Government College of Engineering and Research, Avasari(Khurd)

Department: Mechanical Engineering

Learning Resource Material (LRM)

Name of the course: Mechanical System Design **Course Code:** 402048

Name of the faculty: J. M. Arackal **Class:** BE(Mech)

SYLLABUS(5)

Unit 5: Design of I.C. Engine Components
Introduction to selection of material for I. C. engine components, Design of cylinder and cylinder head, construction of cylinder liners, design of piston and piston-pins, piston rings, design of connecting rod. Design of crank-shaft and crank-pin,

Lecture Plan format:

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Unit No	**Lecture No.**	**Topics to be covered**	**Text/Reference Book/ Web Reference**
		UNIT 5	
5	1	Introduction to selection of material for I. C. engine components	1,2
5	2	Design of cylinder and cylinder head,	1,2
5	3	Construction of cylinder liners	1,2
5	4	Problem session on Design of cylinder and cylinder head	1,2
5	5	Problem session on Design of cylinder and cylinder head	1,2
5	6	Piston rings, Design of connecting rod.	1,2
5	7	Design of piston and piston-pins	1,2
5	8	Piston rings, Thermal Analysis	1,2

List of Text Books /Reference Books/ Web Reference

1-Bhandari V.B. ―Design of Machine Elements‖, Tata McGraw Hill Pub. Co. Ltd.

2-R.K. Jain- Machine Design, Khanna Publishers

3-Johnson R.C., ―Mechanical Design Synthesis with Optimization Applications‖, Von Nostrand Reynold Pub

~~Cylind~~

Design of IC Engine

Cylinder & Cylinder liner.

Two function.

- Retain working fluid
- Guide the piston.

(1)

Cylinder has to be cooled

· Air cooled ⟶ fins → scooter & motorcycle

water cooled.

In small engines ~~&~~, cylinder & frame → one piece

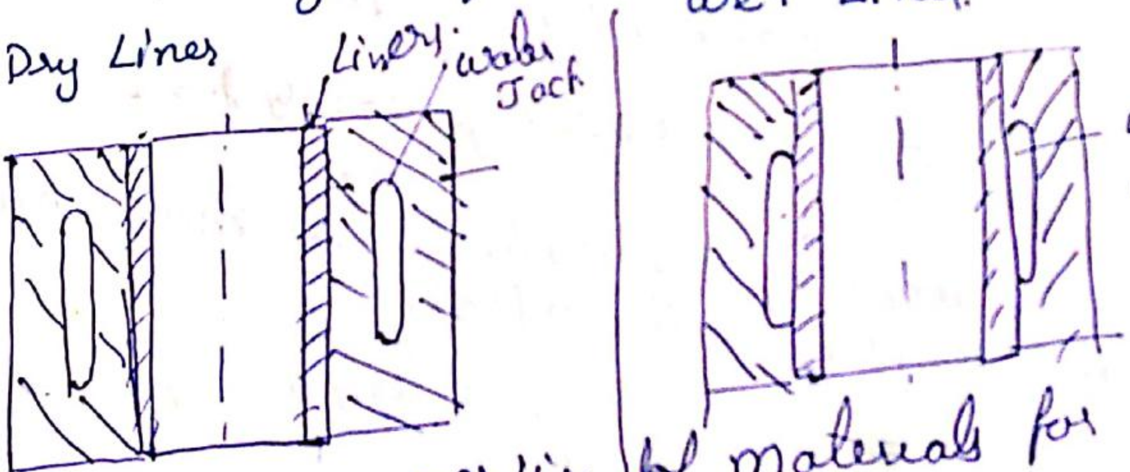
In large – assembly.

Advantages of cylinder liners.

- Can be replaced
- Liner – wear resistant.
- allows Longitudnal expansion

Two types of Line. · wet Liner.

Dry Liner



Desirable properties of materials for cylinder & Liners (for cylinder.

- withstand high gas pressure
- withstand thermal stresses
- Resist wear due to piston movement
- corrosion resistant

⟶ made of Grey Cast Iron / Chromium CI / Centrifugally Cast CI (Heavy duty cylinder

⟶ nickel CI

⟶ cast steel & aluminium

Bore & Length of Cylinder

Bore – Inner dia of cylinder

$$IP = \frac{BP}{\eta}$$

IP → Indicated power (W)

BP → Brake power (W).

