FUEL INJECTION SYSTEMS DIESEL

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1090039

Sistemas Automóveis

Ano lectivo 2009/2010

Fuel injection systems - diesel

1 - Basic diesel fuel systems

2 – Injection pumps

3 - Injectors

4 - Inline injection pump

5 – Radial rotary injection pump

6 – Electronic injection systems

7 - Bibliography

Sistemas Automóveis

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1 - Basic diesel fuel systems

Sistemas Automóveis

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Basic diesel fuel systems

Sistemas Automóveis

-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

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Basic diesel fuel systems

- Basic diesel fuel systems

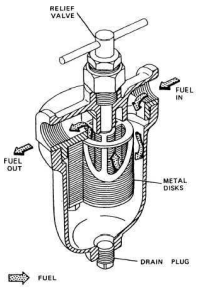
  - Divided in 2 sections

    - Low pressure side
      - Clean the fuel
      - Deliver fuel to high pressure side
    - High pressure side
      - Raise the fuel pressure high enough to injection stage

Sistemas Automóveis

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)

Sistemas Automóveis

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 %)

Basic diesel fuel system

- Basic diesel fuel system

  - 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)

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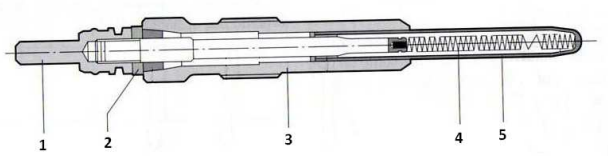
Sistemas Automóveis

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



1- Connector 2 - Insulating grommet 3 - Plug body 4 - Electric filament 5 - Glow pipe

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2 - Injection pumps

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Sistemas Automóveis

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

Sistemas Automóveis

Injection pumps

- Injection pumps
  - Sent fuel to each injector

    - under pressure
    - In controlled quantities
    - At the right time

↓

function of engine speed and load

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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

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Sistemas Automóveis

3 - Injectors

Injectors

- Sprays fuel into combustion chamber

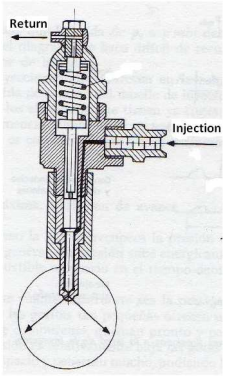
- Mechanic type

- Electric types
  - Electromagnetic – solenoid valve
  - Piezo electric

Sistemas Automóveis

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)

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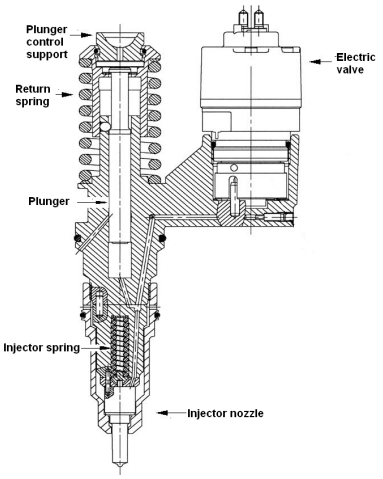
Injectors



- 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

Sistemas Automóveis

Injectors

- 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 mm^3 fuel precision

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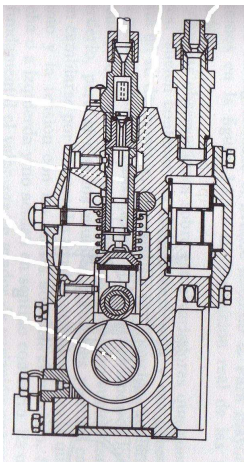
4 - Inline injection pump

