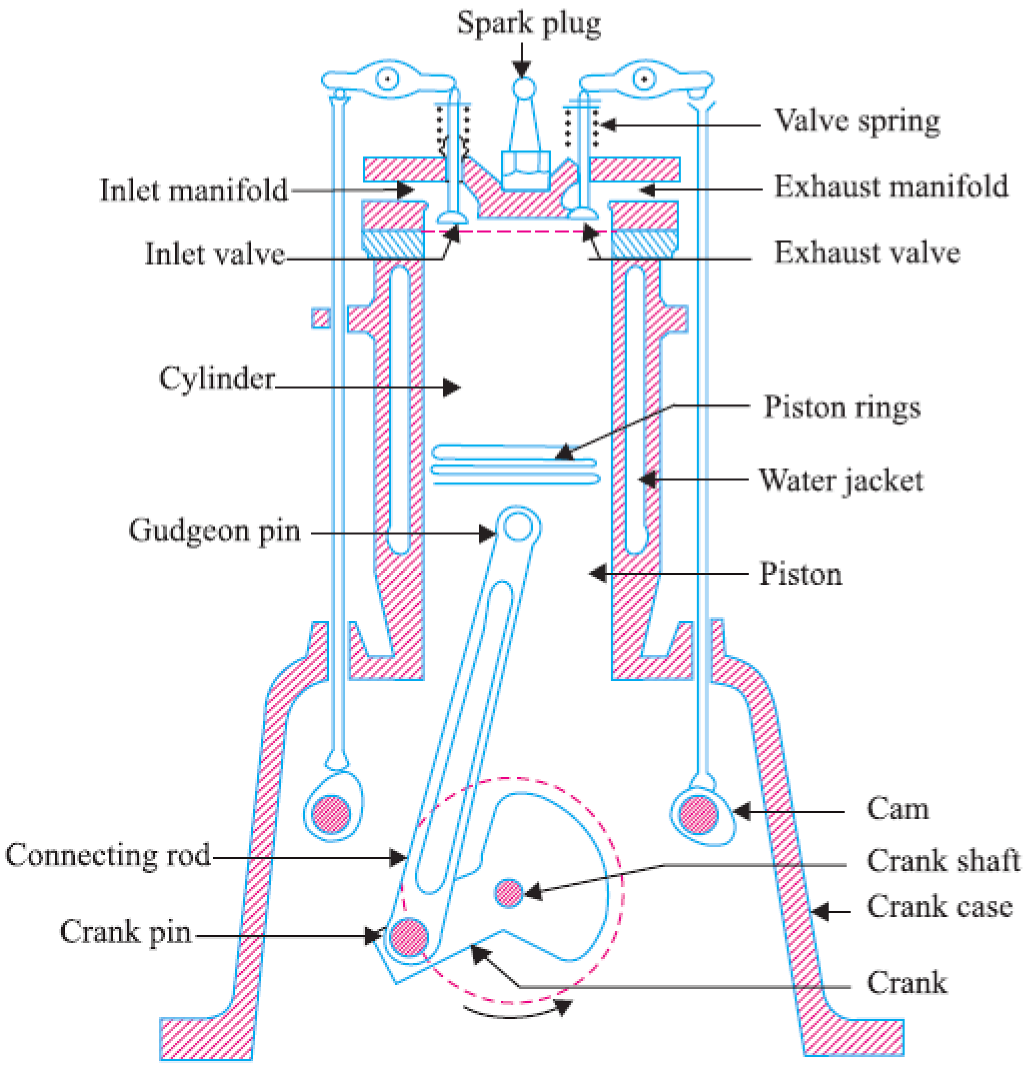
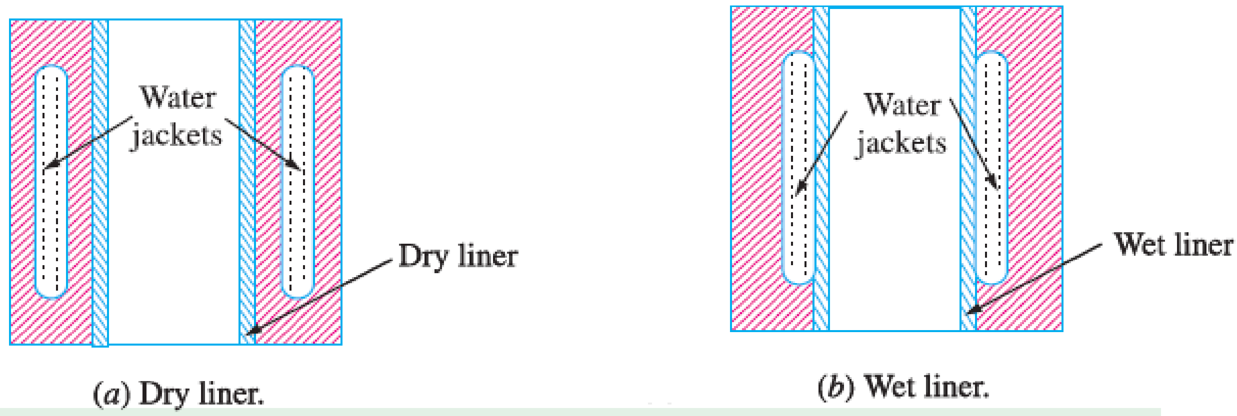
Design of Internal Combustion Engine



