Fuel Injection System

Introduction

- The fuel injection system is one of the most important components in CI engines

- The *effectiveness of fuel injection system is greatly affects the engine performance with respect to*

  - Power output
  - Fuel economy
  - Smooth engine operation
  - Clean burn

Functional Requirements of An Injection System

i. Accurate metering of the fuel injected per cycle
   - To met changing speed and load requirements of the engine

ii. Correct fuel injection timing in the cycle
   - To obtain maximum power, ensuring fuel economy and clean burning

iii. Proper control of rate of injection:
   - During combustion, desired heat release pattern can be achieved

iv. Proper spray pattern
   - To ensure rapid mixing of fuel and air

Functional Requirements of An Injection System

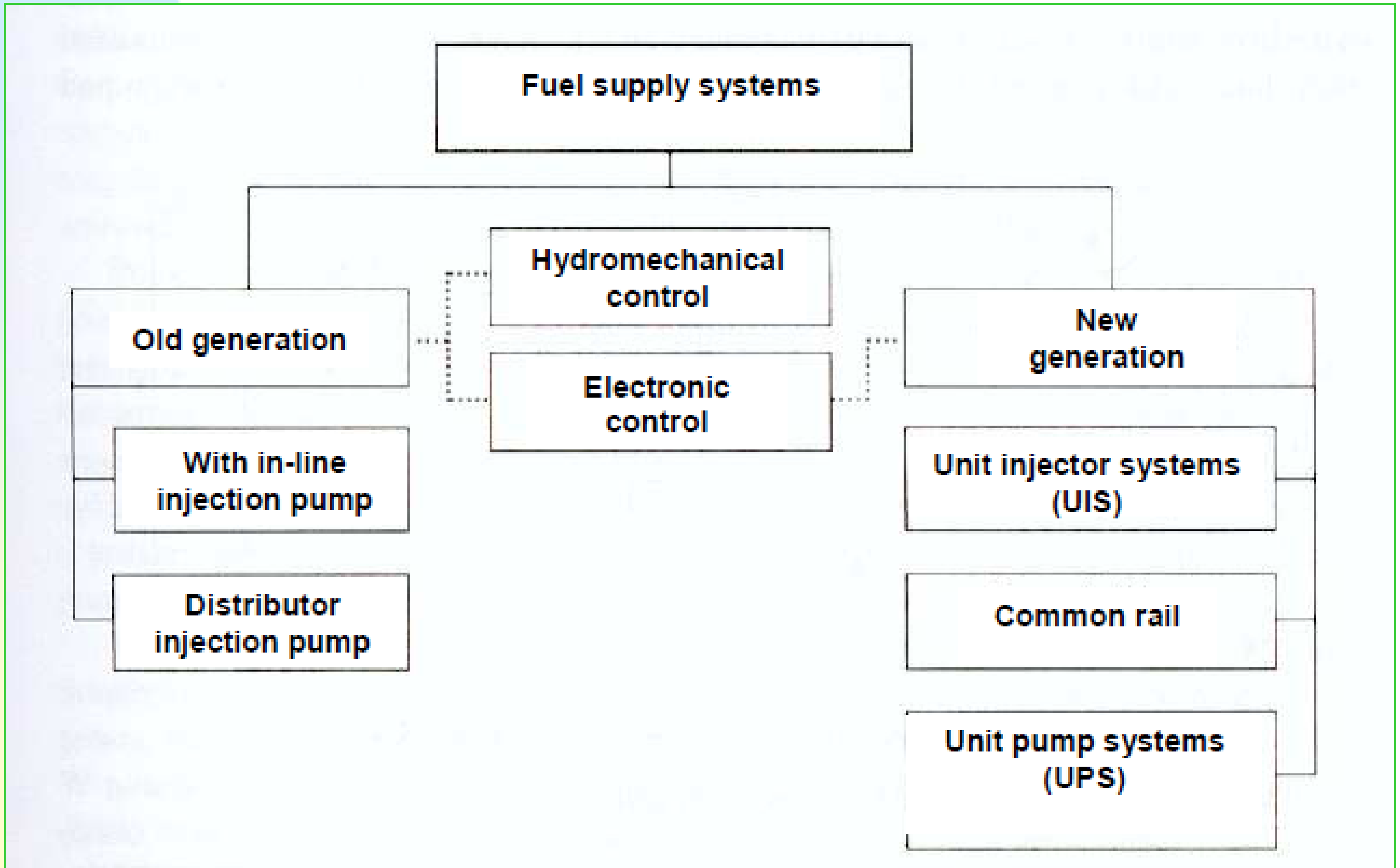
v. Proper atomization of fuel into very fine droplets.

vi. Uniform distribution of fuel droplets throughout the combustion chamber

vii. To supply equal quantities of metered fuel to all cylinders in case of multi cylinder engines

viii. No lag during beginning and end of injection i.e., to eliminate dribbling of fuel droplets into the cylinder

Types of fuel supply systems in CI engines



Classification of Injection Systems

- For producing the required pressure for atomizing the fuel either air or a mechanical means is used.

- Thus the injection systems can be classified as:
  - Air injection system
  - Solid injection systems

*A*ir *I*njection *S*ystem

- Fuel is forced into the cylinder by means of compressed air
- It has good mixing of fuel with the air with resultant higher mean effective pressure
- It has the ability to utilize high viscosity (less expensive) fuels
- The system is obsolete due to the requirement of multistage air compressors.

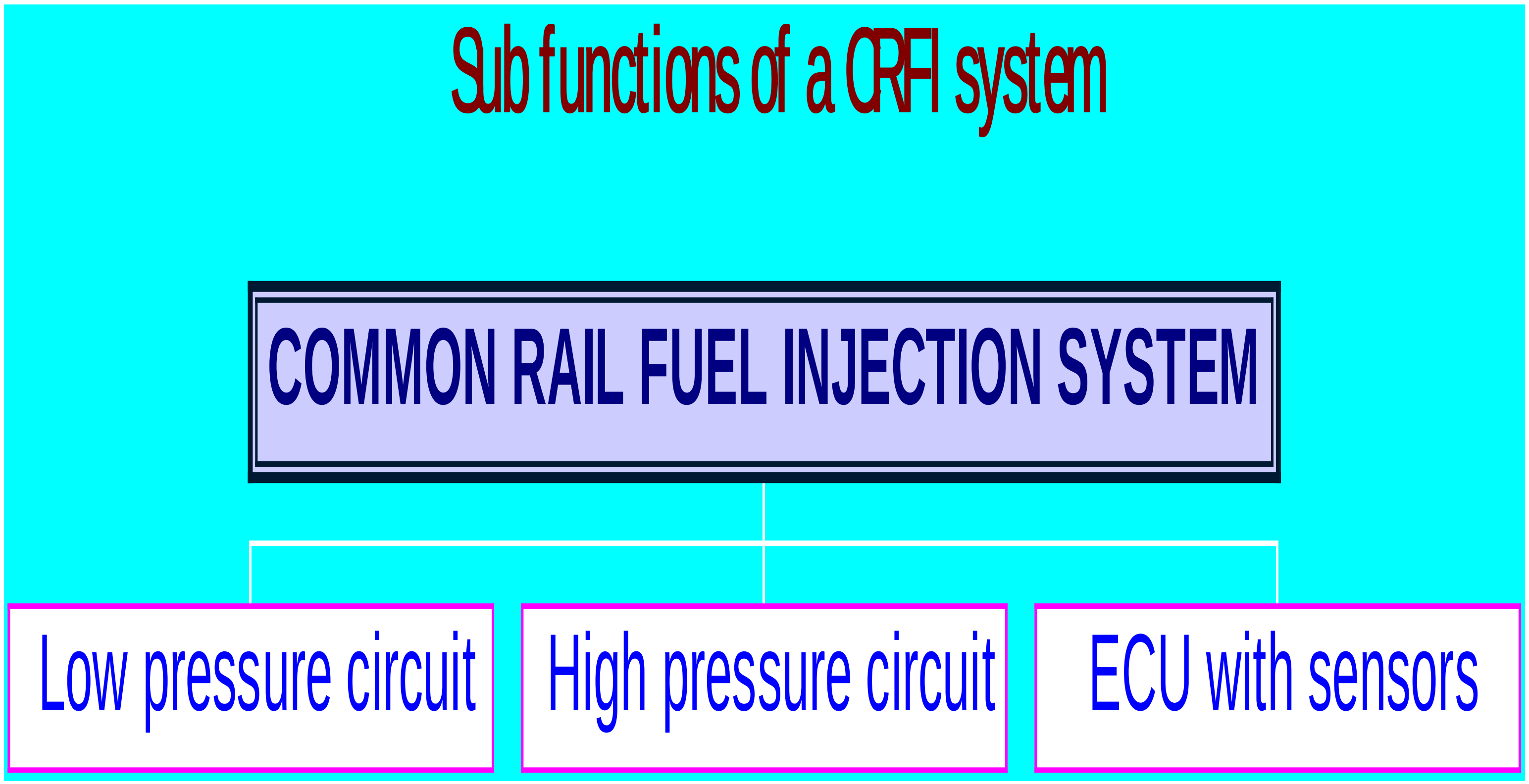
Solid Injection System

- In solid injection system, the liquid fuel is injected directly into the combustion chamber without the aid of compressed air.

