Fuel Injection System

Introduction

- The ***Functions of Fuel Injection System***
  - ***To enhance the engine***
    - *performance*
    - *Fuel economy*
  - ***initiating and controlling the combustion process***
  - ***preparation of the combustible charge (Just like carburetor)***

The main difference between Carburetor and Fuel injection system

- ***Carburetor***
  - Fuel is atomized by processes relying *on the air speed greater than fuel speed at the fuel nozzle*,
  - The *amount of fuel drawn into the engine depends upon the air velocity in the venturi*
- ***Fuel Injection System***
  - *The fuel speed at the point of delivery is greater than the air speed to atomize the fuel.*
  - the *amount of fuel delivered into the air stream going to the engine is controlled by a pump* which forces the fuel under pressure

Functional Requirements of An Injection System

i. ***Accurate metering of the fuel injected per cycle:*** The quantity of the fuel metered should vary to met changing speed and load requirements of the engine

ii. ***Timing the injection of the fuel correctly in the cycle:*** to obtain maximum power ensuring fuel economy and clean burning

iii. ***Proper control of rate of injection:*** The desired heat-release pattern is achieved during combustion

iv. ***Proper atomization of fuel into very fine droplets.***

v. ***Proper spray pattern to ensure rapid mixing of fuel and air***

vi. ***Uniform distribution of fuel droplets throughout the combustion chamber*** *vii.* ***To supply equal quantities of metered fuel to all cylinders 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

Classification of Injection Systems

- A ***fuel-injection system*** is required to ***inject and atomize fuel*** in to the cylinder of CI engines.

- 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***

Air Injection System

- ***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- ***The system is obsolete due to the requirement of multistage air compressors***.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 this system the ***liquid fuel is injected directly into the combustion chamber without the aid of compressed air***.

- Solid injection systems can be classified into four types.
  - ***Individual pump and nozzle system***
  - ***Unit injector system***
  - ***Common rail system***
  - ***Distributor system***

Components of Fuel Injection System

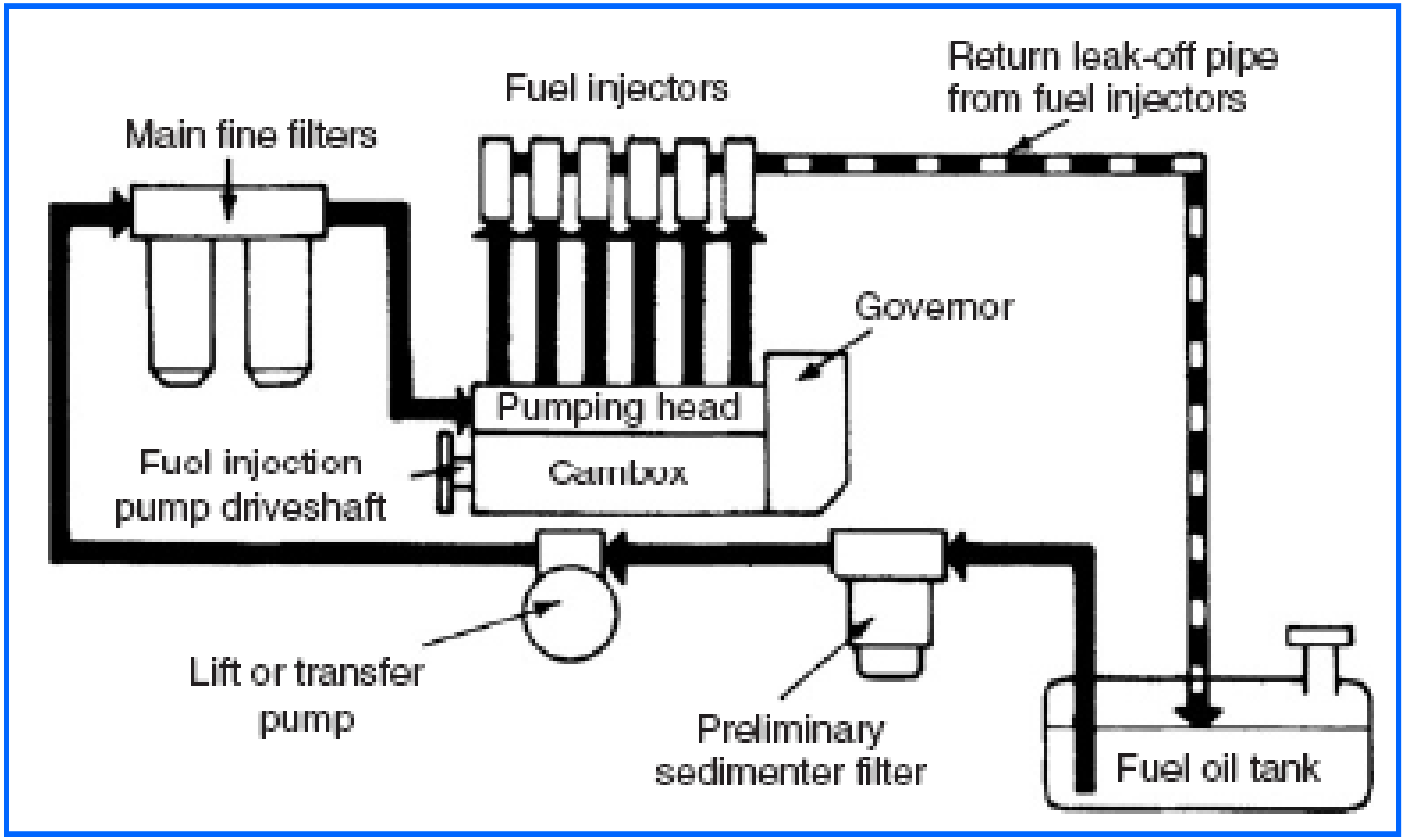
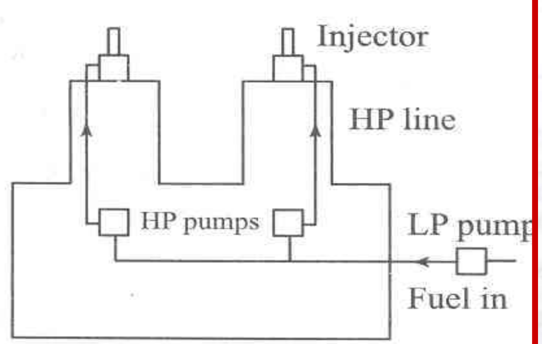


Fig: Simple Representation of Diesel Engine Fuel Injection System (In-line Pump)

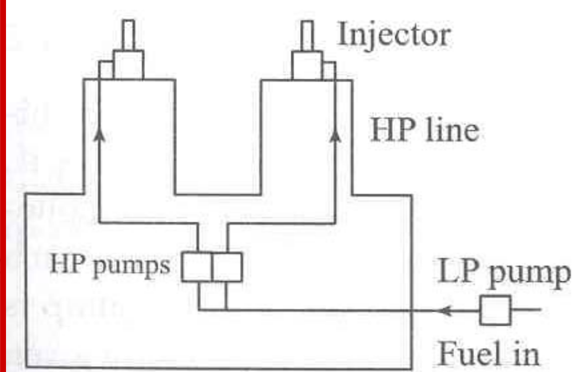
- ***Fuel tank***
- ***Fuel filters:*** to ***prevent dust and abrasive*** particles from ***entering the pump*** and injectors thereby ***minimizing the wear and tear*** of the components
- ***Fuel feed pump:*** to *supply fuel from the main fuel tank to the injection system*.
- ***Injection pump:*** 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,

I. Individual Pump and Nozzle System

- In this system, ***each cylinder is provided with one pump and one injector.***
- The pump may be placed close to the cylinder or they be arranged in cluster
- 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.



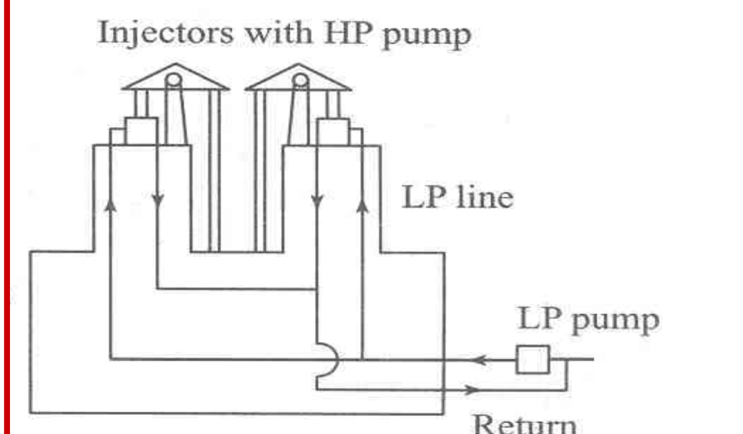
(a) Individual pump and nozzle with separated pumps



(b) Individual pump and nozzle with pumps in cluster

Unit Injector System (Internet Fig)

- is one in which the ***pump and the Injector nozzle are combined with one housing.***
- Each cylinder is provided with one of these unit injectors
- ***Fuel is brought up*** to the injector by ***low pressure pump***, where at the proper time, ***a rocker arm actuates the plunger*** and thus injects the fuel into the cylinder

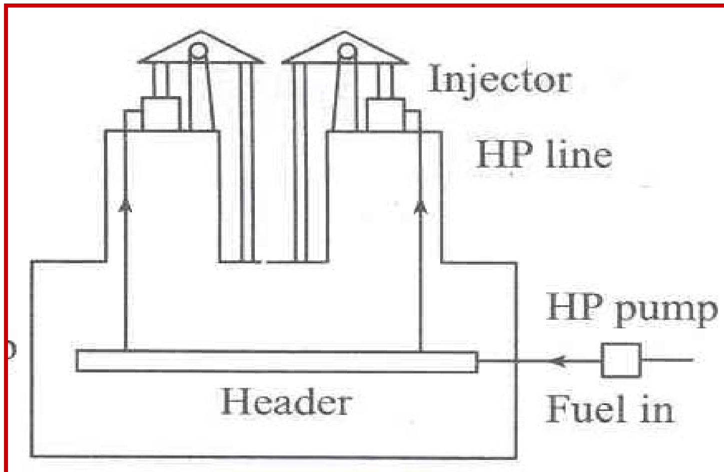


(c) Unit injector system

Common Rail System

- A ***HP pump*** supplies fuel, ***under high pressure***, to a fuel header.
- High pressure in the header forces ***the fuel to each of the nozzles*** located in the cylinders
- At the proper time ***mechanically operated valve allows the fuel to enter the cylinder*** through the nozzle.

