

MODULE-2

CARBURETION:

The process of preparing a combustible fuel-air mixture outside engine cylinder is known as carburetion.

Factors influencing Carburetion;

- time available for the mixture preparation i.e. atomisation, mixing and the vaporisation
- Temperature of the incoming air
- quality of the fuel supply
- design of combustion chamber and induction system

1.Simple Carburettor

It consists of a fuel jet of small diameter placed in a constricted tube called venturi or choke tube, float chamber as shown in Fig. 1. The fuel pump delivers fuel from the fuel tank to the float chamber. When sufficient fuel enters the float chamber, the float is lifted due to buoyancy and the conical needle valve engages and thus shuts off the fuel supply. If the fuel level tends to fall the float drops and thereby opens needle valve thus admitting more fuel. The float chamber vented to atmosphere a small hole, so that the pressure on the surface of the fuel remains constant and equal to that of atmosphere.

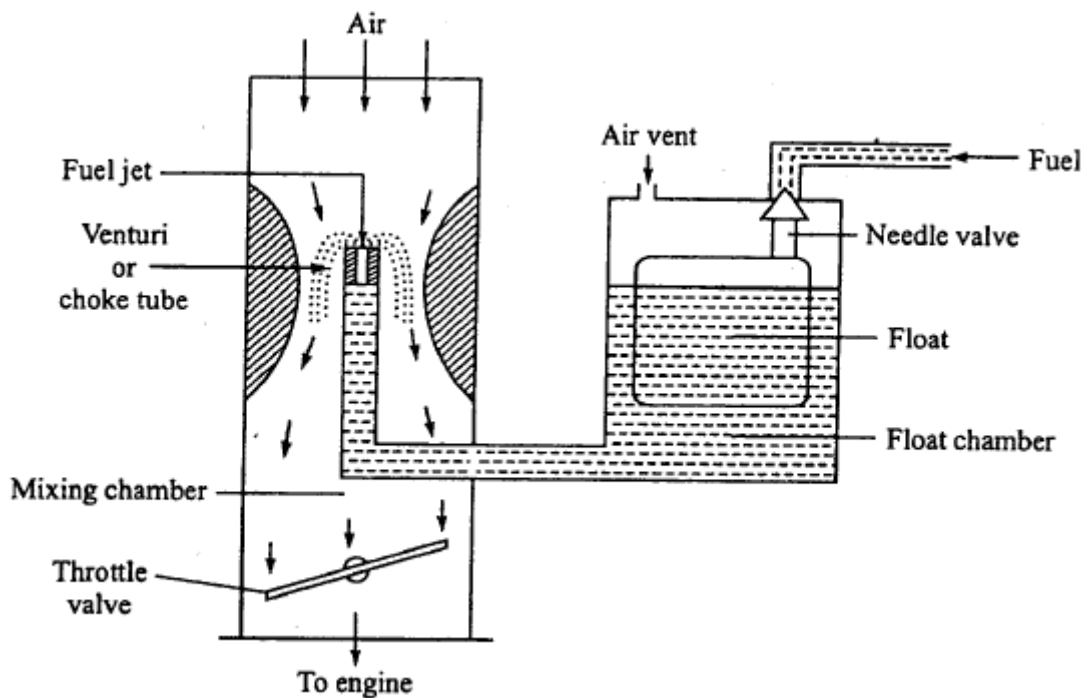


Fig. 1. Simple Carburettor

At the throat of the venturi tube, area of the cross section is minimum where the fuel discharge jet is situated. Air thus inducted increases its velocity from inlet and becomes maximum at the throat whereas pressure at the throat is below atmospheric. Due to the pressure difference fuel the fuel is forced out of the jet where it mixes with high velocity air and atomized and finally passed through the engine via throttle valve.

1.1 Calculation of A/F Ratio considering compressibility of air

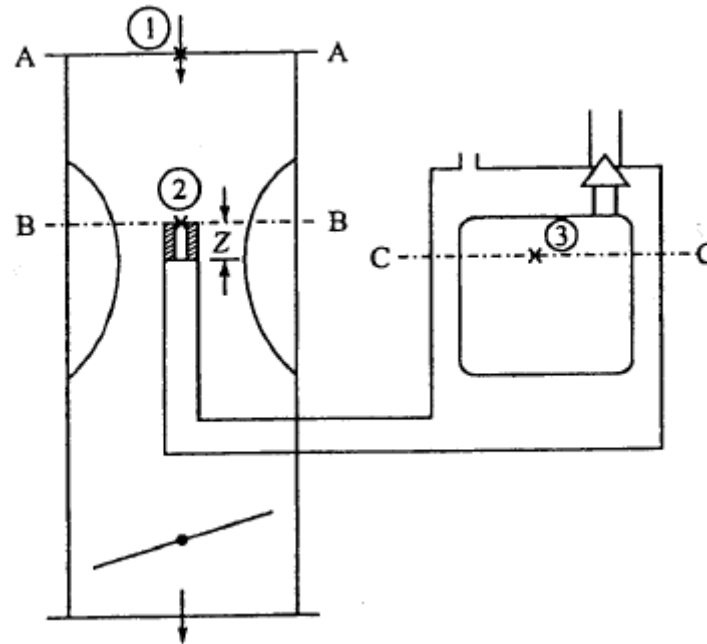


Fig. 1.1 Simple Carburettor showing section AA, BB and CC

Assumption

- flow is isentropic, $q = 0$
- work transfer between plane 1 and plane 2 is zero
- $Ca_1 \ll Ca_2$, So Ca_1 is negligible
- Cf_3 is negligible since the level of fuel does not drop in the reservoir
- Air is ideal gas, $h = c_p T$
- Pressure at plane 1 and plane 3 are both atmospheric, $P_3 = P_1$

Derivation

Applying SFEE between section AA (plane 1) and BB (plane 2) per unit mass of air flow

$$h_1 + \frac{Ca_1^2}{2} + q = h_2 + \frac{Ca_2^2}{2} + w \quad (1.1)$$

Where, q , w heat transfer and work transfer in between plane 1 and plane 2 and assumed zero.

Ca_1, Ca_2 are velocity of air in plane 1 and plane 2 respectively. Ca_1 is assumed to be zero.

h_1, h_2 are enthalpy of air in plane 1 and plane 2 respectively

$$Ca_2 = \sqrt{2(h_1 - h_2)} \quad (1.2)$$

$$Ca_2 = \sqrt{2C_p(T_1 - T_2)}$$

$$Ca_2 = \sqrt{2C_p T_1 \left(1 - \frac{T_2}{T_1}\right)} \quad (1.3)$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \quad (1.4)$$

$$Ca_2 = \sqrt{2C_p T_1 \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}\right]} \quad (1.5)$$

$$\dot{m}_a = \rho_1 A_1 Ca_1 = \rho_2 A_2 Ca_2 \quad (1.6)$$

where A_1, A_2 are area of crosssection in plane 1 and plane 2 respectively

$$\frac{P_2}{P_1} = \left(\frac{v_1}{v_2}\right)^\gamma = \left(\frac{\rho_2}{\rho_1}\right)^\gamma$$

$$\Rightarrow \rho_2 = \rho_1 \left(\frac{P_2}{P_1}\right)^{\frac{1}{\gamma}} \quad (1.7)$$

Now, $\dot{m}_a = \rho_2 A_2 Ca_2$

$$\dot{m}_a = \rho_1 \left(\frac{P_2}{P_1}\right)^{\frac{1}{\gamma}} A_2 \sqrt{2C_p T_1 \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}\right]}$$

$$\dot{m}_a = \rho_1 A_2 \sqrt{2C_p T_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{2}{\gamma}} - \left(\frac{P_2}{P_1}\right)^{\frac{\gamma+1}{\gamma}}\right]} \quad (1.8)$$

$$\dot{m}_a = \frac{P_1}{R\sqrt{T_1}} A_2 \sqrt{2C_p \left[\left(\frac{P_2}{P_1}\right)^{\frac{2}{\gamma}} - \left(\frac{P_2}{P_1}\right)^{\frac{\gamma+1}{\gamma}}\right]} \quad \text{since } \rho_1 = \frac{P_1}{RT_1} \quad (1.9)$$

$$(\dot{m}_a)_{act} = Cd_a \cdot \dot{m}_a$$

Where Cd_a coefficient of discharge for venturi

$$(\dot{m}_a)_{act} = Cd_a \frac{P_1}{R\sqrt{T_1}} A_2 \sqrt{2C_p \left[\left(\frac{P_2}{P_1} \right)^{\frac{2}{\gamma}} - \left(\frac{P_2}{P_1} \right)^{\frac{\gamma+1}{\gamma}} \right]} \quad (1.10)$$

Applying Bernoulli's theorem between section CC (plane 3) and BB (plane 2)

$$\frac{P_3}{\rho_f} + \frac{Cf_3^2}{2} = \frac{P_2}{\rho_f} + \frac{Cf_2^2}{2} + gZ \quad (1.11)$$

Where Cf_2 and Cf_3 are the velocity of fluid at plane 2 and plane 3 respectively. Cf_3 is negligible since the level of fuel does not drop in the reservoir.

