FUEL INJECTION SYSTEMS
DIESEL

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Fuel injection systems - diesel

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1 - Basic diesel fuel systems

- Basic diesel engine operation

  - Diesel engine force air by the intake valve into the cylinder
  - High compression ratio heats the air enough to ignite the fuel
  - Fuel is injected into the cylinder at high pressure
  - The amount of fuel injected suits to the load and controls engine speed
Basic diesel fuel systems

- Basic diesel fuel systems
  - Divided in 2 sections
    - Low pressure side
      - Clean the fuel
      - Deliver fuel to high pressure side
    - High pressure side
      - Raise the fuel pressure high enough to injection stage

Basic diesel fuel system

- Basic diesel fuel system
  - A lift pump takes fuel from the tank and keeps the injection pump full with fuel (electric or mechanical, on the engine or on the injection pump)
  - A filter removes water and large particles of the fuel
  - A fuel filter removes extremely small particles
  - Fuel under high pressure passes along injector pipes (steel, with same length) to injectors by the action of injector pump (synchronism with engine cycle)
### Basic diesel fuel system

- **Basic diesel fuel system**
  - Injector sprays fuel into combustion chamber
    - Direct injection engine
      - Combustion chamber not divided
      - Direct injection on combustion chamber
      - Superior efficiency
    - Indirect injection engine
      - Combustion chamber divided
      - Low noise level
      - Low production costs
      - More fuel consumption (10–15 %)

- **Leak off pipes** take excess of fuel back to the tank (also remove air from the system)
- The combustion pressures are greater in a diesel engine than in a similar gasoline engine (components stronger and heavier)
Basic diesel fuel system

- Basic diesel fuel system

  - To make cold starting easier
    - Extra fuel injection
    - Combustion chamber heater system (glow plugs) that can work some minutes after the engine start

2 - Injection pumps
Injection pumps

- High injection pressures needed to
  - Exceed the compression pressure in the combustion chamber
  - Exceed the combustion pressure in the combustion chamber
  - Break up the fuel into small particles

INJECTION PUMPS

Injection pumps

- Injection pumps
  - Sent fuel to each injector
    - under pressure
    - In controlled quantities
    - At the right time

function of engine speed and load
Injection pumps

- Injection systems

  - Types
    - Inline pump injection
    - Individual injection pumps
    - Pump pipe injector (PLD)
    - Unit injector (UI)
    - Common rail
    - Radial plungers injection pumps
    - Axial plungers injection pumps

- the next sections will analyze the inline pump and the radial rotary injection pump
- PLD, UI and Common rail basic analysis is made in electronic injection section

3 - Injectors
Injectors

- Sprays fuel into combustion chamber
- Mechanic type
- Electric types
  - Electromagnetic – solenoid valve
  - Piezo electric

Injectors

- Mechanic type (typical)
  - Fuel injection pressure exceed the injector spring
  - The needle valve rises and fuel is sprayed in combustion chamber
  - When injection ends, the pressure drop causes the return of needle valve to the initial position
  - Some of them can be tuned (spring strength adjust)
Injectors

- Electromechanic type
  - Electronic control unit sends electric signal to electro-valve
  - A solenoid electric valve allows fuel to pass to injector nozzle
  - Injection made in typical way (already explained)
  - In figure the injection pump and the injector are a same unit

- Electric piezo Injectors
  - Electromagnetic injector valve replaced by electric piezo control
  - Piezo effect - mechanical distortion causes electric current and vice-versa (Ex. quartz)
  - Injector control valve movement with a 1 mm³ fuel precision
4 - Inline injection pump

- Traditional inline injection pump
  - Have a pump element (plunger, cylinder) for each engine cylinder
  - Pump elements in line disposal
Inline injection pump

- Traditional inline injection pump
  - Body
  - Crankcase
    - Camshaft
    - Feeding pump (or not)
    - Pushers (or not)
  - Visit window
    - Gear rack
    - Pump elements (plungers, cylinder, gear)
  - Feeding collector
  - Retention valves
  - Automatic speed regulator

- Camshaft
  - It have the same rotation as the engine camshaft (one turn for two turns of the crankshaft)
  - Causes an linear movement on the plungers

- Plungers
  - Push the fuel in the direction of the injector

- Gear rack
  - Causes an rotation movement on the plungers that is function of the accelerator pedal

- Pump elements
  - Control the amount of fuel that goes to the injector
Inline injection pump

- Basic operation

- The eccentric on the camshaft causes constant linear movement of the pushers.

- The plungers, by the action of the pushers, push the fuel in the direction of the retention valve.

- The pressure is high enough to open the retention valve and the fuel is conducted by pipes to the injectors.

- The amount of fuel is controlled by the gear rack.

Inline injection pump

- Basic operation

- The gear rack causes an rotation movement to the plunger that is function of the accelerator pedal.
Inline injection pump

- Basic operation

- The plunger has cannelures around itself to fuel flow, and the position of the rack determines the position of the plunger that determines the amount of fuel injected.

![Diagram of injection pump stages]

- The end of injection occurs when the cannelure of the plunger reaches a position that makes connection between the cylinder and the feeding collector, balancing the pressure.