Internal combustion engine parts.

The Cylinder and Cylinder liner:-

- The cylinders are usually made of cast iron or cast steel.
- The cylinder liner are in the following two types.



Dry and wet liner.

- ***Design of the cylinder:***
  - ✓ Bore and Length of the cylinder.

    From the power idecated from the cylinder

    $\text{The mechanical efficiency} \Rightarrow \eta_m = \dfrac{BP}{IP}$

    $\text{The Indecated power} \Rightarrow \text{IP} = \text{imep} \times \dfrac{\pi}{4} \times D^2 \times l \times \dfrac{n}{x} \times \dfrac{N}{60} \Rightarrow watt$

    where :

    imep is indecated mean effective pressure in N/mm^2

    D is Cylinder bore in mm

    l is Length of stroke in mm

    N is Speed of the engine in rpm

    n is Numper of engine cylinder

    Note :

    The Length of stroke is generally taken = 1.25D to 2D

    Sothat :

    The Length of Cylinder $\Rightarrow$ L = 1.15l

- ✓ <u>Thickness</u>

The thickness of cylinder is usually obtain from the thin cylindrical formula

$$t = \frac{P_{\max} \times D}{2\sigma_c} + C$$

where:

P_{max} is Maximum pressure inside the cylinder in N/mm^2

its be (9 to 10) imep

D is Cylinder bore in mm

σ_c is Permissible circumferential stress for the cylinder material in N/mm^2.

its value may be taken from 35 MPa to 100 MPa depending on the size and material

C is Allowance for reboring

The allowance for reboring (C) depending on the cylinder bore for internal combustion engine is given from the table.

Allowance for reboring for I. C. engine cylinders.

D (mm)	75	100	150	200	250	300	350	400	450	500
C (mm)	1.5	2.4	4.0	6.3	8.0	9.5	11.0	12.5	12.5	12.5

- ✓ <u>Cylinder head thickness</u>

The cylinder head may be approximately taken as a flat circular plate whose thickness (t_h) may be determine from the following relation:

$$t_h = D \times \sqrt{\frac{C. \times P_{\max}}{\sigma_c}}$$

where:

P_{max} is Maximum pressure inside the cylinder in N/mm^2

D is Cylinder bore in mm

σ_c is Permissible circumferential stress for the cylinder material in N/mm^2.

its value may be taken from 30 MPa to 50 MPa.

C is Constant whose value be = 0.1

- ✓ Cylinder flange and stude
  - ✓ The cylinders are cast integral with the upper half of the crank case or they are attached to the crank case by means of flange with studs or bolts and nuts.
  - ✓ The cylinder flange is integral with the cylinder and should be made thicker than the cylinder wall.
  - ✓ The flange thickness should be taken as 1.2 *t* to 1.4 *t*, where *t* is the cylinder wall thickness.
  - ✓ The diameter of studs or bolts may be obtained by equating the gas load due to the maximum pressure in the cylinder to the resisting force offered by all the studs or bolts, mathematically.