Z is the height of the nozzle exit above the level of fuel in the float chamber.

$$Cf_2 = \sqrt{2 \left(\frac{P_3 - P_2}{\rho_f} - gZ \right)} \quad (1.12)$$

Pressure at plane 1 and plane 3 are both atmospheric, $P_3 = P_1$

$$Cf_2 = \sqrt{2 \left(\frac{P_1 - P_2}{\rho_f} - gZ \right)} \quad (1.13)$$

$$Cf_2 = \sqrt{\frac{2}{\rho_f} (\Delta P - \rho_f gZ)} \quad (1.13a)$$

$$\dot{m}_f = A_j Cf_2 \rho_f = A_j \sqrt{2\rho_f (\Delta P - \rho_f gZ)} \quad (1.14)$$

A_j is the area of cross section of the fuel jet at the exit from the nozzle.

$$(\dot{m}_f)_{act} = Cd_f A_j \sqrt{2\rho_f (\Delta P - \rho_f gZ)} \quad (1.15)$$

Cd_f is the coefficient of discharge for fuel nozzle

$$A/F \text{ Ratio} = \frac{(\dot{m}_a)_{act}}{(\dot{m}_f)_{act}}$$

$$A/F \text{ Ratio} = \frac{Cd_a P_1}{Cd_f R\sqrt{T_1}} \frac{A_2}{A_j} \sqrt{\frac{C_p \left[\left(\frac{P_2}{P_1} \right)^{\frac{2}{\gamma}} - \left(\frac{P_2}{P_1} \right)^{\frac{\gamma+1}{\gamma}} \right]}{\rho_f (\Delta P - \rho_f gZ)}} \quad (1.16)$$

1.2 Calculation of A/F Ratio considering compressibility of air

Applying Bernoulli's Theorem between section AA(plane1) and section BB(plane 2) by neglecting compressibility of air

$$\frac{P_1}{\rho_a} + \frac{Ca_1^2}{2} = \frac{P_2}{\rho_a} + \frac{Ca_2^2}{2} \quad (1.17)$$

Where Ca_1 is assumed to be zero.

$$Ca_2 = \sqrt{\frac{2(P_1 - P_2)}{\rho_a}} = \sqrt{\frac{2\Delta P}{\rho_a}} \quad (1.18)$$

$$\dot{m}_a = A_2 Ca_2 \rho_a = A_2 \sqrt{2\rho_a \Delta P} \quad (1.19)$$

$$(\dot{m}_a)_{act} = Cd_a A_2 \sqrt{2\rho_a \Delta P} \quad (1.20)$$

$$\frac{A}{F} \text{ Ratio} = \frac{(\dot{m}_a)_{act}}{(\dot{m}_f)_{act}} = \frac{Cd_a A_2}{Cd_f A_j} \sqrt{\frac{\rho_a \Delta P}{\rho_f (\Delta P - \rho_f gZ)}} \quad (1.21)$$

1.3 Comments

❖ From equation 1.14, when $\Delta P \leq \rho_f gZ$ no flow of fuel

when $\Delta P > \rho_f gZ$ fuel flow takes place

❖ From equation 1.18, minimum air velocity at the throat which may cause fuel flow

$$Ca_2 = \sqrt{\frac{2\Delta P}{\rho_a}} = \sqrt{\frac{2\rho_f gZ}{\rho_a}}$$

❖ At high rate of flow of air, $\Delta P \gg \rho_f gZ$. Hence $\rho_f gZ$ can be neglected compared to ΔP

So, equation 1.21 becomes

$$\frac{A}{F} \text{ Ratio} = \frac{Cd_a A_2}{Cd_f A_j} \sqrt{\frac{\rho_a}{\rho_f}}$$

❖ From equation 1.21, if density of air reduces the A/F ratio also reduces i.e mixture becomes richer. Therefore, at high altitude density of air is low for which mixture is richer.

1.4 Drawbacks of Simple Carburettor

- ❖ At low loads throttle valve is partially open, so the mixture is lean where as engine requires rich mixture at low loads
- ❖ At high load throttle valve is fully open that leads to maximum air flow. However engine requires the rich mixture at high load
- ❖ The simple carburettor cannot enrich the mixture during engine start and warm-up
- ❖ The simple carburettor cannot adjust to change in altitude

1.5 Morden Carburettor

Morden Carburettors vary considerably in design and in the means adopted for mixture compensation for speed and throttle opening. The essential parts in addition to float chamber, venturi tube, fuel nozzle and throttle are choke, main metering system.

1.5.1 Choke

All Morden Carburettors are provided with a choke valve in the air intake passage of the carburettor. It is butterfly type of valve as shown in the Fig. 1.2. Pulling the knob out closes the choke valve partially, providing a rich mixture for starting. After the engine has started, the knob is pushed back to open the valve which increases air flow through the carburettor, thus leaning the mixture.

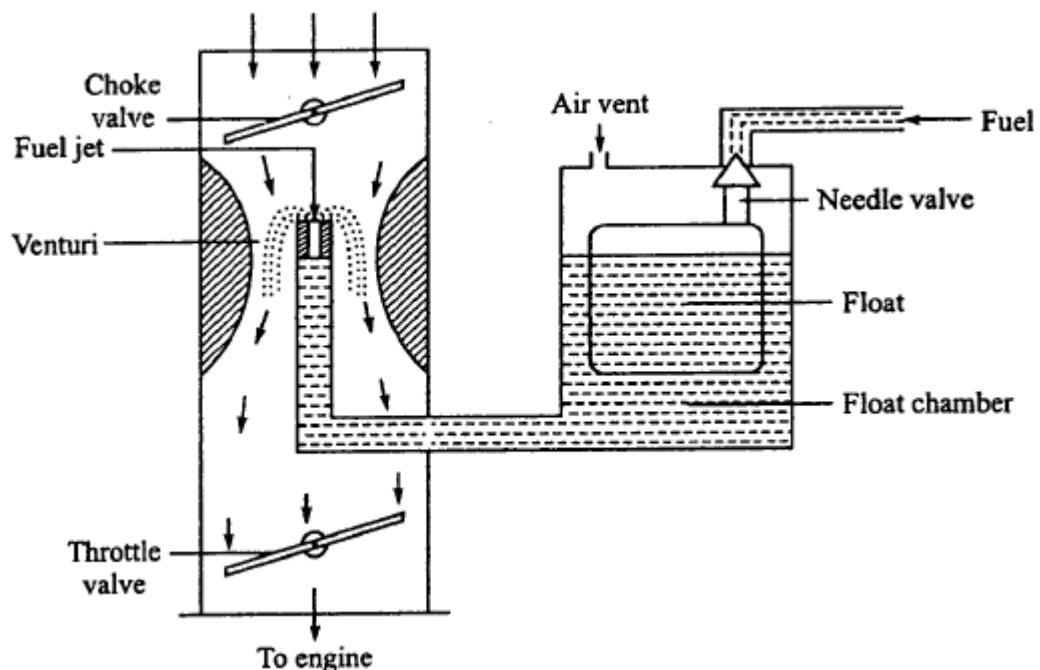


Fig. 1.2 : Choke

1.5.2 Main Metering System

The tendency of simple Carburettor is to increase the richness of charge with increase in load and speed. To compensate for this tendency of a simple Carburettor, several devices are used i.e Main Metering System.

An auxilliary air valve

Fig. 1.3 shows a carburettor with an auxilliary air valve. It automatically admits additional air as the mixture flow increases. The valve spring is operated by the vaccum which increases with increase in engine load and increases air admission in propertion in the lift of the valve.

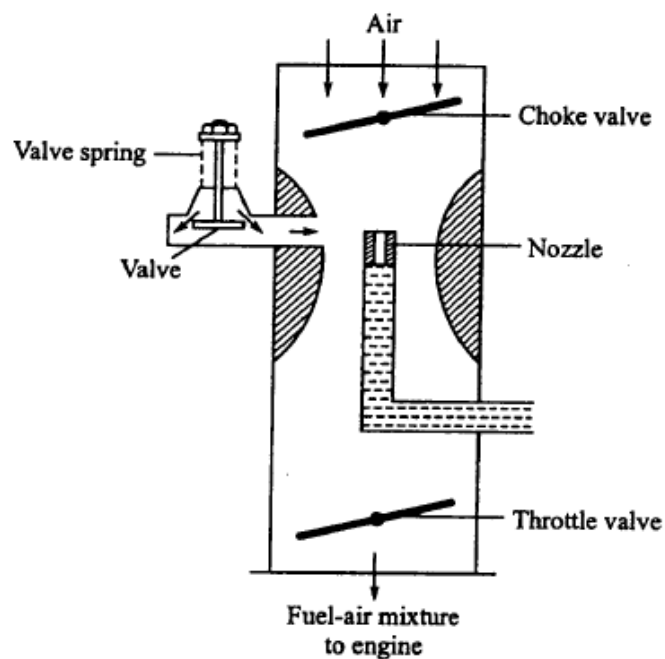


Fig. 1.3 Carburettor with an auxilliary air valve

The metering pin

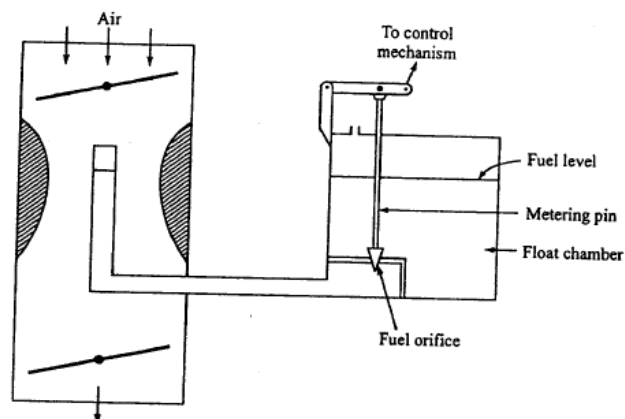


Fig. 1.4 Carburettor with the main fuel orifice metering pin

Fig. 1.4 shows a carburettor with a metering pin in the main fuel orifice to control the mixture. It is a tapered pin, arranged to be moved in and out of the fuel orifice, thus changing the quantity of fuel drawn into the venture tube.

