SEMBODAI RUKMANI VARATHARAJAN ENGINEERING COLLEGE

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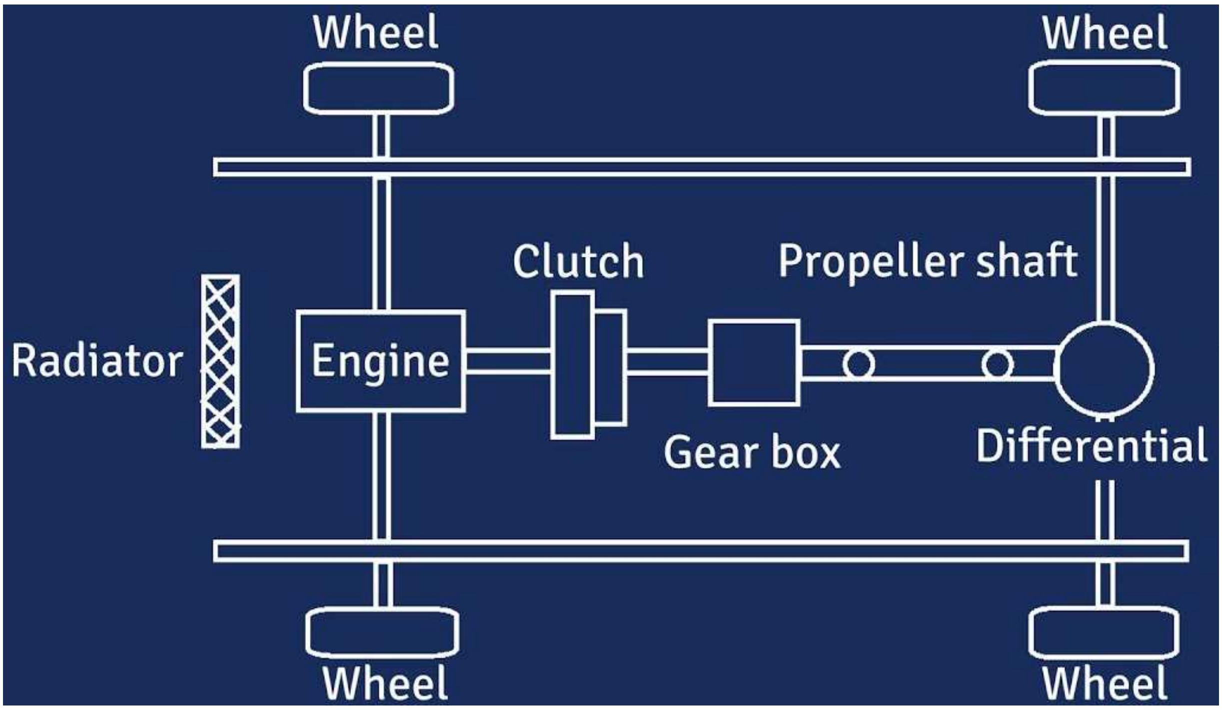
UNIT I INTRODUCTION TO I.C ENGINES

I. INTRODUCTION TO I.C ENGINES

Classification of I.C Engines-Thermodynamics of Air Standard Otto and Diesel Cycles – Working of 4 Stroke and 2 stroke –S.I and C.I engines– Comparison of S.I and C.I Engines-I.C engine fuels, types, Combustion of fuels-Rating of fuels – composition of petrol and diesel fuels - importance Of valve and port timing.



As the name implies or suggests, the internal combustion engines (briefly written as IC engines) are those engines in which the combustion of fuel takes place inside the engine cylinder. These are petrol, diesel, and gas engines.

CLASSIFICATION OF IC ENGINES

The internal combustion engines may be classified in many ways, but the following are important from the subject point of view

1. According to the type of fuel used

(a) Petrol engines. (b) Diesel engines or oil engines, and (c) Gas engines.

2. According to the method of igniting the fuel

(a) Spark ignition engines (briefly written as S.1. engines), (b) Compression ignition engines (briefly written as C.I. engines), and (c) Hot spot ignition engines

3. According to the number of strokes per cycle

(a) Four stroke cycle engines, and (b) Two stroke cycle engines.

4. According to the cycle of operation

(a) Otto. cycle (also known as constant volume cycle) engines, (b) Diesel cycle (also known as constant pressure cycle) engines, and (c) Dual combustion cycle (also known as semi-diesel cycle) engines.

5. According to the speed of the engine

(a) Slow speed engines, (b) Medium speed engines, (c) High speed engines.

6. According to the cooling system

(a) Air-cooled engines. (b) Water-cooled engines. (c) Evaporative cooling engines.

7. According to the method of fuel injection

(a) Carburettor engines, (b) Air injection engines, (c) Airless or solid injection engines.

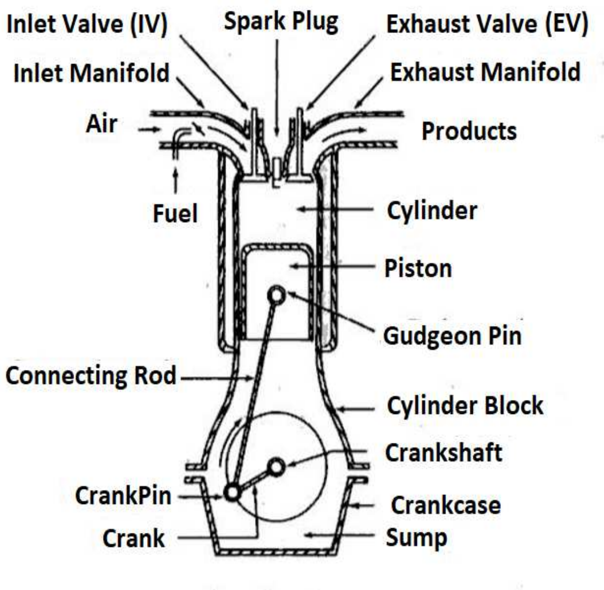
8. According to the number of cylinders

(a) Single cylinder engines (b) Multi-cylinder engines.

9. According to the arrangement of cylinders

(a) Vertical engines, (b) Horizontal engines, (c) Radial engines, (d) In-line multi-cylinder engines, (e)V-type multi-cylinder engines, (j) Opposite-cylinder engines, (g) Opposite- piston engines

Main Components of an IC engine



IC engines – Components - Functions and Materials

Cylinder

The main function of cylinder is to guide the piston.

Material :

Grey cast iron – Wear and Corrosion

Aluminium alloy – Aluminium –silicon - Better casing properties

Cast iron is mainly used because of the following advantages:

It is a good foundry material

It has high machinability

It does not wrap under the high temperature and pressures developed in the cylinders

Due to its slightly porous nature, it retains better the lubricating oil film

It does not wear too much

It has sound - damping properties

It has a low value of coefficient of thermal expansion

It is relatively cheap.

Cylinder head

The main function of cylinder head is to seal the cylinder block and not to permit entry and exit of gases on cover head valve engine.

Types:

Loop flow type cylinder head

Off set cross – flow type cylinder head

In-line cross-flow type cylinder head

Piston

Functions:

To transmit the force of explosion to the crankshaft.

To form a seal so that the high pressure gases in the combustion chamber do not escape in to the crankcase.

To serve as guide and a bearing for small end of the connecting rod.

Material:

Cast iron and aluminium alloy (Aluminium – silicon) Advantages of aluminium alloy:

Three time lighter than cast iron

Higher thermal conductivity Disadvantages:

It is not as strong as cast iron (Hence thicker section have to be is used)

Piston rings

Functions:

Prevention of leakage of gas into the crank case

Prevention of lubricating oil film

Prevention of lubricant entry into the combustion chamber above the piston head.

Removing unnecessary and excessive lubricating oil from cylinder wall.

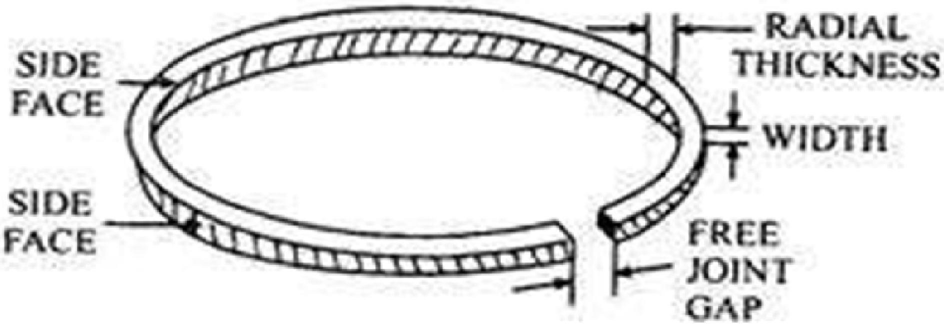
Prevention of carbon deposit and other impurities.

Easy transmission of heat from piston to cylinder wall.

Balancing of side thrust of the piston

Piston rings are made of cast iron of fine grain and high elastic material which is not affected by the working heat. Sometimes it is made by alloy spring steel.

Compression ring , Oil ring



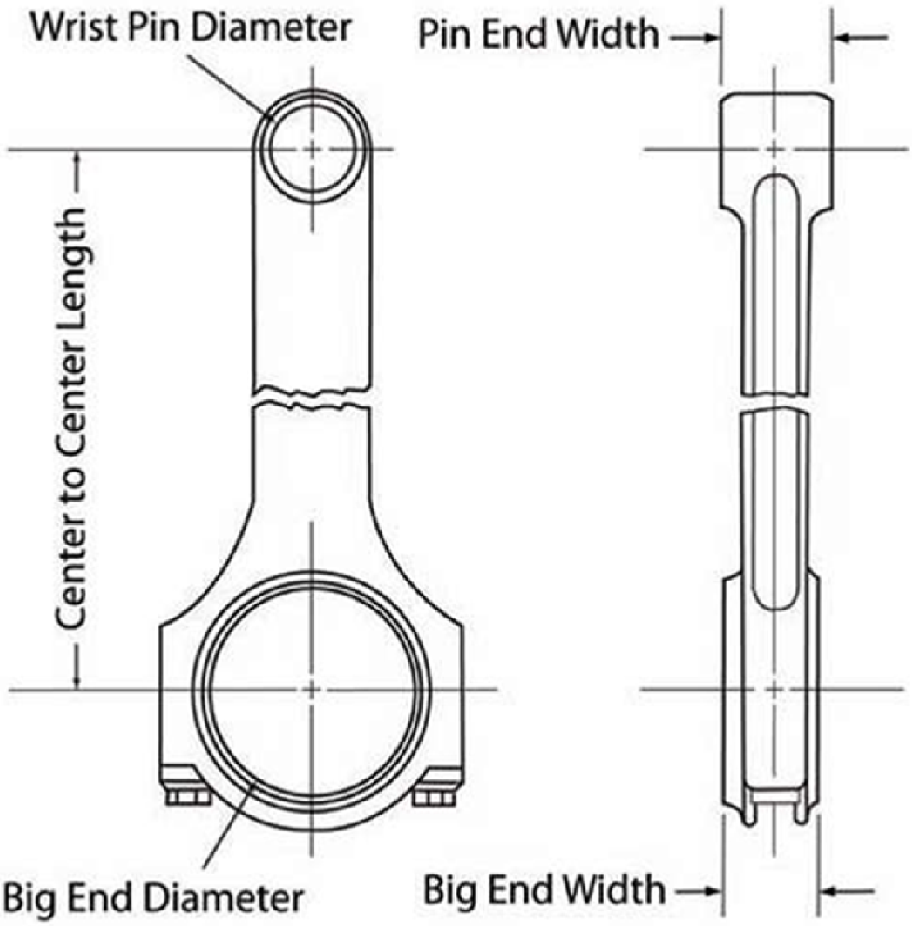
Connecting rod

The function of connecting rod is to convert the reciprocating motion of the piston in to the rotary motion of the crankshaft.

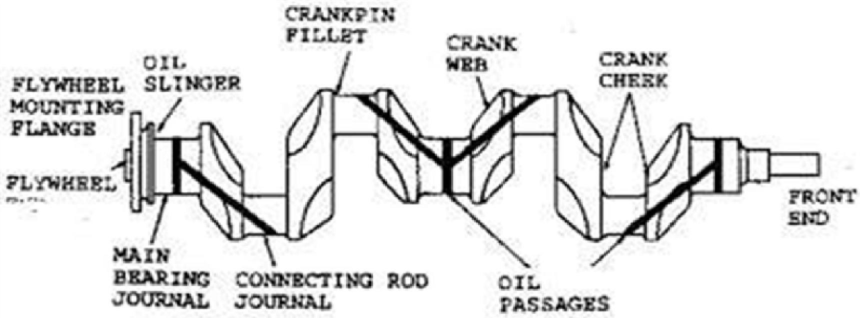
Material:

Drop forging of steel or duralumin.

Malleable or Spheroidal graphite cast iron.


Wrist Pin Diameter
Pin End Width
Center to Center Length
Big End Diameter
Big End Width

Crank shaft



The function of crank shaft is receives the efforts or thrust supplied by piston to the connecting rod and converts the reciprocating motion of piston into rotary motion of crankshaft

Material:

Forging steel

Spheroidal graphitic

Nickel alloy castings

Crankcase (or) Oil sump (or) Oil pan

The main body of the engine to which the cylinder are attached and which contains the crankshaft and crankshaft bearing is called crankcase.

Function:

To store the oil for the engine lubricating system.

To collect the return oil draining from the main bearings or from the cylinder walls.

To serve as a container in which any impurities or foreign matter.

To enable the hot churned up lubricating oil to settle for a while before being circulated.

To provide for cooling of the hot oil in the sump by transfer of heat to the outside air stream.

Material:

Pressed steel sheet

Aluminium alloy casting (stiffness & rigidity) – higher thermal conductivity.

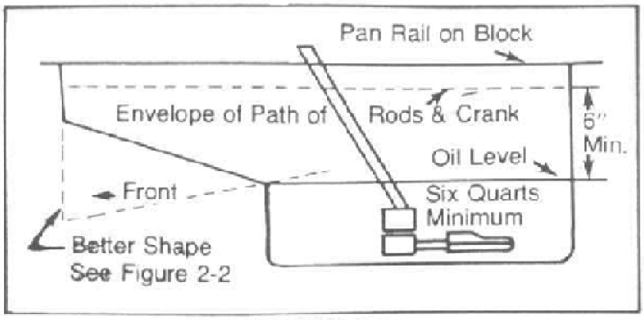
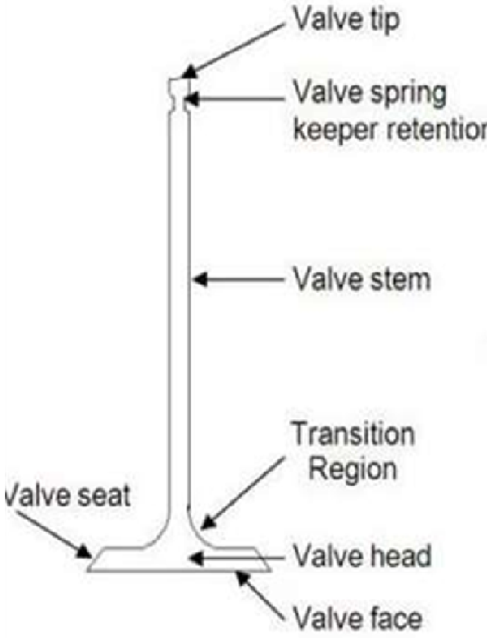


FIGURE 2-1

Valves

To control the inlet and exhaust of internal combustion engine, valves are used.

Two valves are used for each cylinder one for inlet of air-fuel mixture inside the cylinder and other for exhaust of combustion gases.



Spark plug

It is used in spark ignition engine. The main function of a spark plug is to conduct the high potential from the ignition system into the combustion chamber to ignite the compressed air fuel mixture.

THERMODYNAMICS OF AIR STANDARD OTTO AND DIESEL CYCLE

AIR STANDARD EFFICIENCY

To compare the effects of different cycles, it is of paramount importance that the effect of the calorific value of the fuel is altogether eliminated and this can be achieved by considering air (which is assumed to behave as a perfect gas) as the working substance in the engine cylinder. Theefficiency of engine using air as the working medium is known as an “Air standard efficiency”. This efficiency is often called ideal efficiency. The actual efficiency of a cycle is always less than the air-standard efficiency of that cycle under ideal conditions. This is taken into account by introducing a new term “Relative efficiency” which is defined as the ratio of Actual thermal efficiency to Air standard efficiency.

The analysis of all air standard cycles is based upon the following assumptions:

1. The gas in the engine cylinder is a perfect gas i.e., it obeys the gas laws and has constant specific heats.

2. The physical constants of the gas in the cylinder are the same as those of air at moderate temperatures i.e., the molecular weight of cylinder gas is 29.Cp = 1.005 kJ/kg-K, Cv= 0.718 kJ/kg-K.

3. The compression and expansion processes are adiabatic and they take place without internal friction, i.e., these processes are isentropic.

4. No chemical reaction takes place in the cylinder. Heat is supplied or rejected by bringing a hot body or a cold body in contact with cylinder at appropriate points during the process.

5. The cycle is considered closed with the same ‘air’ always remaining in the cylinder to repeat the cycle.

CONSTANT VOLUME OR OTTO CYCLE

This cycle is so named as it was conceived by ‘Otto’. On this cycle, petrol, gas and many types of oil engines work. It is the standard of comparison for internal combustion engines.

Figs. 1 (a) and (b) shows the theoretical p-V diagram and T-s diagrams of this cycle respectively.

The point 1 represents that cylinder is full of air with volume V_1, pressure P_1 and absolute temperature T_1.

Line 1-2 represents the adiabatic compression of air due to which P_1, V_1 and T_1 change to P_2, V_2 and T_2 respectively.

Line 2-3 shows the supply of heat to the air at constant volume so that P_2 and T_2 change to P_3 and T_3 (V_3 being the same as V_2).

Line 3-4 represents the adiabatic expansion of the air. During expansion P_3, V_3 and T_3 change to a final value of P_4, V_4 or V_1 and T_4, respectively.

Line 4-1 shows the rejection of heat by air at constant volume till original state (point 1) reaches.

Consider 1 kg of air (working substance):

Heat supplied at constant volume $= c_v(T_3 - T_2)$.

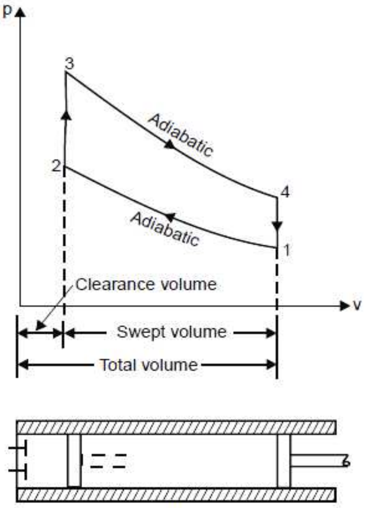
Heat rejected at constant volume $= c_v\,(T_4 - T_1)$.

But, work done $=$ Heat supplied $-$ Heat rejected

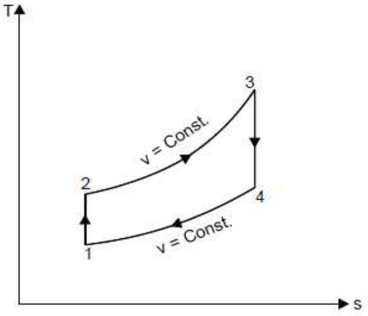
$$= c_v\,(T_3 - T_2) - c_v\,(T_4 - T_1)$$

$$\therefore \quad \text{Efficiency} = \frac{\text{Work done}}{\text{Heat supplied}} = \frac{c_v\,(T_3 - T_2) - c_v\,(T_4 - T_1)}{c_v\,(T_3 - T_2)}$$

$$= 1 - \frac{T_4 - T_1}{T_3 - T_2}$$



(a)



(b)

Let compression ratio, $r_c\ (= r) = \dfrac{v_1}{v_2}$

and expansion ratio, $r_e\ (= r) = \dfrac{v_4}{v_3}$

(These *two ratios are same* in this cycle)

As $\dfrac{T_2}{T_1} = \left(\dfrac{v_1}{v_2}\right)^{\gamma - 1}$

Then, $T_2 = T_1 \,.\, (r)^{\gamma - 1}$

Similarly, $\dfrac{T_3}{T_4} = \left(\dfrac{v_4}{v_3}\right)^{\gamma - 1}$

or $T_3 = T_4 \,.\, (r)^{\gamma - 1}$

Inserting the values of T_2 and T_3 in equation (*i*), we get

$$\eta_{otto} = 1 - \frac{T_4 - T_1}{T_4 \,.\, (r)^{\gamma - 1} - T_1 \,.\, (r)^{\gamma - 1}} = 1 - \frac{T_4 - T_1}{r^{\gamma - 1}(T_4 - T_1)}$$

$$= 1 - \frac{1}{(r)^{\gamma - 1}}$$

This expression is known as the air standard efficiency of the Otto cycle. It is clear from the above expression that efficiency increases with the increase in the value of r, which means we can have maximum efficiency by increasing r to a considerable extent, but due to practical difficulties its value is limited to about 8.

CONSTANT PRESSURE OR DIESEL CYCLE

This cycle was introduced by Dr. R. Diesel in 1897. It differs from Otto cycle in that heat is supplied at constant pressure instead of at constant volume. Fig. (aand b) shows the p-v and T-s diagrams of this cycle respectively.

This cycle comprises of the following operations:

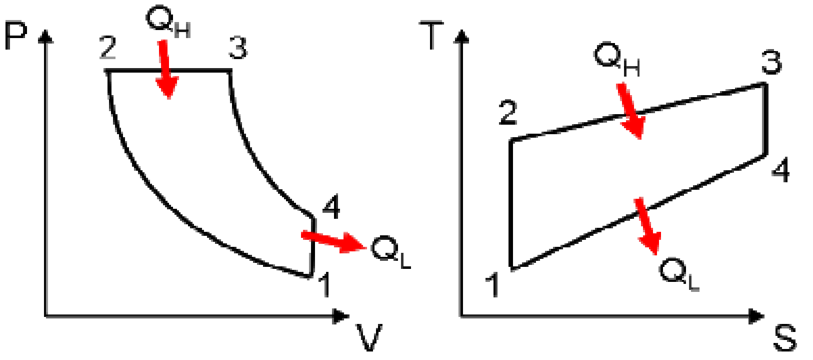


Fig.3. P-V and T-S diagrams of Ideal Diesel Cycle

(i) 1-2......Adiabatic compression.

(ii) 2-3......Addition of heat at constant pressure.

(iii) 3-4......Adiabatic expansion.

(iv) 4-1......Rejection of heat at constant volume.

Point 1 represents that the cylinder is full of air. Let P_1, V_1 and T_1 be the corresponding pressure, volume and absolute temperature. The piston then compresses the air adiabatically (i.e.,pV^r= constant) till the values become P_2, V_2 and T_2 respectively (at the end of the stroke) at point 2. Heat is then added from a hot body at a constant pressure. During this addition of heat let volume increases from V_2 to V_3 and temperature T_2 to T_3, corresponding to point 3. This point (3) is called the point of cut-off. The air then expands adiabatically to the conditions P_4, V_4 and T_4 respectively corresponding to point 4. Finally, the air rejects the heat to the cold body at constant volume till the point 1 where it returns to its original state.

Consider 1 kg of air.

Heat supplied at constant pressure $= c_p(T_3 - T_2)$

Heat rejected at constant volume $= c_v(T_4 - T_1)$

Work done $=$ Heat supplied $-$ heat rejected

$$= c_p(T_3 - T_2) - c_v(T_4 - T_1)$$

$$\therefore \quad \eta_{\text{diesel}} = \frac{\text{Work done}}{\text{Heat supplied}}$$

$$= \frac{c_p(T_3 - T_2) - c_v(T_4 - T_1)}{c_p(T_3 - T_2)}$$

$$= 1 - \frac{(T_4 - T_1)}{\gamma(T_3 - T_2)} \qquad \ldots(i) \quad \left[\because \frac{c_p}{c_v} = \gamma\right]$$

Let compression ratio, $r = \frac{v_1}{v_2}$, and cut-off ratio, $\rho = \frac{v_3}{v_2}$ *i.e.,* $\frac{\text{Volume at cut-off}}{\text{Clearance volume}}$

Now, during *adiabatic compression 1-2,*

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{\gamma - 1} = (r)^{\gamma - 1} \quad \text{or} \quad T_2 = T_1 \,.\, (r)^{\gamma - 1}$$

During *constant pressure process 2-3,*

$$\frac{T_3}{T_2} = \frac{v_3}{v_2} = \rho \quad \text{or} \quad T_3 = \rho \,.\, T_2 = \rho \,.\, T_1 \,.\, (r)^{\gamma - 1}$$

During *adiabatic expansion 3-4*

$$\frac{T_3}{T_4} = \left(\frac{v_4}{v_3}\right)^{\gamma - 1}$$

$$= \left(\frac{r}{\rho}\right)^{\gamma - 1} \qquad \left(\because \frac{v_4}{v_3} = \frac{v_1}{v_3} = \frac{v_1}{v_2} \times \frac{v_2}{v_3} = \frac{r}{\rho}\right)$$

$$\therefore \quad T_4 = \frac{T_3}{\left(\frac{r}{\rho}\right)^{\gamma - 1}} = \frac{\rho \,.\, T_1 (r)^{\gamma - 1}}{\left(\frac{r}{\rho}\right)^{\gamma - 1}} = T_1 \,.\, \rho^{\gamma}$$

By inserting values of T_2, T_3 and T_4 in eqn. (i), we get

$$\eta_{\text{diesel}} = 1 - \frac{(T_1 \,.\, \rho^{\gamma} - T_1)}{\gamma\,(\rho \,.\, T_1 \,.\, (r)^{\gamma - 1} - T_1 \,.\, (r)^{\gamma - 1})} = 1 - \frac{(\rho^{\gamma} - 1)}{\gamma (r)^{\gamma - 1} (\rho - 1)}$$

or

$$\eta_{\text{diesel}} = 1 - \frac{1}{\gamma (r)^{\gamma - 1}} \left[\frac{\rho^{\gamma} - 1}{\rho - 1}\right] \qquad \ldots(13.7)$$

It may be observed that eqn. (13.7) for efficiency of diesel cycle is different from that of the Otto cycle only in bracketed factor. This factor is always greater than unity, because r > 1. Hence for a given compression ratio, the Otto cycle is more efficient.

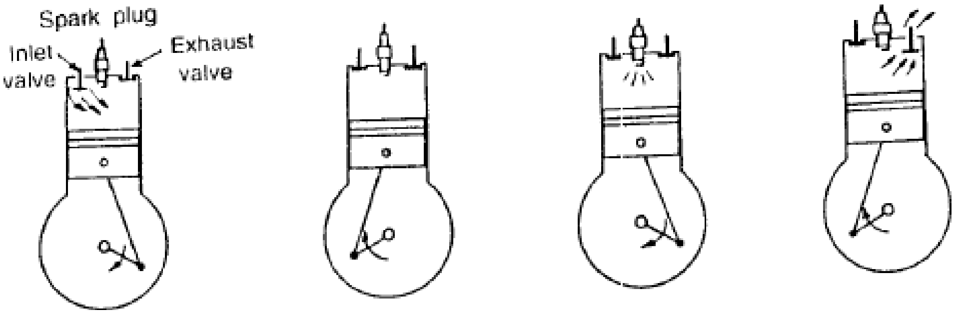
FOUR STROKE CYCLE PETROL ENGINE

It is also known as Otto cycle. It requires four strokes of the piston to complete one cycle of operation in the engine cylinder. The four strokes of a petrol engine sucking fuel-air mixture (petrol mixed with proportionate quantity of air in the carburetor known as charge) are described below:

1. Suction or charging stroke: In this stroke, the inlet valve opens and charge is sucked

into the cylinder as the piston moves downward from top dead centre *(T.D.C.)*. It continues till the piston reaches its bottom dead centre *(B.D.* C.) as shown in (a).

2. Compression stroke: In this stroke, both the inlet and exhaust valves are closed and the charge is compressed as the piston moves upwards from *B.D.* C. to *TD.* C. As a result of compression, the pressure and temperature of the charge increases considerably (the actual values depend upon the compression ratio). This completes one revolution of the crank shaft. The compression stroke is shown in (b).



(*a*) Suction or charging stroke.

(*b*) Compression stroke.

(*c*) Expansion or working stroke.

(*d*) Exhaust stroke.

Four-stroke cycle petrol engine.

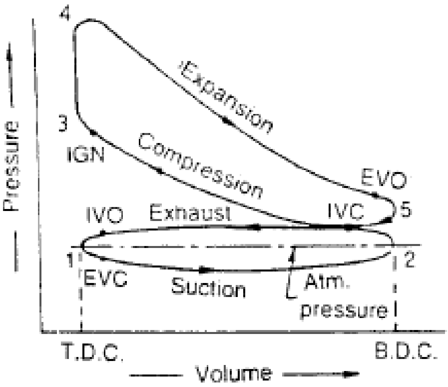
3. Expansion or working stroke Shortly before the piston reaches *T.D.*C. (during compression stroke), the charge is ignited with the help of a spark plug. It suddenly increases the pressure and temperature of the products of combustion but the volume, practically, remains constant. Due to the rise in pressure, the piston is pushed down with a great force. The hot burnt gases expand due to high speed of the piston. During this expansion, some of the heat energy produced is transformed into mechanical work. It may be noted that during this working stroke, as shown in *(c),* both the valves are closed and piston moves from *T.D.C.* to *B.D.C*

4. Exhaust stroke: In this stroke, the exhaust valve is open as piston moves from *B.D.C.* to *T.D.*C. This movement of the piston pushes out the products of combustion, from the engine cylinder and are exhausted through the exhaust valve into the atmosphere, as shown in *(d).* This completes the cycle, and the engine cylinder is ready to suck the charge again.

ACTUAL INDICATOR DIAGRAM FOR A FOUR STROKE CYCLE PETROL ENGINE

The actual indicator diagram for a four stroke cycle petrol engine is shown. The

suction stroke is shown by the line 1-2, which lies below the atmospheric pressure line. It is this pressure difference, which makes the fuel-air mixture to flow into the engine cylinder. The inlet valve offers some resistance to the incoming charge. That is why, the charge can not enter suddenly into the engine cylinder. As a result of this, pressure inside the cylinder remains somewhat below the atmospheric pressure during the suction stroke. Thecompression stroke is shown by the line 2-3, which shows that the inlet valve closes (lVC)a little beyond 2 (i.e. BDC*)*. At the end of this stroke, there is an increase in the pressure inside the engine cylinder. Shortly before the end of compression stroke *(i.e. TDC),*the charge is ignited (lGN)with the help of spark plug as shown in the figure. The sparking suddenly increases pressure and temperature of the products of combustion. But



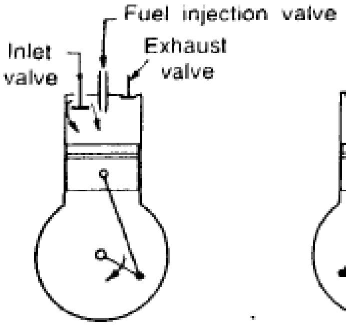
the volume, practically, remains constant as shown by the line 3-4. The expansion stroke is shown by the line 4-5, in which the exit valve opens *(EVO)* a little before 5 *(i.e. BDC).* Now the burnt gases are exhausted into the atmosphere through the exit valve. The exhaust stroke is shown by the line 5-1, which lies above the atmospheric pressure line. It is this pressure difference, which makes the burnt gases to flow out of the engine cylinder. The exit valve offers some resistance to the outgoing burnt gases. That is why the burnt gases cannot escape suddenly from the engine cylinder. As a result of this, pressure inside the cylinder remains somewhat above the atmospheric pressure line during the exhaust stroke

FOUR-STROKE CYCLE DIESEL ENGINE

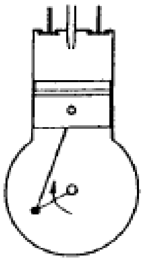
It is also known as *compression ignition engine* because the ignition takes p\ace due to the heat produced in the engine cylinder at the end of compression stroke. The four strokes of a diesel engine sucking pure air are described below:

1. Suction or charging stroke: In this stroke, the inlet valve opens and pure air is sucked into the cylinder as the piston moves downwards from the top dead centre *(TDC)*. It continues till the piston reaches its bottom dead centre *(BDC)* as shown *(a)*.

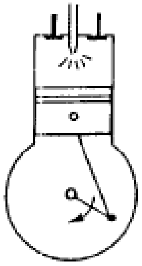
2. Compression stroke: In this stroke, both the valves are closed and the air is compressed as the piston moves upwards from *BDC* to *TDC*. As a result of compression, pressure and temperature of the air increases considerably (the actual value depends upon the compression ratio). This completes one revolution of the crank shaft. The compression stroke is shown in *(b)*.