The ***amount of fuel entering the cylinder*** is regulated by ***varying the length of the push rod stroke***



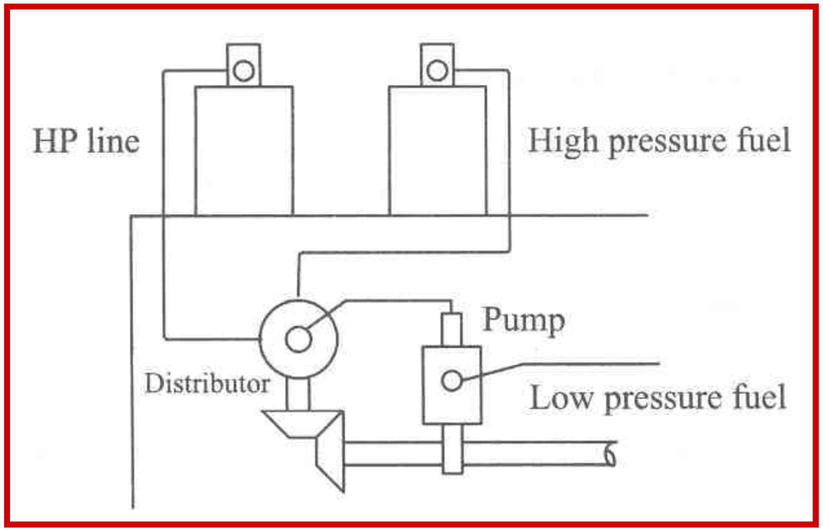
(d) Common rail system

Distributor System

- In this system the pump which ***pressurizes the fuel also meters and times it***.
- Fuel pump after metering the required amount of fuel supplies it to a ***rotating distributor at the correct time for supply to each cylinder.***

The number of injection strokes per cycle for the pump ***is equal to the number of cylinders***

Since there is ***one metering element*** in each pump, ***a uniform distribution is automatically ensured***

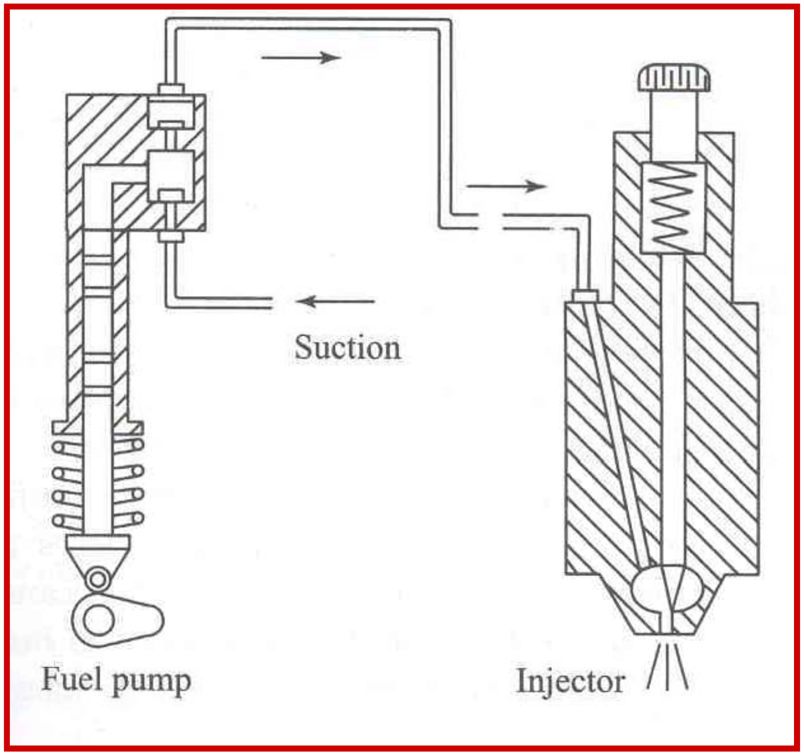


Fuel Feed Pump

- It is of spring loaded plunger type. *The plunger is actuated through a push rod from the Cam shaft.*

At the minimum lift position of the cam the spring force on the plunger creates *a suction which causes fuel flow from the main tank into the pump.*

When the cam is turned to its maximum lift position, the plunger is lifted upwards. At the same time *the inlet valve is closed and the fuel is forced through the outlet valve*

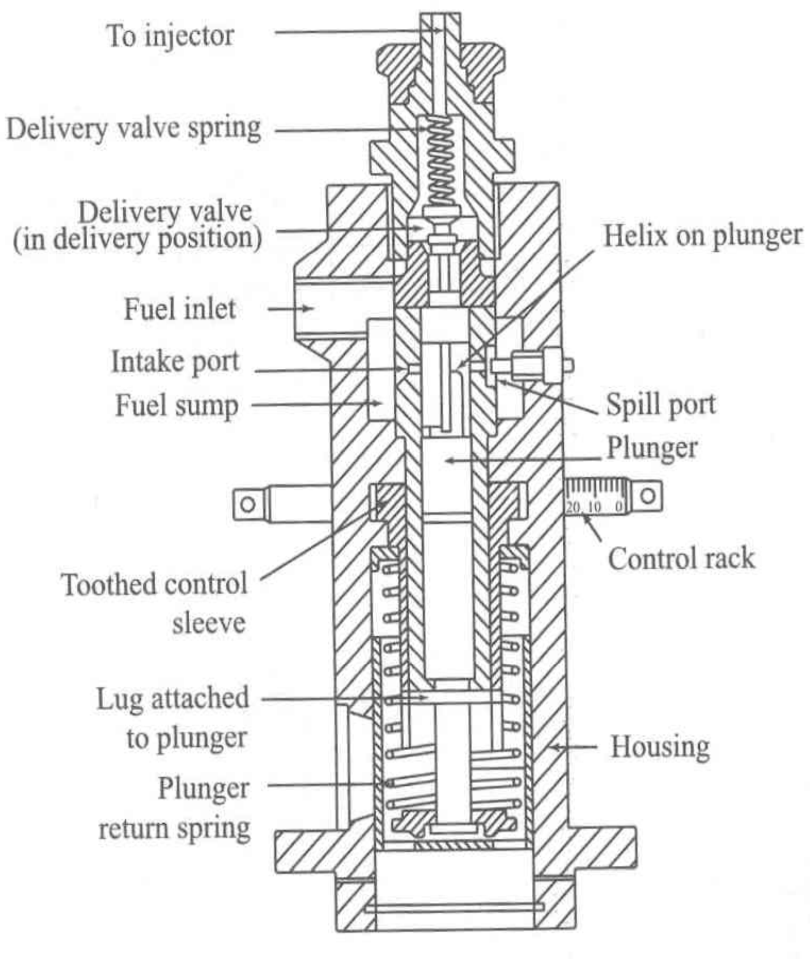


INJECTION PUMP

- The main objectives of ***fuel-injection pump*** is to deliver ***accurately metered quantity of fuel under high pressure*** (in the range from ***120 to 200 bar***) at the correct instant to the injector fitted on each cylinder.