- Currently there are two main groups of high-pressure solid injection systems
  1. Common Rail System (CRS(
  2. Unit Injector System (UIS)

- All the above systems comprise the following components
  - Fuel tank , fuel filters, fuel feed pump, injection pump, governors, injectors

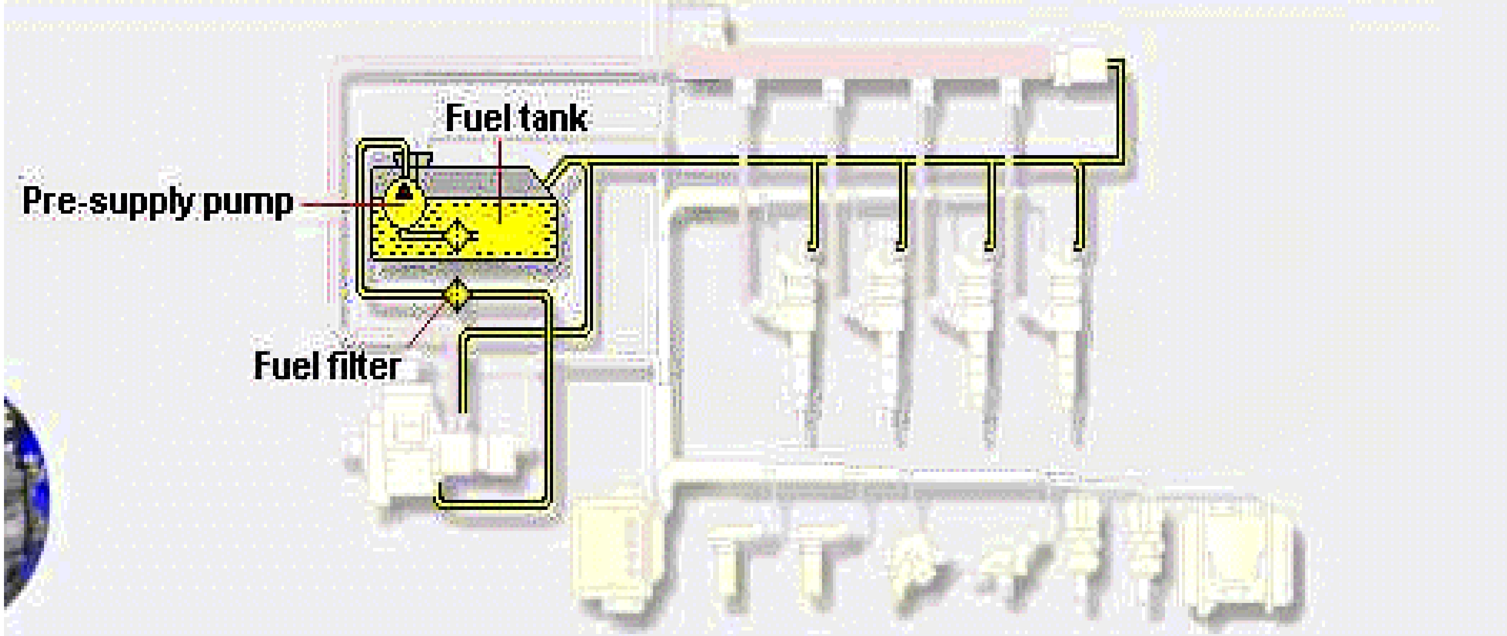
1. Common Rail System (CRS)



The Common Rail Sub functions

- Low pressure circuit comprises of Fuel tank, Pre-supply pump, Fuel filter, And the respective connection lines.

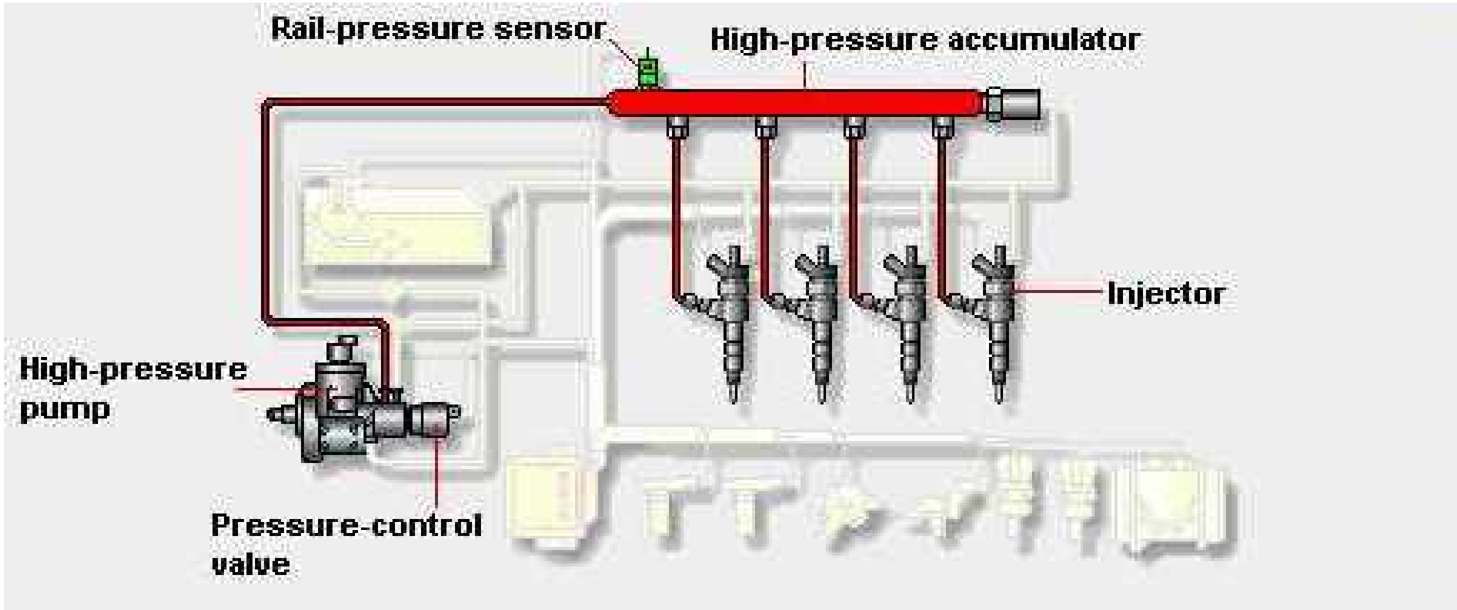
- The low –pressure circuit is responsible for transporting the fuel to the high –pressure circuit



The Common Rail Sub System

High – pressure circuit comprises:

- High – pressure pump with pressure control valve
- The high – pressure accumulator (Rail)with the rail – pressure sensor
- Injectors, and
- The respective high – pressure connection lines.



The Common Rail Sub System

High pressure circuit

It is the responsibility of the high pressure circuit to generate a constant unvarying high pressure in the high pressure accumulator (the rail) and to inject the fuel through the injectors into the engine's combustion chambers.