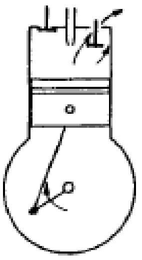
(*a*) Suction or charging stroke.



(*b*) Compression stroke.



(*c*) Expansion or working stroke.



(*d*) Exhaust stroke.

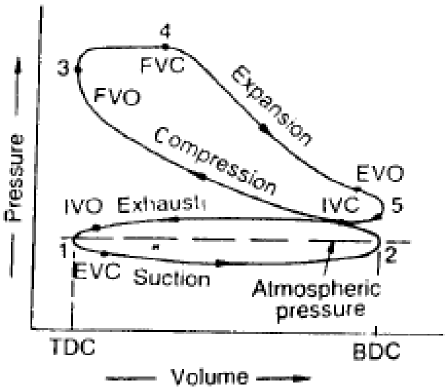
3. Expansion or working stroke: Shortly before the piston reaches the *TDC* (during the

compression stroke), fuel oil is injected in the form of very fine spray into the engine cylinder, through the nozzle, known as fuel injection valve. At this moment temperature of the compressed air is sufficiently high to ignite the fuel. It suddenly increases the pressure and temperature of the products of combustion. The fuel oil is continuously injected for a fraction of the revolution. The fuel oil is assumed to be burnt at constant pressure. Due to increased pressure, the piston is pushed down with a great force. The hot burnt gases expand due to high speed of the piston. During this expansion, some of the heat energy is transformed into mechanical work. It may be noted that during this working stroke, both the valves are closed and the piston moves from *TDC* to *BDC*.

4. Exhaust stroke: In this stroke, the exhaust valve is open as the piston moves from *BDC* to *TDC*. This movement of the piston pushes out the products of combustion from the engine cylinder through the exhaust valve into the atmosphere. This completes the cycle and the engine cylinder is ready to suck the fresh air again.

ACTUAL INDICATOR DIAGRAM FOR A FOUR STROKE CYCLE DIESEL ENGINE

The actual indicator diagram for a four-stroke cycle diesel engine is shown. The suction stroke is shown by the line 1-2 which lies below the atmospheric pressure line. It is this pressure difference, which makes the fresh air to flow into the engine cylinder. The inlet valve offers some resistance to the incoming air. That is why, the air can not enter suddenly into the engine cylinder. As a result **of this pressure inside the cylinder remains somewhat below** the atmospheric pressure during the suction stroke. The compression stroke is shown by the line 2-3, which shows that the inlet valves closes *(/VC)* a little beyond 2 *(i.e. BDC).*At the end of this stroke, there is an increase of pressure inside the engine cylinder. Shortly before the end of compression stroke *(i.e. TDC),* fuel valve opens *(FVO)* and the fuel is injected into the engine cylinder. The fuel is ignited.



The ignition suddenly increases volume and temperature of the products of combustion. But the pressure, practically, remains constant as shown by the line 3-4. The expansion stroke is shown by the line 4-5, in which the exit valve opens a little before 5 *(i.e. BDC).* Now the burnt gases are exhausted into the atmosphere through the exhaust valve. The exhaust stroke is shown by the line 5-1, which lies above the atmospheric pressure line. It is this pressure difference, which makes the burnt gases to flow out of the engine cylinder. The exhaust valve offers some resistance to the outgoing burnt gases. That is why, the burnt gases cannot (escape suddenly from the engine cylinder. As a result of this, pressure inside the cylinder remains somewhat above the atmospheric pressure during the exhaust stroke.

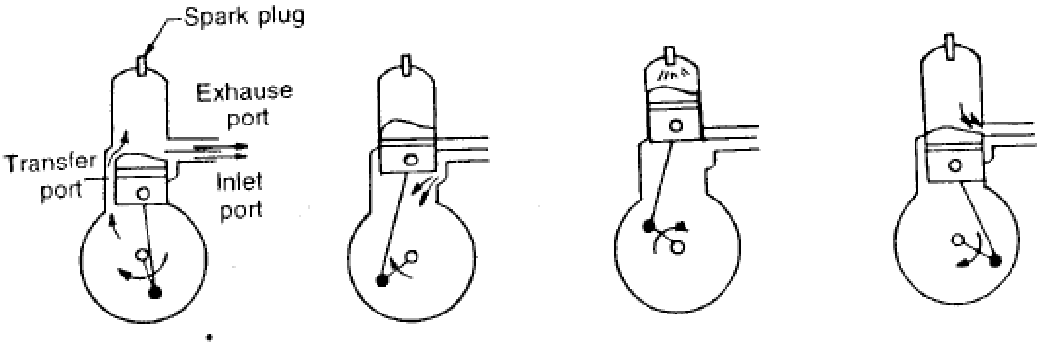
TWO-STROKE CYCLE PETROL ENGINE

A two-stroke cycle petrol engine was devised by Duglad Clerk in I RHO. In this cycle, the suction, compression, expansion and exhaust takes place during two strokes of the piston. It means that there is one working stroke after every revolution of the crank shaft. A two stroke engine has ports instead of valves. All the four stages of a two stroke petrol engine are described below:

1. Suction stage: In this stage, the piston, while going down towards *BDC,* uncovers both the transfer port and the exhaust port The fresh fuel-air mixture flows into the engine cylinder from the crank case, as shown *(a).*

2. Compression stage: In this stage, the piston, while moving up, first covers the transfer port and then exhaust port. After that the fuel is compressed as the piston moves upwards as shown *(b).* In this stage, the inlet port opens and fresh fuel-air mixture enters into the crank case.

3. Expansion stage: Shortly before this piston reaches the *TDC* (during compression stroke), the charge is ignited with the help of a spark plug. It suddenly increases the pressure and temperature of the products of combustion. But the volume, practically, remains constant. Due to rise in the pressure, the piston is pushed downwards with a great force as shown in *(c).* The hot burnt gases expand due to high speed of the piston. During this expansion, some of the heat energy produced is transformed into mechanical work.

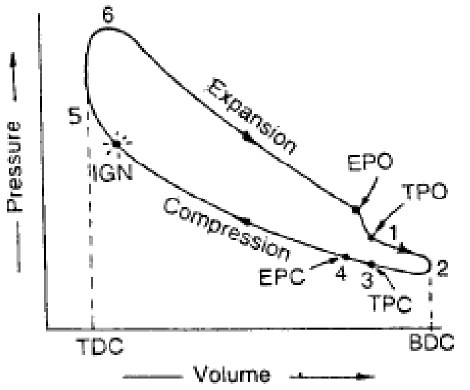


(*a*) Suction. (*b*) Compression. (*c*) Expansion. (*d*) Exhaust.

4. Exhaust stage: In this stage, the exhaust port is opened as the piston moves downwards. The products of combustion, from the engine cylinder are exhausted through the exhaust port into the atmosphere, as shown *(d).* This completes the cycle and the engine cylinder is ready to suck the charge again

ACTUAL INDICATOR DIAGRAM FOR A TWO STROKE CYCLE PETROL ENGINE

The actual indicator diagram for a two-stroke cycle petrol engine is shown in suction is shown by the line 1-2-3, *i.e.* from the instant transfer port opens *(TPO)* and transfer port closes *(TPC).* We know that during the suction stage, the exhaust port is also open. In the first half of suction stage, the volume of fuel-air mixture and burnt gases increases. This happens as the piston moves from I to 2 *(i.e. BDC).* In the second half of the suction stage, the volume of charge and burnt gases decreases. This happens as the piston moves upwards from 2 to 3. A little beyond 3, the exhaust port closes *(EPC)* at 4. Now the charge inside the engine cylinder is compressed which is shown by the line 4-5.



At the end of the compression, there is an increase in the pressure inside the engine cylinder. Shortly before the end of compression *(i.e. TDC)* the charge is ignited *(IGN)* with the help of spark plug. The sparking suddenly increases pressure and temperature of the products of combustion. But the volume, practically, remains constant as shown by the line 5-6. The expansion is shown by the line 6-7. Now the exhaust port opens *(EPO)* at 7, and the burnt gases are exhausted into the atmosphere through the exhaust port. It reduces the pressure. As the piston is moving towards *BDC,* therefore volume of burnt gases increases from 7 to 1. At 1, the transfer port opens *(TPO)* and the suction starts.

TWO-STROKE CYCLE DIESEL ENGINE

A two-stroke cycle diesel engine also has one working stroke after every revolution of the crank shaft. All the four stages of a two stroke cycle diesel engine are described below:

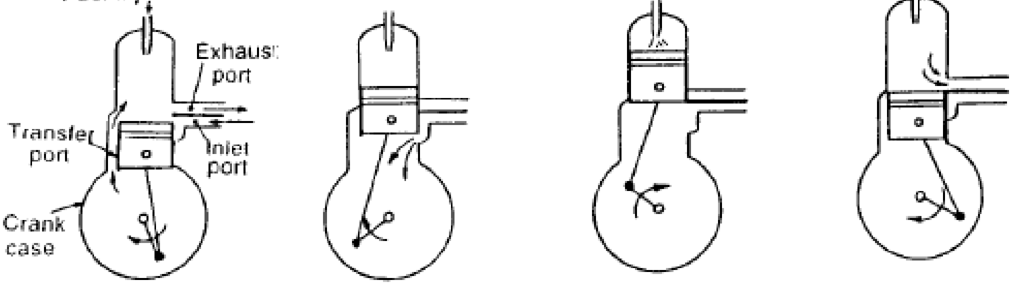
1. Suction stage: In this stage, the piston while going down towards *BDC* uncovers the

transfer port and the exhaust port. The fresh air flows into the engine cylinder from the crank case, as shown in *(a).*

2. Compression stage: In this stage, the piston while moving up, first covers the transfer

port and then exhaust port. After that the air is compressed as the piston moves upwards as shown in *(b).* In this stage, the inlet port opens and the fresh air enters into the crank case.

3. Expansion stage: Shortly before the piston reaches the *TDC* (during compression stroke), the fuel oil is injected in the form of very fine spray into the engine cylinder through the nozzle known as fuel injection valve, as shown in *(c).* At this moment, temperature of the compressed air is sufficiently high to ignite the fuel. It suddenly increases the pressure and temperature of the products of combustion. The fuel oil is continuously injected for a fraction of the crank revolution. The fuel oil is assumed to be burnt at constant pressure. Due to increased pressure, the piston is pushed with a great force. The hot burnt gases expand due to high speed of the piston. During the expansion, some of the heat energy produced is transformed into mechanical work .



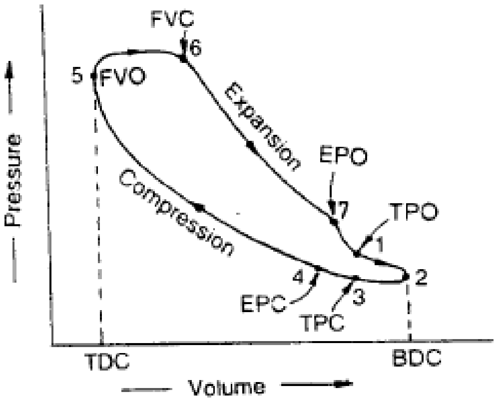
(*a*) Suction. (*b*) Compression. (*c*) Expansion. (*d*) Exhaust.

4. Exhaust stage: In this stage, the exhaust port is opened and the piston moves downwards. The products of combustion from the engine cylinder are exhausted through the exhaust port into the atmosphere as shown in *(d).* This completes the cycle, and the engine cylinder is ready to suck the air again.

ACTUAL INDICATOR DIAGRAM FOR TWO STROKE CYCLE DIESEL ENGINE

The actual indicator diagram for a two-stroke cycle diesel engine is shown. The suction is shown by the line: 1-2-3 *i.e.* from the instant transfer port opens *(TPO)* and transfer port

closes*(TPC).* We know that during the suction stage, the exhaust port is also open. In the first half of suction stage, the volume: of air and burnt gases increases. This happens as :the piston moves from *1-2 (i.e. BDC).* In the second half of the suction stage, the volume of air and burnt gases decreases. This happens as the piston moves upwards from 2-3. A little beyond 3, the exhaust port closes *(EPC)* at 4. Now the air inside the engine cylinder is compressed which is shown by the line 4-5. At the end of compression, there is an increase in the pressure inside the engine cylinder. Shortly before the end of compression *(i. e. TDC),* fuel valve opens *(FVO)* and the fuel is injected into the engine cylinder. The fuel is ignited by high temperature of the compressed air.



The ignition suddenly increases volume and temperature of the products of combustion. But the pressure, practically, remains constant as shown by the line 5-6. The expansion IS shown by the line 6-7, Nowth~ exhaust port opens *(EPO)* at 7 and the burnt gases are exhausted into the atmosphere through the exhaust port. It reduces the pressure. As the piston is moving towards *BDC,* therefore volume of burnt gases increases from 7 to 1. At 1, the transfer port opens *(TPO)* and the suction starts

TWO STROKE AND FOUR STROKE CYCLE ENGINE

In a two-stroke engine, the working cycle is completed in two strokes of the piston or one revolution of the crankshaft. This is achieved by carrying out the suction and compression processes in one stroke (or more precisely in inward stroke), expansion and exhaust processes in the second stroke (or more precisely in outward stroke). In a four-stroke engine, the working cycle is completed in four-strokes of the piston or two-revolutions of the crankshaft. This is achieved by carrying out suction, compression, expansion and exhaust processes in each stroke. It will be interesting to know that from the thermodynamic point of view, there is no difference between two-stroke and four-stroke cycle engines. The difference is purely mechanical.

Advantages and Disadvantage of Two-stroke over Four-stroke Cycle Engines

Advantages

1. A two stroke cycle engine gives twice the number of power strokes than the four stroke cycle engine at the same engine speed. Theoretically, a two-stroke cycle engine should develop twice the power as that of a four-stroke cycle engine. But in actual practice, a two-stroke cycle engine develops 1.7 to 1.8 times greater value for slow speed engines the power developed by four-stroke cycle engine of the same dimensions and speed. This is due to lower compression ratio and effective stroke being less than the theoretical stroke.
2. For the same power developed, a two-stroke cycle engine is lighter, less bulky and occupies less floor area. Thus it makes, a two-stroke cycle engine suitable for marine engines and other light vehicles.
3. As the number of working strokes in a two-stroke cycle engine are twice than the four-stroke cycle engine, so the turning moment of a two-stroke cycle engine is more uniform. Thus it makes a two-stroke cycle engine to have a lighter flywheel and foundations. This also leads to a higher mechanical efficiency of a two-stroke cycle engine.
4. The initial cost of a two-stroke cycle engine is considerably less than a four-stroke cycle engine.
5. The mechanism of a two-stroke cycle engine is much simpler than a four-stroke cycle engine.
6. The two-stroke cycle engines are much easier to start.

Disadvantages

1. Thermal efficiency of a two-stroke cycle engine is less than that a four-stroke cycle engine, because a two-stroke cycle engine has less compression ratio than that of a four-stroke cycle engine.
2. Overall efficiency of a two stroke cycle engine is also less than that of a four-stroke cycle engine because in a two-stroke cycle, inlet and exhaust ports remain open simultaneously for some time. In spite of careful design, a small quantity of charge is lost from the engine cylinder.
3. In case of a two-stroke cycle engine, the number of power strokes is twice as those of a four-stroke cycle engine. Thus the capacity of the cooling system must be higher. Beyond a certain limit, the cooling capacity offers a considerable difficulty. Moreover, there is a greater wear and tear in a two-stroke cycle engine.

4. The consumption of lubricating oil is large in a two-stroke cycle engine because of high operating temperature.
5. The exhaust gases in a two-stroke cycle engine create noise, because of short time available for their exhaust.

COMPARISON OF PETROL AND DIESEL ENGINES (SI and CI Engines)

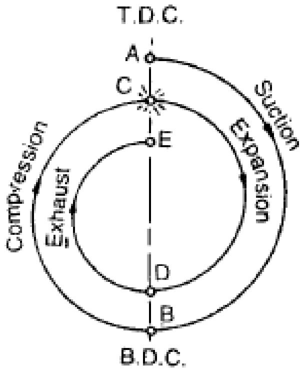
Following points are important for the comparison of petrol engines and diesel engines:

Petrol Engines	**Diesel Engines**
• A petrol engine draws a mixture of petrol and air during suction stroke. • The carburetor is employed to mix air and petrol in the required proportion and to supply it to the engine during suction stroke • Pressure at the end of compression is about 10 bar • The charge *(i.e.* petrol and air mixture) is ignited with the help of spark plug • The combustion of fuel takes place approximately at constant volume. In other words, it works on Otto cycle • A petrol engine has compression ratio approximately from 6 to 10. • The starting' is easy due to low compression ratio. • As the compression ratio is low, the petrol engines are lighter and cheaper. • The running cost of a petrol engine is high because of the higher cost of petrol. • The maintenance cost is less. • The thermal efficiency is up to	• A diesel engine draws only air during suction stroke • The injector or atomizer is employed to inject the fuel at the end of compression stroke. • Pressure at the end of compression is about 35 bar. • The fuel is injected in the form of fine spray. The temperature of the compressed air (about 600"C at a pressure of about *35*bar) is sufficiently high to ignite the fuel. • The combustion of fuel takes place approximately at constant pressure. In other words. It works on Diesel cycle. • A diesel engine has compression ratio approximately from 15 to 25. • The starting is little difficult due. to high compression ratio. • As the compression ratio is high. the diesel engine;; are heavier and costlier. • The running cost of diesel engine is low because of the lower cost of diesel. • The maintenance cost is more.

about 26%. • Overheating trouble is more due to low thermal efficiency. • These are high speed engines. • The petrol engines arc generally employed in light duty vehicles such as scooters, motorcycles, cars. These are also used in aero planes	• The thermal efficiency is up to about 40% • Overheating trouble is less due to high thermal efficiency • These are relatively low speed engines. • The diesel engines are generally employed in heavy duty vehicles like buses. trucks, and earth moving machines etc.

VALVE TIMING DIAGRAM

A valve timing diagram is a graphical representation of the exact moments, in the sequence of operations, at which the two valves *(i.e.* inlet and exhaust valves) open and close as well as firing of the fuel. It is, generally, expressed in terms of angular positions of the crankshaft. Here we shall discuss theoretical valve timing diagrams for four stroke and two stroke cycle engines.



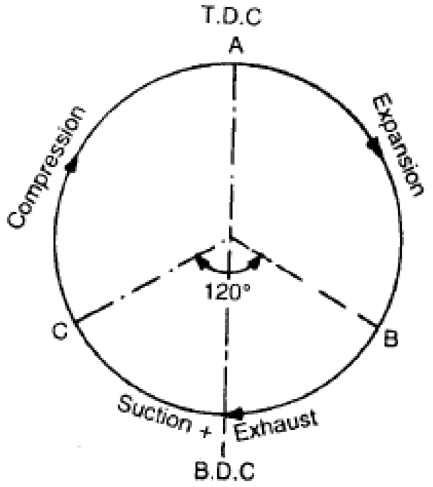
Four-stroke cycle engine.

1. Theoretical valve timing diagram for four stroke cycle engine

The theoretical valve timing diagram for a four-stroke cycle engine is shown In this diagram, the inlet valve opens at *A* and the suction takes place from *A* to *B.* The crankshaft revolves through 180^0 and the piston moves from *T.D.C.* to *B.D.C. At B,* theinlet valve closes and the compression takes place from *B* to C. The crankshaft revolves through 180^0 and the piston moves from *B.D.* C. to *T.D.* C. At C, the fuel is fired and theexpansion takes place from C to *D.* The crankshaft revolves through 180^0 and the piston again moves from *T.D.C.* to *B.D.C.* At *D,* the exhaust valve opens and the exhaust takes place from *D* to *E.* The crankshaft again revolves through 180^0 and the piston moves back to *T.D.*C.

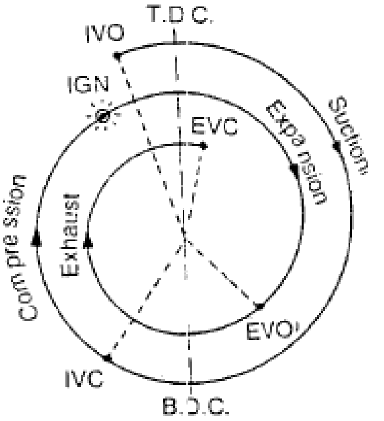
2. Theoretical valve timing diagram for two-stroke cycle engine.

The theoretical valve timing diagram for a two-stroke cycle engine is shown. In this diagram, the fuel is fired at *A*and the expansion of gases takes place from *A* to *B.* The crankshaft revolves through approximately 120^0 and the piston moves from *T.D.C.* towards *B.D.C.* At *B,* the valves open and suction as well as exhaust take place from *B* to C. The crankshaft revolves through approximately 120^0 and the piston moves first to *B.D.C* and then little upwards. At C. both the valves close and compression takes place from C to *A.* The crankshaft revolves through approximately $120^0$and the piston moves to T.D.C



Two-stroke cycle engine.

VALVE TIMING DIAGRAM FOR A FOUR STROKE CYCLE PETROL ENGINE



TDC : Top dead centre

BDC : Bottom dead centre

IVO : Inlet valve opens (10°-20° before *TDC*)

IVC : Inlet valve closes (30°- 40° after *BDC*)

IGN : Ignition (20°-30° before *TDC*)

EVO : Exit valve opens (30°-50° before *BDC*)

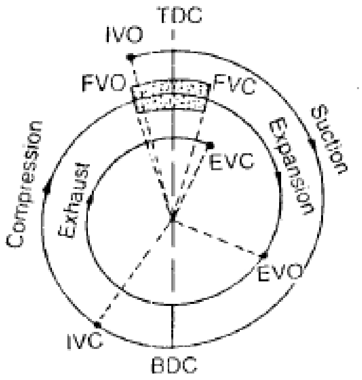
EVC : Exit valve closes (10°-15° after *TDC*)

In the valve timing diagram, as shown we see that the inlet valve opens before the piston reaches *TDC* or in other words, while the piston is still moving up before the beginning of the suction stroke. Now the piston reaches the *TDC* and the suction stroke starts. The piston reaches the *BDC* and then starts moving up. The inlet valve closes, when the crank has moved a little beyond the *BDC* This is done as the incoming charge continues to flow into the cylinder although the piston is moving upwards from *BDC* Now the charge is compressed (with both valves closed) and then and temperature) push the piston downwards with full force and the expansion or working stroke takes place. Now the exhaust valve opens before the piston again reaches *BDC* and the burnt gases start leaving the engine cylinder. Now the piston reaches *BDC* and then starts moving up, thus performing the exhaust stroke. The inlet valve opens before the piston reaches *TDC* to start suction stroke. This is done as the fresh incoming charge helps in pushing out the burnt gases. Now the piston again reaches *TDC,* and the suction stroke starts. The exit valve closes after the crank has moved a little beyond the *TDC.* This is done as the burnt gases continue to leave the engine cylinder although the piston is moving downwards. It may be noted that for a small fraction of a crank revolution, both the inlet and outlet valves are open. This is known as valve overlap

VALVE TIMING DIAGRAM FOR A FOUR-STROKE CYCLE DIESEL ENGINE

In the valve timing diagram as shown we see that the inlet valve opens before the

piston reaches *TDC;* or in other words while the piston is still moving up before the beginning of the suction stroke. Now the piston reaches the *TDC* and the suction stroke starts. The piston reaches the *BDC* and then starts moving up. The inlet valve closes, when the crank has moved a little beyond the BDC.



TDC : Top dead centre

BDC : Bottom dead centre

IVO : Inlet valve opens (10° - 20° before *TDC*)

IVC : Inlet valve closes (25° - 40° after *BDC*)

FVO : Fuel valve opens (10° - 15° before *TDC*)

FVC : Fuel valve closes (15° - 20° after *TDC*)

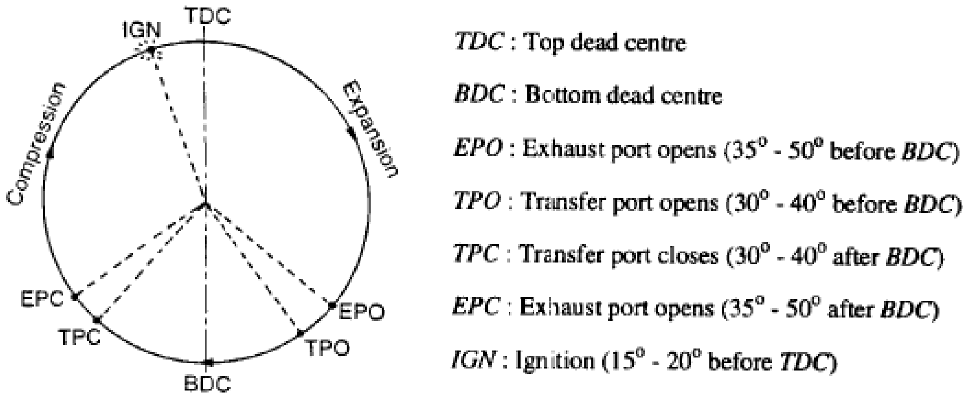
EVO : Exhaust valve opens (39° - 50° before *BDC*)

EVC : Exhaust valve closes (10° - 15° after *TDC*)

This is done as the incoming air continues to flow into the cylinder although the piston is moving upwards from *BDC.* Now the air is compressed with both valves closed. Fuel valve opens a little before the piston reaches the *TDC.* Now the fuel is injected in the form of very fine spray, into the engine cylinder, which gets ignited due to high temperature of the compressed air. The fuel valve closes after the piston has come down a little from the *TDC.* This is done as the required quantity of fuel is injected into the engine cylinder. The burnt gases (under high pressure and temperature) push the piston downwards, and the expansion or working stroke takes place. Now the exhaust valve opens before the piston again reaches *BDC* and the burnt gases start leaving the engine cylinder. Now the piston reaches *BDC* and then starts moving up thus performing the exhaust stroke. The inlet valve opens before the piston reaches *TDC* to start suction stroke. This is done as the fresh air helps in pushing out the burnt gases. Now the piston again reaches *TDC,* and the suction starts. The exhaust valve closes when the crank has moved a little beyond the *TDC.* This is done as the burnt gases continue to leave the engine cylinder although the piston is moving downwards.

VALVE TIMING DIAGRAM FOR A TWO-STROKE CYCLE PETROL ENGINE

In the valve timing diagram, as shown we see that the expansion of the charge (after ignition) starts as the piston moves from *TDC* towards *BDC.* First of all, the exhaust port opens before the piston reaches *BDC* and the burnt gases start leaving the cylinder. After a small fraction of the crank revolution, the transfer port also opens and the fresh fuel-air mixture enters into the engine cylinder. This is done as the fresh incoming charge helps in pushing out the burnt gases. Now the piston reaches *BDC* and then starts moving upwards. As the crank moves a little beyond *BDC,* first the transfer port closes and then the exhaust port also closes. This is done to suck fresh charge through the transfer port and to exhaust the burnt gases through the exhaust port simultaneously. Now the charge is compressed with both ports closed, and then ignited with the help of a spark plug before the end of compression stroke. This is done as the charge requires some time to ignite. By the time the piston reaches *TDC,* the burnt gases (under high pressure and temperature) push the piston downwards with full force and expansion of the burnt gases takes place. It may be noted that the exhaust and transfer ports open and close at equal angles on either side of the *BDC* position.



TDC : Top dead centre

BDC : Bottom dead centre

EPO : Exhaust port opens (35° - 50° before *BDC*)

TPO : Transfer port opens (30° - 40° before *BDC*)

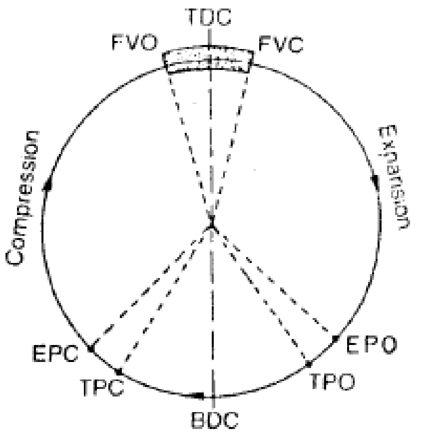
TPC : Transfer port closes (30° - 40° after *BDC*)

EPC : Exhaust port opens (35° - 50° after *BDC*)

IGN : Ignition (15° - 20° before *TDC*)

VALVE TIMING DIAGRAM FOR A TWO-STROKE CYCLE DIESEL ENGINE

In the valve timing diagram, as shown, we see that the expansion of the charge (after ignition) starts as the piston moves from *TDC* towards *BDC.* First of all, the exhaust port opens before the piston reaches *BDC* and the burnt gases start leaving the cylinder. After a small fraction of the crank revolution, the transfer port also opens and the fresh air enters into the engine cylinder. This is done as the fresh incoming air helps in pushing out the burnt gases. Now the piston reaches *BDC* and then starts moving upwards. As the crank moves a little beyond *BDC,* first the transfer port closes and then the exhaust port also closes. This is done to suck fresh air through the transfer port and to exhaust the burnt gases through the exhaust port simultaneously. Now the charge is compressed



TDC : Top dead centre
BDC Bottom dead centre
FVO : Fuel valve opens (10° - 15° before *TDC*)
FVC : Fuel valve closes (15° - 20° after *TDC*)
EPO : Exhaust port opens (35° - 50° before *BDC*)
TPO : Transfer port opens (30° - 40° before *BDC*)
TPC : Transfer port closes (30° - 40° after *BDC*)
EPC : Exhaust port closes (35° - 50° after *BDC*)

with both the ports closed. Fuel valve opens a little before the piston reaches the *TDC.* Now the fuel is injected in the form of very fine spray into the engine cylinder, which gets ignited due to high temperature of the compressed air. The fuel valve closes after the piston has come down a little from the *TDC.* 'This is done as the required quantity of fuel is injected into the engine cylinder. Now the burnt gases (under high pressure and temperature) push the piston downwards with full force and expansion of the gases takes place. It may be noted that in a two-stroke cycle diesel engine, like two-stroke petrol engine, the exhaust and transfer ports open and close at equal angles on either side of the *BDC* position.

RATING OF SI ENGINE FUELS OCTANE NUMBER

The hydrocarbon fuels used in spark ignition (S.I.) engine have a tendency to cause engine knock when the engine operating conditions become severe. The knocking tendency of a fuel in S.I. engines is generally expressed by its *octane number.* The percentage, by volume, of iso-octane in a mixture of iso-octane normal heptane ,which exactly matches the knocking intensity of a given fuel, in a standard engine, under given standard operating conditions, is termed as the *octane number rating* of that fuel. Thus, if a mixture of 50 percent iso-octane and 50 percent normal heptane matches the fuel under test, then this fuel is assigned an octane number rating of 50. If a fuel matches in knocking intensity a mixture of 75 percent iso-octane and 25 percent normal heptane, then this fuel would be assigned an octane number rating of 75. This octane number rating is an expression which indicates the ability of a fuel to resist knock in a S.1. engine. Since iso-octane is a very good anti-knock fuel, therefore it is assigned a rating of 100 octane number. On the other hand, normal heptane has very poor anti-knock qualities, therefore it is given a rating of 0 (zero) octane number. These two fuels, *i.e.* iso-octane and normal heptane are known as primary reference fuels. It may be noted that higher the octane number rating of a fuel, the greater will be its resistance to knock and the higher will be the· compression ratio. Since the power output and specific fuel consumption are functions of compression ratio, therefore we may say that these are also functions of octane number rating. This fact indicates the extreme importance of the octane number rating in fuels for S.I. engines.

RATING OF CI ENGINE FUELS CETANE NUMBER

The knocking tendency is also found in compression ignition (C.I.) engines with an effect similar to that of S.1. engines, but it is due to a different phenomenon. The knock in C.I. engines is due to sudden ignition and abnormally rapid combustion of accumulated fuel in the combustion chamber Such a situation occurs Because of an Ignition lag in the combustion of the fuel between the time of injection and the actual burning. The property of ignition lag is generally measured in terms of *cetane number.* It is defined as the percentage, by volume, of cetane in a mixture of cetane and alpha-methyl-naphthalene that produces the same ignition lag as the fuel being tested in the same engine and under the same operating conditions. For example, a fuel of cetane number 50 has the same ignition quality as a mixture of 50 percent cetane and 50 percent alpha-methyl-naphthalene. The cetane which is a straight chain paraffin with good ignition quality is assigned a cetane number of 100 and alpha-methyl-naphthalene which is a hydrocarbon with poor ignition quality, is assigned a 0 (zero) cetane number.