Take the number of studs be (n_s)

$n_s = 0.01\mathrm{D} + 4 \quad \text{and} \quad = 0.02\mathrm{D} + 4$

$$\text{Resistance Force} = n_s \times \frac{\pi}{4} d_s^2 \times \sigma_t = \frac{\pi}{4} \times D^2 \times P_{max}$$

where:

P_{max} is Maximum pressure inside the cylinder in N/mm^2

D is Cylinder bore in mm

σ_t is Tensile stress for the cylinder material in N/mm^2.
its value may be taken from 35 MPa to 70 MPa.

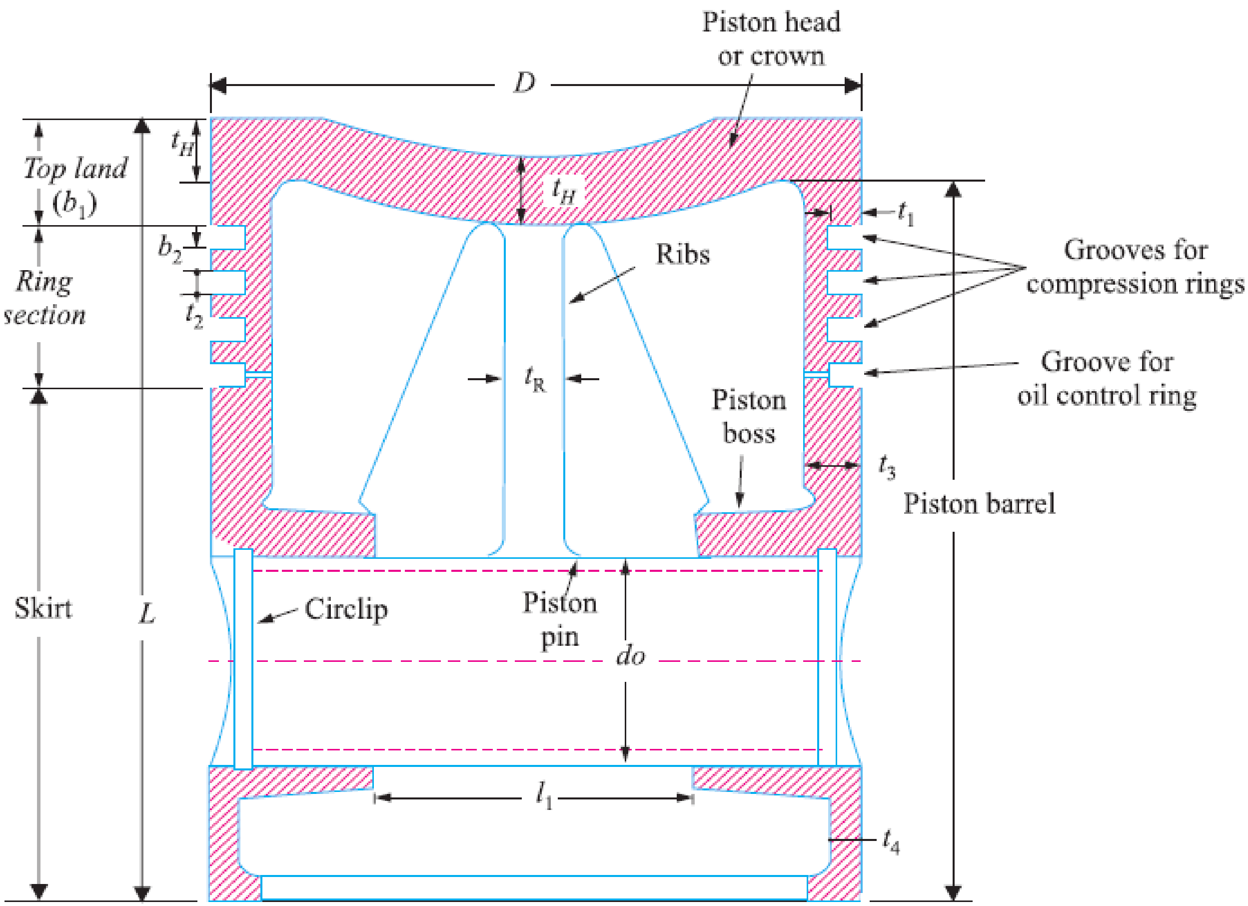
d_s is Core or Minor diameter of stud in mm

The stude diameter (d) be

$d_s = 0.84 \times d$

***Piston*:-**

- The piston is a disc which reciprocates within a cylinder.
- The main function of piston is to receive the impulse from the expanding gas and to transmit the energy to the crankshaft through the connecting rod.