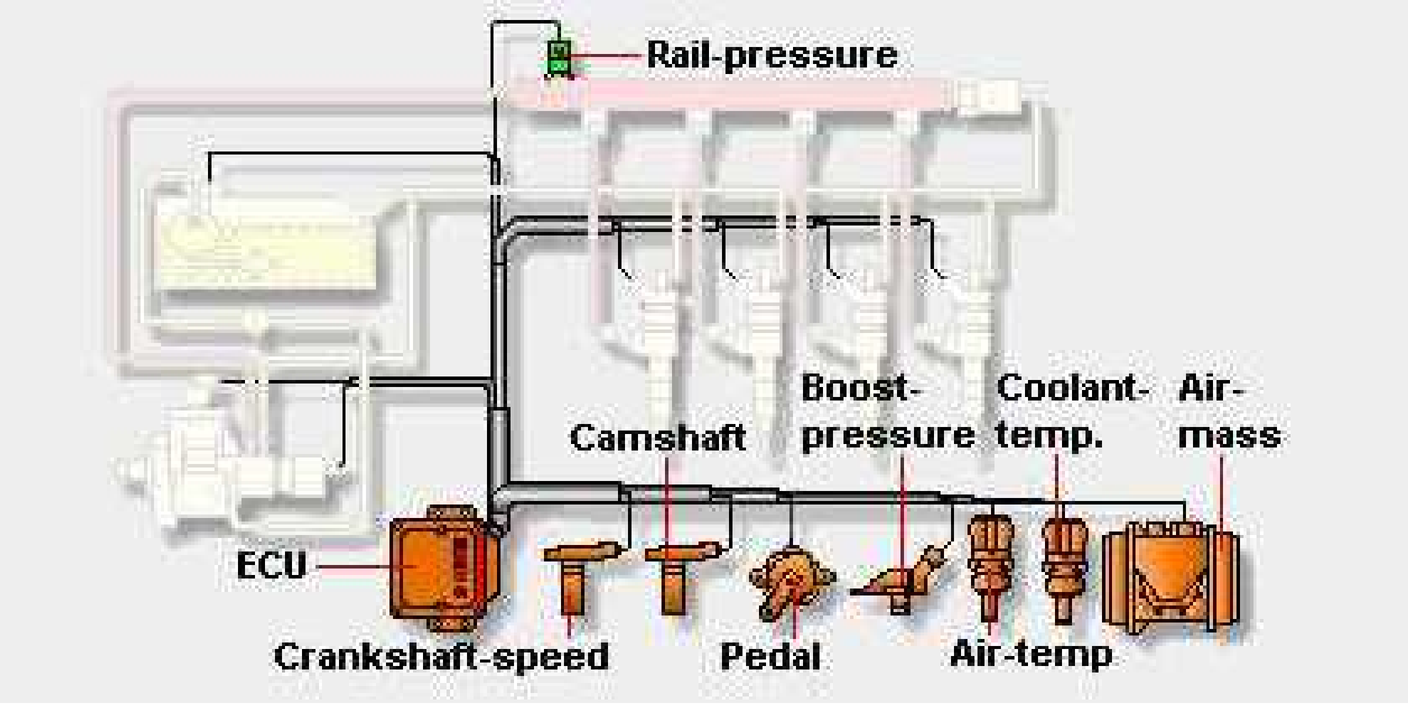
ECU and sensors

The common rail ECU evaluates the signals from the following sensors. Crankshaft – speed sensor, Camshaft sensor, Accelerator-pedal travel sensor

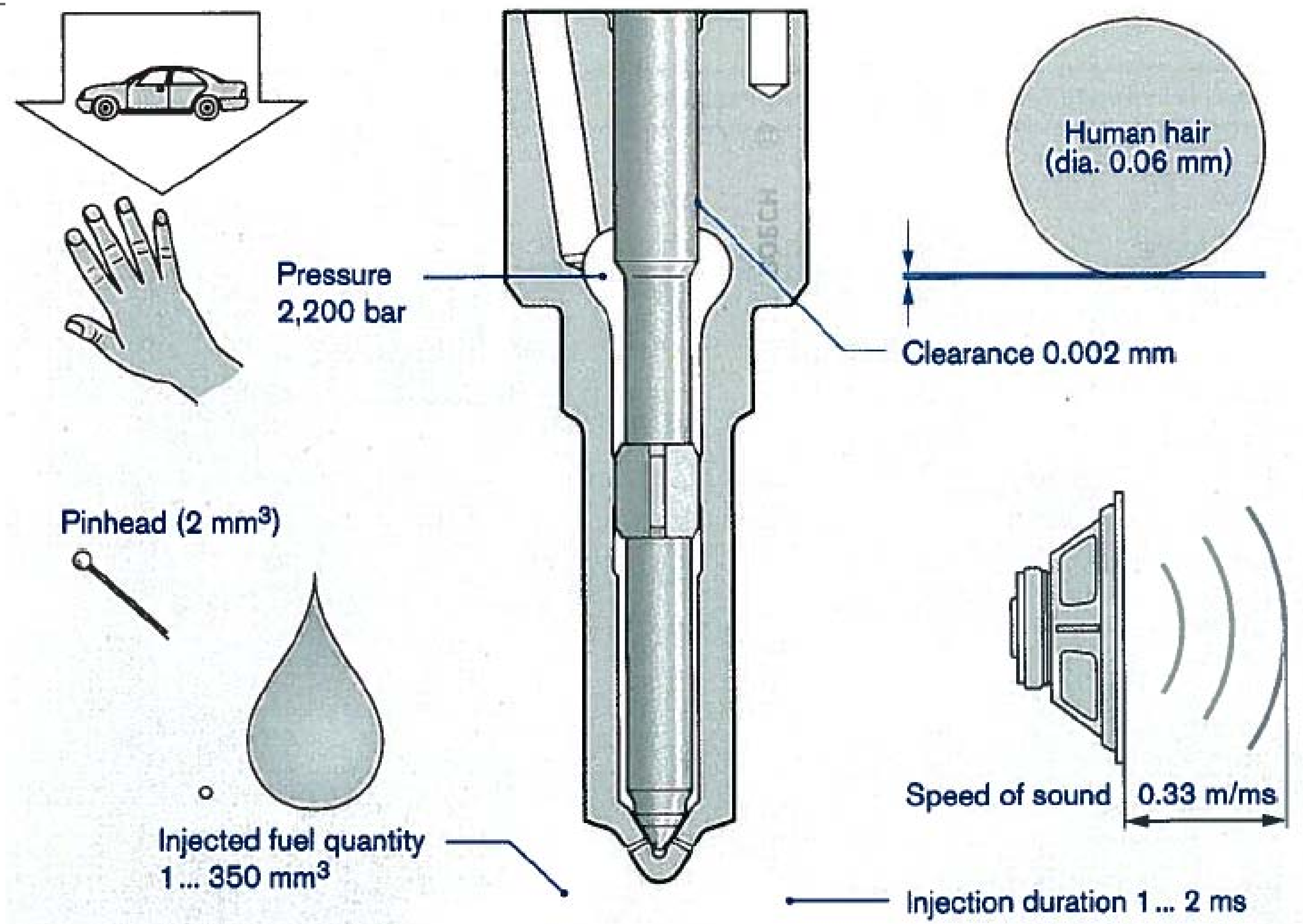
The Common Rail Sub System

ECU and sensors

The sensor are responsible for measuring important physical quantities. The ECU calculates injected fuel quantity, start of injection, duration of injection, and rate of discharge curve, as well supervises the correct functioning of the injection system as a whole.



Dimension of modern injection technology

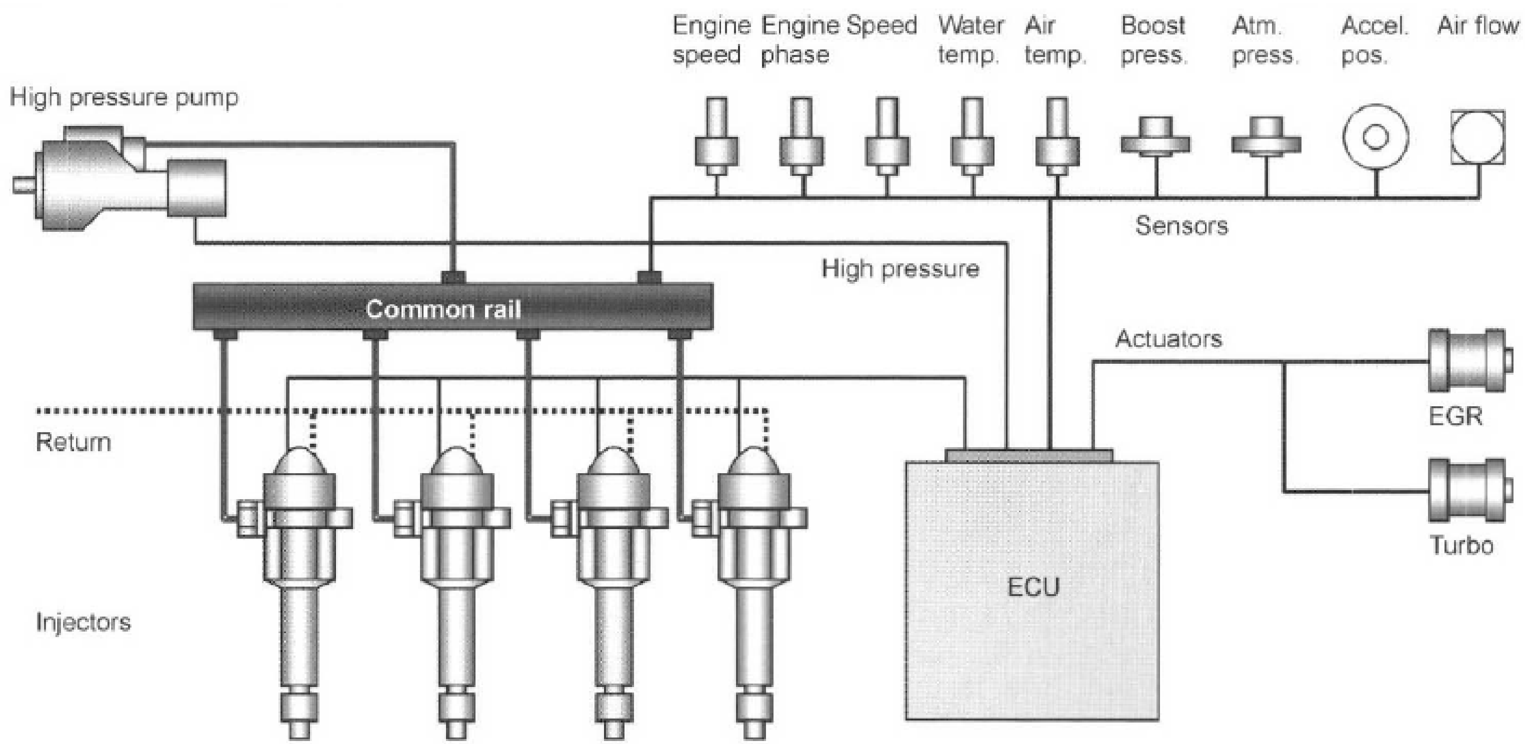


Common Rail System (CRS) working principle

- Pressure generation and the injection event are not coupled
- Fuel under high pressure is stored inside the rail, which usually consists of a thick-walled closed pipe
- A pressure sensor adjusts the desired rail pressure via an additional valve that controls the mass flow of excess fuel back to the fuel tank.
- The injection pressure is not dependent on engine speed as UIS does
- CRS enables a greater flexibility of injection and mixture formation compared to injection system driven by camshaft (UIS)
- Short pipes connect the rail with the injectors.