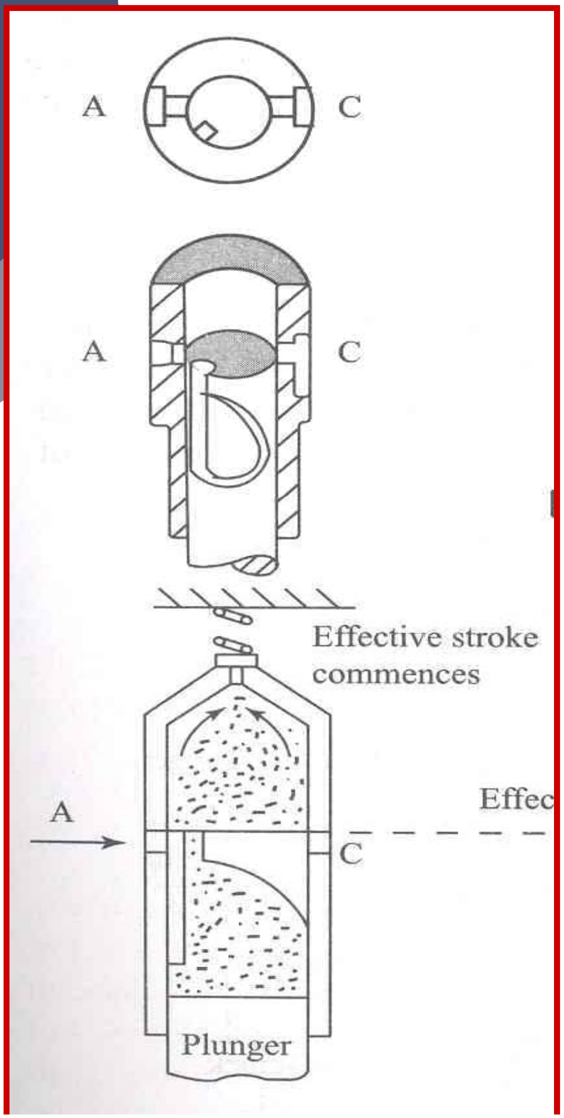
- Injection pumps are generally of two types,
  - ***Jerk type pumps***
  - ***Distributor type pumps***

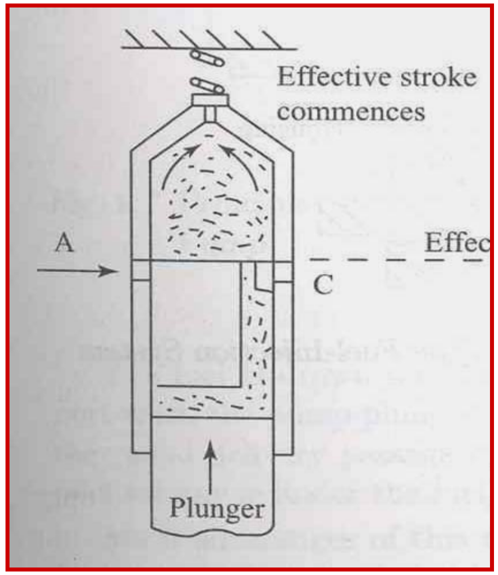
Fig: Single Cylinder Jerk Pump Type Fuel-Injection System

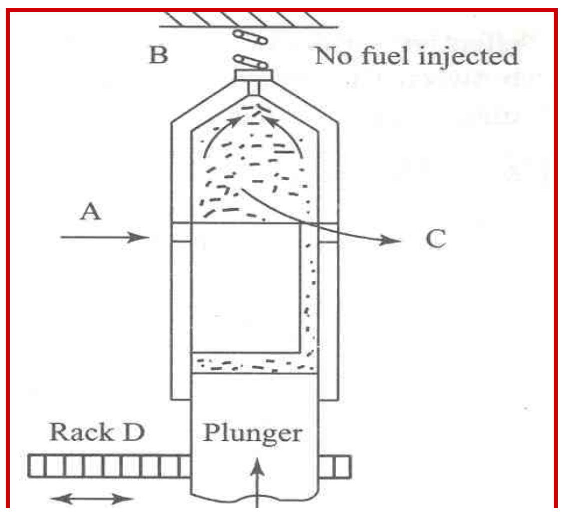


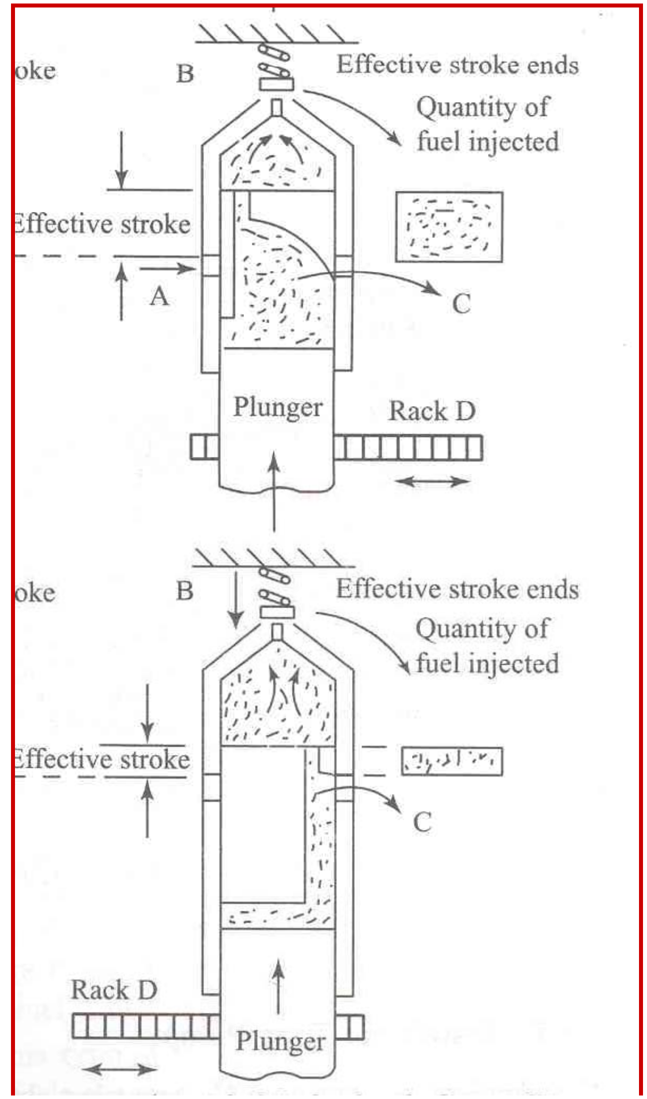
g. 9.6 Single Cylinder Jerk Pump Type Fuel-Injection Syst

Jerk Type Pumps





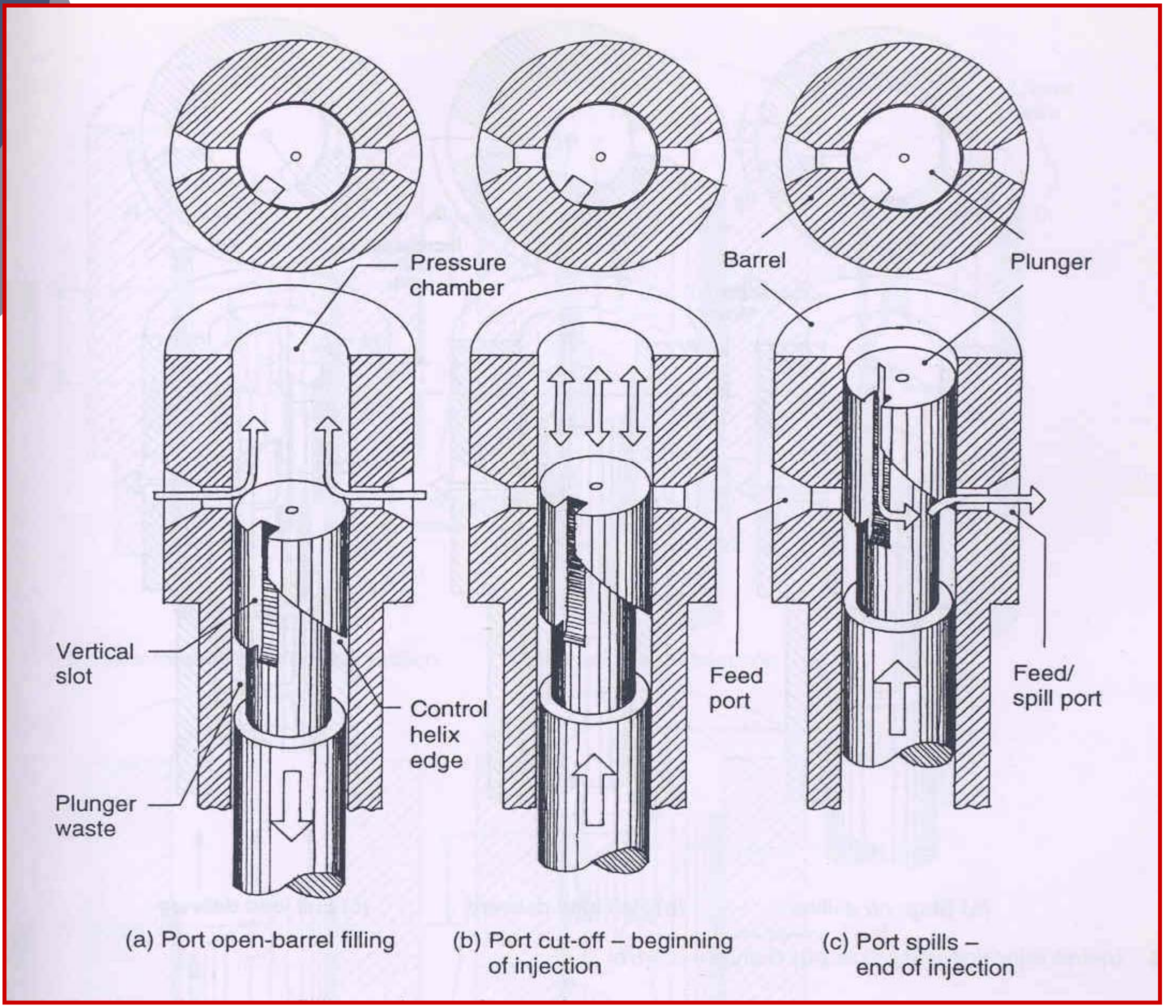




Jerk Type Pumps

- the ***axial movement of the plunger*** is through ***cam shaft,*** its ***rotational movement*** about its axis by means of ***rack D.***
- the fuel gets filled in the barrel, When *the plunger is below port A*
- the port A is closed, As the plunger rises
- the fuel will flow out through port C
- Port C is closed, when rack rotates the plunger
- the fuel is past the check valve through orifice B to the injector due to the high pressure developed
- The injection continues till the helical indentation on the plunger uncovers port C