Piston for I.C. engines (Trunk type).

- The most commonly used materials for pistons of IC engine are cast iron, cast aluminium, forged aluminium, cast steel and forged steel.

➢ ***Design of the Piston:***

✓ Piston head or Crown

The piston head or crown is designed keeping in view the following two main considerations, *i.e.*

1. It should have adequate strength to withstand the straining action due to pressure of explosion inside the engine cylinder, and

2. It should dissipate the heat of combustion to the cylinder walls as quickly as possible.

On the basis of first consideration of straining action, the thickness of the piston head is determined by treating it as a flat circular plate of uniform thickness, fixed at the outer edges and subjected to a uniformly distributed load due to the gas pressure over the entire cross-section.

The thickness of piston head (t_H) according to Grashoff's Formula is given

$$\text{Thickness}(t_H) = \sqrt{\frac{3 \times P_{max} \times D^2}{16\sigma_t}}$$

where: σ_t is tensile stress be 35 MPa to 40 MPa for Gray cast Iron and 50 MPa to 90 MPa for Aluminum Alloy or Nickel Cast Iron

Also the thickness of piston head should be quickly transferred heat from combustion of fuel to the cylinder walls. So that piston head as flat circular plate, have thickness by

$$\text{Thickness}(t_H) = \frac{H}{12.56 \times k \times (T_C - T_H)} \quad mm$$

where: H is Heat flow rate by Watt

$H = BP. \times CV. \times m \times C$ Watt

where: *BP.* is Brake Power for cylinder

CV. is calorific value of fuel it be 47000 kJ/kg for petrol fuel and 45000 kJ/kg for diesel fuel

m is mass of fuel its unit kg/kW.s

C is constant be 0.05

k is thermal conductivity it be 46.6 W/mC for Cast iron and 147.75 W/mC for Aluminium

T_C is temperature at center of piston in ^oC

T_E is temperature at the edge of piston in ^oC

From the two equation take the large thickness value.

✓ <u>Piston Rib</u>

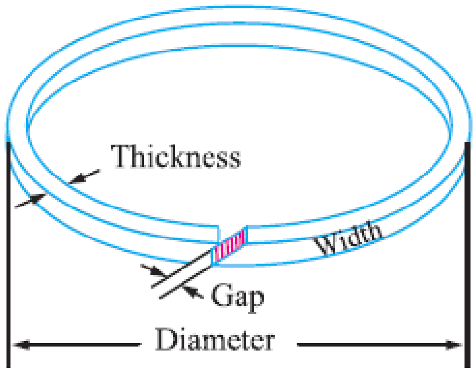
- ✓ The piston rib may be four.

Its thickness (t_R)

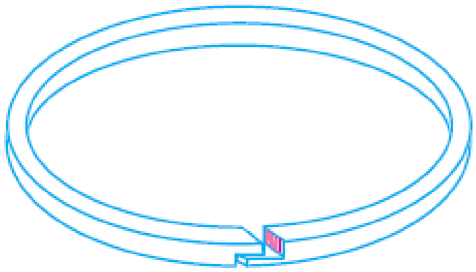
$$\text{Thickness}(t_R) = \frac{t_H}{3} \quad to \quad \frac{t_H}{2}$$

✓ <u>Piston Rings.</u>

- ✓ The piston rings used to impart the necessary radial pressure to maintain the seal between the piston and the cylinder bore
- ✓ The piston rings usually made of grey cast iron or alloy cast iron because of its good wearing properties.
- ✓ The piston rings are of the following types:
  - Compression rings or Pressure rings
  - Oil control rings or oil scraper



(a) Diagonal cut.