Common Rail System (CRS) working principle

- The volume of the rail is large enough to suppress pressure fluctuations due to injection.
- Injection timing and duration are controlled by solenoid valves and are independent of the pressure generation.



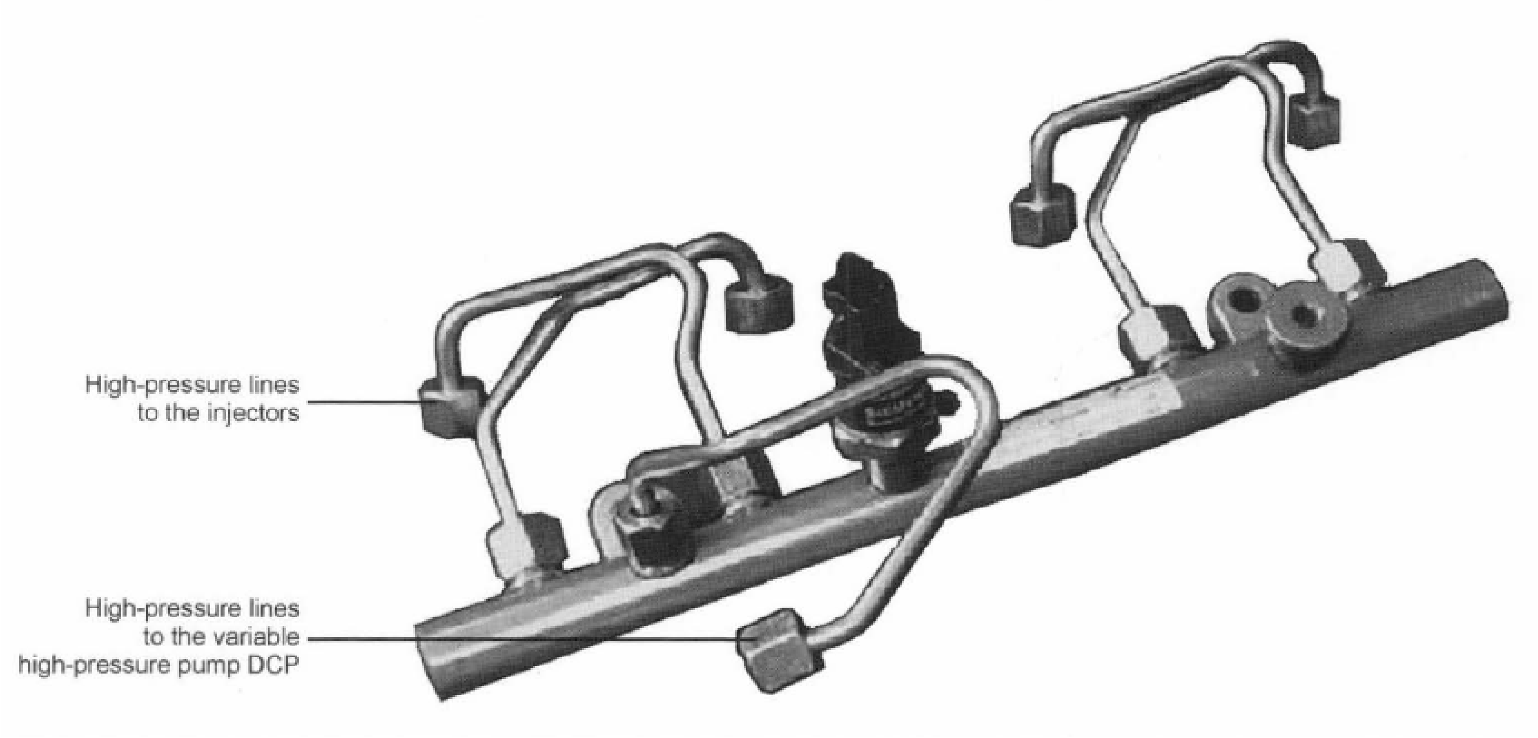
Common rail

Rail is a forged-steel tube.

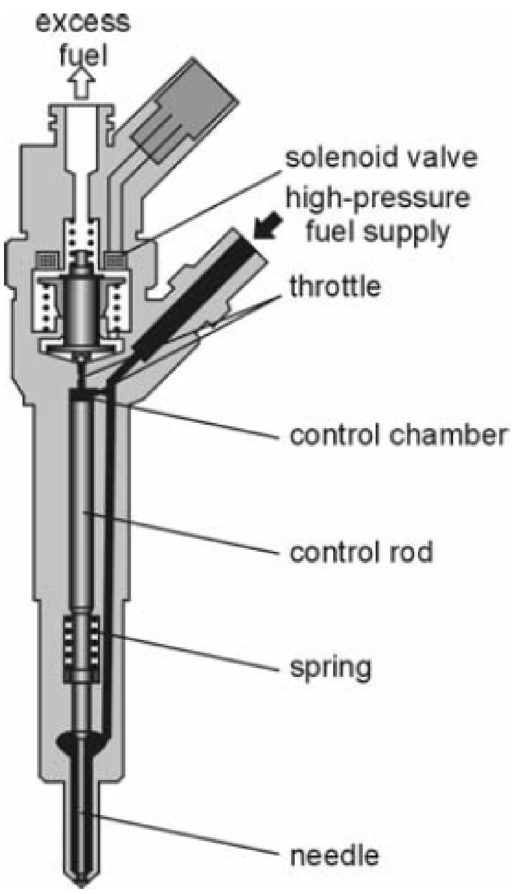
ID is approx.. 10mm

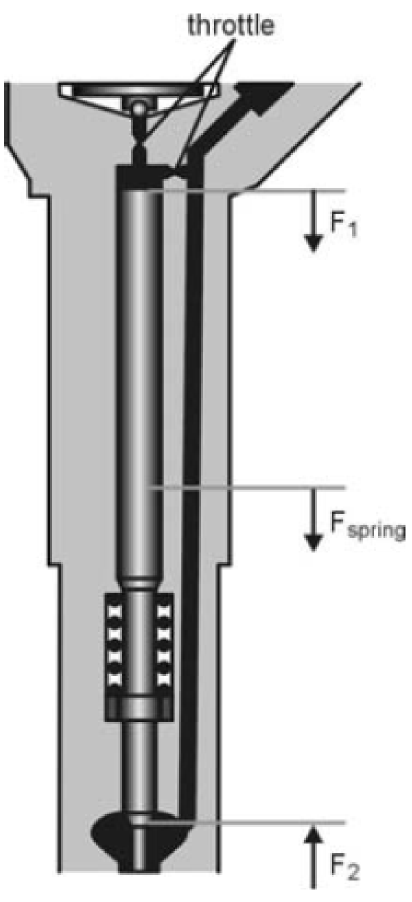
Length is between 280 and 600mm

The volume must be " as small as possible, as large as necessary"



A typical Common rail injector





Common Rail System(CRS) working principle

- The needle movement is controlled by a solenoid valve hydraulically.

- The spring force F_{spring} *and the hydraulic force* F_1 *of the high pressure fuel on top of the control rod* are larger than the hydraulic force F_2 *on the circular ring area, and the needle is* kept closed.

- As soon as the solenoid valve opens, the pressure in the control chamber above the control rod decreases and the needle begins to open, because the inlet throttle connecting the control chamber with the high-pressure fuel supply is smaller than the outlet throttle.

- Excess fuel passes off through the outlet throttle and then flows back to the fuel tank.

Common Rail System(CRS) working principle

- The opening speed of the needle is determined by the size ratio of both throttles.
- The closing process is initiated by closing the solenoid valve.
- The pressure inside the control chamber increases and the control rod closes the needle.
- The closing speed is again influenced by the size of the throttle.

