Sessional Problems on Horizontal Internal Combustion Engine

- **PART – I:**

In a single cylinder 4 stroke horizontal diesel engine running at 1500 rpm and producing power of 22 kW, the gas force vs crank angle values are given as follows:

Table – I : Gas Forces at various crank rotational angles

Crank Angle, θ (in degree)	0	20	40	60	80	100	120	140	160	180 – 240
Gas Force (kN)	65	85	66	24	13	9	7.5	4.5	2.1	0.25
Crank Angle, θ (in degree)	270 – 360	390 - 540	570	600	630	660	690	720	-	-
Gas Force (kN)	0.25	- 0.1	0.01	0.6	2.0	6.0	30	65	-	-

Other data:

(a) Weight of piston, pin and ring etc. = 50 N

(b) Weight of connecting rod:

(i) Weight of big end = 30 N acting through big end centre

(ii) Weight of shank = 6 N acting at a distance of 80 mm from the big end centre.

(iii) Weight of small end = 5 N acting through the small end centre

(c) Stroke length = 180 mm
(d) Connecting rod length to crank radius ratio = 4
(e) Crank pin diameter = 112 mm
(f) Crank pin length = 56 mm

Determine the average bearing pressure, p_{av} on the crank pin from the values of the resultant forces acting on the crank pin at various crank angles.

- **PART – II:**

If the oil sump temperature is 80^0 C , find the followings:

(i) Diametral clearance (C)
(ii) Minimum oil film thickness (h_0)
(iii) Oil flow rate (Q) through the minimum clearance of bearing

Plot the following curves:

(i) Bearing mean temperature Vs diametral clearance (C)
(ii) Minimum oil film thickness (h_0) Vs diametral clearance (C)
(iii) Oil flow rate (Q) Vs diametral clearance (C)

Other Necessary Data:

Density of oil, $\rho = 860$ kg / m^3

Specific heat of oil, $C_p = 1700$ N –m / kg – ^{0}C

Table – II : Absolute viscosity of oil at various oil temperature

Oil temperature (^0C)	105	107	109	112	116	127
Absolute viscosity, η (Pa-s)	8.5×10^{-3}	8.2×10^{-3}	7.9×10^{-3}	7.4×10^{-3}	6.9×10^{-3}	5.8×10^{-3}

Table – III: Data for obtaining the targeted values of S, ($2h_0$ /C) & 2Q/ (DCNL) from the polynomial interpolation curve equations

i	0	1	2	3
$\lambda_i = (\rho\, C_p\, \Delta T) / p_{av}$	9.80	15.0	26.0	43.0
$S_i = (\eta\, N' / p_{av})\, (D / C)^2$	0.0314	0.0921	0.3210	0.7940

Given the polynomial interpolation curve equations:

$$S(\lambda) = 0.0314 + 0.011673 \times (\lambda - \lambda_0) + 5.64197 \times 10^{-4} \times (\lambda - \lambda_0) \times (\lambda - \lambda_1) - 0.09452 \times 10^{-4} \times (\lambda - \lambda_0)(\lambda - \lambda_1)(\lambda - \lambda_2) \quad \text{.... (1)}$$

$$(2h_0 / C) = 0.2 + 3.2949 \times (S - S_0) - 5.3432 \times (S - S_0)(S - S_1) + 5.3218 \times (S - S_0)(S - S_1)(S - S_2) \quad \text{..... (2)}$$

$$(2\,Q / DCNL) = 3.17 + 6.42504 \times (S - S_0) - 16.6043 \times (S - S_0) \times (S - S_1) + 21.82871 \times (S - S_0)(S - S_1)(S - S_2) \quad \text{...... (3)}$$

Where,

C = diametral clearance of bearing

D = diameter of crank pin

L = length of crank pin

$N^{/}$ = no. of rotation per sec

P_{av} = average pressure on crank pin due to average resultant load, F_R

= $F_R / (L \times D)$

Q = Flow rate of oil through the minimum film thickness, h_0

$\Delta T = (T_o - T_i) / 0.8$ = Temperature rise of oil as per Cameron's formula

T_o = Oil temperature (^{0}C)

T_i = Oil sump temperature (^{0}C)