(b) Step cut.

The radial thickness of the ring be

$$\text{Radial Thickness}(t_1) = D\sqrt{\frac{3\times P_w}{\sigma_t}}$$

where: P_w is pressure of gas on cylinder wall it be 0.025 to 0.042 N/mm^2

σ_t is tensile stress it be 85 to 110 MPa for Cast Iron

The axial thickness of the ring be

$$\text{Axial Thickness}(t_2) = 0.7t_1 \quad to \quad t_1$$

$$\text{where: the minimum thickness b}(t_2) = \frac{D}{10\times n_R} \qquad \text{also } n_R \Rightarrow$$

The distance from top of piston to first ring groove:

$$b_1 = t_H \quad to \quad 1.2t_H$$

Width of other rings:

$$b_2 = 0.75t_2 \quad to \quad t_2$$

The gap between two ends of ring:

$$G_1 = 3.5t_1 \quad to \quad 4t_1$$

The gap when ring in cylinder:

$$G_2 = 0.002D \quad to \quad 0.004D$$

- ✓ Piston Barrel
  - ✓ It is a cylindrical portion of the piston.

$$\text{Thickness}(t_3) = 0.03D + b + 4.5 \qquad mm$$

$$\text{wall thickness}(t_4) = 0.25\ t_3 \quad \text{to} \quad 0.35\ t_3$$

$$where: radial\ dipth of\ rings = b = t_1 + 0.4 \qquad mm$$

- Piston Skirt
  - The portion of the piston below the ring section is known as *piston skirt*.
  - The side thrust (R) on the cylinder liner is usually taken as 1/10 of the maximum gas load on the piston.

$$\text{Length } (l) = \frac{R}{P_b D}$$

$$where:$$

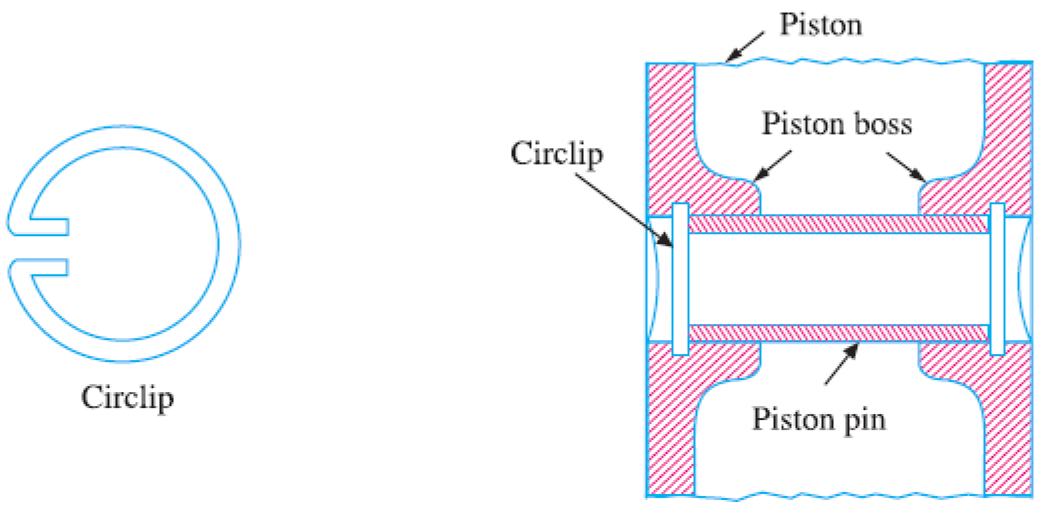
$$R = 0.1 P_{\max} \frac{\pi}{4} D^2$$

$$P_b = Bearing\ pressure\ take\ it\ be \quad 0.45 N/mm^2$$

$$\text{Total length of piston (L)} = \text{Length of skirt} + \text{Length of ring section} + \text{Top land}$$

$$\therefore \text{L} = l + (4t_2 + 3b_2) + b_1$$

- Piston Pin
  - The piston pin is used to connect the piston and the connecting rod.
  - The material used for the piston pin is usually case hardened steel alloy containing nickel, chromium, molybdenum or vanadium having tensile stress from 710 MPa to 910 MPa.