A Compensating jet

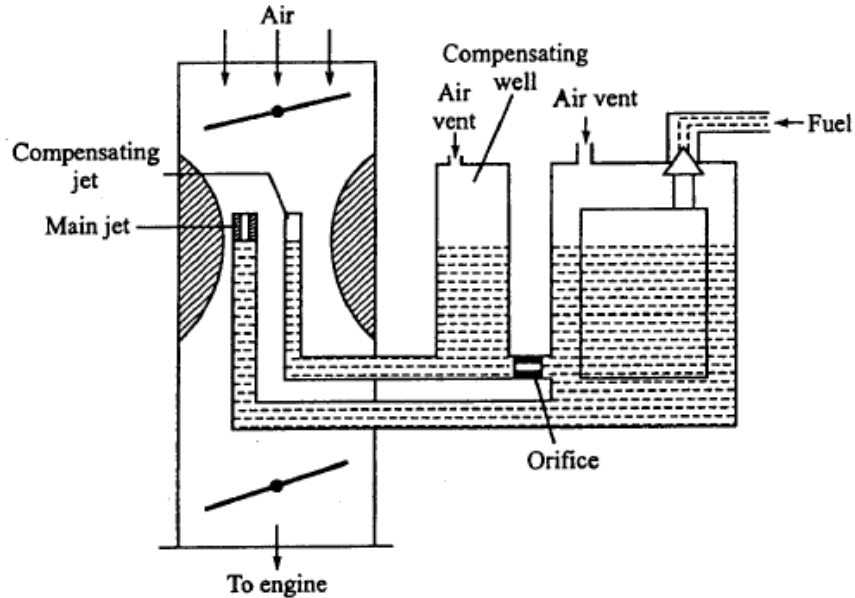


Fig. 1.4 Carburettor with a compensating jet

Fig. 1.5 shows carburettor with a compensating jet. In addition to main jet a compensating jet is incorporated which is connected to the compensating well. The main jet delivers the richer mixture with increase in air flow. The compensating jet gives a mixture i.e. too lean and which becomes still leaner with increase in engine speed and load.

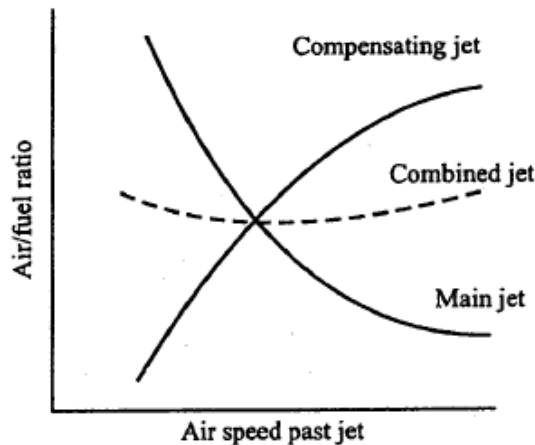


Fig.1.5 Variation of A/F ratio with Main jet, Compensating jet, combined jet

Two jets working together, properly proportioned compensate one another and keep the fuel air mixture almost constant as shown in Fig. 1.5.

1.5.3 Idling system:

Idling jet is added for the idling and low load operation which requires rich mixture of about A/F ratio 12:1. It consists of small fuel line from the float chamber to a point of throttle side. Idling jet may stop by gradual opening of throttle.

1.5.4 Power enrichment or economiser system:

This system provides the richer mixture for maximum power range of operation. It has meter rod economiser of large orifice opening to the main jet as the throttle is opened beyond a certain point

1.5.5 Acceleration pump system:

At the time of engine acceleration or rapid increase in engine speed condition throttle valve may open more rapidly which will not able to provide rich mixture. To overcome such limitation acceleration pump of spring loaded plunger is used for fuel supply.

1.6 Drawbaks of Morden Carburettor:

- ❖ Improper mixture proportion in multi-cylinder engine
- ❖ surging when carburettor is tilted or during acrobatics in aircraft
- ❖ loss of volumetric efficiency due to obstruction of flow of mixture from choke tubes, jets, throttle valve etc
- ❖ Freezing at low temperature
- ❖ wear of carburettor parts
- ❖ backfiring in fuel pipe line

2. FUEL INJECTION SYSTEM

The purpose of the fuel injection system is to deliver fuel into the engine cylinders, while precisely controlling the injection timing, fuel atomization, and other parameters.

2.1 Fuel Injection System in SI Engine

To avoid above problem of modern carburettor, fuel is injected in SI Engine just like Diesel Engine. The System is getting more popular on Modern vehicles with multi cylinder engine. Petrol injected during the suction stroke in the intake manifold at low pressure.

2.2.1. Mechanical Fuel Injection System in SI Engine

i. Continuous Injection

The principle of continuous injection is to introduce a steady flow of fuel at low pressure into air supply.

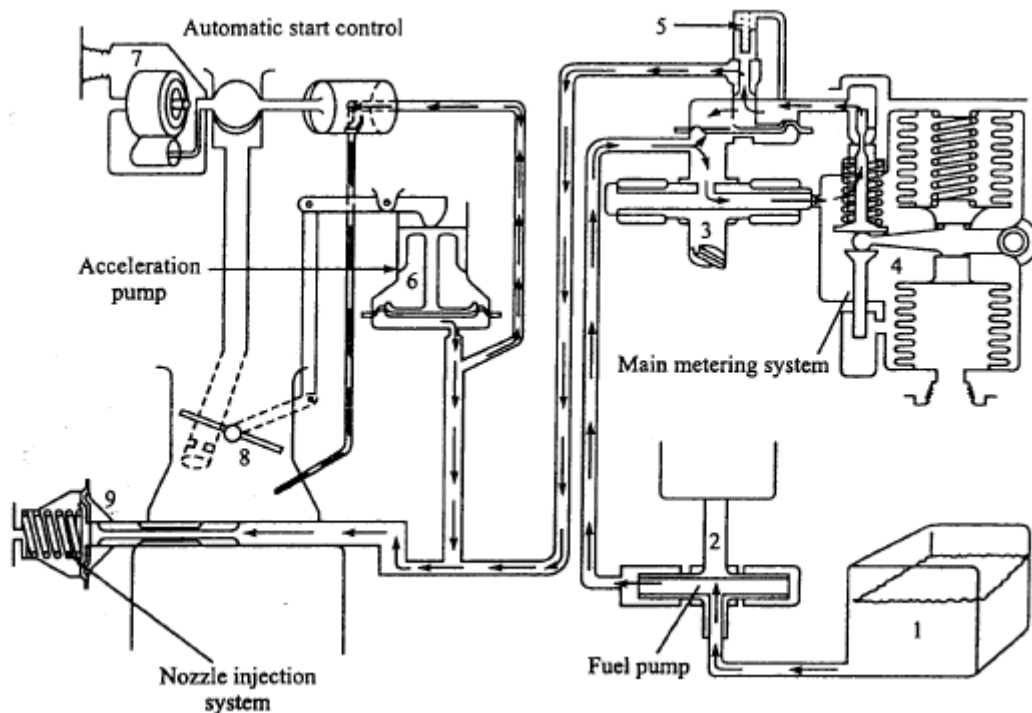


Fig. 2: Continuous Fuel Injection System

The fuel is drawn from a fuel tank (1) by a fuel pump, (2) and delivered to a speed sensing mechanism (3), which is driven by the engine. The fuel at a pressure around 2 bar is delivered to the main metering system (4), which is a density bellows chamber unit for the purpose of regulating the amount of fuel according to the inlet manifold and atmospheric pressures.

The fuel then passes through an engine idling unit (5). The acceleration pump (6) delivers an extra supply of fuel for quick acceleration purposes. It consists of a diaphragm which is forced upwards by the fuel pressure so as to store the extra fuel for acceleration. When the accelerator pedal is depressed sharply, this fuel is forced into the delivery side of the fuel nozzle injection system.