Sistemas Automóveis

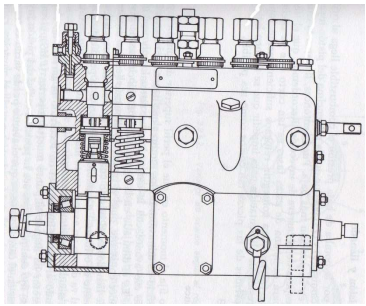
Inline injection pump

-Traditional inline injection pump



- Have a pump element (plunger, cylinder) for each engine cylinder

- Pump elements in line disposal



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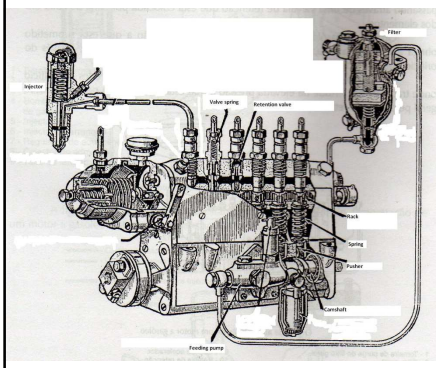
Inline injection pump

-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

Sistemas Automóveis

Inline injection pump

- 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

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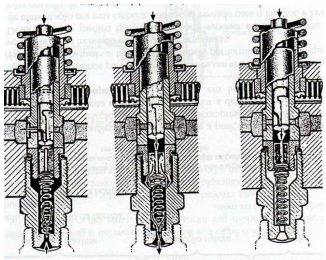
Inline injection pump

- 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

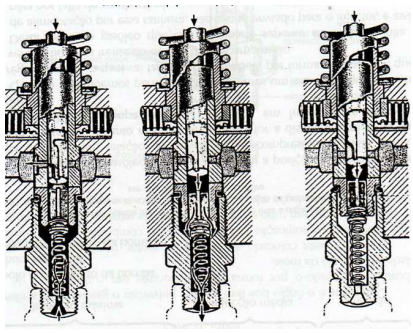
- the pressure is high enough to open the retention valve and the fuel is conducted by pipes to the injectors

- the amount of fuel is controlled by the gear rack

Inline injection pump

- Basic operation

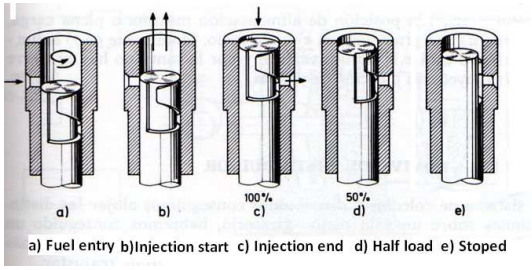
-The gear rack causes an rotation movement to the plunger that is function of the accelerator pedal



Inline injection pump

- Basic operation

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

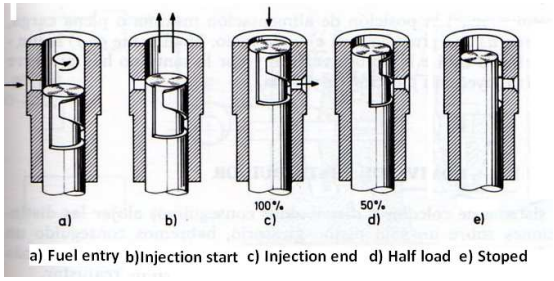


a) Fuel entry b)Injection start c) Injection end d) Half load e) Stoped

Inline injection pump

- Basic operation

- 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



a) Fuel entry b)Injection start c) Injection end d) Half load e) Stoped

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5 – Radial rotary injection pump

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Radial rotary injection pump

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

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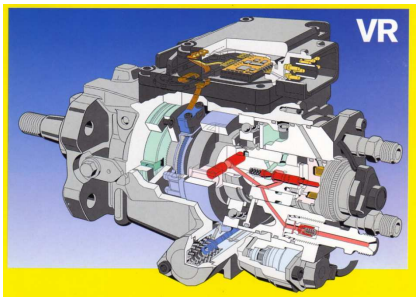
Radial rotary injection pump

- 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

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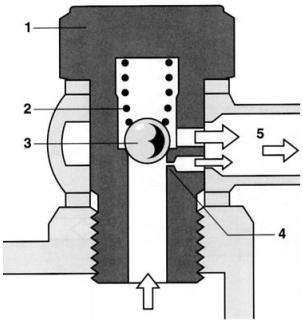
Radial rotary injection pump

- Components



Overflow valve
1 - Valve body
2 - Spring
3 - Spherical valve
4 - Air channel
5 - to tank

- 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)