Pump filling & Pumping Cycle



- Open-Barrel Filling
- Port Cut-off-beginning of injection
- Port spills end of injection

Fuel Delivery Output Control

- the axial distance traversed by the plunger is same for every stroke

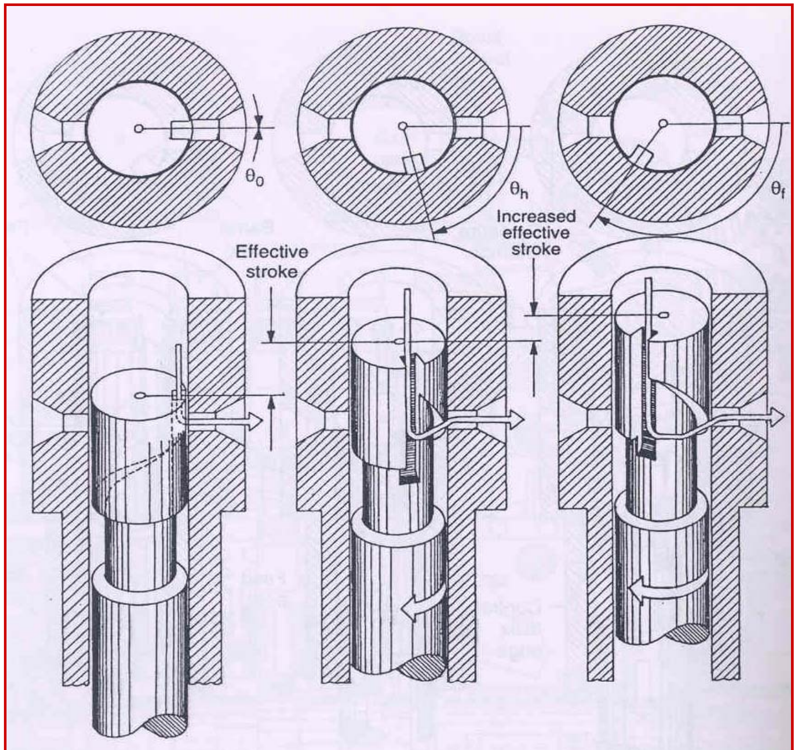
- ***The point on the upward travel of the plunger at which the spill occurs*** can be altered by ***twisting the plunger relative to the barrel***

- This enables ***the position of the plunger helical spill groove to be varied*** relative to the fixed barrel spill port, it there by ***increase or decreases the effective pumping stroke the plunger.***

Fuel Delivery Output Control

- ***To reduce delivery (b):*** The helical groove must be made to align with the spill port earlier in the plunger up stroke by rotating the plunger θ_h degree

- ***To increase Delivery (c):*** The helix groove must be aligned with the spill port later in the plunger stroke by rotating the plunger θf degrees so that the effective plunger stroke will be lengthened before spill occur



(a) Stop: no delivery (b) Half load delivery (c) Full load delivery

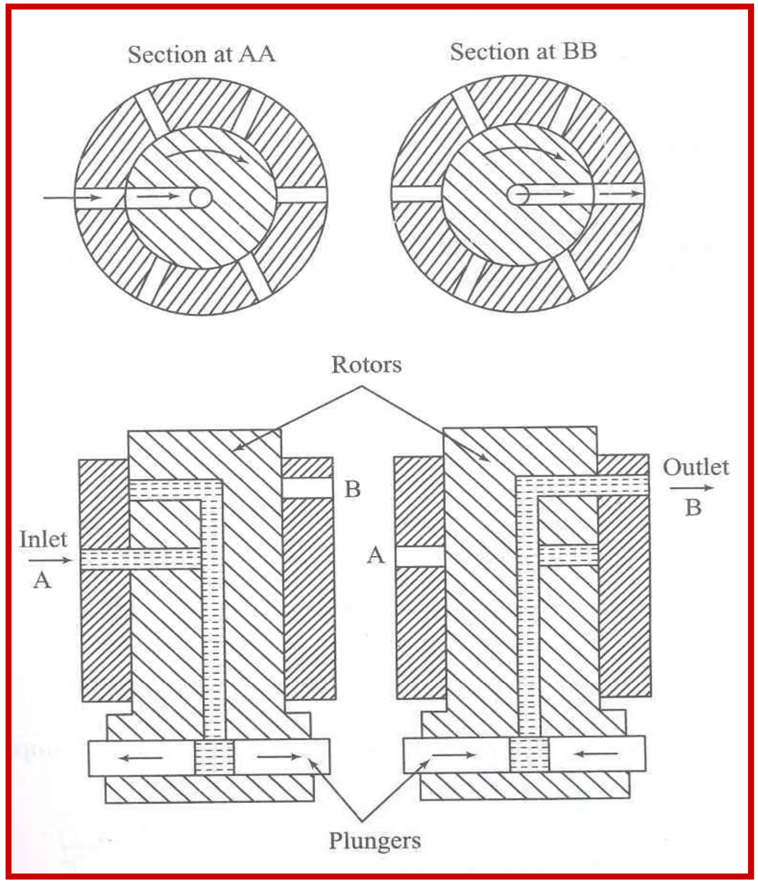
o***No delivery (shut-off Position) (a):*** by rotating it until the helical groove uncovers the spill Port in the barrel for entire strike

Distributor Type Pump (DPA Type)

- This pump has only a *single pumping element* and the *fuel is distributed to each cylinder by means of a rotor*

A *central longitudinal passage in the rotor* and *also two sets of radial holes (each equal to the number of engine cylinders)* located at different heights.

One set is connected to pump inlet via central passage whereas *the second set is connected to delivery lines* leading to injectors of the various cylinders.