Full floating type piston pin.

Where:

d_o	outside diameter of pin	mm
l_1	length of pin in bush of small end of connecting rod	mm
P_{b1}	Bearing pressure at small end of connecting rod	its value for bronze is 25 N/mm^2

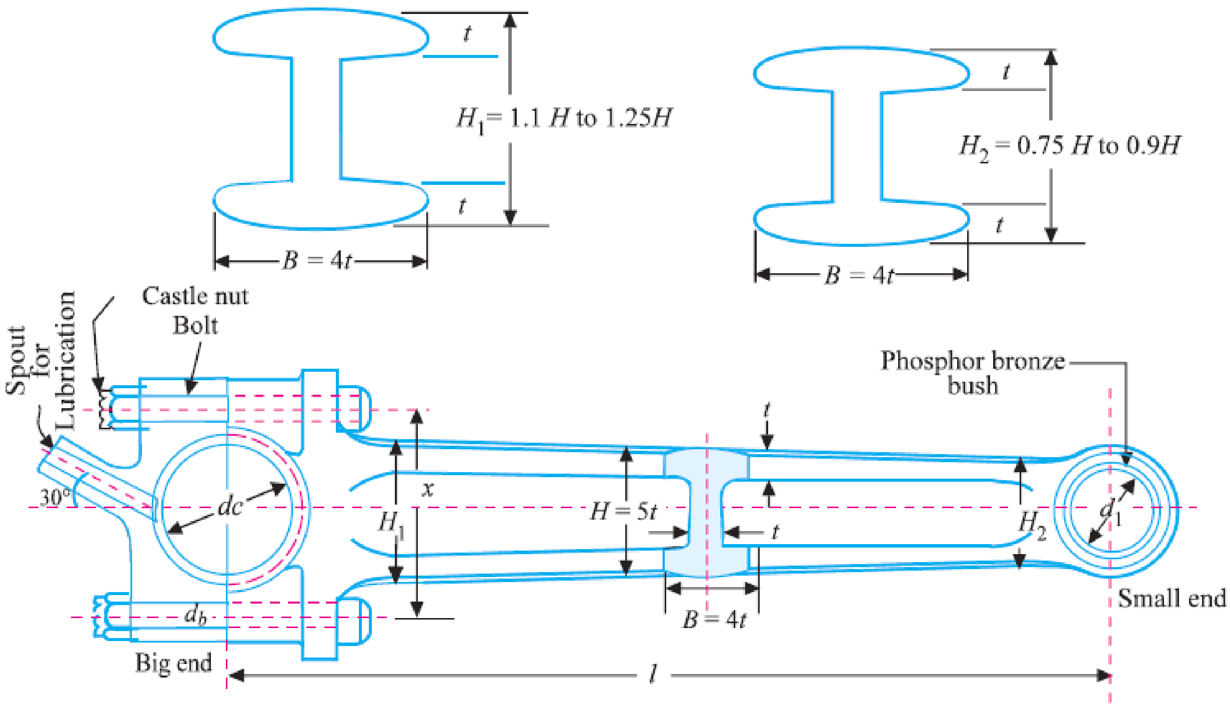
So that:-

$$\text{Load on the piston pin} = \frac{\pi}{4} D^2 P_{max} = P_{b1} d_o l_1$$

$$\text{Where: } l_1 = 0.45D \quad \text{and} \quad d_i = 0.6 d_o$$

Connecting Rod:

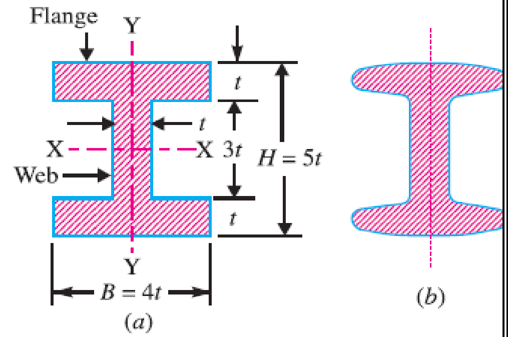
- It is the intermediate member between the piston and crankshaft.
- Its primary function is to transmit the push and pull from the piston pin to the crankpin and convert the reciprocating motion of the piston into the rotary motion of the crank.
- It consists of a long shank, small end and a big end.