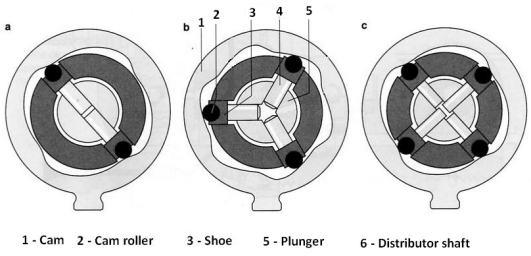
Sistemas Automóveis

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

Radial rotary injection pump

- Components
  - High pressure side
    - Fuel high pressure caused by radial plungers



- In figure: 3 possible plungers disposal

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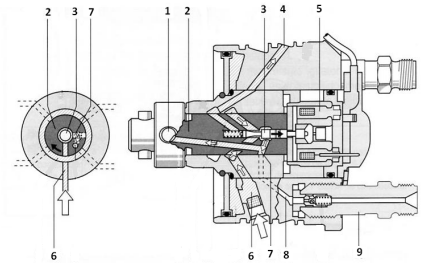
Radial rotary injection pump

- Basic operation

-Distributor functions



1 - Plunger 2 - Distributor 3 - Valve needle 4 - Fuel return 5 - High pressure electro-valve
6 - Low pressure entry 7 - Distribution channel 8 - High pressure to injector 9 - Pipe connection

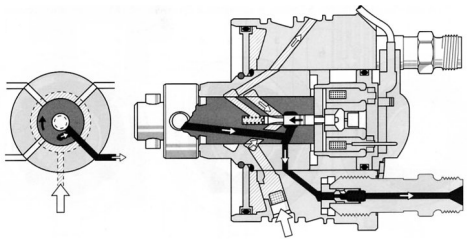
- Send fuel to plungers

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

Radial rotary injection pump

- Basic operation

-Distributor functions



- Send fuel to injectors

- The plungers are pressed by cam

-Fuel high pressure generated

- Distributor rotates to injector flow position

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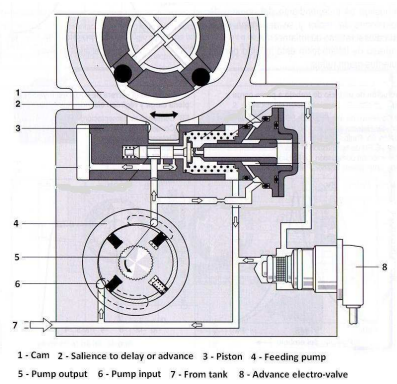
Sistemas Automóveis

Radial rotary injection pump

- Basic operation

-Advance elements



1 - Cam 2 - Salience to delay or advance 3 - Piston 4 - Feeding pump
5 - Pump output 6 - Pump input 7 - From tank 8 - Advance electro-valve

- Change the injection moment

- Analyses crankshaft position and rotation angle sensor

-Rotate cam causing delay or advance on injection

- Controlled by control unit (hidraullic control with electro-valve)

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6 – Electronic injection systems

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Sistemas Automóveis

Electronic injection of Diesel Engines

Sistemas Automóveis

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

Electronic injection of Diesel Engines

Sistemas Automóveis

- 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

EDC (Electronic Diesel Control)

- Mechanical governor replaced by a fuel electromagnetic control device controlled by the electronic control unit

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Sistemas Automóveis

EDC (Electronic Diesel Control)

Sistemas Automóveis

- 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)

Sistemas Automóveis

- 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)

Sistemas Automóveis

- 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 acutates in injection pump)

EDC (Electronic Diesel Control)

Sistemas Automóveis

- EDC electronic control unit

⬇

- By default from factory:
  - Speed limit
  - Maximum constant rotations
  - Programmed constant speed (maximum and minimum)

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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

UI (UNIT INJECTOR)

- 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 switchs
  - 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

UI (UNIT INJECTOR)

- 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)

Sistemas Automóveis

- 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)

Sistemas Automóveis

-Injection angle

- Definition: Rotation angle of crankshaft in reference with Top Dead Center (injection point) – 18^{o} before or 6^{o} 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