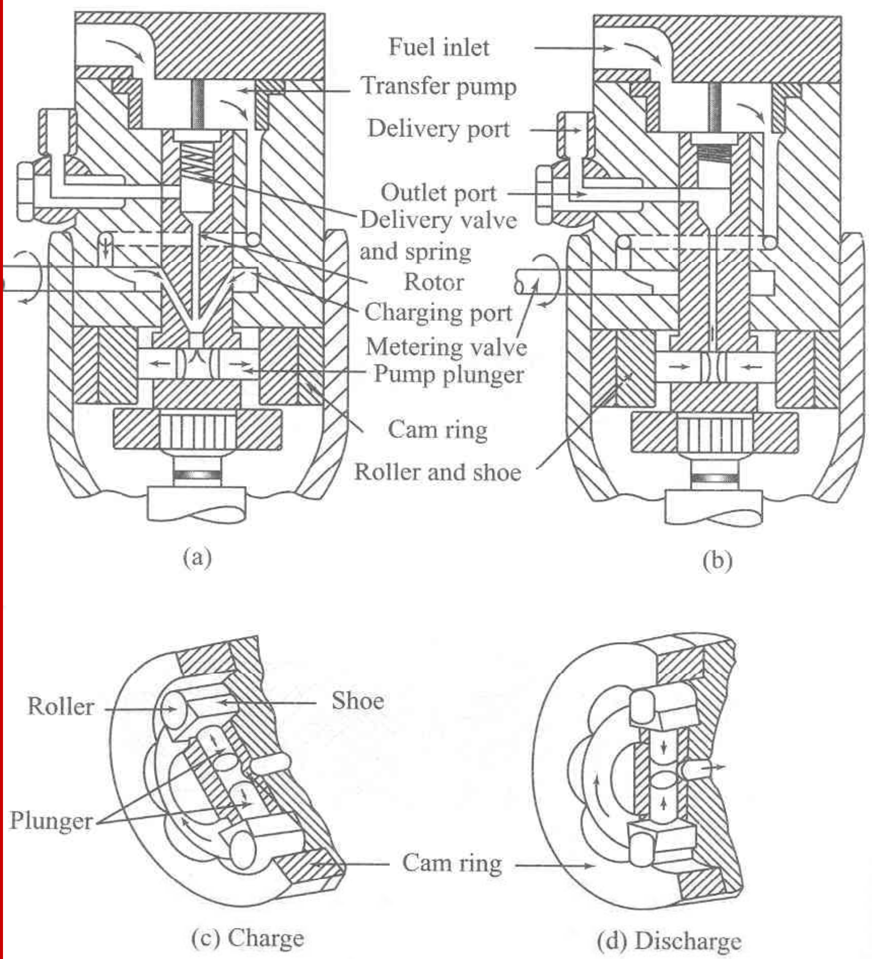


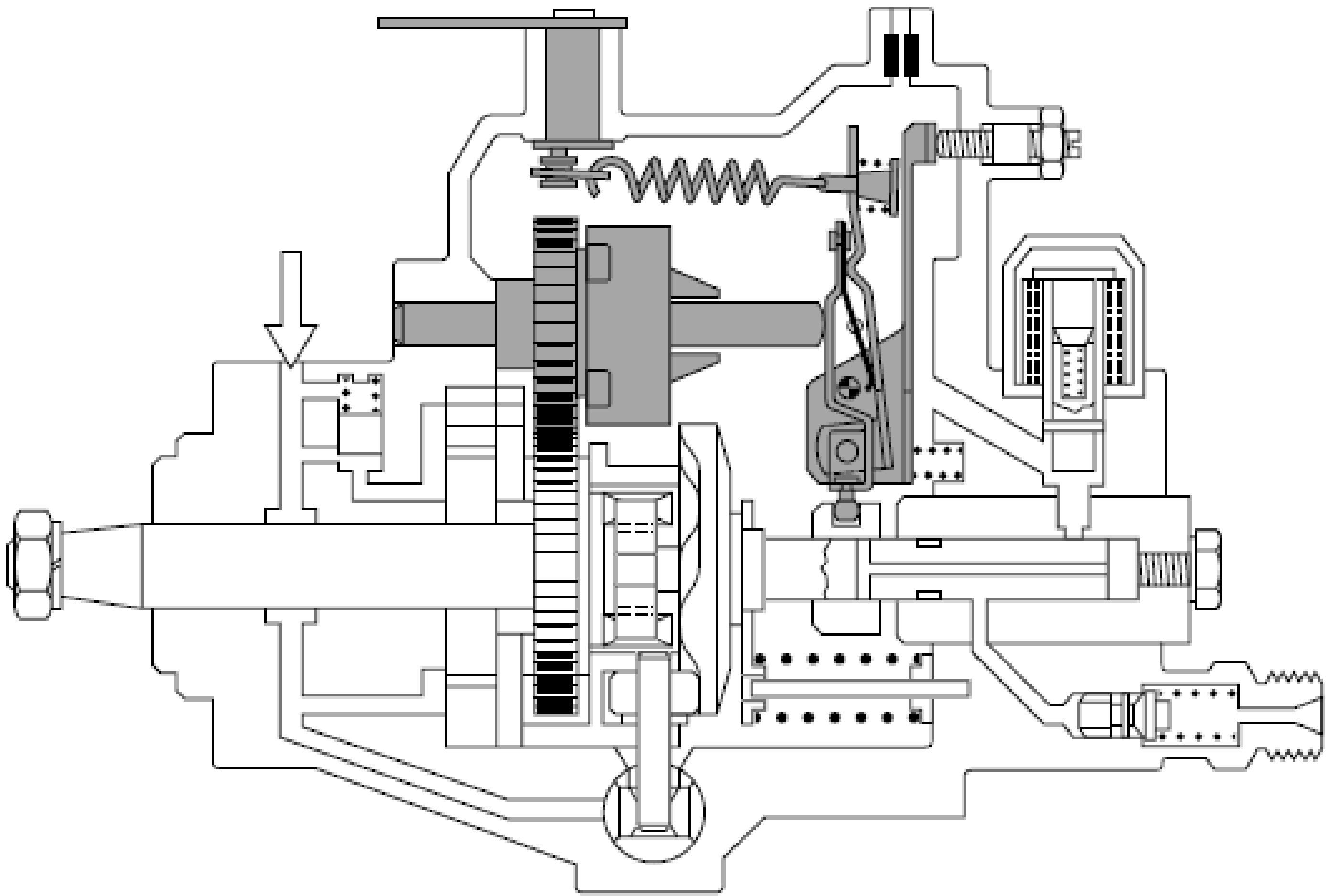
Fig. 9.8 Schematic of Roosa Master Distributor Pump

- *The fuel is drawn into the central rotor passage from the inlet port when the pump plunger move away from each other.*

- *Wherever, the radial delivery passage in the rotor coincides with the delivery port for any cylinder the fuel is delivered to each cylinder in turn.*

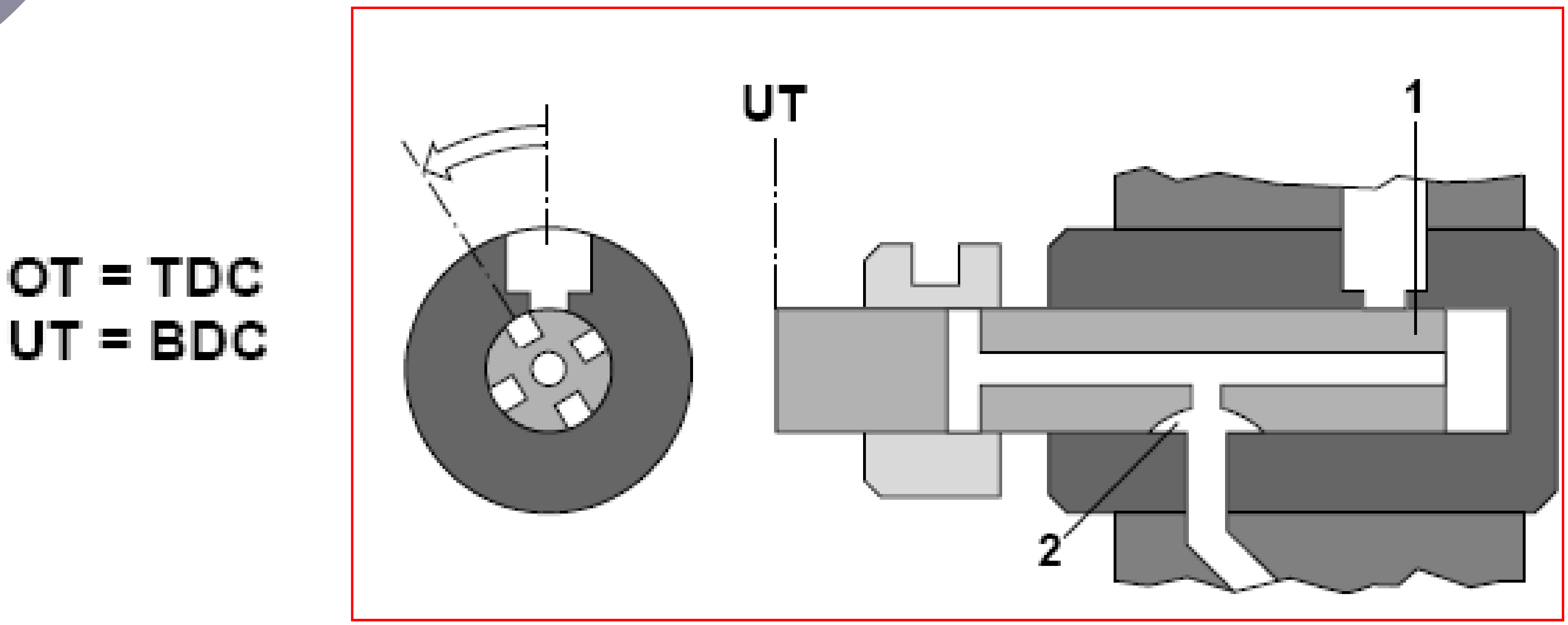
- Main advantages of this type of pump lies in its ***small size and its light weight***

Diesel distributor fuel-injection pumps VE (Bosch Type)



A) Inlet Passage Closes

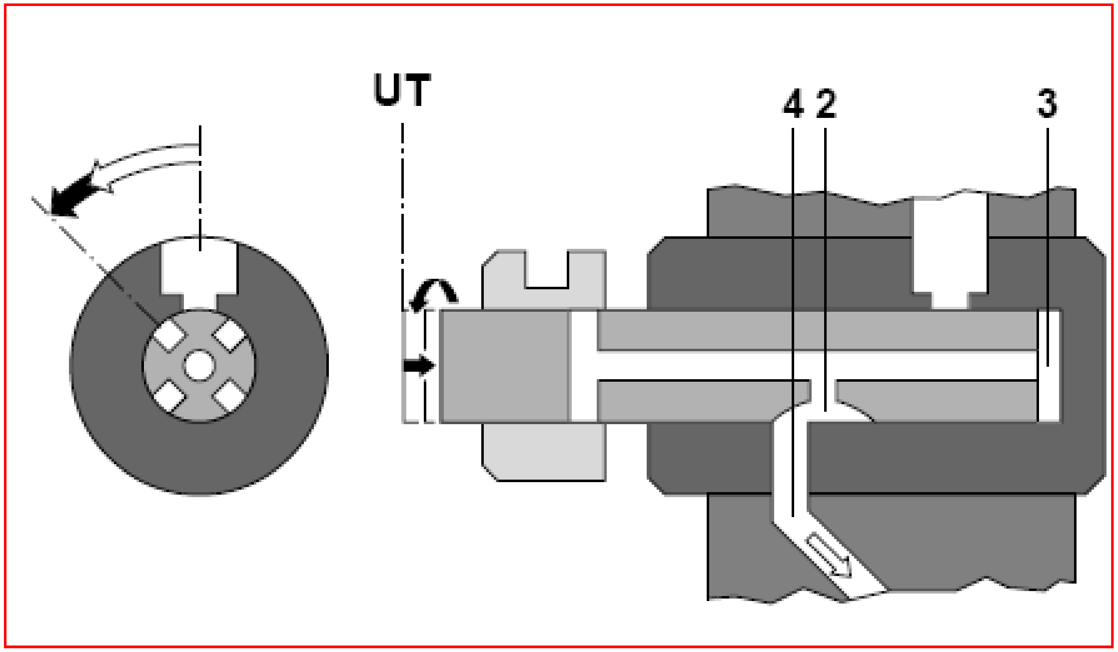
- *At BDC, the metering slot (1) closes the inlet passage, and the distributor slot (2) opens the outlet port.*



B) Fuel Delivery

- During the plunger stroke towards TDC (working stroke), the plunger pressurizes the fuel in the high pressure chamber (3). The fuel travels through the outlet-port passage (4) to the injection nozzle.

