near future.

For further information about courses, course dates, fees, venues and all other enquiries including on site and overseas training, please contact AK Training direct. In the meantime, please enjoy the following presentation for your technical information.

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Aims, objectives and disclaimer:

The aim of this presentation is to give a generic technical overview of the main features and operating principles of the common rail diesel fuel injection system. The objectives are that by the end of this presentation, you will have gained a working knowledge and understanding of the fundamental principles of common rail diesel fuel systems.

Please bear in mind that all facts and figures quoted are intended to show typical examples only for explanation purposes. Always refer to manufacturer technical data for exact system specifications and repair procedures.

Finally this slide show does not include speaker notes. If you have any comments or would like further information, please contact AK Training directly.
Common Rail Diesel Fuel Systems

Advantages of common rail:

- Fuel pressure available on demand.....
- Higher injection pressures and finer atomization of fuel.....
- Injection pressure created independent of engine speed.....
- Multiple injections per cylinder combustion are possible.

Benefits of common rail:

- Reduction of overall exhaust emissions.....
- Reduction of particulate emissions.....
- Reduction of noise emissions.....
- Improved fuel efficiency.....
- Higher performance.
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Examples of typical common rail system maximum fuel pressures:

- **Bosch:**
  - Generation 1: up to 1350 Bar (19845 psi). Unijet
  - Generation 2: up to 1600 Bar (23520 psi) EDC 16
  - Generation 3: up to 2000 Bar + (29400 psi)

- **Denso:**
  - 1st generation: up to 1450 Bar (21315 psi) ECD-U2P
  - 2nd generation: 1800 Bar + (26460 psi) HP3/HP4

- **Delphi**
  - Multec: up to 2000 Bar
  - Direct acting diesel common rail system: up to 2000 Bar

Various systems differ in design, components layout and specific functions. However, all operate in a similar way.
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The fuel system can be divided into three basic circuits:

- Low pressure supply circuit
- High pressure delivery circuit
- Fuel leak back and return

Example: Bosch EDC16
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Components overview (example: Bosch EDC 16)
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High pressure fuel pump

The High pressure pump is the interface between the low pressure and the high pressure side of the fuel system.

Basic function:
To ensure that enough fuel is delivered at sufficient pressure across the engine’s entire operating range. This includes delivery of sufficient fuel for a rapid engine start and pressure increase in the rail.
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High pressure fuel pump

Example: Bosch CP3

The pump has several pumping chambers
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High pressure fuel pump

1: Pressure valve
2: Suction valve
3: Low pressure (yellow)
4: High pressure (red)

Pumping chamber
Transfer pump
Fuel metering valve
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High pressure fuel pump

Transfer pump supplies fuel from the fuel tank to the pumping chambers of the high pressure pump.

Fuel metering valve regulates the fuel intake volume to the pumping chambers of the high pressure pump.
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High pressure fuel pump

3 pumping pistons are operated by a polygon ring on an eccentric cam on the pump shaft.
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High pressure fuel pump

As the pump rotates, the polygon ring moves in a circular motion to operate the pump pistons.
An electric pre supply pump in fuel tank may be used instead of a transfer pump. Some systems may use a combination of electric pump and transfer pump.
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Fuel metering control valve

- Located at back of high pressure pump.
- Controls the fuel intake volume to the pump.
- Receives battery voltage supply from engine ECM.
- Energized by ECM via negatively triggered PWM.
- Operating frequency: approximately 180Hz.

Example: Bosch CP3
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Fuel metering control valve

When solenoid de energized, valve is open
= **LOW** fuel volume intake to pump.

When solenoid energized, valve is closed
= **HIGH** fuel volume intake to pump.

The fuel volume intake is controlled as follows.....
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Fuel volume intake control

1. Pump piston
2. Pressure valve
3. to common rail
4. Suction valve
5. Return
6. Safety valve
7. Feed (from the tank)
8. Gear pump
9. Fuel metering control valve
10. Throttle bore
11. Control piston
12. Lubricating-oil bore
13. High-pressure pump

Valve de energized OPEN
More fuel returns to tank
LOW fuel volume to pump
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Fuel volume intake control

1  Pump piston  
2  Pressure valve  
3  to common rail  
4  Suction valve  
5  Return  
6  Safety valve  
7  Feed (from the tank)  
8  Gear pump  
9  Fuel metering control valve  
10  Throttle bore  
11  Control piston  
12  Lubricating-oil bore  
13  High-pressure pump

Valve energized **CLOSED**
Less fuel returns to tank
**HIGH** fuel volume to pump
Advantages of fuel intake volume regulation:

- Only the required volume of fuel is supplied to the common rail from the high pressure pump.....

- Reduced fuel flow around system results in lower fuel return flow temperature.....

- Reduced parasitic load on engine from high pressure pump contributes towards further reductions in exhaust emissions.
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Fuel metering control valve failure symptoms and diagnosis

Solenoid circuit monitored by engine ECM. If an open or short circuit is detected:

**Engine stops or will not start.**
**DTC stored and MIL illuminated.**

Mechanical failure of the metering control valve does not necessarily prevent the engine from starting.