Automatic starting requirements for the engine are taken care of by a bimetallic regulator device (7), which when actuated controls a separate starting or idling air valve in the body of the throttle. The throttle plate (8) is as usual. The injection nozzle (9) can be arranged under the throttle body or at each of the cylinder inlet ports. The Nozzle has a spring-actuated pressure regulator which controls the fuel flow in accordance with the fuel line pressure

ii. **Timed injection system:**

Components of timed injection are fuel feed or lift pump, fuel pump and distributor unit, fuel injection nozzles and mixture controls. This is similar to diesel engine fuel-injection pump. The individual plunger controls the amount of fuel and its time of injection.

- **Direct Cylinder Injection**

In this method, fuel is directly injected inside the engine cylinder during the compression stroke.

- **Lucas Petrol Injection System**

In this method, measured small quantity of fuel is delivered into each cylinder during the induction stroke at low pressure, but at a definite time and over a definite period of the stroke.

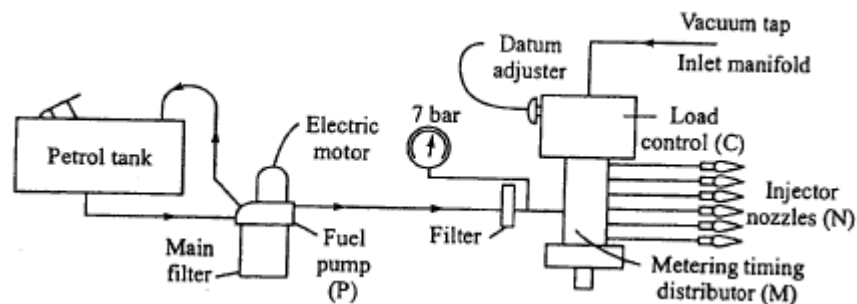


Fig. 2.2: Lucas Petrol Injection System

It contains a high pressure (7 bar) gear pump P, a metering and timing distributor M (geared to the engine), a load control C and the atomizing injector nozzles N (3.5 bar).

An electrically driven fuel pump supplies fuel at a pressure of nearly 7 bars to the combined metering distributor and mixture control unit mounted on, and driven by the engine. From the metering distributor, the accurately timed and metered quantities of fuel are delivered at each injector in turn. A relief valve returns excess fuel to the tank and maintains the line pressure 7 bar.

2.2.2 Electronic Fuel Injection System:

Fuel injection systems discussed earlier were Mechanical and used in complex design. They have been suppressed by Electronic fuel-injection Systems (EFI). The EFI Systems are of two types mentioned below.

I. Single Point Throttle body Injection

Electronically controlled Injector meters the fuel and injects into the air flow. The Injector meters the fuel based on intake manifold pressure, air temperature and engine speed. Disadvantage of this system is unequal distribution of fuel in each cylinder, deposit of fuel particles on the wall of intake manifold and less power.

II. Multi-point Port Injection (MPPI)

To overcome the limitation of Single Point Throttle body Injection, fuel injectors are placed before the inlet valve of each cylinder where the fuel is injected into the intake port of each cylinder. Advantages of MPPI are increased power and torque through improved volumetric efficiency and uniform distribution of fuel to each cylinder.

Fuel delivery system:

- ❖ Electrically driven fuel pump draws fuel from tanks to distribute
- ❖ fuel and manifold pressure kept constant by pressure regulator

Air induction system:

- ❖ air flow meter generate voltage signal according to air flow
- ❖ cold start magnetic injection valve give good fuel atomisation and also provide extra fuel during warm up condition

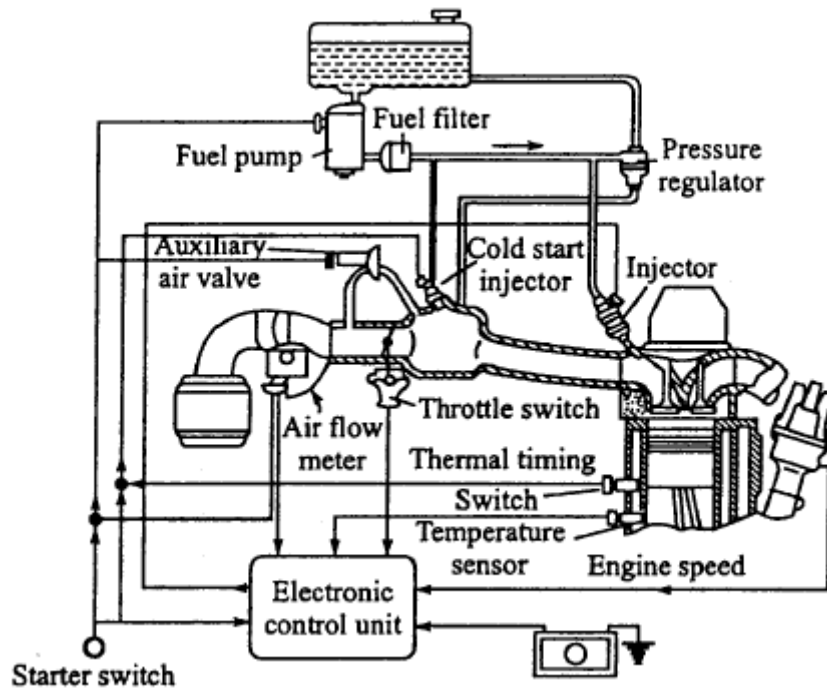


Fig. 2.3: L-jetronic EFI System with Multi Point Port Injection

Electronic control unit (ECU):

- ❖ Sensors for manifold pressure, engine speed and temperature at intake manifold
- ❖ Sensor measures operating data from locations and transmitted electrically to ECU

Injection timing:

- ❖ injected twice for every revolution of crank shaft
- ❖ triggering of injectors

2.3 Diesel injection system:

In Diesel engine fuel injection system is implemented to inject a definite quantity of fuel at the desired time and a definite rate into the combustion chamber.

2.3.1: Requirements of diesel injection system:

- ❖ fuel must introduce precisely defined period of cycle
- ❖ good atomisation of fuel
- ❖ good spray pattern for rapid mixing of fuel and air
- ❖ distribution of fuel in multi-cylinder should uniform
- ❖ no dribbling and after injection of fuel i.e. sharp injection
- ❖ rate of injection meet desired heat release pattern
- ❖ quantities of fuel meet changing speed and load condition
- ❖ injection timing suits the speed and load requirements

2.3.2: Types of diesel injection System

a. Air Injection System

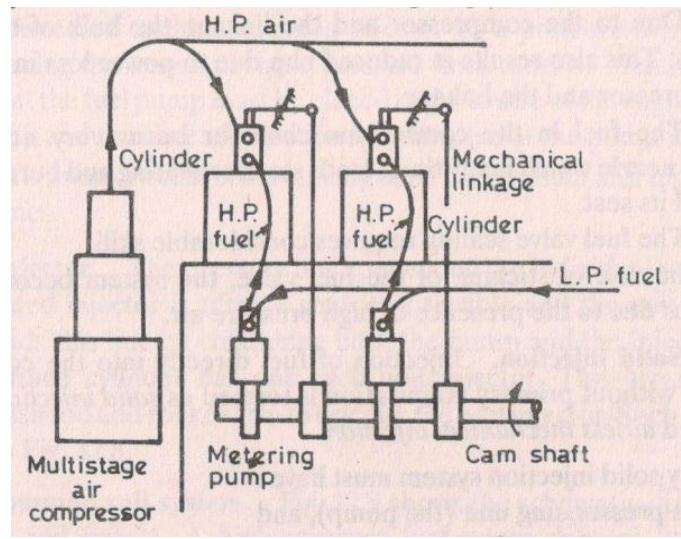


Fig.2.4: Air Injection System

- ❖ Injecting Air along with liquid fuel.
- ❖ fuel supplied through camshaft driven fuel pump
- ❖ fuel valve is also connected with high pressure airline to inject into cylinder
- ❖ multi-stage compressor which supply air at a pressure of about 60 to 70 bar
- ❖ blast air sweeps the fuel along with it
- ❖ good atomisation results in good mixture formation and hence high mean effective pressure
- ❖ heavy and viscous fuels are used
- ❖ fuel pump require small pressure
- ❖ complicated due to compressor arrangement and expensive
- ❖ bulky engine and low bhp
- ❖ overheating and burning of valve seat

b. Solid Injection System

- ❖ Fuel directly injected to combustion chamber without primary atomisation termed as solid injection.
- ❖ Also known as airless mechanical injection
- ❖ 2 units-pressurise and atomising unit
- ❖ 3 different types which are described below

i) Individual pump and injector or jerk pump system:

- ❖ Separate metering and compression pump is used for each cylinder
- ❖ reciprocating fuel pump is used to meter and set the injection pressure of the fuel
- ❖ heavy gear arrangements which gives jerking noise, hence name is given is jerk pump
- ❖ jerk pump is used for medium and high speed diesel engines