η → mechanical efficiency (0.8 or 80%)

$$IP = \frac{P_m \times A \times l \times n}{60}$$ [Indicated Mean eff. pressure = P_m]

$n = N$ (for 2-S) | l = length of stroke

$n = \frac{N}{2}$ (for 4-S).

N → engine speed rpm.

n = no of working strokes/min.

A = Crossectional Are $= \frac{\pi}{4} D^2$.

$\frac{l}{D}$ = 1.25 to 2 (generally 1.5).

The length of the cylinder (L) is more than the length of the stroke.

the length of cylinder,

$L = 1.15\, l$. [L = length of cylinder

Thickness of Cylinder wall.

$$t = \frac{P_{max}\, D}{2\sigma_c} + C.$$ (Engine cylinder or cylinder liner is treated as thin cylinder)

t = cylinder wall thickness.

P_{max} = max gas pressure inside cylinder.

σ_c = Circumferential or hoop stress for cylinder material (N/mm²).

C = Reboring allowance (in m

Note

i) when not specified

$$P_{max} = 10 (P_m)$$

ii) $$\sigma_c = \sigma_t = \frac{S_{ut}}{f(S)}.$$

iii). σ_c = 35 to 100 N/mm² (Assumed)

iv) Reboring allowance → additional metal thickness over & above that required to withstand maximum gas pressure inside the cylinder,

Q) The cylinder head of a four stroke diesel engine has following specifications (1)

Brake power = 3.75 k.W.

Speed = 1000 rpm

Indicated mean effective pressure = 0.35 MPa

Mechanical effeciency = 80%.

Determine the bore & length of the cylinder

A). we have

$$IP = \frac{P_m \, l \, A \, n \times 10^3}{60} \quad (1) \quad (kW).$$

we have $P_m = 0.35$.

$n = \frac{N}{2}$ (4-S). $\Rightarrow n = \frac{1000}{2} = 500.$

$\frac{l}{D} = 1.5$ (Assume) $\Rightarrow l = 1.5D$. [l = length of stroke]

$A = \frac{\pi}{4} D^2$; put all in (1).

$$\eta = \frac{BP}{IP}.$$

$0.8 = \frac{3.75}{Ip}$. $Ip = 4.69$ kW.

put all in (1)

$$4.69 \times 10^3 = \frac{0.35 \times (1.5D) \times \pi \times D^2 \times 500}{4 \times 60 \times 1000} \times 10^3.$$

D = 112 mm.

$l = 1.5 \times 112 = 168$ mm [Length of stroke]

L = length of the cylinder = $1.15 \times l$

L = 194 mm

Q) The cylinder of a four stroke diesel engine has the following specifications.

Cylinder bore = 150 mm

Max gas pressure = 3.5 MPa.

cylinder material → Grey CI FG 200 (S_{ut} = 200 N/mm²)

fos = 5

Poissons ratio = 0.25.

Determine the thickness of cylinder wall. Also, calculate the apparent and net circumferential & longitudinal stresses in the cylinder wall.

Ans. from table 25.1.

for D = 150

C = 4.

Thickness of cylinder wall.

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

$$\sigma_c = \sigma_t = \frac{200}{5} = 40 \text{ N/mm}^2.$$

$$t = \frac{3.5 \times 150}{2 \times 40} + 4 = 10.56 \text{ mm} \simeq 12 \text{ mm}$$

Apparent stress

$$\sigma_c = \frac{P_m D}{2.(t)} = \frac{3.5 \times 150}{2 \times 12} = 21.88 \text{ N/mm}^2$$

$$\sigma_\ell = \frac{P_{max} D^2}{(D_o^2 - D^2)} = \frac{3.5 \times 150^2}{[174^2 - 150^2]} \quad // D_o = D + 2t = 150 + 24 = 174$$

$$\sigma_\ell = 10.13 \text{ N/mm}^2$$

Net stresses

$\sigma_{c_{net}} = \sigma_c - \mu \sigma_\ell .$

$= 21.88 - 0.25 [10.13]$

$(\sigma_c)_{net} = 19.35 \; N/mm^2$

$(\sigma_\ell)_{net} = \sigma_\ell - \mu \sigma_c .$

$= 10.13 - 0.25 (21.88)$

$= 4.66 \; N/mm^2$

Q) The cylinder of a 4-S diesel engine has following specifications.