TEXT / REFERENCES BOOKS

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UNIT II SI ENGINES

SI ENGINES

Air Fuel ratio requirements-Carburetion-types of Automobile carburetor-working principle, injection system in SI Engines. Combustion in SI Engines-Combustion Chambers, Factors controlling combustion chamber design, stages of combustion-Factors affecting Flame propagation, Knock in SI engines, variables affecting Knocking.

Combustion & Combustion Chamber in SI Engines

Introduction

Combustion is a chemical reaction in which certain elements of the fuel like hydrogen and carbon combine with oxygen liberating heat energy and causing an increase in temperature of the gases.

The conditions necessary for combustion are the presence of

Combustible mixture (Fuel +oxidizer)

Some means of initiating the process

Depending on the type of engines, process of combustion generally takes place either in

A homogeneous or

A heterogeneous fuel vapor-air mixture

Homogeneous Mixture

In spark-ignition engines homogeneous mixture of air and fuel is formed in the (Carburetor, PFI and DFI) then combustion is initiated at the end of compression stroke.

Once the fuel vapor-air mixture is ignited, a flame front appears and rapidly spreads through the mixture The flame propagation is caused by heat transfer and diffusion of burning fuel molecules from the combustion zone to the adjacent layers of fresh mixture. The velocity at which the flame front moves, with respect to the unburned mixture in a direction normal to its surface is called the normal flame velocity. In SI Engine working with gasoline/ petrol the maximum flame speed is obtained when Φ is between 1.1 and 1.2, i.e., when the mixture is slightly richer than stoichiometric. If the equivalence ratio is outside this range the flame speed drops rapidly to a low value and ceases to propagate

Introducing turbulence and incorporating proper mixture movement can increase flame speed in a mixtures outside the above range. Combustion in the SI engine can be classified as Normal Combustion and Abnormal Combustion

Stages of Combustion in SI Engine

From the theoretical pressure-crank angle diagram

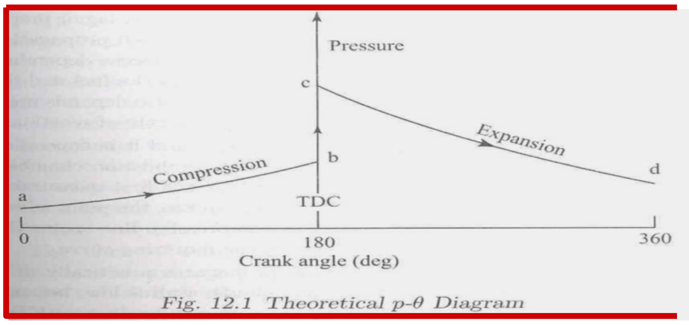


Fig. 12.1 Theoretical p-θ Diagram

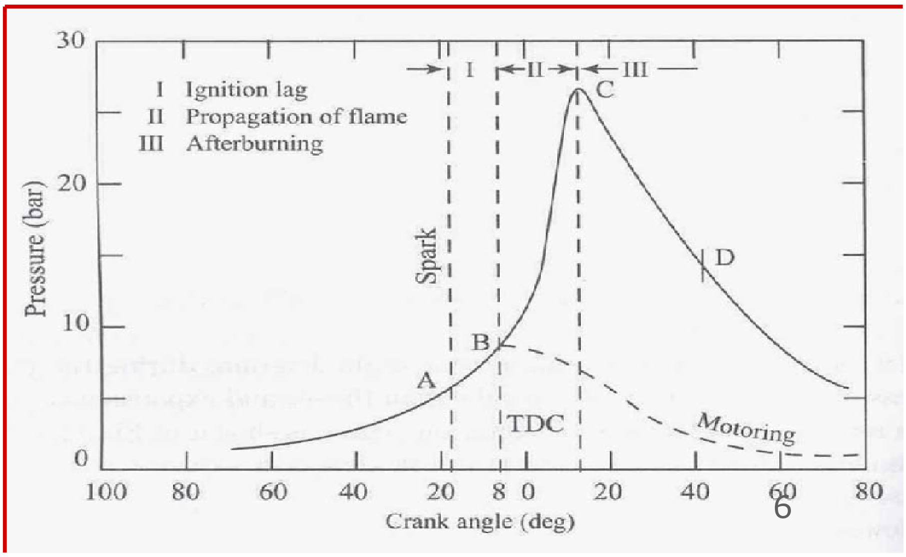
a-b Compression process

b-c Combustion process

c-d Expansion process

The entire pressure rise during combustion takes place at constant volume,

In actual engines this does not happen. Actual SI engine combustion process consists of three stages.



The 3 stages Actual engine combustion process

Point A is the point of spark initiation (say 200bTDC)

Point B is the point at which the beginning of pressure rise can be detected (say 80 bTDC)

Point C is the attainment of peak pressure.

AB- First stage (Delay Period)

BC-Second stage (flame Propagation)

CD-Third stage (wall Quenching)

AB- First stage (Delay Period)

The first stage is referred to as the ignition lag or preparation phase in which growth and development of a self-propagating nucleus of flame takes place

This process is a **chemical process** depending upon

Both temperature and pressure,

The nature of the fuel and

The proportion of the exhaust residual gas.

The relationship between the temperature and the rate of reaction.

BC-Second stage (flame Propagation)

The second stage is a physical one and it is concerned with the spread of the flame throughout the combustion chamber.

The starting point of the second stage is where the first measurable rise of pressure is seen on the indicator diagram i.e., the point where the line of combustion departs from the compression line (point B).

During the second stage the flame propagates practically at a constant velocity.

Heat transfer to the cylinder wall is low, because only a small part of the burning mixture comes in contact with the cylinder wall during this period

The rate of heat-release depends largely on

the turbulence intensity and

the reaction rate which is dependent on the mixture composition

the rate of pressure rise is proportional to the rate of heat- release because during this stage, the combustion chamber volume remains practically constant

CD-Third stage (wall Quenching)

Third stage starts at instant at which the maximum pressure is reached on the indicator diagram (point C). The flame velocity decreases during this stage. The rate of combustion becomes low due to lower flame velocity and reduced flame front surface. The expansion stroke starts before this stage of combustion, with the piston moving away from the top dead centre, there can be no pressure rise during this stage.

Flame Front Propagation

The two important factors which determine the rate of movement of the flame front across the combustion chamber are:

Reaction rate: is the result of a purely chemical combustion process in which the flame eats its way into the unburned charge

Transposition rate: is due to the physical movement of the flame front relative to the cylinder wall and is also the result of pressure differential between the burning gases and the unburnt gases in the combustion chamber.

Other Factors Influencing the Flame Speed

The most important factors which affect the flame speed are the turbulence, the fuel-air ratio, temperature and pressure, compression ratio, engine output and engine speed

Turbulence

Flame speed is quite low in non-turbulent mixtures and increases with increasing turbulence

Design of the combustion chamber which involves the geometry of cylinder head and piston crown increases the turbulence during the compression stroke.

Turbulence increases the heat flow to the cylinder wall. It also accelerates the chemical reaction by increasing the rate of contact of burning and unburned particles.

The increase of flame speed due to turbulence reduces the combustion duration and hence minimizes the tendency of abnormal combustion.

However, excessive turbulence may extinguish the flame resulting in rough and noisy operation of the Engine.

2. Fuel-Air Ratio

The fuel-air ratio has a very significant influence on the flame speed

The highest flame velocities (minimum time for complete combustion) are obtained with somewhat richer mixture (point A)

When the mixture is made leaner or richer from point A, the flame speed decreases

Less thermal energy is released in the case of lean mixtures resulting in lower flame temperature.

Very rich mixtures lead to incomplete combustion which results again in the release of less thermal energy

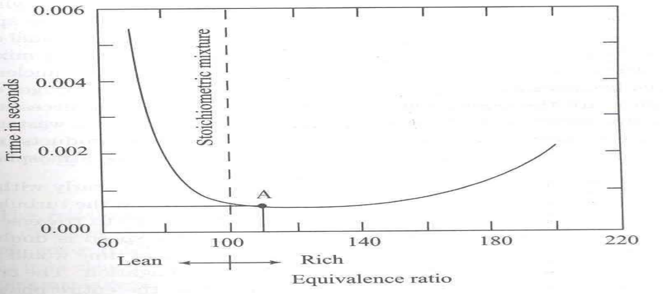


Fig. 12.4 Effect of Mixture Strength on the Rate of Burning

Temperature and Pressure

Flame speed increases with an increase in intake temperature and pressure.

A higher initial pressure and temperature may help to form a better homogeneous air-vapour mixture which helps in increasing the flame speed.

This is possible because of an overall increase in the density of the charge.

Compression Ratio

A higher compression ratio increases the pressure and temperature of the working mixture which reduce the initial preparation phase of combustion and hence less ignition advance is needed.

Increased compression ratio reduces the clearance volume and therefore increases the density of the cylinder gases during burning.

Increasing the density increases the peak pressure and temperature and the total combustion duration is reduced.

Thus engines having higher compression ratios have higher flame speeds.

Engine Output

With the increased throttle opening the cylinder gets filled to a higher density. The cycle pressure increases when the engine output is increased.

When the output is decreased by throttling, the initial and final compression pressures decreased and the dilution of the working mixture increases.

The smooth development of self-propagating nucleus of flame becomes unsteady and difficult.

The main disadvantages of SI engines are the poor combustion at low loads and the necessity of mixture enrichment (Ø> between 1.2 to 1.3) which causes wastage of fuel and discharge of unburnt hydrocarbon and the products of incomplete combustion like carbon monoxide etc. in the atmosphere.

Engine Speed

The flame speed increases almost linearly with engine speed since the increase in engine speed increases the turbulence inside the cylinder.

The time required for the flame to traverse the combustion space would be halved, if the engine speed is doubled.

ABNORMAL COMBUSTION

Abnormal combustion reveals itself in many ways. The two major abnormal combustion processes which are important in practice are **knock and surface-ignition.**

Knocking

Knock is the name given to the noise which is transmitted through the engine structure when essentially spontaneous ignition of a portion of the end gas - the fuel, air, residual gas, mixture ahead of the propagating flame occurs.

There is an extremely rapid release of most of the chemical energy in the end-gas, causing very high local pressures and the propagation of pressure waves of substantial amplitude across the combustion chamber.

Surface Ignition

Surface Ignition is ignition of the fuel-air mixture by a hot spot on the combustion chamber walls such as an overheated valve or spark plug, or glowing combustion-chamber deposit: i.e., by any means other than the normal spark discharge.

Following surface ignition, a flame develops at each surface-ignition location and starts to propagate across the chamber in an analogous manner to what occurs with normal spark-ignition.

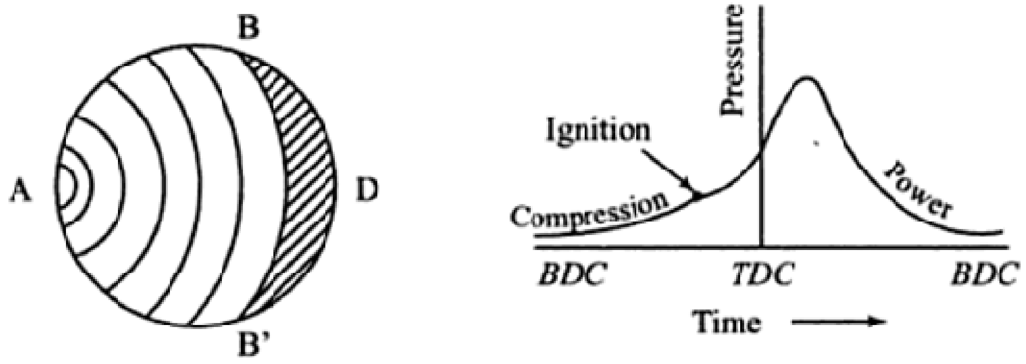
Causes for end gas combustion

Heat-release due to combustion in SI engines, increases the temperature and the pressure, of the burned part of the mixture above those of the unburned mixture

In order to effect pressure equalization the burned part of the mixture will expand, and compress the unburned mixture adiabatically thereby increasing its pressure and temperature.

If the temperature of the unburnt mixture exceeds the self- ignition temperature of the fuel spontaneous ignition or auto- ignition occurs at various pin-point locations.

The advancing flame front compresses the end charge BB'D farthest from the spark plug, thus raising its temperature.

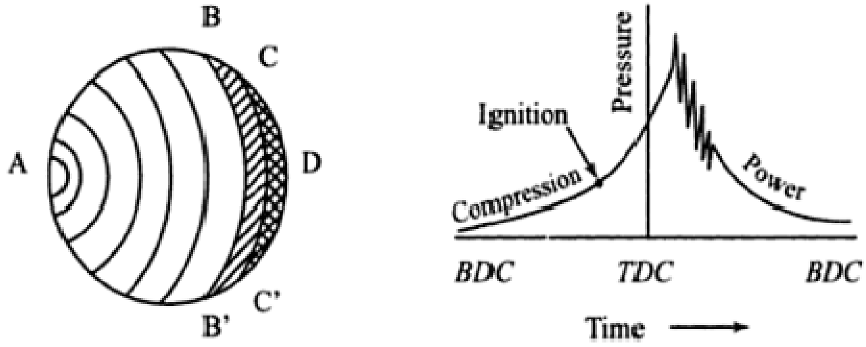


(a) (b)

Normal combustion

In spite of these factors if the temperature of the end charge had not reached its self-ignition temperature, the charge would not auto ignite and the flame will advance further and consume the charge BB'D.

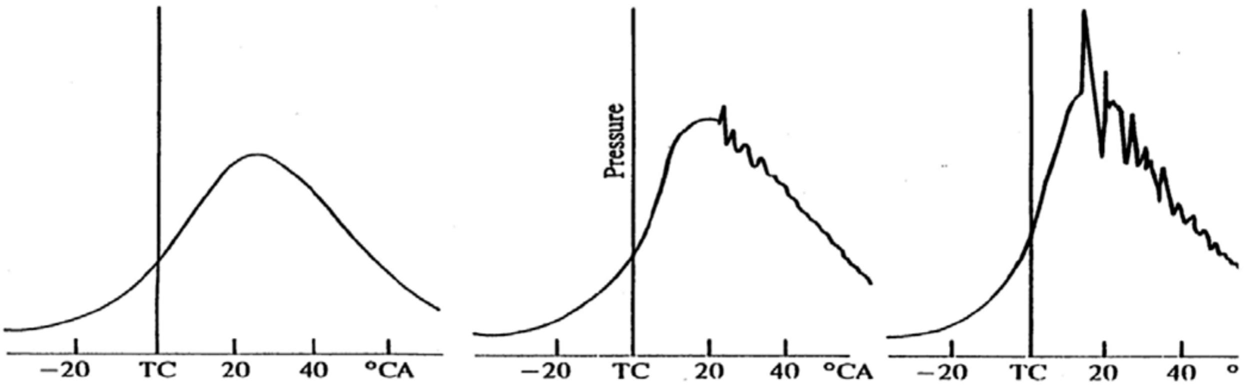
However, if the end charge BB'D reaches its auto ignition temperature the charge will auto ignite, leading to knocking combustion.it is assumed that when flame has reached the position BB', the charge ahead of it has reached critical auto-ignition temperature.

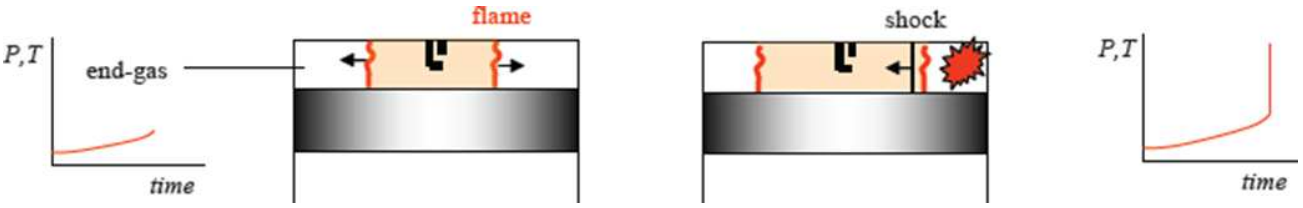


(c) (d)

Combustion with detonation

Pressure variation in the cylinder during knocking combustion for normal combustion, light knock and heavy knock, respectively





Because of the auto ignition, another flame front starts traveling in the opposite direction to the main flame front. When the two flame fronts collide, a severe pressure pulse is generated. The presence or absence of knocking in combustion is often judged from a distinctly audible sound.

A scientific method to detect the phenomenon of knocking is to use a pressure transducer.

Knocking is very much dependent on the properties of fuel

If the unburned charge does not reach its auto ignition temperature there will be no knocking.

If the ignition delay period is longer the time required for the flame front to burn through the unburned charge will be short, then there will be no knocking.

Hence, in order to avoid or inhibit detonation, and a high auto ignition temperature, a long ignition delay is the desirable qualities for SI engine fuels.

Effect of Engine Variables on Knock

Effect of temperature

Reduced temperature of the unburned charge reduces the possibility of knocking by reducing the temperature of the end charge for auto ignition.

Effect of Compression Ratio

Increase in compression ratio increases the pressure and temperature of the gases at the end of the compression stroke, increases the tendency for knocking.

Effect of density

Reduction in density of the charge tends to reduce knocking by providing lower energy release. The overall increase in the density of the charge due to higher compression ratio increases the pre-flame reactions in the end charge thereby increasing the knocking tendency of the engine.

Inlet Temperature of the Mixture:

Increase in the inlet temperature of the mixture makes the compression temperature higher thereby, increasing the tendency of knocking. Further, volumetric efficiency will be lowered. Hence, a lower inlet temperature is preferable to reduce knocking.

Mass of inducted charge

A reduction in the mass of the inducted charge into the cylinder by throttling or reducing the amount of supercharging reduces both temperature and density of the charge at the time of ignition. This decreases the tendency of knocking.

Temperature of the Combustion Chamber Walls

To prevent knocking the hot spots in the combustion chamber should be avoided.Since, the spark plug and exhaust valve are two hottest parts in the combustion chamber, the end gas should not be compressed against them

Retarding the Spark Timing

Retarding the spark timing from the optimized timing, i.e., having the spark closer to TDC, the peak pressures are reached farther down on the power stroke and are thus of lower magnitude. This might reduce the knocking. However, the spark timing will be different from the MBT timing affecting the brake torque and power output of the engine.

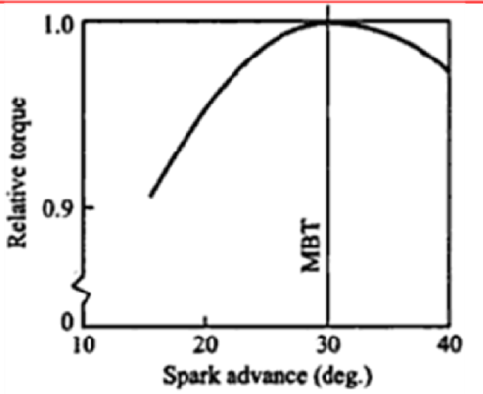


Figure 6.7 Effect of spark advance on brake torque.

Power Output of the Engine

A decrease in the output of the engine decreases the temperature of the cylinder and the combustion chamber walls and also the pressure of the charge thereby lowering mixture and end gas temperatures. This reduces the tendency to knock.

Turbulence

Turbulence depends on the design of the combustion chamber and on engine speed. Increasing turbulence increases the flame speed and reduces the time available for the end charge to attain auto ignition conditions thereby decreasing the tendency to knock.

Engine Speed

An increase in engine speed increases the turbulence of the mixture considerably resulting in increased flame speed, and reduces the time available for pre-flame reactions. Hence knocking tendency is reduced at higher speeds.

Flame travel Distance

The knocking tendency is reduced by shortening the time required for the flame front to traverse the combustion chamber.Engine size, combustion chamber shape, and spark plug position are the three important factors governing the flame travel distance.

Engine size

The flame requires a longer time to travel across the combustion chamber of a larger engine. Therefore, a larger engine has a greater tendency for knocking than a smaller engine since there is more time for the end gas to auto ignites. Hence, an SI engine is generally limited to size of about 150 mm bore.

Combustion Chamber Shape

Generally, the more compact the combustion chamber is, the shorter is the flame travel and the combustion time and hence better antiknock characteristics.

The combustion chambers are made as spherical as possible to minimize the length of the flame travel for a given volume.

If the turbulence in the combustion chamber is high, the combustion rate is high and consequently combustion time and knocking tendency are reduced.

Hence, the combustion chamber is shaped in such a way as to promote turbulence.

Location of Spark PLUG

In order to have a minimum flame travel, the spark plug is centrally located in the combustion chamber, resulting in minimum knocking tendency.

The flame travel can also be reduced by using two or more spark plugs in case of large engines.

Composition Factors

Fuels-Air Ratio:

The flame speeds are affected by fuel-air ratio. Also the flame temperature and reaction time are different for different fuel-air ratios.

Maximum flame speed and temperature is obtained when $\Phi \approx 1.1 - 1.2$.

Octane Value of the fuel

A higher self-ignition temperature of the fuel and a low pre-flame reactivity would reduce the tendency of knocking.

In general, Paraffin series of hydrocarbon have the maximum and aromatic series the minimum tendency to knock. The naphthene series comes in between the two

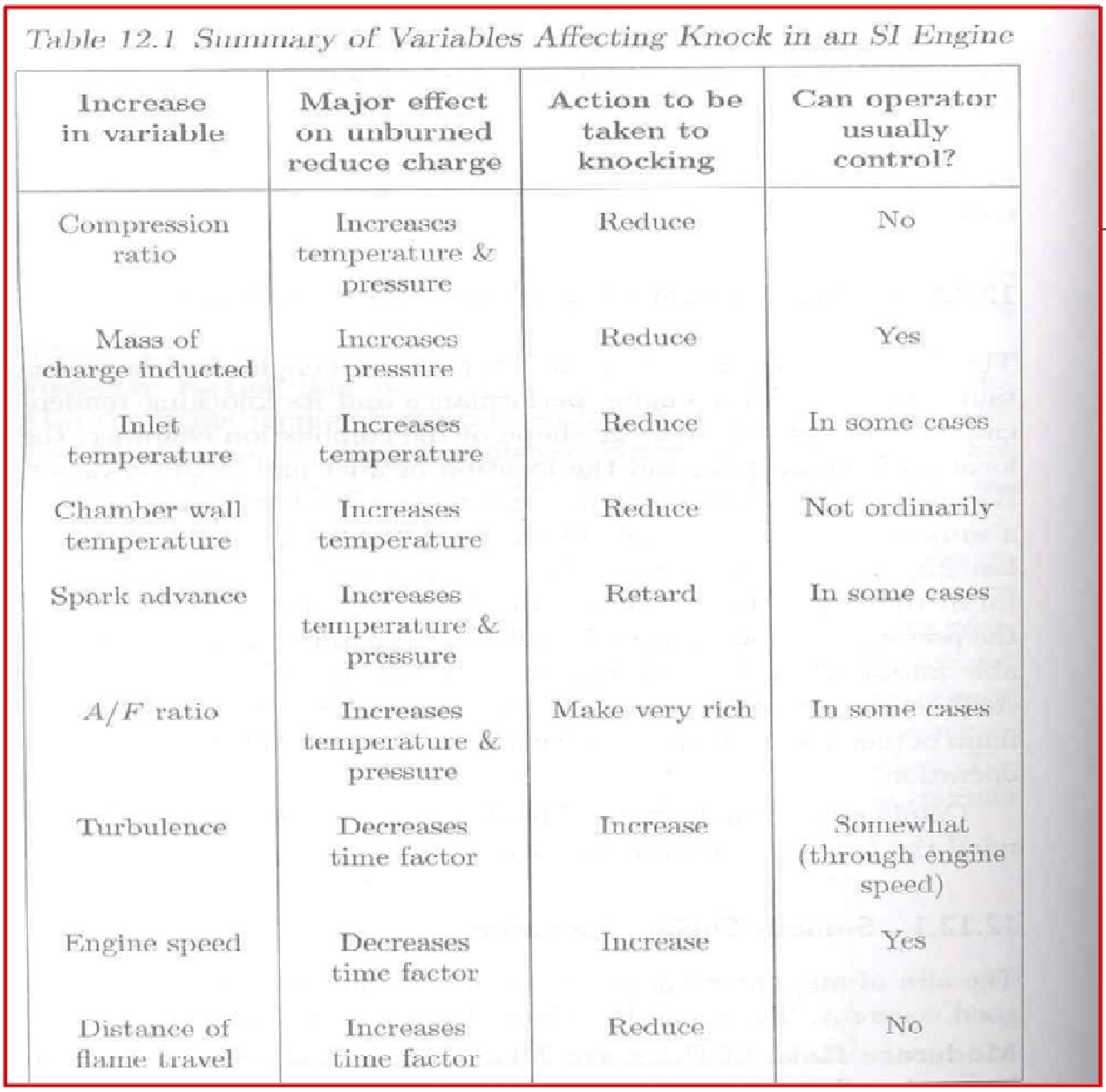


Table 12.1 Summary of Variables Affecting Knock in an SI Engine

Increase in variable	Major effect on unburned reduce charge	Action to be taken to knocking	Can operator usually control?
Compression ratio	Increases temperature & pressure	Reduce	No
Mass of charge inducted	Increases pressure	Reduce	Yes
Inlet temperature	Increases temperature	Reduce	In some cases
Chamber wall temperature	Increases temperature	Reduce	Not ordinarily
Spark advance	Increases temperature & pressure	Retard	In some cases
A/F ratio	Increases temperature & pressure	Make very rich	In some cases
Turbulence	Decreases time factor	Increase	Somewhat (through engine speed)
Engine speed	Decreases time factor	Increase	Yes
Distance of flame travel	Increases time factor	Reduce	No

Combustion Chambers for SI Engines

Smooth engine operation

The aim of any engine design is to have a smooth operation and a good economy.

These can be achieved by the following:

Moderate Rate of Pressure Rise

Limiting the rate of pressure rise as well as the position of the peak pressure with respect to TDC affect smooth engine operation.

Reducing the Possibility of Knocking

Reduction in the possibility of knocking in an engine can be achieved by,

Reducing the distance of the flame travel, by centrally locating the spark plug and also by avoiding pockets of stagnant charge.

Satisfactory cooling of the spark plug and of exhaust valve area , which are the source of hot spots in the majority of the combustion chambers.

Reducing the temperature of the last portion of the charge, through application of a high surface to volume ratio in that part where the last portion of the charge burns.

High Power Output and Thermal Efficiency

This can be achieved by considering the following factors:

A high degree of turbulence is needed to achieve a high flame front velocity.

Turbulence is induced by inlet flow configuration or squish

Squish is the rapid radial movement of the gas trapped in between the piston and the cylinder head into the bowl or the dome. Squish can be induced in spark-ignition engines by having a bowl in piston or with a dome shaped cylinder head.

High Volumetric Efficiency

More charge during the suction stroke, results in an increased power output. This can be achieved by providing ample clearance around the valve heads, large diameter valves and straight passages with minimum pressure drop.

Improved anti-knock characteristics

Improved anti-knock characteristics permits the use of a higher compression ratio resulting in increased output and efficiency.

A Compact Combustion Chamber

Reduces heat loss during combustion and increases the thermal efficiency.

Different types combustion chambers have been developed over a period of time Some of them are shown in Fig.

T-Head Type

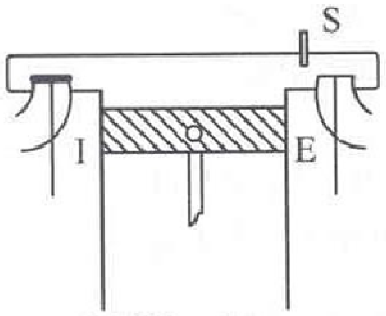
L-Head Type

I-Head Type or Overhead Valve

F-Head Type

T-Head Type:

The T-head combustion chambers were used in the early stage of engine development. Since the distance across the combustion chamber is very long, knocking tendency is high in this type of engines. This configuration provides two valves on either side of the cylinder, requiring two camshafts. From the manufacturing point of view, providing two camshafts is a disadvantage.

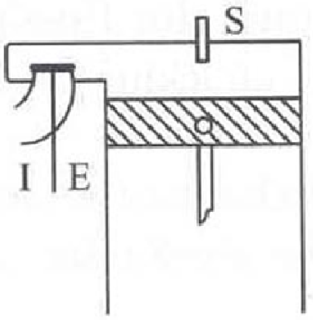


(a) T-head type

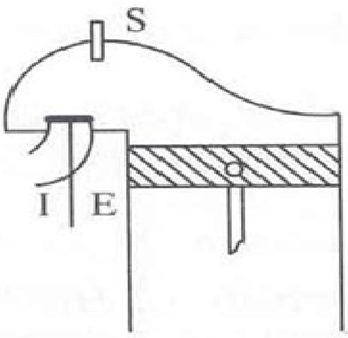
L-Head Type

A modification of the T-head type of combustion chamber is the L-head type which provides the two valves on the same side of the cylinder and the valves are operated by a single camshaft.

The main objectives of the Ricardo's turbulent head design, Fig (c), axle to obtain fast flame speed and reduced knock



(b) L-head type



(c) L-head type

I Head Type or Overhead Valve:

In which both the valves are located on the cylinder head.

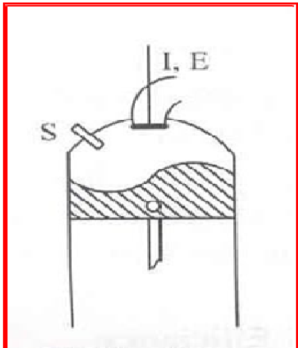
The overhead valve engine is superior to a side valve or an L-head engine at high compression ratios.

Some of the important characteristics of this type of valve arrangement are:

less surface to volume ratio and therefore less heat loss

less flame travel length and hence greater freedom from knock

higher volumetric efficiency from larger valves or valve lifts



(d) I-head type

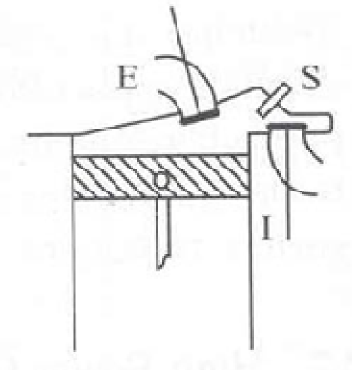
F-Head Type:

The F-head type of valve arrangement is a compromise between L-head and I-head types.

Combustion chambers in which one valve is in the cylinder head and the other in the cylinder block are known as F-head combustion chambers’

Modern F-head engines have exhaust valve in the head and inlet valve in the cylinder block.

The main disadvantage of this type is that the inlet valve and the exhaust valve are separately actuated by two cams mounted on to camshafts driven by the crankshaft through gears.



(e) F-head type

FUEL SYSTEM

Carburetion

Spark-ignition engines normally use volatile liquid fuels. Preparation of fuel-air mixture is done outside the engine cylinder and formation of a homogeneous mixture is normally not completed in the inlet manifold. Fuel droplets, which remain in suspension, continue to evaporate and mix with air even during suction and compression processes. The process of mixture preparation is extremely important for spark-ignition engines. The purpose of carburetion is to provide a combustible mixture of fuel and air in the required quantity and quality for efficient operation of the engine under all conditions.

Definition of Carburetion

The process of formation of a combustible fuel-air mixture by mixing the proper amount of fuel with air before admission to engine cylinder is called carburetion and the device which does this job is called acarburetor.