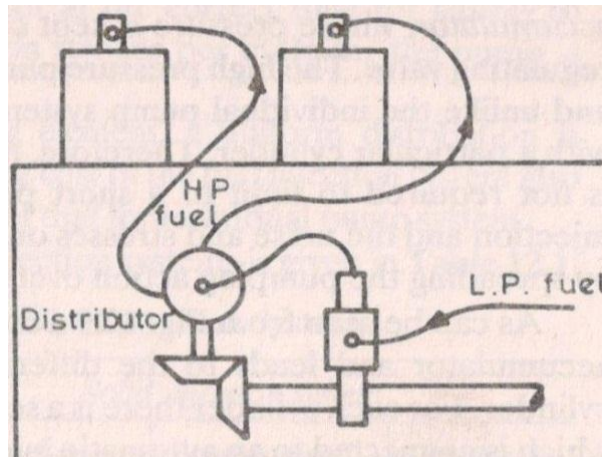


Fig. 2.5 Individual pump and injector or jerk pump system

ii) Common Rail System:

- ❖ high pressure fuel pump delivers fuel to an accumulator whose pressure is constant
- ❖ plunger type of pump is used
- ❖ driving mechanism is not stressed with high pressure hence noise is reduced
- ❖ common rail or pipe is connected in between accumulator and distributing elements
- ❖ separate metering and timing elements connected to automatic injector
- ❖ self-governing type

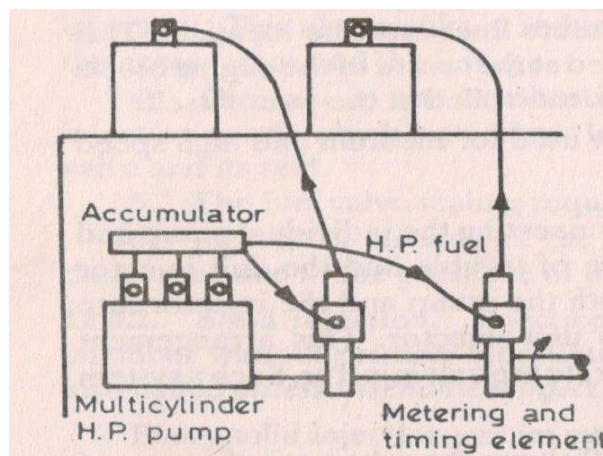


Fig. 2.6 Common rail system

iii) Distributor System:

- ❖ fuel pump pressurises, meters and times the fuel supply to rotating distributor
- ❖ number of injection strokes per cycle for the pump equals to the number of cylinder
- ❖ One metering element which ensure uniform distribution

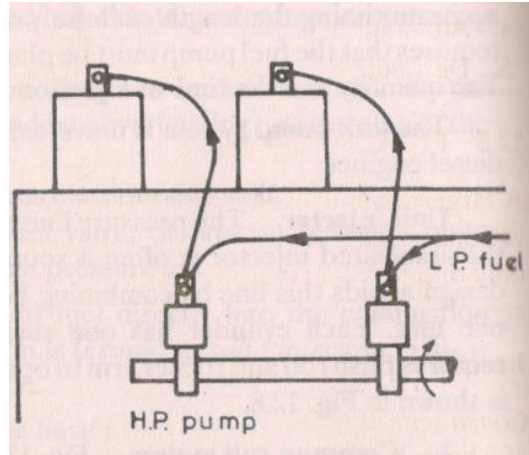


Fig. 2.6 Distributor System

2.3.3 Fuel Injector

Mainly there having 3 types of fuel injectors, namely:

A. Blast injector:

- ❖ These are superseded by mechanically operated injectors used in air injection system

B. Mechanically operated injector:

- ❖ Consist of a set of camshaft, cams and rocker gear and other cams for controlling the timing of the fuel injection

C. Automatic injector:

- ❖ Consists of spring loaded needle valve and operated hydraulically by the pressure of fuel
- ❖ Quantity of fuel is metered by the fuel pump

3. IGNITION SYSTEM:

3.1 Conventional Ignition System

- ❖ Based on mutual electromagnetic induction principle
- ❖ Basically Convectional Ignition systems are of 2 types:
 - (a) Battery or Coil Ignition System
 - (b) Magneto Ignition System

3.1.1 Battery or Coil Ignition System:

The ignition system is divided into 2-circuits:

(i) Primary Circuit:

- ❖ Consists of 6 or 12 V battery, ammeter, ignition switch, primary winding
- ❖ it has 200-300 turns of 20 SWG (Sharps Wire Gauge) gauge wire, contact breaker, capacitor.

(ii) Secondary Circuit:

- ❖ Consists of secondary winding or coil which have 21000 turns of 40 (S WG) gauge wire.
- ❖ bottom end of which is connected to bottom end of primary and top end of secondary winding or coil is connected to centre of distributor rotor
- ❖ Distributor rotors rotate and make contacts with contact points and are connected to spark plugs which are fitted in cylinder head

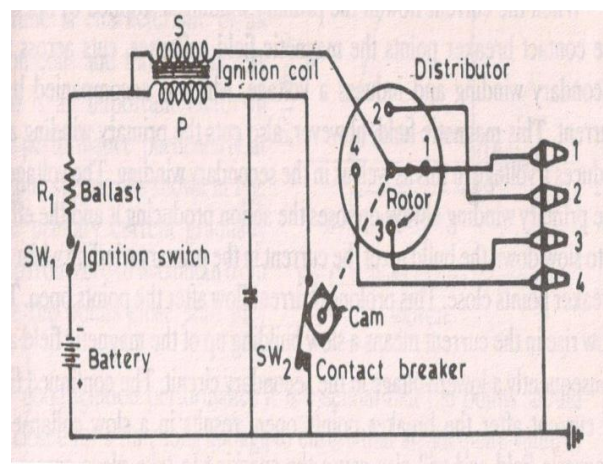


Fig. 3.1 Circuit diagram for a conventional spark ignition system

Nomenclature

1. C=condenser,
2. P=primary coil
3. S=secondary coil
4. R1=ballast resistance
5. SW1=ignition switch

6. SW2=contact breaker

Principle

When the ignition switch is closed and engine is cranked, as soon as the contact breaker closes, a low voltage current will flow through the primary winding. It is also to be noted that the contact breaker cam opens and closes the circuit 4-times (for 4 cylinders) in one revolution. When the contact breaker opens the contact, the magnetic field begins to collapse. Because of this collapsing magnetic field, current will be induced in the secondary winding. And because of more turns (@ 21000 turns of secondary, voltage goes upto 28000-30000 volts.

This high voltage current is brought to centre of the distributor rotor. Distributor rotor rotates and supplies this high voltage current to proper spark plug depending upon the engine firing order. When the high voltage current jumps the spark plug gap, it produces the spark and the charge is ignited-combustion starts-products of combustion expand and produce power.

The Function of the capacitor is to reduce arcing at the contact breaker (CB) points. Also when the CB opens the magnetic field in the primary winding begins to collapse. When the magnetic field is collapsing capacitor gets fully charged and then it starts discharging and helps in building up of voltage in secondary winding. Contact breaker cam and distributor rotor are mounted on the same shaft.

3.1.2 Magneto Ignition System:

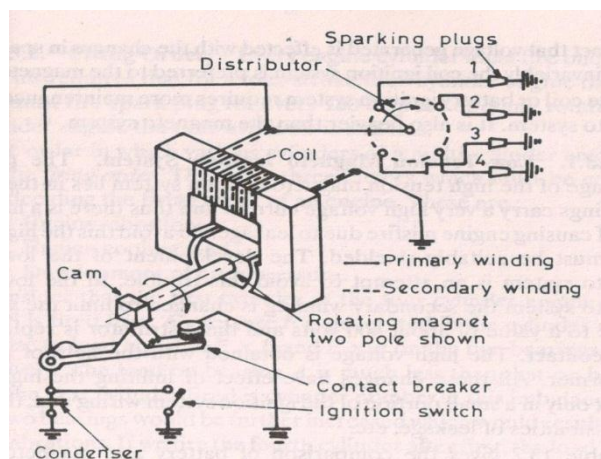


Fig.3.2 High tension magneto ignition system

- ❖ Magneto will produce and supply the required current to the primary winding or coil
- ❖ rotating magneto with fixed coil or rotating coil with fixed magneto for producing and supplying current to primary, remaining arrangement is same as that of a battery ignition system
- ❖ no battery required
- ❖ during starting the quality of spark is poor due to slow speed

3.1.3 Disadvantages of Conventional Ignition System

- ❖ Because of arcing, pitting of contact breaker point
- ❖ Poor starting: After few thousands of kilometres of running, the timing becomes inaccurate, which results into poor starting (Starting trouble)
- ❖ At very high engine speed, performance is poor because of inertia effects of the moving parts in the system
- ❖ Sometimes it is not possible to produce spark properly in fouled spark plugs

3.2 Electronic ignition system

To overcome the limitation of Conventional Ignition System, Electronic Ignition System is developed.