- Cylinder bore = 145 mm
- Max gas pressure = 3.5 MPa.
- Reboring allowance = 5 mm.
- Cylinder material = FG 200.
- Poissons ratio = 0.25
- fos = 5.

Determine.

i) Thickness of cylinder wall.
ii) stresses induced in cylinder wall.

A). Thickness of cylinder wall.

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

$$\sigma_c = \sigma_t = \frac{200}{5} = 40 \; N/mm^2$$

$$t = \frac{P_{max} D}{2\sigma_t} + C .$$

$$t = \frac{3.5 \times 145}{2 \times 40} + 5 = 12 \; mm .$$

Apparent stress.

$$\sigma_c = \frac{P_{max} D}{2t} = \frac{3.35 \times 145}{2 \times 12} = 21.14\ N/mm^2$$

$$\sigma_{\ell} = \frac{P_{max} D^2}{(D^2 - D_o^2)} \qquad D_o = D + 2t = 145 + 24 = 169\ mm$$

$$\therefore \sigma_{\ell} = \frac{3.5 \times 145^2}{(169^2 - 140^2)} = 8.22\ N/mm^2$$

Net stresses

$$(\sigma_c)_{net} = \sigma_c - \mu \sigma_\ell = 21.14 - (0.25 \times 8.22)$$
$$= 19.08\ N/mm^2$$

$$(\sigma_\ell)_{net} = \sigma_\ell - \mu \sigma_c = 8.22 - (0.25 \times 21.14)$$
$$= 2.93\ N/mm^2.$$

The bore of a cylinder of the four stroke diesel engine is 150 mm. The maximum gas pressure inside the cylinder is limited to 3.5 MPa. The cylinder head is made of Grey C.I. FG 200 ($S_{ut} = 200 N/mm^2$) & the fos is 5. Determine the thickness of the cylinder head.

Studs are used to fix the cylinder head to the cylinder & obtain a leak proof joint. They are made of steel FeE 250 ($S_{yt} = 250 N/mm^2$) & fos is 5. Calculate

i) no of studs.

ii) nominal dia of studs.

iii) pitch of studs.

Ans).

$$t_h = D\sqrt{\frac{K\, P_{max}}{\sigma_c}}$$

$K = 0.162$ $\qquad$ $\sigma_c = \frac{200}{5} = 40 N/mm^2$

$P_{max} = 3.5$ $\qquad$ $D = 150.$

$$t_h = 150\sqrt{\frac{0.162 \times 3.5}{40}}$$

$t_h = 17.8$ $\qquad$ $t_h = 18 mm$

i) no of studs

min $= 0.01D + 4 = 5.5 \rightarrow 6 = 2$

max $= 0.02D + 4 = 7.$

Force due to gas pressure $= P_{max} \times \frac{\pi}{4} D^2$ — ①.

Resistance by studs $= \left(\sigma_t \times \frac{\pi}{4} d_c^2\right) \times z$ — ②.

equating 1 & 2.

$$P_{max} \times \frac{\pi}{4} D^2 = \sigma_t \times \frac{\pi}{4} d_c^2 \times 2.$$

[core or minor dia].

$$\sigma_t = \frac{250}{5} = 50 \text{ N/mm}^2.$$

$$3.5 \times \frac{\pi}{4} \times 150^2 = 50 \times \frac{\pi}{4} \times d_c^2 \times 6.$$

d_c = nominal dia $d = \frac{d_c}{0.8} = 20$ mm

Pitch of the studs.

D_p (PCD) $= D + 3d. = 150 + 3(20) = 210.$

Also D_p = Pitch $= \frac{\pi D_p}{2} = 109.91$

Limits

Min. pitch $= 19\sqrt{d} = 84.97$

Max pitch $= 28.5\sqrt{d} = 127.41.$

∴ 109.9 is within the limits.

The bore of a cylinder of the 4-S diesel engine is 150 mm.