S = Sommerfeld's number = $(\eta N^{/} / p_{av})(D / C)^2$

h_0 = minimum film thickness

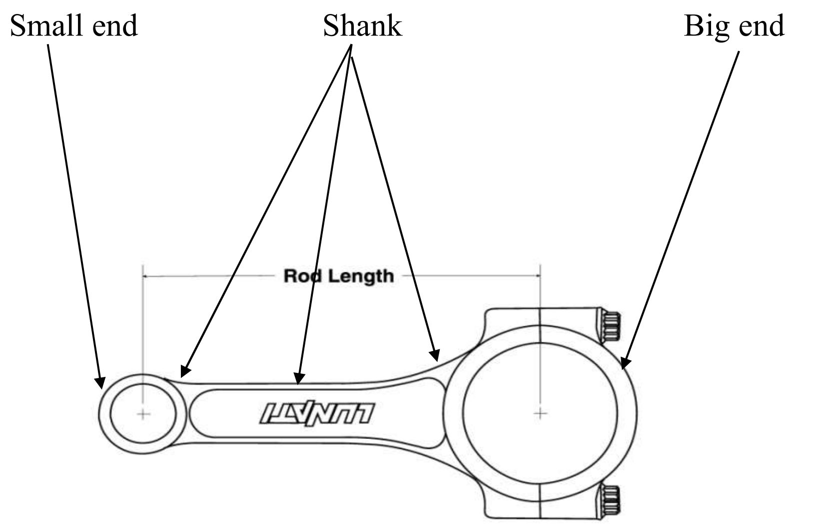
ρ = mass density of oil

C_p = Specific heat of oil

Instruction Sheet for Solution

PART – I :

- Conversion of the connecting rod shank into two lumped masses



Let

W_B = Weight of the big end mass

W_S = Weight of the small end mass

W_C = Weight of the connecting rod-shank mass

W_{CB} = Weight of the lumped mass at the big end which replaces partly the connecting rod shank mass

W_{CS} = Weight of the lumped mass at the small end which replaces the rest of the connecting rod shank mass

W_p = Weight of piston, pin and ring etc.

Thus, total weight of connecting rod

= Weight of small end + Shank weight + Weight of big end

$= W_S \quad + \quad W_C \quad + \quad W_B$

$= W_S + W_{CS} \leftarrow W_C \rightarrow W_{CB} + W_B$

After the conversion into two-lumped mass system

Total weight of small end = $W_S + W_{CS}$ which reciprocates with piston.

Total weight of big end = $W_B + W_{CB}$ which rotates with the crank

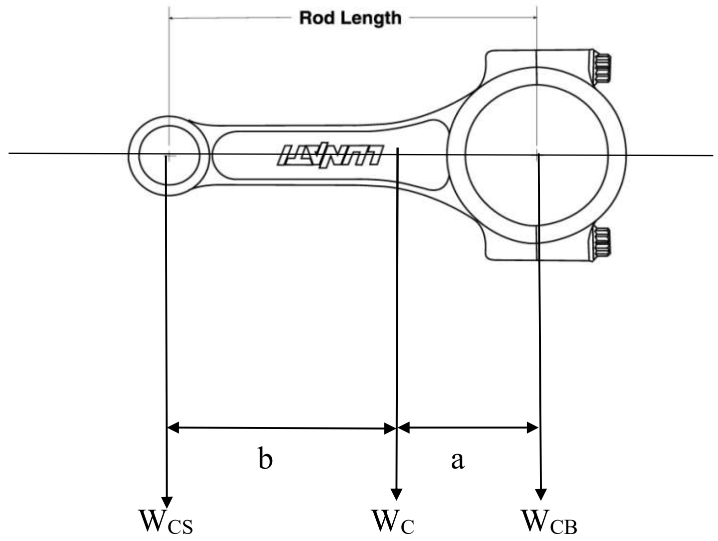
- **Determination of weights of two lumped masses, W_{CS} & W_{CB}**

W_{CS} & W_{CB} can be determined by satisfying the conditions of dynamic equivalence of two systems viz. connecting rod and two lumped masses system as follows.

(i) Total mass of both systems will be same.
(ii) The location of centroid of both systems remains same.
(iii) Mass moment of inertia of both systems about the centroid remains same.

For the present problem, the first two conditions are sufficient to be satisfied.

Referring to the following figure



From the first condition

$$W_{CS} + W_{CB} = W_C = 6 \text{ N} \qquad \ldots\ldots\ldots (1)$$

From the second condition

$$W_{CB} \times a = W_{CS} \times b \qquad \ldots\ldots\ldots (2)$$

Where, $a + b = L = 360$ mm & $a = 80$ mm

So, from equations (1) and (2) W_{CS} and W_{CB} can be obtained.