Advantages of Electronic Ignition System

- ❖ Moving parts are absent-so no maintenance.
- ❖ Contact breaker points are absent-so no arcing
- ❖ Spark plug life increases by 50% and they can be used for about 60000 km without any problem
- ❖ Better combustion in combustion chamber, about 90-95% of air fuel mixture is burnt compared with 70-75% with conventional ignition system
- ❖ More power output
- ❖ More fuel efficiency

3.3 Firing Order

The order or sequence in which the firing takes place, in different cylinders of a multi-cylinder engine is called Firing Order.

In case of SI engines the distributor connects the spark plugs of different cylinders according to Engine Firing Order.

Firing order differs from engine-to-engine.

Advantages

- (a) A proper firing order reduces engine vibrations
- (b) Maintains engine balancing.
- (c) Secures an even flow of power.

Firing Order for different Engine

- ❖ 3 cylinder = 1-3-2
- ❖ 4 cylinder engine (inline) = 1-3-4-2
1-2-4-3

- ❖ 4 cylinder horizontal opposed engine (Volkswagen engine) = 1-4-3-2
- ❖ 6-cylinder in line engine = 1-5-3-6-2-4
 - (Crank in 3 pairs) 1-4-2-6-3-5
 - 1-3-2-6-4-5
 - 1-2-4-6-5-3
- ❖ 8 cylinder in line engine 1-6-2-5-8-3-7-4
 - 1-4-7-3-8-5-2-6
- 8 cylinder V type 1-5-4-8-6-3-7-2
 - 1-5-4-2-6-3-7-8
 - 1-6-2-5-8-3-7-4
 - 1-8-4-3-6-5-7-2

3.4 Ignition timing:

Ignition timing refers to the timing, relative to the current piston position and crankshaft angle, of the release of a spark in the combustion chamber near the end of the compression stroke.

It is very important, since the charge is to be ignited just before (few degrees before TDC) the end of compression, since when the charge is ignited, it will take some time to come to the required rate of burning.

3.5 Ignition Advance:

The purpose of spark advance mechanism is to assure that under every condition of engine operation, ignition takes place at the most favourable instant in time i.e. most favourable from a standpoint of engine power, fuel economy and minimum exhaust dilution.

By means of these mechanisms the advance angle is accurately set so that ignition occurs before TDC point of the piston. The engine speed and the engine load are the control quantities required for the automatic adjustment of the ignition timing.

Most of the engines are fitted with mechanisms which are integral with the distributor and automatically regulate the optimum spark advance to account for change of speed and load. Mechanisms used for spark advancing are as follows:

- (a) Centrifugal advance mechanism
- (b) Vacuum advance mechanism

3.6 Factors affecting energy requirement of ignition system

(a) Effect of series resistance:

- ❖ Energy dissipated during discharge and hence circuit energy stored in capacitance is more
- ❖ longer discharge time

(b) Effect of electrode material:

- ❖ Ignition energy for electrode gaps larger than the quenching distance varies with materials for the electrode and increases with any change to material having higher boiling point

(c) Effect of stray inductance:

- ❖ presence of small stray inductance cause oscillatory discharge
- ❖ larger resistance, minimum inductance longer the discharge time

(d) Effect of electrode configuration:

- ❖ Reduction in the capacitance reduces the discharge time and increase in the gas resistance which reduces the diameter of the spark channel
- ❖ increase the electrode gap means supply of ignition energy over interval of time decreases and spark channel also reduces

MODULE-3

1. SI Engine Combustion

In SI engine homogeneous mixture of vaporised fuel, air and residual gases is ignited by a single intense and high temperature spark between the spark plug electrode (electrodes exceeds 10,000 °C) and generate pre-flame which spreads to envelope of mixture for combustion.

1.1: Stages of combustion in SI engine

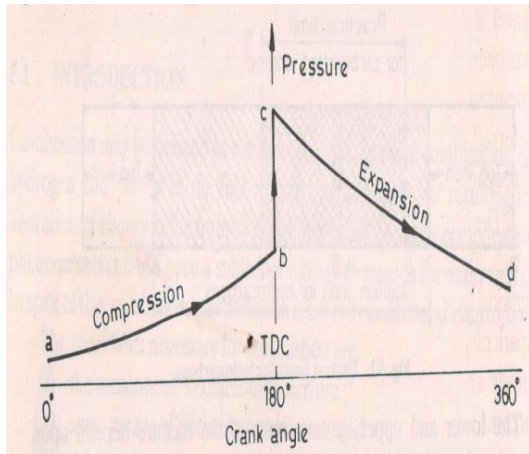


Fig. 1.1: Theoretical p-θ diagram

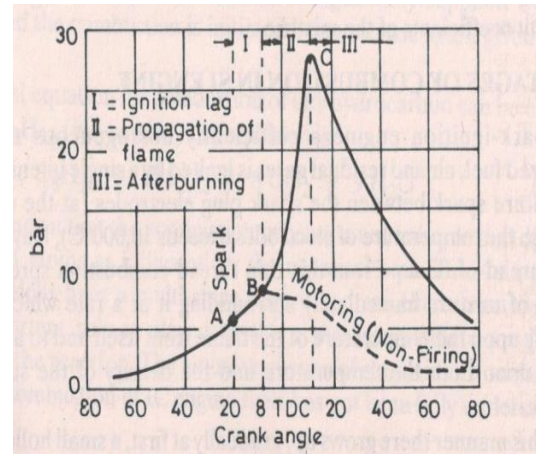


Fig. 1.2: Stages of Combustion in SI Engine

Stage 1-Ignition lag or preparation phase (AB):

- ❖ growth and development of a semi propagating nucleus of flame
- ❖ chemical process depending upon the nature of the fuel, upon both temperature and pressure, the proportion of the exhaust gas, and also upon the temperature coefficient of the fuel, that is, the relationship of oxidation or burning
- ❖ point A shows the passage of spark and point B is the first rise of pressure
- ❖ ignition lag is generally expressed in terms of crank angle
- ❖ Ignition lag is very small and lies between 0.00015 to 0.0002 seconds
- ❖ ignition lag of 0.002 seconds corresponds to 35 degree crank rotation when the engine is running at 3000 RPM
- ❖ Angle of advance increase with the speed

Stage 2-propagation of flame (BC):

- ❖ Period from the point B where the line of combustion departs from the compression line to point C, the maximum rise of pressure in P-θ diagram
- ❖ flame propagates at the constant velocity
- ❖ Heat transfer to the cylinder wall is low
- ❖ rate of heat release depends upon the turbulence intensity and reaction rate

Stage 3-After burning (CD):

- ❖ After point C, the heat release is due to the fuel injection in reduced flame front after the starts of expansion stroke
- ❖ no pressure rise during this period

1.2: Detonation or knocking in SI Engine

- ❖ Knocking is due to auto ignition of end portion of unburned charge in combustion chamber.
- ❖ As the normal flame proceeds across the chamber, pressure and temperature of unburned charge increase due to compression by burned portion of charge.
- ❖ This unburned compressed charge may auto ignite under certain temperature condition and release the energy at a very rapid rate compared to normal combustion process in cylinder.
- ❖ This rapid release of energy during auto ignition causes a high pressure differential in combustion chamber and a high pressure wave is released from auto ignition region.
- ❖ The motion of high pressure compression waves inside the cylinder causes vibration of engine parts and pinging noise and it is known as knocking or detonation.

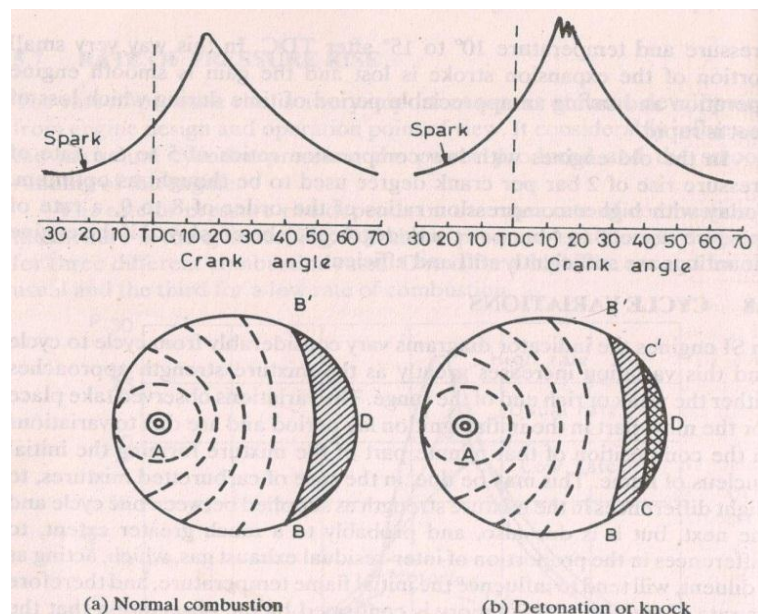


Fig. 1.3: Detonation in SI Engine

1.3: Effect of detonation in SI Engine:

1. Noise and roughness:

Knocking produces a loud pulsating noise and pressure waves. These waves vibrate back and forth across the cylinder. The presence of vibratory motion causes crankshaft vibrations and the engine runs rough.