Factors Affecting Carburetion

Of the various factors, the process of carburetion is influenced by

The engine speed

The vaporization characteristics of the fuel

The temperature of the incoming air and

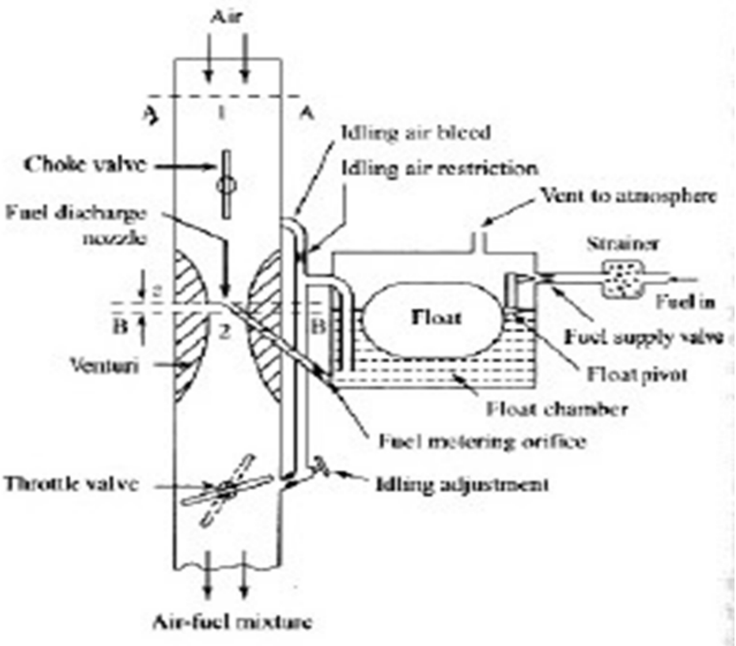
The design of the carburetor

Principle of Carburetion

Both air and gasoline are drawn through the carburetor and into the engine cylinders by the suction created by the downward movement of the piston. This suction is due to an increase in the volume of the cylinder and a consequent decrease in the gas pressure in this chamber. It is the difference in pressure between the atmosphere and cylinder that causes the air to flow into the chamber. In the carburetor, air passing into the combustion chamber picks up discharged from a tube. This tube has a fine orifice called carburetor jet that is exposed to the air path. The rate at which fuel is discharged into the air depends on the pressure difference or pressure head between the float chamber and the throat of the venturi and on the area of the outlet of the tube. In order that the fuel drawn from the nozzle may be thoroughly atomized, the suction effect must be strong and the nozzle outlet comparatively small. In order to produce a strong suction, the pipe in the carburetor carrying air to the engine is made to have a restriction. At this restriction called throat due to increase in velocity of flow, a suction effect is created. The restriction is made in the form of a venturi to minimize throttling losses. The end of the fuel jet is located at the venturi or throat of the carburetor. The geometry of venturi tube is as shown in Fig.16.6. It has a narrower path at the center so that the flow area through which the air must pass is considerably reduced. As the same amount of air must pass through every point in the tube, its velocity will be greatest at the narrowest point. The smaller the area, the greater will be the velocity of the air, and thereby the suction is proportionately increased. As mentioned earlier, the opening of the fuel discharge jet is usually loped where the suction is maximum. Normally, this is just below the narrowest section of the venturi tube. The spray of gasoline from the nozzle and the air entering through the venturi tube are mixed together in this region and a combustible mixture is formed which passes through the intake manifold into the cylinders. Most of the fuel gets atomized and simultaneously a small part will be vaporized. Increased air velocity at the throat of the venturi helps he rate of evaporation of fuel. The difficulty of obtaining a mixture of sufficiently high fuel vapour-air ratio for efficient starting of the engine and for uniform fuel-air ratio indifferent cylinders (in case of multi cylinder engine) cannot be fully met by the increased air velocity alone at the venturi throat.

The Simple Carburetor

Carburetors are highly complex. Let us first understand the working principle of a simple or elementary carburetor that provides an air fuel mixture for cruising or normal range at a single speed. Later, other mechanisms to provide for the various special requirements like starting, idling, variable load and speed operation and acceleration will be included. Figure shows the details of a simple carburetor. The simple carburetor mainly consists of a float chamber, fuel discharge nozzle and a metering orifice, a venturi, a throttle valve and a choke. The float and a needle valve system maintain a constant level of gasoline in the float chamber. If the amount of fuel in the float chamber falls below the designed level, the float goes down, thereby opening the fuel supply valve and admitting fuel. When the designed level has been reached, the float closes the fuel supply valve thus stopping additional fuel flow from the supply system. Float chamber is vented either to the atmosphere or to the” upstream side of the venturi.During suction stroke air is drawn through the venturi.



As already described, venturi is a tube of decreasing cross-section with a minimum area at the throat, Venturi tube is also known as the choke tube and is so shaped that it offers minimum resistance to the air flow. As the air passes through the venturi the velocity increases reaching a maximum at the venturi throat. Correspondingly, the pressure decreases reaching a minimum. From the float chamber, the fuel is fed to a discharge jet, the tip of which is located in the throat of the venturi. Because of the differential pressure between the float chamber and the throat of the venturi, known as carburetor depression, fuel is discharged into the air stream. The fuel discharge is affected by the size of the discharge jet and it is chosen to give the required air-fuel ratio. The pressure at the throat at the fully open throttle condition lies between 4 to 5 cm of Hg, below atmospheric and seldom exceeds8 cm Hg below atmospheric. To avoid overflow of fuel through the jet, the level of the liquid in the float chamber is maintained at a level slightly below the tip of the discharge jet. This is called the tip of the nozzle. The difference in the height between the top of the nozzle and the float chamber level is marked h in Fig.3.

The gasoline engine is quantity governed, which means that when power output is to be varied at a particular speed, the amount of charge delivered to the cylinder is varied. This is achieved by means of a throttle valve usually of the butterfly type that is situated after the venturi tube. As the throttle is closed less air flows through the venturi tube and less is the quantity of air-fuel mixture delivered to the cylinder and hence power output is reduced. As the” throttle is opened, more air flows through the choke tube resulting in increased quantity of mixture being delivered to the engine. This increases the engine power output. A simple carburetor of the type described above suffers from a fundamental drawback in that it provides the required A/F ratio only at one throttle position. At the other throttle positions the mixture is either leaner or richer depending on whether the throttle is opened less or more. As the throttle opening is varied, the air flow varies and creates a certain pressure differential between the float chamber and the venturi throat. The same pressure differential regulates the flow of fuel through the nozzle. Therefore, the velocity of flow of air II and fuel vary in a similar manner. At the same time, the density I of air decrease as the pressure at the venturi throat decrease with increasing air flow whereas that of the fuel remains unchanged. This results in a simple carburetor producing a progressively rich mixture with increasing throttle opening.

The Choke and the Throttle

When the vehicle is kept stationary for a long period during cool winter seasons, may be overnight, starting becomes more difficult. As already explained, at low cranking speeds and intake temperatures a very rich mixture is required to initiate combustion. Some times air-fuel ratio as rich as 9:1 is required. The main reason is that very large fraction of the fuel may remain as liquid suspended in air even in the cylinder. For initiating combustion, fuel-vapour and air in the form of mixture at a ratio that can sustain combustion is required. It may be noted that at very low temperature vapour fraction of the fuel is also very small and this forms combustible mixture to initiate combustion. Hence, a very rich mixture must be supplied. The most popular method of providing such mixture is by the use of choke valve. This is simple butterfly valve located between the entrance to the carburetor and the venturi throat as shown in Fig.3.

When the choke is partly closed, large pressure drop occurs at the venturi throat that would normally result from the quantity of air passing through the venturi throat. The very large depression at the throat inducts large amount of fuel from the main nozzle and provides a very rich mixture so that the ratio of the evaporated fuel to air in the cylinder is within the combustible limits. Sometimes, the choke valves are spring loaded to ensure that large carburetor depression and excessive choking does not persist after the engine has started, and reached a desired speed. This choke can be made to operate automatically by means of a thermostat so that the choke is closed when engine is cold and goes out of operation when engine warms up after starting. The speed and the output of an engine is controlled by the use of the throttle valve, which is located on the downstream side of the venturi. The more the throttle is closed the greater is the obstruction to the flow of the mixture placed in the passage and the less is the quantity of mixture delivered to .the cylinders. The decreased quantity of mixture gives a less powerful impulse to the pistons and the output of the engine is reduced accordingly. As the throttle is opened, the output of the engine increases. Opening the throttle usually increases the speed of the engine. But this is not always the case as the load on the engine is also a factor. For example, opening the throttle when the motor vehicle is starting to climb a hill may or may not increase the vehicle speed, depending upon the steepness of the hill and the extent of throttle opening. In short, the throttle is simply a means to regulate the output of the engine by varying the quantity of charge going into the cylinder.

Compensating Devices

An automobile on road has to run on different loads and speeds. The road conditions play a vital role. Especially on city roads, one may be able to operate the vehicle between 25 to 60% of the throttle only. During such conditions the carburetor must be able to supply nearly constant air-fuel ratio mixture that is economical (16:1).However, the tendency of a simple carburetor is to progressively richen the mixture as the throttle starts opening. The main metering system alone will not be sufficient to take care of the needs of the engine. Therefore, certain compensating devices are usually added in the carburetor along with the main metering system so as to supply a mixture with the required air- fuel ratio. A number of compensating devices are in use. The important ones are

i.Air-bleed jet

ii.Compensating jet

iii.Emulsion tube

iv.Back suction control mechanism

v.Auxiliary air valve

vi.Auxiliary air port

As already mentioned, in modern carburetors automatic compensating devices are provided to maintain the desired mixture proportions at the higher speeds. The type of compensation mechanism used determines the metering system of the carburetor. The principle of operation of various compensating devices are discussed briefly in the following sections.

Air-bleed jet

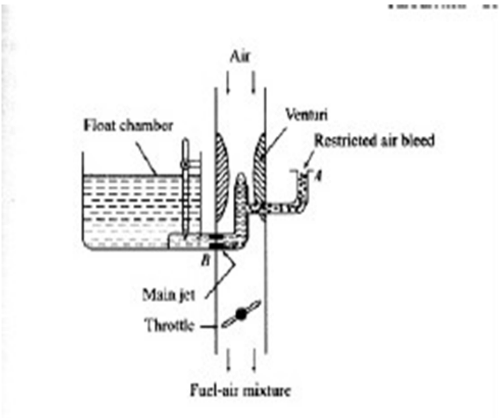
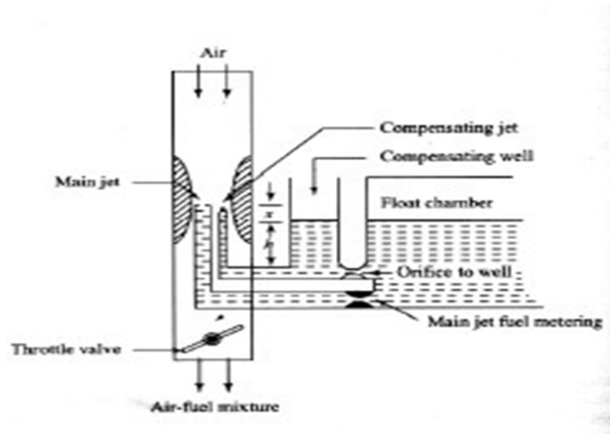


Figure illustrates a principle of an air-bleed system in atypical modern downdraught carburetor. As could be seen it contains an air-bleed into the main nozzle. An orifice restricts the flow of air through this bleed and therefore it is called restricted air-bleed jet that is very popular. When the engine is not operating the main jet and the air bleed jet will be filled with fuel. When the engine starts, initially the fuel starts coming through the main as well as the air bleed jet (A). As the engine picks up, only air starts coming through the air bleed and mixes with fuel at B making a air fuel emulsion. Thus the fluid stream that has become an emulsion of air and liquid has negligible viscosity and surface tension. Thus the flow rate of fuel is augmented and more fuel is sucked at low suctions. ‘By proper design of hole size at B compatible with the entry hole at A, it is possible to maintain a fairly uniform mixture ratio for the entire power range of the operation of an engine. If the fuel flow nozzle of the air-bleed system is placed in the centre of the venturi, both the air-bleed nozzle and the venturi are subjected to same engine suction resulting approximately same fuel-air mixture for the entire power range of operation

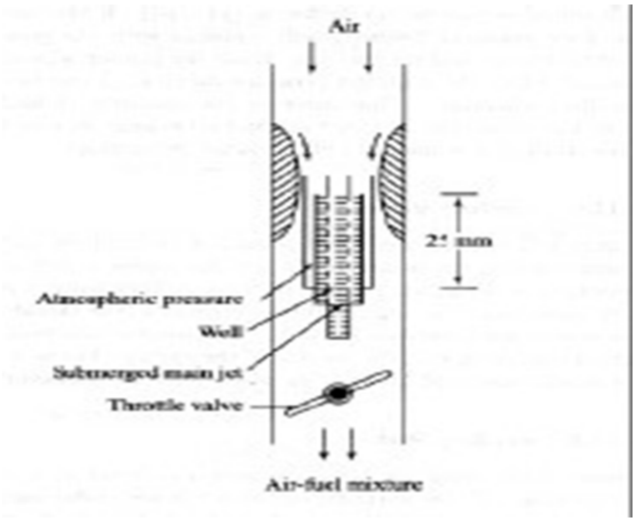
Compensating Jet



The principle of compensating jet device is to make the mixture leaner as the throttle opens progressively. In this method, as can be seen from Fig. in addition to the main jet, a compensating jet is incorporated. The compensating jet is connected to the compensation well. The compensating well is also vented to atmosphere like the main float chamber. The compensating well is supplied with fuel from the main float chamber through a restricting orifice. With the increase in airflow rate, there is decrease of fuel level in the compensating well, with the result that fuel supply through the compensating jet decreases. The compensating jet thus progressively makes the mixture leaner as the main jet progressively makes the mixture richer. The main jet curve and the compensating jet curve are more or less reciprocals of each other.

Emulsion Tube

The mixture correction is attempted by air bleeding in modern carburetor. In one such arrangement as shown in Fig., the main metering jet is kept at a level of about 25 mm below the fuel level in the float chamber. Therefore, it is also called submerged jet. The jet is located at the bottom of a well. The sides of the well have holes. As can be seen from the figure these holes are in communication with the atmosphere. In the beginning the level of petrol in the float chamber and the well is the same. When the throttle is opened the pressure at the venturi throat decreases and petrol is drawn into the air stream. This results in progressively uncovering the holes in the central tube leading to increasing air-fuel ratios or decreasing richness of mixture when all holes have been uncovered. Normal flow takes place from the main jet. The air is drawn through these holes in the well, and the fuel is emulsified and the pressure differential across the column of fuel is not as high as that in simple carburetor.

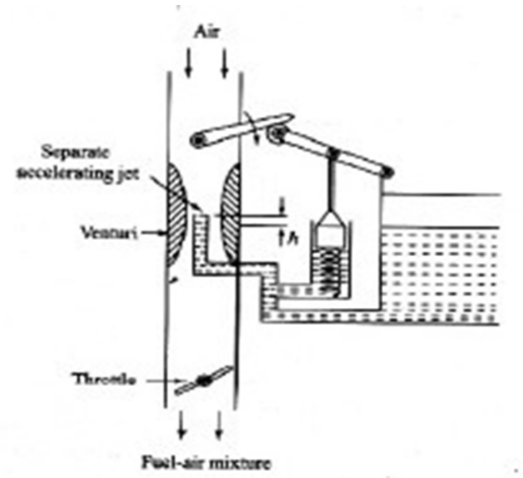


Acceleration Pump System

Acceleration is a transient phenomenon. In order to accelerate the vehicle and consequently its engine,the mixture required is very rich and the richness of the mixture has to be obtained quickly and very rapidly. In automobile engines situations arise when it is necessary to accelerate the vehicle. This requires an increased output from the engine in a very short time. If the throttle is suddenly opened there is a corresponding increase in the air flow. However, because of the inertia of the liquid fuel, the fuel flow does not increase in proportion to the increase in air flow. This results in a temporary lean mixture ca11singtheengine to misfire and a temporary reduction in power output.

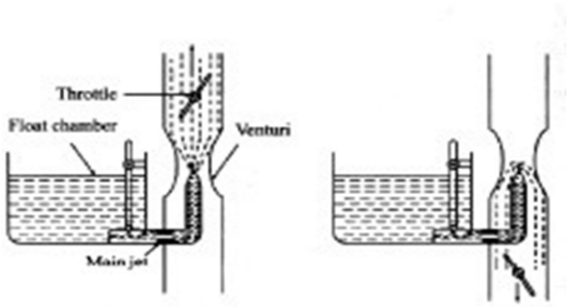
To prevent this condition, all modern carburetors are equipped with an accelerating system. Figure illustrates simplified sketch of one such device. The pump comprises of a spring loaded plunger that takes care of the situation with the rapid opening of the throttle valve. The plunger moves into the cylinder and forces an additional jet of fuel at the venturi throat. When the throttle is partly open, the spring sets the plunger back. There is also an arrangement which ensures that fuel in the pump cylinder is not forced through the jet when valve is slowly opened or leaks past the plunger or some holes into the float chamber.

Mechanical linkage system, in some carburetor, is substituted by an arrangement where by the pump plunger is held up by manifold vacuum. When this vacuum is decreased by rapid opening of the throttle, a spring forces the plunger down pumping the fuel through the jet.

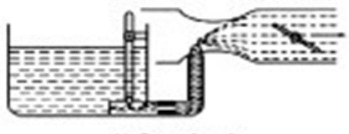


Types of Carburetors

There are three general types of carburetors depending on the direction of flow of air. The first is the up draught type shown in Fig.8(a) in which the air enters at the bottom and leaves at the top so that the direction of its flow is upwards. The disadvantage of the up draught carburetor is that it must lift the sprayed fuel droplet by air friction. Hence, it must be designed for relatively small mixing tube and throat so that even at low engine speeds the air velocity is sufficient to lift and carry the fuel particles along. Otherwise, the fuel droplets tend to separate out providing only a lean mixture to the engine. On the other hand, the mixing tube is finite and small then it cannot supply mixture to the engine at a sufficiently rapid rate at high speeds.



(a) Updraught (b) Downdraught



(c) Cross-draught

In order to overcome this drawback the downdraught carburetor [Fig.8 (b)] is adopted. It is placed at a level higher than the inlet manifold and in which the air and mixture generally follow a downward course. Here the fuel does not have to be lifted by air friction as in the up draught carburetors but move into the cylinders by gravity even if the air velocity is low. Hence, the mixing tube and throat can be made large which makes high engine speeds and high specific outputs possible.

A cross-draught carburetor consists of a horizontal mixing tube with a float chamber on one side of it [Fig.8(c)]. By using across-draught carburetor in engines, one right-angled turn in the inlet passage is eliminated and the resistance to flow is reduced.

Constant Choke Carburetor:

In the constant choke carburetor, the air and fuel flow areas are always maintained to be constant. But the pressure difference or depression, which causes the flow of fuel and air, is being varied as per the demand on the engine. Solex and Zenith carburetors belong to this class.

Constant Vacuum Carburetor:

In the constant vacuum carburetor, (sometimes called variable choke carburetor) air and fuel flow areas are being varied as per the demand on the engine, while the vacuum is maintained to be always same. The S.U. and Carter carburetors belong to tills class.

Multiple VenturiCarburetor:

Multiple venturi system uses double or triple venturi. The boost venturi is located concentrically within the main venturi.The discharge edge of the boost venturi is located at the throat of the main venturi. The boost venturi is positioned upstream of the throat of the larger main venturi. Only a fraction of the total air flows though the boost venturi. Now the pressure at the boost venturi exit equals the pressure at the main venturi throat. The fuel nozzle is located at the throat of the boost venturi.

GASOLINE INJECTION SYSTEM

A modern gasoline injection system uses pressure from an electric fuel pump to spray fuel into the engine intake manifold. Like a carburetor, it must provide theengine with the correct air-fuel mixture for specificoperating conditions. Unlike a carburetor, howevev ,PRESSURE, not engine vacuum, is used to feed fuelinto the engine .This makes the gasoline injection system very efficient.

A gasoline injection system has several possible advantages over a carburetor type of fuel system. Some advantages are as follows:

* Improved atomization. Fuel is forced into the intake manifold under pressure that helps break fuel droplets into a fine mist.

* Better fuel distribution. Equal flow of fuel vapors into each cylinder.

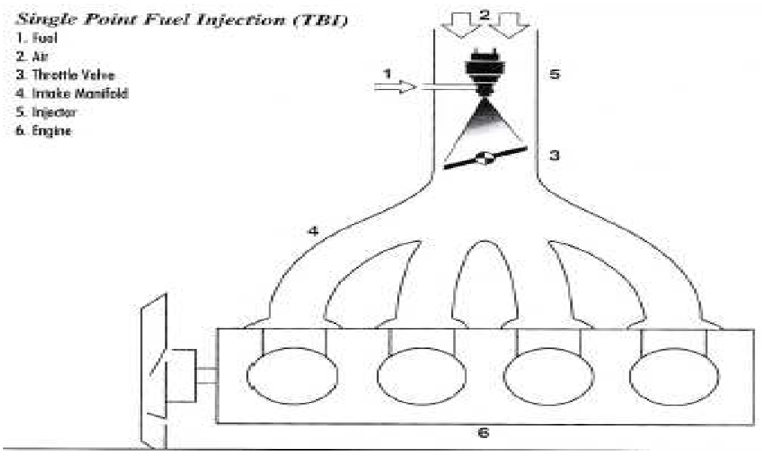
* Smoother idle. Lean fuel mixture can be used without rough idle because of better fuel distribution and low-speed atomization.

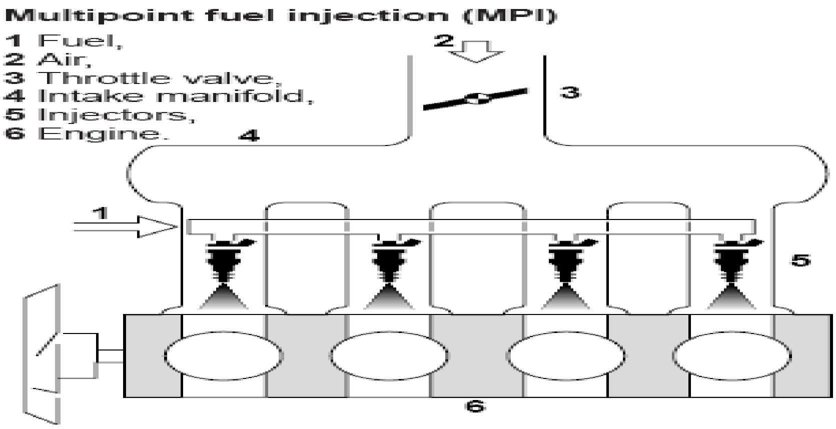
There are many types of gasoline injection systems. Before studying the most common ones, we should have a basic knowledge of the different classifications:

Single or multi-point injection indirect or direct injection.

The point or location of fuel injection is one way to classify a gasoline injection system. A single-point injection system, also call throttle body injection (TBI), has the injector nozzles in a throttle body assembly on top of the engine. Fuel is sprayed into the top center of the intake manifold.

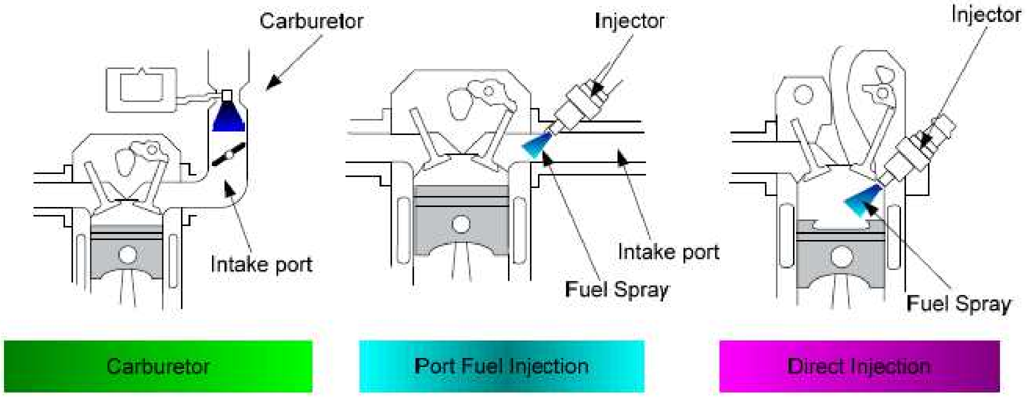
A multi-point injection system, also called port injection, has an injector in the port (air-fuel passage) going to each cylinder. Gasoline is sprayed into each intake port and toward each intake valve. Thereby, the term multipoint (more than one location) fuel injection is used.





An indirect injection system sprays fuel into the engine intake manifold or inlet port. Most gasoline injection systems are of this type.

Direct injection forces fuel into the engine combustion chambers. Diesel injection systems are direct type.



ELECTRONICLLY CONTROLLED GASOLINE INJECTION SYSTEM

Description

The Bosch D-Jetronic electronic fuel injection system is composed of 3 major subsystems: the air intake system, the fuel system, and the electronic control system. The D-Jetronic system uses constant fuel pressure and flow, so that only injection duration needs to be modified to control air/fuel mixture. The D-Jetronic system measures incoming airflow by monitoring intake manifold pressure. Engine speed, temperature, and other factors are monitored for the purpose of fine-tuning injection duration. An auxiliary air valve, cold start injector and thermo time switch aid in cold starting and operation.

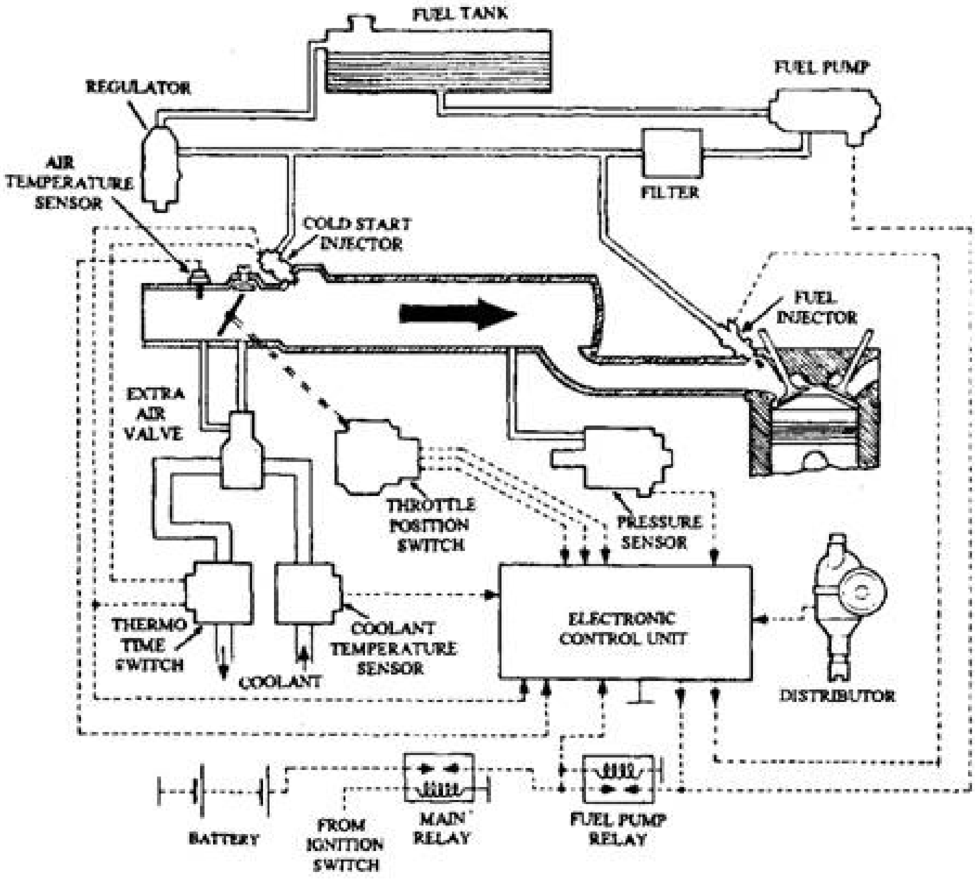
Operation

Fuel system

An electrically driven fuel pump forces fuel through a filter, into the main system. Main system consists of one injector for each cylinder, a cold start injector and a pressure regulator, which maintains fuel pressure at 28 psi (2.0 kg/cm2). A secondary system carries excess fuel from the pressure regulator back to fuel tank.

Air system

Intake manifold, connected to an intake air distributor, supplies the cylinders with air. A pressure sensor is connected to intake air distributor. The pressure sensor operates according to difference in manifold pressure and atmospheric pressure and signals control unit accordingly. A throttle valve, operated by accelerator pedal, is located at the mouth of the intake air distributor. The throttle valve and intake air distributor are connected to air cleaner by an air duct elbow. The idling air system is in the form of a by-pass system located between the air filter and air intake distributor. Its size can be varied with an idling air adjusting screw. An auxiliary air line, from air cleaner (auxiliary air valve), to intake air distributor forms the warming-up air system. Its volume is varied, depending on engine temperature, by the auxiliary air valve.



BOSCH D-JETRONIC ELECTRONIC FUEL INJECTION SYSTEM

Electronic control system

Electronic Control Unit

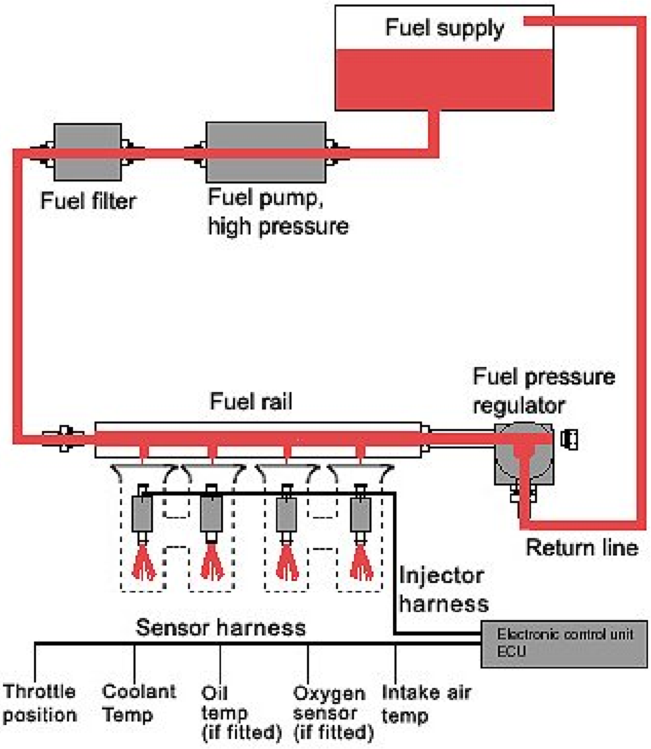
Control unit regulates the correct amount of fuel to be injected, depending on engine speed, intake pressure and engine temperature. When ignition is switched on, control unit receives its operating voltage directly from battery, via voltage supply relay. It also controls the fuel pump, which normally is provided with current from pump relay, only with engine running. A time switch, in control unit, allows fuel pump to run approximately 1 to 1.5 seconds after ignition is turned on. The control unit is connected to all sender units by a special wiring harness, coupled to a multiple plug. The control unit is usually located inside vehicle under the dash, under one of the seats or in the trunk.

Pressure Sensor

The pressure sensor is located in the engine compartment and is connected to the intake manifold by a vacuum hose. This sensor controls the basic amount of fuel to be injected, depending on pressure in the intake manifold and load on the engine

Air Intake Temperature Sensor

The air temperature sensor provides control unit with information about air temperature, so that control unit can increase the injection quantity as necessary at low intake air temperature. This compensation ceases when intake air temperature is greater than 68F (2O^{0}C).



SIMPLE LAYOUT OF ELECTRONIC FUEL INJECTION SYSTEM

Engine Temperature Sensor

The engine temperature sensor provides the control unit with information about coolant temperature (cylinder head temperature on VW). This enables control unit to adapt injection interval and determine how long the cold start injector should remain open during cold starting.

Triggering Contacts

The triggering contacts are located in the distributor. They provide signals which determine when and to which cylinder fuel is to be injected. The contacts also supply information concerning engine speed to determine the amount of fuel that needs to be injected into the engine.

Throttle Valve Switch

The throttle valve switch is mounted on the throttle housing. This switch signals the control unit of throttle position. During deceleration, above 1500 RPM, throttle switch cuts fuel supply off and below 900 RPM, fuel supply is turned on.

Auxiliary Air Valve

During cold starts, the auxiliary air valve opens to allow additional air into the inlet duct. As engine heats up, a bi-metallic element expands and closes valve. At approximately 140F (800C) the auxiliary air pipe is completely closed by the valve.

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UNIT III CI ENGINES

CI ENGINES

Diesel Fuel injection system, MPFI&CRDI, Function of components, jerk type pump, Distributor pump. Mechanical and pneumatic Governor, Fuel injector, Types of nozzle, importance of swirl, squish, Turbulence air motion, Combustion in CI Engines-Combustion Chambers, Factors controlling combustion chamber design. Stages of combustion, Factors affecting ignition delay, knock in CI Engines, variables affecting knocking.

Fuel injection system

The Functions of Fuel Injection System are

To enhance the engine performance

Fuel economy

initiating and controlling the combustion process

preparation of the combustible charge (Just like carburetor)

Functional Requirements of an Injection System

i.Accurate metering of the fuel injected per cycle: The quantity of the fuel metered should vary to meet 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 and

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

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.