![Diagram of injection pump stages]
5 – Radial rotary injection pump

- Radial rotary injection pump
  - Used on small diesel engines
  - Low volume and weight
  - High efficiency
Radial rotary injection pump

- Radial rotary injection pump
  - It will be studied the VR BOSCH radial rotary injection pump
  - One pump element for all the engine cylinders
  - Presence of internal sensors (fuel temperature, rotation angle)
  - Has a pump control unit, independent from the engine control unit

Radial rotary injection pump

- Components
  - Low pressure side
    - Fuel pump (actuated by VR pump shaft)
    - Pressure regulator valve (to avoid high pressures caused by pump high rotation in engine high speed)
    - Overflow valve (let fuel passes to tank when a default pressure is achieved, air automatic bleed off made easily)
Radial rotary injection pump

- Components

- High pressure side
  
  - High pressure electro-valve
    - Controlled by pump control unit
    - Determines the injection flow
    - Determines the injection duration

- Fuel high pressure caused by radial plungers

- In figure: 3 possible plungers disposal
Radial rotary injection pump

- Basic operation

-Distributor functions

- Send fuel to plungers

- Time duration in close position of electro-valve determines the injection flow


Sistemas Automóveis

Ano lectivo 2009/2010
Radial rotary injection pump

- Basic operation

- Advance elements
  - Change the injection moment
  - Analyses crankshaft position and rotation angle sensor
  - Rotate cam causing delay or advance on injection
  - Controlled by control unit (hydraulic control with electro valve)

6 – Electronic injection systems
Electronic injection of Diesel Engines

- EDC (Electronic Diesel Control)
- UI (Unit Injector)
- PLD (Pumpe Leitung Duse)
- Common Rail

Main objective
- Reduce air pollution caused by diesel combustion
- Fuel quantity injection electronic control
EDC (Electronic Diesel Control)

- Used on VOLVO trucks

- Electronic control of the fuel injection

- Mechanical governor replaced by a fuel electromagnetic control device controlled by the electronic control unit
EDC (Electronic Diesel Control)

- Electronic control unit
  - Receives sensors information
  - Calculate the amount of fuel to be injected in function of engine load
  - Generate failure codes (if necessary)
  - Sends orders to the fuel control device

EDC (Electronic Diesel Control)

- EDC components (sensors and input signals)
  - Test socket
  - Accelerator pedal sensor (potentiometer)
  - Contact of the brake pedal
  - Contact of the clutch pedal
  - Turbo load pressure sensor (electric signal in proportion of the turbo pressure + atmospheric pressure)
  - Air temperature sensor in admission (NTC resistance)
  - Coolant temperature sensor (NTC resistance)
  - 2 x Rotations sensor
  - Velocity sensor
EDC (Electronic Diesel Control)

- EDC components (actuators and output signals)
  - Diagnosis lamp (blinks to give failure code – Ex. coolant temperature, turbo charge, air temperature in admission, tension on the alternator belt)
  - Electromagnetic fuel control device
  - Cut of injection (In emergency situations done by a pneumatic valve that actuates in injection pump)

EDC (Electronic Diesel Control)

- EDC electronic control unit
  - By default from factory:
    - Speed limit
    - Maximum constant rotations
    - Programmed constant speed (maximum and minimum)
EDC (Electronic Diesel Control)

- EDC electronic control unit

- Special functions:
  - Constant speed programmer (Keeps the same speed independent of the load)
  - Constant rotations programmer (Engine keeps constant rotations independent of the load – Ex. winch)
  - Stop engine by start key instead of a mechanical way
  - Maximum rotations limited in cold running

EDC (Electronic Diesel Control)

- Electromagnetic fuel control device (components)

  - Composed by an electromagnet that controls the injection pump rack (see in line pumps)

  - Position sensor that inform the electronic control unit about the pump rack and determines the intensity of the electric current in the electromagnet

  - Rotations sensor (2x) – One in the electromagnetic fuel control device (principal) and another (reserve) given by the tachometer
UI (UNIT INJECTOR)

- Used on VOLVO trucks, VW automobile diesel engines, CATERPILLAR engines

- Injector units controlled by the electronic control unit

- Electronic control unit

  - Calculates and controls the amount of fuel that will be injected (duration of injection)

  - Calculates and controls the injection angle
UI (UNIT INJECTOR)

- Electronic control unit - sensors and cut switches
  - Velocity sensor
  - Crankshaft rotations sensor
  - Accelerator pedal sensor
  - Identification of cylinder sensor
  - Clutch pedal switch
  - Brake pedal switch
  - Air temperature sensor in admission
  - Coolant temperature sensor

- Injection process
  - Electric signal sent to the electric valve of the injector unit closes it
  - Fuel return system closes and injection pump movement causes high pressure
UI (UNIT INJECTOR)

- Injection process (cont.)