2. Mechanical damage:

- ❖ High pressure waves generated during knocking can increase rate of wear of parts of combustion chamber. Severe erosion of piston crown (in a manner similar to that of marine propeller blades by cavitation), cylinder head and pitting of inlet and outlet valves may result in complete wreckage of the engine.
- ❖ Detonation is very dangerous in engines having high noise level. In small engines the knocking noise is easily detected and the corrective measures can be taken but in aero-engines it is difficult to detect knocking noise and hence corrective measures cannot be taken. Hence severe detonation may persist for a long time which may ultimately result in complete wreckage of the piston.

3. Carbon deposits:

Detonation results in increased carbon deposits.

4. Heat transfer:

Knocking is accompanied by an increase in the rate of heat transfer to the combustion chamber walls. This is mainly two reasons

- ❖ The minor reason is that the maximum temperature in a detonating engine is about 150°C higher than in a non-detonating engine, due to rapid completion of combustion
- ❖ The major reason for increased heat transfer is the scouring away of protective layer of inactive stagnant gas on the cylinder walls due to pressure waves. The inactive layer of gas normally reduces the heat transfer by protecting the combustion and piston crown from direct contact with flame.

5. Power output and efficiency:

Due to increase in the rate of heat transfer the power output as well as efficiency of detonating engine decreases.

6. Pre-ignition:

Increase in the rate of heat transfer to the walls has yet another effect which may reach a temperature high enough to ignite the charge before the passage of spark, thus causing pre-ignition. An engine detonating for a long period would most probably lead to pre-ignition and this is the real danger of detonation.

7. Autoignition:

A mixture of fuel and air can react spontaneously and produce heat by chemical reaction in the absence of flame to initiate the combustion or self-ignition. This type of self-ignition in the absence of flame is known as Auto-Ignition.

1.4: Effect of engine operating variables on the engine knocking in SI Engine

(a) Temperature factors:

- ❖ Increasing the temperature of the unburned mixture increase the possibility of knock in SI engine due to pre ignition.
- ❖ Increasing the compression ratio increases both the temperature and pressure which in turn increases the tendency to knock.
- ❖ By supercharging increases both temperature and density, which increase the knocking tendency of engine
- ❖ Increase in coolant temperature decreases delay period which in turn increase the tendency to knock
- ❖ Sparking plug and exhaust valve are two hottest parts in the combustion chamber and uneven temperature leads to pre-ignition and hence the knocking.

(b) Density factors:

Increasing the density of unburnt mixture will increase the possibility of knock in the engine.

The engine parameters which affect the density are as follows:

- ❖ Increased compression ratio increase the density
- ❖ Increasing the load opens the throttle valve more and thus increases density
- ❖ Supercharging increase the density of the mixture
- ❖ Increasing the inlet pressure increases the overall pressure during the cycle. The high pressure end gas decreases the delay period which increase the tendency of knocking.
- ❖ The temperature of charge increases by increasing the spark advance and it increases with rate of burning and does not allow sufficient time to the end mixture to dissipate the heat and increase the knocking tendency

(c) Time factors:

By increasing the time of exposure of the unburned mixture to auto-ignition conditions increase the possibility of knock in SI engines.

- ❖ Flame travel distance: If the distance of flame travel is more, then possibility of knocking is also more. This problem can be solved by combustion chamber design, spark plug location and engine size. Compact combustion chamber will have better anti-knock characteristics, since the flame travel and combustion time will be shorter. Further, if the combustion chamber is highly turbulent, the combustion rate is high and consequently combustion time is further reduced; this further reduces the tendency to knock.

- ❖ Location of sparkplug: A spark plug which is centrally located in the combustion chamber has minimum tendency to knock as the flame travel is minimum. The flame travel can be reduced by using two or more spark plugs.
- ❖ Location of exhaust valve: The exhaust valve should be located close to the spark plug so that it is not in the end gas region; otherwise there will be a tendency to knock.
- ❖ Engine size: Large engines have a greater knocking tendency because flame requires a longer time to travel across the combustion chamber. In SI engine therefore, generally limited to 100mm
- ❖ Turbulence of mixture: decreasing the turbulence of the mixture decreases the flame speed and hence increases the tendency to knock. Turbulence depends on the design of combustion chamber and one engine speed.

(d) Composition:

The properties of fuel and A/F ratio are primary means to control knock:

- ❖ Molecular Structure: Increasing the carbon-chain increases the knocking tendency and centralizing the carbon atoms decreases the knocking tendency. Unsaturated hydrocarbons have less knocking tendency than saturated hydrocarbons.
- ❖ Fuel-air ratio: When the mixture is nearly 10% richer than stoichiometric (fuel-air ratio =0.08) ignition lag of the end gas is minimum and the velocity of flame propagation is maximum. By making the mixture leaner or richer (than F/A 0.08) the tendency to knock is decreased. A too rich mixture is especially effective in decreasing or eliminating the knock due to longer delay and lower temperature of compression.
- ❖ Humidity of air: Increasing atmospheric humidity decreases the tendency to knock by decreasing the reaction time of the fuel

1.5: SI Engine Combustion Chamber:

(a) T-head combustion chamber: 2 cam shaft, prone to detonation, average octane number 45-50

(b) I-head or side valve combustion chamber:

- ❖ lack of turbulence
- ❖ extremely sensitive to ignition timing
- ❖ prone to detonation

(c) F-head combustion chamber:

- ❖ Compromise between I-head and L-head

2.1 Stages of Combustion in CI Engine

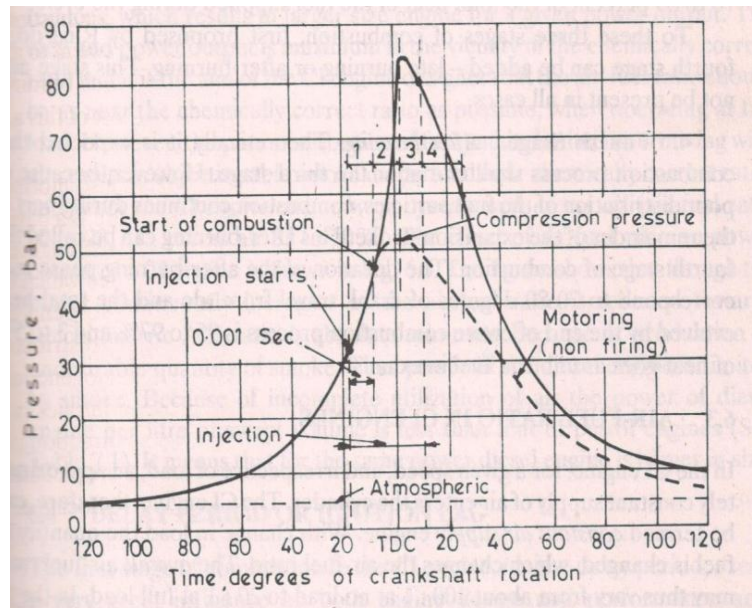


Fig. 2.1: Stages of combustion in CI engine

Stage1. Ignition delay period:

- ❖ The period between the start of fuel injection into the combustion chamber and the start of combustion is termed as ignition delay period.
- ❖ The start of combustion is determined from the change in slope on p- θ diagram or from heat release analysis of the p- θ data, or from luminosity detector in experimental conditions.
- ❖ Start of injection can be determined by a needle-lift indicator to record the time when injector needle lifts off its seat.
- ❖ Both physical and chemical processes must take place before a significant fraction of the chemical energy of the injected liquid is released.
 - Physical processes are fuel spray atomization, evaporation and mixing of fuel vapour with cylinder air. Good atomization requires high fuel-injection pressure, small injector hole, optimum fuel viscosity, high cylinder pressure (large divergence angle). Rate of vaporization of the fuel droplets depends on droplet diameter, velocity, fuel volatility, pressure and temperature of the air.
 - Chemical processes similar to that described for auto ignition phenomenon in premixed fuel-air, only more complex since heterogeneous reactions (reactions occurring on the liquid fuel drop surface) also occur.

Stage 2: Rapid or uncontrolled or pre-mixed combustion phase:

- ❖ Combustion of the fuel which has mixed with air within flammability limits during ignition delay period occurs rapidly in a few crank angle degrees - high heat release characteristics in this phase. If the amount of fuel collected in the combustion chamber during the ignition delay is much - high heat release rate results in a rapid pressure rise which causes the diesel knock.
- ❖ For fuels with low cetane number, with long ignition delay, ignition occurs late in the expansion stroke - incomplete combustion, reduced power output, poor fuel conversion efficiency. If the pressure gradient is in the range 0.4 - 0.5 MPa/oCA, engine operation is not smooth and diesels knock starts. This value should be in the range 0.2 to 0.3 MPa/oCA for smooth operation (max allowable value is 1.0 MPa/oCA) of the engine.

Stage 3. Controlled or diffusion combustion phase:

- ❖ Once the fuel and air which is pre-mixed during the ignition delay is consumed, the burning rate (heat release rate) is controlled by the rate at which mixture becomes available for burning. The rate of burning in this phase is mainly controlled by the mixing process of fuel vapour and air. Liquid fuel atomization, vaporization, pre flame chemical reactions also affect the rate of heat release.
- ❖ Heat release rate sometimes reaches a second peak (which is lower in magnitude) and then decreases as the phase progresses. Generally it is desirable to have the combustion process near the TDC for low particulate (soot) emissions and high performance (and efficiency).