Q) The cylinder of a 4-S diesel engine has following specifications

Brake power = 7.5 kW.
Speed = 1400 rpm
Indicated mean eff pressure = 0.35 MPa.
Mechanical effeciency = 80%.
Maximum gas pressure = 3.5 MPa,
The cylinder liner & head made of grey CI FG 260 (S_{ut} = 260 N/mm² & μ = 0.25). The studs are made of plain - CS 40C8 (S_{yt} = 380 N/mm²)
The fos for all parts is 6.
Calculate.
i) Bore & length of the cylinder liner
ii) Thickness of cylinder liner
iii) Thickness of the cylinder head.
iv) Size no & pitch of studs

Ans). 1) Bore & Length of cylinder

$$I_P = \frac{P_m \, l A n}{60} \quad -① $$

$$\eta = \frac{BP}{IP} \quad \Rightarrow \quad I_P = \frac{BP}{\eta} = \frac{7.5}{0.8} = 9375 \text{ kW}$$

$$l = \frac{1.5D}{1000}$$

(D is in mm)

$$A = \frac{\pi}{4} D^2$$

Put in 1.

$$n = \frac{1400}{2} = 700$$

$$\therefore 9375 = 0.35 \times \frac{1.5 \times D}{1000} \times \frac{\pi}{4} \times D^2 \times \frac{700}{60}$$

$D = 125\,mm$

$l = 187.5$ (length of stroke)

$L =$ length of cylinder $= 216\,mm$

II) Thickness of cylinder liner

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

$$\sigma_c = \frac{260}{6} = 43.33$$

$C = 3.2$

$$t = \frac{3.5 \times 125}{2 \times 43.33} + 3.2$$

$t = 10\,mm$

III) Thickness of cylinder head.