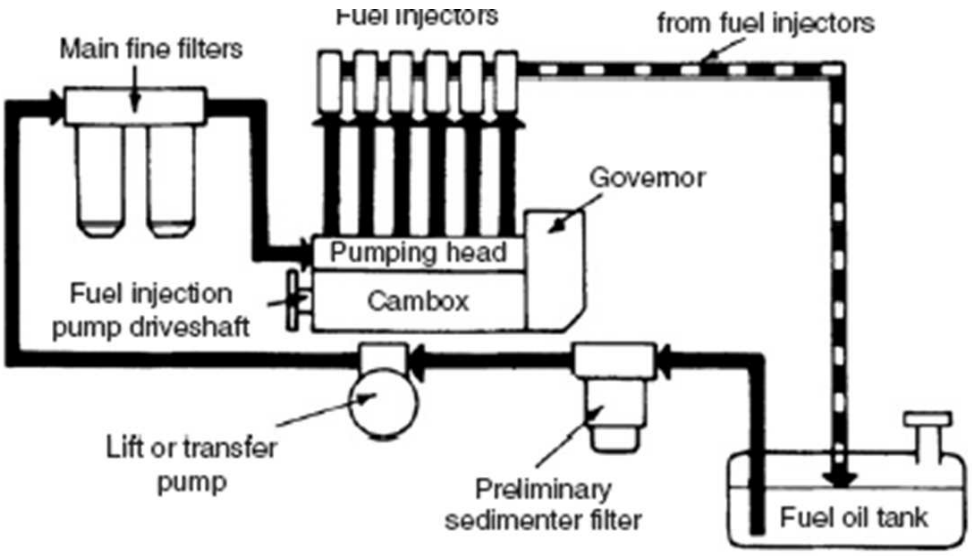
Individual pump and nozzle system

Unit injector system

Common rail system

Distributor system

Components of Fuel Injection System



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,

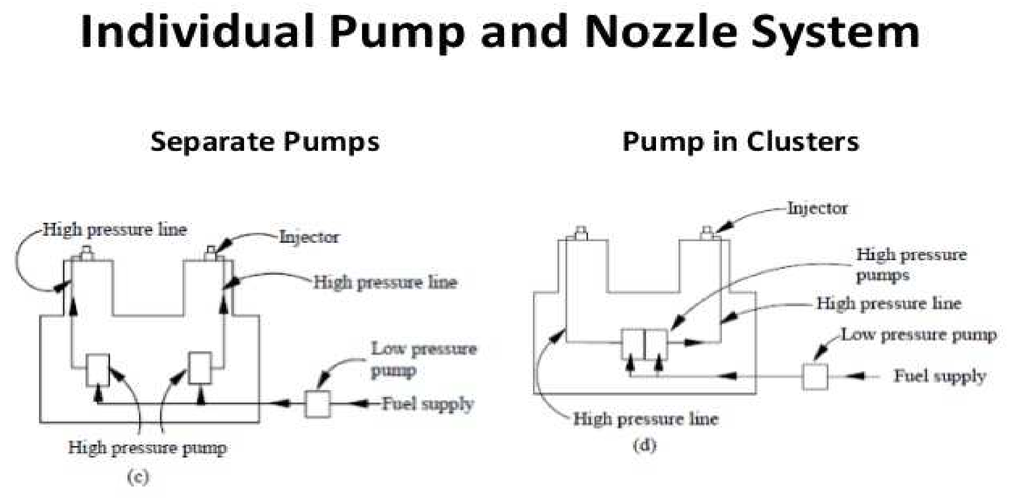
Injector: to take the fuel from the pump and distribute it in the combustion chamber by atomizing it into fine droplets

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.

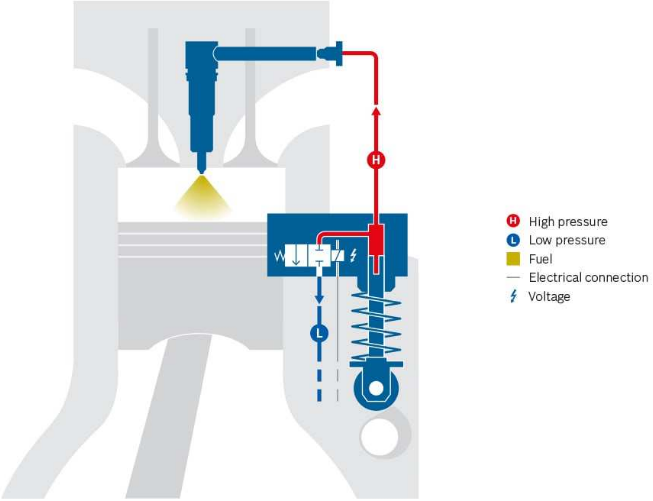


Unit Injector System

This system 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



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 push rod and stroke

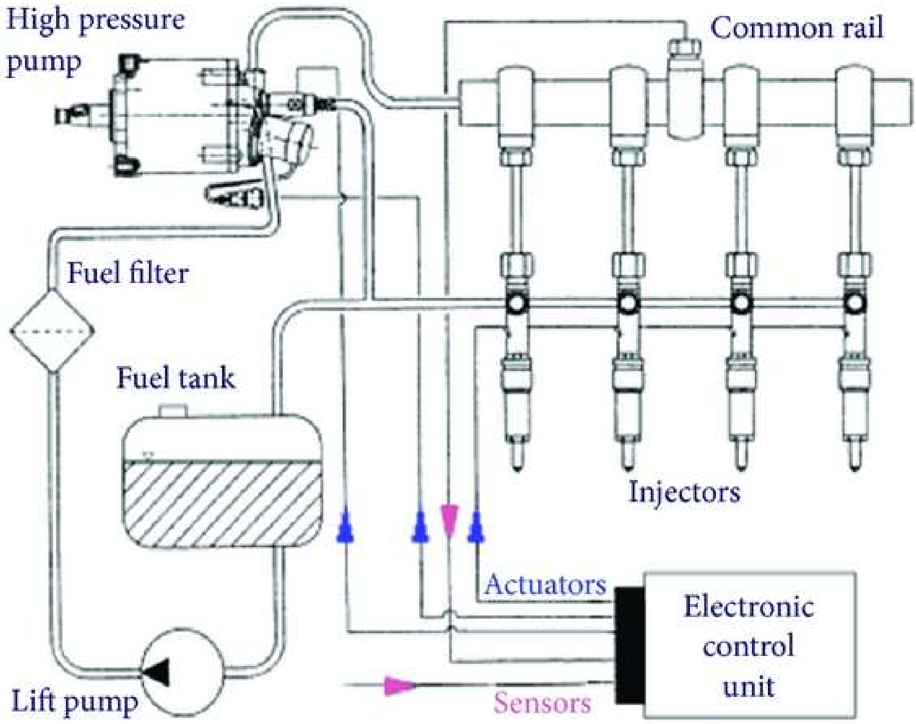
Distributor System

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



Distributor System

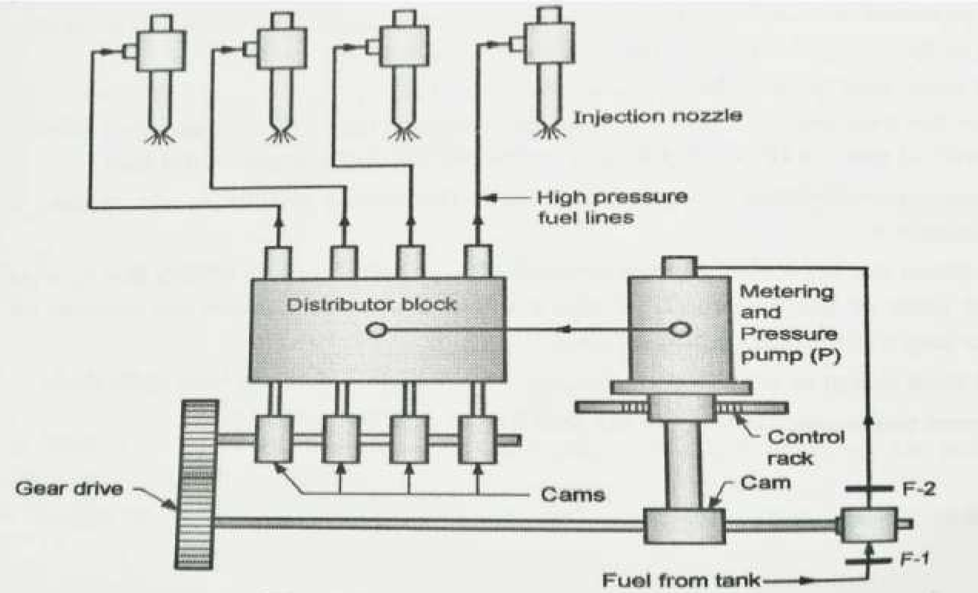


Fig. 4.31.3 : Distributor system

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

Fuel feed pump

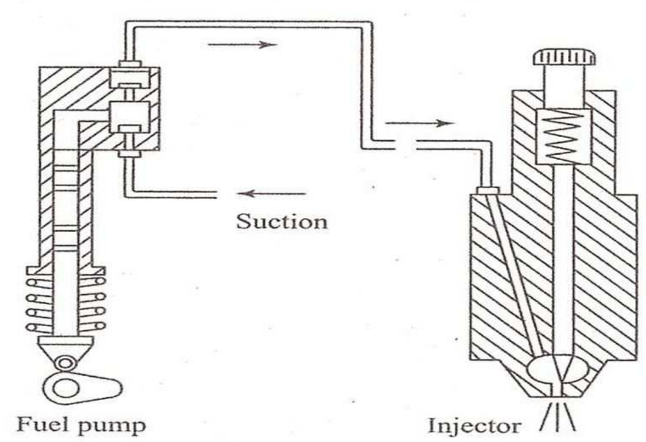


Fig. 8.4 Schematic diagram of fuel feed pump

Fuel-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,

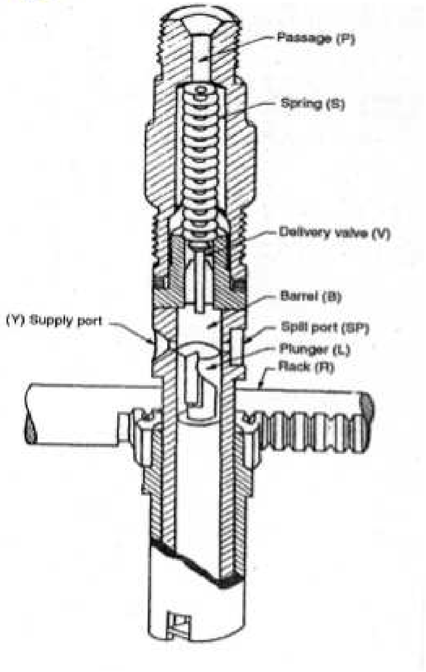
Jerk type pumps

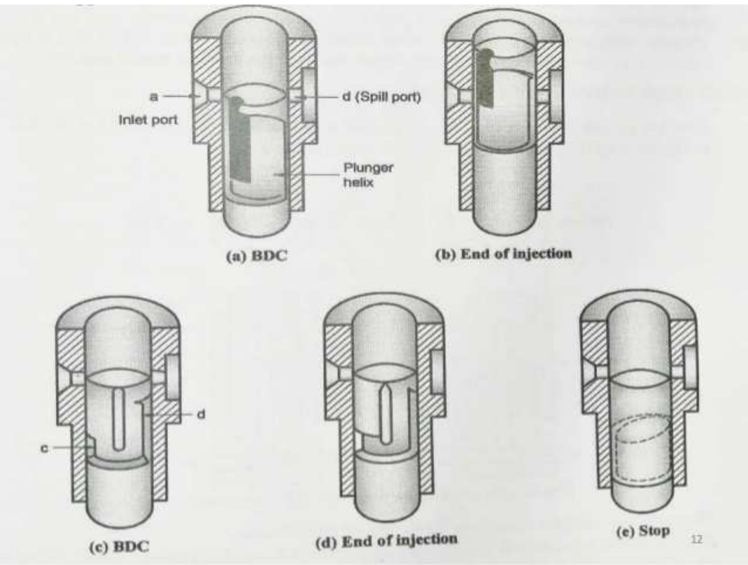
Distributor type pumps

Jerk type pumps

I C ENGINES – II : Fuel Injection System

- **Jerks Type Pumps**





(a) BDC (b) End of injection (c) BDC (d) End of injection (e) Stop

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

Inlet port A is closed, As the plunger rises

The fuel will flow out through spill port

Spill port 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 spill port

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.

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

Distributor Type Fuel Pump

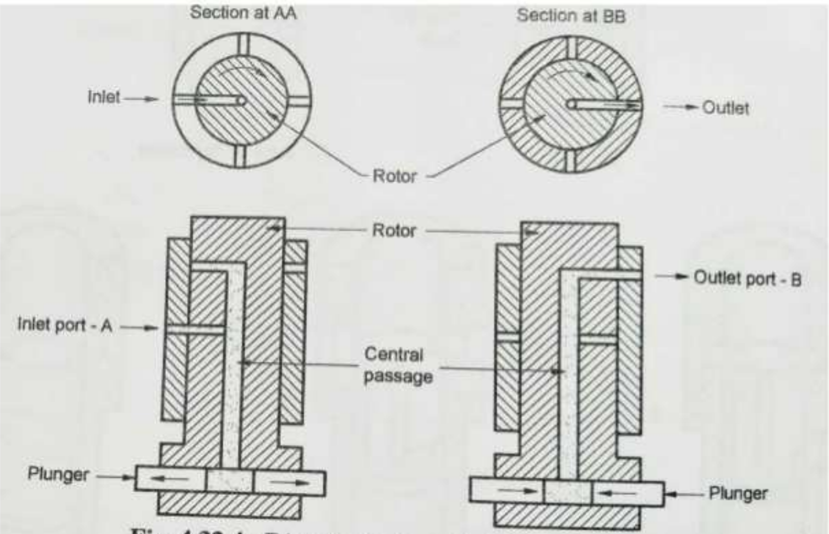


Fig. 4.32.4 : Distributor type fuel injection pump

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 result in

overfuelling 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

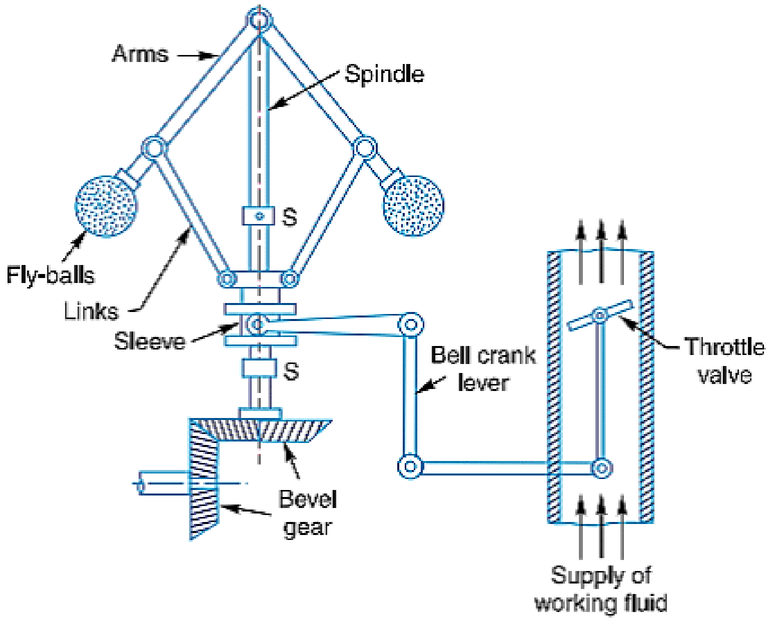
Mechanical Governor

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

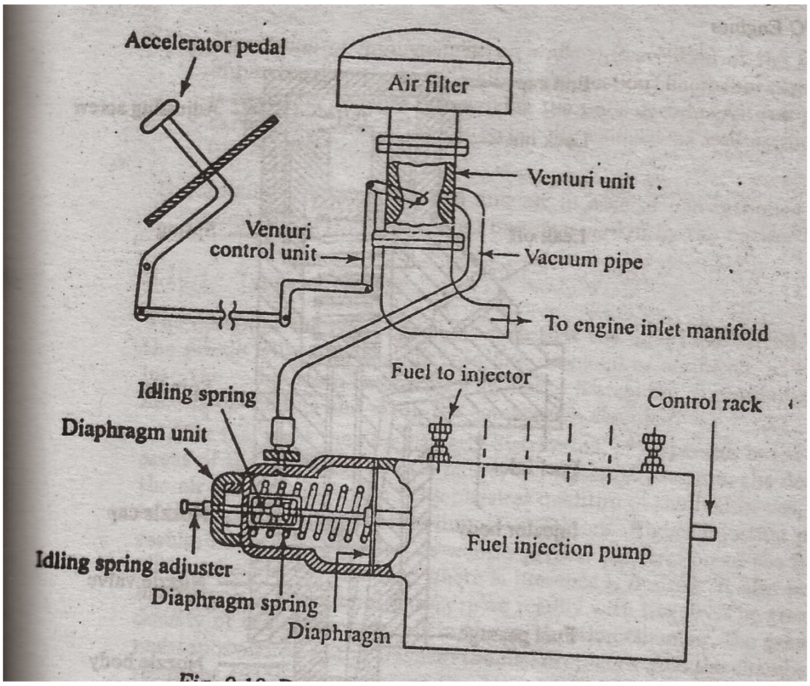


Pneumatic Governor

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.



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

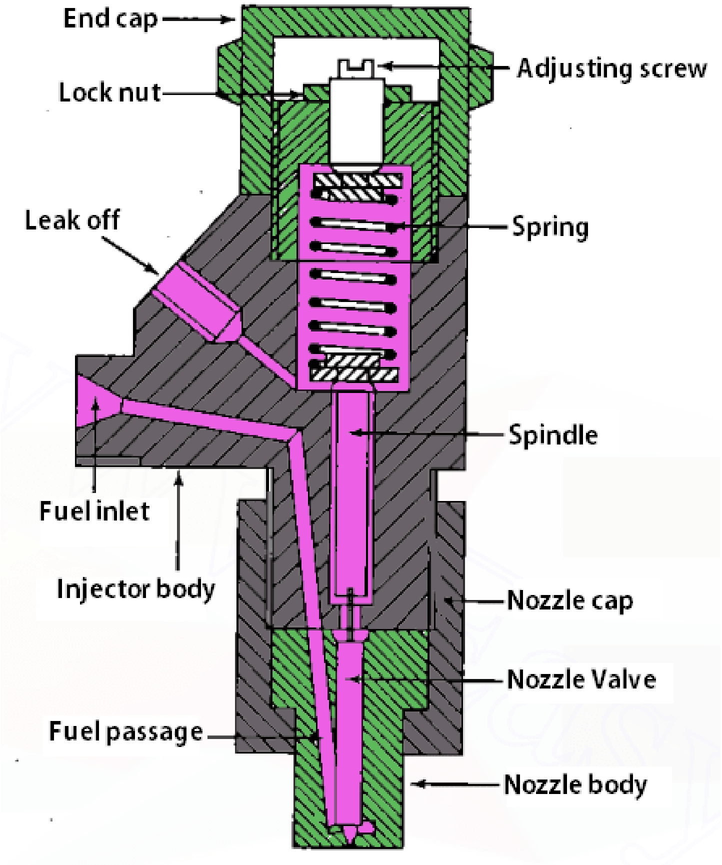
a nozzle

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)



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.

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.

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

Ignition temperature,

vapour pressure,

Viscosity, etc.

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.

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

Types

Pintle nozzle,

single hole nozzle

multi-hole nozzle,

pintaux nozzle

(i) Pintle Nozzle:

The stem of the nozzle valve is extended to form a pin or pintIe 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 isabout 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

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.

Pintaux Nozzle

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

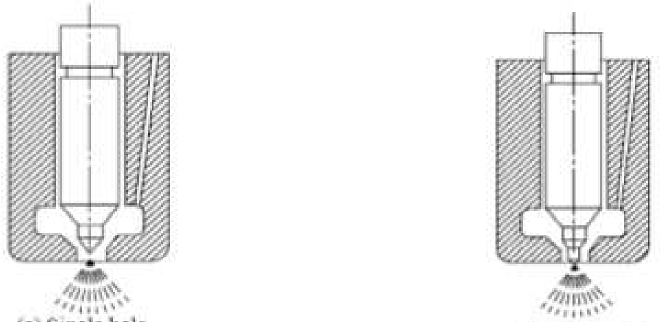
It injects a small amount of fuel through this additional hole (pilot injection) in the upstream direction slightly before the main injection.

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.

Types of Nozzles



(a) Single hole

(b) Pintle nozzle

(c) Multiple hole

(d) Pintaux nozzle

Combustion in CI engines

Only air is compressed through a high compression ratio (14:1 to 24:1) raising its temperature and pressure to a high value.

Fuel is injected into the cylinders late in compression stroke through one or more injectors into highly compressed air in the combustion chamber.

Injection time is usually about 20° of crankshaft rotation, starting at about 15° bTDC and ending about 5° aTDC.

Combustion in a CI engine is an unsteady process occurring simultaneously at many spots in a very non-homogeneous mixture at a rate controlled by fuel injection.

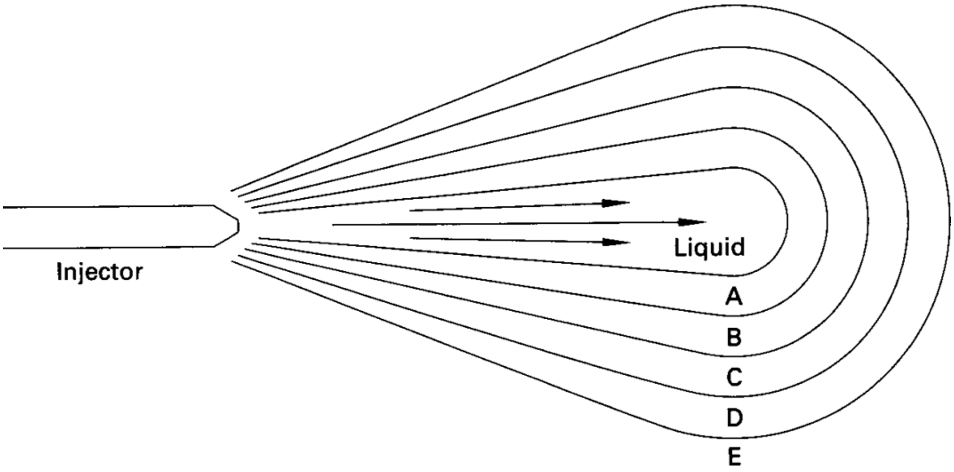
In addition to the swirl and turbulence of the air, a high injection velocity is needed to spread the fuel throughout the cylinder and cause it to mix with the air.

After injection the fuel must go through a series of events to assure the proper combustion process:

I.Atomization. Fuel drops break into very small droplets, the smaller the original drop size emitted by the injector, the quicker and more efficient will be this atomization process.

II.Vaporization. The small droplets of liquid fuel evaporate to vapor. This occurs very quickly due to the hot air temperatures created by the high compression of CI engines. High air temperature needed for this vaporization process requires a minimum compression ratio in CI engines of about 12:1. About 90% of the fuel injected into the cylinder can be vaporized within 0.001 second after injection.

III.Mixing. After vaporization, the fuel vapor must mix with air to form a mixture within the AF range which is combustible. This mixing is formed because of the high fuel injection velocity added to the swirl and turbulence in the cylinder air. Combustion can occur within the equivalence ratio limits of= 1.8 (rich) and = 0.8 (lean). The non-homogeneous distribution of air-fuel ratio that develops around the injected fuel jet.



The liquid core is surrounded by successive zones of vapor which are

i.(A) too rich to burn

ii.(B)rich combustible

iii.(C) stoichiometric

iv.(D) Lean Combuatible

v.(E) Too lean to burn

Self-ignition starts mainly in zone B and solid carbon and soot formation occur in A and B

Self-Ignition. At about 8° bTDC, 6-8° after the start of injection, the air-fuel mixture starts to self-ignite.

Actual combustion is preceded by secondary reactions, including breakdown of large hydrocarbon molecules into smaller species and some oxidation.

These reactions caused by the high-temperature air, are exothermic and further raise the air temperature in the immediate local vicinity. This finally leads to an actual sustained combustion process.

Combustion: Combustion starts from self-ignition simultaneously at many locations in the slightly rich zone of the fuel jet, where the equivalence ratio is = 1 to 1.5 (zone B in the previous fig).

When combustion starts, somewhere between 70% and 95% of the fuel in the combustion chamber is in the vapor state.

When combustion starts, multiple flame fronts spreading from the many self-ignition sites quickly consume all the gas mixture which is in a correct combustible air-fuel ratio, even where self- ignition wouldn't occur.

Stages of Combustion In CI Engines

The combustion in a CI engine is considered to be taking place in four stages

Ignition delay period

Rapid combustion

Controlled combustion and

After-burning.

Ignition delay

Ignition delay (0.7-3ms) period is counted from the start of injection to the point where the pressure time curve separates from the compression curve indicated as start of combustion.

The delay period in the CI engine influence both engine design and performance.

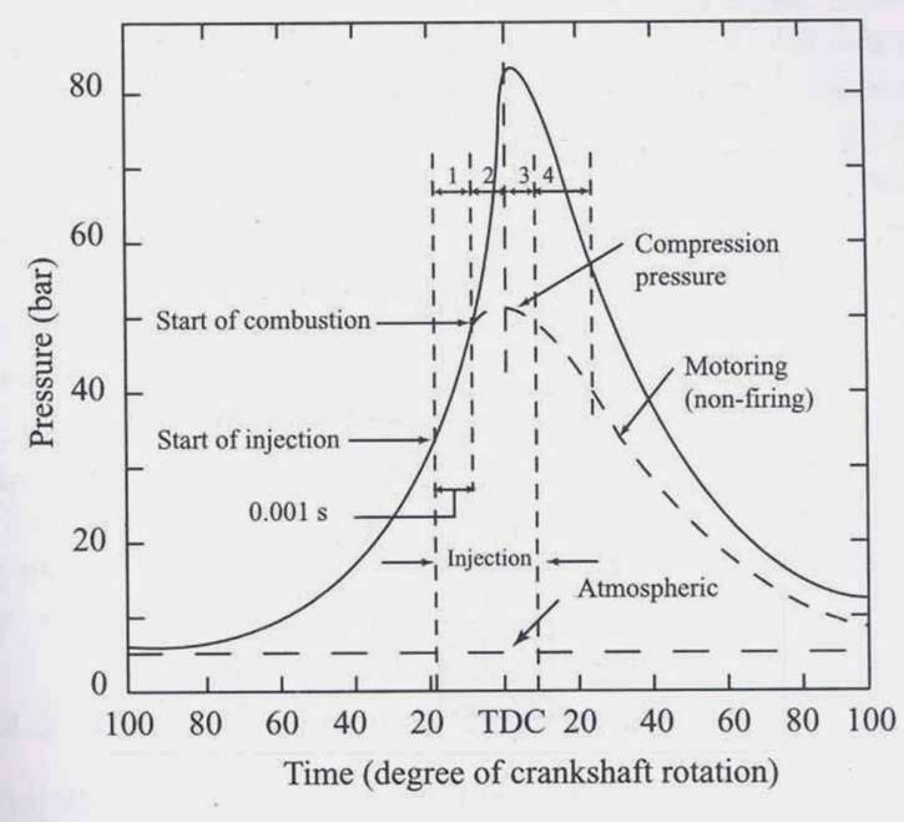
It affects

combustion rate

knocking

engine starting ability

the presence of smoke in the exhaust.



•Point a represents the time of injection

•Point b represents the time at which the pressure curve (caused by combustion) first separates from the compression process

The ignition delay period can be divided into two parts,

I.Physical delay

II.Chemical delay.

•Physical Delay

The physical delay is the time between the beginning of injection and the attainment of chemical reaction conditions.

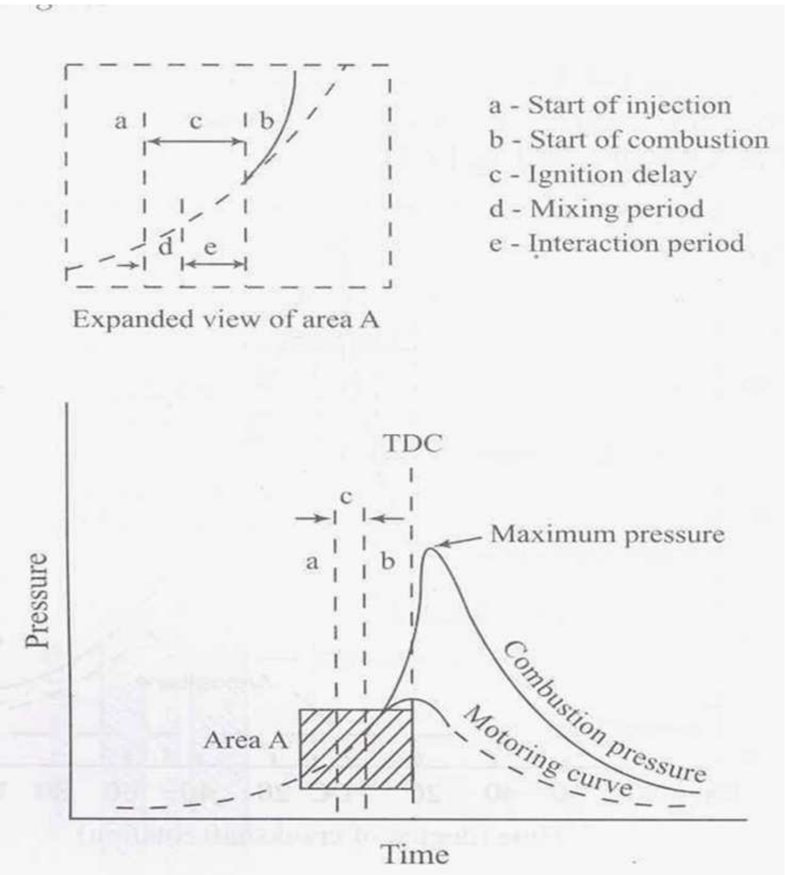
During this period

the fuel is atomized,

vaporized,

mixed with air and

raised to its self-ignition temperature.



The physical delay depends on

The type of fuel,

for light fuel the physical delay is small

for heavy viscous fuels the physical delay is high.

Injection Pressure

The physical delay is greatly reduced by using high injection pressures

Combustion chamber temperatures and Turbulence to facilitate

breakup of the jet and

improving evaporation

Chemical Delay:

During the chemical delay, reactions start slowly and then accelerated ignition taking place.

Generally, the chemical delay is larger than the physical delay.

Chemical delay depends on

the temperature of the surroundings

At high temperatures, the chemical reactions are faster

In most CI engines the ignition lag is shorter than the duration of injection.

Factors Affecting the Delay Period

Many design and operating factors affect the delay period. The important ones are:

Cetane number

Ignition timing

Compression ratio

Engine speed

Output

Atomization of fuel and duration of injection

Quality of the fuel

Intake temperature

Intake pressure

Period of rapid combustion

The period of rapid combustion also called the uncontrolled combustion, is that phase in which the pressure rise is rapid.

The period of rapid combustion is counted from the beginning of the combustion to the point of maximum pressure on the indicator diagram.

Period of Controlled Combustion

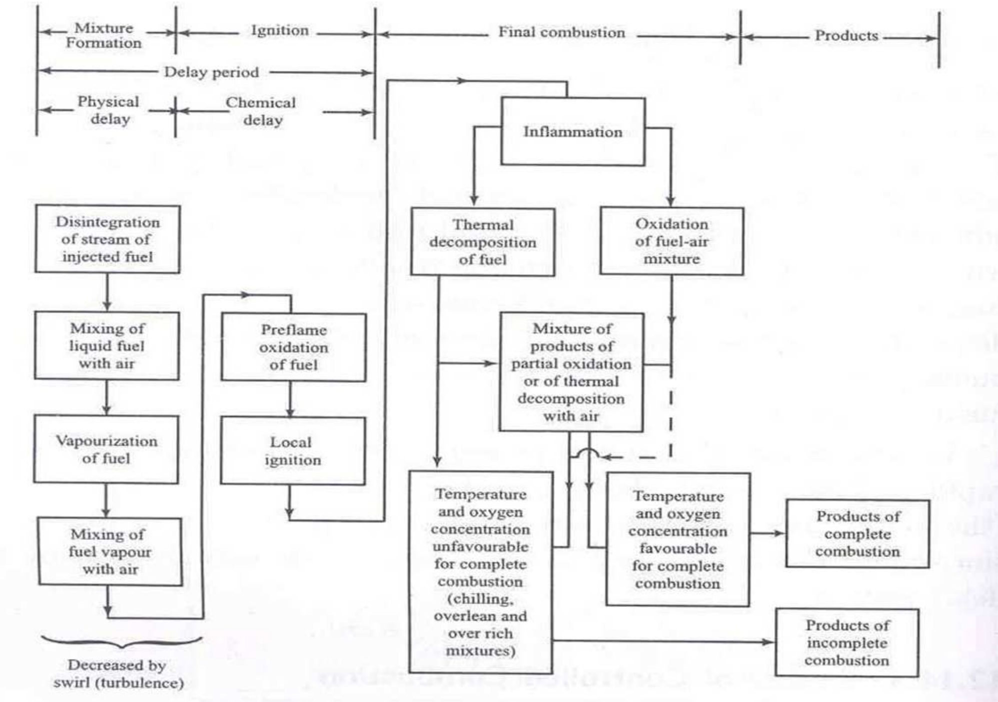
The temperature and pressure in the second stage is already quite high.