Total reciprocating weight of mass, $\mathbf{W_{rec} = W_S + W_{CS} + W_p}$

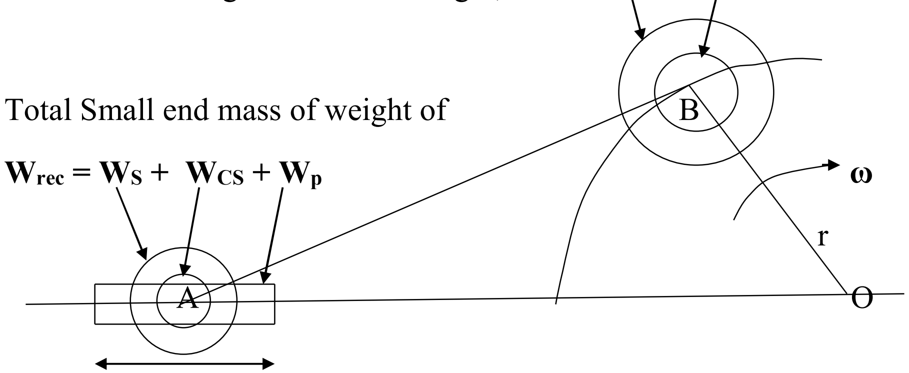
Total rotating weight of mass, $\mathbf{W_{rot} = W_B + W_{CB}}$

After conversion into two lumped masses, the small and big ends are shown in the figure below:

Total Big end mass of weight, $\mathbf{W_{rot} = W_B + W_{CB}}$

Total Small end mass of weight of

$\mathbf{W_{rec} = W_S + W_{CS} + W_p}$

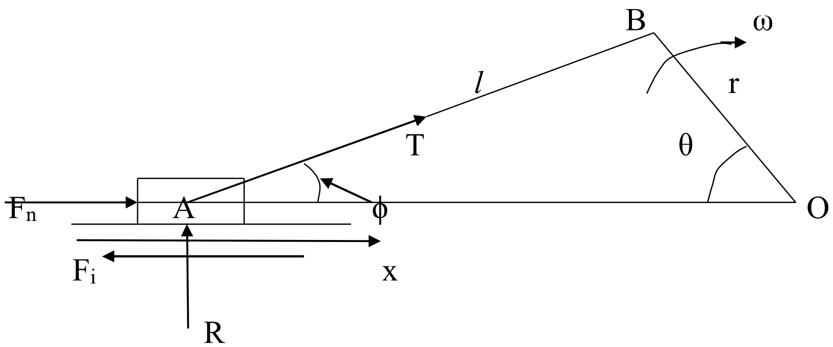


$$\text{Amplitude of the inertia force} = \frac{W_{rec}\,\omega^2\,\mathrm{r}}{g}$$

$$\text{Centrifugal force, } F_{cr} = \frac{W_{rot}\,\omega^2\,\mathrm{r}}{g} \qquad \mathrm{r = crank\ radius = stroke\ length / 2}$$

- **Determination of Inertia force, F_i of reciprocating mass and Resultant force, F_R on the crank pin at the big end**

Force diagram for the slider crank mechanism:



F_n = Net force on the reciprocating mass = Gas Force + Inertia Force

$= F_g + F_i$

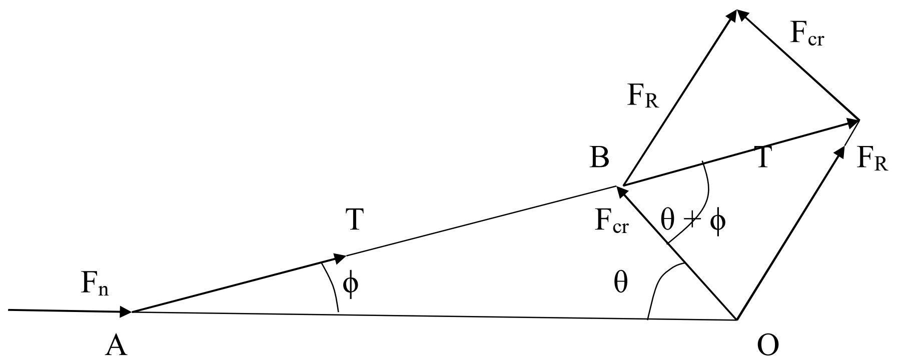
$$\mathbf{F_i = Inertia\ force = -\frac{W_{rec}\,\omega^2 r}{g}\left[\cos\theta + \cos(2\theta)/n\right],\quad n = l/r}$$

$F_n = T\cos\phi$, R = Reaction force on the cylinder wall $= T\sin\phi$

Thrust load in the connecting rod, $T = \mathbf{F_n / \cos\phi} = (F_g + F_i)/\cos\phi$

Now, the crank pin is subjected to two forces viz. thrust load, T and centrifugal force, F_{cr}. The resultant bearing reaction on the crank pin at B is the resultant of these two forces as shown in the figure below.