- Injection of fuel in cylinder when injector opens (about 400 bar)

- During injection, pressure reaches 1600 bar (caused by injector nozzles)

- Injection ends when the electric signal stops opening the electric valve (spring) and return, reducing the pressure

UI (UNIT INJECTOR)

- Injection angle

- Definition: Rotation angle of crankshaft in reference with Top Dead Center (injection point) – 18° before or 6° after the TDC

- Crankshaft rotations sensor information is used to determine when electric valve of fuel should open or close
UI (UNIT INJECTOR)

- Cylinder balance (to cause smooth and regular low speed) – only occurs in low speed
  
  - Electronic control unit determines, in each injection, the speed and acceleration of the engine wheel in order to determine if there is the same power in each cylinder
  
  - If not the electronic control unit compensates by the duration of injection

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UI (UNIT INJECTOR)

- Fuel amount limit
  
  - Electronic control unit determines the amount of fuel to inject with restrictions such as:
    - Speed limit
    - Rotations limit
    - Toxic gases limit
    - High temperature limit
    - Engine protection
1 - In the rise of plunger (return spring + plunger control) the electric valve is open (input of fuel in the cylinder)
2 - Plunger control pushes plunger down, the fuel returns while the electric valve is open
3 - an electric signal is sent to the electric valve closing it, the pressure of fuel rises until overcome the injectors resistance - injection
4 - Injection ends when electric valve cuts off (opens) and pressure decreases

- Notes about injection

- Superior injection pressure (2000 bar) in comparison with inlines and rotary pumps
- Plunger always completes its course, however the amount of fuel depends of the electric valve controlled by the electronic control unit
- As seen before there are limits to the amount of fuel injected
PLD (Pumpe Leitung Duse)

- Pumpe = pump, Leitung = pipe, Duse = injector
- Used on MERCEDES BENZ trucks
- to comply with new rules of gases emission

PLD (Pumpe Leitung Duse)

- Engine controlled by an electronic module (microcomputer) programmed
- Electromechanical injection system
PLD (Pumpe Leitung Duse)

- Electronic module (PLD)
  - Injection angle determined by an encoder information (assembled on the engine wheel) that measures the piston speed
  - Sensors information + PLD program parameters + ADM (administration module) determines the beginning and duration of injection

- ADM (administration module)
  - Data acquirer of maximum and minimum values of
    - Engine rotation
    - Vehicle speed
    - Torque
  - Interaction with other modules (CAN) as
    - Brake system (ABS)
    - PLD
    - Automatic transmission
PLD (Pumpe Leitung Duse)

- ADM (administration module)
  - Control cabin equipment
  - Control of accelerator pedal (If it fails, vehicle change to low speed and ADM rotation management takes control)
  - Due to functions parametrization characteristic there are several possible functioning modes to vehicles
  - If failure, the PLD impose a 1300 rpm constant value

- Electromechanical fuel injection components
PLD (Pumpe Leitung Duse)

- Electromechanical fuel injection stage 1 - Admission

- The cam position makes spring pull down the plunger

- The electromagnetic valve spring allows the cylinder to be filled with fuel by pump action

PLD (Pumpe Leitung Duse)

- Electromechanical fuel injection stage 2 - previous course

- The cam pushes up the plunger

- The electromagnetic valve remains open and the fuel returns (plunger pressure is higher than the pump's one)
PLD (Pumpe Leitung Duse)

- Electromechanical fuel injection stage 3 - injection

- The electromagnetic valve closes (energized by control unit)
- The plunger keeps its upside movement
- The fuel is sprayed by the injector in combustion chamber (up to 1600 bar)

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PLD (Pumpe Leitung Duse)

- Electromechanical fuel injection stage 4 – residual course

- The electromagnetic valve opens (deenergized by the control unit)
- The plunger keeps its upside movement
- The fuel returns to the tank
COMMON RAIL

- The fuel is pressurized in a distribution pipe (rail)
- The distribution pipe (rail) is common to all cylinder
- Injection is made with electromagnetic valves (up to 1400 bar)

COMMON RAIL

- Components
  - Tank
  - Pipes
  - Water separator filter
  - Manual pump (to bleed off air),
  - Water sensor - water may cause cavitation, a frequent cause of structural damage
  - Bleed off screw
COMMON RAIL

- Components

- Low pressure circuit
  - Gear pump (5 to 13 bar) - ensures fuel supply to main filter and to high pressure pump
  - Filter
  - Security pressure valve
  - Fuel control electro-valve (control the amount of fuel by ECU to high pressure pump)

- Fuel control electromagnetic valve
  - PWM (pulse wave modulation) control
  - Rail fuel quantity controlled by opening time (more rail pressure means more open time)
COMMON RAIL

- Components

- High pressure circuit - rises the fuel pressure to levels that allow pulverization
  - Plungers (3 or more) pump
  - Retention valve to avoid rail fuel discharge
  - Security valve (returns fuel to tank)
  - distribution pipe (rail)
  - High pressure pipes
  - Injectors

- Components

- Plungers pump
  - Fuel transfer to rail, pipes and injectors
  - Gear pump (by engine mechanical distribution)
  - No engine synchronism needed
- Components
  - Injectors
    - Injection duration controlled by ECU (sensors information)
    - Fuel quantity depends on electro-valve opening time, fuel pressure and injector type


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