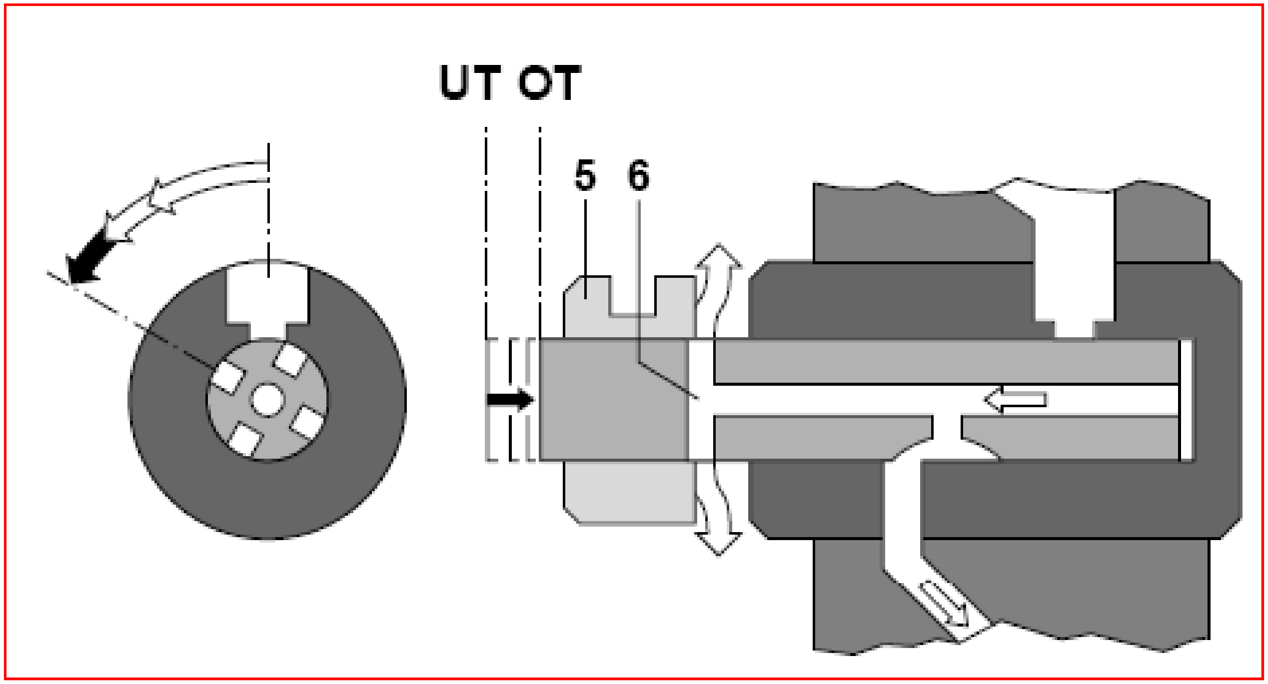
OT = TDC
UT = BDC



C) End of Delivery.

- *Fuel delivery ceases as soon as the control collar (5) opens the transverse cutoff bore (6).*

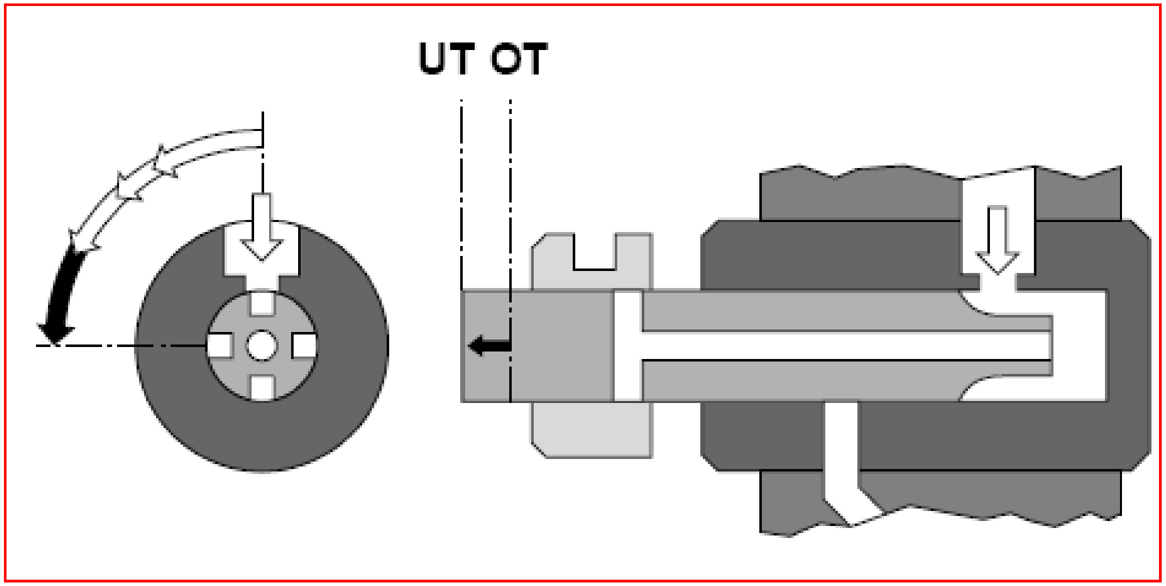
OT = TDC
UT = BDC



D) Entry of Fuel

Shortly before TDC, the inlet passage is opened. During the plunger's return stroke to BDC, the high-pressure chamber is filled with fuel and the transverse cutoff bore is closed again. The outlet-port passage is also closed at this point.

OT = TDC
UT = BDC



Governor

- In a CI Engine the fuel delivered is independent of the injection pump characteristic and the air intake
- *Fuel delivered by a pump increases with speed* whereas *the opposite 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.*
- *Quantity of fuel delivered increases with load* causing *excessive carbon deposits and high exhaust temperature*
- Drastic reduction in load will cause over speeding to dangerous values

Mechanical Governor

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

When the *engine speed tends to exceed the limit the weights fly apart.* This causes the *bell crank levers to raise the sleeve* and *operate the control lever in downward direction. This actuates the* ***control rack***

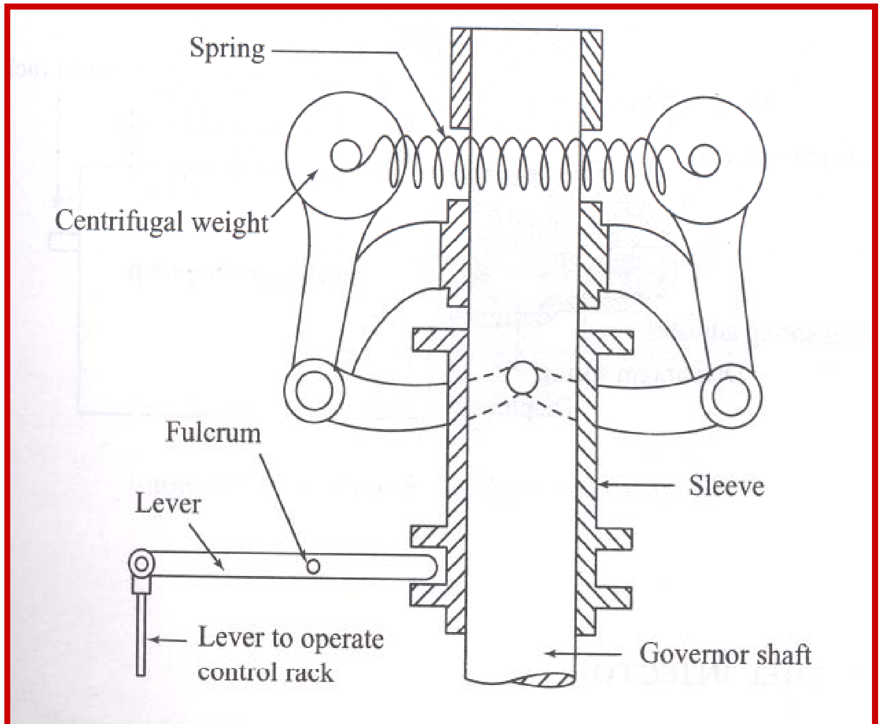


Fig. 9.9 Principle of Mechanical Governor

Pneumatic Governor

- The *amount of vacuum applied to the diaphragm is controlled by the accelerator pedal* through the position of the butterfly valve in the venturi unit
- *A diaphragm is connected to the fuel pump control rack*
- *position of the accelerator pedal* also *determines the position of the pump control rack* and *hence the amount of fuel injected*.