Connecting rod.

- The material mostly used for connecting rods varies from mild carbon steels with tensile stress 650 MPa to alloy steel with tensile stress 1050 MPa.

- *<u>Design of Connecting Rod</u>*
- Dimension of cross-section of connecting rod
  - ✓ Thckness of flange and web of the section:



I-section of connecting rod.

$$\text{BucklingLoad(Wc)} = \text{Fc} \times \text{Fs} = \frac{\sigma_c \times A}{1 + a\left(\frac{L}{Kxx}\right)^2}$$

where :

Fs $\quad$ *Factor of sefty*

Fc $\quad$ *Force of connecting rod* $F_C = F_L = \frac{\pi}{4} D^2 P_{\max}$

L $\quad$ *Connecting rod length*

A $\quad$ *area of section* $= 11 \times t^2$

Kxx $\quad$ *radius of gyration of section about x-axis* $= \sqrt{\frac{Ixx}{A}} = 1.78 \times t$

$a = Const. \quad = 1/7500 \quad for \quad meeld \quad steel$

$= 1/9000 \quad for \quad \text{wrought} \quad iron$

$= 1/1600 \quad for \quad cast \quad iron$

also :

$Depth\ near\ big\ end\ (H_1) = 1.1\,H \quad to \quad 1.25H$

$Depth\ near\ small\ end\ (H_2) = 0.75\,H \quad to \quad 0.9H$

also :

$\text{width of the section } (B) = 4t$

$Depth \text{ or height of the section } (H) = 5t$

- Dimension of the crankpin at the big end bearing and piston pin at small end bearing.

- ✓ The piston pin bearing is usually a phosphor bronze of about 3 mm thickness and the allowable bearing pressure (P_{bc})be 10.5 N/mm^2 to 15 N/mm^2.

$$F_L = \text{max. gas force} = \text{Projected area x Bearing pressure}$$
$$\therefore F_L = 13 \times (d_c)^2$$
$$where:$$
$$d_c \text{ is diameter of crank pin at big end bearing, mm}$$
$$l_c \text{ is length of crank pin at big end bearing,} = 1.3 \times \mathrm{d_c} \text{ mm}$$

$$F_L = \text{max. gas force} = \text{Projected area x Bearing pressure}$$
$$\therefore F_L = 30 \times (d_p)^2$$
$$where:$$
$$d_p \text{ is diameter of piston pin, mm}$$
$$l_p \text{ is length of piston pin,} = 2 \times \mathrm{d_p} \text{ mm}$$

- Size of bolts for securing the big end cap:
- ✓ The bolts and the big end cap are subjected to tensile force which corresponds to the inertia force of the reciprocating parts at the top dead center on the exhaust stroke.
- ✓ Take the tensile strength of the bolts material be 60 N/mm^2
- ✓ The enertia force of reciprocating parts F_I

$$F_I = m_R \cdot \omega^2 \cdot r \left(\cos\theta + \frac{\cos 2\theta}{l/r} \right)$$

Where: Ɵ is crank angle which equal to Zero at the top dead center.

$$\therefore \qquad F_I = m_R \cdot \omega^2 \cdot r\left(1 + \frac{r}{l}\right)$$

where m_R = Mass of the reciprocating parts in kg,

ω = Angular speed of the engine in rad / s,

r = Radius of the crank in metres, and

l = Length of the connecting rod in metres.

- ✓ The bolts may be made of high carbon steel or nicle alloy steel. So that the factor of safety for bolts are equal to 6.
- ✓ Equation of inertia force on bolts:

$$F_I = \frac{\pi}{4}(d_{cb})^2 \sigma_t \times n_b$$

Let d_{cb} = Core diameter of the bolt in mm,

σ_t = Allowable tensile stress for the material of the bolts in MPa, and

n_b = Number of bolts. Generally two bolts are used.

The normal or major diameter (d_b) of the bolts is given:

$$d_b = \frac{d_{cb}}{0.84}$$

- ➢ *Design of Crank Shaft*
- ➢