Unit Injector System (UIS)

- UIS is one in which the pump and the Injector nozzle are combined with one housing.
- In this high pressure injection systems the generation of injection pressure and the injection itself occur synchronously
- UIS is driven by a camshaft, which is mechanically coupled with the engine.
- A basic characteristic of these systems is the intermittent pressure generation: high pressure is only available during a small crank angle interval.
- Each cylinder is provided with one of these unit injectors

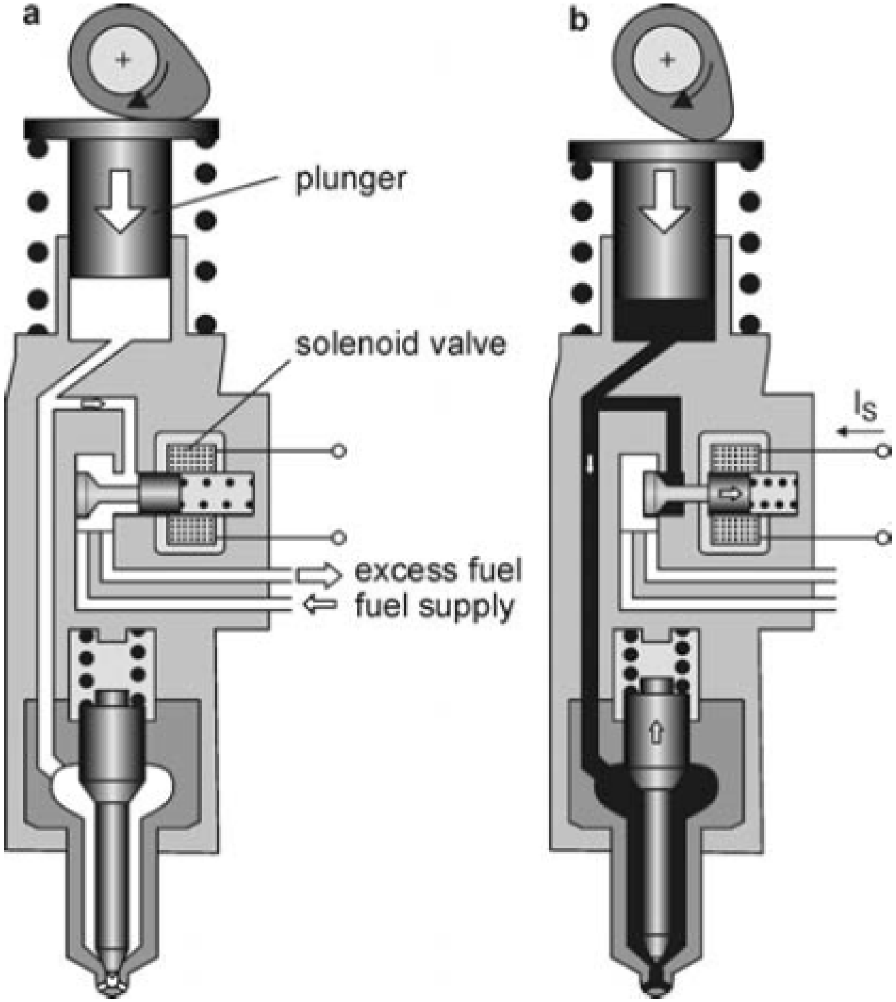
Unit Injector System (UIS)

- The omission of the high-pressure pipes between the pump and the injector allows significantly higher peak injection pressures (about 200 MPa and more)

- The shape of the cam determines the motion of the plunger and thus the generation of pressure as a function of crank angle.

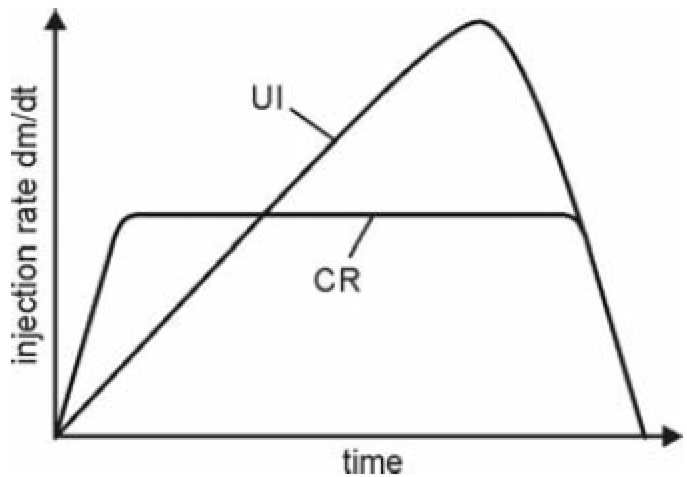
- The spring at the upper part of the injector presses the plunger against the rocker arm and the rocker arm against the cam, and guaranteeing force closure during operation

Unit Injector System (UIS)



Typical injection rate profiles of common rail and unit injector

- Due to the large feed rate of the plunger, the injection pressure strongly increases during injection, resulting in a triangle shaped injection rate profile



- In CRS maximum injection pressure is already present at the start of injection (resulting in a rectangular-shaped injection rate profile and in maximum spray atomization during the complete injection event)

Unit Pump System (UPS)

- The functionality of the so-called Unit Pump System (UPS) is practically identical to that of the unit injector system (UIS) and offers the same advantages and disadvantages.

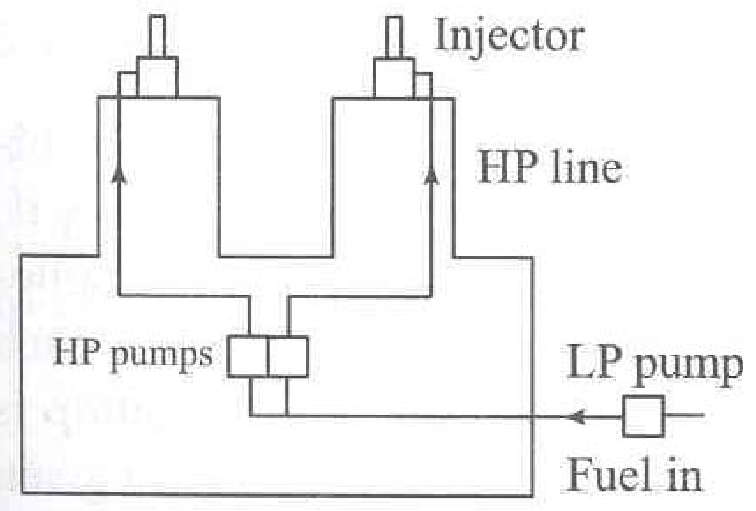
- In this system, each cylinder is provided with one pump and one injector.

- The high-pressure pump is again driven by a camshaft and thus directly coupled with the engine speed

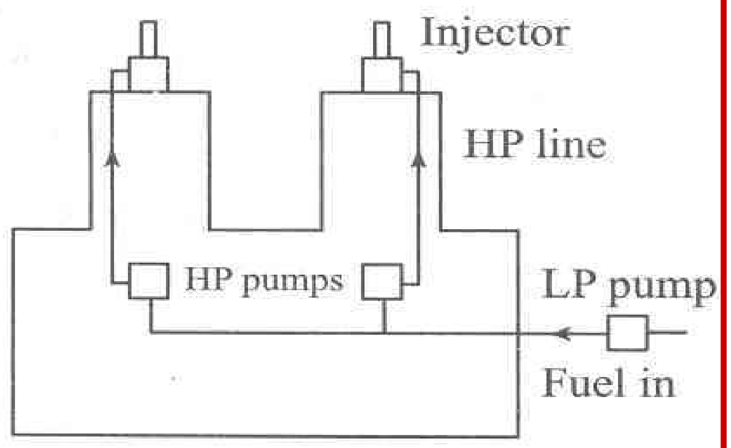
- The high pressure pump plunger is actuated by a cam, and produces the fuel pressure necessary to open the injector valve at the correct time.

Unit Pump System (UPS)

- The pump may be placed close to the cylinder or they may be arranged in cluster