Stage 4. After burning or late combustion phase:

- ❖ Heat release rate continues at a lower rate into the expansion stroke -there are several reasons for this: a small fraction of the fuel may not yet burn, a fraction of the energy is present in soot and fuel-rich combustion products and can be released. The cylinder charge is non-uniform and mixing during this phase promotes more complete combustion and less dissociated product gases. Kinetics is slower.

2.2: Variables affecting Ignition Delay Period

(i) Cetane number:

- ❖ Straight chain parafinic compounds (normal alkanes) have highest ignition quality, which improves as the chain length increases.
- ❖ Aromatic compounds, alcohols have poor ignition quality.
- ❖ Cetane number can be increased by ignition-accelerating additives like organic peroxides, nitrates, nitrites and various sulphur compounds.

(ii) Injection timing:

- ❖ At normal operating conditions min ignition delay (ID) occurs with start of injection at 10 to 15 OCA BTDC
- ❖ Cylinder temperature and pressure drops if injection is earlier or later (high at first but decrease as delay proceeds)

(iii) Injection quantity (load)

- ❖ Reducing engine load changes AFR, cools down the engine, reduces wall temperatures, reduces residual gas temperatures and increase ID
- ❖ Droplet size, injection velocity and rate Ignition quality within practical limits do not have significant effect on ID
- ❖ Increase in injection pressure produces only modest decrease in ID Injector nozzle diameter -effects of droplet size but has no significant effect on ID

(iv) Intake air temperature and pressure

- ❖ Reducing intake air T and p increase ID
- ❖ Strong dependence of ID on charge temperature below 1000 K – above this value effect of intake air conditions is not significant.

(v) Engine speed

- ❖ Increase in engine speed increases the air motion and turbulence, reduces ID time slightly (in ms), in terms of CA degrees ID increases almost linearly.
- ❖ A change in engine speed, changes “temp~time” and “pressure~time” relationships

(vi) Combustion chamber design

- ❖ Spray impingement on the walls effect fuel evaporation and ID increase in compression ratio, increase p and T and reduces ID
- ❖ Reducing stroke volume, increase surface area to volume ratio, increase engine cooling and increase ID

(vii) Swirl rate

- ❖ Change of evaporation rate and air-fuel mixing - under normal operating conditions the effect is small.
- ❖ At start-up (low engine speed and temperature) more important, high rate of evaporation and mixing is obtained by swirl

(viii) Oxygen concentration

- ❖ Residual gases reduce O₂ concentration and reducing oxygen concentration increases ID

2.3 Diesel Knock

Knock in CI Engine is associated with an extremely high rate of pressure rise during the second phase of combustion and also with heavy vibration thus causing overheating of piston and cylinder head

- ❖ The Injection process of a fuel takes place over a definite period of time in terms of degree crank angle. As a result first few drops which are injected into the chamber pass through the ignition delay while the additional droplets are being injected into the chamber. Normally, the fuel injected period is more than the delay period
- ❖ If the delay period of injected fuel is short, the first few droplets commence will commence the burning phase in a relatively short time after injection, and a relatively small amount of fuel will be accumulated in the chamber when actual burning commences. As a result, the rate of burned mass of fuel will be such as to produce a rate of pressure rise that will exert a smooth force on the piston as shown in Fig. 2.2(a)

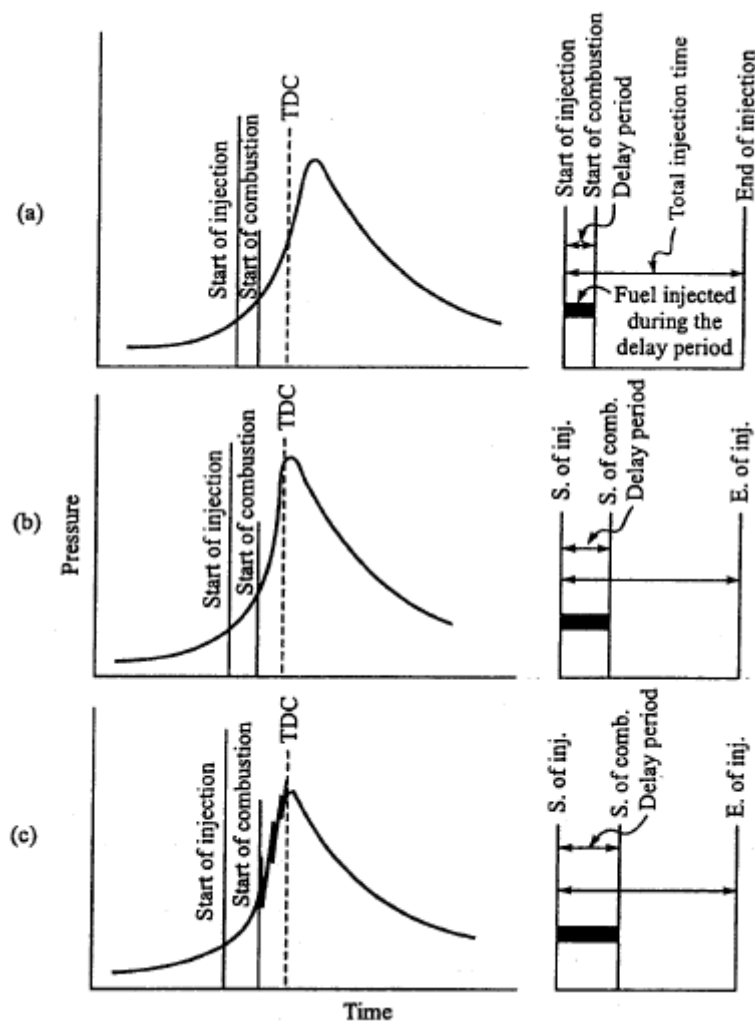


Fig.2.2: Diagram showing the effect of ignition delay on the rate of pressure rise in a CI Engine

- ❖ If the delay period is longer, the burning of the first few droplets is delayed and therefore a greater quantity of fuel droplets will accumulate in the chamber. When the actual burning commences the additional fuel may cause rapid rate of pressure rise (Fig.2.2 (b)).
- ❖ If the delay period is too long much fuel will be accumulated resulting in instantaneous pressure rise (Fig. 2.2(c)) resulting in knocking and vibration.

2.4: Comparison of Knock in CI and SI Engines

- ❖ In SI Engine, knocking occurs at the end of combustion while in the CI Engine knocking occurs at the start of combustion.

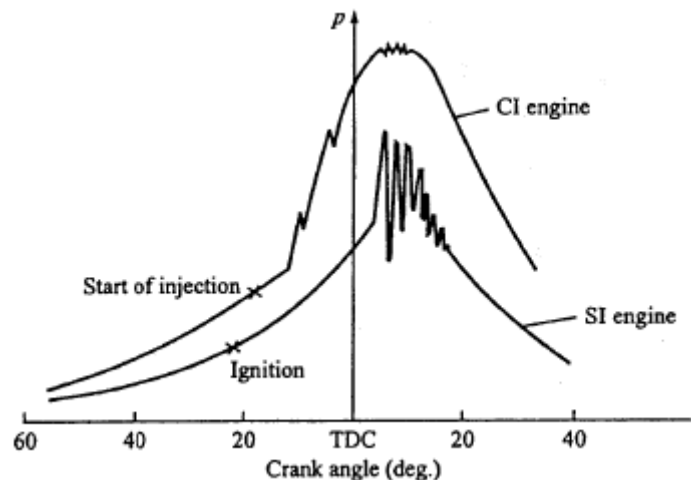


Fig.2.3 Comparison of knock in CI and SI Engine

- ❖ In SI Engine homogenous charge that autoignites and causes knocking resulting in a very high rate of pressure rise. In CI Engine fuel and air are not homogeneously mixed and hence the pressure rise in CI engine is less than the SI Engine. However peak pressure is higher in CI Engine due to high compression ratio.
- ❖ There having no chance of pre ignition in CI Engine, whereas pre ignition may occur in SI Engine
- ❖ In SI Engine knocking is clearly audible whereas CI Engine not possible.
- ❖ The factors which tend to prevent knock in SI Engine, the same factors may promote knocking in CI Engine.

2.5: Combustion chamber design types in CI Engine

(i) According to the swirl of air:

- ❖ Induction swirl or open chamber or non-turbulent chamber
- ❖ Compression swirl
- ❖ Combustion induced swirl

(ii) According to speed of the engine:

- ❖ Low speed engine ($n < 1500$ rpm):
 - Shallow, swirl-less combustion chambers
 - Direct, multi-jet fuel injection
- ❖ Medium speed engine ($n = 1500-3000$ rpm):
 - Deep combustion chambers with intensive swirl of charge
 - Direct injection of atomised fuel
- ❖ high speed engine ($n = 3000-5000$ rpm):
 - Pre-chambers (sectional combustion chambers)
 - Indirect injection of fuel into the pre-chamber