Mechanical faults can cause DTC’s relating to positive or negative rail pressure deviations.
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High pressure regulator valve

System variant.

Fitted to back of HP pump.

Controls high pressure fuel delivery to common rail.

Excess fuel returns to tank.

Fuel cooler required to cool return fuel flow.

Low pressure fuel inlet (from fuel tank)

Fuel return (to fuel tank)

High pressure fuel delivery to common tail

High pressure fuel delivery to common tail

High pressure regulator valve
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High pressure accumulator (common rail)

Fuel is supplied to the common rail at high pressure from the high pressure pump.

The rail stores the fuel and distributes it to the individual injectors.

It also damps pressure vibrations caused by the high pressure pump and injection processes.

Typical volume of fuel held in common rail: 16 – 20cm³.
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High pressure accumulator (common rail)

Typical fuel rail pressure with engine **idling** and at running temperature:
approximately between 300 – 400 Bar (4410 – 5880 psi)

Typical maximum possible fuel rail pressure:
approximately between 1600 – 2000 Bar (23520 – 28400 psi)
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High pressure accumulator (common rail)

Typical fuel rail pressure with engine **idling** and at running temperature:
approximately between 300 – 400 Bar (4410 – 5880 psi)

**Health and safety**

Due to the extremely high working fuel pressures in the common rail fuel system, **NEVER** slacken fuel or injector pipes or try to disconnect components of the fuel system whilst the engine is running and high pressure is present in the system!

Typical maximum possible fuel rail pressure:
approximately between 1600 – 2000 Bar (23520 – 28400 psi)
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Fuel rail pressure sensor

A fuel rail pressure sensor is located on the fuel rail.
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Fuel rail pressure sensor

Monitors the fuel pressure in the common rail.

Typically a piezo resistive type sensor.

Three wires:
- 5 Volt supply from engine ECM.
- Sensor ground via engine ECM.
- Linear signal voltage output to ECM.

Signal utilization:
To enable the engine ECM to determine the fuel rail pressure.....
Used by the ECM as part of the calculation for the % duty cycle applied to the rail pressure control solenoid and fuel metering solenoid.
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Fuel rail pressure sensor

The engine ECM applies a stabilized 5 Volts supply to the signal wire of the fuel pressure sensor.....

The resistive value of the sensor creates a change in the voltage on the signal wire relative to the fuel rail pressure.
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Fuel rail pressure sensor

Signal voltage
(0 - 5V)

5 Volts supply
from ECM

Sensor ground
(<0.2 Volts)

Piezo crystal
sensor

Pressure

Typical signal voltages from rail pressure sensor:

- Engine stationary: approximately 0.5 volts.
- Engine idling: approximately 1.32 volts.
- Snap acceleration: approximately 3.77 volts +

(Example figures Bosch EDC16).
A mechanical pressure limiter valve is fitted to some systems. It is located at the end of the fuel rail. Its function is to relieve rail pressure if abnormally high system pressure is generated.
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Rail pressure limiter valve

If excessive fuel pressure is generated, the valve opens a fuel return port.

Excess fuel is relieved back to the fuel tank.
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Rail pressure limiter valve

Example operating pressure of rail pressure limiter valve (Denso HP3 system):

valve opens at 230 MPa (2300 Bar)
valve closes at 50 MPa (500 Bar)
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Fuel rail pressure control valve solenoid

A rail pressure control valve solenoid is fitted to the common rail on some systems.

The valve controls fuel pressure by opening and closing a return port in the rail.

Excess fuel returns to the fuel tank via the fuel return.
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Rail pressure control valve solenoid

Receives battery voltage supply from engine ECM. Energized by engine ECM via a negatively triggered PWM.

Operating frequency: approximately 1000Hz

Used in conjunction with fuel metering solenoid, the rail pressure solenoid provides more accurate and faster control of pressure, particularly when reducing rail pressure during overrun.
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Rail pressure control valve **de energized**

**More** fuel is returned to fuel tank via return port.

Rail pressure **Decreases**.
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Rail pressure control valve **energized**

**Less** fuel is returned to fuel tank via return port.

Rail pressure **Increases**.
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Rail pressure control valve failure symptoms and diagnosis

Most likely consequence:

**Engine stops or will not start.**

Solenoid circuit monitored by engine ECM.
Open or short circuit detected:

**DTC stored and MIL illuminated.**
(Engine stops or will not start).

Mechanical failure:

A minimum amount of fuel rail pressure is required to enable the engine to start.

**Typical value:**

approximately between 200 - 300 Bar
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Rail pressure control valve failure symptoms and diagnosis

Most likely consequence:

**Engine stops or will not start.**

Solenoid circuit monitored by engine ECM. Open or short circuit detected:

**DTC stored and MIL illuminated.**  
(Engine stops or will not start).

Mechanical failure:

Valve stuck open = Low rail pressure.  
Engine stops or will not start.