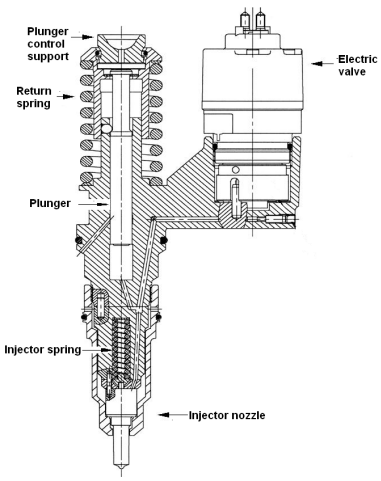
UI (UNIT INJECTOR)

- 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

UI (UNIT INJECTOR)



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 de injector resistance - injection
4 – Injection ends when electric valve cuts off (opens) and pressure decreases

UI (UNIT INJECTOR)

- 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

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Sistemas Automóveis

PLD (Pumpe Leitung Duse)

Sistemas Automóveis

-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

PLD (Pumpe Leitung Duse)

Sistemas Automóveis

- 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

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PLD (Pumpe Leitung Duse)

- ADM (administration module)

  - Control cabin equipment

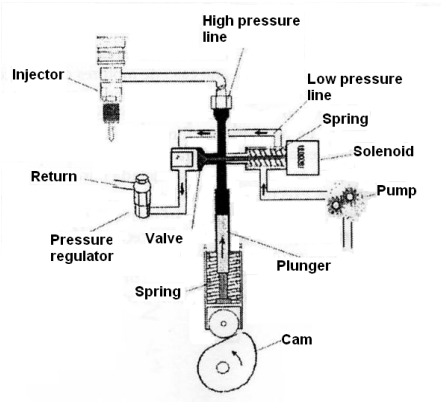
  - Control of accelerator pedal (If it fails, vehicle change to low speed and ADM rotation management takes control)

  - Due to functions parametrization characteristic there are several possible functioning modes to vehicles

  -If failure, the PLD impose a 1300 rpm constant value

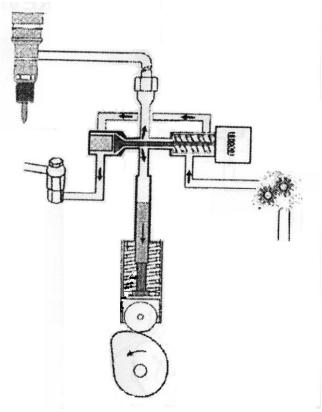
PLD (Pumpe Leitung Duse)

- Electromechanical fuel injection components



PLD (Pumpe Leitung Duse)

- Electromechanical fuel injection stage 1 - Admission



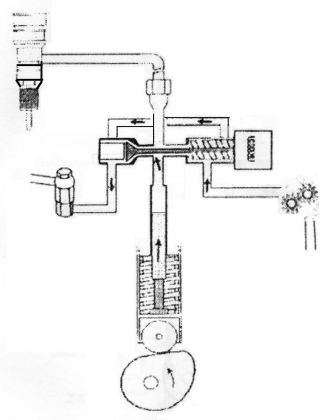
-The cam position makes spring pull down the plunger

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

Sistemas Automóveis

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)

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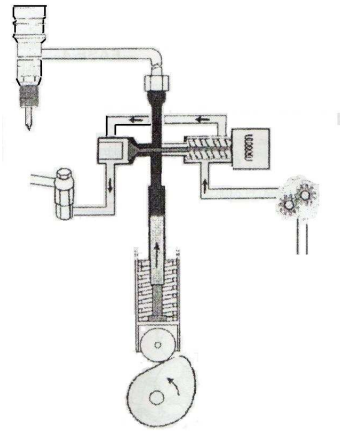
PLD (Pumpe Leitung Duse)

- Electromechanical fuel injection stage 3 - injection



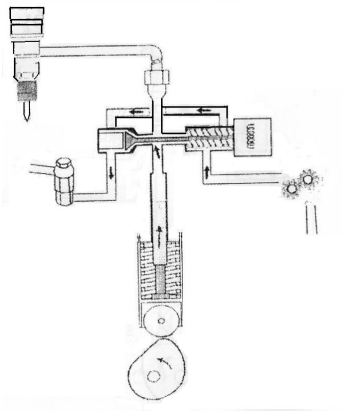
-The electromagnetic valve closes (energized by control unit)