$$t_h = D\sqrt{\frac{K P_{max}}{\sigma_3}}$$

$$t_h = 125\sqrt{\frac{0.162 \times 3.5}{43.33}}$$

$= 15\,mm$

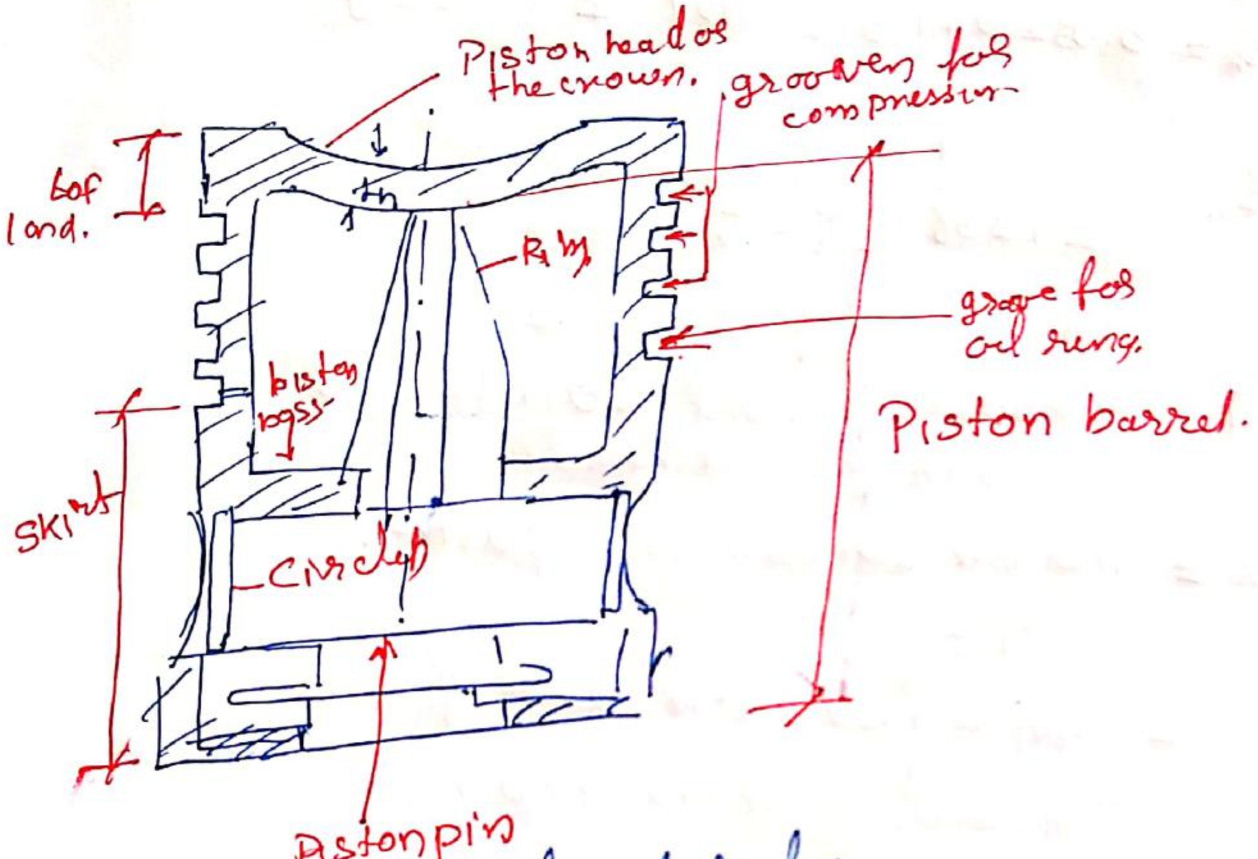
IV) No of studs $= 6.$

$d_c = 12$

$d = 15.$

Pitch $=$ ~~H~~ $89.01.$

Piston.



Cast Iron – moderately rates

Al. Alloys – High speed

Two types of piston head

flat type & cup type.

Thickness of Piston Head.

As per Grashoff formula.

$$t_h = D\sqrt{\frac{3\,P_{max}}{16\,\sigma_b}}$$

t_h = thickness of piston head

D = Cylinder bore

P_{max} = max gas pressure

$$\sigma_b = \sigma_t = \frac{S_{ut}}{FOS}$$

σ_b = 35 - 40 [Grey CI]

= 50 to 90 [Al Alloy]

Emperical relation:

$t_h = 0.032 D + 1.5$ [Hed & Kavary]

$$t_h = \left[\frac{H}{12.56\, k [T_c - T_e]} \right] \times 10^3$$

t_h = thickness of piston head

H = amount of heat conducted through piston head.

K = Thermal conductivity factor. (w/m/°c).

T_c = Temperature at the center of piston head. °c.

T_e = Temperature at the edge of piston head

for i) grey C I   K = 46.6 w/m/°c.

for A   K = 175 w/m/°c

Amount of heat conducted through piston head.

$$H = [C \times HCV \times m \times BP] \times 10^3$$

HCV = Higher calorific value of fuel [KJ/kg]

m = mass of fuel used / BP / sec (kg/kW/s)

BP = Brake Power of the engine per cylinder.

C is the ratio of heat absorbed by the piston to the total heat developed in the cylinder [C = 5% / 0.05].

Piston Rings.

Two types – compression & oil rings

functions

- Maintain a seal between the cylinder wall and the piston.
- Transfer heat from piston head to cylinder wall.
- Absorbs fluctuations in side thrust.

Material

grey CI & some cases alloy CI.

No of piston rings

usually 3–4. (comp. rings)

oil scrapper rings – 1 to 3.

Dimensions

radial width of the ring

$$b = D\sqrt{\frac{3P_w}{\sigma_t}}$$

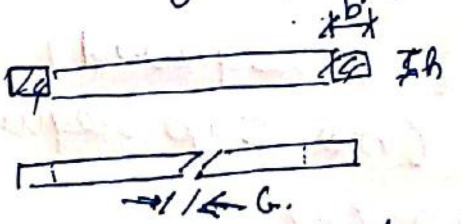
P_w = allowable radial pressure on the cylinder wall [0.025 – 0.042 MPa]

σ_t = Permissible tensile stress = 85 to 110 N/mm²

axial thickness, $h = (0.7b)$ to b.

$$h_{min} = \frac{D}{10Z}$$ [Z = no of rings].

Thin rings preffered.