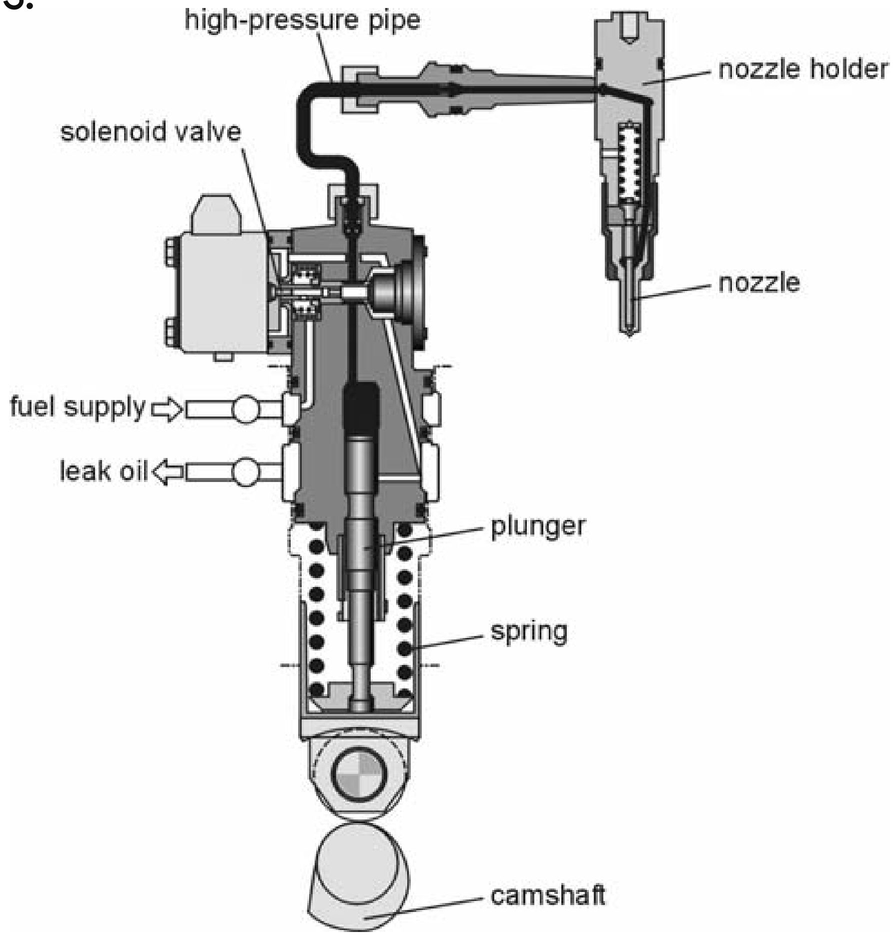
(b) Individual pump and nozzle with pumps in cluster



(a) Individual pump and nozzle with separated pumps

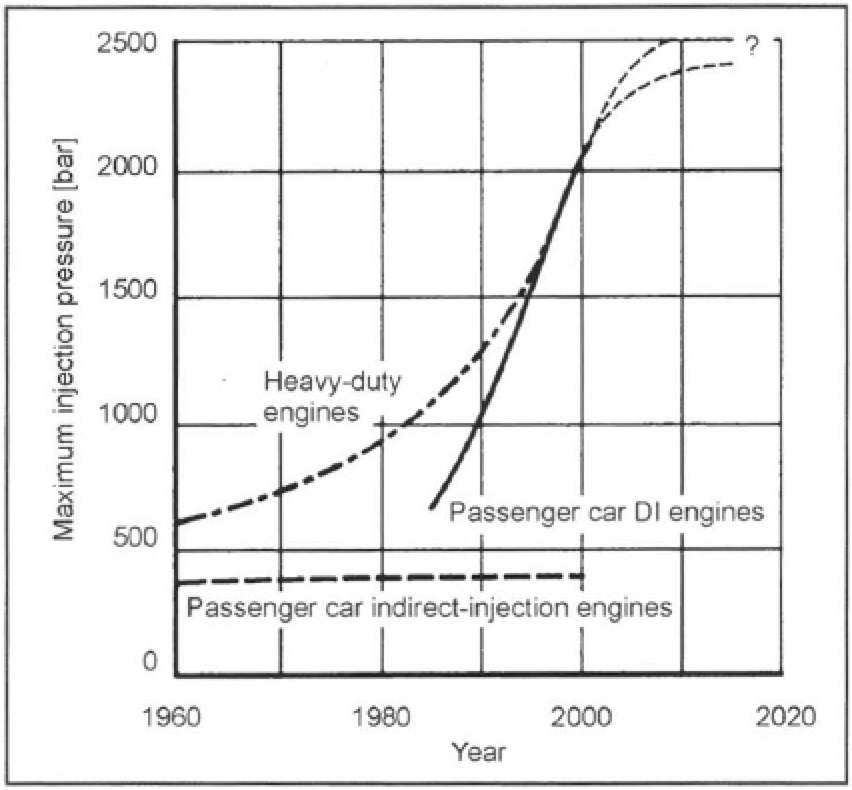
Unit Pump System (UPS)

The maximum attainable injection pressures of the UPS are smaller than those of the UIS.



INJECTION PUMP

- The main objectives of fuel-injection pump is to deliver accurately metered quantity of fuel under high pressure (in the range from 120 to 250 MPa) at the correct instant to the injector fitted on each cylinder.



Components of Earlier Fuel Injection System

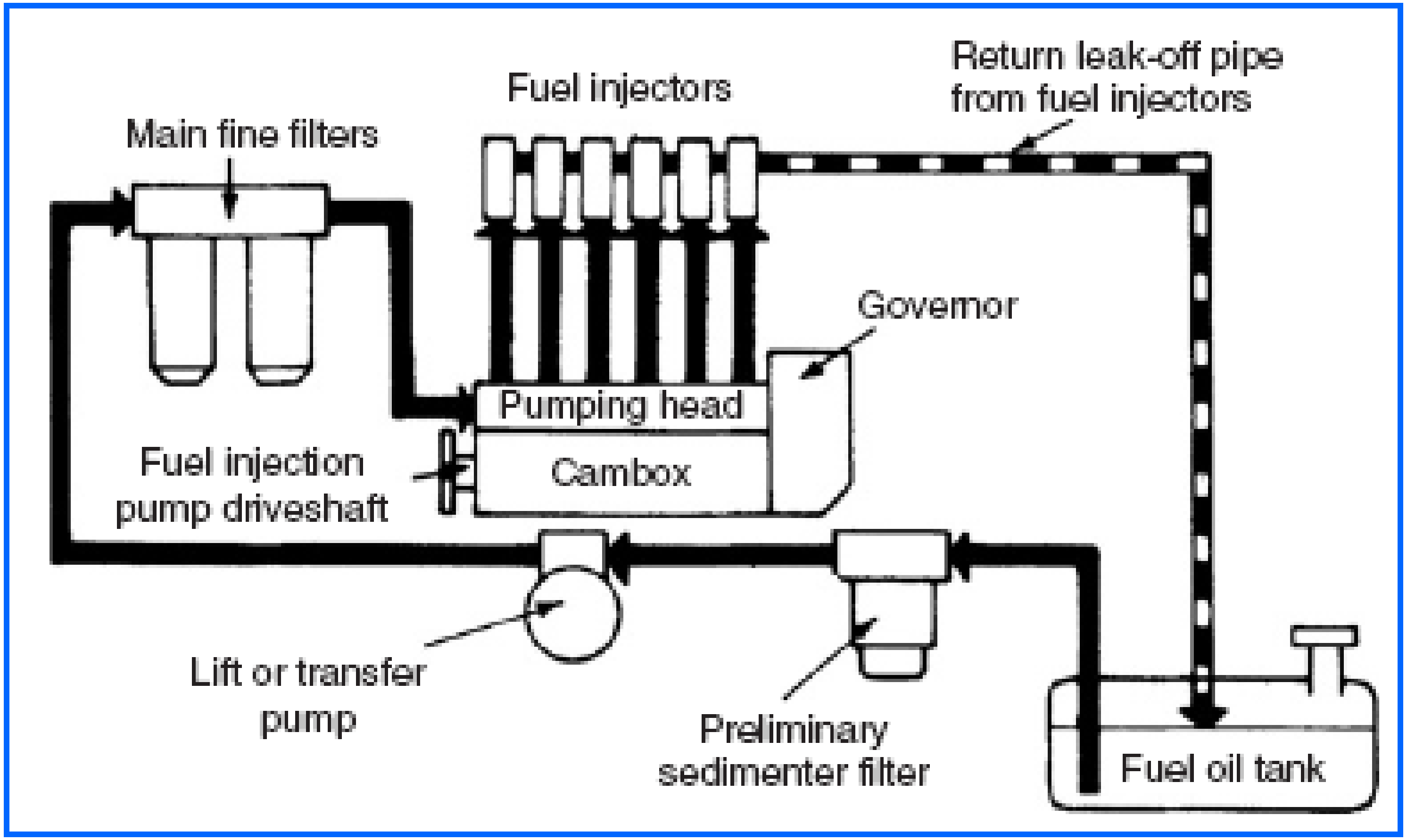


Fig: Simple Representation of Diesel Engine Fuel Injection System (In-line Pump)

Components of Fuel Injection System

- Fuel filters:
  - To prevent dust and abrasive particles from entering the pump
- Fuel feed pump
  - To supply fuel from the main fuel tank to the injection system.
- Injection pump
  - To meter and pressurize the fuel for injection,
- Governor
  - To ensure that the amount of fuel injected is in accordance with variation in load,
- Injector
  - To take the fuel from the pump and distribute it in the combustion chamber by atomizing it into fine droplets,

Injection pump Governor

- Fuel delivered by a pump increases with speed the same is true about the air intake

- This results in
  - Over fueling at higher speeds.
  - The engine tends to stall at idling speeds (low speeds) due to insufficiency of fuel.