Hence the fuel droplets injected during the second stage burn faster with reduced ignition delay as soon as they find the necessary oxygen and any further pressure rise is controlled by the injection rate.

The period of controlled combustion is assumed to end at maximum cycle temperature.

Period of after burning

Combustion does not cease with the completion of the injection process. The unburnt and partially burnt fuel particles left in the combustion chamber start burning as soon as they come into contact with the oxygen. This process continues for a certain duration called the after-burning period. Usually this period starts from the point of maximum cycle temperature and continues over a part of the expansion stroke. Rate of after-burning depends on the velocity of diffusion and turbulent mixing of unburnt and partially burnt fuel with the air. The duration of the after-burning phase may correspond to 70-80 degrees of crank travel from TDC.



Sequence of events in entire combustion process

Knock in CI engines

If the ignition delay is longer,

The actual burning of the first few droplets is delayed and a greater quantity of fuel droplets gets accumulated in the chamber.

When the actual burning commences, the additional fuel can cause too rapid a rate of pressure rise as shown resulting in a jamming of forces against the piston and rough engine operation

Engine knock phenomenon is similar to that in the SI engine.

In SI engine,

Knocking occurs near the end of combustion

In CI engine,

Knocking occurs near the beginning of combustion.

In order to decrease the tendency of knock

it is necessary to decrease the ignition delay and

Thus decrease the amount of fuel present when the actual burning of the first few droplets starts.

CI engine combustion chambers

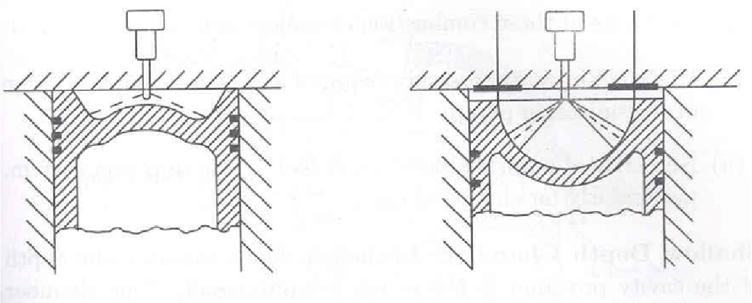
CI engine combustion chambers are classified into two categories

Direct-Injection (DI)

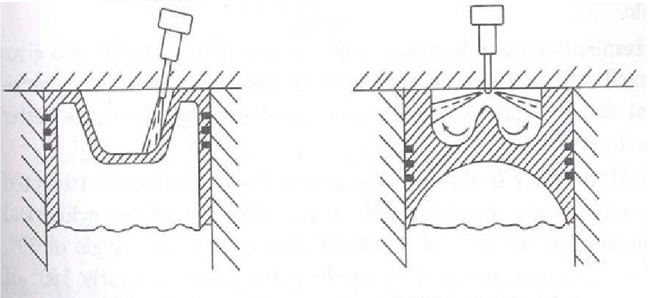
Indirect-Injection (IDI)

Direct-Injection (DI)

This type of combustion chamber is also called an open combustion chamber.In this type the entire volume of the combustion chamber is located in the main cylinder and the fuel is injected into this volume. Direct- Injection (DI) Combustion Chamber.



(a) Shallow depth chamber (b) Hemispherical chamber



(c) Cylindrical chamber (d) Toroidal chamber

Open combustion chamber

Direct-Injection (Open Combustion Chamber)

The main advantages of this type of chambers are:

Minimum heat loss during compression because of lower surface area to volume ratio and hence, better efficiency.

No cold starting problems.

Fine atomization because of multi hole nozzle.

The drawbacks of these combustion chambers are:

High fuel-injection pressure required and hence complex design of fuel-injection pump.

Necessity of accurate metering of fuel by the injection system, particularly for small engines.

Indirect-Injection (IDI) Type

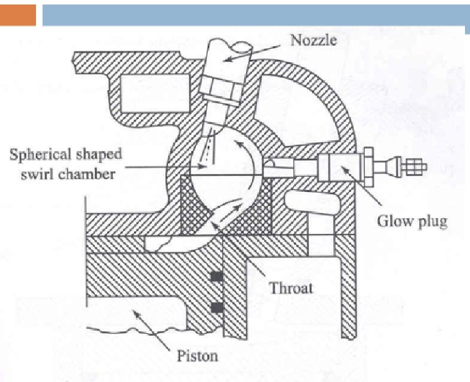


Fig. 12.20 Ricardo Swirl Chamber Comet, Mark II

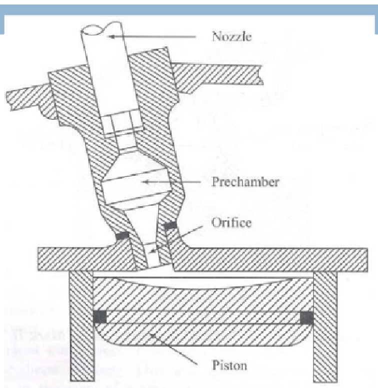
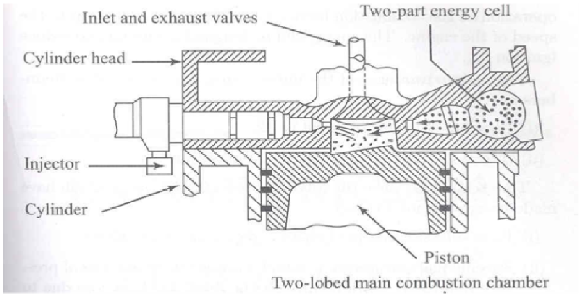
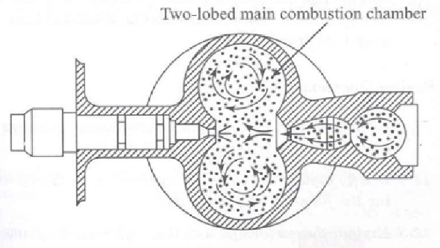


Fig. 12.21 Precombustion Chamber





ig. 12.22 Lanova Air-Cell Combustion Chamber

In this type of combustion chambers, the combustion space is divided into two parts, one part in the main cylinder and the other part in the cylinder head.

The fuel-injection is effected usually into that part of the chamber located in the cylinder head.

These chambers are classified further into

Swirl chamber

in which compression swirl is generated.

Pre combustion chamber

in which combustion swirl is induced.

Air cell chamber

in which both compression and combustion swirl are induced.

The main advantages of the indirect-injection combustion chambers are:

Injection pressure required is low

Direction of spraying is not very important.

These chambers have the following serious drawbacks which have

Poor cold starting performance requiring heater plugs.

Specific fuel consumption is high because there is a loss of pressure due to air motion through the duct and heat loss due to large heat transfer area.

TEXT / REFERENCES BOOKS

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UNIT V IGNITION, COOLING AND LUBRICATION SYSTEM

IGNITION, COOLING AND LUBRICATION SYSTEM

Types of ignition systems, inlet and exhaust manifold arrangements, engine Cooling System: Cooling requirement, Air cooling, Type of liquid cooling system, Advantage and disadvantage of air cooling and water cooling system, Antifreeze mixture. Lubrication System: Function of lubricating system, Properties of lubricating oil, Wet sump, Dry sump and mist lubrication system.

INTRODUCTION

We know that in case of Internal Combustion (IC) engines, combustion of air and fuel takes place inside the engine cylinder and the products of combustion expand to produce reciprocating motion of the piston. This reciprocating motion of the piston is in turn converted into rotary motion of the crank shaft through connecting rod and crank.

This rotary motion of the crank shaft is in turn used to drive the generators for generating power. We also know that there are 4-cycles of operations viz.: suction; compression; power generation and exhaust. These operations are performed either during the 2-strokes of piston or during 4-strokes of the piston and accordingly they are called as 2-stroke cycle engines and 4-stroke cycle engines. In case of petrol engines during suction operation, charge of air and petrol fuel will be taken in. During compression this charge is compressed by the upward moving piston. And just before the end of compression, the charge of air and petrol fuel will be ignited by means of the spark produced by means of for spark plug. And the ignition system does the function of producing the spark in case of spark ignition engines

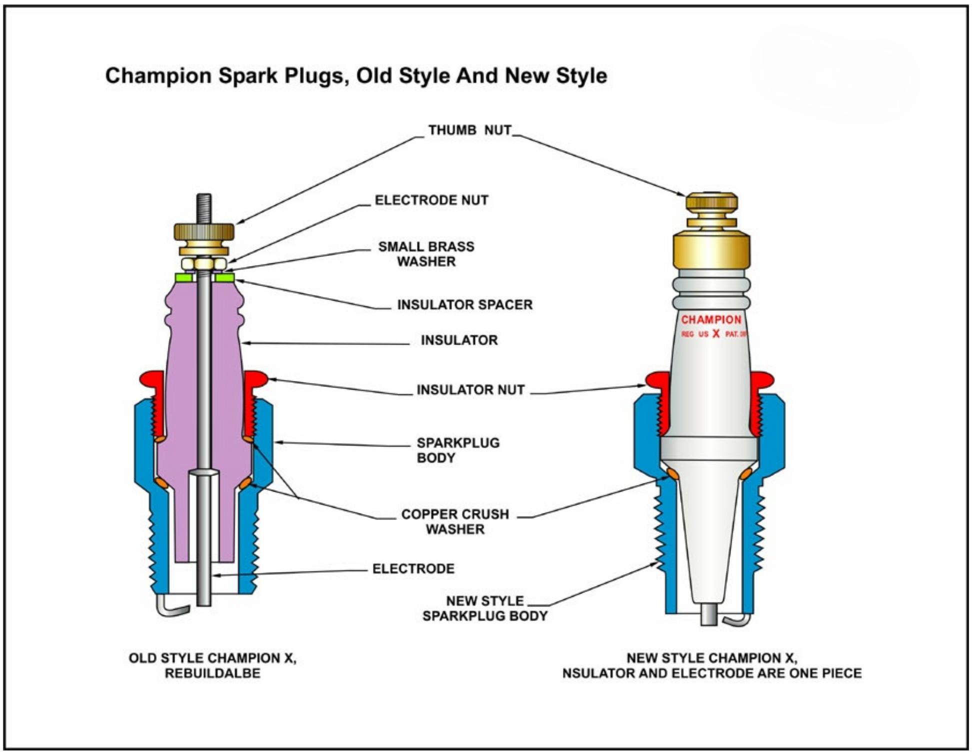


Figure shows a typical spark plug used with petrol engines. It mainly consists of a central electrode and metal tongue. Central electrode is covered by means of porcelain insulating material. Through the metal screw the spark plug is fitted in the cylinder head plug. When the high tension voltage of the order of 30000 volts is applied across the spark electrodes, current jumps from one electrode to another producing a spark.

Whereas in case of diesel (Compression Ignition-CI) engines only air is taken in during suction operation and in compressed during compression operation and just before the end of compression, when diesel fuel is injected, it gets ignited due to heat of compression of air.

Once the charge is ignited, combustion starts and products of combustion expand, i.e. they force the piston to move downwards i.e. they produce power and after producing the power the gases are exhausted during exhaust operation.

IGNITION SYSTEM TYPES

Basically Convectional Ignition systems are of 2 types :

(a)Battery or Coil Ignition System, and

(b)Magneto Ignition System.

Both these conventional, ignition systems work on mutual electromagnetic induction principle.

Battery ignition system was generally used in 4-wheelers, but now-a-days it is more commonly used in 2-wheelers also (i.e. Button start, 2-wheelers like Pulsar, Kinetic Honda; Honda-Activa, Scooty, Fiero, etc.). In this case 6 V or 12 V batteries will supply necessary current in the primary winding.

Magneto ignition system is mainly used in 2-wheelers, kick start engines. (Example, Bajaj Scooters, Boxer, Victor, Splendor, Passion, etc.).

In this case magneto will produce and supply current to the primary winding. So in magneto ignition system magneto replaces the battery.

Battery or Coil Ignition System

Figure shows line diagram of battery ignition system for a 4-cylinder petrol engine. It mainly consists of a 6 or 12 volt battery, ammeter, ignition switch, auto-transformer (step up transformer), contact breaker, capacitor, distributor rotor, distributor contact points, spark plugs, etc.

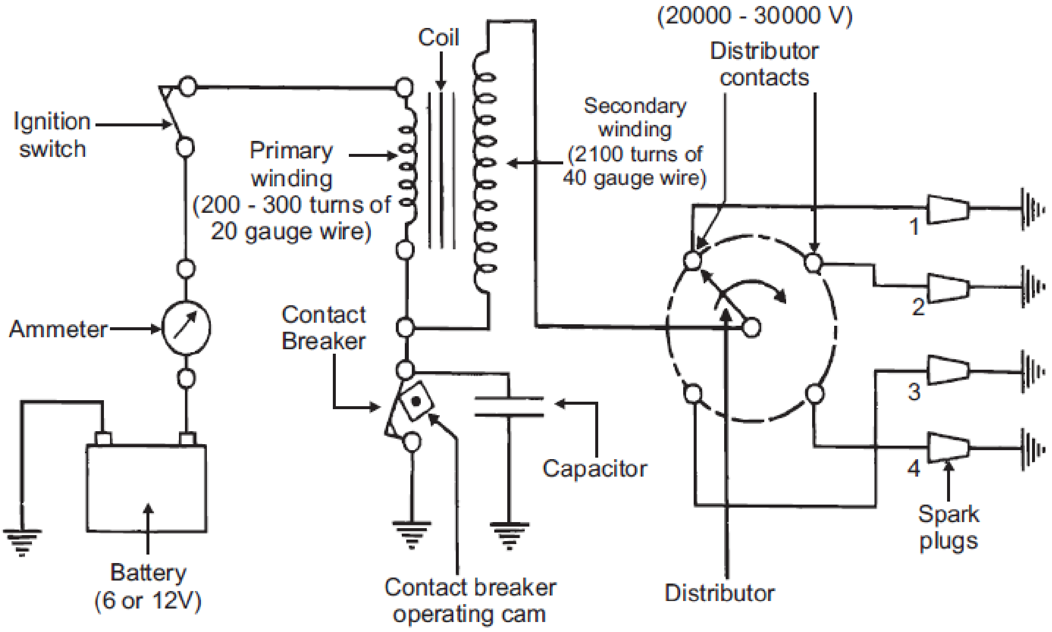
Note that the Figure 4.1 shows the ignition system for 4-cylinder petrol engine, here there are 4-spark plugs and contact breaker cam has 4-corners. (If it is for 6-cylinder engine it will have 6-spark plugs and contact breaker cam will be a perfect hexagon).

The ignition system is divided into 2-circuits :

(i)Primary Circuit : It 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: It consists of secondary winding. Secondary winding consists of about 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 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 heads (engine earth).

(iii)Working: When the ignition switch is closed and engine in 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 beaker 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 upto28000-30000 volts.



Battery or Coil Ignition System

This high voltage current is brought to centre of the distributor rotor. Distributor rotor rotates and supplies this high voltage current to proper stark 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.

Note :

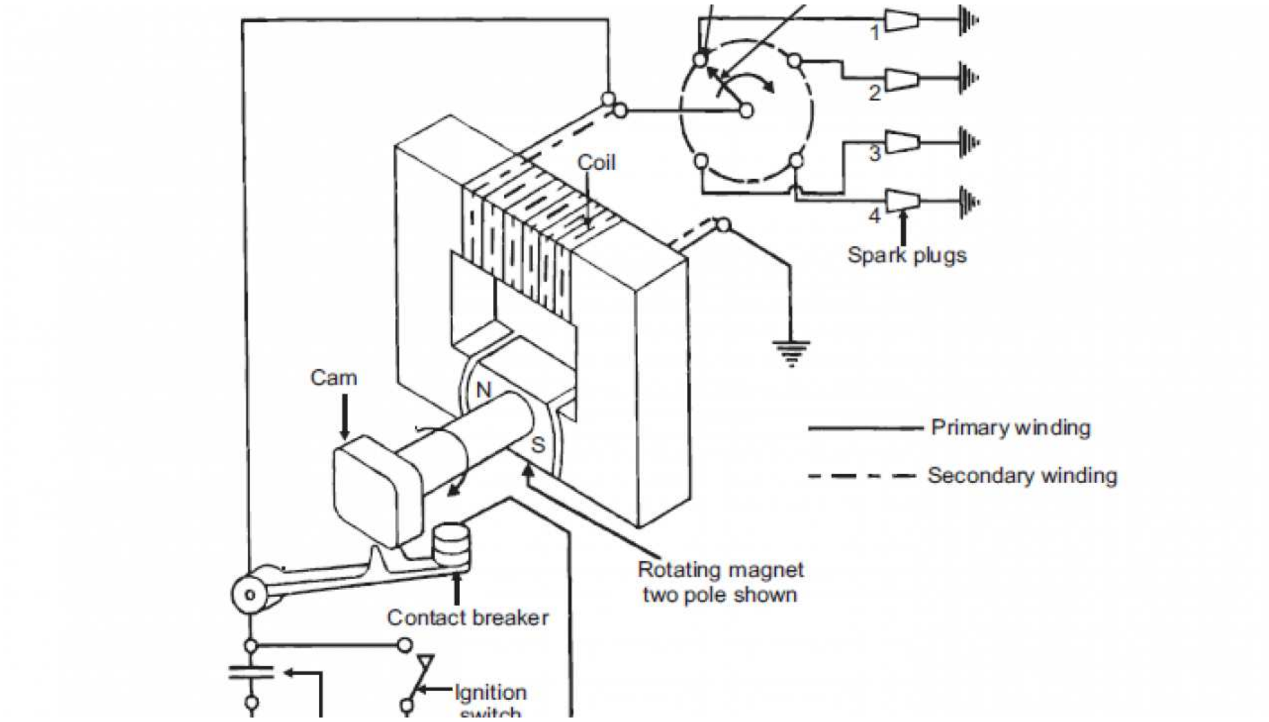
(a)The Function of the capacitor is to reduce arcing at the contact breaker (CB) points. Also when the CB opens the magnetic field in the primary winding begins to collapse. When the magnetic field is collapsing capacitor gets fully charged and then it starts discharging and helps in building up of voltage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

(b)Contact breaker cam and distributor rotor are mounted on the same shaft.

In 2-stroke cycle engines these are motored at the same engine speed. And in 4-stroke cycle engines they are motored at half the engine speed.

Magneto Ignition System

In this case magneto will produce and supply the required current to the primary winding. In this case as shown, we can have 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.



Magneto Ignition System

COMPARISON BETWEEN BATTERY AND MAGNETO IGNITION SYSTEM

Battery Ignition	**Magneto Ignition**
Battery is a must.	No battery needed.
Battery supplies current in primary circuit.	Magneto produces the required current for primary circuit.
A good spark is available at low speed also.	During starting the quality of spark is poor due to slow speed.
Occupies more space.	Very much compact.
Recharging is a must in case battery gets discharged.	No such arrangement required.

Mostly employed in car and bus for which it is required to crank the engine.	Used on motorcycles, scooters, etc.
Battery maintenance is required.	No battery maintenance problems.

DRAWBACKS (DISADVANTAGES) OF CONVENTIONAL IGNITION SYSTEMS

Following are the drawbacks of conventional ignition systems :

Because of arcing, pitting of contact breaker point and which will lead to regular maintenance problems.

Poor starting : After few thousands of kilometers 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.

Some times it is not possible to produce spark properly in fouled spark plugs.

In order to overcome these drawbacks Electronic Ignition system is used.

ADVANTAGES OF ELECTRONIC IGNITION SYSTEM

Following are the advantages of electronic ignition system :

Moving parts are absent-so nomaintenance.

Contact breaker points are absent-so noarcing.

Sparkplug life increases by 50% and they can be used for about 60000km without any problem.

Better combustion in combustion chamber, about 90-95% of air fuel mixture is burnt compared with70-75% with conventional ignition system.

More power output.

More fuel efficiency.

TYPES OF ELECTRONIC IGNITION SYSTEM

Electronic Ignition System is as follows :

Capacitance Discharge Ignition system

Transistorized system

Piezo-electric Ignition system

The Texaco Ignition system

Capacitance Discharge Ignition System

It mainly consists of 6-12 V battery, ignition switch, DC to DC convertor, charging resistance, tank capacitor, Silicon Controlled Rectifier (SCR), SCR-triggering device, step up transformer, spark plugs. A 6-12 volt battery is connected to DC to DC converter i.e. power circuit through the ignition switch, which is designed to give or increase the voltage to 250-350 volts. This high voltage is used to charge the tank capacitor (or condenser) to this voltage through the charging resistance. The charging resistance's also so designed that it controls the required current in the SCR.

Depending upon the engine firing order, whenever the SCR triggering device sends a pulse, then the current flowing through the primary winding is stopped, and the magnetic field begins to collapse. This collapsing magnetic field will induce or step up high voltage current in the secondary, which while jumping the spark plug gap produces the spark, and the charge of air fuel mixture is ignited.

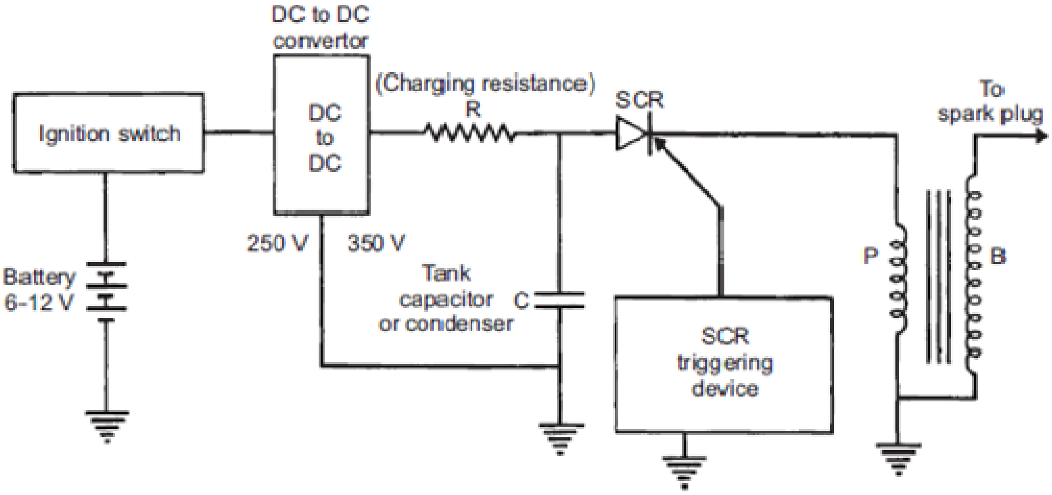


Figure 4.4 : Capacitance Discharge Ignition System

Following are the advantages of capacitance discharge 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.

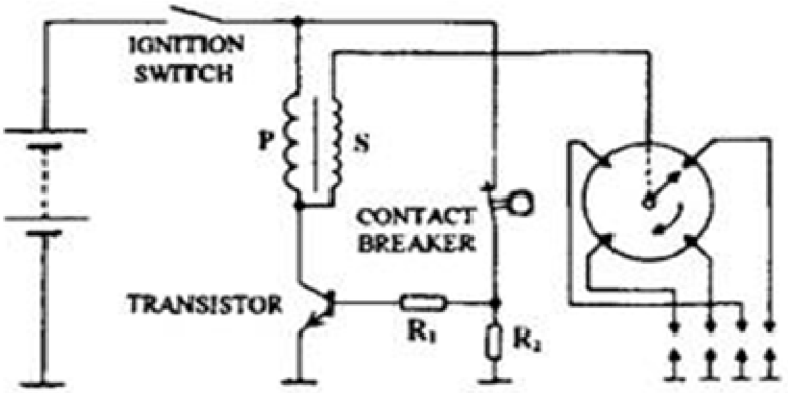
Better combustion in combustion chamber, about 90-95% of air fuel mixture is burnt compared with 70-75% with conventional ignition system.

More power output.

More fuel efficiency.

Transistorized Assisted Contact (TAC) Ignition System

This system incorporates normal mechanical breakers, which drives a transistor to control the current in the primary circuit. Since a very small breaker current is used, erosion of the contacts is eliminated so that good coil output is maintained. Also it provides accurate spark timing for a much longer period. When a low inductive coil and ballast resistor are used with this system, excessive contact arcing produced by the high primary current is also eliminated. The basic principle of a breaker-triggered, inductive, semiconductor ignition system is illustrated in Fig where a transistor works as of the contact breaker, by acting as power switch to make and break the primary circuit. The transistor performs as a relay, which is operated by the current supplied by a cam-operated control switch and thereby called as breaker-triggered.



Transistorized Assisted Contact (TAC) Ignition System

A small control current passes through the base-emitter of the transistor when the contact breaker is in closed condition. This switches-on the collector-emitter circuit of the transistor and allows full current to flow through the primary circuit to energize the coil. The flow of current, at this stage, in the control circuit and transistor base is governed by the total and relative values of the resistors R1 and R2. These resistance values are chosen to provide a control current of about 0.3 A, which is sufficient to provide a self-cleaning action of the contact surfaces without overloading the breaker. When the spark is required, the cam opens the con¬tact to interrupt the base circuit, which causes the transistor to switch-off. With sudden opening of the primary circuit a high voltage is induced into the secondary, which produces a spark at the plug. This sequence is repeated to provide the required number of sparks per each revolution of the cam (Fig. 16.26). The T.A.C. arrangement provides a quicker break of the circuit compared with a non- transistorised system, and, as a result, a more rapid collapse of the magnetic flux takes place. Consequently a high HT secondary voltage is obtained. The components of this ignition system are similar to those used with a conventional system except for the extra control module containing the power transistor.

Advantages

Breaker point contact surfaces last the life of the engine.

Improved cold starting due to faster rise time offered by transistor switching.

Improved consistency and repeatability of secondary voltage energy and waveform without degradation over time.

Ability to fire partially fouled plugs due to aforementioned rise time improvement.

Disadvantages

As in the conventional system, mechanical breaker points are necessary for timing the spark.

The cost of the ignition system is increased.

The voltage rise-time at the spark plug is about the same as before.

Piezo-electric Ignition System

The development of synthetic piezo-electric materials producing about 22 kV by mechanical loading of a small crystal resulted in some ignition systems for single cylinder engines. But due to difficulties of high mechanical loading need of the order of 500 kg timely control and ability to produce sufficient voltage, these systems have not been able to come up.

The Texaco Ignition System

Due to the increased emphasis on exhaust emission control, there has been a sudden interest in exhaust gas recirculation systems and lean fuel-air mixtures.

To avoid the problems of burning of lean mixtures, the Texaco Ignition system has been developed. It provides a spark of controlled duration which means that the spark duration in crank angle degrees can be made constant at all engine speeds.

It is a AC system. This system consists of three basic units, a power unit, a control unit and a distributor sensor.

This system can give stable ignition up to A/F ratios as high as 24 : 1.

FIRING ORDER

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

Incase of SI engines the distributor connects the sparkplugs of different cylinders according to Engine Firing Order.

Advantages

A proper firing order reduces engine vibrations.

Maintains engine balancing.

Secures an even flow of power.

Firing order differs from engine-to-engine.

Probable firing orders for different engines are:

3 cylinder =1-3-2

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

4 cylinder horizontal opposed engine =1-4-3-2 (Volkswagen engine)

6-cylinder in line engine =1-5-3-6-2-4 (Cranks in3pairs) 1-4-2-6-3-5 1-3-2-6-4-5 1-2-4-6-5-3

8 cylinder inline 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

Cylinder 1 is taken from front of inline and front right side in V engines.

COOLING SYSTEMS OF IC ENGINES

INTRODUCTION

We know that in case of Internal Combustion engines, combustion of air and fuel takes place inside the engine cylinder and hot gases are generated. The temperature of gases will be around 2300-2500^o C. This is a very high temperature and may result into burning of oil film between the moving parts and may result into seizing or welding of the same. So, this temperature must be reduced at which the engine will work most efficiently. Too much cooling is also not desirable since it reduces the thermal efficiency. So, the object of cooling system is to keep the engine running at its most efficient operating temperature.

It is to be noted that the engine is quite inefficient when it is cold and hence the cooling system is designed in such a way that it prevents cooling when the engine is warming up and till it attains to maximum efficient operating temperature, then it starts cooling.

It is also to be noted that:

About 20-25% of total heat generated is used for producing brake power (useful work).

Cooling system is designed to remove 30-35% of total heat.

Remaining heat is lost in friction and carried away by exhaust gases.

AIR COOLING SYSTEM

There are mainly two types of cooling systems

Air cooled system and

Water cooled system.

Air Cooled System

Air cooled system is generally used in small engines say up to 15-20 kW and in aero plane engines.

In this system fins or extended surfaces are provided on the cylinder walls, cylinder head, etc. Heat generated due to combustion in the engine cylinder will be conducted to the fins and when the air flows over the fins, heat will be dissipated to air.

The amount of heat dissipated to air depends upon:

Amount of air flowing through the fins

Fin surface area.

Thermal conductivity of metal used for fins.

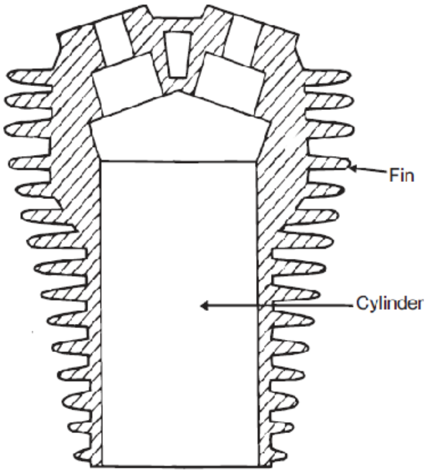


Figure 3: Cylinder with fins

Advantages of Air Cooled System

Following are the advantages of air cooled system :

Radiator/pump is absent hence the system is light.

In case of water cooling system there are leakages, but in this case there are no leakages.

Coolant and antifreeze solutions are not required.

This system can be used in cold climates, where if water is used it may freeze.

Disadvantages of Air Cooled System

Comparatively it is less efficient.

It is used in aero planes and motorcycle engines where the engines are exposed to air directly.

WATER COOLING SYSTEM

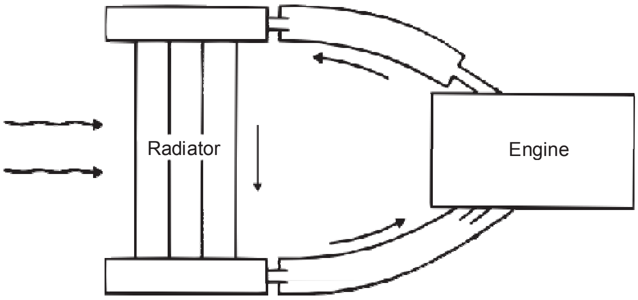
In this method, cooling water jackets are provided around the cylinder, cylinder head, valve seats etc. The water when circulated through the jackets, it absorbs heat of combustion. This hot water will then be cooling in the radiator partially by a fan and partially by the flow developed by the forward motion of the vehicle. The cooled water is again recirculated through the water jackets.

Types of Water Cooling System

There are two types of water cooling system :

Thermo Siphon System

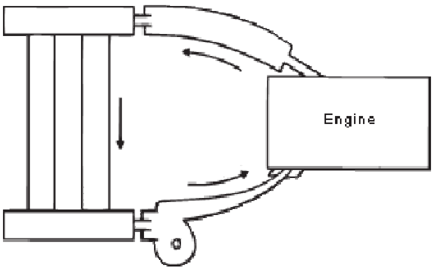
In this system the circulation of water is due to difference in temperature (i.e. difference in densities) of water. So in this system pump is not required but water is circulated because of density difference only.