$G = 3.5b$ to $4b$ [before assembly]

$G = 0.002D$ to $0.004D$ [after assembly]

i) for Diesel HCV = 44×10^3 kJ/kg.
for Petrol HCV = 47×10^3 kJ/kg.

ii) The average consumption of fuel in diesel engine:

0.24 to 0.3 kg/kW/hr.

$$m = \left[\frac{0.24 \text{ to } 0.3}{60 \times 60}\right] \text{ kg/kW/s}$$

Piston Ribs & Cup

Ribs transmit a large portion of combustion heat from the piston head to the piston rings.

→ when thickness of piston head is 6mm or less, no ribs needed.

$t_h \leq 6$ (no ribs)

$t_h > 6$ (ribs needed)

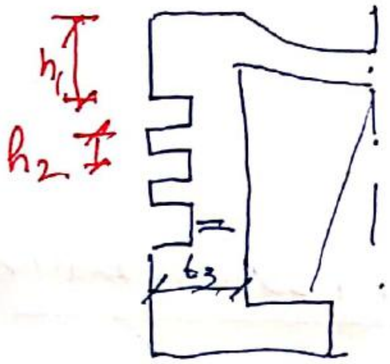
no of ribs = 4 to 6.

thickness of ribs

$$t_R = \left(\frac{t_h}{3}\right) \text{ to } \left(\frac{t_h}{2}\right)$$

when $l/D \leq 1.5$ (cup required)
$l/D > 1.5$ (no cup required).

Radius of cup = 0.7 D.



top land [Dist from top of the piston to first ring groove]

$h_1 = t_h$ or $1.2\, t_h$.

dist. between two consecutive ring

$h_2 = 0.75\, h$ to h.

Piston Barrel.

thickness of piston barrel at the top

$t_3 = (0.03 D + b + 4.9)$

$\Rightarrow b =$ radial with of ring.

thickness at the lower end / open end

$t_4 = (0.25\, t_3)$ to $(0.35\, t_3)$.

Piston skirt (bearing surface for side thrust)

Maximum gas force on piston head $= \left(\frac{\pi}{4} D^2\right) P_{max}$

side thrust $= \mu \left(\frac{\pi D^2}{4}\right) P_{max}$ $[\mu = 0.1]$

side thrust (skirt) $= P_b D l_s$

P_b = allowable bearing pressure

l_s = length of skirt.

$\mu \left(\frac{\pi}{4} D^2\right) P_{max} = P_b D l_s$

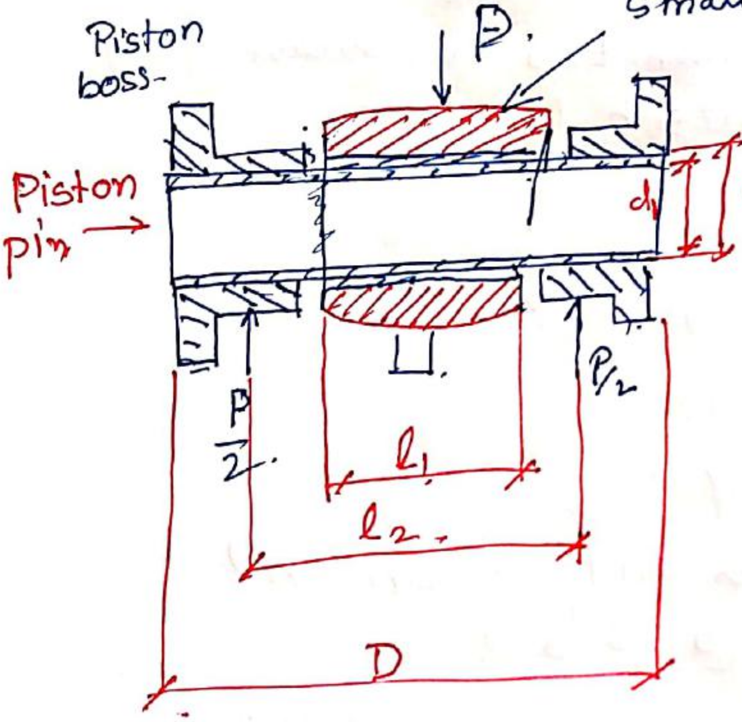
emperical relation.

$l_s = (0.65 D)$ to $(0.8 D)$.

$\therefore L$ (Total length) = top land + length of ring section + length of skirt

$L = D$ to $1.5 D$

Piston pin. / Gudgeon / wrist pin



i) Bearing Consideration

Force on piston $= \left(\frac{\pi}{4} D^2\right) P_{max}$

Resisting force $= (P_b)_1 \times l_1 \times d_o$.