- The plunger keeps it's upside movement

- The fuel is sprayed by the injector in combustion chamber (up to 1600 bar)

PLD (Pumpe Leitung Duse)

- Electromechanical fuel injection stage 4 – residual course



-The electromagnetic valve opens (deenergized by the control unit)

- The plunger keeps it's upside movement

- The fuel returns to the tank

COMMON RAIL

Sistemas Automóveis

- 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

Sistemas Automóveis

- 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

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COMMON RAIL

Sistemas Automóveis

- 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)

COMMON RAIL

Sistemas Automóveis

- Components

  - 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

Sistemas Automóveis

- 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

COMMON RAIL

Sistemas Automóveis

- Components

  - Plungers pump
    - Fuel transfer to rail, pipes and injectors
    - Gear pump (by engine mechanical distribution
    - No engine synchronism needed

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COMMON RAIL

- Components

  - Injectors

    - Injection duration controlled by ECU (sensors information)
    - Fuel quantity depends of electro-valve opening time, fuel pressure and injector type

Sistemas Automóveis

Sistemas Automóveis

6 - Bibliography

1 - http://files.asme.org/asmeorg/Communities/History/Landmarks/10001.pdf [Consult. Nov. 2009].

2 - http://www.asme.org/ (American Society of mechanical engineers) [Consult. Nov. 2009].

3 - http://rb-kwin.bosch.com/za///en/powerconsumptionemissions/dieselsysteme/dieselsystem/passenger-car/injection_systems/index.html [Consult. Nov. 2009].

4 - http://www.google.pt/imgres?imgurl=http://moodle.student.cnwl.ac.uk/moodledata_shared/CDX%2520eTextbook/dswmedia/images/heuidieselinject.jpg&imgrefurl=http://moodle.student.cnwl.ac.uk/moodledata_shared/CDX%2520eTextbook/dswmedia/fuelSys/diesel/elec/heuidieselinject.html&h=280&w=350&sz=55&tbnid=N2Sl3kg7ZTS-tM:&tbnh=96&tbnw=120&prev=/images%3Fq%3D%2522diesel%2Binjection%2Bsystem%2522&hl=pt-PT&usg=__YQ8g0kdi7Y4w6E2DcLqkRrEImo0=&ei=pU4KS_CPHcy2jAfR0aj3AQ&sa=X&oi=image_result&resnum=1&ct=image&ved=0CAkQ9QEwAA [Consult. Nov. 2009].

5 - http://www.lydallfiltration.com/tech/documents/DesignandPerformanceDieselFuelFilters.pdf [Consult. Dez. 2009].

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6 - http://images.google.pt/imgres?imgurl=http://www.tpub.com/content/engine/14081/img/14081_29_8.jpg&imgrefurl=http://www.tpub.com/content/engine/14081/css/14081_29.htm&usg=__h5J7mpqaPFV24BuuHAThDdRaM-I=&h=491&w=384&sz=23&hl=pt-PT&start=1&um=1&itbs=1&tbnid=GxsUfyBUzD_iDM:&tbnh=130&tbnw=102&prev=/images%3Fq%3Ddiesel%2Bfuel%2Bfilters%2Boperation%26hl%3Dpt-PT%26sa%3DN%26um%3D1
[Consult. Dez. 2009].

7 - http://www.dieselpowermag.com/tech/general/0809dp_stanadyne_db2_injection_pump/photo_02.html
[Consult. Dez. 2009].

8 - http://www.emeraldinsight.com/fig/0330220301001.png
[Consult. Dez. 2009].

9 – BOSCH – Bombas rotativas de inyección de émbolos radiales, para motores diesel VR, control electrónico del motor para motores diesel, Instrucciónj Técnica Edición 1999

10 – Da Silva, Edson – Injecão Electrônica de Motores Diesel, EDC, PLD, UI e Common rail, conceitos básicos funcionamento e manutenção, Ensino Profissional Editora, ISBN 85-99823-05-1

11 – De Imperial, Juan Miralles – Bombas de Inyeccion Diesel, Biblioteca del automóvil, Ceac, ISBN 84-329-1110-0

12 – Costa, António Alves, Mecânica Automóvel para o Exame de Pesados, Edições Alves Costa, ISBN 972-8073-05-4