Injection pump Governor

- Quantity of fuel delivered increases with load causing excessive carbon deposits and high exhaust temperature

- It is the duty of the injection pump governor to take care of the above limitation

- Governors are generally of two types,
  - *Mechanical governor*
  - *Pneumatic governor*

Fuel Injector

- Fuel injectors atomize the fuel into very fine droplets, and resulting in better mixing and subsequent combustion
- Atomization is done by forcing the fuel through a small orifice under high pressure.
- The injector assembly consists of
  - a needle valve
  - a compression spring
  - a nozzle
  - an injector body

Fuel Injector

- Fuel supplied by the injection pump exerts sufficient force against the spring to lift the nozzle valve
- After injection the spring pressure pushes the nozzle valve back on its seat
- Small quantity of fuel is allowed to leak through the clearance between nozzle valve and its guide for proper lubrication
- Valve opening pressure is controlled by adjusting the screw (spring tension)

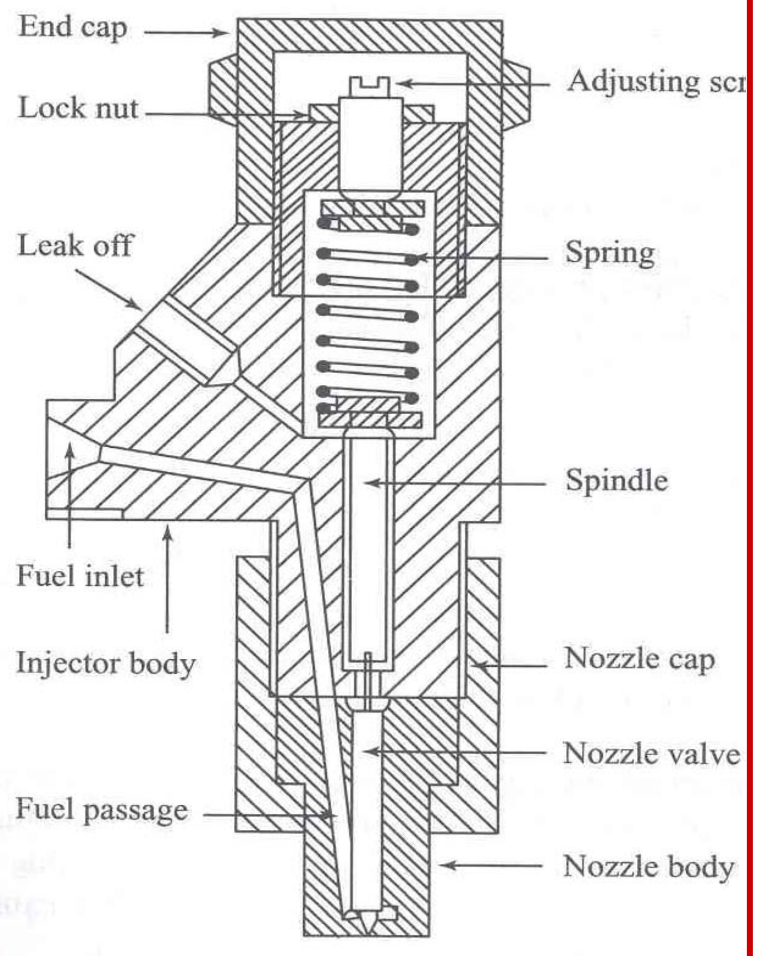


Fig. 9.11 Fuel Injector (Bosch)

Nozzle

- The main tasks of the nozzle in combination with the nozzle-holder assembly are to form the rate-of-discharge curve, atomize and distribute the fuel in the combustion chamber, and seal the hydraulic system from the combustion chamber.

- The nozzle construction and design need to be precisely harmonized with the different engine conditions. These are primarily:

  - Combustion processes [direct injection (DI), indirect injection (IDI)]
  - Geometry of the combustion chamber
  - Number of injection jets, the spray shape, and spray direction
  - Injection time
  - Injection rate

NOZZLE

- The nozzle should fulfill the following functions.

i. Atomization:

- This is a very important function since it is the first phase in obtaining proper mixing of the fuel and air in the combustion chamber.

ii. Distribution of fuel:

- Distribution of fuel to the required areas within the combustion chamber.

NOZZLE

Factors affecting fuel distribution

- Injection pressure
- Density of air in the cylinder
- Physical properties of fuel
  - The properties like self- ignition temperature, vapor pressure, viscosity, etc.

NOZZLE

iii. *Prevention of impingement on walls*

- Prevention of the fuel from impinging directly on the walls of combustion chamber or piston. F*uel striking the walls, decomposes and produces carbon deposits.*

  - This causes smoky exhaust as well as increase in fuel consumption.

iv. Mixing

- Mixing the fuel and air in case of *non-turbulent type of combustion chamber* should be taken care of by the nozzle.

Types of Nozzle

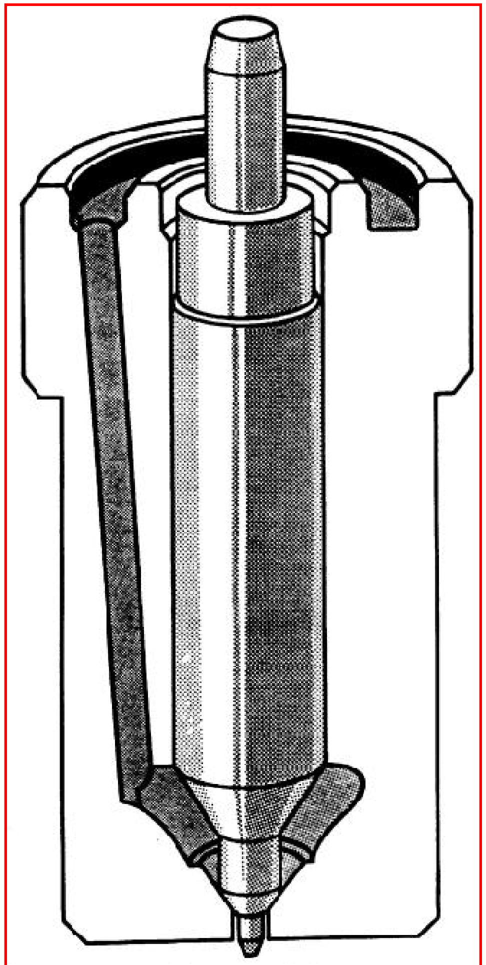
The most common types of Nozzles are:

i. pintle nozzle,

ii. single hole nozzle

iii. multi-hole nozzle,

iv. pintaux nozzle



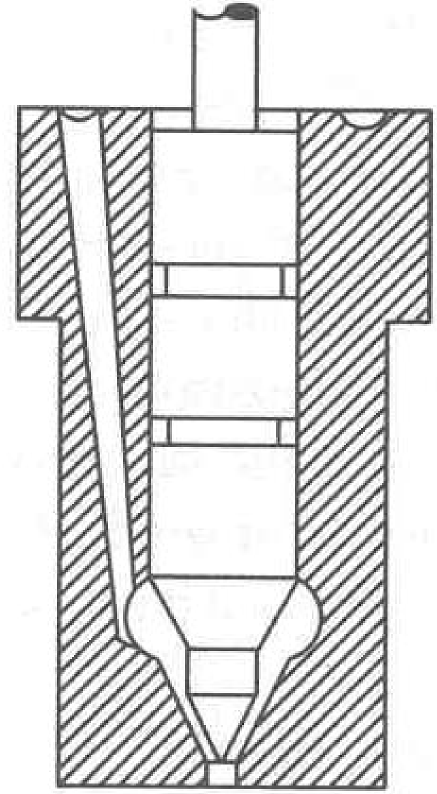
Type of nozzle

(i) ***Pintle Nozzle:***

- It provides a spray operating at low injection pressures of 8-10 Mpa
- The spray cone angle is generally 60^0
- Advantage of this nozzle is that
  - It avoids weak injection and dribbling.
  - It prevents the carbon deposition on the nozzle hole.

Single Hole Nozzle

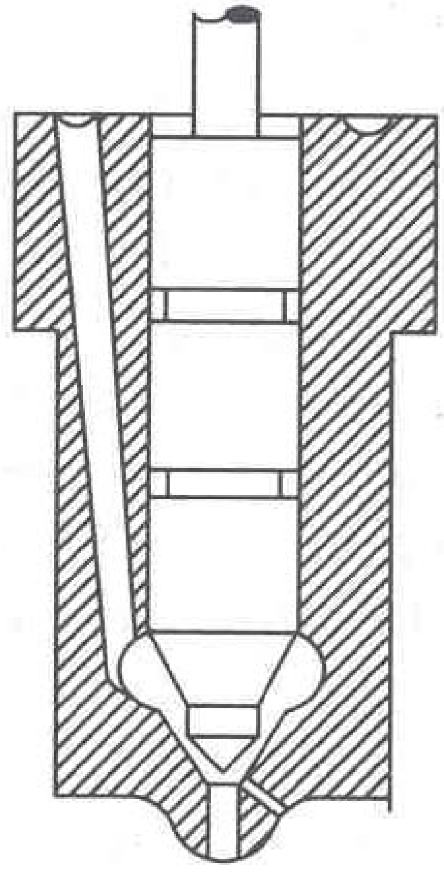
- At the centre of the nozzle body there is a *single hole which is closed by the nozzle valve*
- The size of the hole is usually of the order of ***0.2 mm.***
- Injection pressure is of order of *8-10 MPa* and spray cone angle is about 15^0.
- Major *disadvantage with such nozzle is that they tend to dribble*
- Besides, their *spray angle is too narrow to facilitate good mixing* unless higher velocities are used



Single hole

Multi-hole Nozzle

- It consists of a number of holes bored in the tip of the nozzle.
- The number of holes varies from 4 to 18 and the size from 35 to 200μm.
- The hole angle may be from 20^0 upwards.
- These nozzles operate at high injection pressures of the order of 18 MPa.
- Their advantage lies in the ability to distribute the fuel properly even with lower air motion available in open combustion chambers.