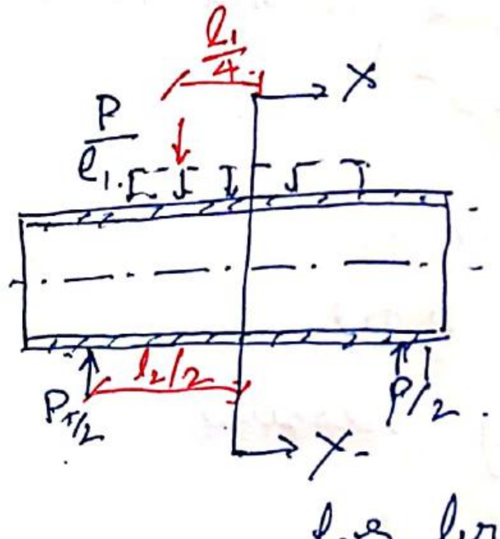
$(P_b)_1$ = bearing pressure at the bushing of small end of connecting rod.

d_o = outer dia of piston ~~pub~~ pin.

$l_1 = 0.45D$.

$(P_b)_1 = \approx 25\,MPa$.

$d_1 = 0.6\,d_o$.



for grey CI.

Mean dia of Piston bosses $= 1.4\,d_o$.

$= 1.5\,d_o$ (aluminium alloy).

ii) Bending Considerations

$$M_b = \left(\frac{P}{2}\right)\left(\frac{l_2}{2}\right) - \left(\frac{P}{l_1} \times \frac{l_1}{2}\right) \times \frac{l_1}{4}$$

$$= \left(\frac{P}{2}\right)\left(\frac{l_2}{2}\right) - \left(\frac{P}{2}\right)\left(\frac{l_1}{4}\right)$$

$l_2 = \frac{D + l_1}{2}$. Put in above.

~~Put in~~

$$M_b = \left(\frac{P}{2}\right)\left(\frac{l_1 + D}{2}\right) \times \frac{1}{2} - \frac{P}{2} \times \frac{l_1}{4}$$

$$= \left(\frac{PD}{8}\right) + \left(\frac{Pl_1}{8}\right) - \left(\frac{Pl_1}{8}\right)$$

$$M_b = \frac{PD}{8}$$

$$I = \frac{\pi}{64}\left(d_o^4 - d_i^4\right)$$

$$y = \frac{d_o}{2}$$

$$\sigma_b = \frac{M_b y}{I}$$

$\sigma_b = 84 \, N/mm^2$ (Case hardened CS).

$\sigma_b = 140 \, N/mm^2$ (for heat treated alloy steel)

iii) Piston clearance.

Lack of clearance leads to 'piston seizure'.

excessive clearance cause 'piston slap' resulting in excessive noise.'

generally – 0.0375 to 0.1875 [clearance]

Aluminium alloy piston has twice the clearance of CI piston.

ASSIGNMENT- DESIGN OF IC ENGINE COMPONENTS

1- Explain the step by step procedure for designing of cylinder of IC engine
2- Explain the step by step procedure for designing of crank shaft of IC engine
3-What is the function of the cup on the piston head?
4- Why do inlet and exhaust valves have conical heads and seats?
5- Why are connecting rod made of I sections?
6- Four stroke diesel engine has following specifications: B Power = 5 kW, Speed = 1200 RPM, IMEP = 0.35 N/mm^2, efficiency = 80%, Gas pressure 3.15MPa, Permissible stress for cylinder = 42 N/mm^2. Determine cylinder dimensions & cylinder head thickness
7- Explain the procedure of designing connecting rod.
8- Four stroke diesel engine has following specifications: Cylinder bore=85mm, Gas pressure 3MPa, Allowable bearing pressure for skirt=0.4MPa, ratio of side thrust to gas load=0.1, Width of top land=20mm, width of grooves=2.75mm, piston rings=4, thickness of rings=3mm. Calculate length of skirt and piston length
9- Explain the procedure of designing crank shaft and crank pin.
10- Explain the step by step procedure for designing of piston of IC engine.