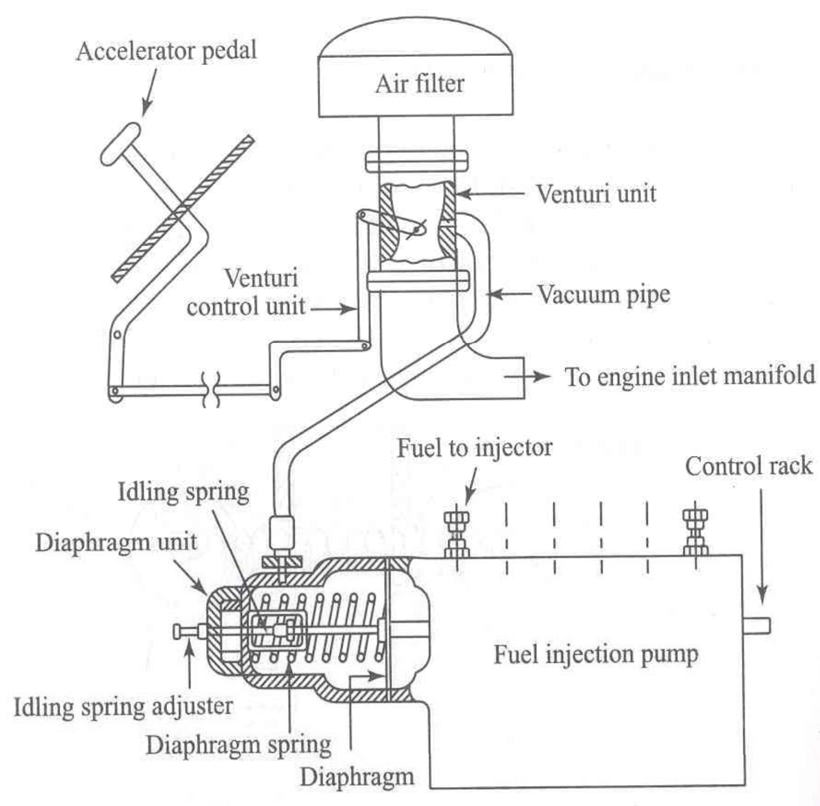


Fig. 9.10 Principle of Pneumatic Governor

Fuel Injector

- Fuel injectors ***atomize the fuel*** into very fine droplets, and ***increases the surface area*** of the fuel droplets ***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 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)

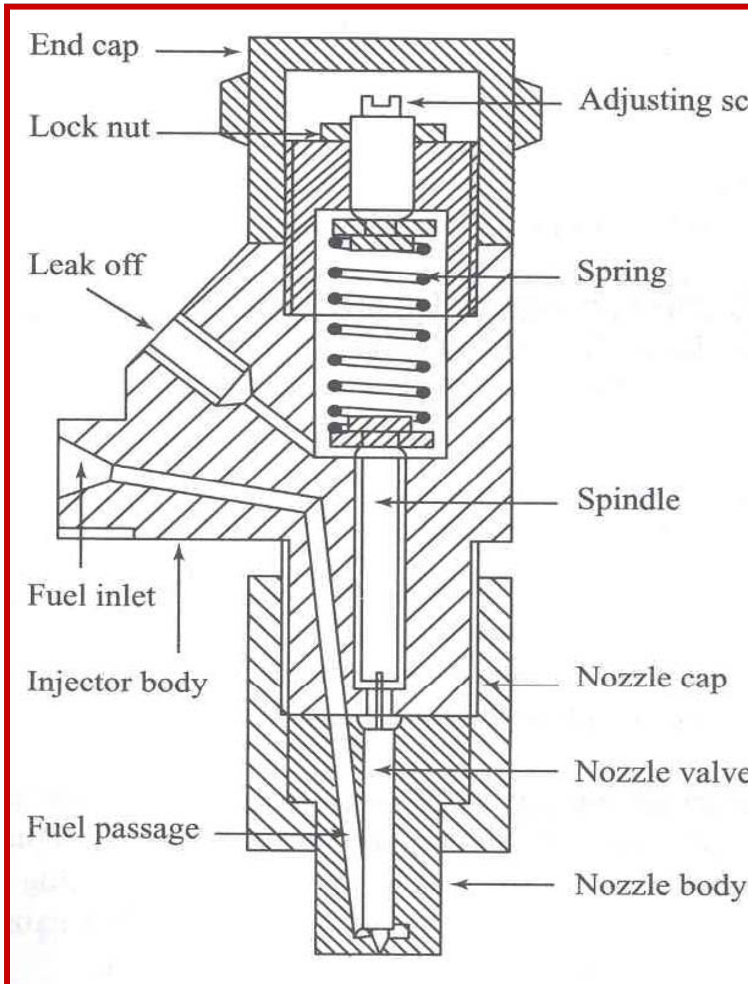


Fig. 9.11 Fuel Injector (Bosch)

NOZZLE

- Nozzle is that part of an injector through which ***the liquid fuel is sprayed*** into the combustion chamber.
- 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.

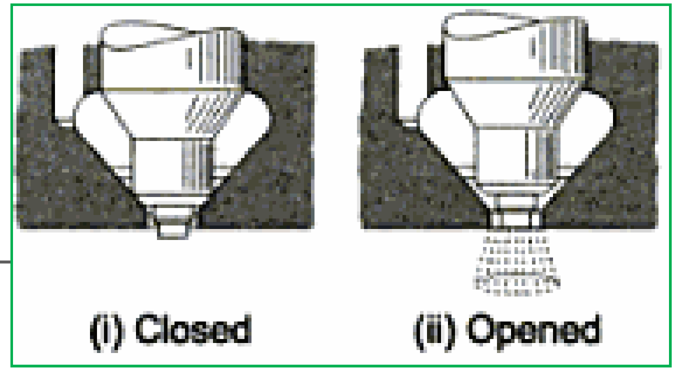
ii. ***Distribution of fuel:*** Distribution of fuel to the required areas within the combustion chamber. Factors affecting this are:

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

iii. Prevention* of *impingement* on *walls:
Prevention of the fuel from impinging directly on the walls of combustion chamber or piston. This is necessary because ***fuel 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



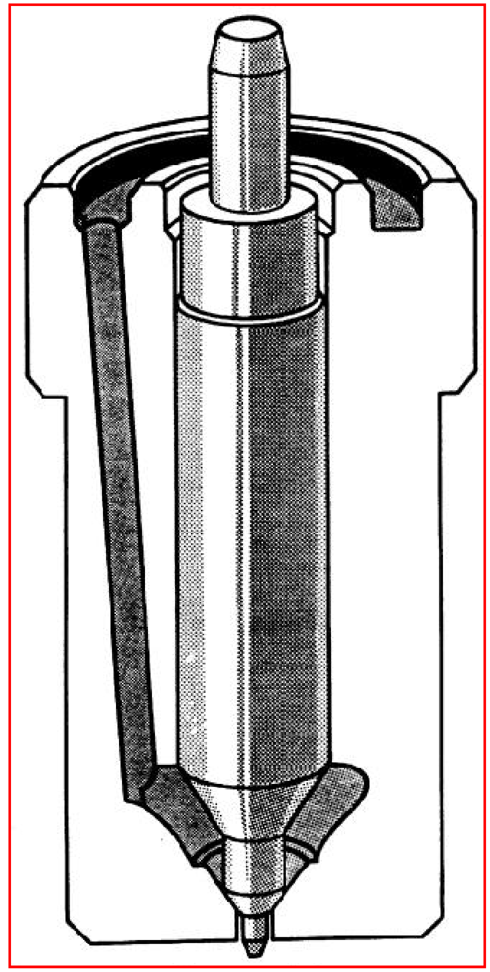
The most common types of Nozzles are:

i. *pintle nozzle,*

ii. *single hole nozzle*

iii. *multi-hole nozzle,*

iv. *pintaux nozzle*

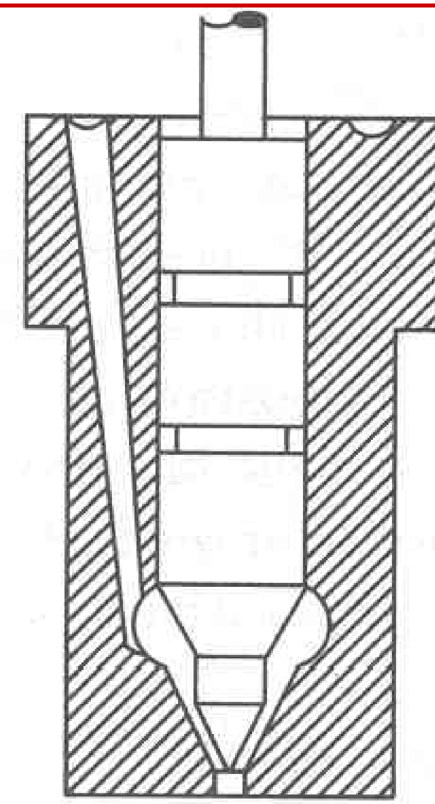


(i) Pintle Nozzle:

- The ***stem of the nozzle valve is extended*** to form a pin or pintle which protrudes through the mouth of the 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

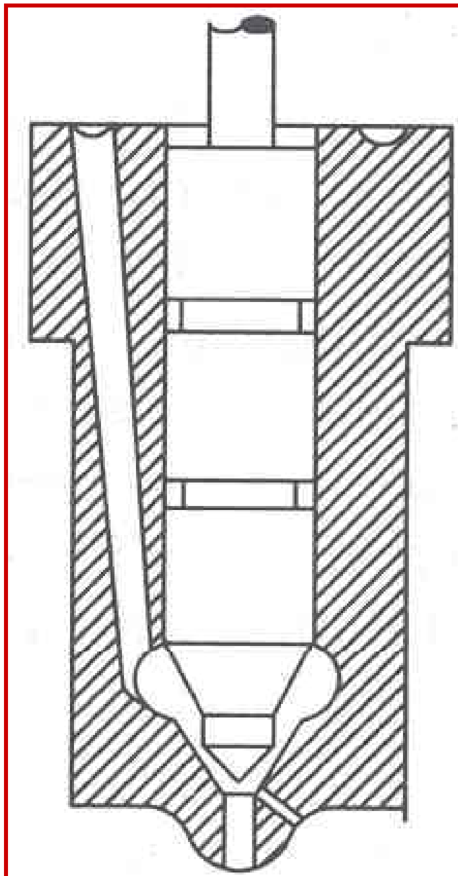
- At the centre of the nozzle body there is a *single hole which is closed by the nozzle valve*
- The size of the hole is usually of the order of ***0.2 mm.***
- Injection pressure is of order of ***8-10 MPa*** and spray cone angle is ***about 15^0.***
- Major *disadvantage with such nozzle is that they 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.