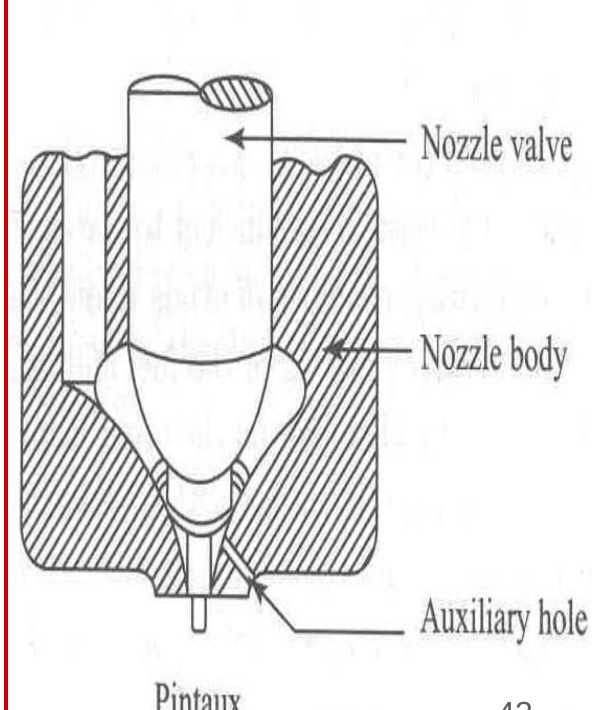
Multihole

Pintaux Nozzle

It is a type of pintle nozzle which has an auxiliary hole drilled in the nozzle body

It injects a small amount of fuel through this additional hole (pilot injection) in the upstream direction slightly before the main injection.

- The needle valve does *not lift fully at low speeds and most of the fuel is injected through the auxiliary hole.*
- Main advantage of this nozzle is *better cold starting performance (20 to 25 °C lower than multi hole design).*
- A major drawback of this *nozzle is that its injection characteristics are poorer than the multi hole nozzle.*



Spray Formation

- *At the start of the fuel-injection the pressure difference across the orifice is low. Therefore single droplets are formed (fig a) .*
- As the *pressure difference increases*

i. A stream of fuel emerges from the nozzle ***(fig b),***

ii. The stream encounters aerodynamic resistance from the dense air in the combustion chamber ***(fig c)***

break-up distance (l_3): the length at which a fuel start forming spray

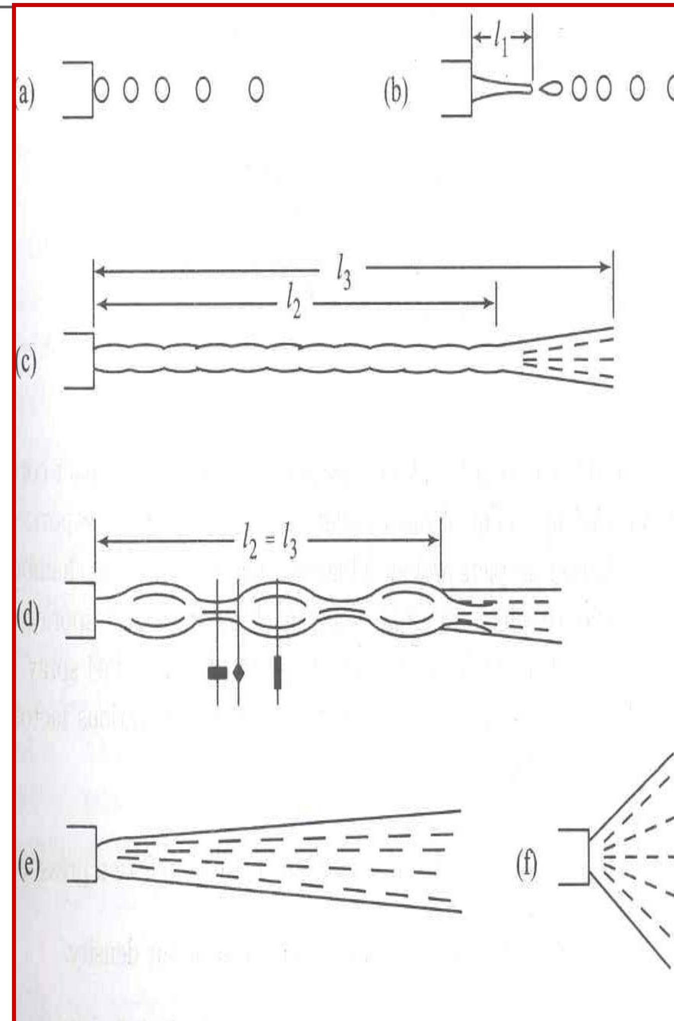
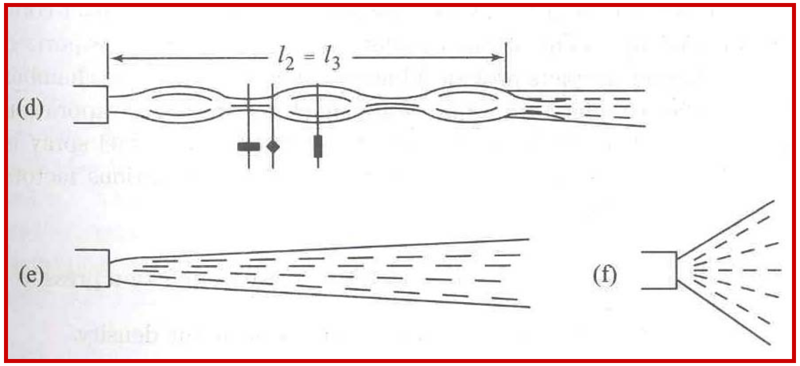


Fig. 9.13 Successive Phases of Spray Formation

Spray Formation

iii. With further and further increase in the pressure difference, the break-up distance decreases and the cone angle increases until the apex of the cone practically coincides with the orifice



The fuel jet velocity at the exit of the orifice, V_f, is of the order of 400 m/s. It is given by the following equation

$$V_f = C_d \sqrt{\frac{2(P_{inj} - P_{cyl})}{\rho_f}}$$

Where: C_d = coefficient of discharge for the orifice

P_{inj} = fuel pressure at the inlet to injector, N /m^2

P_{cyl} = pressure of charge inside the cylinder, N/m^2

ρ_f = fuel density, kg/m^3

Spray formation

- Larger droplets provide a higher penetration into the chamber but smaller droplets are required for quick mixing and evaporation of the fuel.
- The diameter of most of the droplets in a fuel spray is less than 5 microns.

Spray formation

The droplet sizes depends on various factors which are listed below

i. *Mean droplet size* decreases *with increase in injection pressure.*

ii. *Mean droplet size* decreases *with increase in air density.*

iii. *Mean droplet size* increases *with increase in fuel viscosity.*

iv. *Size of droplets* increases with *increase in the size of the orifice.*

Quantity of Fuel & the Size of Nozzle Orifice

- The quantity of the fuel injected per cycle depends to a great extent up on the power output of the engine.
- The volume of the fuel injected per second, Q, is given by

$$Q = (Area\ of\ all\ orifices) \times (Fuel\ jet\ velocity) \times (time\ of\ one\ injection) \times (No.\ of\ injection\ per\ \sec\ for\ one\ orifice)$$

$$Q = \left(\frac{\pi}{4} d^2 \times n\right) \times V_f \times \left(\frac{\theta}{360} \times \frac{60}{N}\right) \times \left(\frac{N_i}{60}\right)$$

where : N_i is the number of injections per minute.

N for four-stroke engine is rpm/2 and for a two-stroke engine Ni is rpm itself

d is the diameter of one orifice in m,

n is the number of orifices,

Θ is the duration of injection in crank angle degrees and

Quantity of Fuel & the Size of Nozzle Orifice

- The *rate of fuel injected/degree of crankshaft rotation* is a function of
  - *injector camshaft velocity,*
  - *the diameter of the injector plunger, and*
  - *flow area of the tip orifices.*

Quantity of Fuel & the Size of Nozzle Orifice

- Increasing the rate of injection decreases the duration of injection for a given fuel input
- A higher rate of injection may permit injection timing to be retarded from optimum value. This helps in maintaining fuel economy without excessive smoke emission.
- However, an increase in injection rate requires an increased injection pressure and increases the load on the injector push rod and the cam. This may affect the durability of the engine.