Thermo Siphon System

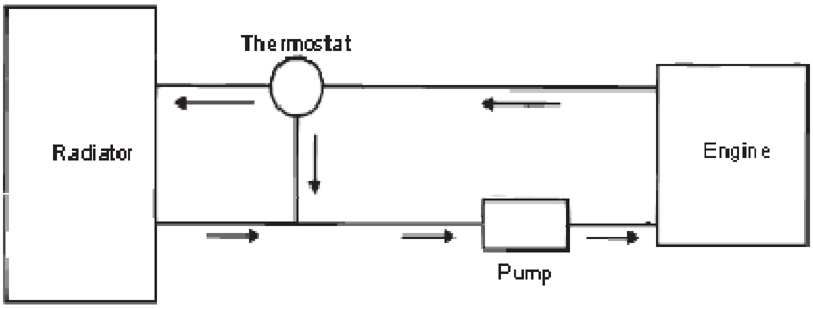
Pump Circulation System

In this system circulation of water is obtained by a pump. This pump is driven by means of engine output shaft through V-belts

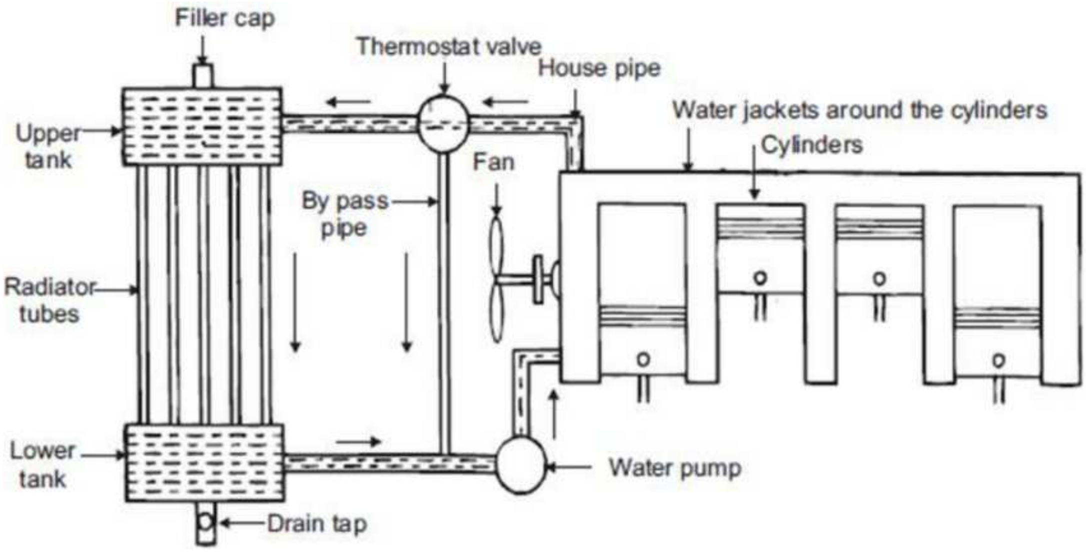


Pump Circulation System

Components of Water Cooling System



Water Cooling System using Thermostat Valve



Water cooling system for 4 cylinder engine

Water cooling system mainly consists of :

Radiator,

Thermostat valve,

Water pump,

Fan,

Water Jackets, and

Antifreeze mixtures.

Radiator

It mainly consists of an upper tank and lower tank and between them is a core. The upper tank is connected to the water outlets from the engines jackets by a hose pipe and the lover tank is connect to the jacket inlet through water pump by means of hose pipes.

There are 2-types of cores :

Tubular

Cellular as shown.

When the water is flowing down through the radiator core, it is cooled partially by the fan which blows air and partially by the air flow developed by the forward motion of the vehicle.

As shown through water passages and air passages, water and air will be flowing for cooling purpose.

It is to be noted that radiators are generally made out of copper and brass and their joints are made by soldering.

Thermostat Valve

It is a valve which prevents flow of water from the engine to radiator, so that engine readily reaches to its maximum efficient operating temperature. After attaining maximum efficient operating temperature, it automatically begins functioning. Generally, it prevents the water below 70 ^{0}C.

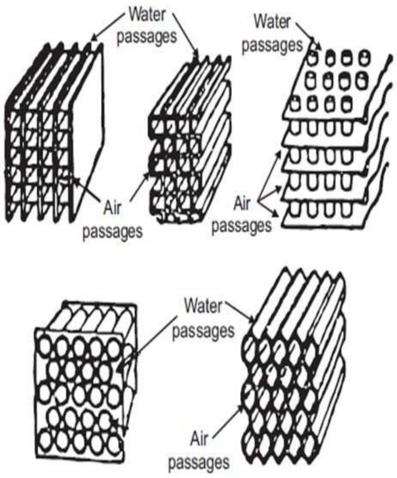
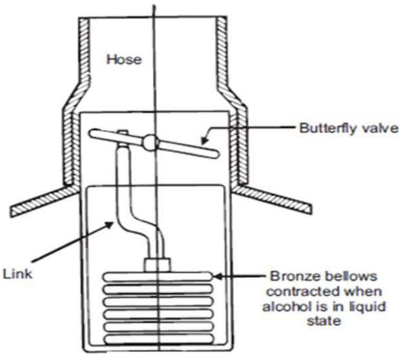


Figure 5.6 : Types of Cores (a) Tabullar Radiator Sections and (b) Circullar Radiator Sections



Thermostat Valve

Fig shows the Bellow type thermostat valve which is generally used.

It contains a bronze bellow containing liquid alcohol. Bellow is connected to the butterfly valve disc through the link.

When the temperature of water increases, the liquid alcohol evaporates and the bellow expands and in turn opens the butterfly valve, and allows hot water to the radiator, where it is cooled.

Water Pump

It is used to pump the circulating water. Impeller type pump will be mounted at the front end.

Pump consists of an impeller mounted on a shaft and enclosed in the pump casing. The pump casing has inlet and outlet openings.

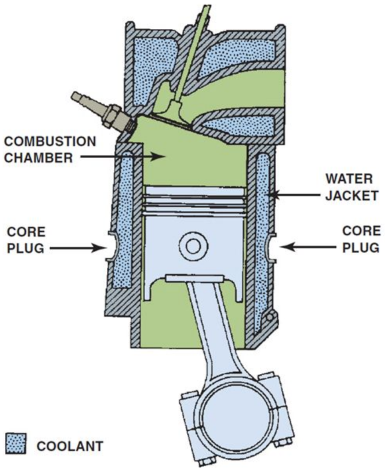
The pump is driven by means of engine output shaft only through belts. When it is driven water will be pumped.

Fan

It is driven by the engine output shaft through same belt that drives the pump. It is provided behind the radiator and it blows air over the radiator for cooling purpose.

Water Jackets

Cooling water jackets are provided around the cylinder, cylinder head, valve seats and any hot parts which are to be cooled. Heat generated in the engine cylinder, conducted through the cylinder walls to the jackets. The water flowing through the jackets absorbs this heat and gets hot. This hot water will then be cooled in the radiator (Referred Figure).



Antifreeze Mixture

In western countries if the water used in the radiator freezes because of cold climates, then ice formed has more volume and produces cracks in the cylinder blocks, pipes, and radiator. So, to prevent freezing antifreeze mixtures or solutions are added in the cooling water.

The ideal antifreeze solutions should have the following properties :

It should dissolve in water easily.

It should not evaporate.

It should not deposit any foreign matter in cooling system.

It should not have any harmful effect on any part of cooling system.

It should be cheap and easily available.

It should not corrode the system.

No single antifreeze satisfies all the requirements. Normally following are used as antifreeze solutions :

Methyl, ethyl and isopropyl alcohols.

A solution of alcohol and water.

Ethylene Glycol.

A solution of water and Ethylene Glycol.

Glycerin along with water, etc.

Advantages and Disadvantages of Water Cooling System

Advantages

Uniform cooling of cylinder, cylinder head and valves.

Specific fuel consumption of engine improves by using water cooling system.

If we employ water cooling system, then engine need not be provided at the front end of moving vehicle.

Engine is less noisy as compared with air cooled engines, as it has water for damping noise.

Disadvantages

It depends upon the supply of water.

The water pump which circulates water absorbs considerable power.

If the water cooling system fails then it will result in severe damage of engine.

The water cooling system is costlier as it has more number of parts. Also it requires more maintenance and care for its parts.

Lubrication System

Function of Lubrication

To reduce friction and wear between the moving parts

To provide sealing action

To cool the surfaces by carrying away the heat generated in engine components

To clean the surfaces by washing away carbon and metal particles caused by wear

Is to provide sufficient quantity of cooled & filtered oil to give +ve and adequate lubrication to all the moving parts

The various lubrication system used for IC engine

Mist Lubrication

Wet sump Lubrication

Dry sump Lubrication

Mist Lubrication System

This system is used where crankcase lubrication is not suitable

In 2-stroke engine as the charge is compressed in the crankcase, it is not possible to have the lubricating oil oil in the sump

In such engines the lubricating oil is mixed with the fuel, the usual ratio being 3% to 6%

The oil and the fuel induced through the carburetor the fuel is vaporized and the oil is in the form of mist goes via the crankcase in to the cylinder

Advantage of this system

simplicity,

low cost (does not required oil pump, filter)

Disadvantages

Causes heavy exhaust smoke

Get contaminated with acids and result in the corrosion of bearings surface

Calls for through mixing for effective lubrication (this requires either separate mixing prior to use of some additive to give the oil good mixing characteristics)

The engine will suffer from insufficient lubrication as the supply of fuel is less

Wet Sump lubrication System

The bottom of the crankcase contains an oil pan or sump from which the lubricating oil is pumped to various components by a pump .After lubricating the parts the oil flows back to the sump by gravity

There are 3 varieties in wet sump lubricating system

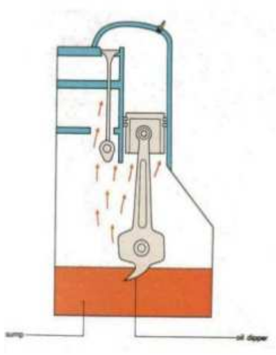
The splash system

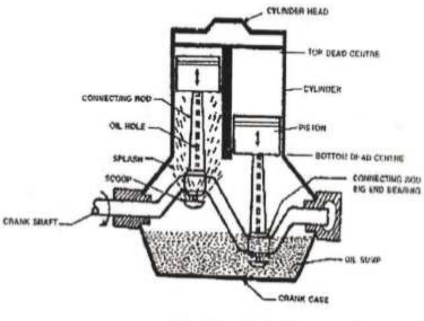
The splash and pressure system

The pressure feed system

Splash System

This type of lubrication system is used in light duty engines. The lubricating oil charged in to the bottom of the crankcase and maintained at predetermined level. The oil is drawn by a pump and delivered through a distributing pipe in to the splash troughs. A splasher or dipper is provided under each connecting rod cap.





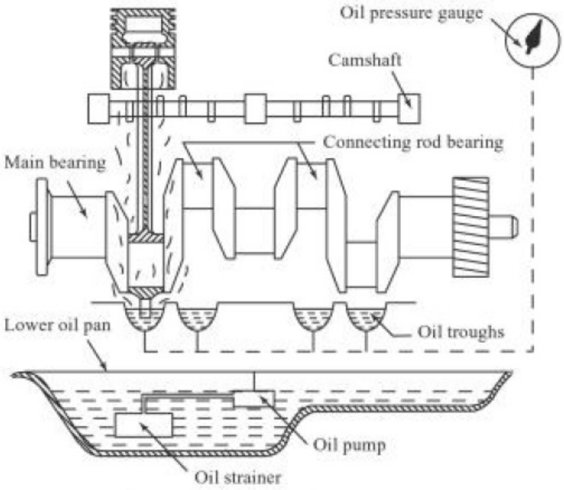
SPLASH LUBRICATION

Splash & pressure lubrication system

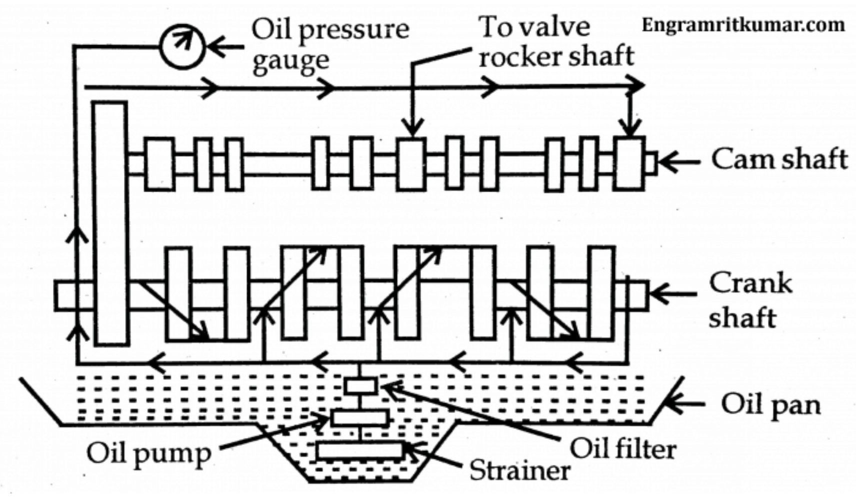
The lubricating oil is supplied under pressure to main and camshaft bearings . The oil is also supplied under pressure to pipes which direct a stream of oil against the dippers on the big end connecting rod bearing cup. The crankpin bearings are lubricated by the splash or spray of oil thrown up by dipper

Pressure feed system

The oil is forced to all the main bearings of crankshaft .Pressure relief valve is fitted to maintain the predictable pressure values . Oil hole is drilled from the center of each crankpin to the center of an adjacent main journal through which oil can pass from the main bearing to the crankpin.



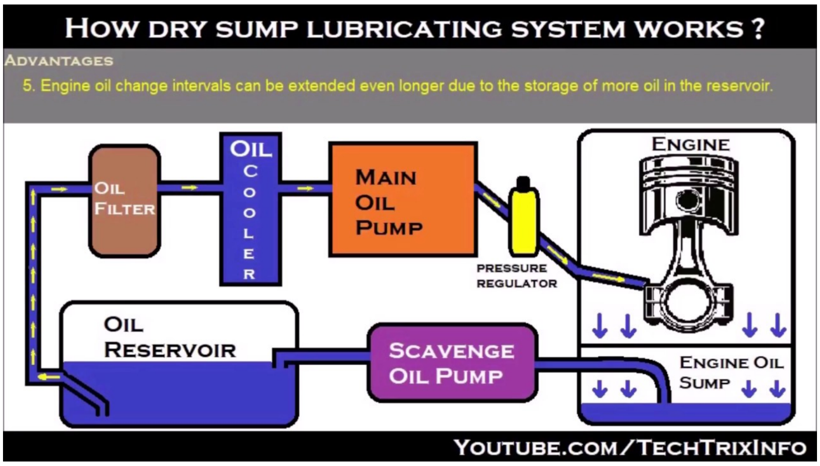
Splash & pressure lubrication system



Pressure feed system

Dry sump lubrication system

In this system the oil is carried in an external tank. An oil pump draws oil from the supply tank and circulates it under pressure to the various bearings of the engine. Oil dripping from the cylinders and bearings in to the sump is removed by a scavenging pump which in turn the oil is passed through a filter and fed back to the supply tank. The capacity of scavenging pump is always greater than the oil pump. A separate oil cooler provided to remove heat from the oil.


HOW DRY SUMP LUBRICATING SYSTEM WORKS ?

ADVANTAGES

5. Engine oil change intervals can be extended even longer due to the storage of more oil in the reservoir.

Lubricants

Classification of Lubricant

Animal

Vegetable

Mineral

Synthetic

Animal Lubricants

Lubricants with animal origin:

Tallow

Tallow oil

Neat’s foot oil

Sperm oil

Porpoise oil

These are highly stable at normal temperatures . Animal lubricants may not be used for internal combustion because they produce fatty acids.

Vegetable Lubricants

Examples of vegetable lubricants are:

Castor oil

Olive oil

Cottonseed oil

Animal and vegetable oils have a lower coefficient of friction than most mineral oils but they rapidly wear away steel.

Mineral Lubricants

These lubricants are used to a large extent in the lubrication of internal combustion engines There are three classifications of mineral lubricants:

Solid

Semisolid

Fluid

Synthetic Lubricants

Because of the high operating temperatures of engines, it became necessary to develop lubricants which would retain their characteristics at temperatures that cause petroleum lubricants to evaporate and break down .Synthetic lubricants do not break down easily and do not produce coke or other deposits

Lubricating Oil Properties

Gravity

Flash Point

Viscosity

Cloud Point

Pour Point

Carbon-Residue Test

Ash Test

Precipitation Number

Corrosion and Neutralization Number

Oiliness

Extreme-Pressure (Hypoid) Lubricants

Chemical and Physical Stability

TEXT / REFERENCES BOOKS

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UNIT V RECENT TRENDS

UNIT V RECENT TRENDS

Introduction to Modern engine technologies- Lean Burn Engine, Stratified Charge Engine, Surface Ignition Engine-Measurement Techniques. Four Valve and Overhead cam Engines, Electronic Engine Management, Common Rail Direct Injection Diesel Engine, Gasoline Direct Injection Engine, Data Acquisition System –pressure pick up, charge amplifier PC for Combustion and Heat release analysis in Engines.

Homogeneous charge compression ignition Engine

Homogeneous charge compression ignition (HCCI) is a form of internal combustion in which well-mixed fuel and oxidizer (typically air) are compressed to the point of auto-ignition. As in other forms of combustion, this exothermic reaction releases chemical energy into a sensible form that can be transformed in an engine into work and heat.

Operation Methods

A mixture of fuel and air will ignite when the concentration and temperature of reactants is sufficiently high. The concentration and/or temperature can be increased by several different ways:

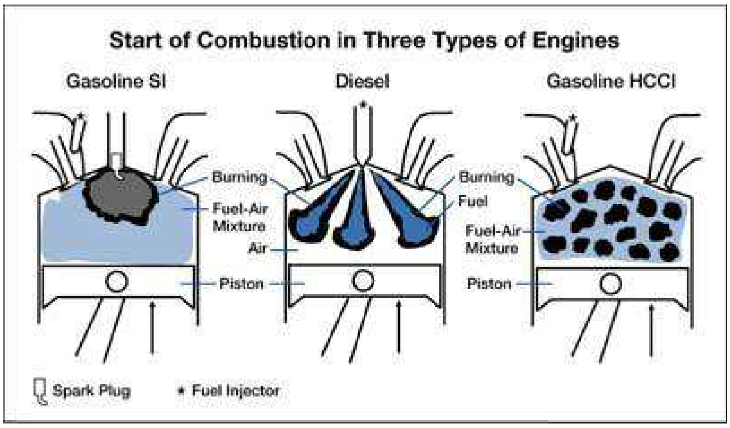
High compression ratio

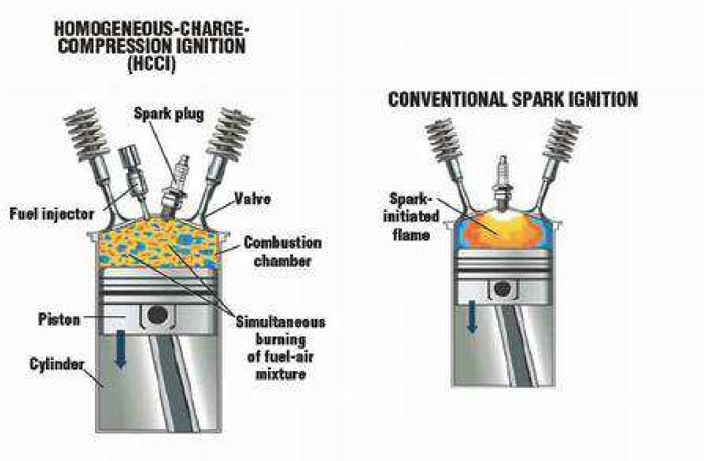
Pre-heating of induction gases

Forced induction

Retained or re-inducted exhaust gases

Once ignited, combustion occurs very quickly. When auto-ignition occurs too early or with too much chemical energy, combustion is too fast and high in-cylinder pressures can destroy an engine. For this reason, HCCI is typically operated at lean overall fuel mixtures. In an HCCI engine (which is based on the four-stroke Otto cycle), fuel delivery control is of paramount importance in controlling the combustion process. On the intake stroke, fuel is injected into each cylinder's combustion chamber via fuel injectors mounted directly in the cylinder head. This is achieved independently from air induction which takes place through the intake plenum. By the end of the intake stroke, fuel and air have been fully introduced and mixed in the cylinder's combustion chamber.





As the piston begins to move back up during the compression stroke, heat begins to build in the combustion chamber. When the piston reaches the end of this stroke, sufficient heat has accumulated to cause the fuel/air mixture to spontaneously combust (no spark is necessary) and force the piston down for the power stroke. Unlike conventional spark engines (and even diesels), the combustion process is a lean, low temperature and flameless release of energy across the entire combustion chamber. The entire fuel mixture is burned simultaneously producing equivalent power, but using much less fuel and releasing far fewer emissions in the process.

At the end of the power stroke, the piston reverses direction again and initiates the exhaust stroke, but before all of the exhaust gases can be evacuated, the exhaust valves close early, trapping some of the latent combustion heat. This heat is preserved, and a small quantity of fuel is injected into the combustion chamber for a pre-charge (to help control combustion temperatures and emissions) before the next intake stroke begins.

Advantages

HCCI provides up to a 30-percent fuel savings, while meeting current emissions standards.

Since HCCI engines are fuel-lean, they can operate at a Diesel-like compression ratios (>15), thus achieving higher efficiencies than conventional spark-ignited gasoline engines.

Homogeneous mixing of fuel and air leads to cleaner combustion and lower emissions. Actually, because peak temperatures are significantly lower than in typical spark ignited engines, NOx levels are almost negligible. Additionally, the premixed lean mixture does not produce soot.

HCCI engines can operate on gasoline, diesel fuel, and most alternative fuels.

In regards to gasoline engines, the omission of throttle losses improves HCCI efficiency.

Disadvantages

High in-cylinder peak pressures may cause damage to the engine.

High heat release and pressure rise rates contribute to engine wear.

The auto ignition event is difficult to control, unlike the ignition event in spark ignition (SI) and diesel engines which are controlled by spark plugs and in-cylinder fuel injectors, respectively.

HCCI engines have a small power range, constrained at low loads by lean flammability limits and high loads by in-cylinder pressure restrictions.

Carbon monoxide (CO) and hydrocarbon (HC) pre-catalyst emissions are higher than a typical spark ignition engine, caused by incomplete oxidation (due to the rapid combustion event and low in-cylinder temperatures) and trapped crevice gases, respectively.

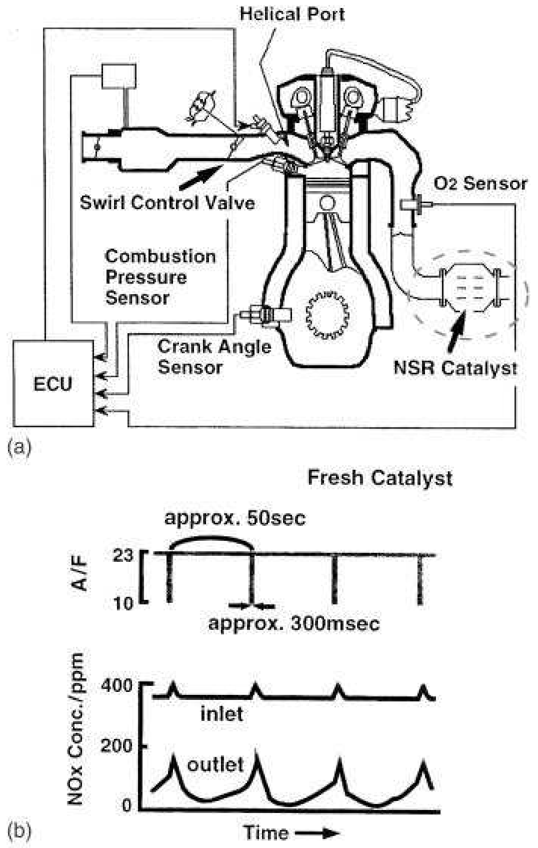
Lean Burn Engine

Lean-burn means pretty much what it says. It is a lean amount of fuel supplied to and burned in an engine's combustion chamber. Normal air-to-fuel ratio is on the order of 15:1 (15 parts air to 1 part fuel). True lean-burn can go as high as 23:1. Lean-burn engines (both gasoline and diesel) enjoy higher fuel economy and cleaner emissions than conventionally tuned engines. By nature they use less fuel and emit fewer unburned hydrocarbons and greenhouse gases while producing equivalent power of a like-sized "normal" combustion engine. They achieve lean burn status by employing higher combustion chamber compression ratios (higher cylinder pressure), significant air intake swirl and precise lean-metered direct fuel injection.

Working Principle:

A lean burn mode is a way to reduce throttling losses. An engine in a typical vehicle is sized for providing the power desired for acceleration, but must operate well below that point in normal steady-speed operation. Ordinarily, the power is cut by partially closing a throttle. However, the extra work done in pumping air through the throttle reduces efficiency. If the fuel/air ratio is reduced, then lower power can be achieved with the throttle closer to fully open, and the efficiency during normal driving (below the maximum torque capability of the engine) can be higher.

The engines designed for lean burning can employ higher compression ratios and thus provide better performance, efficient fuel use and low exhaust hydrocarbon emissions than those found in conventional petrol engines. Ultra lean mixtures with very high air-fuel ratios can only be achieved by direct injection engines. The main drawback of lean burning is that a complex catalytic converter system is required to reduce NOx emissions. Lean burn engines do not work well with modern 3-way catalytic converter which requires a pollutant balance at the exhaust port so they can carry out oxidation and reduction reactions so most modern engines run at or near the stoichiometric point. Alternatively, ultra-lean ratios can reduce NOx emissions.



Advantages of lean burn engine

Higher fuel economy

Emit fewer unburned hydrocarbons and greenhouse gases

A lean burn mode is a way to reduce throttling losses

Disadvantages of lean burn engine

Lean burning is that a complex catalytic converter system is required to reduce NOx emissions.

High relatively cost

Stratified charge engine

An internal-combustion engine with a divided ignition cylinder that is used for the ignition of rich fuel in a small chamber near the spark plug to improve the combustion of a very lean mixture throughout the rest of the cylinder. The stratified charge engine is a type of internal-combustion engine which runs on gasoline. It is very much similar to the Diesel cycle. The name refers to the layering of the charge inside the cylinder. The stratified charge engine is designed to reduce the emissions from the engine cylinder without the use of exhaust gas recirculation systems, which is also known as the EGR or catalytic converters.

Stratified charge combustion engines utilize a method of distributing fuel that successively builds layers of fuel in the combustion chamber. The initial charge of fuel is directly injected into a small concentrated area of the combustion chamber where it ignites quickly.

Principle:-

The principle of the stratified charge engine is to deliver a mixture that is sufficiently rich for combustion in the immediate vicinity of the spark plug and in the remainder of the cylinder, a very lean mixture that is so low in fuel that it could not be used in a traditional engine. On an engine with stratified charge, the delivered power is no longer controlled by the quantity of admitted air, but by the quantity of petrol injected, as with a diesel engine.

Working:

One approach consists in dividing the combustion chamber so as to create a pre-combustion chamber where the spark plug is located. The head of the piston is also modified.

It contains a spheroid cavity that imparts a swirling movement to the air contained by the cylinder during compression. As a result, during injection, the fuel is only sprayed in the vicinity of the spark plug. But other strategies are possible.

For example, it is also possible to exploit the shape of the admission circuit and use artifices, like swirl or tumble stages that create turbulent flows at their level. All the subtlety of engine operation in stratified mode occurs at level of injection.

This comprises two principal modes: a lean mode, which corresponds to operation at very low engine load, therefore when there is less call on it, and a ,normal mode, when it runs at full charge and delivers maximum power.

In the first mode, injection takes place at the end of the compression stroke. Because of the swirl effect that the piston cavity creates, the fuel sprayed by the injector is confined near the spark plug. As there is very high pressure in the cylinder at this moment, the injector spray is also quite concentrated.

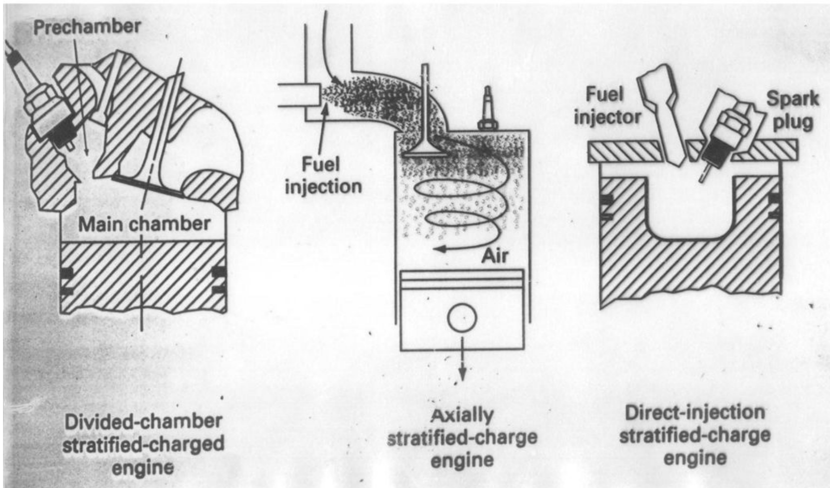
The directivity of the spray encourages even greater concentration of the mixture.

A very small quantity of fuel is thus enough to obtain optimum mixture richness in the zone close to the spark plug, whereas the remainder of the cylinder contains only very lean mixture.

The stratification of air in the cylinder means that even with partial charge it is also possible to obtain a core of mixture surrounded by layers of air and residual gases which limit the transfer of heat to the cylinder walls. This drop in temperature causes the quantity of air in the cylinder to increase by reducing its dilation, delivering the engine additional power. When idling, this process makes it possible to reduce consumption by almost 40% compared to a traditional engine. And this is not the only gain.

Functioning with stratified charge also makes it possible to lower the temperature at which the fuel is sprayed. All this leads to a reduction in fuel consumption which is of course reflected by a reduction of engine exhaust emissions. When engine power is required, injection takes place in normal mode, during the admission phase. This makes it possible to achieve a homogeneous mix, as it is the case with traditional injection. Here, contrary to the previous example, when the injection takes place, the pressure in the cylinder is still low. The spray of fuel from the injector is therefore highly divergent, which encourages a homogeneous mix to form.

Charge Stratification



IGURE 7.20
ypes of spark-ignited-stratified charge engines [Amann, by courtesy of General Motors Corp.]

Advantages of Stratified Charge Engine

Compact, lightweight design &good fuel economy.

Good part load efficiency.

Exhibit multi fuel capability.

The rich mixture near spark-plug &lean mixture near the piston surface provides Cushing to the exploit combustion.

Resist the knocking & provides smooth resulting in smooth & quite engine operation over the entire speed & load range.

Low level of exhaust emissions, Nox is reduced considerably.

Usually no starting problem.

Can be manufactured by the existing technology.

Disadvantages

For a given engine size, charge stratification results in reduced efficiency

These engines create high noise level at low load conditions.

More complex design to supply rich & lean mixture & quantity is varied with load on the engine.

Higher weight than of a conventional engine.

Unthrottledstratified charge emits high percentage of HC due to either incomplete combustion of lean charge or occasional misfire of the charge at low load conditions.

Reliability is yet to be well established.

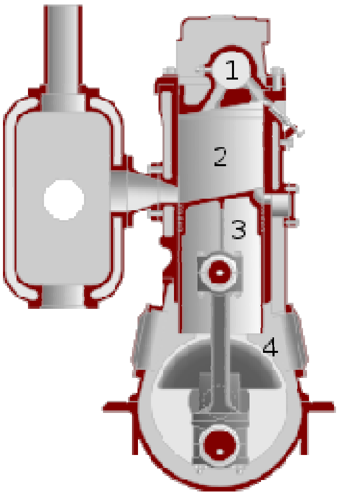
Higher manufacturing cost.

Surface ignition engine (Hot bulb engine)

The initiation of a flame in the combustion chamber of an automobile engine by any hot surface other than the spark discharge. The hot bulb engine, or hot bulb or heavy oil engine is a type of internal combustion engine. It is an engine in which fuel is ignited by being brought into contact with a red-hot metal surface inside a bulb followed by the introduction of air (oxygen) compressed into the hot bulb chamber by the rising piston. There is some ignition when the fuel is introduced but it quickly uses up the available oxygen in the bulb. Vigorous ignition takes place only when sufficient oxygen is supplied to the hot bulb chamber on the compression stroke of the engine. Most hot bulb engines were produced as one-cylinder low-speed two-stroke crankcase scavenging units.

Operation and working cycle

The hot-bulb engine shares its basic layout with nearly all other internal combustion engines, in that it has a piston, inside a cylinder, connected to a connecting rod and crankshaft. The flow of gases through the engine is controlled by valves in four-stroke engines, and by the piston covering and uncovering ports in the cylinder wall in two-strokes. The type of blow-lamp used to start the Hot Bulb engine.