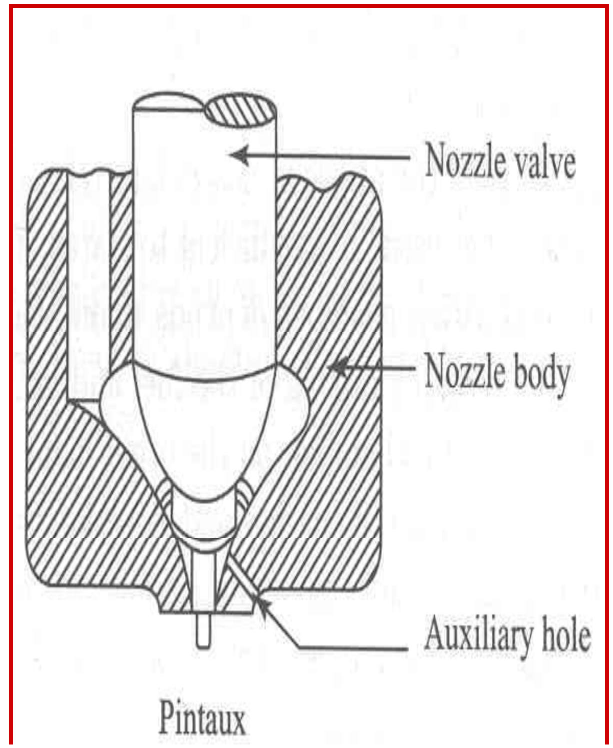
Multihole

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

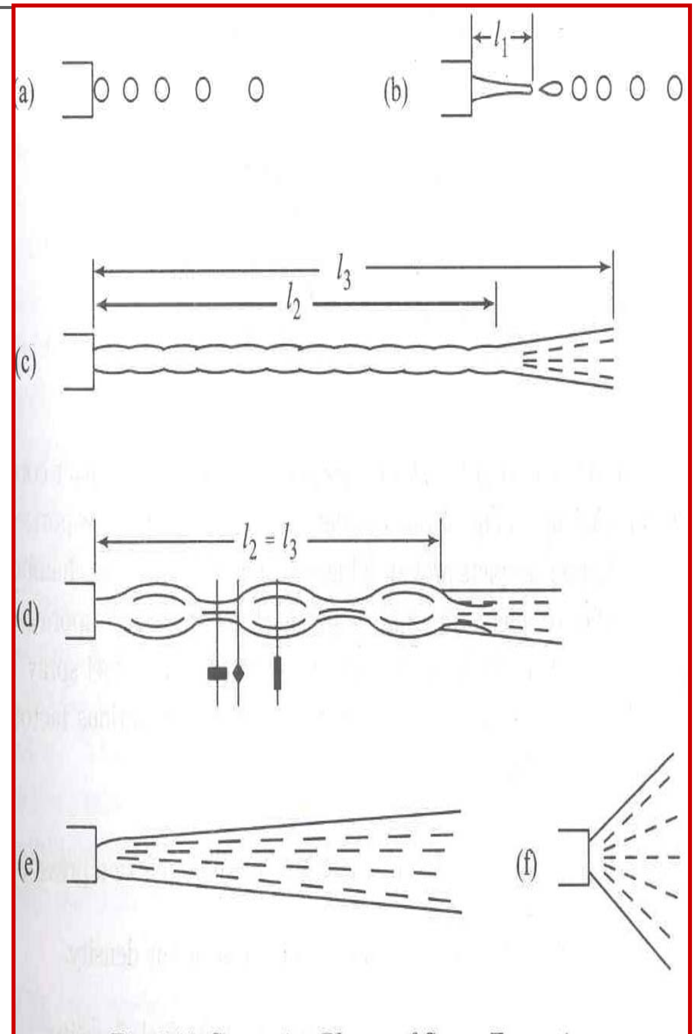
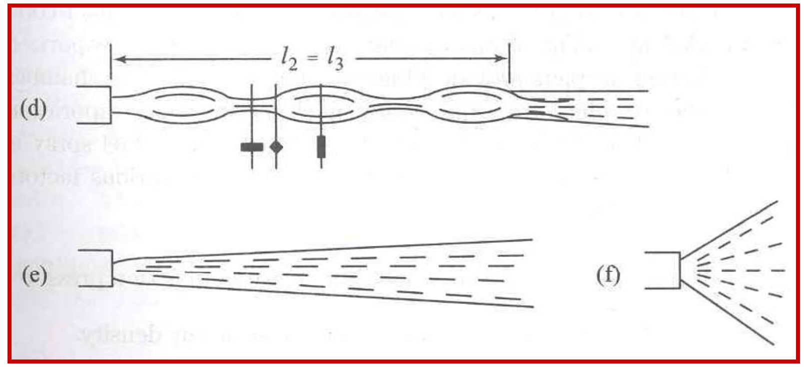


Fig. 9.13 Successive Phases of Spray Formation

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

- ***The spray from a circular orifice*** has a ***denser and compact core, surrounded by a cone of fuel droplets*** of various sizes and vaporized liquid.

- ***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.***

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_i 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

- ***Usually the rate of fuel-injection is expressed in mm^3/degree crank angle/litre cylinder displacement volume to normalize the effect of engine size.***

- 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.*

- *Increasing the rate of injection decreases the duration of injection* for a given fuel input and subsequently introduces a change in injection timing.
- 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.

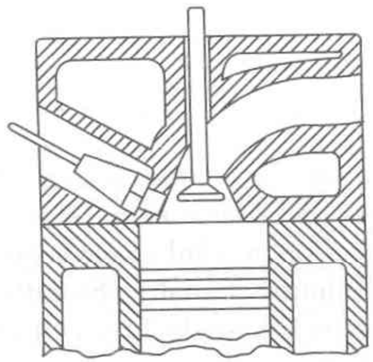
Injection in SI Engine

Presently *gasoline injection system is coming into vogue* in SI engines because of the following drawbacks of the carburetion.

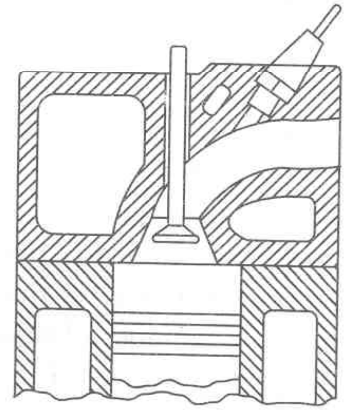
- *Non uniform distribution of mixture in multi cylinder engines.*
- *Loss of volumetric efficiency due to restrictions for the mixture flow and*
- *the possibility of back firing*

The injection of fuel into an SI engine can be done by employing any of the following methods

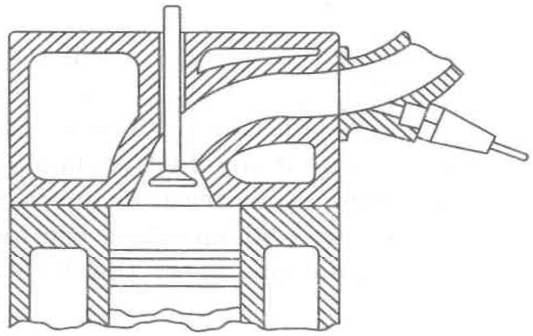
- *direct injection of fuel into the cylinder*
- *injection of fuel close to the inlet valve*
- *injection of fuel into the inlet manifold*



(a) Direct injection into the cylinder



(b) Injection upstream of inlet valve



(c) Injection into the inlet manifold

There are ***two types of gasoline injection systems***

- ***Continuous Injection:*** Fuel is continuously injected. It is *adopted when manifold injection is contemplated*
- ***Timed Injection:*** Fuel injected only during induction stroke over a limited period. Injection timing is not a critical factor in SI engines.

- Major *advantages of fuel-injection in an SI engine* are:
  - *Increased volumetric efficiency*
  - *Better thermal efficiency*
  - *Lower exhaust emissions*
  - *High quality fuel distribution*
- The use of petrol injection is limited by
  - *high initial cost,*
  - *complex design and*
  - *increased maintenance requirements.*