Force Diagram:



$$\overline{F}_R = \overline{T} + \overline{F}_{cr}$$

$$\left|\overline{F}_R\right| = \sqrt{\left|\overline{T}\right|^2 + \left|\overline{F}_{cr}\right|^2 - 2\left|\overline{T}\right|\left|\overline{F}_{cr}\right|\cos(\theta+\phi)}$$

Here, the thrust load, T and resultant force on the crank pin are the function of crank rotational angle, θ. So, these forces are to be evaluated for various crank angles.

Where,

$T = \mathbf{F_n / \cos\phi = (}F_g + F_i) / \cos\phi$, $\quad \phi = \sin^{-1}[(\sin \boldsymbol{\theta}) \mathbf{/ n\ ]}$

$$\mathbf{F_i = -} \frac{W_{rec}\,\omega^2\, r}{g} \mathbf{[\cos\theta + (\cos 2\theta) / n\ ],} \qquad \mathbf{n} = l \mathbf{/ r}$$

n = l **/ r = connecting rod length / crank radius**

$$F_{cr} = \frac{W_{rot}\,\omega^2\, r}{g}$$ which remains constant throughout crank rotation.

Table IA for calculating the resultant bearing reaction force, F_R for various, θ in step of 20^0

θ	ϕ	F_g (kN)	cos θ + (cos 2 θ) / n	F_i (kN)	$F_n = F_g + F_i$ (kN)	$T = F_n / \cos\phi$ (kN)	F_{cr} (kN)	F_R (kN)
0								
20								
40								
60								
80								
100								
120								
140								
160								
180								
200								
220								
240								

Table IB for calculating the resultant bearing reaction force, F_R for various, θ in step of 30^0

θ	ϕ	F_g (kN)	$\cos\theta + (\cos 2\theta)/n$	F_i (kN)	$F_n = F_g + F_i$ (kN)	$T = F_n / \cos\phi$ (kN)	F_{cr} (kN)	F_R (kN)
270								
300								
330								
360								
390								
420								
450								
480								
510								
540								
570								
600								
630								
660								
690								
720								

- **Determination of Average crank pin pressure**

In order to determine the average crank pin pressure, the area of F_R vs θ curve is to be determined.

Average bearing reaction = Total area of F_R vs θ curve / Total crank angle, 720^0

Total area, A of F_R vs θ curve = $A_1 + A_2$

A_1 = Area of F_R vs θ curve for crank rotation from 0^0 to 240^0 in step of 20^0

A_2 = Area of F_R vs θ curve for crank rotation from 240^0 to 720^0 in step of 30^0

A_1 and A_2 are evaluated numerically by using Simpson's 1/ 3 rd rule.for integration

$$\mathbf{A_1 = [(\Delta\theta)_1 / 3] \times [\, B_1 + 4 \times B_2 + 2 \times B_3 \,]}$$

Where, $\mathbf{B_1 = (F_R)_0 + (F_R)_{240}}$

$$\mathbf{B_2 = (F_R)_{20} + (F_R)_{60} + (F_R)_{100} + (F_R)_{140} + (F_R)_{180} + (F_R)_{220}}$$

$$\mathbf{B_3 = (F_R)_{40} + (F_R)_{80} + (F_R)_{120} + (F_R)_{160} + (F_R)_{200}}$$

$$\mathbf{(\Delta\theta)_1 = 20^0}$$

$$\mathbf{A_2 = [(\Delta\theta)_2 / 3] \times [\, B_4 + 4 \times B_5 + 2 \times B_6 \,]}$$

Where,

$$\mathbf{B_4 = (F_R)_{240} + (F_R)_{720}}$$

$$\mathbf{B_5 = (F_R)_{270} + (F_R)_{330} + (F_R)_{390} + (F_R)_{450} + (F_R)_{510} + (F_R)_{570} + (F_R)_{630} + (F_R)_{690}}$$

$$\mathbf{B_6 = (F_R)_{300} + (F_R)_{360} + (F_R)_{1420} + (F_R)_{480} + (F_R)_{540} + (F_R)_{600} + (F_R)_{660}}$$

$$\mathbf{(\Delta\theta)_2 = 30^0}$$

$$\mathbf{(F_R)_{av} = (A_1 + A_2) / 720 \quad kN}$$

Average crank pin pressure = $(p)_{av} = (F_R)_{av} \times 10^3 / (L \times D) \quad N / m^2$

L = Crank pin length (m)

D = Crank pin diameter (m)