Valve stuck closed = High rail pressure.  
Engine stops or will not start.
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Testing rail pressure control valve

**Multimeter:**
Test internal resistance of valve solenoid winding.

Typical value: approximately 3.6 Ohms.

**Diagnostic scan tool:**
DTC’s and monitoring of rail pressure values.

**Oscilloscope:**
Test supply voltage and earth switching signal from engine ECM.

Test stability of waveform.
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Pressure control valve waveform: engine idling

Green = % duty cycle
Blue = rail pressure
Red = current draw
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Pressure control valve waveform: snap acceleration

Green = % duty cycle
Blue = rail pressure
Red = current draw
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Pressure control valve waveform

Remember:
The engine stops or will not start if the fuel rail pressure control valve fails!
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Fuel injectors

The fuel injectors are controlled by either a solenoid or piezo actuator. They are energized sequentially by the engine ECM. The ECM simultaneously switches a live voltage supply and an earth for each injector. Multiple injection processes per cylinder combustion are possible.
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Fuel injectors

- Solenoid actuator
- Injector valve
- Valve piston
- Nozzle spring
- Thrust piece
- Valve needle
- Fuel leak back (return)
- Electrical connection
- High pressure fuel inlet (from common rail)
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Operation of fuel injectors

Fuel pressure is supplied to the injector needle seat area.....

and also to a small chamber above the injector piston via a calibrated inlet port.
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Operation of fuel injectors

When the solenoid is energized, the injector valve opens.

Fuel pressure is relieved above the injector piston and returns to the fuel tank via the injector leak back (return) ports.
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Operation of fuel injectors

This creates a pressure difference above and below the injector piston.

Fuel pressure below the injector needle lifts the needle.
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Operation of fuel injectors

Fuel is now injected into the cylinder.

Maximum stroke of solenoid valve: approximately 50 micrometers (0.05 mm).
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**Piezo injector**

- **Primary advantage:**
  - Quicker response time (up to four times faster than solenoid controlled injector).

**Features**

- Piezo stack has several hundred wafer thin slices of Piezo crystal material.
- When voltage is applied, the piezo stack expands and opens the injector valve.
- Mechanical principle of operation is similar to the solenoid injector.
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Injector codes

Most injectors have a code that must be programmed into the engine ECM.

Bosch injector generation 2
IMA code for injector flow adjustment

Denso injector
QR (Quick Response) code

The code relates to the calibrated flow rate of the injector.

It enables the ECM to correct the injection quantity to compensate for manufacturing tolerances.
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Oscilloscope waveform: Solenoid injector de energized

Blue = switched +  
Red = switched -  
Green = current draw
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Oscilloscope waveform: Solenoid injector energized

- Blue = switched +
- Red = switched -
- Green = current draw
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Oscilloscope waveform: Piezo injector de energized

Blue = switched +
Red  = switched -
Green = current draw
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Oscilloscope waveform: Piezo injector energized

Blue = switched +
Red = switched -
Green = current draw
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Engine management closed loop control functions:

Rail pressure calculation

Example: Bosch EDC16 (2 point control)

Engine Stationary → Rail pressure calculation (pre set values) → Engine Start

Comparison: Actual value with set value

% duty cycle: Fuel metering and rail pressure control solenoids

Actual fuel rail pressure value

Closed loop control
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Engine management closed loop control functions:

- APP
- CKP
- ECT
- B+
- DPF

Example: Bosch EDC16 (2 point control)
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Fuel system diagnosis

Common rail diesel fuel systems operate on a closed loop basis.

The system carries out a great many complex calculations to precisely control fuel quantity and injection timing.

A range of tools and test equipment is commercially available to assist with diagnosis of the system.

The following is a brief overview to highlight some of the basic tests that can be carried out to diagnose faults with the system.
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Fuel system diagnosis

**Basics first!**

- Sufficient diesel in the fuel tank?
- Fuel contamination (e.g., from petrol).
- Fuel leaks and damage to components.
- Battery state of charge?
- Adequate low pressure fuel supply from fuel tank?
- Does engine start or crank and try to start?
- Is white smoke emitted from exhaust during engine cranking? (not always easy to see but indicates some fuel is entering cylinders).
- Are any DTC’s stored in fault memory of engine ECM?
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Fuel system diagnosis

Is the system capable of generating sufficient fuel pressure?

Typical minimum ‘manufacturer specified’ value during engine cranking:
approximately between 200 – 300 Bar

In practice, the figure is usually higher for a good system. Above example shows fuel pressure during engine cranking.
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Fuel system diagnosis

Injector leak back test

There should **not** normally be any fuel collected in receptacles during engine cranking.

Example of acceptable leak back value with engine idling:

- approximately 20ml per injector over a 2 minute period.

*(Always refer to manufacturer data for exact specifications)*
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Fuel system diagnosis

Maximum fuel pressure

- Engine cranking: (approx 500 Bar)
- Engine idling: (approx 362 Bar)
- Snap acceleration: (approx 1519 Bar)

362.6 Bar
Thank you for attending a technical overview of Common Rail Diesel Fuel Systems presented by Tony Kitchen (AK Training)