Hot-bulb engine (two-stroke). 1. Hot bulb. 2. Cylinder. 3. Piston. 4. Crankcase

In the hot-bulb engine combustion takes place in a separated combustion chamber, the "vaporizer" (also called the "hot bulb"), usually mounted on the cylinder head, into which fuel is sprayed. It is connected to the cylinder by a narrow passage and is heated by the combustion while running; an external flame such as a blow-lamp or slow-burning wick is used for starting (on later models sometimes electric heating or pyrotechnics was used). Another method is the inclusion of a spark plug and vibrator coil ignition.[citation needed] The engine could be started on petrol and switched over to oil after it had warmed to running temperature. The pre-heating time depends on the engine design, the type of heating used and the ambient temperature, but generally ranges from 2”5 minutes (for most engines in a temperate climate) to as much as half an hour (if operating in extreme cold or the engine is especially large). The engine is then turned over, usually by hand but sometimes by compressed air or an electric motor. Once the engine is running, the heat of compression and ignition maintains the hot-bulb at the necessary temperature and the blow-lamp or other heat source can be removed. From this point the engine requires no external heat and requires only a supply of air, fuel oil and lubricating oil to run. However, under low power the bulb could cool off too much, and a throttle can cut down the cold fresh air supply. Also, as the engine's load increased, so does the temperature of the bulb, causing the ignition period to advance; to counteract pre-ignition, water is dripped into the air intake. Equally, if the load on the engine is low, combustion temperatures may not be sufficient to maintain the temperature of the hot-bulb.Many hot-bulb engines cannot be run off-load without auxiliary heating for this reason.

Four Valve and Overhead cam Engines

Four Valve Engine:

A multi-valve design typically has three, four, or five valves per cylinder to achieve improved performance. Any four-stroke internal combustion engine needs at least two valves per cylinder: one for intake of air and fuel, and another for exhaust of combustion gases. Adding more valves increases valve area and improves the flow of intake and exhaust gases, thereby enhancing combustion, volumetric efficiency, and power output. Multi-valve geometry allows the spark plug to be ideally located within the combustion chamber for optimal flame propagation. Multi-valve engines tend to have smaller valves that have lower reciprocating mass, which can reduce wear on each cam lobe, and allow more power from higher RPM without the danger of valve bounce.

Four-valve cylinder head

This is the most common type of multi-valve head, with two exhaust valves and two similar (or slightly larger) inlet valves. This design allows similar breathing as compared to a three-valve head, and as the small exhaust valves allow high RPM, this design is very suitable for high power outputs.

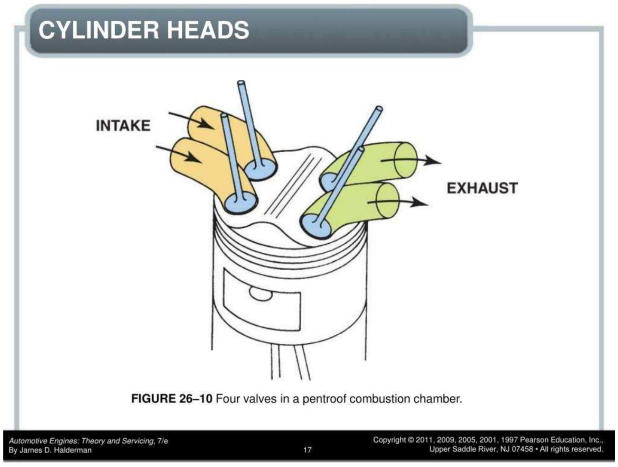

CYLINDER HEADS

FIGURE 26–10 Four valves in a pentroof combustion chamber.

Automotive Engines: Theory and Servicing, 7/e
By James D. Halderman

17

Overhead camshaft Engine

Overhead camshaft, commonly abbreviated to OHC. avalve train configuration which places the camshaft of an internal combustion engine of the reciprocating type within the cylinder heads ('above' the pistons and combustion chambers) and drives the valves or lifters in a more direct manner compared to overhead valves (OHV) and pushrods

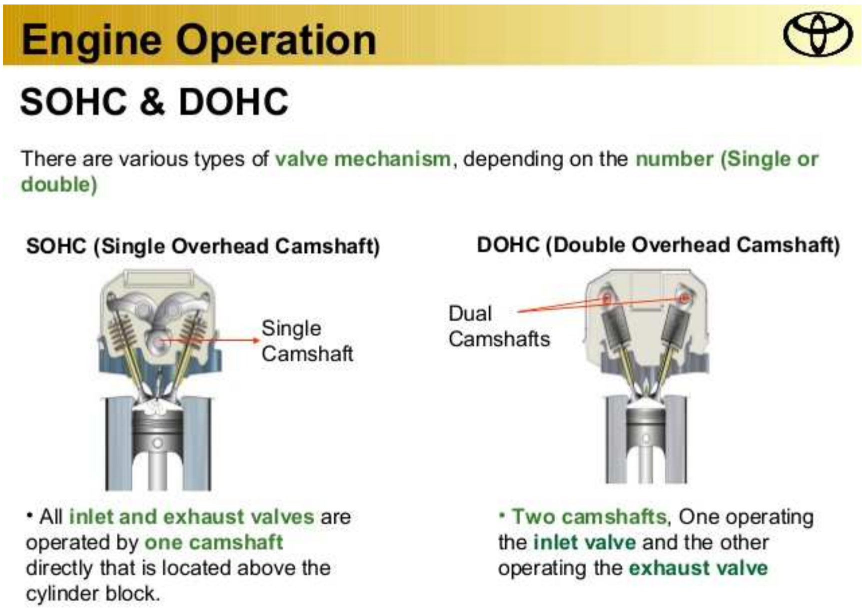
Types of OHC

Single overhead camshaft (SOHC)

Double overhead camshaft (DOHC)

Single overhead camshaft

Single overhead camshaft (SOHC) is a design in which one camshaft is placedwithin the cylinder head. In an inline engine, this means there is one camshaft inthe head, whilst in an engine with more than one cylinder head, such as a Vengine or a horizontally-opposed engine (boxer; flat engine) „ there are twocamshafts: one per cylinder bank.



Engine Operation

SOHC & DOHC

There are various types of **valve mechanism**, depending on the **number (Single or double)**

SOHC (Single Overhead Camshaft)

- All **inlet and exhaust valves** are operated by **one camshaft** directly that is located above the cylinder block.

DOHC (Double Overhead Camshaft)

- **Two camshafts**, One operating the **inlet valve** and the other operating the **exhaust valve**

Double overhead camshaft

A double overhead camshaft(DOHC) valve train layout (also known as 'dual overhead camshaft') is characterised by two camshafts located within the cylinder head, one operating the intake valves and one operating the exhaust valves. This design reduces valve train inertia more than a SOHC engine, since the rocker arms are reduced in size or eliminated.

A DOHC design permits a wider angle between intake and exhaust valves than SOHC engines. This can allow for a less restricted airflow at higher engine speeds. DOHC with a multivalve design also allows for the optimum placement of the spark plug, which in turn, improves combustion efficiency.

Electronic Engine Management

An engine control unit (ECU), most commonly called the powertrain control module (PCM), is a type of electronic control unit that controls a series of actuators on an internal combustion engine to ensure the optimum running. It does this by reading values from a multitude of sensors within the engine bay, interpreting the data using multidimensional performance maps (called Look-up tables), and adjusting the engine actuators accordingly.

Engine management

Sensors

Oxygen sensor

The oxygen sensor provides information about the fuel mixture. The PCM uses this to constantly re-adjust and fine tune the air/fuel ratio. This keeps emissions and fuel consumption to a minimum. A bad O2 sensor will typically make an engine run rich, use more fuel and pollute. O2 sensors deteriorate with age and may be contaminated if the engine burns oil or develops a coolant leak.

Coolant sensor

The coolant sensor monitors engine temperature. The PCM uses this information to regulate a wide variety of ignition, fuel and emission control functions. When the engine is cold, for example, the fuel mixture needs to be richer to improve drivability. Once the engine reaches a certain temperature, the PCM starts using the signal from the O2 sensor to vary the fuel mixture. This is called "closed loop" operation, and it is necessary to keep emissions to a minimum.

Throttle position sensor (TPS)

The throttle position sensor (TPS) keeps the PCM informed about throttle position. The PCM uses this input to change spark timing and the fuel mixture as engineload changes. A problem here can cause a flat spot during acceleration (like a bad accelerator pump in a carburetor) as well as other drivability complaints.

Airflow Sensor

The Airflow Sensor, of which there are several types, tells the PCM how much air the engine is drawing in as it runs. The PCM uses this to further vary the fuel mixture as needed. There are several types of airflow sensors including hot wire mass airflow sensors and the older flap-style vane airflow sensors. All are very expensive to replace

Manifold absolute pressure (MAP)

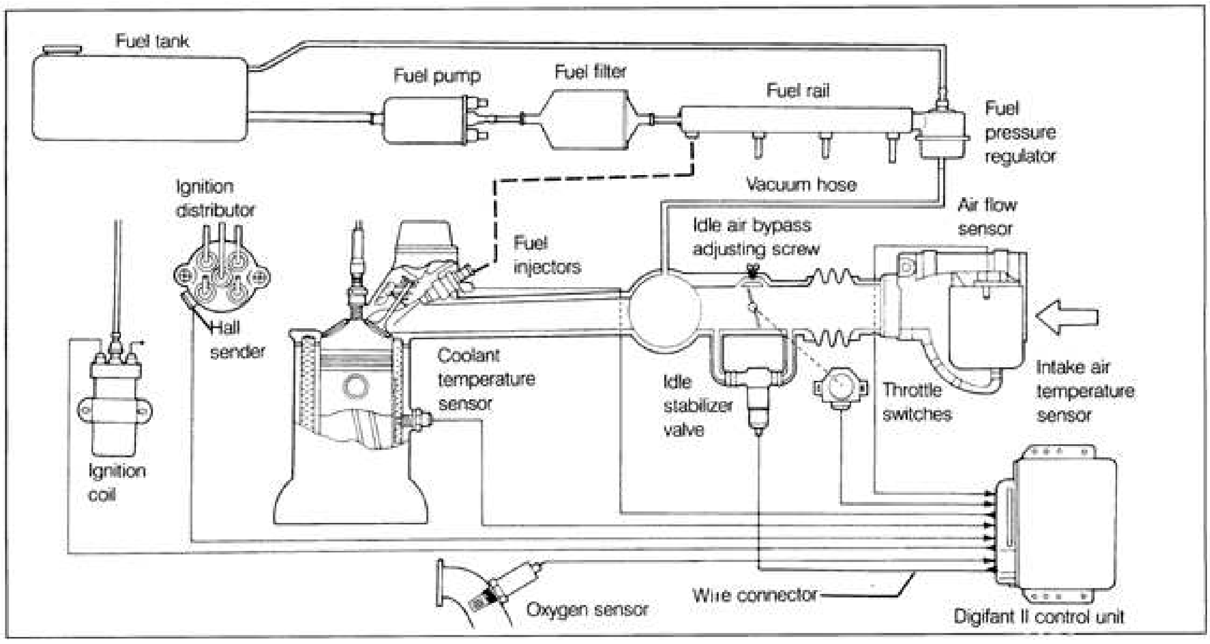
The manifold absolute pressure (MAP) sensor measures intake vacuum, which the PCM also uses to determine engine load. The MAP sensor's input affects ignition timing primarily, but also fuel delivery.

Knock sensors

Knock sensors are used to detect vibrations produced by detonation. When the PCM receives a signal from the knock sensor, it momentarily retards timing whilethe engine is under load to protect the engine against spark knock.

EGR position sensor

The EGR position sensor tells the PCM when the exhaust gas recirculation (EGR) valve opens (and how much). This allows the PCM to detect problems with the EGR system that would increase pollution.



Vehicle speed sensor (VSS)

The vehicle speed sensor (VSS) keeps the PCM informed about how fast the vehicle is traveling. This is needed to control other functions such as torque converter lockup. The VSS signal is also used by other control modules, including the antilock brake system (ABS).

Crankshaft position sensor

The crankshaft position sensor serves the same function as the pickup assembly in an engine with a distributor. It does two things: It monitors engine rpm and helps the computer determine relative position of the crankshaft so the PCM can control spark timing and fuel delivery in the proper sequence. The PCM also uses thecrank sensor's input to regulate idle speed, which it does by sending a signal to an idle speed control motor or idle air bypass motor. On some engines, an additional camshaft position sensor is used to provide additional input to the PCM about valve timing.

GASOLINE INJECTION SYSTEM

A modern gasoline injection system uses pressurefrom an electric fuel pump to spray fuel into the engineintake manifold. Like a carburetor, it must provide theengine with the correct air-fuel mixture for specificoperating conditions. Unlike a carburetor, however ,PRESSURE, not engine vacuum, is used to feed fuelinto the engine .This makes the gasoline injectionsystem very efficient.

A gasoline injection system has several possible advantages over a carburetor type of fuel system. Some advantages are as follows:

* Improved atomization. Fuel is forced into the intake manifold under pressure that helps break fuel droplets into a fine mist.

* Better fuel distribution. Equal flow of fuel vapors into each cylinder.

* Smoother idle. Lean fuel mixture can be used without rough idle because of better fuel distribution and low-speed atomization.

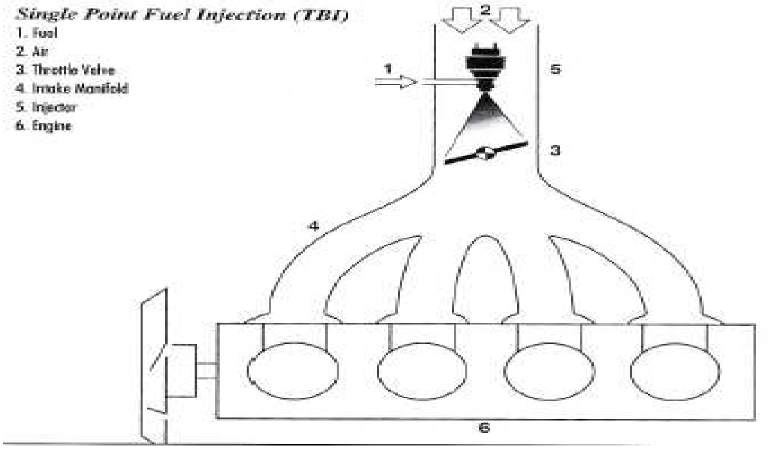
There are many types of gasoline injection systems. Before studying the most common ones, we should have a basic knowledge of the different classifications

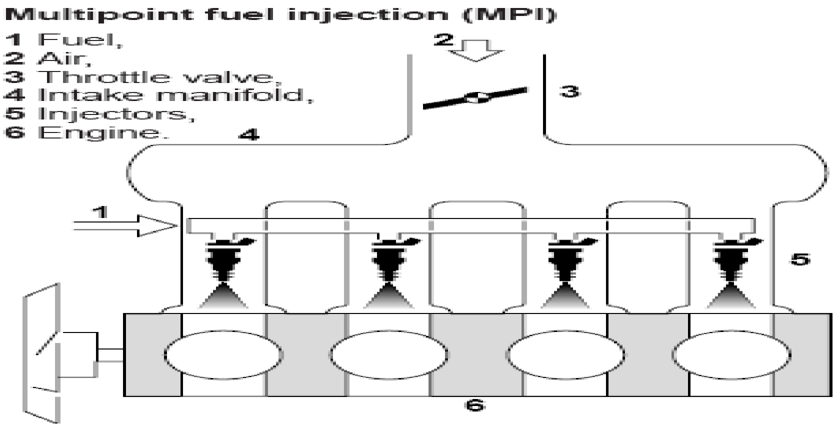
Single or multi-point injection

Indirect or direct injection

The point or location of fuel injection is one way to classify a gasoline injection system. A single-point injection system, also call throttle body injection (TBI), has the injector nozzles in a throttle body assembly on top of the engine. Fuel is sprayed into the top center of the intake manifold.

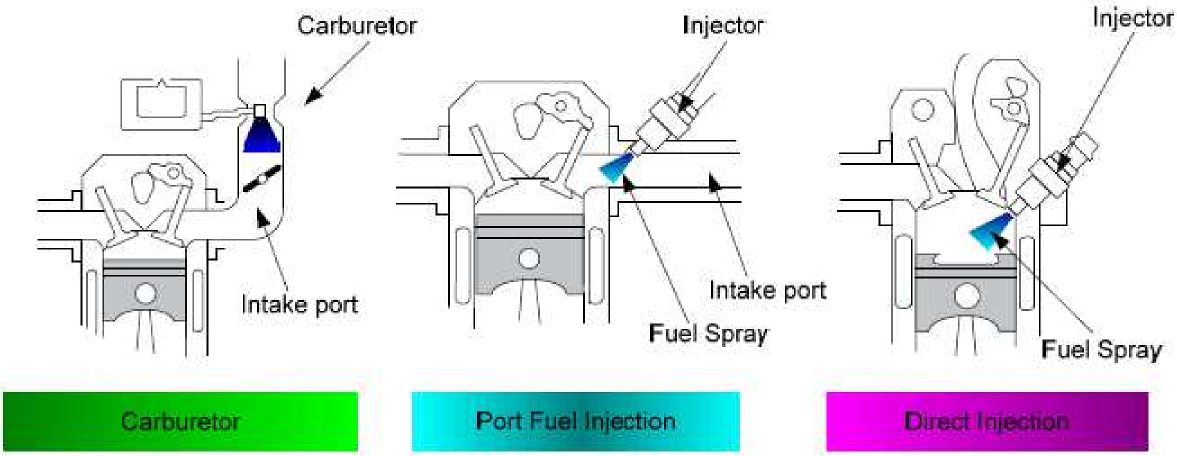
A multi-point injection system, also called port injection, has an injector in the port (air-fuel passage) going to each cylinder. Gasoline is sprayed into each intake port and toward each intake valve. Thereby, the term multipoint (more than one location) fuel injection is used.





An indirect injection system sprays fuel into the engine intake manifold or inlet port. Most gasoline injection systems are of this type.

Direct injection forces fuel into the engine combustion chambers. Diesel injection systems are direct type.



ELECTRONICLLY CONTROLLED GASOLINE INJECTION SYSTEM

Description

The Bosch D-Jetronic electronic fuel injection system is composed of 3 major subsystems: the air intake system, the fuel system, and the electronic control system. The D-Jetronic system uses constant fuel pressure and flow, so that only injection duration needs to be modified to control air/fuel mixture. The D-Jetronic system measures incoming airflow by monitoring intake manifold pressure. Engine speed, temperature, and other factors are monitored for the purpose of fine-tuning injection duration. An auxiliary air valve, cold start injector and thermo time switch aid in cold starting and operation.

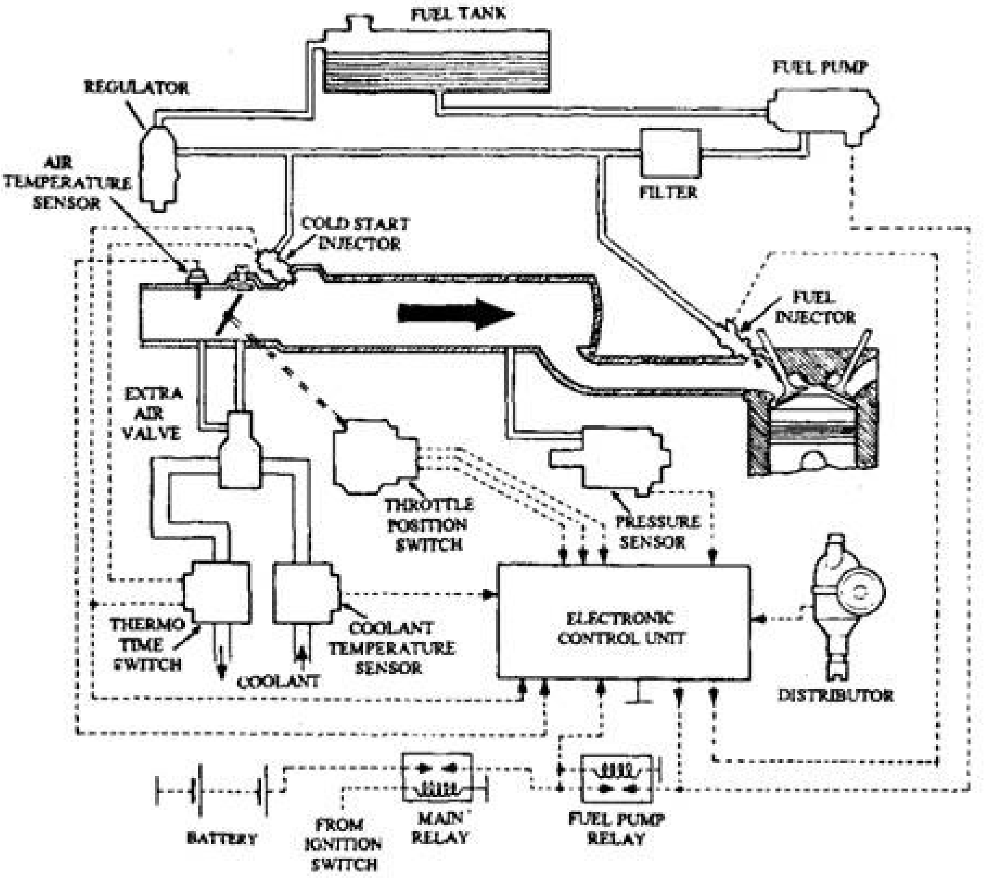
Operation

Fuel system

An electrically driven fuel pump forces fuel through a filter, into the main system. Main system consists of one injector for each cylinder, a cold start injector and a pressure regulator, which maintains fuel pressure at 28 psi (2.0 kg/cm2). A secondary system carries excess fuel from the pressure regulator back to fuel tank.

Air system

Intake manifold, connected to an intake air distributor, supplies the cylinders with air. A pressure sensor is connected to intake air distributor. The pressure sensor operates according to difference in manifold pressure and atmospheric pressure and signals control unit accordingly. A throttle valve, operated by accelerator pedal, is located at the mouth of the intake air distributor. The throttle valve and intake air distributor are connected to air cleaner by an air duct elbow. The idling air system is in the form of a by-pass system located between the air filter and air intake distributor. Its size can be varied with an idling air adjusting screw. An auxiliary air line, from air cleaner (auxiliary air valve), to intake air distributor forms the warming-up air system. Its volume is varied, depending on engine temperature, by the auxiliary air valve.



BOSCH D-JETRONIC ELECTRONIC FUEL INJECTION SYSTEM

Electronic control system

Electronic Control Unit

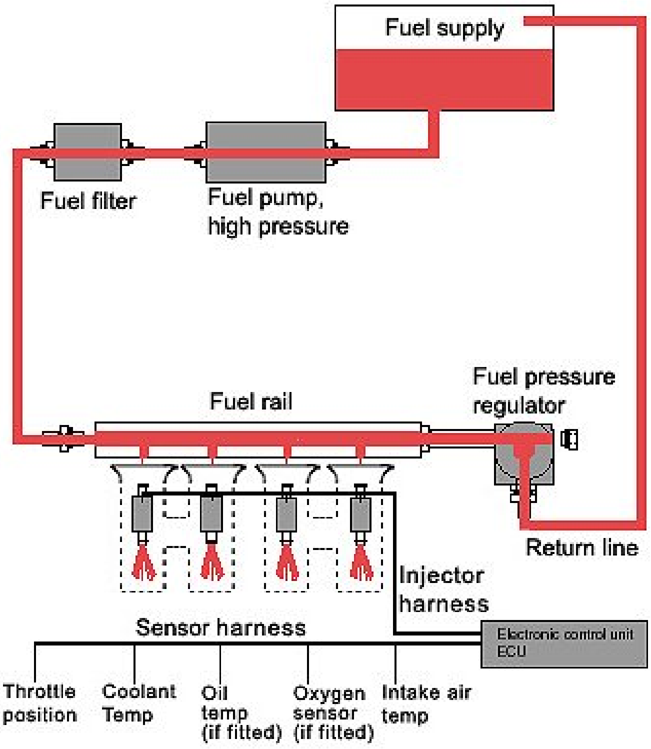
Control unit regulates the correct amount of fuel to be injected, depending on engine speed, intake pressure and engine temperature. When ignition is switched on, control unit receives its operating voltage directly from battery, via voltage supply relay. It also controls the fuel pump, which normally is provided with current from pump relay, only with engine running. A time switch, in control unit, allows fuel pump to run approximately 1 to 1.5 seconds after ignition is turned on. The control unit is connected to all sender units by a special wiring harness, coupled to a multiple plug. The control unit is usually located inside vehicle under the dash, under one of the seats or in the trunk.

Pressure Sensor

The pressure sensor is located in the engine compartment and is connected to the intake manifold by a vacuum hose. This sensor controls the basic amount of fuel to be injected, depending on pressure in the intake manifold and load on the engine

Air Intake Temperature Sensor

The air temperature sensor provides control unit with information about air temperature, so that control unit can increase the injection quantity as necessary at low intake air temperature. This compensation ceases when intake air temperature is greater than 68F (2O^{0}C).



SIMPLE LAYOUT OF ELECTRONIC FUEL INJECTION SYSTEM

Engine Temperature Sensor

The engine temperature sensor provides the control unit with information about coolant temperature (cylinder head temperature on VW). This enables control unit to adapt injection interval and determine how long the cold start injector should remain open during cold starting.

Triggering Contacts

The triggering contacts are located in the distributor. They provide signals which determine when and to which cylinder fuel is to be injected. The contacts also supply information concerning engine speed to determine the amount of fuel that needs to be injected into the engine.

Throttle Valve Switch

The throttle valve switch is mounted on the throttle housing. This switch signals the control unit of throttle position. During deceleration, above 1500 RPM, throttle switch cuts fuel supply off and below 900 RPM, fuel supply is turned on.

Auxiliary Air Valve

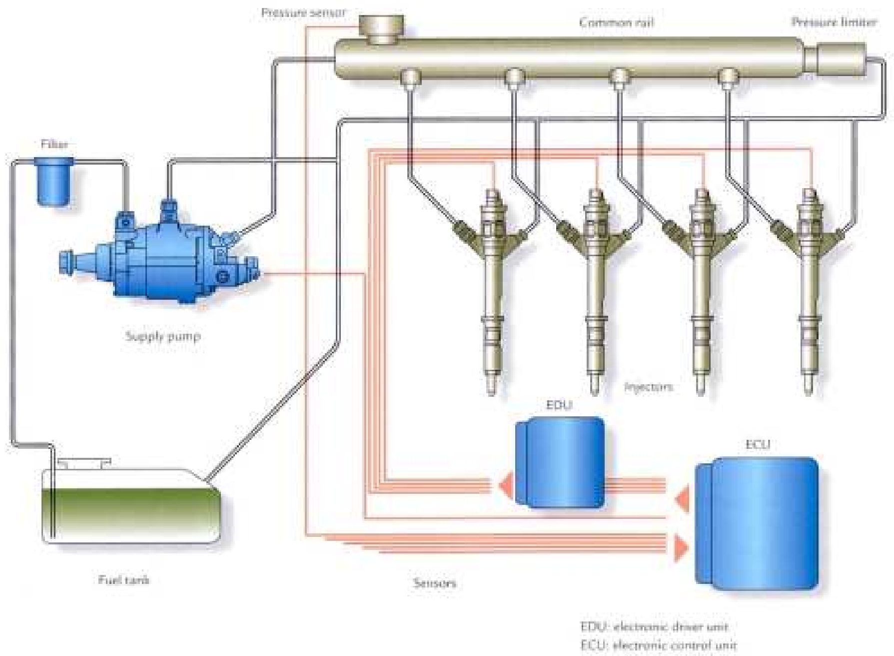
During cold starts, the auxiliary air valve opens to allow additional air into the inlet duct. As engine heats up, a bi-metallic element expands and closes valve. At approximately 140F (80^0C) the auxiliary air pipe is completely closed by the valve.

COMMON RAIL TYPE FUEL INJECTION

ELECTRONIC CONTROL

Increasingly stringent emission regulations will be impossible to meet with conventional diesel systems. With their greater accuracy and reduced emissions, Common rail injection systems will be instrumental in engineering diesel engines that will comply with future emission regulations.

Injection parameters are very important for diesel power. Injection pressure is much higher, with multiple, precisely controlled injections at each combustion stroke. With common rail technology, the quantity, timing and pressure of injections are controllable separately. This allows for more precise fine-tuning of engine performance than with petrol systems. The common rail type system is completely different than conventional fuel injection pumps. With previous pumps, fuel is distributed from the high pressure pipe to each cylinder. With this system, high pressure fuel is accumulated at a common rail. This eliminates the need for fuels force-feed system based on the number of cylinders. The supply pump draws the fuel up from the tank for force-feeding to the common rail, until the required common rail pressure is reached. An injector mounted on each cylinder then distributes the high-pressure fuel to each injector via the common rail. The ECU controls fuel delivery timing and amount. EDU (Electronic Driving Unit) CDI type high voltage driver. It is used for high speed driving of the electromagnetic spill valve that works under high pressure. The EDU allows precise control of the injection timing of highly pressurised and finely atomised fuel which decreases emissions.



ELECTRONICALLY CONTROLLED COMMON RAIL TYPE FUEL INJECTION

Data Acquisition System

The requirements of a combustion data acquisition system are to record cylinder pressure data and align it to cylinder volume data. This is achieved by using a triggered acquisition, (acquisition does not begin until TDC is reached), and sampling using an external clock, (one acquisition per clock pulse). In addition tocylinder pressure data other parameters may be measured including:

Inlet or exhaust manifold pressure

Spark current

Injector needle lift

Fuel pressure

Engine angular velocity

Acceleration of engine components

ADC Resolution

The analogue to digital converter (ADC) resolution determines the minimum amount of pressure change that can be recorded

$$\Delta p = \frac{\Delta P}{2^r}$$

Where ΔP is the total pressure range (typically 100 bars) and r is the bit resolution of the ADC.

Triggering

In order to phase the measured data with the cylinder volume it is necessary to accurately determine at what point in the engine's thermodynamic cycle the data acquisition started. A common method is to begin the acquisition when the crank is a TDC. This has the disadvantage that the recorded data may begin at either compression TDC or exhaust TDC. A simple check can be used to correct this by comparing data acquired at zero and 360 degrees.

External Clock

Engine rotational velocity will always vary with time due to cycle-to-cycle variability in combustion timing and strength. It is therefore not possible to acquire data with a clock frequency dependent on engine speed and still accurately align measured data with the corresponding cylinder volume. Hence an external clock is used. This provides a Phase Locked Loop (PLL) signal that indicates when a certain amount of engine rotation has occurred.

Pressure Transducers

Piezoelectric pressure transducers are the most commonly used form of pressure transducer for the purpose of acquiring in-cylinder pressure data. They howeverhave several disadvantages, these include sensitivity to thermal shock, long and short-term drift, sensitivity to temperature and that the output has to be referenced to an absolute pressure.

Charge Amplifiers

Charge amplifier range and time constants should be set to give the longest system time with minimal signal drift. The time constant of a piezoelectric system is a measure of the time for a given signal to decay, not the time it takes the system to respond to an input. It is important that all connections between the charge amplifier and transducer be degreased with contact cleaner. This is because low insulation resistance in the transducer or cables and connection causes drift of the charge amplifier output. Charge amplifier is allowed to warm up for one hour before measurements are taken.

Pressure pick up

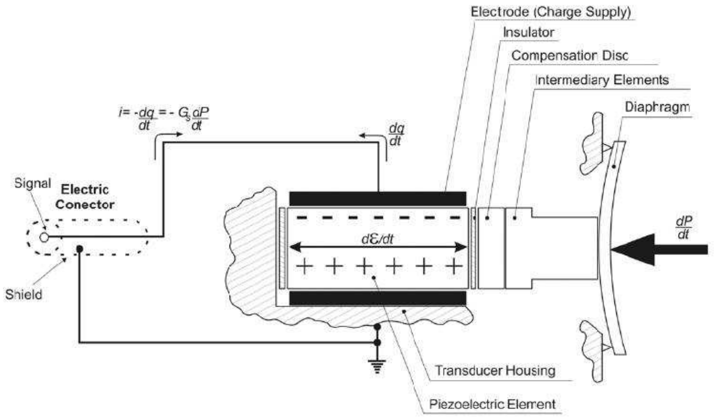
The transducer for in-cylinder pressure measurement

Piezoelectric pressure transducer

The principle of operation of a piezoelectric pressure transducer. The pressure change rate (dP/dt) experienced by the transducer diaphragm is transmitted to a piezoelectric crystal through intermediate elements, causing its deformation at a rate $d\varepsilon/dt$. Due to the piezoelectric effect, this deformation polarizes charge q in the transducer electrode originating an electric current i, which constitutes the transducer output signal:

$$i = -\frac{dq}{dt} = -G_s \frac{dP}{dt}$$

Where Gs is the transducer sensitivity (gain).



During the measurement of in-cylinder pressure, the transducer is exposed to a transient heat flow that causes continuous changes in its temperature. These temperature changes modify the sensitivity of the piezoelectric element and impose thermal stresses in the diaphragm and in the sensor housing, generating spurious forces that act on the quartz element and cause additional distortion of the signal provided by the transducer.

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